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NETWORK SUITABILITY STUDY FOR TRANSMISSION LINE SLOPE MONITORING USING GIS-BASED TECHNIQUE

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Abstract

Transmission line slope monitoring is crucial to the electricity utility company in ensuring an uninterruptable power supply to the public. Common practice in slope monitoring is by deploying appropriate sensors that can automatically detect displacement or anomalies of the slopes. Sensor data were collected electronically via wireless communications and distributed through a communication network to a centralized location (base station) for data processing. Such system relied heavily on communication stability at the slope area. However, in a challenging terrain, the communication tasked becomes daunting and raised the need to hop the data from one site to the other until a site with a telecommunication coverage is found. Hence, the requirement of optimized location determination is becoming an important measure. This study proposes a site suitability identification technique for base station placement in transmission line slope monitoring to ensure uninterrupted communications. The GIS-based technique using Weighted Linear Combination for generating a suitability map with standardized Fuzzy Membership functions and Analytical Hierarchy Process were designed and applied in this study. This had been done by assigning the weightage of each contributing factor such as the network coverage, slope, elevation and land use. A case study was conducted in Cameron Highland, Malaysia. From this study, 7 sites for base station location placement were identified and they can cover the length of the transmission line at the study area. For future study and application, this methodology can be used for other remote network suitability identification analysis.

Keywords: Analytical hierarchy process (AHP), Energy, Fuzzy membership functions, Multi-criteria decision analysis (MCDA), Transmission line monitoring, Weighted linear combination (WLC).

1. Introduction

A large number of transmission towers that networked electricity distribution throughout Peninsular Malaysia has been in existence for over 40 years. Most of the towers spanned through very remote and difficult topography areas such as mountains, thick forest, lakes, and are far from settlement areas which add to the cost and difficulties of monitoring them. To ensure the health of the transmission towers, monitoring potential hazards from landslide and surrounding risks has become an urgency.

Slope monitoring can be regarded as regular observation and recording of slope changes that may risk the structure of the towers to fail [1]. Failed towers will not only cause inconveniences to the common person but may disrupt commercial and industrial operations too. Accidents can happen that may cause lives in the vicinity of the failed tower. It will challenge the credibility of the utility provider. Transmission line monitoring involved several factors that include soil parameters such as water content, vegetation, erosion, and drainage, as well as the geomorphology and historical information about the area. Several types of sensors such as inclinometer, rain gauge, and piezometer can be deployed at the transmission towers to help monitor the condition automatically and remotely. The data collected by the sensors would need to be transferred through a communications medium to a processing station. Such monitoring would be highly dependent on the availability of wide-area wireless communication.

In remote areas, the availability of coverage from the telecommunication provider is poor or not available. To manage the situation, a local RF network can be used to hop the data to an access point that is within the telecommunication coverage area. Since the location of the antenna will be sparsely distributed, a Geographical Information System (GIS) can be used to manage the information of the locality and be the basis for decision making in network planning in the area. The installations of RF antennas require several assessments such as the height of the potential location and line of sight, compatibility of radio systems, and connection to adjacent radio cells. The long-term availability of the site, the economic feasibility of the installation, and structural suitability need to be also taken into consideration.

This study presented the use of geographic information system (GIS) and multicriteria evaluation (MCE) technique to select a suitable site for landslide monitoring base stations along the transmission tower line in Cameron Highland. First, a brief description of the study is given followed by a detailed description of the steps adopted in the methodology. This includes description and pre-processing of constraint and factor criteria and sub-criteria. Five main criteria have been selected for site suitability analysis of the antenna base station (BS) which are technical, topography, accessibility, risk assessment and landcover.

Based on the study and discussion with experts from various field of disciplines, 13 sub-criteria and 4 restricted areas were identified. The generated thematic maps of these criteria were standardized using ranking method and Fuzzy membership. For weight evaluation, pairwise comparison matrix known as analytical hierarchy process (AHP) was used. used. A weight for each criterion was generated by comparing them with each other according to their importance. With the help of these weights and criteria, the final site suitability map was modelled using weight linear combination (WLC). WLC analysis examines several possible choices for base station placement problem, taking into consideration of multiple criteria and conflicting objectives.

Once the suitability map is finalized, the base station placement will be identified. Finally based on the given criteria and properties, the recommendation of communication technology will be decided.

This paper proposes a GIS-based methodology for network planning of the transmission line slope monitoring network. Section 2 of the paper covers related works. Section 3 discusses the methodology and Section 4 presents results and discussion. Section 5 concludes the paper.

2. Related Works

Optimization of base station placement in a distributed antenna system (DAS) was proposed by Wang et al. [2] with the establishment of a composite channel model that takes path loss, log-normal shadowing, and Rayleigh fading into consideration. This study derived the downlink system capacity by approximating the number of distributions of mobile stations. This study claimed that the proposed scheme performs well in terms of running time and storage space.

Yang et al. [3] covered on optimization of base station problem in distributed multi-input-multi-output (MIMO) radar by using particle swarm optimization (PSO) based placement [4]. There were also studies to incorporate decision support system (DSS) and Geographical Information System (GIS).

Clímaco et al. [5] proposed a spatial DSS by the integration of a multi-objective optimization technique with GIS. The main criteria for the cell-planning approach are the technical, financial, and environmental criteria. However, this study does not consider the Digital Elevation Model (DEM) of the conducted area to obtain the altitude factor according to the siting protocol.

Zhen et al. [6] and Wang et al [7] conducted a study on designing transmission line monitoring for smart grid. In this work, the introduction of a cost-optimized algorithm in designing real-time data transmission networks involves the installation of a low cost private wireless sensor network (WSN) and low data rate connections. Furthermore, the design also uses the existing optical fibre network and a wide area network (WAN) that includes an LTE network with high data rate connections. A set of wireless sensors on each tower is installed as part of the WSN. Also, the study involves the formulation of solution optimization for placement problem to locate cellular-enabled transmission towers. However, this study did not consider other geographical environment characteristics in their framework.

Monitoring of transmission lines based on condition monitoring agents (CMA) in remote locations by using fibre optic and wireless communication technology was introduced by Fateh et al. [8]. This technique centralized the collection of the distributed data.

Hung et al. [9] showed the monitoring of transmission lines in the power delivery system by installing sensors and analysing the data in a linear network model. But it was found that the technique is inefficient in supporting future smart grid applications and the researchers proposed the extension of their work to enhance the capability of sensors to communicate with other remote sensors. The study did not include geographical characteristics and was solely based on using genetic algorithm (GA). Table 1 summarizes the base station placement optimization studies.

Table 1. Base station placement optimization studies.

Year, Reference	Research	Method
2008, [10]	Antenna placement optimization for downlink transmission in a distributed antenna system	Generic Algorithm (GA)
2015, [11]	Fast optimal antenna placement for distributed MIMO radar with surveillance performance	Particle Swarm Optimization (PSA) based algorithm
2016, [12]	A genetic algorithm-based decision support system for multi-objective node placement problem	Genetic algorithm (GA) - optimization GIS integrated
2017, [13]	BS placement, planning cell problem, involves choosing position and infrastructure configuration for cellular network	Genetic algorithm (GA) Only applicable on flat area
2017, [14]	Optimal sensor placement for deployable antennae module health monitoring in SPSS	Generic Algorithm (GA)

As summarized in Table 1, most studies used mathematical based algorithms in the determination of base station placement. GIS technique can address the spatial variability in one regional area [15]. GIS can also picture the actual scenario and characteristics of the study area as a whole. This is important to find the optimal place for network access points [16]. This study explored the use of a spatial decision support system for communication network planning to support remote transmission line slope monitoring. A Multi-Criteria Decision Making (MCDM) method was established for base station placement determination. GIS and MCDM were used for placement suitability analysis based on qualitative and quantitative factors [17].

3. Methodology

The integration of GIS and the MCDM method transforms and combines geographical data and value to formulate facts or other parameters to be used in the decision-making process. The decision-making process was based on the allocation of a suitable ratio score value for each criterion. To identify the potential position for base station placement using GIS, the effective factors, criteria, and constraints are constructed as map layers. The GIS dataset available for this study comprises of contours of the area of Cameron Highland with a contour interval of 30 meters taken from the Department of Survey and Mapping Malaysia (JUPEM). The digital elevation model (DEM) was derived from the contour obtained. The slope and aspect within the area of interest were obtained from the DEM. Land use data of the area is obtained from the Department of Agriculture (DOA).

The road network is divided into three categories which are the main, secondary, and residential road digitised from the OpenStreetMap base map. These were used as overlays to show topographic details about the digitised road network. The dataset is in a vector point and polyline format. The determination of the optimum locations for base stations placement for landslide monitoring along transmission line depends on the comprehensive and correct understanding of factors and how to select them. In this study, the selected factors are based on various research studies and expert opinions. The criteria used are shown in Fig. 1 which are Technical, Topography, Accessibility, Risk Assessment, and Landcover together with their sub-criteria

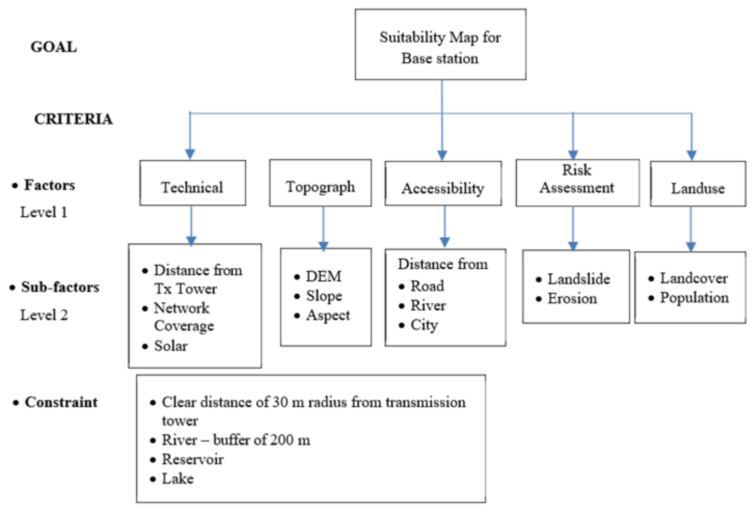

Fig. 1. The criteria used in decision making

The criteria used in decision making process (Fig. 1) involved 5 main factors. The technical factors were associated by 3 sub-factors; distance from transmission tower, network coverage and solar radiation. Since majority of the sensors are laid near to the transmission tower, it is preferred to locate the antenna as close to the transmission tower [18].

Topography criteria have 3 sub-criteria which are elevation, slope and aspect. Elevation is one of the significant factors in finding the optimal location of base station placement. The height of base station placement is an important factor in accessing the effect of earth reflected signals which may limit the range communication coverage. The higher the location of the antenna, the signal transmission or reception are better. In addition, the influence of multipath effect can be reduced. Accessibility criteria consist of distance from road, city and river. Readily available roads and transport will have a significant impact on the issue of maximizing the benefits of the wireless data transmission technologies for transmission line monitoring. However, the unavailability of accessible roads compounded with poor levels of rural transport infrastructure networks, which are often small and not well maintained in rural areas hinders both mobility and accessibility. This will subsequently increase the cost of establishing, operating and maintaining wireless networks in rural and remote areas [19]. Furthermore, the sub criteria for risk assessment are landslide and erosion risk [20].

Previous study conducted produced landslide and erosion hazard map classes from 1 to 6. This classification has been used in a few observations related with transmission tower maintenance [16]. Finally, there were two sub criteria under land use which are landcover and population density. Landcover criteria includes 6 sub criteria which are primary forest, secondary forest, tea plantation, vegetable area, floriculture and residential [21, 22]. According to Mekni and Moulin [23], radio transmissions are subjected to propagation effects which deeply affect the received signals because of the vegetation, foliage and buildings. Town area is assumed to be extremely important due to high population densities. Therefore, it is assumed that town area is identified to be the highest ranking for landslide monitoring followed by vegetable and tea plantation, and finally forest and shrub area. Based on these criteria, site suitability analysis was conducted to decide the location of base station. Figure 2 shows the example of technical criteria maps for the distance from transmission tower, solar irradiance and network coverage to determine base station placement.

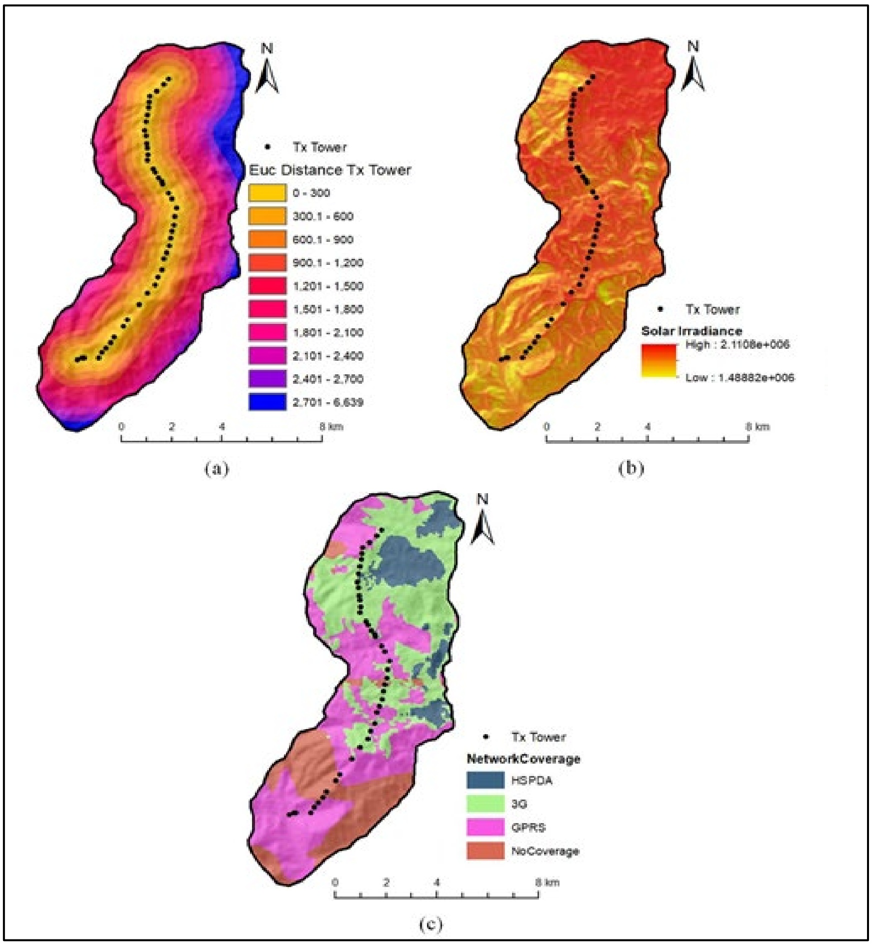

Fig. 2. The technical criteria maps of a) Distance from transmission tower, b) Solar irradiance and c) Network coverage

A suitability analysis was conducted in finding optimal locations of the base stations based on the mapped layers of the criteria. Suitability analysis using fuzzy membership function involved 5 important phases in identifying an optimal location for base station. In general, the flow of work of this study is illustrated in Fig. 3.

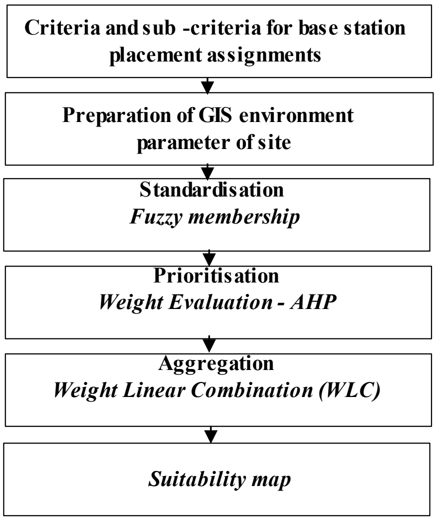

Fig. 3. Flow of base station placement determination.

Fuzzy membership function was used in standardizing by reclassifying the input data to a 0-1 scale value based on the possibility of the parameter's contribution to the strategic base station placement, where 1 represents highly contributing to the placement, and 0 not contributing to the placement. The prioritization method to produce the criteria weight of each parameter is modelled using the Analytical Hierarchy Process (AHP) [24]. A matrix was constructed, and each criterion was compared with each other and categorized on a scale of 1 to 9. The criteria data were then converted to a Boolean map where the index value of 1 was assigned as suitable for base station placement while 0 is least suitable.

Weighted Linear Combination

In the aggregation procedure, Weighted Linear Combination (WLC) is used based on the concept of weight averaged analysis where each factor is multiplied by a weight, with the result being summed to arrive at a multi-criteria solution. It will then be multiplied with the constraint to exclude the area that is not preferred in any way or considered unsuitable. This when applied to GIS maps can produce a suitability map and can be presented as Eq. (1)[25].

$$S = \sum w_i x_i \times \prod c_j \quad (1)$$

where S is the suitability index, w_i is the weights assigned to each criterion, x_i is the criterion scores, c_j is the constraints according to Boolean factors while $\sum$ is the sum of weighted factors and $\prod$ is product of constraints where 1 indicates suitable and 0 is unsuitable. Fuzzy overlay analysis is based on set theory, where a set generally corresponds to a class. Fuzzy overlay analysis reclassifies or transforms the data values to a common scale, but the transformed values represent the probability of belonging to a specified [26]. The combining analysis step in Fuzzy overlay analysis quantifies each location's possibility to specific sets from various input raster. The combining analysis step in Fuzzy overlay analysis quantifies each location's possibility to specific sets from various input raster.

Li et al. [27] defined fuzzy set theory in Eq. 2 as a set membership for possibility distribution. Let a fuzzy subset F of a set X is a function of $\mu_F(x)$ assigning to every element x of X the degree of membership of x to F.

$$x \in X \rightarrow \mu_F(x) \in [0,1] \quad (2)$$

where all continuous variable data were directly fuzzified using 2 types of fuzzy classes which are large and linear fuzzy function. For categorical data need to have a pre-processing step. First, using the reclassification method (reclassify tool) in order to attribute numeric values to specific category and to further divide the result by a factor to normalize the output values to be between 0 and 1 (divide tool) [28].

In this work, the digitization, conversion, and data analysis were performed by using ArcGIS Desktop Software.

4. Results and Discussion

A case study was conducted along a 275kV transmission line located on the west side of Cameron Highland, Malaysia. The transmission line comprises of 44 transmission towers. The total coverage of the study area is approximately 7,977 ha (80km^2). The average elevation is 1,180m above mean sea level with the highest level of up to 1615 m. The hilly areas are covered by dense tropical rainforest.

The suitability analysis starts with eliminating the constraints given in Fig. 1, i.e., rivers, reservoirs, lakes, and clearance areas. This analysis was conducted by classifying all cells to an integer with 0 as no probability and 1 as a probable base station site. Figure 4 shows the map for restriction analysis.

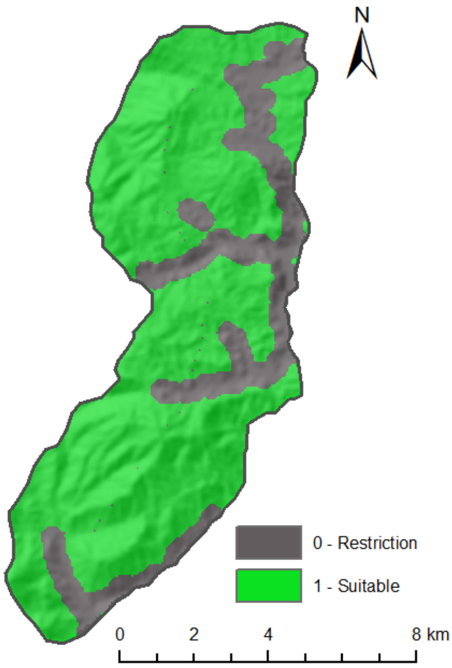

Fig. 4. Boolean map for restriction model.

The standardization using fuzzy functions normalized the map layers. This function associates each pixel to a fuzzy set membership function. All the criteria were combined and assessed as seen in Fig. 5. The criteria weightage for the AHP design is shown in Table 2 which was obtained through a pair-wise comparison of elements in each criterion with priority consideration. The results were then multiplied by the constraint map to exclude the restricted areas. The suitability map obtained from the Fuzzy-AHP and WLC process is shown in Figs. 6 and 7.

Cross-comparison was made with Google Earth image and 7 locations of base station placement were proposed as shown in Fig. 8 to cover for the transmission line slope monitoring which is comprised of 44 transmission towers.

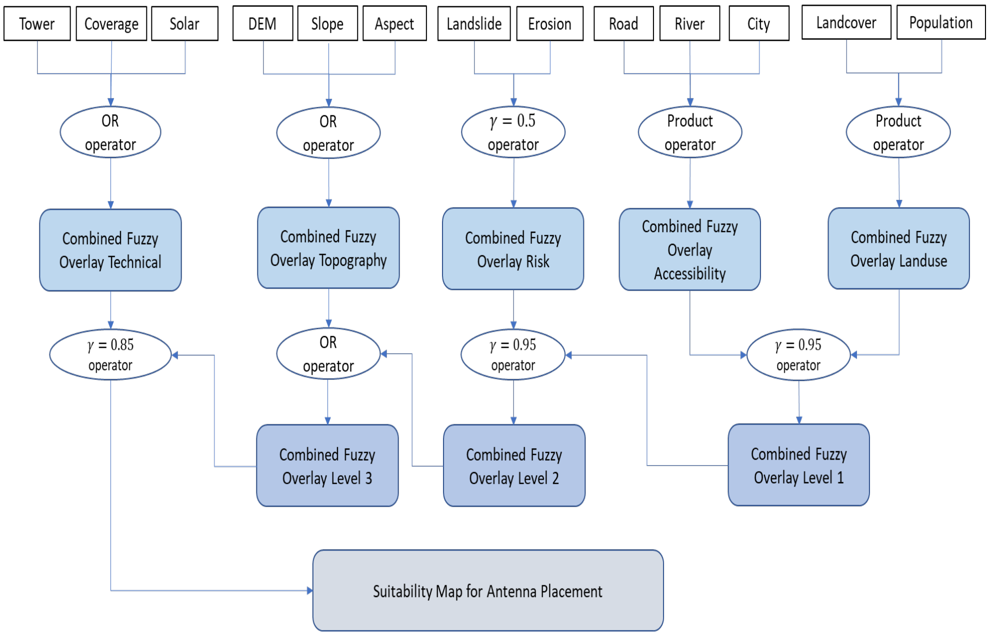

Fig. 5. The Fuzzy standardization process.

Table 2. Base station placement optimization studies.

	Criteria	Level 1	Sub-criteria	Level 2	Original Weight	Normalized
1	Technical	44.68	Distance from Tx. Tower	26.54	11.85	0.118
2			Network Coverage	67.16	30.04	0.300
3			Solar	6.29	2.82	0.028
4	Topography	25.69	DEM	75.14	19.30	0.193
5			Aspect	7.04	1.80	0.018
6			Slope	17.80	4.57	0.046
7	Risk	20.89	Landslide	75.00	15.68	0.157
8			Erosion	25.00	5.23	0.052
9	Access	5.51	Road	61.53	4.02	0.040
10			River	6.60	0.45	0.004
11			City	31.87	1.04	0.010
12	Land Use	3.22	Population	35.00	1.12	0.011
13			Land cover	65.00	2.08	0.021

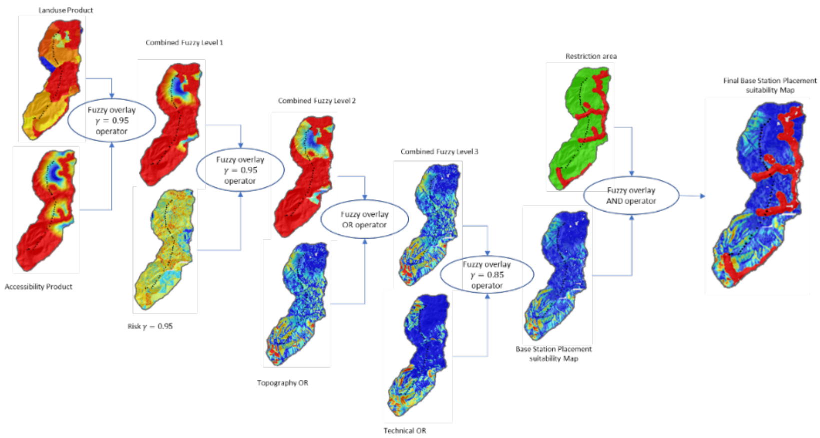

Fig. 6. The Fuzzy standardization base station suitability mapping.

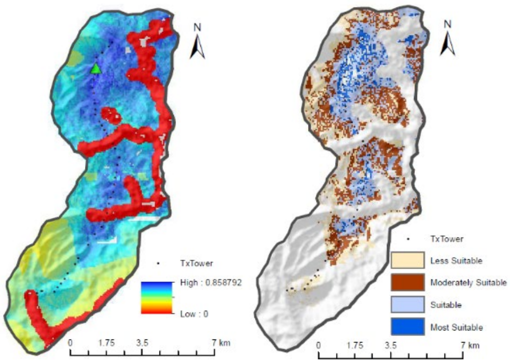

Fig. 7. The Fuzzy standardization and AHP-WLC suitability mapping.

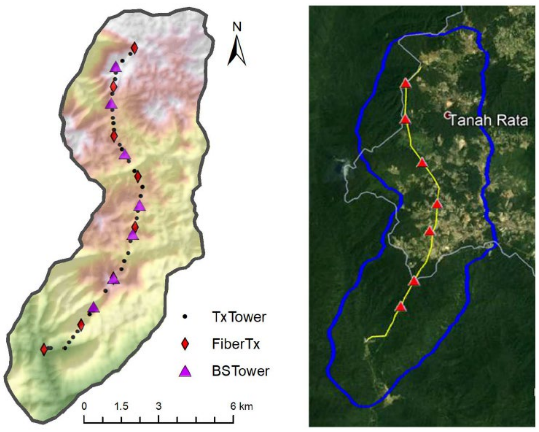

Fig. 8. The 7 optimum locations to cover the 44-transmission tower monitoring.

5. Conclusions

The study has successfully developed a GIS-based methodology to plan base station placement. The importance of suitable base station placement is to guarantee continuous and steady communication network for transmission line slope monitoring. The developed methodology used Weighted Linear Combination technique in suitability map generation for all factors that contribute to the network stability and reliability. Then, standardization process using fuzzy membership functions were applied before the factors' weightage were assigned using Analytical Hierarchy Process. A case study was successfully conducted for a transmission line in Cameron Highland, the remote hilly tropical forest of Malaysia. From this study, 7 sites of suitable base station placement were identified. These locations not only can ensure uninterrupted communication network but can also connect the whole transmission line of the study area. This can be concluded that, the integration of GIS-based MCDM method has helped in network planning for remote and difficult terrain area. The methodology can be used for other remote network suitability planning work and can also be combined with other technique such as Ordered Weight Average (OWA) to study the sensitivity of these technique with the communication network availability.

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