Utilization of Sentinel-1 for Landslide Hazard Zoning on Agricultural Land Cover in Sumedang Regency

Haikal Muhammad Ihsan[1,*], *Herdien* Raka Moch Isya[2]

[1]Geography Information Science, Universitas Pendidikan Indonesia, 49154, Bandung, Indonesia
[2]Geography Education, Universitas Pendidikan Indonesia, 49154, Bandung, Indonesia

Abstract. The Sentinel-1 product can be built into a Synthetic Aperture Radar (SAR) capable of providing terrain data that can be built into landslide mapping parameters. Landslide becomes a disaster if there are affected areas, one of which is an agricultural area, so mapping the landslide hazard in agricultural areas is very important to study. The purpose of this study is to utilize Sentinel-1 products in mapping landslide hazards in agricultural areas in Sumedang Regency. The parameters used are the slope of the SAR data, geological conditions, soil conditions and meteorological conditions. The method used is the overlay intersect technique in which each weight and parameter score refers to the INARISK guidelines of the National Disaster Management Agency. Based on the analysis of the landslide area in Sumedang Regency, it tends to spread in the Southern Region. This area is a complex of hills with steep slopes, old volcanic parent rock which is quite brittle, high rainfall, clay soil texture, and the largest area of lineaments. The biggest proportion of landslide hazard lies in dry land agriculture with a percentage of 75.75%. Sentinel-1 can be an alternative to landslide mapping by building a SAR product into several slope parameters.

1 Introduction

Landslide is a disaster that always occurs in Sumedang Regency. The geographical conditions of Sumedang Regency such as volcano, denudational, structural and other areas make this location a potential for landslides. Some cases always occur landslides almost every year. Landslides are spread over several points with different land cover variations. This condition is very worrying if it occurs in agricultural areas, rice fields and plantations, because there is the potential for material losses. Landslides often occur in geographical environments with high slopes and are influenced by natural and anthropogenic activities [1]. Landslide hazard occurs in differences in land cover and is important to analyze [2].
Sentinel-1 remote sensing product is a radar satellite constellation capable of recording the earth's surface to form a Synthetic Aperture Radar (SAR) with fairly good quality [3]. Synthetic Aperture Radar (SAR) products are able to analyze landslides based on the parameters of the earth's surface terrain, especially on morphological aspects [4]. Terrain parameters are an important part of landslide studies such as slope [5], aspect, curvature and topographic wetness index (TWI). Sentinel-1 is capable of making Synthetic Aperture Radar (SAR) results on terrain aspects with a C-band Synthetic Aperture Radar sensor with medium spatial resolution [6].

Sentinel-1 product is good enough to be used in landslide studies in mountainous areas with slope parameters [7]. Landslides occur on the surface of the earth with terrain characteristics that are influenced by other aspects such as soil conditions [8], geological [9], and meteorological/hydrological. In the geological aspect, the type of rock will affect the occurrence of landslides [10], besides that the closer to the active fault area, the more potential for landslides. Soil texture is the result of rock weathering which is one of the landslide parameters. Landslide events usually occur when it rains, because rain carries energy towards the terrain, so that in some conditions that support the earth's surface, landslides will occur [11]. Several aspects of the terrain can be analyzed using sentinel-1. Sentinel-1 has fairly good accuracy when compared to more accurate spotheight data [12].

Landslide hazard can be mapped using GIS technology with empirical supporting parameters [13]. One of the units that produces landslide mapping parameter products in Indonesia is the National Disaster Management Agency or Badan Nasional Penanggunalangan Bencana (BNPB). The combination of GIS technology and BNPB landslide parameters can build a fairly empirical map product. Multiple terrain parameters can be constructed using the sentinel-1 product as a freely accessible, intermediate spatial resolution solution.

Landslides can be a disaster if there are affected assets, one of which is agricultural areas, plantations and rice fields. In that area there are several types of assets that can materially cause losses. Mapping landslide vulnerability in agricultural areas, plantations and rice fields is very important to do, to minimize disaster risk. The map product is one of the mitigation efforts, so that at several locations of high vulnerability, they are able to anticipate events.

* Corresponding author: haikalmihsan@upi.edu

This study aims to map the landslide hazard in agricultural areas, plantations and paddy fields. The area has large material assets which are a source of food for the community, so it is very important to map it. This study uses sentinel-1 products combined with secondary data on geology, soil, and meteorology. The standard parameter mapping refers to BNPB which is modified with other parameters. This research is useful for GIS users and sentinel-1 products in landslide studies.

2 Method

The research location for the use of sentinel-1 for zoning landslide susceptibility is in the area covered by dry land agriculture, plantations and rice fields in Sumedang Regency, West Java Province, Indonesia. This location has an area of 157697.540355 ha and coordinates 107°44'0"E - 108°16'0"E and 6°55'0"S - 7°30'0"S. This location was chosen because it often experiences landslides. This location has a variety of different landforms and includes landslide-prone categories, such as volcano, denudational and structural. Sumedang Regency experiences landslides almost every year, especially during the rainy season. The use of sentinel-1 is very suitable for studying landslides in this area.

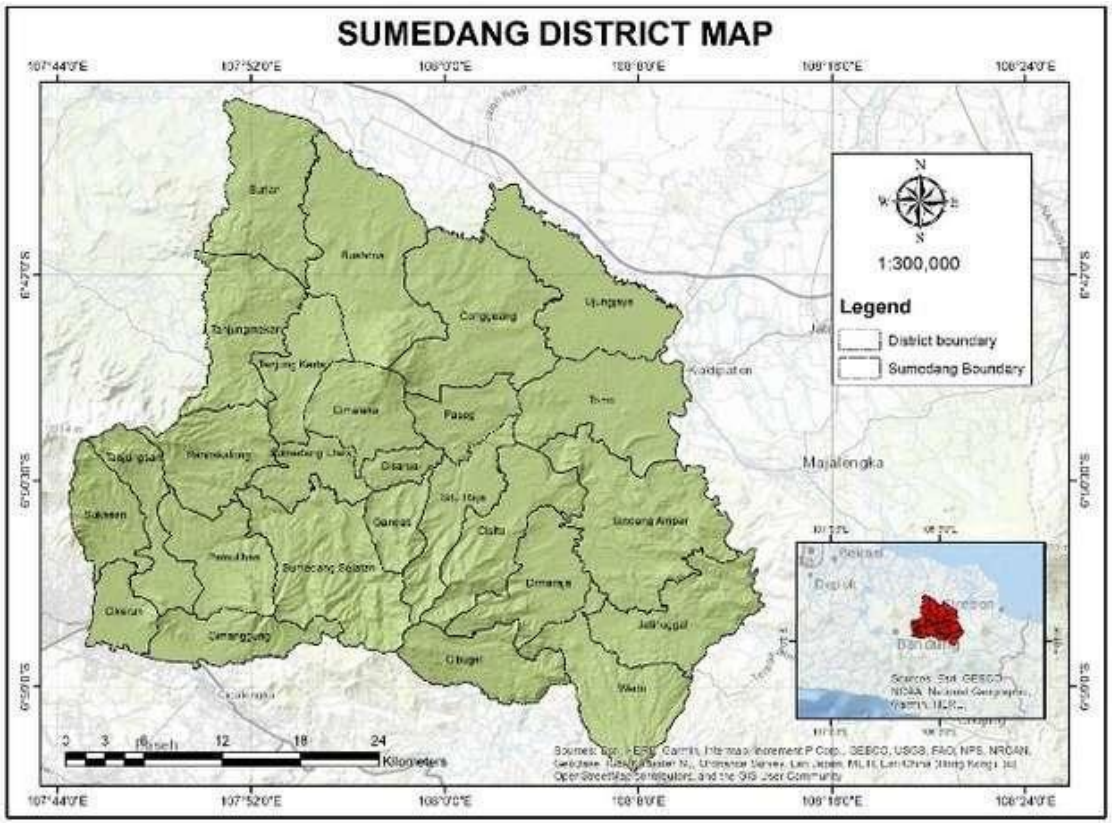

Fig. 1. Research Area.

2.1 Slope

The slope of the slope in the study area was analyzed using slope tools in ArcGIS software. The slope data is constructed from the sentinel-1 product. Sentinel-1 used was produced on 7 April 2023 and can be freely accessed via https://scihub.copernicus.eu/. Sentinel-1 is processed using the Sentinel application Platform (SNAP) software to become radar data [14] which later became the Synthetic Aperture Radar (SAR) with a spatial resolution of 10m. The unit used in the slope study is percent, because it is adjusted to the parameters available at INARISK BNPB, namely 15-30%, 30-50% and 50-70%. Landslides often occur on steep slopes, so there is a statement that the steeper the terrain, the more potential for landslides [15].

2.2 Aspect

Aspect is the direction of slope which is usually associated with landslide events, because it is related to the catchment of the slope to sunlight [16]. Slopes facing east get more morning sunlight than slopes facing west, slopes facing north get more sunlight in the dry season compared to slopes facing south, Aspect was built using Sentinel-1 processed using SNAP and ArcGIS software. SNAP functions for the formation of radar and SAR, while ArcGIS functions for building aspects of SAR.

2.3 Curvature

Curvature is one of the landscape features in the form of slope ridge curvature and slope basin curvature. Curvature is of course very influential on landslide modeling [15]. In general, landslides usually occur in concave curvature, due to gravity and material gaps fall according to the direction of gravity and terrain conditions. This study follows a curvature form built from Sentinel-1 data, with SNAP and ArcGIS software processing. The landslide material will be affected by the shape of the curvature, because it is the inflow and outflow of sediment, so the curvature variable is related to the divergence and convergence of the landslide material [17].

2.4 Rock Type

The rock type will describe the characteristics of the terrain in an area. Similar rock types will generally form regional formations [18]. Landslides occur due to the movement of various types of soil or rock masses, so that geology is one of the landslide parameters [19]. In this study, rock types were classified into three types according to INARISK BNPB, namely alluvial, sedimentary and volcanic rock types. The difference in rock types is caused by the process of formation and location. Volcanic rock types are more prone to landslides than sedimentary and alluvial. The rock type was analyzed based on the geological maps of Bandung and Arjawinangun sheets. Each formation on the geological map will be analyzed for its parent material and narrowed down to the rock type according to the BNPB classification

2.5 Distance Lineament

Faults can be an indication of an area prone to landslides. Faults are areas of fracture accompanied by a relative shift or displacement from one rock block to another. Active faults are usually a trigger for ground movement which triggers landslides. The closer to the fault area, the more prone to landslides [20]. Lineaments were analyzed from Sentinel-1 products using three software, namely SNAP, PCI Geomatica, and ArcGIS. SNAP serves for the construction of radar data. PCI Geomatica functions for fault analysis in the Sumedang Regency area, while ArcGIS functions as a lineament distance buffer.

2.6 Soil Texture

Soil texture is strongly associated with landslide susceptibility. Soil texture has different physical characteristics of the soil [21], the finer it is, the greater the surface area of the soil, and the more water in the ground, so that slopes have a high load and have the potential for landslides [22]. Soil texture In general, there are three fractions, namely sand, silt and clay. In this study, soil texture data was accessed freely through https://drive.google.com/file/d/1dziY70wVxGQNdIjE9dbqwe07_ihmv9c_/view which was sourced from FAO-Unesco in 2007. The product was adjusted to standards at BNPB with three textures namely sandy, clayey sandy and clayey. Products are processed using ArcGIS software.

2.7 Topographic Wetness Index

The Topographic Wetness Index (TWI) parameter is often used in analyzing terrain characteristics. This index describes the wettability associated with surface runoff based on topographical control. The TWI parameter is also able to study the pattern of spatial distribution of the surface water saturation zone. In the study of landslides, the TWI value will be useful when compared with the slope [23]. A high TWI value is assumed to have a high saturation value, on steep slopes and in the highlands water saturation makes the slope load high, so it has the potential to be prone to landslides [24].

2.8 Rainfall

Each amount of precipitation carries energy that falls to the Earth's surface, causing run off and infiltration. Rain triggers landslides, because it becomes a stimulant for increasing the load on slopes with certain terrain specifications. The greater the rain that falls, the more potential for landslides [25]. The rain data used is the CHIRPS satellite product, freely accessible via https://www.chc.ucsb.edu/data/chirps. The data used is annual rainfall from 2017 – 2022. The data used for rain analysis should have been at least ten years old, but in this study, rain was tried using satellite data with a five-year range. Rainfall data is processed using the Inverse Distance Weighting (IDW) technique in GIS software. IDW is used, because it has the concept of literal spatial autocorrelation, which means that the closer the sample point value is to the prediction point, the closer the cell value is to the sample point value [26].

2.9 Agriculture

The agricultural aspects in this study are all forms of agricultural land, both wetland agriculture, dry land, horticultural and others. In this study, there are three types of classification of agricultural land cover, namely dry land agriculture, plantations and paddy fields. These three aspects are typical plants in Sumedang Regency, especially dry land and paddy

fields. Agricultural data obtained from https://tanahair.indonesia.go.id/portal-web which can be accessed freely. Further classified into wetland agriculture, paddy fields and plantations. Agricultural data is mapped using GIS software.

2.10 Landslide

The landslide hazard zoning model refers to the Indonesian Disaster Risk book from BNPB. The weighting and scoring are taken from the model developed by BNPB, but there are modifications to the soil part, namely there is no soil solum, so that in this study the values for the soil solum are replaced with the Topographic Wetness Index values. These indes can identify water accumulations based on topographical control and characterize the morphological conditions of landslides [24]. In general, there are 4 core parameters, namely SAR from Sentinel-1, geology, soil and meteorology (Table 1). Each parameter is divided into scores and weights which are then processed in GIS software with an overlay technique.

Table 1. Research Parameters

No	Data	Parameter	Classification	Class Value	Score	Weight
1	Sentinel-1 / SAR	Slope	15% – 30%	1	0.250	0.3
			30% – 50%	2	0.500	
			50% - 70%	3	0.750	
		Aspect	Flat	0	0.000	0.05
			North	1	0.125	
			Northwest	2	0.250	
			West	3	0.375	
			Northeast	4	0.500	
			Southwest	5	0.625	
			East	6	0.750	
			Southeast	7	0.875	
			South	8	1.000	
		Curvature	<200 m	1	0.250	0.05
			200 – 500m	2	0.500	
			500 – 1000m	3	0.750	
			>1000m	4	1.000	
		Topograhic Wetnes Index	0.509 – 6.122	1	0.250	0.05
			6.122 – 9.981	2	0.500	
			9.981 – 22.874	3	0.750	
2	Geology	Rock Type	Alluvial Rock	1	0.333	0.2
			Sedimentary Rock	2	0.667	
			Volcanic Rock	3	1.000	
		Distance from the Fault	>400	1	0.200	0.05
			300 – 400m	2	0.400	
			200 – 300m	3	0.600	
			100 – 200m	4	0.800	
			0 – 100m	5	1.000	
3	Soil	Soil Texture	Sand	1	0.333	0.1
			Clay – Sand	2	0.667	
			Clay	3	1.000	
4	Meteorology	Rainfall	<2000 mm	1	0.333	0.2
			2000 – 3000 mm	2	0.667	

			>3000 mm	3	1.000	

2.11 Landslides in Agricultural Areas

Landslide studies on agricultural land were carried out using the intersect type overlay technique. This technique combines two types of vectors with slices that are adjusted by parameters. The output of the intersection is the presence of landslide hazard zones on dry land, agricultural land, plantations and paddy fields, so that the spatial distribution of landslide map products in agricultural areas can be seen. The landslide hazard products will be classified into 5 classes, namely very low, low, medium, high and very high

3 Results and Discussion

3.1 Slope

The slope of the slopes in Sumedang Regency is spread over various slope classifications. The slope is divided into three classifications, namely 15% -30% (sloping) with an area of 127972.75448 ha, 30% -50% (rather steep) with an area of 21244.895705 ha, and 50% -70% (very steep) with an area of 6561.398885 ha. Conditions of very steep slopes are scattered in the southern, western and eastern parts of Sumedang Regency. In the southern area it is bordered by hilly areas in the Bandung and Garut Regencies. In the southern area it is bordered by the hills of Subang Regency and Bandung Regency. The hills form the natural boundaries of the Sumedang Regency area so that on both sides the slopes are very steep. The slope of the sloping slopes is spread across the northern part of Sumedang Regency. This area is an average fluvial area so it has a gentle slope. This condition can be seen in figure 2

3.2 Aspect

The aspect at the study location has a slope with a total of 10, namely Flat (-1), North (0-22.5), Northeast (22.5-67.5), East (67.5-112.5), Southeast (112.5-157.5), South (157.5-202.5), southwest (202.5-247.5), West (247.5-292.5) Northwest (292.5-337.5) and North (337.5-360). Based on the analysis, the highest number of aspects is facing Northeast, while the minimum aspect is facing South (Figure 2). In Sumedang Regency, on average, slopes facing east get more morning sunlight than slopes facing west, slopes facing north get more sunlight during the dry season than slopes facing south. This condition is caused by the latitude and longitude of Indonesia and especially Sumedang Regency.

3.3 Curvature

The results of the analysis show that the curvature values in the study area are -27.11148834 to 24.8296566. Negative values indicate the shape of the slope at the study site, which is concave, while positive means the opposite. Based on the analysis of the study area, the majority of them have transitional slopes between concave and convex. The comparison between convex and concave shapes is more dominant with concave slope shapes. This condition is one of the causes of several study areas where landslides often occur during the rainy season. The shape of the slopes in the study area is widely spread in the western, eastern, southern and central areas. The area is hilly to mountainous.

3.4 Rock Type

Based on the geological map, Sumedang Regency has 25 geological formations, namely alluvium, andesite, brecia agglomerate, cilanang formation, cinambo formation, citalang formation, coastal deposits, colluvium, folded breccia, kaliwangu formation, halang formation, hornblende andesite, kaliwangu formation, lava, old volcanic product breccia, old volcanic product lava, older volcanic product, pumiceous tuff, reef limestone, subang formation, tuffaceous clay unit, tuffaceous sandstone conglomerate, and upper member of halang. These formations include sedimentary lithology classes, clastic, alluvium, intrusive intermediate, claystone, sandstone, marl, coarse, breccia, lava, extrusive, pyroclastic, polymict, fine and shale.
In this study, lithology and formations were classified according to the INARISK BNPB rock types, namely alluvial rock with an area of 20140.126167 ha, volcanic rock with an area of 91587.193422 ha, sedimentary rock with an area of 45538.063231 ha and the rest of the water bodies with an area of 432.157544 ha. Alluvial rocks are scattered in the north, northwest and central areas of Sumedang Regency. The scattered volcanic rocks stretch at various angles to the wind direction with the widest proportions. This condition causes the Sumedang Regency area to have a volcano, namely Mount Tampomas, so that volcanic material is widely spread in the study area. The sedimentary area is in the transition area between Alluvial and Volcanic as shown in figure 2.

3.5 Distance Lineament

The faults in this study are associated with lineaments extracted from radar data. The results of the analysis show that there are 2538 lineaments in Sumedang Regency. The lineament flies in the southern area of the study location, then it is followed in the western area of the study. Locations with a large number of lineaments are locations with high landslide potential. Lineament buffer analysis is 100m per class. In this study there are five classifications based on distance, namely 0m - 100m with an area of 14813.314029 ha, 100m - 200m with an area of 19761.345963 ha, 200m - 300m with an area of 25187.486744 ha, 300m - 400m with an area of 33798.446087 ha and more than 400m is the remaining area. The closest distance becomes the smallest area, because there are many lineaments that are close together between one lineament and another as shown in figure 2. Usually the fault area is an area with brittle source rock, especially in active faults. This condition causes the area near the fault to have a high potential for landslides.

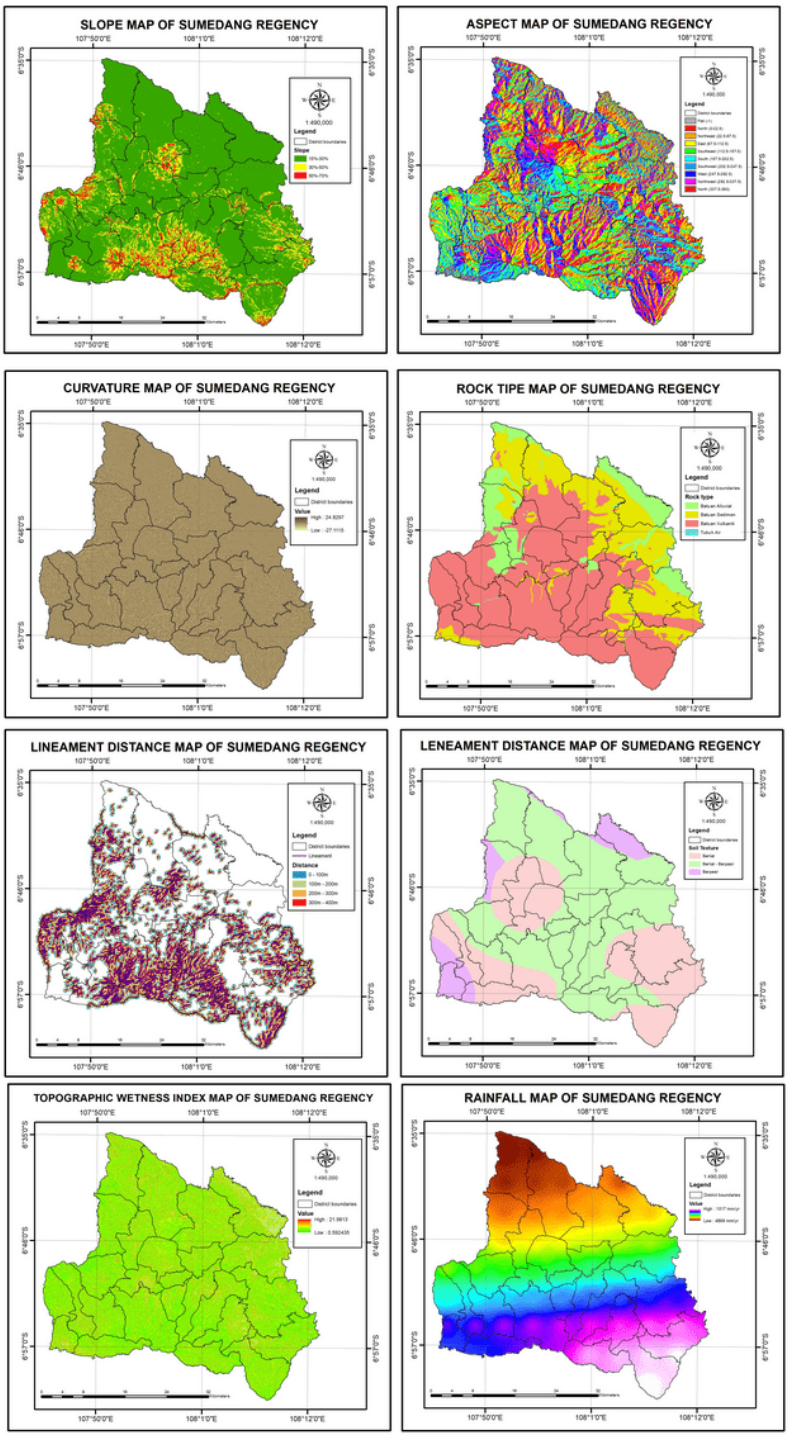

Fig. 2. Research Parameter

3.6 Soil Texture

Based on the results of data analysis from FAO Unesco in 2007, Sumedang Regency has several soil codes with various percentages of topsoil and subsoil textures both in the sand, silt and clay fractions. The symbols available in the analysis results are Ao70-2/3b, Ao83-2/3c, Be116-2c, Vc57-3ab, Bg7-2/3a, Nd54-3b, To24-2c and Lv5-3b. This classification is converted to soil texture for landslide susceptibility of the bnpb version so that there is sand with an area of 13618.140772 ha, sandy-loam with an area of 86498.254508 ha, and clay with an area of 57488.415904 ha. The source rock of origin affects the texture of the soil. The sandy-clay area is the largest area because of the transition area between sedimentary rock and volcanic rock, so that this fraction is the dominant fraction in the study area. The sandy texture is mostly scattered in the north and southeast areas, the sandy-clay fraction is widely distributed in almost the entire study area while the clayey is spread in the central, southern and eastern areas of the study area which can be seen in figure 2.

3.7 Topographic Wetness Index

The study area has a Topographic Wetness Index value of 0.592435 – 21.9813 for each area. In this study the Topographic Wetness Index values were divided into 3 classes, namely 0.422013 - 6.12291 with area, 6.12291 - 9.981979, 9.981979 - 22.874777. Topographic Wetness Index values are spread evenly in each study area. Each Topographic Wetnes Index value describes the hydrological control characteristics based on topography. Areas with high Topographic Wetness values are indicated to have high saturation values. On steep slopes and on plateaus, water saturation makes the slope loads high, making it potentially prone to landslides. In this case the Topographic Wetness Index value can support landslide potential with a combination of slope parameters as shown in figure 2.

3.8 Rainfall

The results of the analysis show that rainfall in Sumedang Regency has a range of 1017 mm/year – 4899 mm/year. The classification is divided into three according to INARISK BNPB, namely <2000 mm with an area of 49829.805081 ha, 2000 mm – 3000 mm with an area of 49292.112224 ha, and >3000 mm with an area of 58561.179558 ha. The analysis results show that rain with more than 3000 mm is scattered in the south of the study area. Rainfall of less than 2000mm is spread in the north of Sumedang Regency. This condition causes the central and southern areas to be included in the category of high landslide potential as shown in figure 2. Rain conditions are related to the existing geographical location, such as hilly and mountainous areas that tend to have high-intensity rain.

3.9 Agricultural

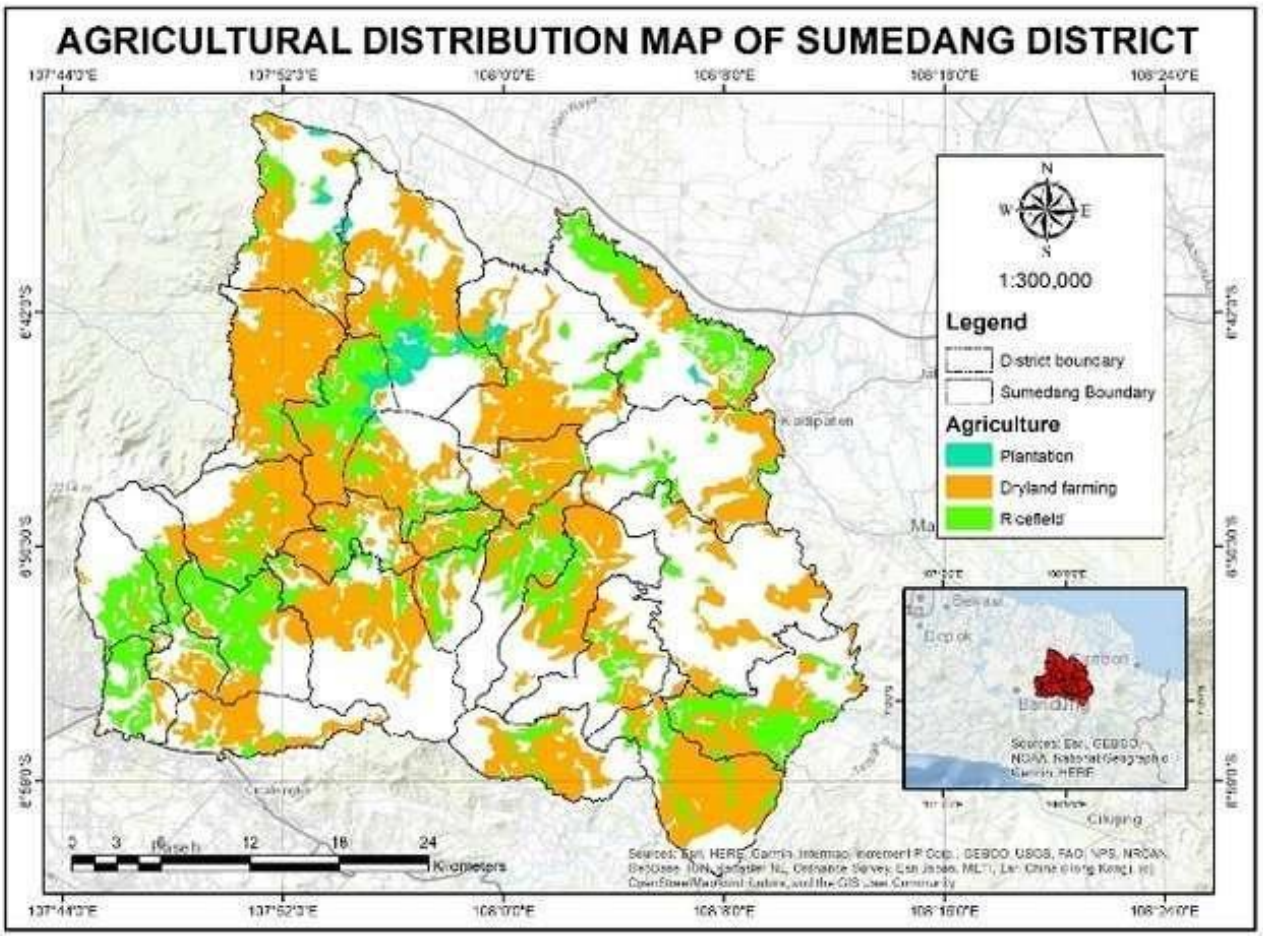

Fig 3. Agricultural Map of Sumedang Regency

Based on the analysis, Sumedang Regency has an agricultural land area of 82292.33224 ha. Agricultural land includes dry land agriculture with an area of 54651.758345 ha, paddy fields with an area of 25860.466019 ha and plantations with an area of 1780.107876 ha. The plantation area is an area with a low area and is only spread around the middle of Sumedang Regency, because the area is part of Mount Tampomas. In general, the study area has dry land agricultural areas which are spread almost entirely in Sumedang Regency. The geographical factor of Sumedang Regency makes this location often found in dry land agriculture. Paddy fields became the second dominant area after dry land farming as shown in figure 3. The pattern of distribution of paddy fields is almost the same as dry land farming which is spread throughout the study area. In some areas, agriculture is one of the people's livelihoods in Sumedang Regency.

3.10 Landslides

Landslides are divided into 5 classifications, namely very low with an area of 5995.762355 ha, low with an area of 19333.832863 ha, medium with an area of 28240.806603, high with an area of 21185.690552 ha and very high with an area of 11856.50693 ha. The spatial distribution explains that the southern area of Sumedang Regency tends to have a high to very high potential for landslides. This area is a hilly area which has brittle parent rock, steep slopes, clay soil texture, high rainfall so that landslides are often found in that location. Several locations with high landslide proneness are near the Mount Tampomas area. The location is a volcanic area with quite fragile material, but moderate rainfall so that landslides are more prone to landslides in the southern area, but several points experience the same landslide vulnerability, because several landslides often occur around Mount Tampomas. The northern area of Sumedang Regency is in the very low category and even there are almost no landslides, because it is a lowland area that rarely has slopes. Spatial landslide hazard conditions can be seen in figure 4.

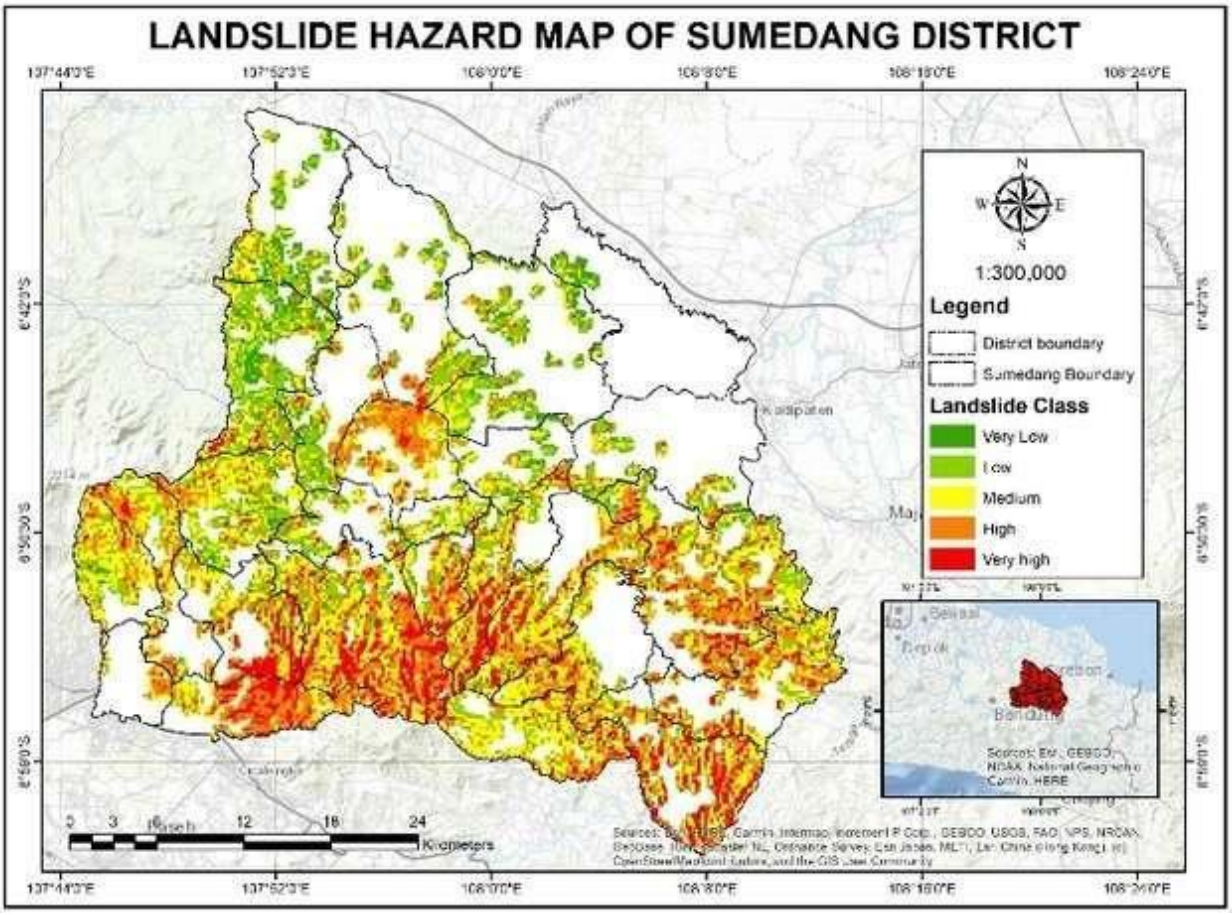

Fig 4. Landslide Hazard Map

3.11 Landslides in Agricultural Areas

The landslide hazard in the agricultural area has an area of 421684550.60 ha. The highest proportion was found in dry land agricultural areas with a proportion of 75.75%, followed by paddy fields with 23.13%, and the lowest proportion with plantations with 1.12%. This condition is in accordance with the proportion of agricultural land area in Sumedang Regency. The proportion of the percentage of landslide hazard is in the moderate classification in dry land farming areas. In dry land agriculture, several conditions often occur with landslides so that there are 15.64% in the high classification (Table 2). The spatial conditions of landslide hazard in agricultural areas can be seen in Figure 5. Sentinel-1 has a spatial resolution on the radar of 10m, this product can be an alternative to landslide mapping by utilizing aspects of medium-scale slopes

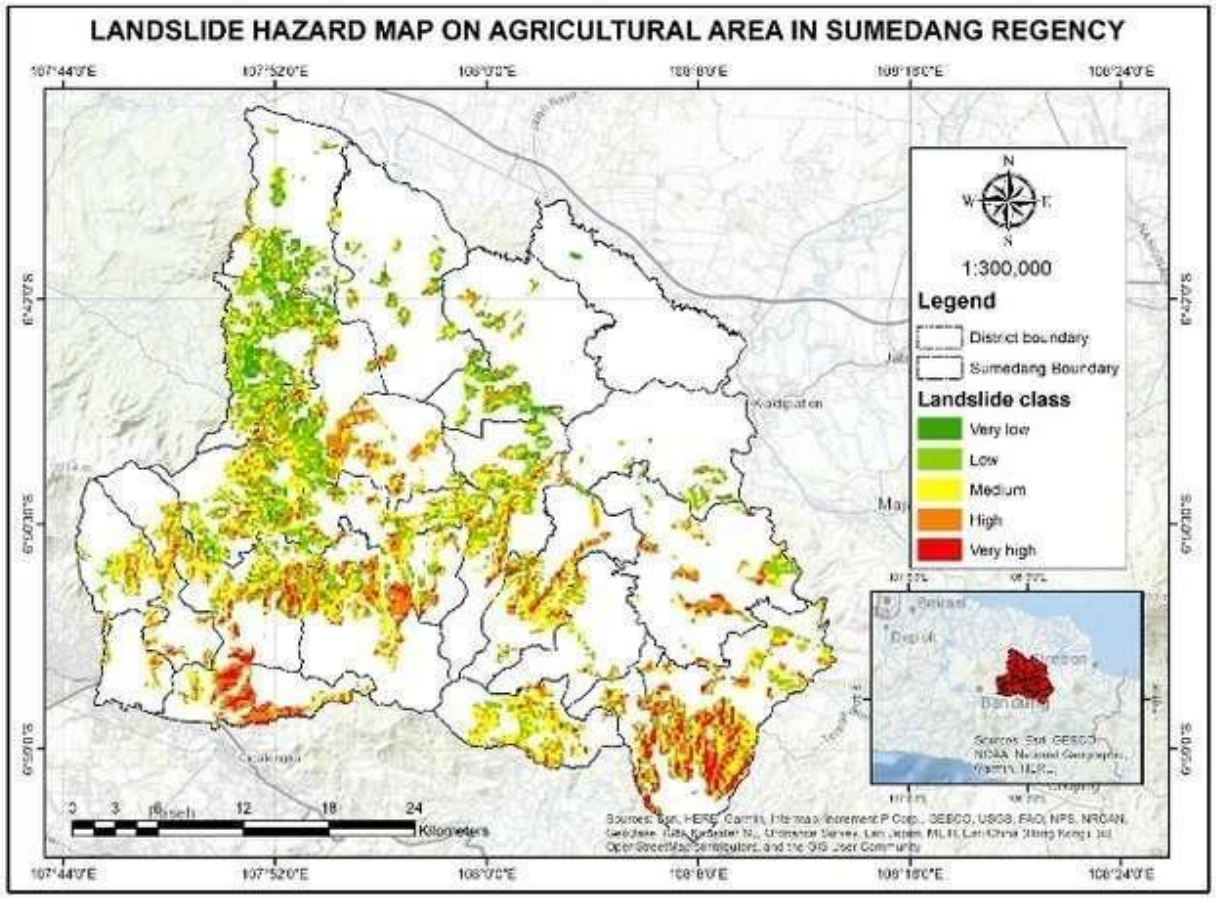

Fig 5. Landslide Hazard on Agricultural Area Map

Table 2 Agricultural Landslide Areas

Agriculture	Classification	Area ha	Percentage	Total Percentage
Dryland farming	Very low	32063093.83	7.60%	75.75%
	Low	88976621.02	21.10%	
	Medium	103744425.51	24.60%	
	High	65932756.29	15.64%	
	Very high	28691337.37	6.80%	
Ricefield	Very low	6284947.02	1.49%	23.13%
	Low	25526360.04	6.05%	
	Medium	33660405.12	7.98%	
	High	21829507.69	5.18%	
	Very high	10249774.63	2.43%	
Plantation	Very low	708385.92	0.17%	1.12%
	Low	1613172.18	0.38%	
	Medium	1092661.39	0.26%	
	High	1119632.96	0.27%	
	Very high	191469.63	0.05%	
Total		421684550.60	100%	100%

4 Conclusion

Landslide areas in Sumedang Regency tend to spread in the Southern Region. This area is a complex of hills with steep slopes, old volcanic parent rock which is quite brittle, high rainfall, clay soil texture, and the largest area of lineaments. Other landslide-prone areas are located around Mount Tampomas, whose geographical conditions are not much different from the Southern Region of Sumedang Regency. The biggest proportion of landslide hazard lies in dry land agriculture with a percentage of 75.75%, while the lowest is plantations around 1.12% and paddy fields with 23.13%. Sentinel-1 can be an alternative to landslide mapping by building a radar product into several slope parameters. The landslide locations in the high and very high classifications correspond to the slope aspect parameters built by Sentinel-1.

References

1. H. Sun, W. Li, M. Scaioni, J. Fu, X. Guo, and J. Gao, "Influence of spatial heterogeneity on landslide susceptibility in the transboundary area of the Himalayas," *Geomorphology*, **vol. 433**, no. May, p. 108723, (2023), doi: 10.1016/j.geomorph.2023.108723.
2. A. . Arrasyid, R., Ihsan, H. M., Darsiharjo., Ruhimat, M., Pratama, "Suitability Evaluation of Land Use / Land Cover (LULC) Towards Landslide Prone Areas in Structural and Volcano Landform," **vol. 19**, no. 6, pp. 61–75, (2023).
3. K. Dai *et al.*, "Monitoring activity at the Daguangbao mega-landslide (China) using Sentinel-1 TOPS time series interferometry," *Remote Sens. Environ.*, **vol. 186**, pp. 501–513, 2016, doi: 10.1016/j.rse.2016.09.009.
4. X. Liu *et al.*, "Integration of Sentinel-1 and ALOS/PALSAR-2 SAR datasets for mapping active landslides along the Jinsha River corridor, China," *Eng. Geol.*, **vol. 284**, no. February, p. 106033, (2021), doi: 10.1016/j.enggeo.2021.106033.
5. H. Shankar, D. Singh, and P. Chauhan, "Landslide deformation and temporal prediction of slope failure in Himalayan terrain using PSInSAR and Sentinel-1 data," *Adv. Sp. Res.*, **vol. 70**, no. 12, pp. 3917–3931, (2022), doi: 10.1016/j.asr.2022.04.062.
6. M. Santangelo, M. Cardinali, F. Bucci, F. Fiorucci, and A. C. Mondini, "Exploring event landslide mapping using Sentinel-1 SAR backscatter products," *Geomorphology*, **vol. 397**, p. 108021, (2022), doi: 10.1016/j.geomorph.2021.108021.
7. T. Zhang *et al.*, "Detection of active landslides in southwest China using sentinel-1 and ALOS-2 data," *Procedia Comput. Sci.*, **vol. 181**, no. (2019), pp. 1138–1145, 2021, doi: 10.1016/j.procs.2021.01.311.
8. K. C. Niraj, S. K. Gupta, and D. P. Shukla, "Kotrupi landslide deformation study in non-urban area using DInSAR and MTInSAR techniques on Sentinel-1 SAR data," *Adv. Sp. Res.*, **vol. 70**, no. 12, pp. 3878–3891, (2022), doi: 10.1016/j.asr.2021.11.042.
9. Q. Xu *et al.*, "Remote sensing for landslide investigations: A progress report from China," *Eng. Geol.*, **vol. 321**, no. August 2022, p. 107156, (2023), doi: 10.1016/j.enggeo.2023.107156.
10. D. K. Dwivedi, A. K. Saraf, and J. D. Das, "Geoinformatics-based investigation of slope failure and landslide damming of chenab river, lahaul-spiti, Himachal Pradesh, India," *Nat. Hazards Res.*, **vol. 3**, no. 2, pp. 186–195, (2023), doi: 10.1016/j.nhres.2023.02.008.
11. B. Li, W. Jiang, Y. Li, Y. Luo, Q. Jiao, and Q. Zhang, "ScienceDirect Monitoring and analysis of Woda landslide (China) using InSAR and Sentinel-1 data," *Adv. Sp. Res.*, no. xxxx, pp. 1–14, (2023), doi: 10.1016/j.asr.2023.04.055.
12. H. M. Ihsan and S. S. Sahid, "Vertikal Accuracy Assessment On Sentinel-1, Alos Palsar, And Demnas In The Ciater Basin," *J. Geogr. Gea*, **vol. 21**, no. 1, pp. 16–25, 2021, doi: 10.17509/gea.v21i1.29931.
13. J. Das, P. Saha, R. Mitra, A. Alam, and M. Kamruzzaman, "GIS-based data-driven bivariate statistical models for landslide susceptibility prediction in Upper Tista Basin, India," *Heliyon*, vol. 9, no. 5, p. e16186, (2023), doi: 10.1016/j.heliyon.2023.e16186.
14. A. A. A. Rahman, N. Abd Majid, N. Adhalysha Ahli, A. Sharifuddin Ab Latip, and A. Mohd Taib, "The capability of SNAP software application to identify landslide using InSAR technique," *Phys. Chem. Earth*, **vol. 131**, no. (August 2022), p. 103427, 2023, doi: 10.1016/j.pce.2023.103427.
15. L. Bragagnolo, R. V. da Silva, and J. M. V. Grzybowski, "Landslide susceptibility mapping with r.landslide: A free open-source GIS-integrated tool based on Artificial Neural Networks," *Environ. Model. Softw.*, **vol. 123**, no. (October 2019), p. 104565, 2020, doi: 10.1016/j.envsoft.2019.104565.
16. Y. Wang *et al.*, "Automatic detection and update of landslide inventory before and after impoundments at the Lianghekou reservoir using Sentinel-1 InSAR," *Int. J. Appl. Earth Obs. Geoinf.*, **vol. 118**, no. February, p. 103224, (2023), doi: 10.1016/j.jag.2023.103224.
17. V. E. Nwazelibe, C. O. Unigwe, and J. C. Egbueri, "Testing the performances of different fuzzy overlay methods in GIS-based landslide susceptibility mapping of Udi Province, SE Nigeria," *Catena*, **vol. 220**, no. PA, p. 106654, (2023), doi: 10.1016/j.catena.2022.106654.
18. N. Abbas, S. Afsar, B. Jan, E. A. Sayla, and F. Nawaz, "GIS based model for the landslides risk assessment. A case study in Hunza-Nagar settlements, Gilgit-Baltistan, Pakistan," *Environ. Challenges*, **vol. 7**, no. February, p. 100487, (2022), doi: 10.1016/j.envc.2022.100487.
19. P. K. Rawat and D. B. Pant, "Geo-Ecological GIS Development to Investigate Landslides and Slope Instability Along Frontal Zone of Central Himalaya," *SSRN Electron. J.*, **vol. 3**, no. 2, pp. 196–204, (2022), doi: 10.2139/ssrn.4251397.

20. D. Asmare, "Landslide hazard zonation and evaluation around Debre Markos town, NW Ethiopia—a GIS-based bivariate statistical approach," *Sci. African*, **vol. 15**, p. e01129, (2022), doi: 10.1016/j.sciaf.2022.e01129.
21. B. Zhao, Q. Dai, L. Zhuo, S. Zhu, Q. Shen, and D. Han, "Assessing the potential of different satellite soil moisture products in landslide hazard assessment," *Remote Sens. Environ.*, **vol. 264**, no. June, p. 112583, (2021), doi: 10.1016/j.rse.2021.112583.
22. A. A. Mekonnen, T. K. Raghuvanshi, K. V. Suryabhagavan, and T. Kassawmar, "GIS-based landslide susceptibility zonation and risk assessment in complex landscape: A case of Beshilo watershed, northern Ethiopia," *Environ. Challenges*, **vol. 8**, no. July, p. 100586, (2022), doi: 10.1016/j.envc.2022.100586.
23. I. Sonker, J. N. Tripathi, and A. K. Singh, "Landslide susceptibility zonation using geospatial technique and analytical hierarchy process in Sikkim Himalaya," *Quat. Sci. Adv.*, **vol. 4**, p. 100039, (2021), doi: 10.1016/j.qsa.2021.100039.
24. J. Efiong, D. I. Eni, J. N. Obiefuna, and S. J. Etu, "Geospatial modelling of landslide susceptibility in Cross River State of Nigeria," *Sci. African*, **vol. 14,** (2021), doi: 10.1016/j.sciaf.2021.e01032.
25. T. Arumugam, S. Kinattinkara, S. Velusamy, M. Shanmugamoorthy, and S. Murugan, "GIS based landslide susceptibility mapping and assessment using weighted overlay method in Wayanad: A part of Western Ghats, Kerala," *Urban Clim.*, **vol. 49**, no. December 2022, p. 101508, (2023), doi: 10.1016/j.uclim.2023.101508.
26. Ihsan, H. M., Astari, A. J., Bratanegara, A. S., Aliyan, S. A. and Wulandari, E. P. "The Comparison of Spatial Models in Peak Ground Acceleration (PGA) Study," *Int. J. Geoinformatics*, **vol. 17**, no. 6, pp. 27–33, (2021), doi: 10.52939/ijg.v17i6.2061.