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Mapping drought prone areas using the weight overlay method in Serang Regency

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Abstract

This research aims to analyse or estimate drought vulnerability in Serang Regency. The background of this research is based on areas that often experience moderate and even high levels of drought. The research method used is quantitative by using rainfall parameters, soil type parameters, and land use parameters which are then put together using the overlay method to obtain drought vulnerability areas in Serang Regency. Based on the results of the research, there are areas with low, medium, and high levels of drought vulnerability. The area with the largest drought vulnerability in Serang Regency is at the medium level of vulnerability. The results of the map analysis of the level of drought vulnerability indicate that there is a relationship between each parameter, with most of the drought vulnerability being influenced by several factors, including rainfall, soil type, and land use.

Keywords: drought; overlay; rainfall

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INTRODUCTION

Indonesia is located between two continents and two oceans, which causes its climate conditions to be influenced by various factors, including the El Niño Southern Oscillation (ENSO) phenomenon. ENSO occurs when sea surface temperatures in the central to eastern equatorial Pacific Ocean increase, which has an impact on changes in rainfall patterns in Indonesia (Cahyono et al., 2017). Drought in Indonesia is influenced by the tropical monsoon climate, which is very sensitive to this phenomenon. The Meteorology Climatology and Geophysics Agency (BMKG) notes that a number of regions in Indonesia experience an intense dry season with very low rainfall. According to BMKG (2021), areas experiencing drought include Sumatra, Java, Bali, West Nusa Tenggara (NTB), East Nusa Tenggara (NTT), and several areas in Sulawesi.

Serang Regency, located in Banten Province, Java Island, Indonesia, is one of the areas experiencing drought. Based on BMKG data (2023), rainfall in Serang Regency has tended to decrease in recent years, making the area vulnerable to drought. Drought often refers to a natural phenomenon with reduced water availability. This occurs due to a combination of the ENSO phenomenon and sea surface temperature anomalies in the Indian Ocean. In addition to climatic factors, human activities that lead to increased water demand and use also contribute to water supply imbalances, thus worsening drought conditions in densely populated areas (Mu'awanah Sukmawati et al., 2022). Drought is a problem that often occurs in Indonesia, especially Serang Regency, but the maintenance and resolution taken are long so that it becomes a prolonged problem (Cahyono et al., 2017).

Drought has complex long-term impacts, ranging from disruption of agricultural production to clean water crisis (Dewi et al., 2023). Therefore, mapping drought vulnerability is an important step in mitigation and adaptation efforts. However, most previous studies have focused on analysing one dominant variable, such as rainfall and temperature, without considering the interrelationship of other factors that influence drought, such as soil type and land cover. This creates a research gap in understanding drought from a holistic and spatial perspective. Rainfall is the main factor that affects the availability of water in a region. Rainfall is defined as the amount of water received on the surface before it undergoes surface flow, evaporation, and infiltration into the soil. The amount of rainfall received by an area depends on several factors, such as water vapour circulation, latitude, altitude, wind direction, distance from water sources, the presence of mountains, and relative soil temperature (Saputra et al., 2021). As a result of these factors, the distribution of rainfall tends to be uneven between one region and another (Swarinoto & Sugiyono, 2011).

However, the effectiveness of water falling on the surface is greatly influenced by soil characteristics and land use. Coarse-textured soils, such as sand, have a low water retention capacity, so water percolates more quickly and is not available to plants for long. In contrast, finer textured soils, such as clays, can retain water longer, but if the clay content is too high, it can lead to poor drainage and increase the risk of inundation. Supinah (2017) revealed that Regosol soils have a higher permeability rate than Latosol, increasing the potential for drought in areas with this soil type. Land use also affects the vulnerability of the area to drought. Forest land use has better water conservation capabilities than open or developed land. Analysing land use patterns and changes can provide insight into its impact on the environment, including water availability. In quantitative research, this approach often uses remote sensing data and Geographic Information Systems (GIS) to map and analyse land use change spatially and temporally. For example, research by Putudewi (2021) used the SHETRAN physically-based hydrological model to assess the impact of land use change on river flow discharge in the Ciwulan watershed, which has implications for water availability during the dry season.

According to Rizki (2023), drought is a natural disaster that has a high frequency of occurrence and almost always occurs every dry season. Drought can occur naturally or due to human activities. Scientifically, drought begins with the reduction of rainfall below the normal limit in a season, which is the initial indicator of this phenomenon. Therefore, mapping drought vulnerability is an important step in understanding the pattern and risk of drought in a region. The novelty of this research lies in the integrative approach used to map drought vulnerability in Serang Regency. This research combines three main spatial parameters: rainfall, soil type, and land use, using a Geographic Information System (GIS)-based weight overlay method. This approach allows for comprehensive mapping of drought risk by taking into account interactions between parameters that have not been widely discussed in previous studies. Thus, this research not only identifies drought-prone areas, but also provides a more accurate spatial basis for future mitigation planning and water resources management (Pasmah et al., 2022).

METHODS

Research on drought vulnerability is a study using quantitative research methods, where the data processed is secondary data or data that is not taken directly from the research location. This research uses spatial analysis methods and secondary data obtained from official data providers.

Research Location

Drought vulnerability mapping research was conducted in Serang Regency, Banten with a geographical location of 105°7' - 105°22' East and 5°50' - 6°21' LS. Serang Regency is geographically bordered by several regions, north of Serang Regency is bordered by Serang City, west of Serang Regency is bordered by Cilegon City, south of Serang Regency is bordered by Lebak Regency, while east of Serang Regency is bordered by Tangerang Regency. The following Figure 1 is an administrative map of banten province.

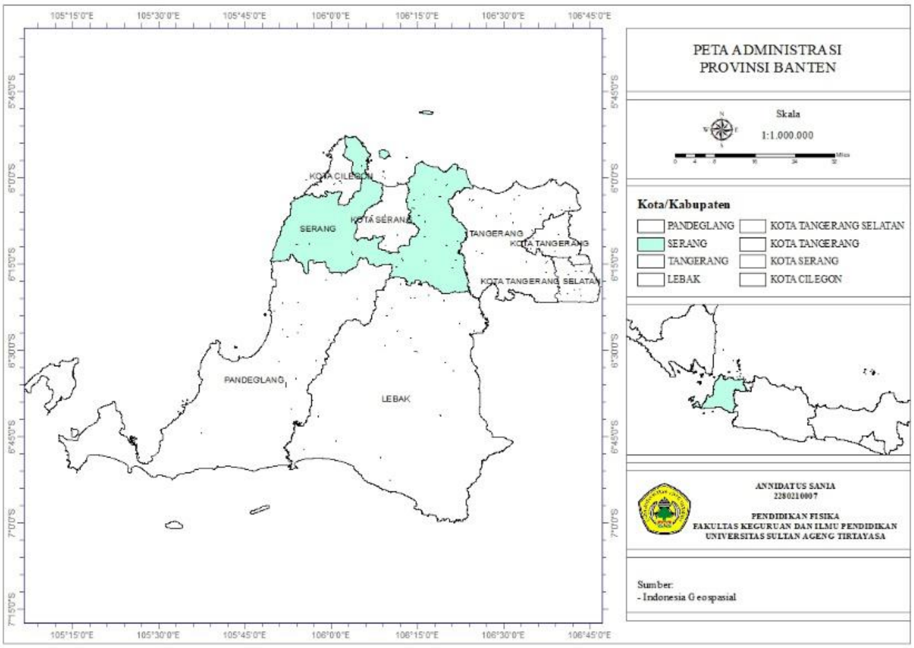

Figure 1. Administrative Map of Banten Province

Materials and Tools

The materials used in this research are related to the location of the drought research in Serang Regency. The materials used are administrative maps of Serang Regency obtained from Indonesia Geospatial, rainfall data obtained from Chrips annual data starting from 2016-2023, soil type maps obtained from the FAO Digital Soil Map of the World, and land cover maps obtained from Indonesia Geospatial.

While the tools used in the data processing process are using software such as Arcgis 10.8 and Ms Excel. The use of spatial data is carried out to produce data on drought distribution patterns and drought areas in Serang Regency.

Methodology

This research has several stages, starting from data collection, parameter scoring and weighting, overlay, identification of low rainfall and drought vulnerability areas of Serang Regency, and the last stage is the presentation of drought vulnerability maps. The data used in this research includes rainfall obtained from CHIRPS, soil type data from the Digital Soil Map of FAO, and land use data from the Indonesia Geospatial database. All data were processed in a geographic information system using ArcGIS software. Scoring was conducted to analyse and determine the score of each class of parameters.

The initial stage of analysis was conducted by classifying each parameter based on characteristics relevant to drought vulnerability. Rainfall parameters were classified into five classes, namely: less than 1500 mm (score 5, highly vulnerable), 1500-2000 mm (score 4), 2000-2500 mm (score 3), 2500-3000 mm (score 2), and more than 3000 mm (score 1, highly vulnerable). Soil types were classified based on permeability and water retention capacity, with the highest score given to Regosol soils (score 5), followed by Litosol (score 4), Alluvial (score 3), Latosol (score 2), and Andosol (score 1). Land use parameters were also scored based on their potential contribution to drought: settlements, ponds and airports were given a score of 5; plantations and dryland farming a score of 4; wetland farming a score of 3; production forests a score of 2; and protected forests and mangroves a score of 1. Scoring was done to reflect the level of drought risk of each parameter class based on its influence on field conditions (Rahmi et al., 2019).

Next, the parameters were weighted to determine their level of importance in the drought vulnerability analysis. The weighting is calculated by the ranking method using the formula:

$$wj = \frac{(n-rj+1)}{\sum_{p=1}^{n}(n-rp+1)} \tag{1}$$

where w_j, is the ke-*j* parameter weight, r_j is the ke-*j*, parameter rank, and n is the number parameters (Prasetyo et al., 2018). Based on the level of influence on drought, rainfall is ranked first (most influential), followed by soil type, and land use.

The next stage is spatial overlay, which is the process of combining several layers of parameter data that have been given scores and weights. The overlay is done using the intersect method to produce a map that illustrates the accumulated drought risk of the three parameters (Pasmah et al., 2022). The overlay results in a final vulnerability score that is then classified into three categories: low, medium and high vulnerability. The division of classes is based on the distribution of total score and weight values from the overlay results. The final step is to calculate the area of each vulnerability class using the Calculate Geometry feature in ArcGIS to obtain quantitative information about the distribution of drought-prone areas (Kusumo & Nursari, 2016). The final results are presented in the form of a drought vulnerability map of Serang Regency that illustrates the level of vulnerability based on the integration of spatial data on rainfall, soil type, and land use.

RESULTS AND DISCUSSION

Parameter data used to determine the weighting value based on existing data in the study, can be seen in Table 1.

Table 1. Parameter Weight

Parameter	Class	Weight (%)
Rainfall	1	50
Soil Type	2	30
Land Use	3	20
Total %		100

Sumber: (Dewa & Sabri, 2023)

Based on table 1 obtained the results of the weighting percentage of drought parameters, namely the rainfall parameter by 50%, the soil type parameter by 30%, and the land use parameter by 20%.

Drought Prone Map Compilation Parameters

Rainfall Parameter

Based on the results of the average annual rainfall parameters in 2016-2023 in Serang Regency ranges from 2,000-3,000 mm/year with an average of moderate rainfall. Moderate rainfall is concentrated in the central part of Serang Regency. Areas with low rainfall ranging from 1,000-2,000 mm/year are located in Tirtayasa, Tanara, Pontang, Lebak Wangi, Garenang, Kramatwatu, and parts of Ciruas. Low levels of rainfall intensity in the dry season can affect the occurrence of drought in the region, the level of groundwater depth is directly affected by rainfall deviations (Dewi et al., 2023). Table 2 is a scoring table of rainfall parameters and a map of rainfall distribution in Serang Regency.

Table 2. Scoring of rainfall parameters

No.	Average Rainfall (mm/year)	Score	Clasification
1.	1000 – 2000	1	Low
2.	2000 – 3000	2	Medium
3.	3000 – 4000	3	High
4.	>4000	4	Very High

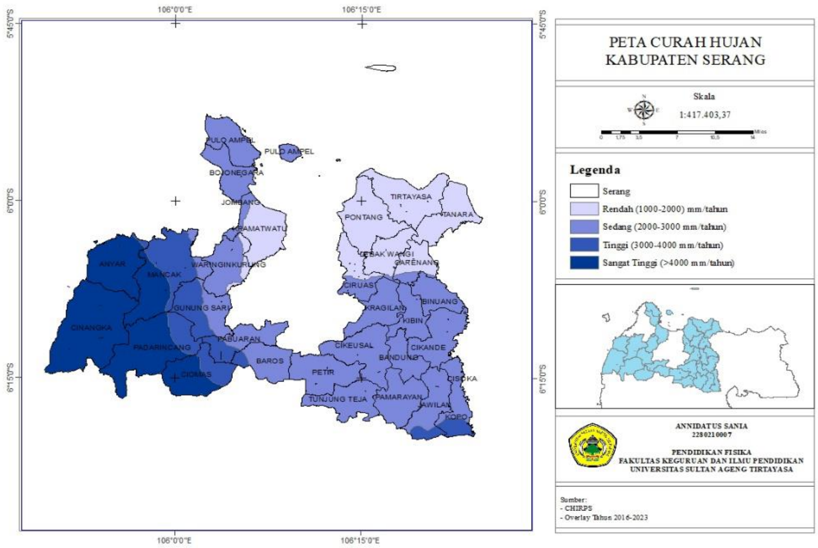

Figure 3. Rainfall Parameter Distribution Map of Serang District

Based on the rainfall distribution map of Serang Regency for the period 2016-2023 (Figure 3), areas that have low rainfall levels (1000 - 2000 mm/year) have a greater potential to experience drought than other areas that have rainfall >2000 mm/year. These areas are shown in light blue and are spread across the northeastern part of Serang District, including Tirtayasa Sub-district and parts of Pontang Sub-district.

Soil Type Parameters

The distribution map of soil type parameters can be seen in Figure 4. The classification of soil type parameters in this study is divided into 4 types, namely Acrisol, Andosol, Nitosol, and Alluvial. The process of infiltration or water absorption and the ability of the soil to hold water is strongly influenced by soil type. So that the greater the infiltration or absorption of water, the greater the possibility of drought and vice versa. (Soewandita, 2019). The following is a scoring table of soil type parameters and a map of soil type distribution in Serang Regency.

Table 3. Scoring of Soil Type parameters

No.	Soil Type	Score
1.	Acrisol	1
2.	Andosol	2
3.	Nitosol	3
4.	Alluvial	4

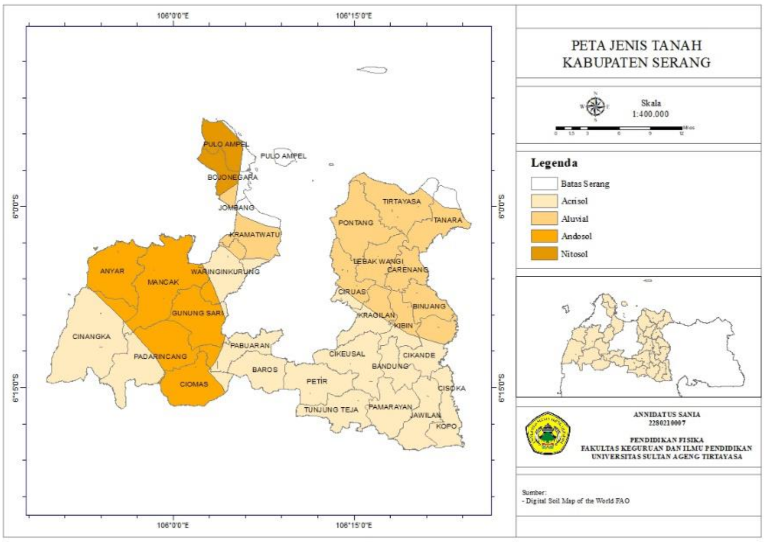

Figure 4. Soil Type Parameter Distribution Map of Serang District

The soil type map of Serang Regency (Figure 4) shows the distribution of four main soil types: alluvial, andosol, latosol, and nitosol. The soil types that have the most potential to exacerbate drought conditions are alluvial soils and latosols because they have a relatively low ability to store water compared to nitosols. Areas dominated by alluvial soils appear to be scattered in the eastern and northern parts of Serang Regency, covering Tirtayasa, Pontang, Kragilan, Tanara, and parts of Ciruas sub-districts.

Land Use Parameters

The land use parameter distribution map can be seen in Figure 5. Serang Regency has an area of approximately 1,467.35 km2. The land use of Serang Regency consists of airports, agriculture, settlements, forests, plantations, mining, open land, plantation forests, mangrove forests, rice fields, and ponds. The Table 4 is a scoring table of land use parameters and a map of land use distribution in Serang Regency.

Table 4. Scoring of Land Use Parameters

No.	Land Use Categories	Score
1.	Agriculture, Settlement, Plantation	1
2.	Forest, Open land	2
3.	Mining, Rice fields	3
4.	Plantation forest, Mangrove forest	4
5.	Airport/Port, Pond	5

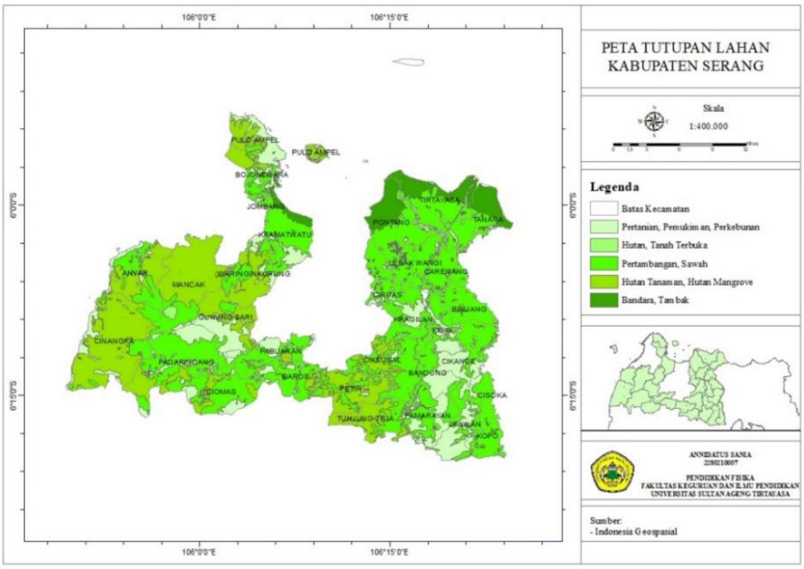

Figure 5. Land Use Parameter Distribution Map of Serang District

Based on the land cover map of Serang District (Figure 5), it shows that land use variations are spread throughout the region. The type of land cover that is most vulnerable to drought is agricultural land, especially dry farmland and paddy fields that are not equipped with adequate irrigation systems. Areas such as Tirtayasa, Tanara, and Pontang sub-districts in the main and eastern parts of Serang Regency are dominated by agricultural land, settlements, and plantations that are highly dependent on the availability of rainwater.

Overlay Analysis

After creating the distribution map of each parameter, the next step is to combine each layer of the parameter and do the overlay process to find out the value of the drought vulnerability area and to serve as a parameter for making a map of the level of drought vulnerability.

Drought Prone Area Map Analysis

Drought vulnerability is the event of water scarcity in an area at a certain time. This is caused by several factors, including an increase in water use in each land unit obtained based on the drought vulnerability index. The results of the Serang Regency drought vulnerability map can be seen in Figure 6, which shows that the Serang Regency area has low, medium and high levels of drought vulnerability. The results of the analysis of the drought vulnerability map of Serang Regency show the relationship between each parameter, where the parameters with the level of vulnerability to drought are mostly influenced by rainfall, soil type, and land use factors.

Based on the results of the normalised value weighting calculation, the overlay results can then be calculated by calculating the geometry according to the level of influence of each parameter. The following overlay results have been calculated geometry based on the level of influence of the parameters.

Tabel 5. Drought Vulnerability Level of Serang District

Interval Value	Level of Drought Vulnerability	Area (Ha)	Percentage of Drought (%)
18 – 26	Low	26779,87	19,2027

Interval Value	Level of Drought Vulnerability	Area (Ha)	Percentage of Drought (%)
27 – 34	Medium	54220,22	38,8789
35 – 42	High	58459,05	41,9184

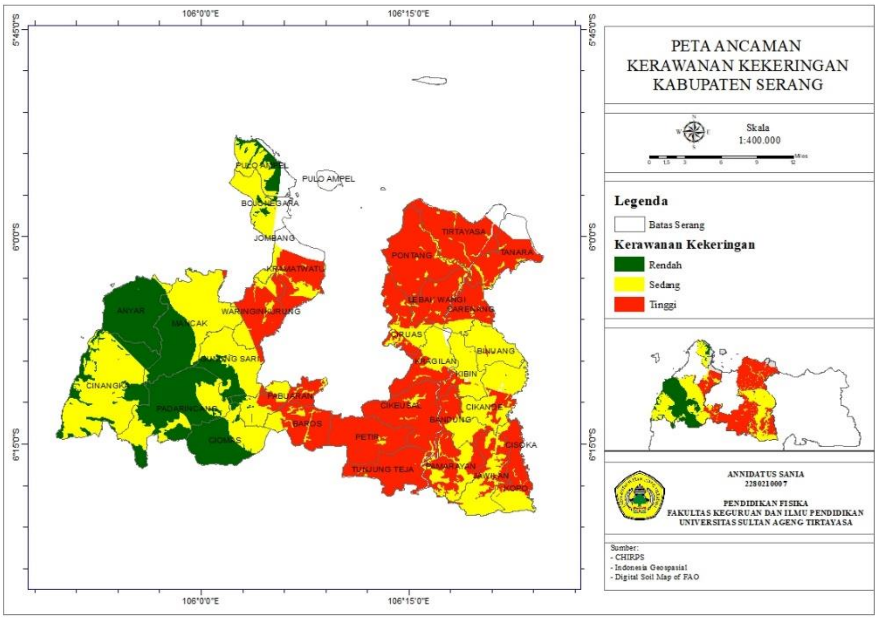

Figure 6. Map of Drought Vulnerability Level in Serang District

Based on the map of drought vulnerability levels in Serang Regency, it shows that areas with high vulnerability levels are located in the eastern and central parts of the district, such as Tirtayasa, Pontang, Lebakwangi, Cikeusal, Petir, and Tunjung Teja. This vulnerability is influenced by low rainfall, soil types less able to store water, and land cover in the form of agriculture without irrigation. Meanwhile, low vulnerability only remains in some western parts such as Cinangka, Anyar, and Mancak sub-districts, which are supported by high rainfall and forest cover. Areas with moderate vulnerability are scattered in the Central transition zone of Serang Regency.

The results of spatial analysis using the weight overlay method show that there are 15 sub-districts in Serang Regency that fall into the high drought vulnerability category. These results were then validated with actual data from the Regional Disaster Management Agency (BPBD) of Serang Regency, which also recorded 15 sub-districts affected by drought during the same period. The alignment of the number of sub-districts between modelling results and field data shows that the analytical method used has a high level of accuracy in identifying drought-prone areas. This validation reinforces that a Geographic Information System (GIS)-based approach that considers rainfall, soil type and land use parameters is an effective method for spatially mapping drought vulnerability.

CONCLUSION

The level of drought vulnerability in Serang Regency based on the results of the study can be divided into three classes: low level, medium level, and high level. The low vulnerability class has an area of 26779,87 ha or 19,2027% of the total area; the medium vulnerability class has an area of 54220,22 ha or 38,8789% of the total area; and the high vulnerability class has an area of 58459,05 ha or 41,9184% of the total area. High vulnerability areas are spread across Tirtayasa, Pontang, Lebakwangi, Cikeusal, Petir, and Tunjung Teja. The use of this geospatial information system is very helpful in processing data on the level of vulnerability of Serang Regency to process rainfall, soil type, and land use data. By combining several parameters, a new overlay result is obtained, namely the drought vulnerability map. This can add insight in the future.

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