Jurnal Teknik Sipil & Perencanaan 26 (1) (2024) p 8 - 16

UNNES JOURNALS

JURNAL TEKNIK SIPIL & PERENCANAAN

10.15294/jtsp.v26i1.47084

Identification of Potential Locations for Soil Investigation based On Geographic Information System (GIS)

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Abstract. A site survey is conducted to analyze the stratification of the earth, identify soil types, measure water table depths, and assess soil deformation characteristics. This data is essential for designing cost-effective substructures, conducting supporting structure research, devising alternative development strategies, and ensuring site safety. The planning of site investigations is pivotal for collecting comprehensive data that accurately represents the on-site soil conditions and supports development objectives. Overly extensive investigations may result in resource wastage, both financially and temporally. On the other hand, inadequate investigations heighten the risk of structural failures and yield data that does not truly represent the site's conditions. Planners utilize mapping of potential investigation sites to strategically decide where site investigations should be carried out. This study uses data from Standard Penetration Tests and Cone Penetration Tests in conjunction with Geographic Information System (GIS) spatial analysis to map potential site investigation locations, ultimately recommending specific sites. The analysis incorporates three key parameters—elevation, slope, and historical site data—using the fuzzy overlay gamma and per-cell statistical maximum methods. The accuracy of the spatial analysis results is validated through an inference matrix, with validation results showing that the weighting method achieves an accuracy rate of 63%. The analysis highlights significant potential for targeted site studies in the southeast, northeast, and western parts of the research site.

Keywords: Spatial analysis, regional development, site investigation

INTRODUCTION

Site investigation is a critical and fundamental aspect of geotechnical development [1]. Soil investigations are conducted to determine the characteristics and properties of the soil, which serve as a reference in designing building substructures [2]. Soil investigations should be meticulously planned and executed to gather the most comprehensive data possible. Preliminary soil investigations provide initial data related to soil stratification, soil type, groundwater table, and soil deformation properties [3]. A tool is necessary for gathering soil investigation data at a location. Geographic information systems (GIS) are extensively utilized for spatial data analysis in the form of maps. GIS is a computer-based system that can manage, process, store, and analyze both geographic and non-geographical data, providing informational and graphical outputs [4]. Geographical information refers to data related to locations on the Earth's surface, object positions, and attributes at known locations [5]. in Civil Engineering, Geographic Information Systems invaluable for planners to predict complex data with accuracy and validity [6]. GIS provides an alternative means of integrating soil investigation data spatially through GIS-based software [7]. GIS can also be used to predict the soil-bearing capacity in areas yet to be sampled, which is instrumental during the planning stage of substructure development [8]. Previous researchers have used the GIS approach for soil investigations. For example, Sutasoma et al. (2017) used geographic information system (GIS) techniques for landslide zone investigations and disaster mitigation. Putranto et al., 2020 integrated soil investigation data into the GIS for analyzing soil bearing capacity, and Nistor et al., 2019 identified suitable soil investigation locations in Singapore using spatial analysis that combined three layers: digital elevation model (DEM), slope angle, and soil sampling locations.

In this research, the mapping of potential soil investigation locations was conducted using spatial analysis in GIS. The spatial analysis then produces an output in the form of a possible map for the location of the site investigation. The study area used is Kalimantan Institute of Technology (ITK) Master Plan. The ArcGIS 10.8 assist program is used to apply the concept of spatial analysis, which specifically manages spatial data information. Five suitability classes are applied to each layer, including very low, low, medium, high, and very high, to indicate the potential for site investigation. The spatial analysis methods include weighted overlay, fuzzy overlay gamma, and per-cell statistical maximum (PCSM). Of the three ways, each produces a map.

A validation test using an inference matrix was carried out to identify the most accurate method. The selection of a suitable site investigation location was based on the distance class from the previous location, as well as the shape of the slope and elevation, using ArcGIS software. The criteria for site suitability include locations where the stratigraphy or soil conditions differ from the reference point. Slopes located at high elevations are more susceptible to environmental conditions, such as cracks due to high temperatures and increased infiltration from rainfall [9]. In addition, the height of the slope also affects the increase in the potential for slope failure [10]. Consequently, investigation in the highland areas is crucial. Steeper slopes are considered very suitable for soil investigation. The slope classification is based on the condition of the local slope angle. The slope parameter significantly influences the risk of landslides [11][12]. In terms of distance, closer site investigation locations provide better soil visualization for planning [3]. However, if the soil conditions are relatively uniform, , selecting investigation points at greater distances can still yield diverse soil characteristics.

A map indicating suitable soil survey locations is very useful during the planning stage of various development projects. Several developed countries already have implemented geotechnical zoning maps, which provide guidelines for designing engineering projects in the geotechnical field [6]. Mapping potential land survey locations offers preliminary information that enables planners to determine the appropriate site for investigation in a development project. This study uses soil investigation location data derived from the SPT (Standard Penetration Test) and CPT (Cone Penetration Test) conducted in the Kalimantan Institute of Technology area. The mapping results can serve as a recommendation in campus development and mitigation plans, as they highlight areas with potential soil movement [13][14]. In addition, the validation of the resulting map will identify the spatial analysis method that achieves the highest level of accuracy.

MATERIAL AND METHODS

The research phase begins with the compilation of a spatial analysis parameter map, which includes a map of the slope, elevation, and previously conducted soil investigation location. These maps are then overlaid to aggregate several spatial elements and create new spatial features. Overlay data formats are typically categorized into vector or raster types [15]. Subsequently, a validation test is conducted to assess the accuracy of the spatial analysis results of the three methods used.

The research was conducted in the master plan area of the Kalimantan Institute of Technology, Jl. Soekarno-Hatta, KM. 15, Ex. Karang Joang, Kec. North Balikpapan, Balikpapan City, covering an area of 313.5 hectares, as shown in Figure 1.

The parameters for elevation and slope are compiled based on DEM data from the DEMNAS website of the Geospatial Information Agency (BIG). In Indonesia, DEM data can be accessed open-source through the Seamless Digital Elevation Model (DEM) website and the National Bathymetry (DEMNAS) [16]. The coordinate data for the location of the previous soil investigation was obtained from the Kalimantan Institute of Technology Campus Planning subsection. This data was utilized to create a buffer map indicating the distance from the last site investigation location. Buffers, formed from line and polygon elements, illustrate the impact of various phenomena on map elements, such as the extent of river overflow [17]. Spatial analysis is a set of techniques used to analyze spatial data [18]. In this research, the methods employed include weighting, fuzzy overlay gamma, and Per-Cell Statistical Maximum (PCSM), all of which utilize the Spatial Analyst Tools feature in ArcGIS. The result of this analysis a classification of potential soil investigation sites into five categories: very low, low, medium, high, and very high. The validation test was carried out to ascertain the accuracy of the results obtained from the three spatial analyses using an inference matrix. The results of this validation test categorized the findings from the weighting method, fuzzy overlay gamma, and PCSM into valid and invalid outputs, thereby identifying the most effective method for generating a map of potential new soil investigation locations in the ITK Master Plan area.

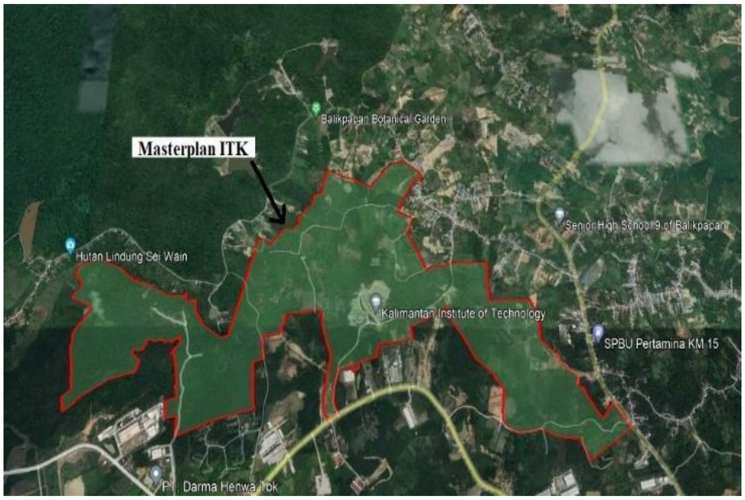

FIGURE 1. Study location in the ITK Masterplan area

The elevation in the study area is categorized into five suitability classes, each defined by equal intervals, as shown in Table 1 [9].

TABLE 1. Distribution Area of Elevation Class

Classes	Elevation	Area (ha)
I	5.5 – 15 m	9.7
II	15 – 24.5 m	49.4
III	24.5 – 34 m	143.4
IV	34 – 43.5 m	97.7
V	43.5 – 53 m	13.3
Total		**313.5**

Source: Analysis (2023)

The slope in the study area is divided into five classes, as seen in Table 2. The classification of the slope class is based on the conditions of the slopes in the ITK master plan area.

TABLE 2. Distribution Area of Slope Class

Classes	Slope	Area (ha)
I	0 – 8 %	84.6
II	8 – 16 %	157.4
III	16 – 24 %	63.5
IV	24 – 32 %	7.7
V	32 – 40 %	0.3
Total		**313.5**

Source: Analysis (2023)

Based on CPT and SPT coordinate data, buffering of soil investigation points is carried out to determine the radius or distance from the existing soil investigation location. Determining the distance class from the current soil investigation point refers to the maximum distance of soil investigation stipulated in SNI 8460-2017, which is 200 meters between points on an elongated structure. This distance was chosen because the type of structures to be built at ITK in the future is unknown, thus warranting the selection of the maximum allowable distance. The maximum distance then serves as a reference for defining the interval for each class. The identification of the potential type for new soil investigation is based on the shortest distance from the existing soil investigation location, which is categorized as having very low potential and is segmented into five classes [9]. The classification and distance intervals from the current soil investigation point are detailed in Table 3.

TABLE 3. Existing Point Distance Class and Interval

Classes	Distance (m) from the existing point	Potential for New Site Investigation
I	0 – 50	Very Low
II	50 – 100	Low
III	100 – 150	Medium
IV	150 – 200	High
V	> 200	Very High

Source: Analysis (2023)

The classification of elevation, slope, and distance to the previous soil investigation location is presented in Figure 2. The height of the ITK master plan area varies from 5.5 m to 53 m, and the slope angle varies from 0 % to 40 %. These parameters of height and slope were reclassified based on five potential classes, each with consistent intervals. The most suitable class for new soil investigations is identified on slopes that are both high and steep [9]. The steeper the slope, the greater the volume and velocity of the surface runoff, which increases the potential for significant landslides. A key criterion for an area to be considered at high risk for landslides is the presence of steep slopes. Specifically, slopes with an angle greater than 15% are highly susceptible to landslides [19]. Therefore, taking soil samples from steep slopes is it provides essential data for slope development. Soil sampling on steep slopes is integral to slope stability analysis, which is vital for assessing slope safety. Unstable slopes pose significant risks to the surrounding environment [20].

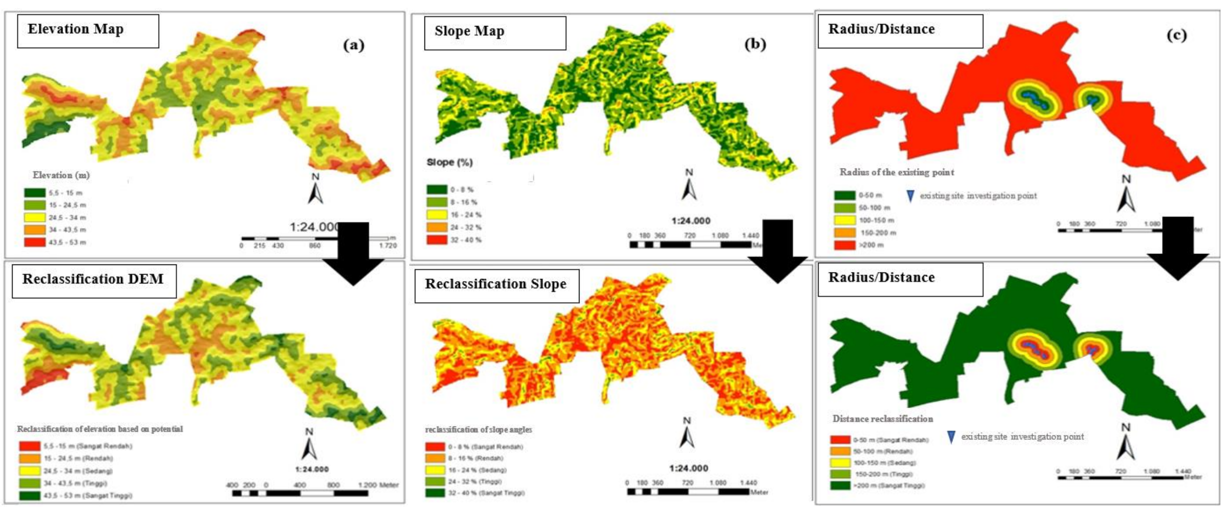

FIGURE 2. Classification and reclassification (a) Elevation, (b) Slope, and (c) Distance to the location of the previous site investigation

Each method of spatial analysis in ArcGIS begins by scoring each parameter to assess its level of significance, as detailed in Table 4. The scores are assigned levels ranging from 1 to 5, dividing the study into five potential classes.

TABLE 4. Value of each parameter

Potential for Site/Soil Investigations	Elevation(m)	Slope (%)	Distance to existing land survey point (m)	Score
Very Low	5.5 - 15	0 - 8	0 - 50	1
Low	15 – 24.5	8 - 16	50 - 100	2
Medium	24.5 - 34	16 - 24	100 - 150	3
High	34 – 43.5	24 – 32	150 - 200	4
Very High	43.5 - 53	32 - 40	> 200	5

Source: Analysis (2023)

RESULT AND DISCUSSION

The analysis using the weighting method is conducted with the weighted overlay tools in the Spatial Analyst Tools suite. Each input raster is assigned a weight, expressed as a percentage, based on its importance to the analysis. The total of all weights must equal 100% [21]. In this study, the elevation and slope factors were assigned a weight of 30 %, reflecting their equal significance in slope stability analysis. The distance from the last soil investigation site was given a 40% weight because it is the most influential parameter in this spatial analysis. Figure 3. (a) shows the results of the weighting method for the map indicating possible soil investigation sites. Overall, the results suggest that the majority of the ITK master plan area has a high potential for soil investigation. High potential areas are dispersed across the north, south, west, southwest, and southeast. These high-potential areas are generally more than 200 meters away from the previous soil investigation site. Several locations with very high level potential for investigation can be found in small areas in the northeast and southeast and the western part of the ITK master plan area. These highly suitable small areas are situated at high elevations and on steep slopes with angles ranging from 32 to 40%. Areas with moderate potential for soil investigation are uniformly spread across the central, north, southeast, west, southwest, and east parts of the ITK master plan. Areas about 100–200 m from the previous survey point exhibit moderate potential. The southwestern and central parts of the ITK master plan area are categorized in the medium potential category due to their lower elevations and slope angles, and their distance from the previous soil investigation site. Additional locations with medium potential for soil investigation can also be found in small areas in the north, southwest, and southeast of the ITK master plan area. Sites approximately 100 m from the previous soil investigation point are considered to have low potential for further soil investigation. The area with a very low potential for soil investigation is the small central area, deemed such due to its proximity to the prior land survey point.

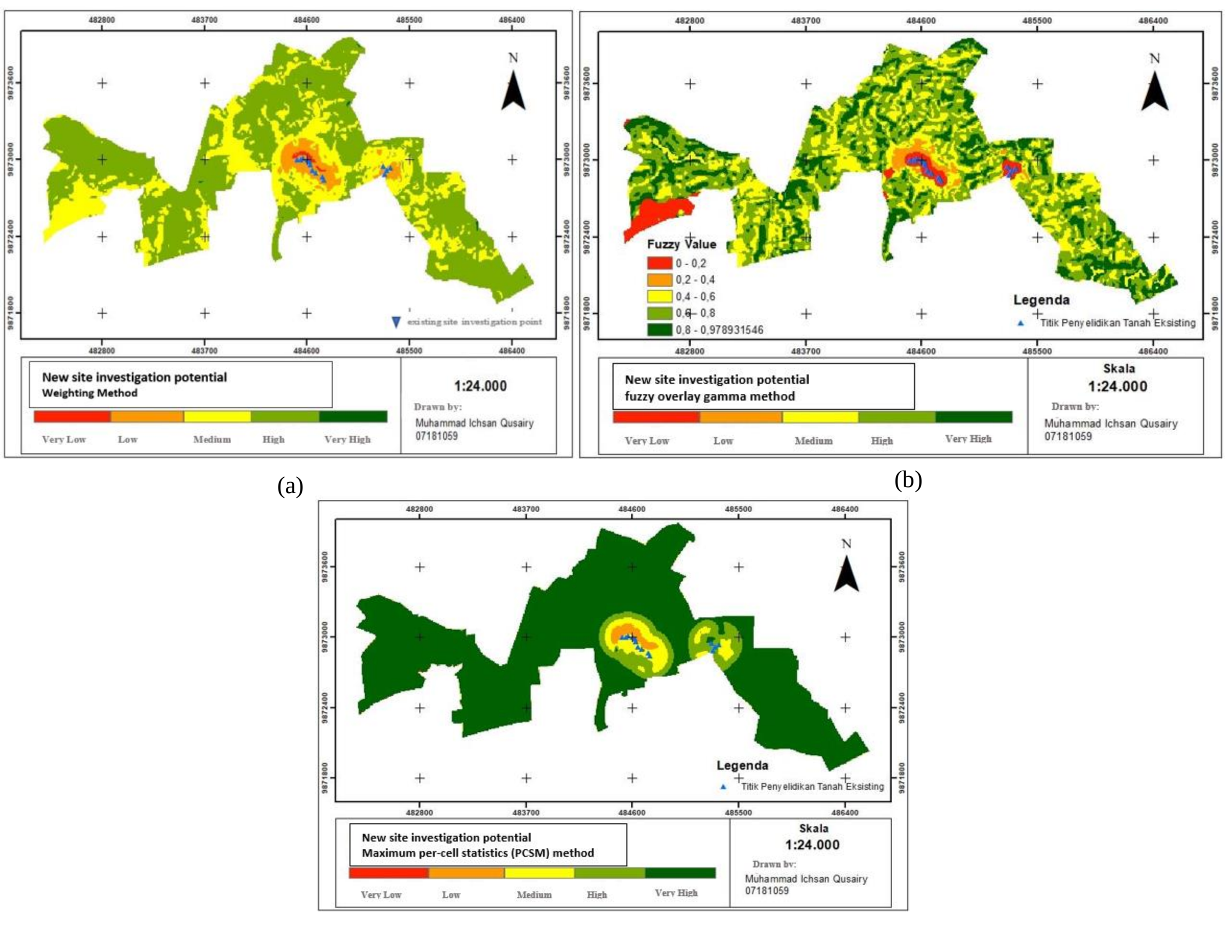

FIGURE 3. Map of potential new soil investigation locations in the ITK Masterplan Area using (a) the weighting method, (b) the fuzzy overlay gamma method, (c) the PCSM method

Spatial analysis using the fuzzy overlay gamma method was conducted using an automated approach in ArcGIS. The fuzzy gamma is an algebraic product of fuzzy product and fuzzy sum, influenced by the strength of the gamma parameter [22]. This method utilizes fuzzy membership and fuzzy overlay tools within ArcGIS. The output from this fuzzy overlay analysis is a fuzzy value ranging from 0 to 1 [23]. During the fuzzification stage, the fuzzy membership feature adjusts the layer to a uniform scale, with intervals between "0" (indicating an unsuitable area) and "1" (indicating a suitable area), as detailed in [24]. After the fuzzification stage, the fuzzy overlay tool is run to get the results, as shown in Figure 3 (b).

The analysis results using fuzzy overlay gamma, as shown in Figure 3 (b), produce values with interval values of 0–1. Fuzzy values close to 1 at 0.80–0.979 are marked in dark green, which means the region is getting closer to potential suitability. Conversely, fuzzy values near 0, in the 0–0.20 range, are marked in red, indicating minimal suitability potential, Figure 3 (b) shows that, in general, most of the ITK master plan area exhibits high potential for soil investigations, encompassing nearly all regions including the north, south, southeast, southwest, west, northwest, and northeast. Areas with very high potential are also spread across all parts of the ITK master plan area. Areas with high potential typically feature an average slope angle of 16–40 %. Moreover, areas with moderate potential are also spread across all parts of the ITK master plan area. Particularly, the central area, ranging approximately 50–200 m from the previous investigation point, was previously categorized as having low potential. The central part of the ITK master plan, about 50 m from the previous soil investigation point, has a very low potential. Additionally, areas at the western end of the ITK master plan are characterized by very low potential due to their low elevation and slope angle, compounded by their distance from the previous soil investigation site.

Spatial analysis using the PCSM method is performed by selecting the maximum value from each cell of the input parameters. This analysis utilizes the cell statistics tool within the Spatial Analyst Tools, with results depicted in Figure 3(c). The spatial analysis results from the PCSM method, as shown in Figure 3(c), indicate that areas with the highest potential are predominantly located in the north, west, southwest, northwest, northeast, and southeast regions of the ITK master plan area. Areas positioned 150–200 meters from the locations of previous soil investigations are classified as having high potential for new investigations. Additionally, the area to the east near the last soil investigation site also shows high potential due to its elevated terrain and steep slopes. The central area, near the previous land survey site, exhibits moderate potential. Very few areas within the ITK master plan area are identified as having low potential. These low potential areas are located centrally, close to the previous soil investigation site.

The validation process begins with the creation of an inference matrix, structured as a 5 x 5 matrix divided into five classes: very low, low, medium, high, and very high. The validation process involves three steps using this inference matrix as a reference. The first step integrates the three parameters (elevation, slope, and distance from the previous soil investigation) with the results from each of the three spatial analysis methods. This integration is conducted using the Intersect tool in the geoprocessing toolbox, which generates intersection attribute data for overlapping polygon parts [25]. The second step involves determining the potential land suitability classification for soil investigation based on the relationship between elevation and slope. The third step assesses the suitability potential for soil investigation based on terrain relationships and proximity to the previous soil investigation site. An inference matrix for determining the potential land suitability for soil investigation, based on the relationship between elevation and slope, is presented in Figure 4. Additionally, an inference matrix for assessing the suitability potential of a soil investigation area, based on terrain relationships and distance to the previous soil investigation site, is provided in Figure 5.

		Slope (%)				
		0 – 8	8 – 16	16 – 24	24 – 32	32 – 40
Elevation (m)	**Potency**	Very low	Low	Medium	High	Very High
5.5 – 15	Very low	Very low	Very low	Low	Low	Medium
15 – 24.5	Low	Very low	Low	Low	Medium	Medium
24.5 – 34	Medium	Low	Low	Medium	Medium	High
34 – 43.5	High	Low	Medium	Medium	High	High
43.5 – 53	Very High	Medium	Medium	High	High	Very High
		Terrain potential for test sites				
		Very low	Low	Medium	High	Very High

FIGURE 4. Inference matrix for the relationship between elevation and slope

		Location data				
		Class 1	Class 2	Class 3	Class 4	Class 5
Distance	**Potency**	Very low	Low	Medium	High	Very High
0 – 50	Very low	Very low	Very low	Low	Low	Medium
50 – 100	Low	Very low	Low	Low	Medium	Medium
100 – 150	Medium	Low	Low	Medium	Medium	High
150 – 200	High	Low	Medium	Medium	High	High
>200	Very High	Medium	Medium	High	High	Very High
		Integrated suitability for the site investigation				
		Very low	Low	Medium	High	Very High

FIGURE 5. Terrain and distance relationship inference matrix

The data is considered valid if the intersection results match those of the inference matrix. Conversely, if the intersection results differ from the inference matrix, they are deemed invalid. The outcomes of the validation test are presented in Table 8. The results concerning the inference matrix reveal that the weighting method demonstrates a higher accuracy level compared to other methods. Specifically, the validity percentages are as follows: the weighting method at 63%, the fuzzy overlay gamma method at 33.7%, and the PCSM method at only 5.6%. In contrast to the weighting and PCSM methods, the fuzzy overlay gamma method processes a more diverse range of data, as indicated in Table 8. This is because the fuzzy overlay gamma method utilizes all available data without filtering, whereas the weighting method applies a weighted overlay technique, assigning weights to each piece of input data based on its significance or impact. In the PCSM method, results are determined by the largest cell values among several input rasters. Consequently, in the fuzzy technique, areas with high and very high potential are evenly distributed across several parts of the ITK master plan area. In contrast, using the area weighting technique, regions with high potential are dispersed in the southeast, south, north, southwest, and west. Areas with very high potential are confined to smaller regions in the southeast, northeast, and west.

TABLE 8. Recapitulation of validation results

No.	Method	Total Attribute Data	Valid		Invalid	
			Percentage	Persentase	Total Data	Percentage
1.	Weighting	2852	1802	63 %	1056	37 %
2.	*Fuzzy Overlay Gamma*	4892	1648	33.7 %	3244	66.3 %
3.	PCSM	2065	115	5.6 %	1950	94.4 %

Source: Analysis (2023)

The PCSM method results demonstrate that the ArcGIS system selects the maximum scoring value for each input parameter. In this system, areas exceeding 200 meters are categorized as having very high potential for soil investigations. This approach is consistently applied across all parts of the cell. Consequently, the potential map produced by the PCSM method exhibits significant differences compared to maps generated using other spatial analysis methods. This disparity results in a markedly lower validity level for the PCSM method relative to the other methods. Given these observations, it is evident that the weighting method, employing the weighted overlay technique, is the most appropriate for assessing the potential suitability of soil investigation locations in the ITK master plan area.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that the weighting method is the most recommended for preparing a map of potential new soil investigation sites. The weighting method exhibits a validation percentage of 63%, in contrast to 33.7% for the fuzzy overlay gamma method and only 5.6% for the PCSM method. The results from the weighting method indicate that areas with very high potential are concentrated in small regions in the southeast, northeast, and west of the ITK master plan area. Additionally, areas with high potential are distributed across the north, south, west, southwest, and southeast. This research is expected to provide preliminary information to assist planners in determining suitable locations for soil investigations in the ITK area. Moreover, the findings from this study can be further enriched by integrating various field test coordinate databases.

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