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Web GIS System for Transmission Tower Planning in Selangor for Spatial Data Integration and Sustainable Infrastructure Solutions

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Abstract – The transmission tower information system is a digital platform that monitors, controls, and assesses transmission tower data to improve operational performance and decision-making. However, integrated transmission tower information systems are limited in Malaysia. This study creates a web-based GIS model of transmission tower planning in Selangor, Malaysia through the combination of transmission tower, topographic, soil, and population data in a GIS environment and the publication of the processed spatial data in a web-based interface. As supporting spatial analysis functions, Kernel Density Estimation (KDE) and Natural Neighbour interpolation were used to analyze spatial patterns and reflect the distribution of soil conditions, respectively. These analytical products are incorporated into the Web-GIS to aid in determining priority areas and in the initial planning of soil-related foundations. A multi-item questionnaire was used to evaluate the usability, functionality, accessibility and perceived usefulness of the developed platform by stakeholders, including 30 surveyors, engineers and urban planners. The analysis showed an average usability rating of 4.5/5 (SD = 0.3), and 88% of participants expressed that they would use the application. The cost-saving and soil-stability solutions of the system directly promote SDG11 and provide a model for rapid urbanization.

Keywords *– transmission, information systems, tower, web-based, GIS system*

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1.0 Introduction

Transmission towers play a very important role in electricity transmission networks, holding overhead conductors and other electrical devices and ensuring the necessary clearance between the transmission system and its environment. The choice of the proper tower site is thus not a purely geometrical problem. It involves taking into account current infrastructure, population density, topography, ground conditions, accessibility, environmental limitations, and other space-related factors that may affect the construction possibility and maintenance in the long run. Geographic Information Systems (GIS) offer an appropriate platform on which these datasets can be combined and the spatial relationships can be studied. It has been shown that GIS is used in the transmission corridor selection process, planning of infrastructure, environmental assessment, and utility data management (Bharadwaj et al., 2020; Sharafat et al., 2021). The case of rapid urban development in Selangor suggests that a current spatial awareness of transmission infrastructure and the coverage areas is more significant. Scattered tower records, population data, topography data and ground-condition data may complicate the process of assessing existing tower distribution in one decision-support setting by planners and utility professionals. One way to resolve this operational problem is to use a web-based GIS that offer centralized access to spatial layers via an interactive interface. In contrast to a static map, a web-based site gives users the ability to query tower attributes, toggle between thematic layers, measure locations, view feature details, and see spatial patterns without having to maintain a unique desktop GIS environment on a case-by-case basis.

Infrastructure design and planning have also been implemented using GIS since spatial analysis can be used to help in selection of routes, environmental screening, management of assets and assessment of construction constraints. In the case of transmission infrastructure, the spatial database may include tower locations and geographic information around them and thus enabling engineers and planners to analyze the correlation between the available assets and the site conditions. Spatial analysis using GIS can thus help in initial identification of areas that need further investigation prior to elaborate engineering design and building. The current study is however not supposed to substitute detailed engineering design or regulatory site assessment. It is intended to offer a spatial decision support and screening environment where the current towers locations and the chosen supporting datasets can be analyzed jointly. More specifically, the study is concerned with population-based spatial patterns and soil-based conditions as two analytical inputs into preliminary planning, although it is noted that terrain, land use, environmental

constraints, accessibility, transmission-line needs, and other engineering criteria must be factored in later phases of the site evaluation. Thus, this study will attempt to create a web-based GIS system to manage information of transmission towers and spatial planning in Selangor, Malaysia. This study aims to develop a web platform for presenting urban utility information and to determine the effectiveness of the web-based GIS system in urban planning.

The application of Web-GIS in utility, infrastructure and spatial management has been on the rise as it offers users access to interactive spatial information through web-based applications. Existing applications have demonstrated the usefulness of Web-GIS for visualizing spatial datasets, accessing geographic information, managing infrastructure-related information, and facilitating spatial decision-making (Kuridza, 2019; Kshetri et al., 2020; Tsagkis & Photis, 2021). These applications show that web-based platforms can enhance traditional GIS by enabling spatial information and analytical products to be accessed and shared via an interactive interface. This functionality is relevant to infrastructure management, where users might need to view asset locations, query related attributes, compare thematic layers, and convey spatial data without necessarily accessing the underlying desktop GIS environment.

Previous studies have also demonstrated the application of GIS in transmission tower planning and location analysis (Bharadwaj et al., 2020; Lin et al., 2023). However, these studies primarily focus on GIS-based analysis for transmission tower location or placement, whereas the reviewed Web-GIS studies focus on utility management, spatial information access, and specific spatial applications. Based on the reviewed studies, the integration of existing transmission tower locations, population spatial patterns, and soil conditions within a single Web-GIS environment for preliminary transmission infrastructure planning remains limited. This study addresses this gap by integrating these spatial datasets and analytical outputs into an interactive Web-GIS platform for preliminary planning in Selangor.

2.0 Material and Method

The research methodology was structured into four sequential phases: project planning, data acquisition, data processing and analysis, and outcome development and evaluation. Each phase consisted of specific procedures designed to address the study's objectives, as illustrated in Figure 1.

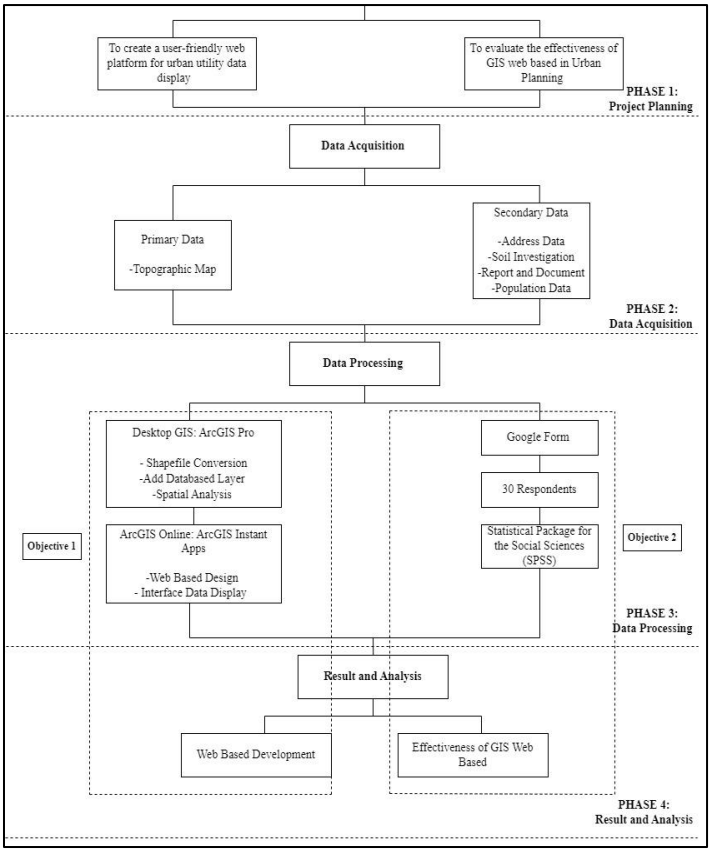

Figure 1: Methodology flowchart

The project requirements during the project planning stage focused on the need for centralized transmission tower data and spatially supported planning. Before data were acquired, the necessary datasets, methods of analysis, Web-GIS operations, and user evaluation processes were determined.

2.1 Project Planning

The scope and data requirements of the study were determined by the project planning phase for the two objectives mentioned above. This move determined the source of the datasets (transmission tower locations, topography, soil conditions, and population), the agencies that possessed each dataset, and how the resulting web application would have to organize them. The spatial modeling of tower distribution and soil-related foundation planning may be made available as separate, quarriable map layers and not a single, static output. The target respondent group and the evaluation tool to assess the objective (ii) were also determined in this phase.

2.2 Data Acquisition

Primary data contained topographical map of the study area that was created as a result of unmanned aerial vehicle (UAV) photogrammetric survey. The topographic map obtained by the UAV is more spatial and vertical accurate as compared to the freely available satellite imagery required to perform the slope and elevation foundation assessment. Second, Selangor is experiencing a rapid physical development. A UAV survey represents the existing conditions on the ground at the time of the study, rather than the older conditions in existing satellite or agency topographic data, eliminating the possibility that the siting analysis will be based on outdated terrain data. Secondary data were address and land-use records that were used to identify the location of towers and infrastructure, soil investigation records obtained through the Mineral and Geoscience department, Malaysia and population data, obtained through the Department of Statistics Malaysia, which was used to characterize tower coverage demand. All secondary data were geographically aligned with the primary topographic data to the same coordinate system before processing.

2.3 Data Processing

The processing of data started with cleaning the raw data; the second step was the conversion of the datasets into the appropriate GIS format, example shapefiles. The database layers were then imported followed by the spatial analysis using ArcGIS. This system was created as an interactive web-based application based on ArcGIS Instant Apps, which allows displaying data and interacting with users. The usefulness of the system was measured through user feedback using Google Forms questionnaires. Professionals who had a background in utility and infrastructure planning evaluated the system. The surveyors, engineers, and urban planners were 30 professionals involved in the system evaluation. The choice of these respondents was due to their professional activity that is related to spatial information, infrastructure planning, site assessment, or the process of decision making. The perceived usefulness, usability and practical applicability of the developed Web-GIS platform were assessed based on their feedback. Besides, the map is developed using Kernel Density estimation where it provides a continuous representation of population density, allowing areas with higher population concentrations to be identified and compared with existing transmission tower locations. Natural neighbour interpolation was applied for the available observations at specific locations and required spatial estimation across the study area. Therefore,

it is used to generate a continuous representation of soil conditions based on neighbouring observations. These methods were selected to provide matching spatial information for preliminary transmission tower planning.

2.4 System Development and User Testing

The processed layers were released as an engaging web-based application with ArcGIS Instant Apps. The platform developed was responsive to the study objective because it offered an easy-to-use interface for viewing and analyzing urban utility data and related spatial information. The KDE and NNI-based results were implementing as independent, switchable map layers that had interactive pop-up features, which allowed the user to analyze the spatial data in the same interface. The display and exploration of the spatial data were facilitated by the inclusion of standard navigation, editing and visualization tools. The efficiency of the created Web-GIS was tested on 30 participants including surveyors, engineers and urban planners. These respondents were chosen since they have professional activities that require spatial information, infrastructure planning, site assessment or decision-making processes associated with these activities. A 14-question structured questionnaire using the Google Forms questionnaire tool was used to evaluate ease of use, interface and map clarity, relevance of functionality to work tasks and intention to adopt the application, and an open-ended question to provide qualitative feedback. Exportation and analysis with SPSS was done to get frequencies, percentages, means and standard deviations as responses. One representative questionnaire item is shown in Figure 2, whereas the results of the overall evaluation were obtained using the entire questionnaire. Thus, the assessment covered the second aspect of the study aim, which is to measure how useful and effective the Web-GIS is for urban planning, according to the perceptions of the concerned professional users.

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Age	Numeric	8	2	Age	{1.00, 18-29...	None	8	Right	Nominal	Input
2	Sector	Numeric	8	2	What sector did you work?	{1.00, Land ...	None	8	Right	Nominal	Input
3	Experience	Numeric	8	2	Years of experience in the field	{1.00, Begin...	None	8	Right	Nominal	Input
4	A1	Numeric	8	2	The interface design seem attractive	{1.00, Stron...	None	8	Right	Scale	Input
5	A2	Numeric	8	2	The graphic design seem attractive	{1.00, Stron...	None	8	Right	Scale	Input
6	A3	Numeric	8	2	Appropriate used of colour theme	{1.00, Stron...	None	8	Right	Scale	Input
7	A4	Numeric	8	2	Logo and pictures used in the web based suitable and attractive	{1.00, Stron...	None	8	Right	Scale	Input
8	A5	Numeric	8	2	Type of font used suitable and attractive	{1.00, Stron...	None	8	Right	Scale	Input
9	A6	Numeric	8	2	The arrangement of buttons used in web based is appropriate	{1.00, Stron...	None	8	Right	Scale	Input
10	A7	Numeric	8	2	The sentences used are easy to understand	{1.00, Stron...	None	8	Right	Scale	Input
11	A8	Numeric	8	2	Button functions are easily identifiable	{1.00, Stron...	None	8	Right	Scale	Input
12	B1	Numeric	8	2	This application is user friendly	{1.00, Stron...	None	8	Right	Scale	Input
13	B2	Numeric	8	2	This Web Based Application provided information related to each point	{1.00, Stron...	None	8	Right	Scale	Input
14	B3	Numeric	8	2	This Web Based Application can work well for smartphone and computer use	{1.00, Stron...	None	8	Right	Scale	Input
15	B4	Numeric	8	2	The Web Based Application can be access and achieve at anywhere	{1.00, Stron...	None	8	Right	Scale	Input
16	B5	Numeric	8	2	The information for each point given is clear	{1.00, Stron...	None	8	Right	Scale	Input
17	B6	Numeric	8	2	The arranggement of button used in Web Based Application is appropriate	{1.00, Stron...	None	8	Right	Scale	Input
18	B7	Numeric	8	2	The sentences used are easy to understand	{1.00, Stron...	None	8	Right	Scale	Input
19	B8	Numeric	8	2	Button functions are easily identifiable	{1.00, Stron...	None	8	Right	Scale	Input
20	C1	Numeric	8	2	The use of Web-based applications is more effective than Excel	{1.00, Stron...	None	8	Right	Scale	Input
21	C2	Numeric	8	2	The Web Based Application is user friendly	{1.00, Stron...	None	8	Right	Scale	Input
22	C3	Numeric	8	2	Access to editing urban utility data is easy to understand.	{1.00, Stron...	None	8	Right	Scale	Input
23	C4	Numeric	8	2	This Web Based Application helps to manage urban utilities data efficiently.	{1.00, Stron...	None	8	Right	Scale	Input
24	C5	Numeric	8	2	This Web Based Application provides real-time updates on urban utilities data.	{1.00, Stron...	None	8	Right	Scale	Input
25											

Figure 2: Variable View from SPSS

3.0 Results and Discussion

3.1 Web-Based Application Development

The designed Web-GIS offers an interactive platform on management and presentation of information about the transmission towers in Selangor. This platform has a user-friendly interface with the necessary GIS functionality, such as data visualization, dynamic editing, interactive legends, base map customization, measurement, layer controls, search, and real-time positioning (Figure 3). Figure 3a displays the front-page design of the site, and the information pop-up tabs (Figure 3b) reveal how complex geospatial data can be successfully integrated into a format that is easy to use by urban planners and managers of infrastructure.

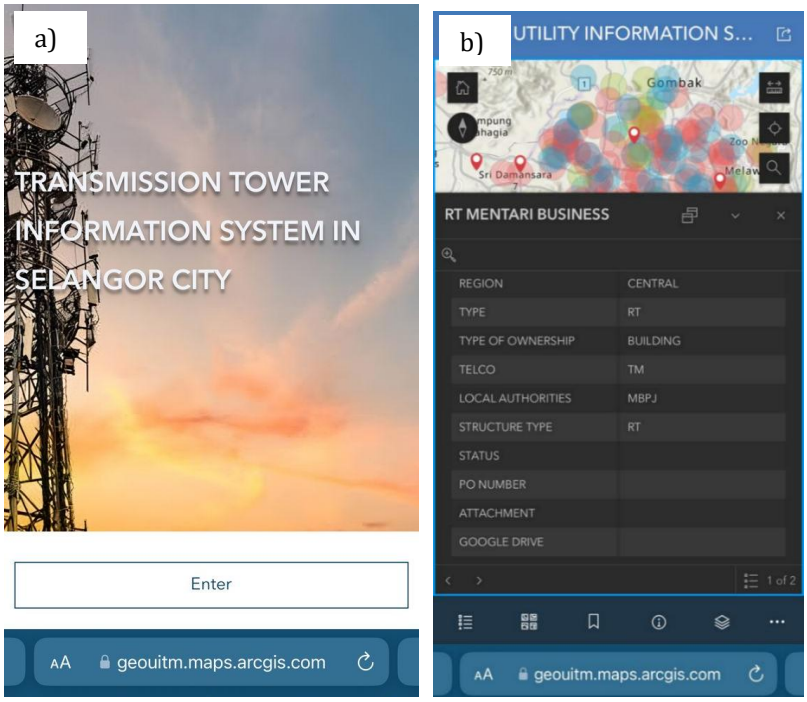

Figure 3: The web-based features desktop view, from left, a) the front-page interface, and b) the information displayed via a pop-up tab

3.2 Population Demand Analysis using Kernel Density Estimation

In order to prevent the ambiguity observed in the review, it is made clear here that population distribution was subjected to KDE, rather than the current tower locations. The resulting density surface is where the population-driven coverage demand is concentrated; the demand surface was then compared to the current tower layer to determine where the tower density has not kept up with population growth. It is on this basis that Petaling and Klang were declared as high-priority areas. Hulu Langat also demonstrated the high population density and should be covered further. Gombak and Kuala Selangor were considered medium density, whereas Hulu Selangor demonstrated relatively low density, which implies that there is a lesser priority on the development of more towers in the immediate future, yet there is still a need to have strategically located coverage as development continues (Figure 4).

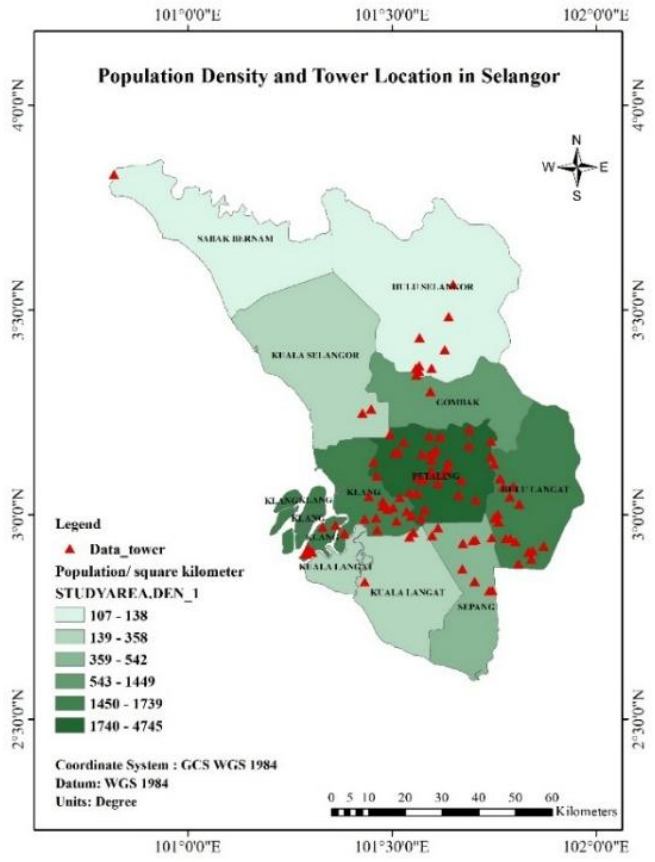

Figure 4: Map of population density pattern and tower location

3.3 Soil Spatial Analysis using Natural Neighbour Interpolation

The Natural Neighbour interpolation created a continuous spatial representation of the available soil conditions of the study area. The resulting layer allows visualizing and comparing the spatial distribution of the classified soil conditions to the positions of the existing transmission towers (Figure 5). The data-supplying company gave the resulting soil data which was categorized into three groups: hard, medium and soft, based on the specifications and needs given by the company. These categories were taken directly in this study and were not re-classified according to the traditional soil-texture classes like sand, clay or silt. Natural Neighbour Interpolation was then applied to the classified soil data to give a spatial coverage of the study area. The findings revealed that Petaling and Kuala Selangor were mainly characterized by hard-soil conditions whereas other locations were characterized by different soil conditions. The resulting soil layer, along with the current sites of transmission towers, give space information to aid preliminary planning and

evaluation of tower sites. These findings show how the NNI output can be incorporated in the Web-GIS where users can analyze soil-related spatial conditions and the existing transmission infrastructure.

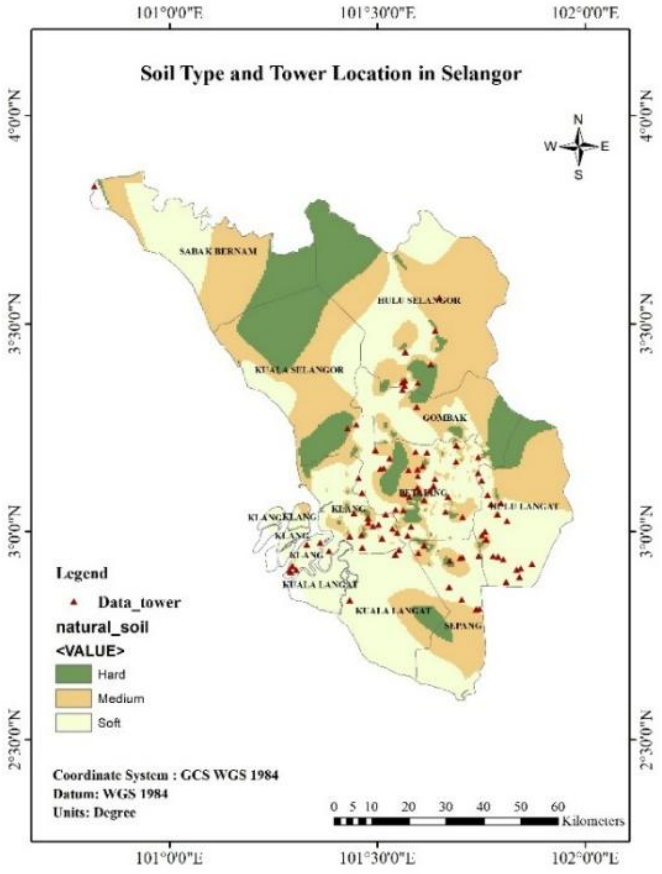

Figure 5: Map of soil type and relationship with tower locations

3.4 User Feedback and System Effectiveness

The system was then tested among 30 respondents, consisting of surveyors, engineers and urban planners on a 14-item questionnaire. One of the items in the questionnaire that is representative of whether the Web-GIS can assist users to manage the urban utility data effectively is shown in Figure 6. In general, the respondents rated the platform highly in all the dimensions considered with an average usability score of 4.5/5 (SD=0.3). Moreover, 88 percent of the respondents reported that they would implement the application in their workflow. These results, derived using a multi-item questionnaire as opposed to a one-question question, show that there is a positive perception

of the usability, relevancy, and feasibility of the system as far as practical application in the management of urban utilities is concerned.

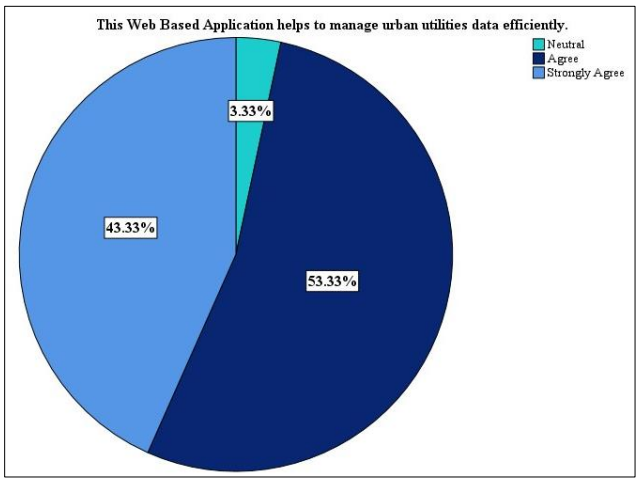

Figure 6: Respondents' evaluation of the Web-GIS for urban utility management

3.5 Discussion

The results reveal that the combination of GIS-based spatial analysis and Web-GIS can be a valuable method of initial evaluation of transmission infrastructure. The KDE analysis allows the spatial concentration of the population to be visualized, and Natural Neighbour interpolation was used to present a continuous representation of the available soil conditions. These results are not new to the literature on GIS and Web-GIS, which have shown the utility of spatial analysis in the planning of infrastructures and web-based visualization and access to spatial data (Kshetri et al., 2020; Kuridza, 2019; Tsagkis and Photis, 2021). In comparison to these methods, the current study incorporates the location of transmission towers with the population, topography, and soil-related data into one Web-GIS platform. This integration enables users to view multiple spatial information layers in one interactive interface and offers a realistic screening environment for preliminary infrastructure planning.

However, the results are to be viewed as initial decision-support data, but not a final tower-site selection criterion. Population and soil conditions are useful spatial indicators, but actual transmission tower planning must also take into account terrain, topography, land use, accessibility, environmental constraints, and detailed engineering and geotechnical requirements. Thus, the primary contribution of the study is the combination of the chosen spatial data, analytical results,

and interactive Web-GIS functionalities into one platform. This further expands the practical use of GIS and Web-GIS in terms of transmission infrastructure management and acknowledges the fact that site-specific evaluation is required prior to the ultimate engineering decisions.

4.0 Conclusion

This study designed and tested a Web-GIS information management platform on transmission towers and initial spatial planning in Selangor, Malaysia, that combines population, topographic, soil and existing tower data with Kernel Density Estimation and Natural Neighbour interpolation. The usefulness of the platform in practice is that it enables end users to have one, browser-friendly platform that allows visualizing the transmission infrastructure, analyzing the population-related spatial patterns, and assessing the spatial soil conditions using interactive map layers. A survey of 30 surveyors, engineers and urban planners achieved a usability rating of 4.5/5 +0.3 SD and an adoption intention of 88, which is a positive user perception of the developed platform. These results show that the Web-GIS has the potential to enhance accessibility, spatial information control and initial decision-making in transmission infrastructure planning. Nevertheless, it is a spatial decision-support and screening tool and not to be used as a substitute to detailed engineering, geotechnical, terrain, land-use, environmental, or regulatory assessment. It should be developed further in the future with new siting criteria, especially terrain slope and land-use limitations, and explore new terrain data to enhance the reliability and applicability of the platform further.

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