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Study of Geotechnical Disaster Indexfor Expansive Soil of Road Subgrade by using GIS-AHP and Fuzzy Logic

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Abstract: Road infrastructure plays important role to support regional economic growth, especially, the distribution of goods and services. Due to the importance of the role of the road, good road conditions greatly affect the smoothness and comfort of users as well as accelerating the distribution of goods and services and support regional economic growth. This study aims to formulate a disaster index that can be used in mapping expansive soil vulnerability using the GIS-AHP and fuzzy logic methods and to formulate a model for handling improvements on expansive land national roads with the influence of traffic and flood. The research conducted is a form of utilizing the application of Geographic Information Systems (GIS) in displaying the results of land survey surveys. The data used is the data from the land survey survey by the Takalar District Public Works Department in collaboration with the University of Hasanuddin. The study area is focused on KM. 52+000-76+000. The research sample in the area is soil samples on the Jalan Takalar-Jeneponto, KM. 52+000-76+000. The results showed that the application of ArcGIS is very helpful in decision making and data processing of soil survey results and is able to visualize or display data in 2 dimensions or in 3 dimensions, so that, it can be easier to see conditions on the ground. An intelligent system based on fuzzy logic can make it easier for users to find out the level of expansiveness of the land and the possibility of areas with road damage vulnerability in the specified coverage area. Fuzzy logic-based intelligent systems have high accuracy in determining expansive soil-prone areas, so that, they can be used as a reference to determine the level of road damage vulnerability in certain areas and can immediately take precautions or efforts to avoid disruption in road networks.

Key words: Road subgrade, expansive land, GIS-AHP, fuzzy logic, accuracy

INTRODUCTION

Development of road infrastructure is faced with the difficulty of achieving qualified stability. This is caused by several factors such as basic soil conditions, topographic influences and weather. In some areas with unique geological conditions, the basic soil characteristics greatly affect the stability of the road. One of the conditions affecting soil characteristics is soil deposition. Expansive soil deposition in the road subrage layer causes deformation of the road body such as rutting, cracking and differential settlement of the road body.

Some roads in South Sulawesi experience land deposition problems as indicated by the presence of damaged roads and clearly visible differential settlement. Among the many regions in South Sulawesi affected by this land disposition, one of them is the Takalar Axis-Jeneponto national road and the Tarumpakkae Axis-Luwu border. Soil conditions on the national road can be seen in Fig. 1.

Fig. 1: Expansive soil conditions on the Takalar-Jeneponto highway

The soil conditions shown in Fig. 1 illustrate the effect of expansive soils that occur. Expansive soils are soils that change in volume due to changes in water content in the soil. Expansive soils contain clay minerals such as smectite and montmorillonite which are able to absorb water. When the mineral absorbs water the soil volume will increase. When the soil volume increases, it will cause cracks as shown in Fig. 1 which can be caused

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by water content that exceeds the limit of land tamping (expansive). Several studies on expansive soils have been carried out previously which have volatile volume properties due to changes in water content (Donaldson, 1969; Chen, 1988). Therefore, this expansive land has the potential to develop volume (swelling) and potential shrinkage. This flower potential is influenced by the water absorption properties of the mineralogical constituents and the clay-size fraction of the soil. Direct and indirect measurement methods for classifying expansive soil levels from volume changes have been developed. The indirect method is carried out by testing atterberg limits, colloidal levels and clay activity (Altmeyer, 1955). Direct methods such as oedometer tests are also widely used to measure developmental potential and development pressure and chemical and mineralogical analysis methods (Cokca, 1991).

Expansive soil testing is not easy because generally soil samples taken from the field are disturbed, disturbed (Holtz and Gibbs, 1956). Therefore, the characteristics of soil development behavior are obtained from empirical correlations of the physical properties of soils that are easily measured in disturbed soil samples such as the Atterberg boundary and clay content.

Empirical correlation of potential and pressure for soil development with plasticity index parameters and clay content in a road area requires a soil investigation database both in situ and laboratory testing which includes borlog, atterberg boundary lab tests and clay content, oedometer and submerged CBR. From this empirical correlation, it can be identified the level of soil activity in the area of the road under review.

Borelog data volumes and physical-mechanical properties of soils must be able to be stored, regulated and visualized with a Geographic Information System (GIS) as an integrated geographical framework. The database method of soil physical properties data for calculating expansive soil development pressures is also carried out by making a map of the soil liquid boundary contour (LL) and soil Plasticity Index (PI). A hazard map of land development potential is based on the percentage value of land development using a modified GIS.

A similar method carried out by the British Geological Survey Agency made geotechnical baseproperty data which contained index data. This index data uses a database of 8000 drill data, 320000 lab data with 10000 soil plasticity data. BGS (British Geological Survey) provides geological information on potential movements or subsidence including a database of potential for flowering/shrinkage. Indications from this index data indicate hazard/disaster index related to Potential Volume Change/VCP (Volume Change Potential) that occurs due to changes in water content. This VCP is calculated from IP (Plasticity Index) and classification using the top quartile statistics. The geotechnical base data was also collected by Jones and Terrington and Diaz *et al*. to map expansive soils. 3D Models are also carried out for detailed assessments on land that provide VCP interpolation and IP visualization. 3D modeling is able to predict the spatial variation in VCP on expansive soils as long as the data needed is complete.

It's just that the validity of the map created will be difficult to improve if the mapping is based on empirical correlation data as conducted by Labib and Nashed and Turkoz and Tosun and not direct test data such as oedometer testing, CBR immersion and mineralogical analysis. The level of data limitations also affects the accuracy of the map because in areas where there is no data, the estimation of the model must be done using a frequency ratio model, fuzzy logic and multivariate regression. This model is used by Pradhan and Youssef for landslide hazard mapping objects and Sun for earthquake hazard mapping.

This estimation model is still lacking in mapping expansive soil hazards whose behavior and data distribution are very different from landslides and earthquakes. This study aims to formulate a disaster index that can be used in mapping expansive soil vulnerability using the GIS-AHP and fuzzy logic methods and to formulate a model for handling improvements in geotechnical structure instability on expansive land national roads with the influence of traffic and flood.

MATERIALS AND METHODS

Research location: This research was conducted in collaboration with the laboratory with a research period of 3 month. With the location of the sampling area of Takalar-Jeneponto, South Sulawesi.

Figure 2 shows the research location of Jalan Takalar-Jeneponto, KM. 52+000-76+000. When the study was conducted for 6 months.

Research types and data sources: The research conducted is a form of utilizing the application of Geographic Information Systems (GIS) in displaying the results of land investigation surveys. The data used is the survey results of land investigations by the Takalar District Public Works Department in collaboration with the University of Hasanuddin. The population in the region is the Takalar-Jeneponto Road section, while the population in terms of objects to be surveyed is

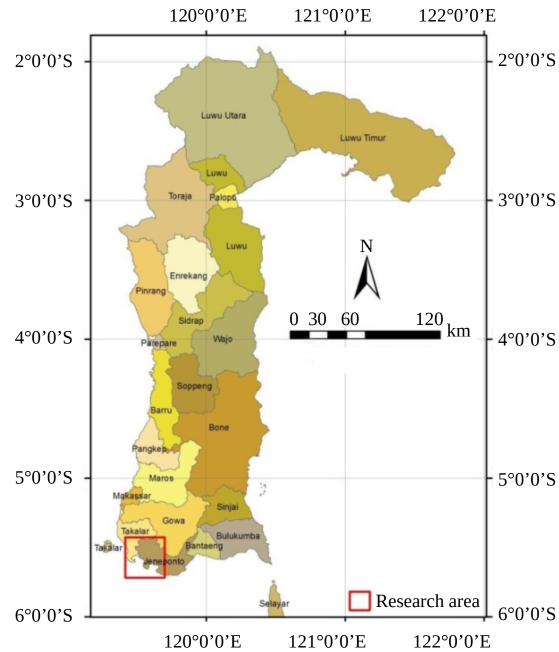

Fig. 2: Research location

KM. 52+000-76+000. The research sample in the study area is a soil sample on the Jalan Takalar-Jeneponto, KM. 52+000-76+000.

Analysis hierarcy process: According to Thomas and Saaty (2005) and Dewa Ayu (2011) states that the Analytical Hiercy Process (AHP) technique depends on the main input, namely the perception of an expert or expert, so that, it involves the subjectivity of the experts or experts. So that, the model or final results will be meaningless if the experts or experts are wrong in providing an assessment in their use is a technique to measure, formulate and analyze decisions. Analysis Herarchy Process (AHP) is used in observations about human nature, analysis of thought and measurement that is useful for solving both qualitative and quantitative problems.

Fuzzy logic: Zimmerman introduced a combination of fuzzy with 5 operators namely fuzzy OR, fuzzy and, fuzzy algebraic products, total fuzzy algebra and fuzzy gamma operators. Frequency ratios are calculated as expansive land contributor factors. The spatial relationship between expansive land location and expansive land contributor factors was analyzed using the ratio frequency model. Frequency ratio is the ratio of the occurrence and occurrence of expansive soils at each pixel where the contributors to expansive soils.

RESULTS AND DISCUSSION

Database: The data used are secondary data obtained from laboratory test results. This data is divided into coordinates, depth, soil classification, index properties, engineering properties and petrography.

Mapping: This study uses the ArcGIS application which requires steps in making maps to match the data in the field, there are several steps needed in making maps according to the rules in the ArcGis application, namely map registration, layer creation, digitization of maps, making bases data (including borehole coordinates and properties, etc.), 2D visualization. After adding the desired attributes, the 2-dimensional visualization process has been completed. Figure 3 shows the appearance of the final layout making process. Compared to conventional 2D maps, the advantage of 2D maps lies in the practical reading of elevation information and the shape of the earth’s surface. On the 2D map the difference in the height of the earth’s surface that appears as a form of the earth's curves can appear visually. One of the advantages of the ArcGIS feature is that it can display maps in 2D through the ArcGIS Pro.

This map is displayed through the initial data in the form of vector data which states the spatial values (coordinates x and y) and the elevation value (height). Furthermore, the data is converted to raster format and then displayed in three dimensions. After the data has been converted to raster format the next step is to open the ArcScene application and call the data that has been converted into ArcScene, then a 2-dimensional display will be seen. Figure 4 is a 2D display of the ArcGIS process that has been carried out. This map will be the acquisition variable that will be a comparison of the AHP method and fuzzy logic. Comparison of AHP and fuzzy logic methods is a very appropriate method for modeling expansive soil hazards in the road area by using a database index system based on direct measurement data using database management and geographical visualization.

The analysis process using fuzzy logic: Direct observations were made to obtain research data such as maps of soil types, rainfall, geological maps, observations of results from laboratory tests, namely Plasticity Index (PI) and drill data collection to determine soil types. The initial step is to select a sample based on variable drilling data and rainfall. The sampling method is to take monthly rainfall data at five stations that cover the observed road area. Rainfall data taken from Maros class I climatology station is first inputted into the Google Earth application, after inputting the coordinates appear in accordance with the latitude and longitude at each station (Fig. 5).

Fig. 3: Map layout results

Fig. 4: 2D visualization of the ArcGIS pro application

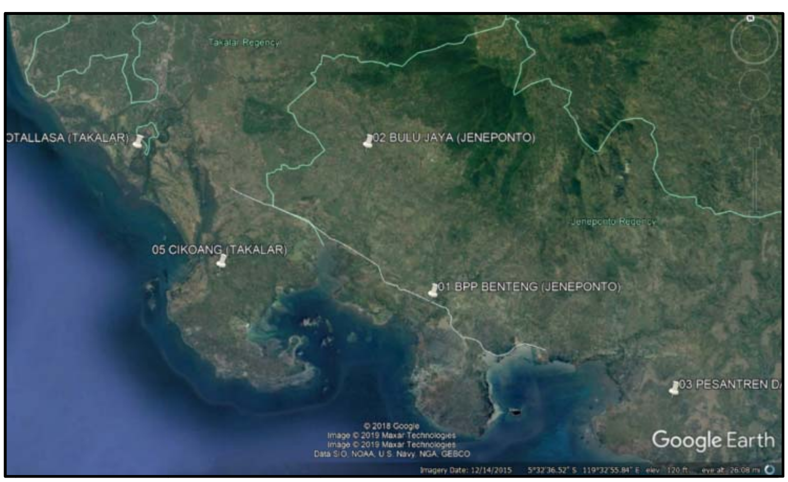

Fig. 5: Checking the coordinate point of the rainfall station

After the location coordinate point is checked on Google Earth, then the longitudinal coordinates of the minute seconds are converted to the UTM standard to get the X & Y value. The X & Y value is inputted into the Microsoft Excel application and then entered into the ArcMap application. In the ArcMap application, the

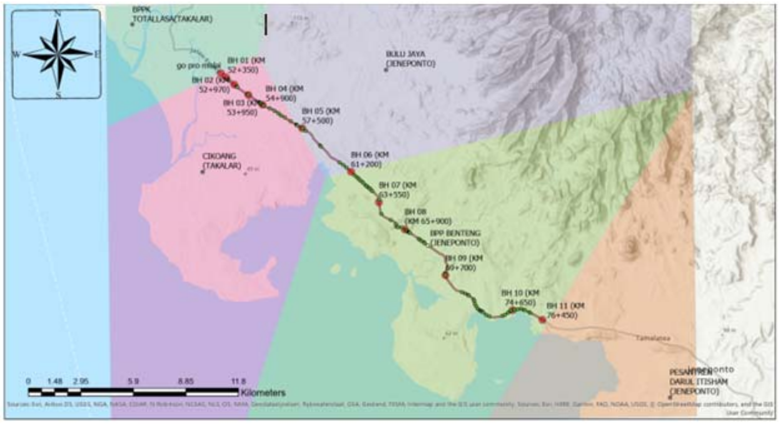

Fig. 6: Thiessen polygon based on 5 rainfall stations

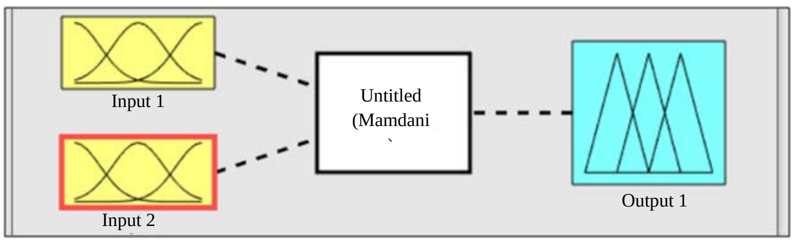

Fig. 7: FIS Mamdani method

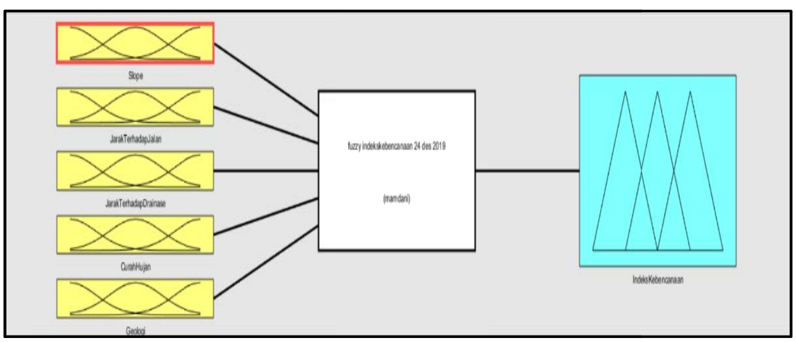

Fig. 8: FIS Mamdani fuzzy logic

coordinates of the station inputted are adjusted to UTM WGS 1984 50S, so that, they can adjust to the observation location. The method used to determine the area of influence of rainfall is by using the Thiessen Polygon method. Weighted average, each rain station is determined by the area of influence based on the polygon formed (drawing the axis lines on the connecting lines between two adjacent rain stations). The method is obtained by using the create Thiessen polygon feature in the ArcMap application (Fig. 6).

Fuzzy logic design using MATLAB: Fuzzy Inference System (FIS) for each fuzzy logic toolbox model that utilizes the Graphical User Interface (GUI). In this case the parameters of the disaster index by building a fuzzy system, there are several steps that need to be done. The first step is to determine the number of inputs and outputs desired by using the fuzzy logic designer using the Mamdani FIS method as shown (Fig. 7).

To add the number of inputs, select on the edit menu, then add variables, then add input. Next will appear a yellow dialog box which is the second input (Fig. 8).

The next step is to define the membership functions of each input variable and output variable through the membership function editor in the following Fig. 9 and 10. To find out the membership function curves can be

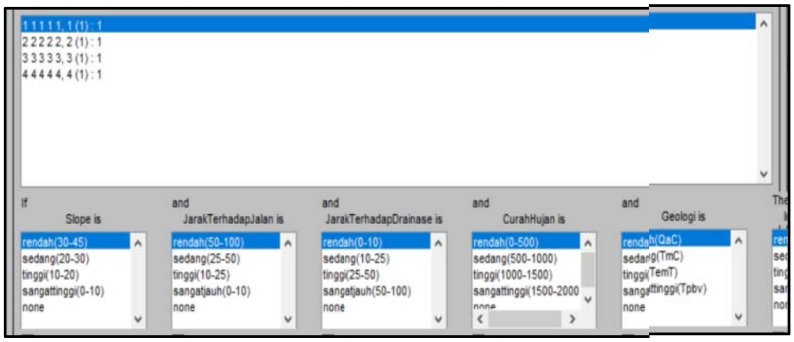

Fig. 9: Fuzzy disaster index rule editor

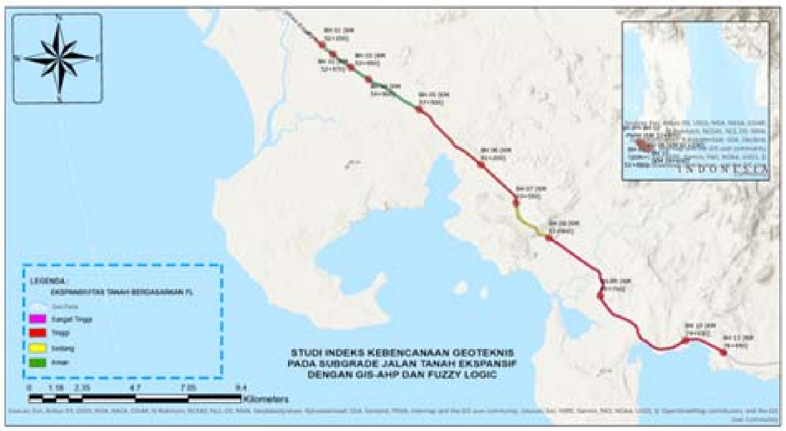

Fig. 10: Map of disaster index based on fuzzy logic

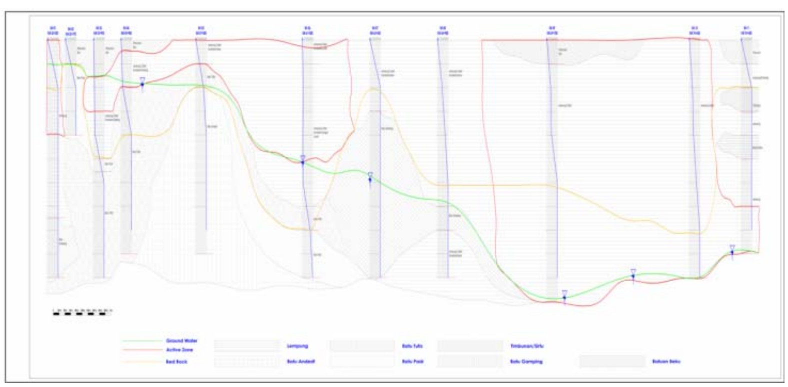

Fig. 11. Bore hole stratigraphy

done by clicking on one of the colored dialogs on the right. The shape of the curve and curve label can be changed as needed by changing it in the type and name columns. Furthermore, to define the if-then rule with the rule editor, the use is to facilitate the compilation of if-then rule statements automatically by clicking an item linguistic value option for each input and output variable. The defined rules will be displayed in verbose format or long sentences. Each statement is given a weight of 1 to declare the rule influential in the system being built. The whole process is displayed in the Rule Viewer shown in the following image.

After analysis the degree of soil expansion is obtained graphically and tabulated in a map as shown in Fig. 11.

Table 1: Disaster index

Drill point	Fuzzy logic	AHP range	Road inventory	IRI 2015	IRI 2016
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	2	3	2	1
6	3	3	1	1	1
7	3	3	3	2	2
8	2	2	2	1	1
9	3	3	3	2	2
10	3	3	4	2	2
11	3	3	2	2	2

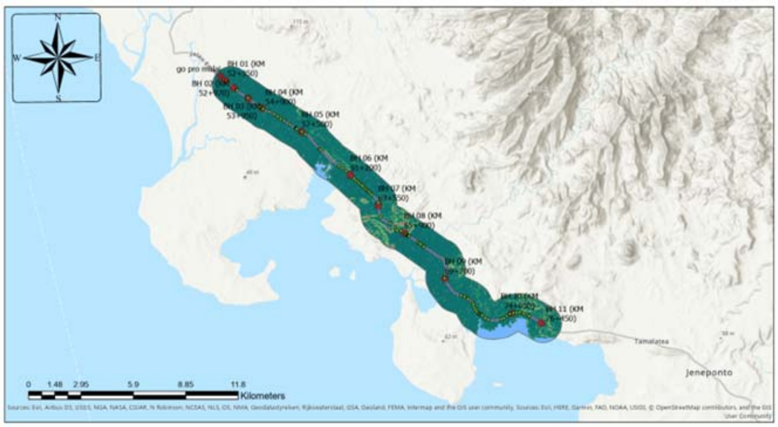

Fig. 12: Slope analysis

Fuzzy logic formulas for degrees of land expansion: The degree of expansiveness of the soil is influenced by 4 things, namely the depth of the soil, the slope of the land, the rainfall and the height of the ground water level (Fig. 12). Fuzzy logic formulas that have been determined based on variables are shown in Table 1.

Analysis process using AHP: Analytical Hierarchy Process (AHP) begins with the identification of the area of the path of the road that is traversed with several criteria, namely the survey of the slope, the distance of the expansive land to the road, the distance of the expansive land to drainage and rainfall. The steps for analyzing soil expansion using the AHP are: retrieval of DEM data from USGS with the TIF format for an expansive soil research area that includes an area of Takalar Jeneponto district road along 24 km. After the DEM data is imported into the ArcGIS application, the DEM data location coordinate system is adjusted to the 1984 50S UTM for the Jeneponto district area.

After the coordinate system has been adjusted to the location of the study, then the dem data is converted to slope (arctoolbox arcgis feature) to determine the slope which will be overlayed with an expansive soil research pathway. The slope has been reclassified using the reclassify feature according to criteria 0-10, 10-20, 20-30, 30-45, >45 (in units of slope degrees) that have been analyzed in the AHP free software (bpmsg.com). The priority resulting from the slope conversion process is the comparison of the slope index (weight) generated from the AHP free software. The first priority is the slope of the road 0°-10° by 60%. The second and third priority respectively in the slope of the road 10°- 20° and 20°-30° by 25.7 and 8.8%. The last priority is at a slope of 30°-45° at 5.6%.

Expansive soil distance criteria for roads and drainage can be determined through a buffer process. The path is buffered 50 m left and 50 m right using the buffer feature on the geoprocessing menu bar. Furthermore with the visualization of contoured slope effects, DEM data is converted using the hillshade feature and then on the converted slope dem layer, the transparency is set to 45%, so that, it can blend with the hillshade that was created. The results of the road buffer buffering process are linked to the DEM data raster. Hydrological maps are obtained from the fill feature then flow direction. After flow direction the next feature is flow accumulation and raster calculator to get a picture of a tributary. After getting the tributary path using the raster calculator, the next features are stream line, stream order and euclidean distance to get

Fig. 13: Hydrology analysis

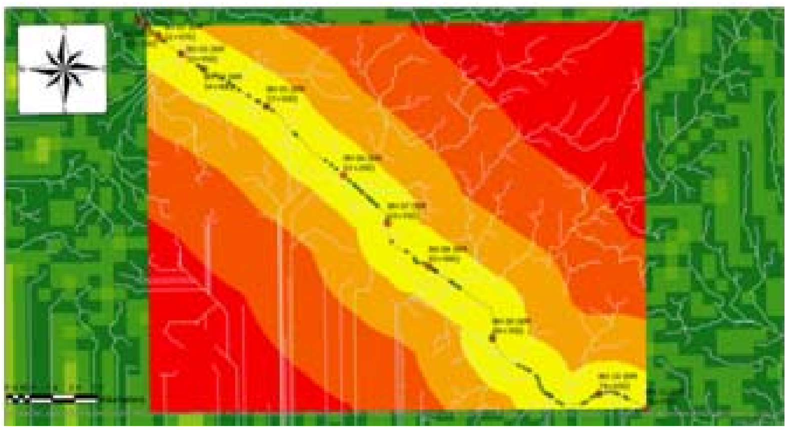

Fig. 14: Distance analysis

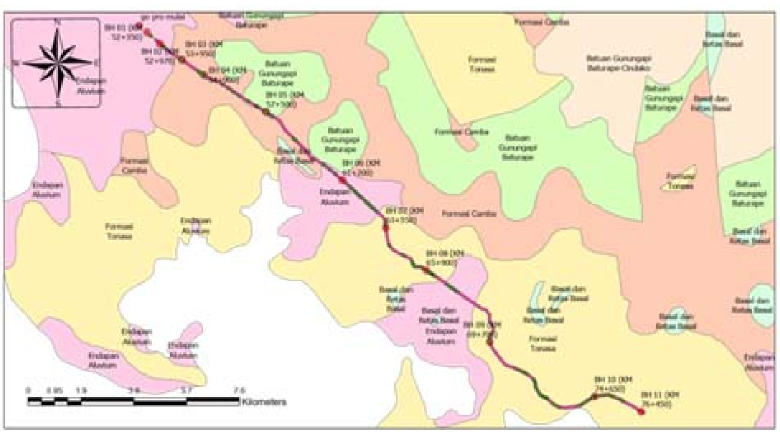

Fig. 15: Geology analysis

the desired visualization, after the visualization appears, then reclassify the raster based on criteria for hydrological maps (expansive soil distance to drainage), 0-10, 20-25, 25-50, 50-100 (m).

To get an expansive land distance to the road. Figure 13 and 14 show the feature used is euclidean distance, then reclassify the raster based on criteria for an expansive land distance map to the road that is 0-10, 20-25, 25-50, 50-100 (m). After making the digitization results, the color zoning is distinguished according to the criteria of rock type/soil sediment in the area by performing the reclassify command (Fig. 15). For zoning

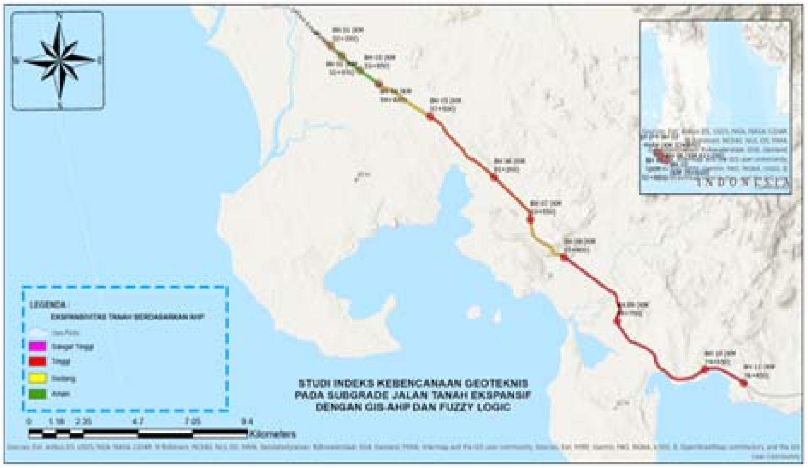

Fig. 16: Land expansion based on AHP

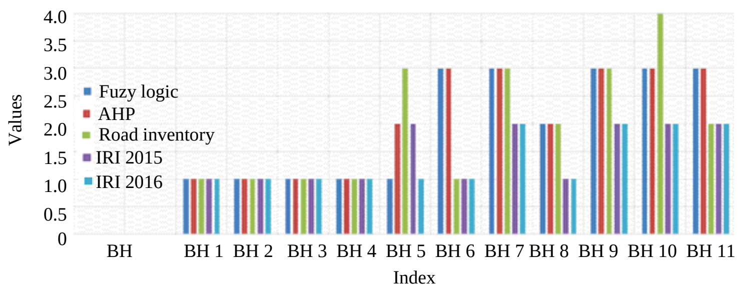

Fig. 17: Disaster index

appearance can be seen in Fig. 14. The Ujung Pandang Geological map displays the Baturape Volcano rock formations, the Camba formation, the Tonasa formation, Basal and Basal Retas as well as the Alluvium Deposition.

The five criteria that have been obtained are then overlaid using the weighted overlay feature to get the AHP results of the five criteria. Final appearance of soil expansion based on AHP can be seen in Fig. 15. The disaster index through the AHP process can be referenced in Fig. 16 and 17.

CONCLUSION

From the research it is known that the ArcGIS application is very helpful in decision making and data processing of land survey results and is able to visualize or display data in the form of 2 dimensions or in the form of 3 dimensions so that it can be easier to see conditions on the ground.

The application of ArcGIS Pro and MATLAB fuzzy logic is known to be very helpful in applying AHP and fuzzy logic methods to analyze areas of land expansion combined with land investigation data and road inventory. The disaster index obtained from AHP and fuzzy logic has similarities with the level of damage that occurs on the road based on the results obtained on the road inventory. An intelligent system based on fuzzy logic can make it easier for users to find out the level of expansiveness of the land and the possibility of areas with landslide vulnerability in the specified coverage area. Fuzzy logic-based intelligent systems have high accuracy in determining landslide-prone areas, so that, they can be used as a reference to determine the level of landslide vulnerability in certain areas and can immediately take precautions or efforts to avoid landslides.

Based on the results of research and analysis using the AHP and fuzzy logic methods, the handling of geotechnical structure instability improvement on the national land expansion road with the influence of traffic and flooding can be categorized into 4 stages, namely the first maintenance (maintenance), minor rehab (minor damage), major rehabilitation (heavy damage) and reconstruction (reconstruction of damaged roads).

REFERENCES

Altmeyer, W.T., 1955. Discussion of engineering properties of expansive clays. Proc. Am. Soc. Civ. Eng., 81: 17-19.

Chen, F.H., 1988. Foundations on Expansive Soils. Elsevier, ?Amsterdam, Netherlands, ISBN: 9780444416629, Pages: 463.

Cokca, E., 1991. Swelling potential of expansive soils with a critical appraisal of the identification of swelling of Ankara soils by methylene blue tests. Ph.D. Thesis, Middle East Technical University, Ankara, Turkey.

Donaldson, G.W., 1969. The occurrence of problems of heave and the factors affeting its nature. Proceedings of the 2nd International Research and Engineering Conference on Expansive Clay Soils (ECS‘1969), December 1969, Texas A & M Press, College Station, Texas, USA., pp: 25-36.

Holtz, W.G. and H.J. Gibbs, 1956. Engineering Properties of Expansive Clays. Bureau of Reclamation Publisher, Denver, Colorado, USA.,.