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Article

Analysis of Water Catchment Area Potential Based on Geographic Information Systems (GIS) Case Study of XIII Koto Kampar District

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ABSTRACT

Recharge areas play a crucial role in maintaining hydrological balance and sustaining groundwater resources. Uncontrolled land use change can reduce infiltration capacity and increase environmental risks such as flooding and groundwater depletion. This study aims to analyze and map the potential of groundwater recharge areas using a Geographic Information System (GIS) to support spatial planning and water resource management. The research employed secondary data consisting of rainfall, slope, soil type, and land use. Each parameter was standardized, weighted, and scored according to its influence on infiltration capacity, then integrated using a weighted overlay method within GIS software to produce a comprehensive recharge potential map. The results classify the study area into low, moderate, and high groundwater recharge potential zones. Areas with high recharge potential are predominantly associated with gentle slopes, coarse-textured soils, relatively high rainfall, and land use dominated by vegetation cover, whereas low potential zones are characterized by steeper slopes, fine-textured soils, and built-up land use. The resulting map provides a spatial representation of recharge capacity that can be used to identify priority areas for conservation and guide land use control. This study demonstrates that GIS-based multi-criteria analysis is effective for evaluating groundwater recharge potential and generating practical spatial information. The findings are expected to support decision making in spatial planning, groundwater conservation strategies, and sustainable environmental management, as well as to serve as a reference for future studies related to hydrological assessment and land use planning. It also enhances data integration, transparency, and consistency across planning processes locally.

1. Introduction

Water resource management is an increasingly pressing global issue, with increasing water demand due to population growth, urbanization, and climate change. Water catchment areas play a crucial role in maintaining hydrological balance, preventing flooding, recharging groundwater, and supporting aquatic ecosystems. According to UNESCO (2020), approximately 30% of urban areas worldwide have lost their air absorption capacity due to the expansion of built-up areas and deforestation, which increases the risk of flooding and drought. This also impacts the availability of air for human and ecosystem needs.

In Indonesia, water management challenges are increasingly complex due to rapid population growth and development. The Ministry of Environment and Forestry (KLHK) reports that 60% of urban areas in Indonesia are experiencing a decline in water absorption capacity due to land conversion for residential, industrial, and plantation purposes (Ministry of Environment and Forestry, 2023).

In Riau Province, economic activities such as oil palm plantations have transformed forest landscapes into monocultures, reducing the soil's ability to absorb rainwater.

Kampar Regency, located in Riau Province, is one of the regions with significant agricultural potential, particularly in the production of oil palm and rubber, which are water-intensive crops. Approximately 67.22% of the regency's population works in the agriculture, plantation, and forestry sectors, indicating a high dependence on water resources. The regency also has significant water infrastructure, such as the Kampar River and the Koto Panjang Hydroelectric Power Plant, which generates 114,240 kWh of energy and supports water needs for irrigation and other activities. The estimated water availability in Kampar Regency of 1,063,281,652 m³/year demonstrates significant potential for sustainable water management, including groundwater recharge through infiltration. However, suboptimal water management can lead to problems such as flooding or drought during the dry season, particularly in agricultural areas.

District XIII Koto Kampar, located in Kampar Regency, covers an area of approximately 117,265 hectares and comprises one sub-district and 12 villages, including Batu Bersurat, Binamang, and Muara Takus. The district boasts unique geomorphological characteristics, including lakes formed by the Koto Panjang hydroelectric power plant and waterfalls such as Gulamo Waterfall, making it a potential tourist destination. Beyond tourism, the district's economy likely relies heavily on agriculture, such as oil palm cultivation, as is common in Kampar Regency. The presence of lakes and waterfalls demonstrates the importance of water resources in supporting tourism and the local ecosystem. However, inadequate water management can threaten the sustainability of these activities, particularly if water infiltration is not properly managed to support groundwater recharge and prevent flooding.

Based on these conditions, efforts are needed to identify and address areas prone to flooding and drought. One way is to compile a map of the potential distribution of water catchment areas using a Geographic Information System (GIS). GIS currently plays a crucial role in inventorying all the spatial information needed to design spatial regulations for an area. GIS has proven to be instrumental in processing research data and presenting the results in map form, making it easier to understand the research findings. Therefore, the resulting map of potential water catchment distribution is expected to be utilized to support groundwater provision in the XIII Koto Kampar District.

Geographic Information Systems (GIS) are a highly relevant tool in spatial analysis to identify water catchment areas. Therefore, considering the importance of water resources in District XIII Koto Kampar, both for agriculture, tourism, and environmental conservation, analyzing the potential of water catchment areas is highly relevant. This study aims to use GIS to map and analyze potential water infiltration areas in District XIII Koto Kampar. By utilizing spatial data such as soil type, land use, rainfall, and land cover, this study is expected to provide valuable information for local planners and decision-makers to support sustainable water resource management, increase agricultural productivity, prevent flooding, and maintain ecosystem sustainability.

2. Literature Riview

2.1 Water Catchment Areas

Water catchment areas are an important component in the hydrological system that functions as a medium for rainwater to enter the soil to replenish groundwater reserves.

Conceptually, water catchment areas not only play a role at the local scale, but also have a regional function in supplying groundwater to the entire groundwater basin through subsurface groundwater flow (Hamzah, 2016). The groundwater catchment process occurs through infiltration and percolation mechanisms, where infiltration is the process of water entering from the ground surface into the soil layer due to capillary forces and gravity, while percolation is the movement of water from the unsaturated zone to the saturated zone or aquifer (Asdak, 2010; Seiler & Gat, 2007). The magnitude of water catchment capacity is greatly influenced by hydrogeological conditions, regional morphology, and land cover, where areas with porous soil conditions, relatively flat topography, and good vegetation cover have higher water catchment potential.

Determining water catchment areas requires considering various interacting environmental factors, including land use, rainfall, slope, and soil texture. These factors influence the magnitude of surface runoff and the ability of water to infiltrate into the soil. Areas with high rainfall and sandy soil texture tend to have greater groundwater recharge potential, while areas with high slopes and clay soil texture generally have low infiltration capacity due to the dominance of surface runoff (Purnama, 2010; Kodoatie, 2010). Furthermore, the presence of impermeable soil layers can slow the groundwater recharge process even when rainfall is relatively high. Therefore, spatial analysis is necessary to comprehensively identify and map water catchment areas as a basis for water resource planning and management.

2.2 Parameters Determining Water Absorption Areas

According to the Minister of Forestry Regulation number 32 of 2009 concerning Procedures for Preparing Technical Plans for Forest and Watershed Land Rehabilitation, if the main problem in question is the magnitude of flow fluctuations, for example high floods and droughts, it is deemed necessary to assess the criticality of the infiltration area for rainwater. The paradigm used is that the greater the infiltration rate, the lower the runoff rate, so that flood discharge can decrease and conversely the base flow can increase, as well as groundwater reserves. To preserve groundwater reserves, the rate of rainwater infiltration into the soil is an important factor. The rate of infiltration or infiltration depends on: rainfall, runoff percentage, soil type, slope gradient, vegetation type and land use. As explained, the environmental components or parameters used for the assessment of infiltration areas consist of rainfall, slope gradient, soil type, and land use.

2.3 Infiltration

Infiltration is the process by which water seeps into the soil. Infiltration flows through the soil surface, and is therefore greatly influenced by the condition of the soil surface. Soil, as a flow medium, has several clarifiers, including soil permeability, soil moisture, soil porosity, soil type, and so on. According to Munaljid et al. (2015), infiltration is the process by which water enters the soil from above (the surface). The movement of water through the soil pores is influenced by gravity and capillary forces. Gravitational forces cause the flow to always move toward lower elevations, while capillary forces cause water to move in all directions. Capillary water always moves from wet areas to drier areas. Dry soil has a greater capillary force than wet soil.

2.4 Factors Affecting Infiltration Rate

Infiltration is the process by which water enters the soil through the surface, which plays a crucial role in the hydrological cycle, particularly in controlling surface runoff and groundwater recharge. The infiltration rate is not constant but is influenced by various environmental conditions and soil characteristics. Key factors influencing the infiltration rate include the depth of the inundation layer and the thickness of the saturated layer, soil moisture, rainfall compaction, the presence of cover crops, rainfall intensity, and soil physical properties. Furthermore, land cover, slope gradient, and differences in soil density also influence the soil's ability to absorb water (Aidatul, 2017). These variations in factors lead to differences in infiltration capacity across land types, making understanding the factors influencing the infiltration rate crucial for water resource planning and management, particularly in hydrological analysis and flood control.

2.5 Geographic Information System (GIS)

Geographic Information Systems (GIS) are computer-based systems used to manage geographically referenced data, including the processes of data collection, storage, processing, analysis, and presentation of spatial information. According to Rahmawati et al. (2011), GIS has the capability to build and manage spatial data that are geographically oriented and referenced by specific coordinate systems, where the data consist of spatial data and attribute data that are integrated within a database. Spatial data represent real-world objects on the Earth's surface in the form of points, lines, and areas, while attribute data contain descriptive information that explains the characteristics of those objects. The integration of spatial and attribute data allows users to access information based on location as well as object characteristics, making GIS an effective tool for spatial mapping and analysis. GIS applications have been widely developed in various fields, such as transportation, regional planning, infrastructure, and environmental management, due to their ability to support spatial modeling, decision-support systems, and integration with Global Positioning System (GPS) and remote sensing technologies, which enhance mapping accuracy and the quality of spatial analysis (Mildawati et al., 2008; Virmani, 2000).

2.6 Geographic Information System (GIS) Components

Geographic Information Systems are one of the modern systems used to analyze spatial phenomena through computer devices (Agnas 2013). Geographic Information Systems have several components to function. John E. Harmon and Steve J. Anderson argue that GIS components consist of:

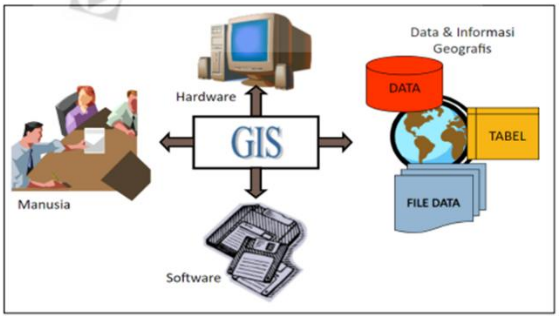

Figure 1. Components SIG

2.7 Function of SIG Analysis

The capabilities of a Geographic Information System (GIS) are reflected in the various analytical functions that can be performed on spatial and attribute data. According to Eddy (2009), based on the characteristics of the data, GIS analysis functions are generally divided into two types, namely attribute (non-spatial) analysis and spatial analysis. Attribute analysis relates to the processing of descriptive data stored in databases through basic database management operations such as grouping, filtering, sorting, and simple statistical analysis, enabling users to select and interpret information based on specific characteristics. Meanwhile, spatial analysis focuses on spatial relationships among objects and includes various techniques, such as reclassification to produce new spatial data, network analysis to model point and line data as interconnected systems, overlay analysis to combine two or more spatial layers, and buffering to generate buffer zones at specified distances from spatial features. In addition, GIS also supports three-dimensional (3D) analysis for the visualization and analysis of spatial data in three-dimensional space, as well as digital image processing that utilizes intensity values as representations of spatial distribution, making GIS an important tool for supporting spatial-based planning, evaluation, and decision-making.

3. Research Methodology

3.1 Research Design

This research falls under the quantitative method. This method involves collecting data on soil type, rainfall, slope gradient, and actual land use. This data is then scored and processed arithmetically to produce a map of water infiltration capacity conditions.

3.2 Data Source

a. Primary Data

- Administrative Map
- Slope Angle
- Soil Type
- Land Use
- Rainfall

b. Secondary Data

In this case, the secondary data used consists of literature studies such as books, journals, articles, and others.

3.3 Research Location

This research was conducted in District XIII Koto Kampar, which astronomically is located at the coordinates 0°17′8.5″N to 100°51′1.24″E, to find out more clearly the location in question is as follows.

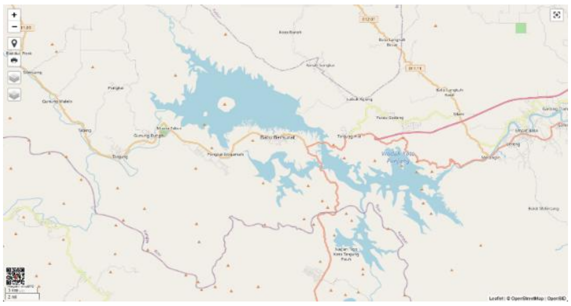

Figure 2. Researh Location

4 Results and Discussion

4.1 Analysis of Parameters Determining Water Catchment Areas

Before conducting weighting (scoring) and overlay for each parameter, what must be done is creating maps of rainfall, slope gradient, land use, and soil type. In this research, the researcher obtained administrative maps and thematic maps from PT. PLN Nusantara Power.Content weight testing.

4.1.1 Rainfall conditions

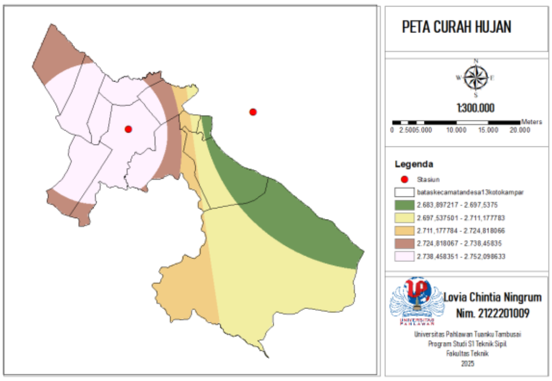

Figure 3 Rainfall Map

Rainfall data can be obtained through measurements at rainfall stations or from official institutions such as the Meteorology, Climatology, and Geophysics Agency (BMKG) and the River Basin Authority (Balai Wilayah Sungai/BWS), which provide coverage for the entire area used in rainfall analysis. Based on the analysis of rainfall data over the last ten years in XIII Koto Kampar District, the study area shows variations in rainfall that influence the rate of infiltration. The average annual rainfall recorded at the Silam rainfall station is 2,670 mm/year, while the Batu Bersurat rainfall station records an average of 2,752 mm/year. Areas with relatively high rainfall are located in Koto Tuo Barat Village, Muara Takus Village, Ranah Sungkai Village, Lubuk Agung Village, Binamang Village, Koto Tuo Village, Pongkai Istiqomah Village, and Batu Bersurat Village. High rainfall provides a significant water supply for the infiltration process; however, when rainfall intensity is excessive, it can trigger surface run off.

4.1.2 Slope condition

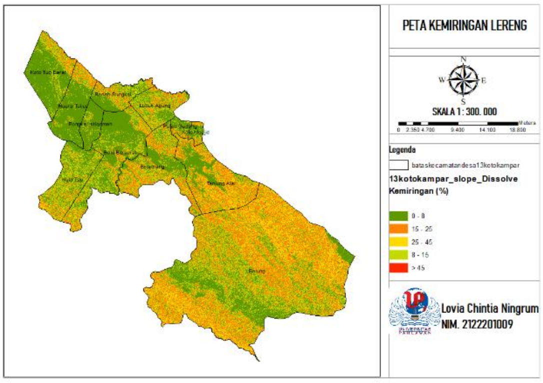

Figure 4 Slope gradient map

Based on the results of area mapping with reference to slope gradients, the slope conditions in XIII Koto Kampar District are classified into five slope categories, namely 0–8%, 8–15%, 15–25%, 25–45%, and greater than 45%. For the slope gradient parameter, the area is grouped into several classes that include: (a) slope gradient of 0–8%, (b) slope gradient of 8–15%, (c) slope gradient of 15–25%, (d) slope gradient of 25–45%, and (e) slope gradient of greater than 40%.

Flat-sloped areas (0-8%) have higher infiltration potential because water has a longer ponding time compared to steep slopes, which accelerate surface runoff rates.

4.1.3 soil type condition

Soil type is a crucial factor in determining permeability. Based on Figure 4.3, the soil texture in this area is dominated by sandy clay texture which has a direct influence on the speed of water infiltration into the aquifer.

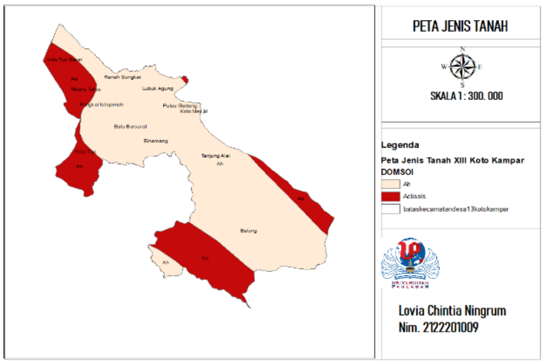

Figure 5. Soil Type Map

4.1.4 Land use conditions

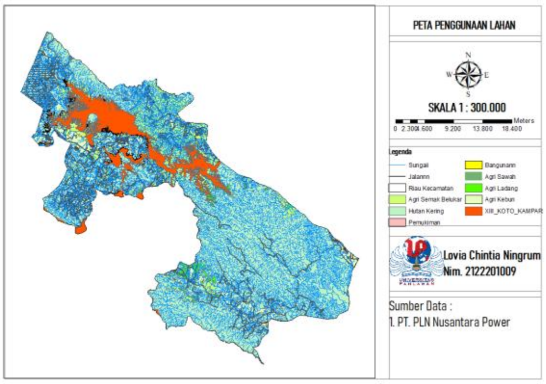

Figure 6. Land Use Map

The land use in XIII Koto Kampar is categorized into several classifications based on its land cover, such as forest land use, residential areas, fields, rice fields, roads, shrubs, buildings, and rivers. Weighting is applied to analyze water infiltration in land use.

For this land use parameter, it is grouped into a number of classes covering:

a. Shrubland
b. Plantation
c. Forest
d. Settlement
e. Rice field
f. Field

The land use map in Figure 4.4 shows the distribution of land cover in the XIII Koto Kampar District. Forest and plantation areas contribute positively to water infiltration because plant roots help create soil pores. Conversely, residential and built-up areas tend to be impermeable and reduce infiltration capacity.

4.2 Analysis of Water Catchment Area Potential

Based on the overlay and weighting results of the four parameters above using a geographic information system, the Water Catchment Area Map of Kecamatan XIII Koto Kampar is obtained as follows:

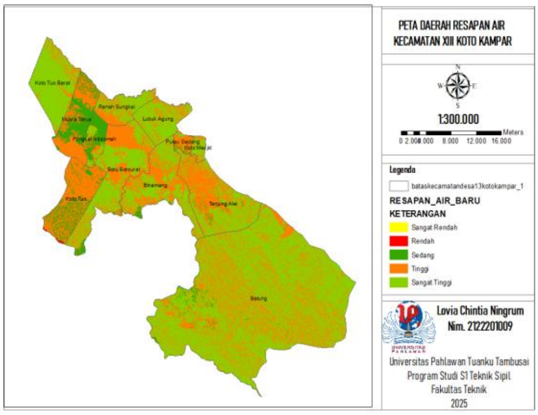

Figure 8. Water Absorption Area Map

Here is the breakdown of the area distribution based on its potential level:

a. High potential
Areas with very high water infiltration potential are distributed in Koto Tuo Barat Village, Ranah Sungkai Village, Lubuk Agung Village, Koto Masjid Village, Batu Bersurat Sub-district, Binamang Village, and Balung Village. These areas are generally dominated by flat topography, soil types with high permeability, and dense vegetation cover.

b. High Potential
Areas with high potential are found scattered in West Koto Tuo Village, Koto Tuo Village, Balung Village, Lubuk Agung Village, Ranah Sungkai Village, Muara Takus Village, Pongkai Istiqomah Village, and Batu Bersurat Sub-district.

c. Current potential
The Moderate potential category dominates parts of Muara Takus Village, Pongkai Istiqomah Village, Batu Bersurat Sub-district, Binamang Village, Balung Village, and Koto Tuo Village. In this zone, limiting factors such as moderately steep slopes or less porous soil types begin to have an influence.

d. Low and Very Low Potential
The condition of potential water catchment areas is identified as Very Low in the border region between Kecamatan XIII

Koto Kampar and Kecamatan Kuok. The low potential in this area is caused by a combination of factors: steep slope gradients, low rainfall, or the dominance of built-up/open land that reduces infiltration.

4.3 Dominant factor discussion

Based on the spatial analysis conducted, the most dominant factors influencing water absorption capacity in District XIII Koto Kampar are soil type and land use.

Influence of Soil Type: Coarse-textured soil types have been proven to support a very high infiltration rate compared to fine-textured soils. This is evident in the alignment between the soil type map and the final potential recharge map.

Role of Land Cover: The analysis indicates that forested areas consistently fall into the 'High' to 'Very High' infiltration potential categories. Vegetation plays a role in retaining the kinetic energy of rainwater and aids absorption through the root system, which is significantly different from open land, which has low infiltration potential.

5 Conclusion

Spatial analysis using GIS produces a map of water infiltration potential distribution in XIII Koto Kampar District based on the overlay of four parameters: soil type, slope inclination, land cover, and rainfall. The map categorizes the area into five infiltration potential classes (very high, high, moderate, low, very low). Thus, the characteristics of the water infiltration area in XIII Koto Kampar District are defined according to the five-level classification.

The dominant factors influencing water absorption capacity are soil type and land use. Soil types with sandy textures support very high infiltration, while land cover dominated by vegetation (forests or plantations) helps maintain the hydrological cycle. Although slope and rainfall parameters are also used in the analysis, their primary influence lies in soil texture and land cover type. Overall, the soil absorption characteristics in XIII Koto Kampar District are significantly influenced by the combination of these four parameters, with the aforementioned two factors being the most significant.

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