Determination of Flow Direction and Catchment Area Model Using Quantum GIS Analysis and Remote Sensing Imagery at Nickel Mining Locations

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ABSTRACT

The research location is located at IUP PT. IFISHDECO, Tbk (122.168° - 122.204° East Longitude (BT) and 4.371° - 4.404° South Latitude (LS), Tinanggea, South Konawe Regency, Southeast Sulawesi Province. The study aims to determine the surface flow direction and catchment area model at nickel mining sites. The data is in the form of topographic data measured with a total station, by conducting spatial analysis with Quantum GIS (QGIS) and remote sensing with the Strahler method in determining the river network. The results of research conducted at the research location obtained 3 catchment areas, namely Catchment 1 covering an area of 19,021 Ha, catchment 2 covering an area of 32,691 Ha and Catchment 3 covering an area of 59.77 Ha which can be used in further analysis in the mining drainage system.

Keywords: PT. IFISHDECO; QGIS; network; catchment area; drainage system.

INTRODUCTION

Catchment area is the surface area where rainwater will flow to a lower place towards the drainage point. Some of the water that falls to the surface will seep into the soil, be retained by plants, and some will fill the twists and turns of the Earth's surface. Not all water that flows on the surface comes from the drainage system. This condition is influenced by many things, including topography, vegetation density, and geological conditions [1]. Catchment areas are generally limited by mountains or hills that are projected to collect rainwater, limiting the catchment area. After the catchment area is found, its area is measured on a contour map by drawing a relationship from the highest point around the mine opening that forms a closed polygon. Then, by looking at the possible direction of water flow, the area of the catchment area can be calculated [2]. With the latest GIS technology, watershed depiction is carried out using remote sensing processed by various digital elevation (DEM) data at various spatial resolutions [3]. There are many ways to analyze rain catchment areas, either manually using the Global Positioning System or with the help of applications such as Global Mapper, ArcGIS, QGIS, and WMS. In the Quantum GIS application, analyzing the availability of rivers or drainage systems can be done by determining the river order using the Strahler method. Determination of the catchment area will be adjusted based on the progress of mining. Geographic Information Systems (GIS) are used as software that is useful for integrating and combining several geological and environmental science data (data layers) into environmental design maps [4]. Geographic Information Systems (GIS) technology is one type of computer-based system that is widely used [5]. The application of GIS and remote sensing is identified as an efficient tool for watershed delineation and morphometric analysis of drainage basins. The study conducted by Horton in the early 1930s and 1940s was continued by Strahler in the 1940s and 1950s, attempting a quantitative evaluation of catchment geomorphology by proposing mathematical expressions to obtain morphometric parameters [6]. Drainage Basin (DPS) or Watershed (DAS) or catchment area, is a place or location where all flowing water collects and flows into the river [7].

Remote sensing technology is related to the requirements of reliability and speed, and is an ideal tool for producing spatial information which is considered a prerequisite for planned and balanced

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development at the watershed level. Geographic information system (GIS) technology provides a suitable alternative for efficient management of large databases while the drainage characteristics of basins and sub-basins have been studied using conventional methods [8].

Delineation of watershed boundaries or catchment areas is the process of determining areas or regions that contribute to flowing rainfall (precipitation) into surface runoff at one outlet point. There are five methods that can be used in determining watershed boundaries. First, determining watershed boundaries with the help of RBI maps. Second, digitizing the RBI map with the help of GIS devices. Third, digitizing watershed boundaries from Google Earth maps that have been previously registered using GIS devices. Fourth, watershed boundary maps are drawn using a combination of contour maps and river networks. Fifth, watershed boundary maps are derived from processing Digital Elevation Model (DEM) data using GIS devices. Of the five methods, there are three methods that utilize geographic information systems or better known as GIS. The accuracy of the watershed boundary delineation process or catchment area and the analysis of other watershed hydrological components through geographic information system (GIS) devices is greatly influenced by the level of accuracy and resolution of the main input data, namely the Digital Elevation Model (DEM), so that the DEM used in the watershed delineation process must have good resolution. Through the DEM data processing process on GIS devices, the process of delineating watershed boundaries or catchments and analyzing watershed hydrological components becomes easier. The watershed hydrological components obtained through DEM data processing on GIS devices include flow direction, flow accumulation, watershed boundaries, watershed area, and river length. Accuracy in the watershed boundary determination (delineation) process is very important in watershed management. The results of the analysis of the watershed delineation process can then be used for design flood prediction purposes [9].

Watershed boundaries, river networks, channels, drainage directions, etc., were analyzed using raster files and converted to vectors using raster to vector conversion tool for each point, line and polygon and the calculation of these parameters was done using different functions such as area, length, and slope provided by QGIS Desktop software [10]. Watershed area, shape, river network, flow density, flow pattern, and slope gradient are the parameters used for morphometric identification of watersheds [11]. Morphometric analysis measures the mathematical properties of watersheds and river networks, including landform length, surface area, size, and slope. These parameters are important determinants of water dynamics within watersheds, and can provide useful information for land and water resource management in areas with limited hydrological data [12]. Hydrological research becomes easier and watershed classification, quantitative data on river networks, and examination of morphological features are all made possible by morphometric analysis [13]. By using morphological analysis, drainage basins can be used to analyze the shape and structure of a geographically and chronologically isolated watershed [14].

There are many methods for determining river order such as Strahler, Horton, Shreve and Scheidegger. In this study, the Strahler method is used because it is easier to apply and is integrated with various current GIS software [15]. Based on the Strahler method, tributaries in the upstream position are classified into the first order (order 1). Furthermore, the confluence of the same branch is classified into the second order (order 2), and the confluence of different orders will not change the flow order. This continues until the river branches meet in the main river with the largest orders as shown in Figure 1 [16]. Due to gravity, surface water always flows from a higher point to a lower point. When individual streams merge, meet, and gradually turn into streams, they turn into rivers. These streams then flow into nearby lakes, larger rivers, and sometimes flow through lakes [17]. With hydro tools in GIS, watershed analysis can be done to identify sub-catchments, river network paths, and drainage points [18]. This study aims to analyze the direction of surface flow and catchment area models in nickel mining using Quantum GIS and remote sensing. The main input data is DEM (digital elevation model) data from direct measurements using a total station which will be processed with GIS (QGIS) and remote sensing so that the data becomes digital elevation model (DEM) data.

Figure 1. Watershed boundaries, river networks, channels, drainage directions

RESEARCH METHOD

Materials

The research location is located at IUP PT. IFISHDECO, Tbk (122.168° - 122.204° East Longitude (BT) and 4.371° - 4.404° South Latitude (LS)), Tinanggea, South Konawe Regency, Southeast Sulawesi Province (figure 2). The method used in this study is to model or analyze the boundaries of the catchment area/DAS using GIS software, namely Quantum GIS and Remote Sensing in processing spatial data. The method used in processing this data is the Strahler method to determine the River order which will later be used as a reference in determining the boundaries of the catchment or DAS. The data used in this study are spatial data of South Konawe Regency, Topographic Data, Drone Imagery, and Mining Situation Data of PT. Ifishdeco, Tbk. The type of research used is experimental research. Morphometric analysis of drainage basins consists of digitizing drainage basins, delineating watershed boundaries, and drainage networks which are carried out using Arc GIS (Hydrology Tools), ERDAS IMAGINE, or QGIS [19].

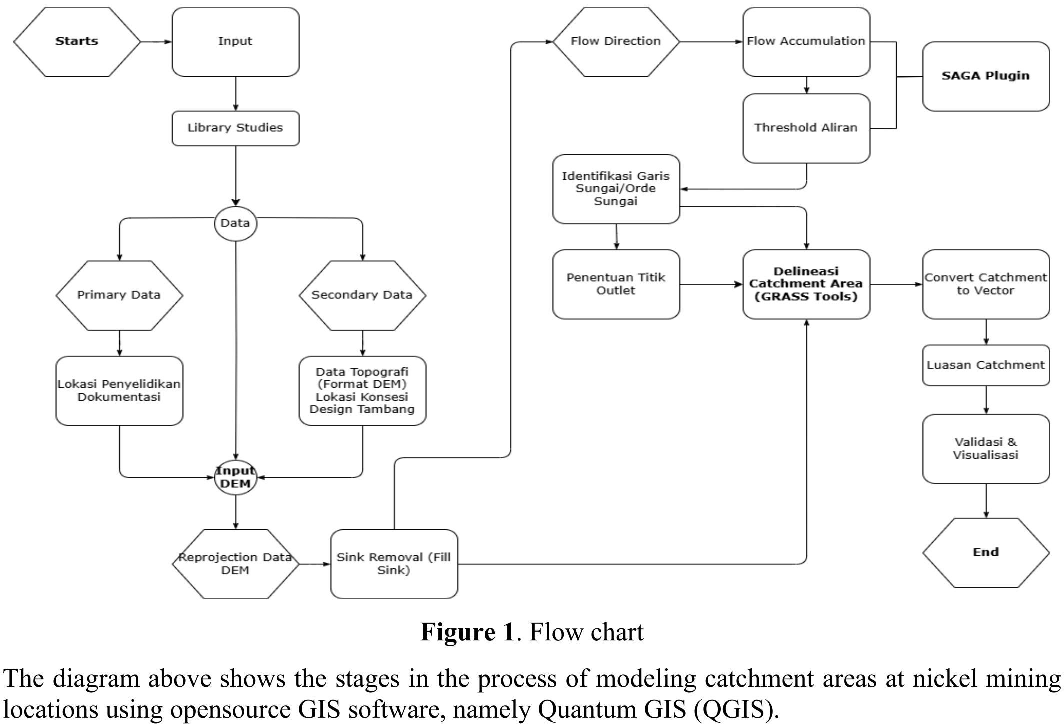

Figure 1. Flow chart

The diagram above shows the stages in the process of modeling catchment areas at nickel mining locations using opensource GIS software, namely Quantum GIS (QGIS).

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Figure 2. Research Location

Method

The research location is located in the IUP of PT. IFISHDECO, Tbk (122.168° - 122.204° East Longitude (BT) and 4.371° - 4.404° South Latitude (LS)), Tinanggea, South Konawe Regency, Southeast Sulawesi Province (figure 2). The method used in this study is to model or analyze the boundaries of the catchment area/DAS using GIS software, namely Quantum GIS and Remote Sensing in processing spatial data. The method used in processing this data is the Strahler method to determine the River order which will later be used as a reference in determining the boundaries of the catchment or DAS. The data used in this study are spatial data of South Konawe Regency, Topographic Data, Drone Imagery, and Mining Situation Data of PT. Ifishdeco, Tbk. The type of research used is experimental research. Morphometric analysis of drainage basins consists of digitizing drainage basins, delineating watershed boundaries, and drainage networks carried out using Arc GIS (Hydrology Tools), ERDAS IMAGINE, or QGIS [19].

Data Analysis

Determination of the catchment area is carried out using topographic data from measurements with a total station and mine design processed in Quantum GIS (QGIS) software into data in DEM (Digital Elevation Model) format. After the data is collected, the DEM is entered into QGIS for further processing via the Add Raster Layer menu. At this stage, if the DEM coordinate system does not match the analysis needs, the data is reprojected to a relevant coordinate system, such as UTM, to ensure spatial consistency throughout the process. The research location has a UTM Zone 51 South coordinate system. The DEM data is then analyzed to eliminate depressions in the DEM through the sink removal process. This depression, if not corrected, can cause inaccuracies in the analysis of flow direction and accumulation. This process produces a filled DEM, which is the basis for hydrological analysis. From the filled DEM, the flow direction is calculated using the flow direction algorithm, where each pixel is assigned a value that indicates the direction of the water surface flow. These results are then used to produce a flow accumulation map, which shows the amount of water collected in each pixel based on the topography of the study area. This accumulation map allows the identification of the main flow path, especially after applying a certain threshold value (stream threshold), which distinguishes between major and minor streams (determining the River order using the Stahler method). In QGIS this method uses the SAGA plugin. The River Network (River Order) formed from this flow accumulation map is then converted to vector format for ease of interpretation and further analysis. At this stage, the outlet point or outlet of the catchment area is manually determined based on the needs of the study, such as the location of the downstream river or certain infrastructure. This outlet becomes a reference for the catchment area delineation process. Where the delineation process involves DEM data, River Order and outlet points processed using GRASS Tools on Quantum GIS (QGIS). The delineation results are in the form of raster catchment areas, which are then converted to vector format to allow calculation of spatial attributes, such as area. This area can be adjusted to certain units, such as square meters or square kilometers, depending on the needs of the analysis. All analysis results are validated with reference data, such as hydrological maps or field surveys, to ensure compliance with actual conditions. The final visualization is done by symbolizing the catchment area and river network using easy-to-read colors and lines, so that the analysis results can be presented or published.

RESULTS AND DISCUSSION

Topographic data is analyzed using remote sensing methods with Quantum GIS software with input data processing being topographic data that will be processed into DEM (Digital Elevation Model) / Raster data, where the topographic data used is vector data in .dxf format which is converted into shapefile (.shp) to be processed into raster data with the help of Quantum GIS in the form of the TIN Interpolation process.

The catchment/DAS delineation process broadly includes the fill sinks process using the Wang and Liu method, Strahler Order and Uplospe Area to obtain river order data and catchment boundaries. The fill sinks process produces data in the form of raster filled DEM data which will be used for analysis and produces raster flowdirection to determine the river order/segment. Raster filled DEM will be used in determining the river order using the Strahler Order method in identifying the river network at the research location. The Strahler order process has not shown any river network, so it is necessary to identify the direction of river flow (stream) using a raster calculator with a raster data threshold greater than or equal to 2. Flowdirection analysis is carried out to determine the tendency of surface water flow direction by classifying the direction of the raster data. This needs to be done as a parameter in determining the identification of a river network in a catchment. The raster calculator process that has been carried out on previous data will show a clearer river flow direction along with its river network. Furthermore, the data from the raster calculator process will be converted to carry out analysis and determine the river order and all its hydrological components. The data will then be overlaid on the mine situation data to determine the river flow outlet boundary. When the outlet coordinate data has been determined, the next step is to carry out the upslope process to determine the catchment or DAS boundary. Then finalize the upslope process data by converting the data into polygons using the raster conversion command. The delineation process is continued by modifying the polygon data with mining progress and plan data in the northern block. The catchment area delineation process can be seen in Figure 3 below.

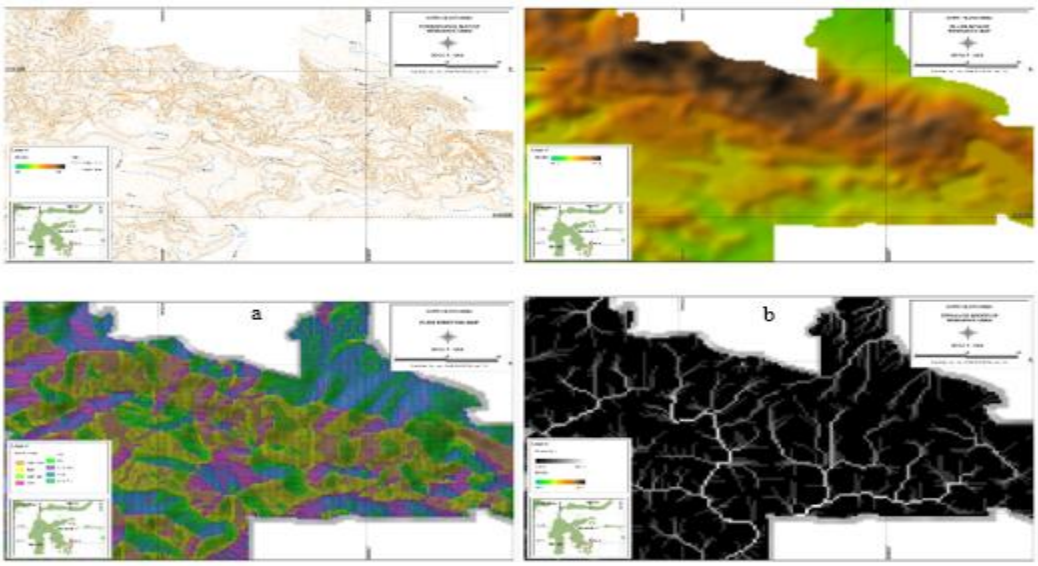

Figure 3. Results of the Catchment Area Delineation Process with Quantum GIS (a) Topography, (b) Filled DEM, (c) FlowDirection, (d) Strahler Order

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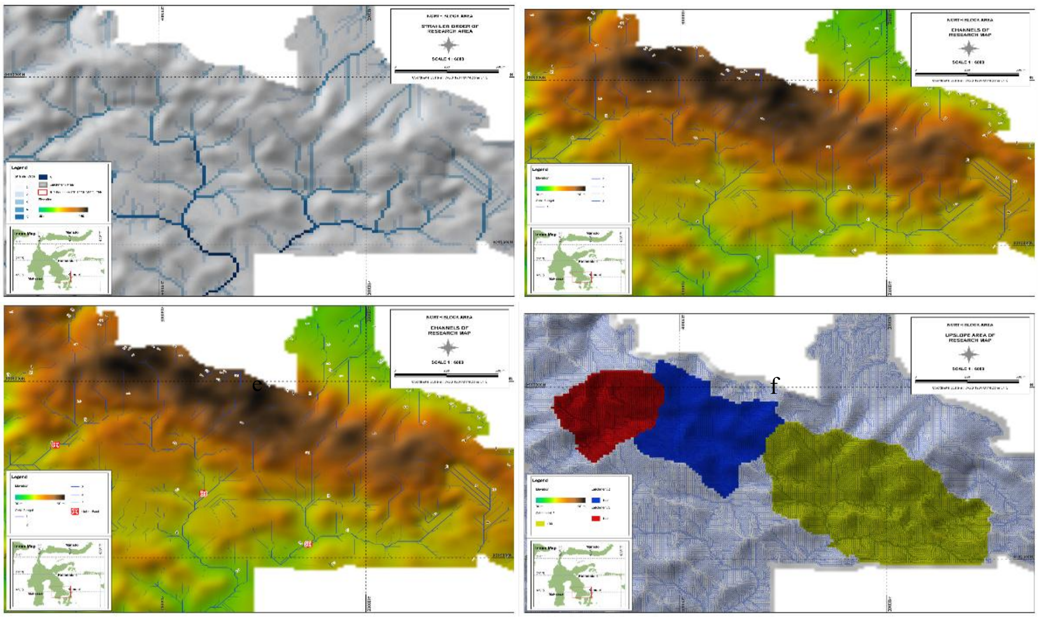

Figure 4. Results of the Catchment Area Delineation Process with Quantum GIS ((e) Stream Raster, (f) Stream Vector, (g) Outlet, (h) Upslope Area

The Grass module embedded in Quantum GIS is used to describe the watershed boundaries. The grass module calculates the direction of water flow from each cell and then summarizes the accumulated water flow. Based on the accumulated water flow, the main water flow is also identified. Grass produces the results in a raster data model, which is converted into a vector data model using the raster-vector conversion module available in Grass [8]. The tools in QGIS are effectively used to calculate the total number and length of stream segments of each order in the sub-watershed to evaluate the linear morphometric parameters summarized in table 1 [6].

The results of the study of the catchment/DAS delineation process and modification with Quantum GIS obtained a catchment area/DAS of 3 catchments, catchment 1 covering an area of 19,021 Ha, catchment 2 covering an area of 32,691 Ha and catchment 3 covering an area of 59.77 Ha. The results of the catchment delineation are shown in Figure 4.

Table 1. Linear Morphometric Parameters of the Research Location Catchment Area

Cacthmen tArea	Stream Order	Stream Length in Km	Total No of Stream Segments	Basin ID	Mean Stream length in Km	Stream Length Ratio	Order Length Ratio	Bifurcation Ratio (Rb)	Mean Bifurcation Ratio (Rb)	Rho Coeficient
Catchment 1	I	2.09	47	55	0.04	-	3.37	2.47	2.33	-
	II	0.62	19	55	0.03	0.30	1.11	1.12		0.27
	III	0.56	17	55	0.03	0.90	3.50	3.40		0.27
	IV	0.16	5	55	0.03	0.29	-	-		-
Catchment 2	I	3.91	74	22	0.05	-	2.88	2.74	2.14	-
	II	1.36	27	22	0.05	0.35	1.39	1.23		0.28
	III	0.98	22	22	0.04	0.72	3.50	2.44		0.29
	IV	0.28	9	22	0.03	0.29	-	-		-

Cacthment Area	Stream Order	Stream Length in Km	Total No of Stream Segments	Basin ID	Mean Stream length in Km	Stream Length Ratio	Order Length Ratio	Bifurcation Ratio (Rb)	Mean Bifurcation Ratio (Rb)	Rho Coeficient
Catchment 3	I	6.93	114	32	0.06	-	2.85	2.11	6.39	-
	II	2.43	54	32	0.05	0.35	2.43	2.25		0.16
	III	1	24	32	0.04	0.41	1.14	1.20		0.34
	IV	0.88	20	32	0.04	0.88	118.31	20.00		0.04
	V	0.01	1	32	0.01	0.01	-	-		-
Linear Morphometric Parameters	Mean stream length in Km = Cumulative length of stream of order u/Total number of stream segments of order u									
	Stream Length Ratio = Cumulative length of stream of order u / Cumulative stream length of order (u-1)									
	Order Length Ratio = Cumulative length of stream of order u/Cumulative stream length of order (u+1)									
	Bifurcation Ratio, Rb = Number of stream segments of order u/ Number of stream segments of order (u+1)									
	Mean bifurcation ratio, Rb = Mean of the bifurcation values									
	Rho coefficient = stream length ratio / bifurcation ratio									

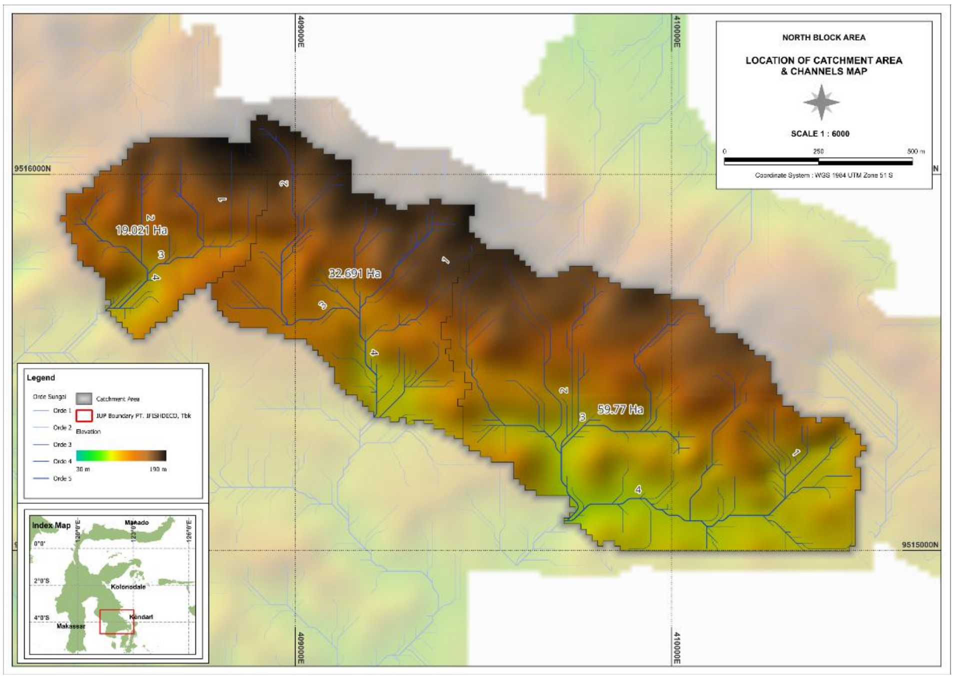

Figure 5. Map of Catchment Area of Research Location

CONCLUSION

Based on the results of the analysis that has been carried out in this study, it can be concluded that the QGIS program is effective for use in the process of extraction or delineation of catchment area boundaries, while the Strahler method obtained good River order modeling results, so that this can be used in conducting further analysis related to the mining drainage system generally in the open pit mining method.

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