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Tree Risk Assessment Using Parameters Extracted from UAV-Based Multispectral Imagery

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ABSTRACT

Trees with structural defects often result from progressive wood decay over time. It is important to assess the risk of the individual tree in order to prevent them from becoming serious incidents in the future. Integration of geospatial techniques in identifying potentially hazardous trees is important to decision-making and action-taking. It reduces the risk. Three main parameters of tree height, tree health, and crown diameter were extracted from Unmanned Aerial Vehicle (UAV) based multispectral imagery. Image segmentation and image classification were used to extract selected tree parameters. Zonal statistics are used to extract the tree height and health mean based on the tree polygon. The tree height is obtained from the raster value of the Normalized Digital Surface Model (nDSM), while the tree health is based on the values of the Normalized Difference Vegetation Index (NDVI). A total of 317 were extracted, with 152 trees categorized with low hazard ratings, 160 trees with medium hazard, and 5 trees with high hazard ratings. Accuracy was obtained by comparing results extracted from UAV-based multispectral imagery and Visual Tree Assessment (VTA) with an accuracy of 90%. The findings could benefit the local authority in identifying the hazardous trees in fast and accurate manners.

Keywords: Tree Risk Assessment, UAV-based Multispectral Imagery, Visual Tree Assessment

INTRODUCTION

Trees provide human with numerous needs for survival, such as clean air, access to clean water, shade, and food. Today, the value of trees continues to rise, and new benefits are being discovered as their role expands to meet the demands of modern lifestyles. However, trees that are initially planted to enhance the landscape and protect and cool the environment have the potential to collapse and threaten the local community.

Trees that are particularly giant and mature may be harmful to humans and the environment. During heavy rainfall and thunderstorms, there is a high possibility of the urban trees collapsing, damaging vehicles and private properties and threatening human well-being. Poor

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planning, management, and maintenance of urban trees are the major factors contributing to serious incidents during extreme weather events. According to Hasan et al. (2016), numerous public complaints have been reported about fallen trees, as well as old and dead trees, in the selected local authorities in Kuala Lumpur and Selangor.

A tree is considered hazardous if its defects cause a failure and hit something as it falls. Not all tree hazards are visible until extreme weather exposes their weakness. In other words, for a tree to be considered hazardous, it should have a structural weakness (Hamzah et al., 2024). Cracks, weak branch unions, branch decay, root damage, and root disease are common indicators of structural weakness that should be checked or observed constantly (National Tree Safety Group, 2011). Moreover, multiple and connected defects increase the potential for failure. Trees with unbalanced or asymmetrical crowns may have their weight distributed incorrectly throughout the stem. These trees are vulnerable to failure when combined with other flaws, such as decay and root disease (Smiley et al., 2008).

Several accidents related to fallen trees have been reported in Malaysia. For example, Malaymail reported on 15th January 2021 that one person reportedly died recently after a massive tree fell due to the strong winds and heavy rain in Kuala Lumpur. The incidents rapidly spread, and the public raised their concern about the safety of road users. According to Maruthaveeran and Yaman (2010), the government's greening policy did not provide effective tree maintenance. As a result, hazardous tree management has become contentious.

Therefore, the potential of hazardous trees in the urban area should be well noticed, especially during heavy rainfall and thunderstorms. In the context of urban trees, hazard-rating assessment evaluates the hazard of trees, how likely they are to fall, and how severe the damage they could cause to their surroundings. The main objective of tree risk assessments is to identify defective trees in high-risk areas, assess the severity of the defects, and recommend corrective actions before the trees fail. Tree-risk assessments can help communities quantify the risk to public safety and prioritize implementing corrective actions. The hazard concept demands a complete risk evaluation and assessment, which reaches a management threshold where the situation cannot continue. Hazard rating is categorized into four levels: low, medium, and high (Chuon et al., 2011).

Based on previous studies, some methods are used to identify hazardous trees, especially in urban areas. According to Sreetheran et al. (2011), who conducted a study on the selected Kuala Lumpur Road of the tree risk assessment and the street tree inventory, a form was used to record information such as tree species, tree structure, tree health, and hazard status. The authors conducted the inventory in order to collect data on tree structure in terms of height, trunk diameter at breast height (DBH), crown spread, and their relationships with species composition, hazard status, and tree health and vigor. For identification purposes, each of these trees was tagged with its street name. At the site, several tree species were identified. When species identification was unsure, leaf samples were collected and sent to the Forest Research Institute Malaysia Herbarium for keying. The tree height was measured with a hypsometer (Ojoatre et al., 2019), and the crown diameter and DBH were measured with a diameter tape.

Next is the study of the identification of criteria and indicators to evaluate hazardous street trees in Kuala Lumpur, Malaysia, using the Delphi method (Maruthaveeran & Yaman, 2010). The Delphi method is a procedure for obtaining the most credible consensus from a group of experts. This is accomplished through the use of a series of intensive questionnaires interspersed with controlled opinion feedback. A pre-test was conducted among 20 respondents from local universities and government agencies. The respondents are from Kuala Lumpur City Hall, Subang Jaya Municipal Council, Forest Research Institute Malaysia, and Universiti Putra Malaysia.

The traditional practice of obtaining hazardous tree information using a form, hypsometer, and diameter tape is tedious and laborious (Sreetheran et al., 2011). The individual process is time-consuming, especially for a large study area. In addition, traditional ways of collecting tree information have primarily relied on labour-intensive field surveys, which are inefficient and costly (Guo et al., 2022). Thus, advances in mapping using the Unmanned Aerial Vehicle (UAV) and digital image processing are promising for providing tree inventories in a timely, flexible, accurate, and cost-effective manner.

UAVs or drones have recently emerged as a ubiquitous and essential part of our society (Mohsan, 2023). UAVs have demonstrated great potential as a type of rapid, flexible, and low-cost data acquisition system, capable of performing a wide range of surveying, mapping, and remote sensing tasks with extremely high-resolution data in low-altitude flying and imaging conditions (Zhenfeng, 2021). According to Suhaizad et al. (2023), UAV multispectral imagery is widely used in vegetation analysis, such as crop analysis, vegetation monitoring, precise farming, and vegetation health assessment. UAV multispectral has been used in observing the impact of productive organs for crops (Li et al., 2021), 3D mapping of vegetation and forest (Dandois & Ellis, 2013; Li et al., 2019), precise agriculture (Candiago et al., 2015; Deng et al., 2018), accurate tracking of the expansion or retraction of invasive plant species (Zaman et al., 2011), map riparian systems

(Jensen et al., 2011), classification of forest burn (Shin et al., 2019), vegetation monitoring (Assmann et al., 2019), rock slope monitoring (Yaacob et al., 2020), plant disease (Albetis et al., 2019) and forest health (Dash et al., 2018). Different implementations are commercially available from the industry, and the scientific community is very interested in spreading its use to the majority of society through cost-effectiveness and ease of use for solutions (Morales et al., 2020).

According to Frey et al. (2018), a forest manager could use the UAV to update stand information immediately after a thunderstorm, as opposed to a manned aircraft, which could take weeks to plan. The UAV has the capability to obtain a high spatial resolution of aerial imagery, and the three-dimensional (3D) model of urban trees can be acquired after the image processing stage using Agisoft or pix4d software (Fraser & Congalton, 2018; Hinge et al., 2019). Other than that, according to Gülci (2021), biophysical and morphological tree information has recently been computed using 3D point cloud data. The precision of studies on different types of trees (coniferous and deciduous) can vary depending on the instruments and methods used.

MATERIALS AND METHOD

The workflow for this study is displayed in Figure 1. The methodology consists of five main phases. The first phase is the preliminary studies, which include site reconnaissance, equipment selection, and software selection. The second phase is data collection, which includes UAV multispectral imagery and Global Positioning System (GPS) data for ground control points. Visual Tree Assessment (VTA) was verified by the certified arborist and used to assess the accuracy of the hazard rating estimated from UAV multispectral imageries. The third phase involves data processing to extract tree parameters such as tree height, crown size, and health from UAV-based multispectral imagery. The covered area is 6-hectare in Section 8, Shah Alam. Phase 4 focuses on data analysis, where the hazard rating for each tree is assessed, followed by the final phase, which involves tree risk assessment and reporting.

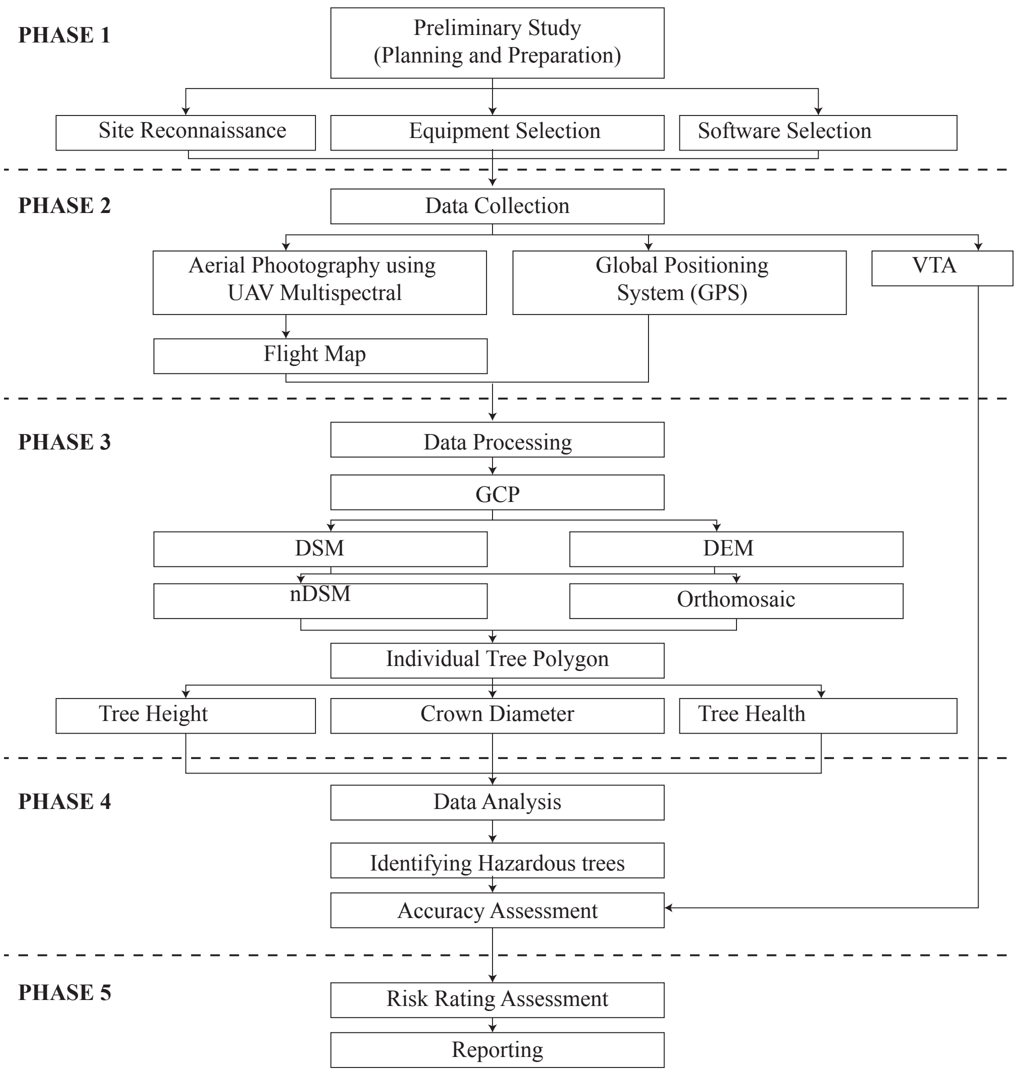

Figure 1. Research workflow

Study Area

Shah Alam is an urban area that is developing in most sectors, such as property, industries, education, and more. Shah Alam consists of three zones: the north, middle, and south. This study covers a 6-hectare area in Section 8, located in the middle zone of Shah Alam, as shown in Figure 2. The study area was chosen based on the analysis of public complaints and recent case data from the city council. Three (3) dominant tree species in the study area are *Samanea saman, Tabebuia rosea,* and *Mimusops elengi*.

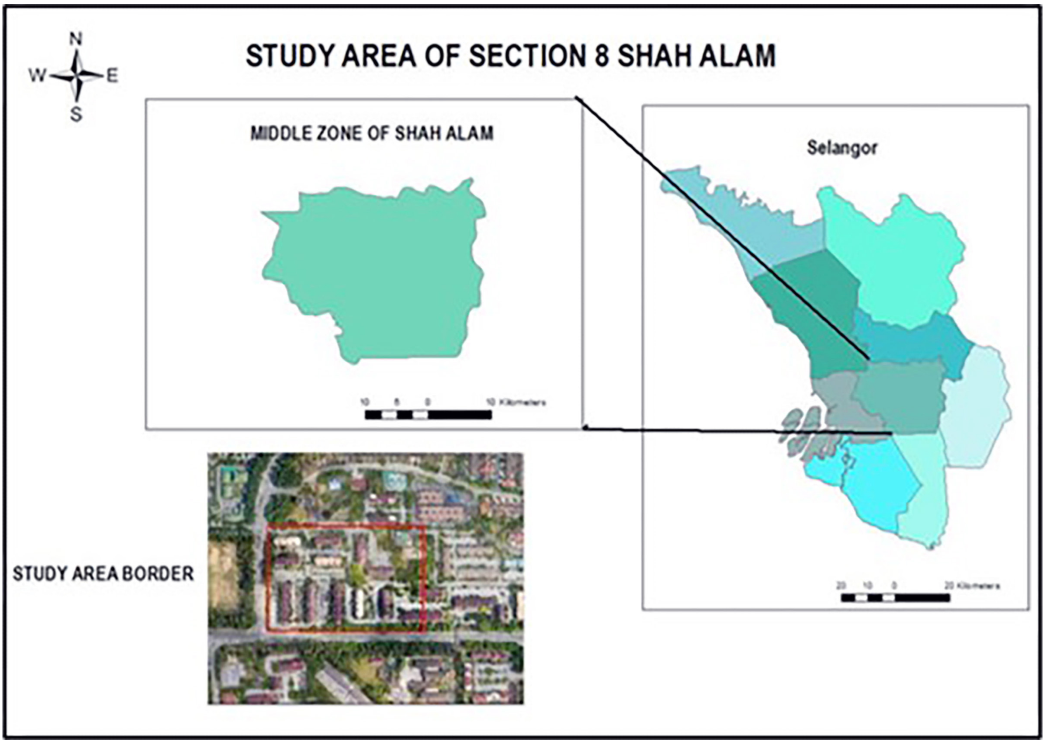

Figure 2. Study area of section 8, Shah Alam

Data Collection

UAV Multispectral Imagery Acquisition

DJI P4 Multispectral UAV is used in this study. The UAV has six cameras with 1 RGB camera and a multispectral camera array with five cameras covering Blue, Green, Red, Red Edge, and Near Infrared bands – all at 2 MP with global shutter, on a 3-axis stabilized gimbal. The multispectral sensor is needed especially for tree health assessment using Normalized Difference Vegetation Index (NDVI). The flying height is set to 80 m with 84% overlap and 72% of sidelap.

Ground Control Points

Ground Control Points (GCPs) are collected to define the location with precise coordinates. 5 post mark GCP for the study area is chosen. Data was collected using a fast or rapid static method with 15 min each epoch and 2 epochs for each point. The height of the instrument and the time are taken during the observation for the post-processing.

Data Processing

Individual Tree Crown Extraction

Image segmentation of the orthomosaic is performed using segment mean shift to segment the image into a few classes based on the spectral and spatial details using ArcGIS software. The possibilities of the image being under-segmented and over-segmented are very high. Running the tools repeatedly to produce good results takes several times. To require a perfect segmentation is almost impossible due to the orthomosaic image quality. Problems happen when the image has a shadow, greatly contributing to the results. Spectral details of 18 are used for further classification since the segmentation of spectral 18 is not over-segmented and under-segmented. The spectral and spatial details 18 and 15 are used in the segmentation process. Then, the features were classified into four classes: trees, built-up, road, and ground, using the Support Vector Machine (SVM) classifier. Figure 3 depicts the individual tree crown derived from image segmentation and SVM classification as shown in red polygon.

Figure 3. Individual tree crown extraction in red polygon

Tree Height Extraction

The zonal statistics tool in ArcGIS software was used to calculate the tree height based on the nDSM and tree polygon. Zonal statistics tools produce a table of minimum, mean, maximum, sum, variety, and more based on research suitability. The maximum value of taster that falls within the polygon was used as the tree height.

Tree Health Extraction

Individual tree health is derived from the assessment using NDVI. The NDVI value classes range from -1 to 1. According to Au (2023), 1 indicating the healthiest and 0 being the least healthy. These values were then categorised into four (4) classes. Ranges of -1 to 0 represent dead trees, 0 to 0.33 represent unhealthy trees, 0.33 to 0.66 represent moderately healthy trees, and 0.66 to 1 represent very healthy trees (Fletcher, 2021).

Hazard Rating Assessment

Hazard rating assessments are the output from the addition of the tree health, tree height, and crown diameter. These three parameters are summed up together based on their classes. Each parameter is classified into four classes based on the condition.

According to United States Department of Agriculture (USDA, 2017), the hazard rating was scored into four (4) categories which are low rating (score 3 – 4), medium (score 5– 7), high risk (score 8 – 10) and severe (score 11 – 12). Figure 4 displays the classification of hazard rating using tree height, tree health, and tree crown diameter parameters. Low hazards are labelled green, medium hazards are labelled in yellow, high hazards are labelled in orange, and severe hazards are labelled in red. The labels are all presented in the last output of the spatial distribution of hazardous trees map.

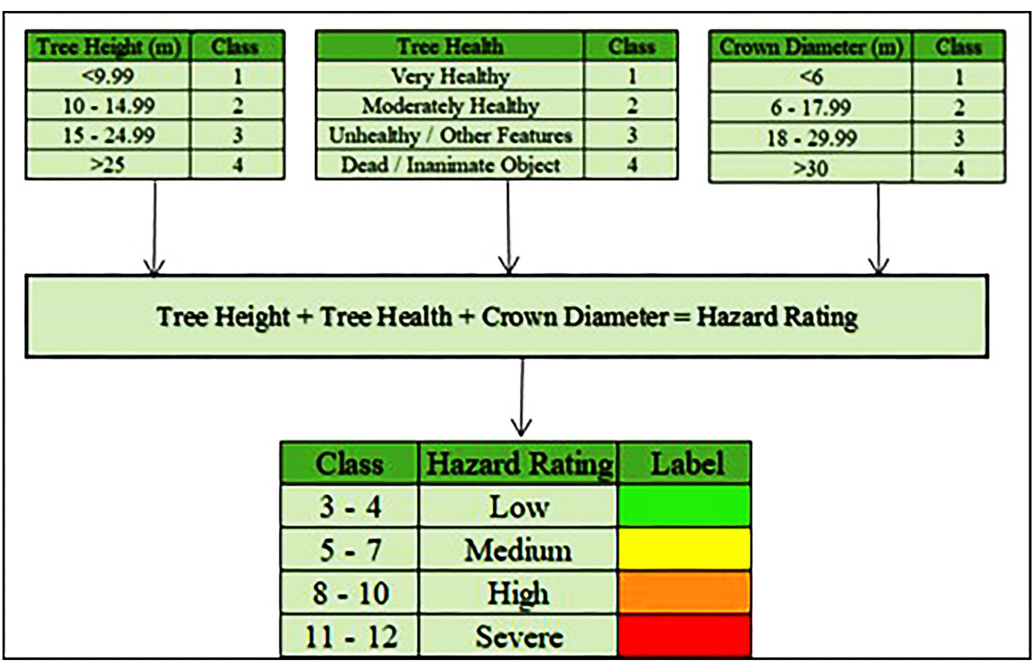

Figure 4. Classification of hazard rating assessment

Visual Tree Assessment (VTA)

The primary goal of visual tree assessment (VTA) is to assess the accuracy of hazard rating using parameters extracted from UAV-based multispectral imagery. Specifically, 20 from 317 trees were visualized, and tree biology was inspected with the advice of the certified arborist and documented using the Basic Tree Risk Assessment form (ISA, 2017). The tree species were identified, and the tree condition, area, and tree health were inspected. This procedure is widely used by urban foresters, and tree risk assessors to evaluate tree stability and detect structural defects.

Results and Discussion

Generation of DEM, DSM, nDSM, and Orthophoto

Figures 5 to 8 display the digital model and orthomosaic for the study area. The DEM range of elevation is between 7.665 m and 38.813 m. The DSM range is between 7.899 m and 55.614 m. The nDSM range is between 0 m and 40.560 m. Orthomosaic is the last output from the imagery processing with red, green, and blue bands.

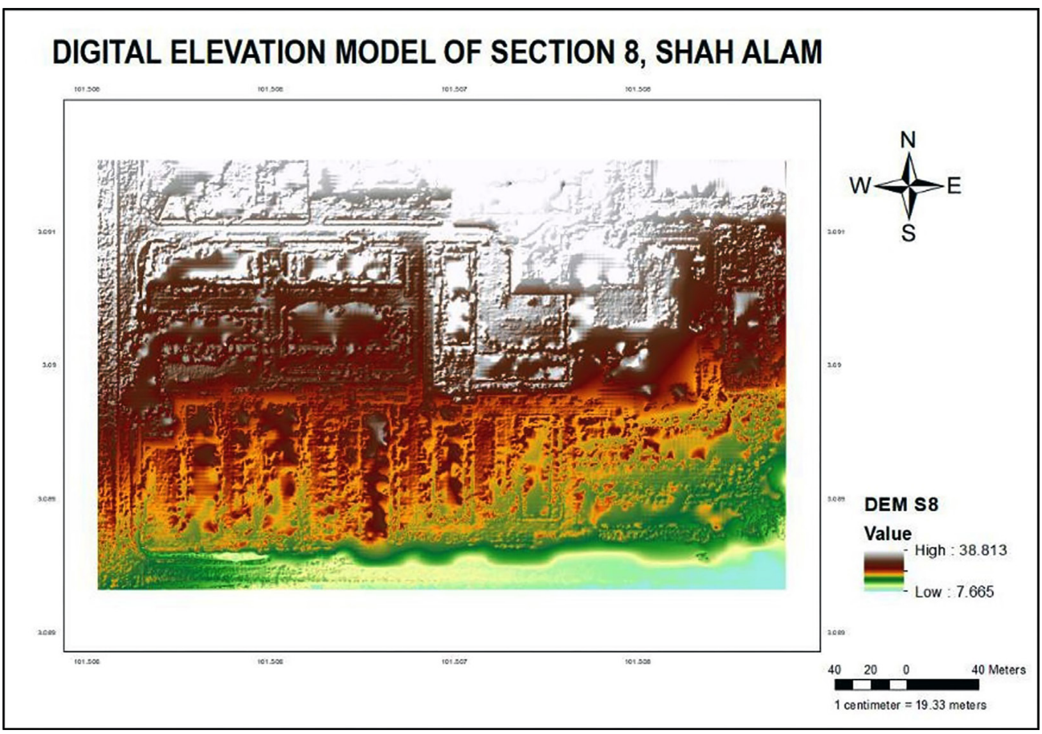

Figure 5. Digital elevation model

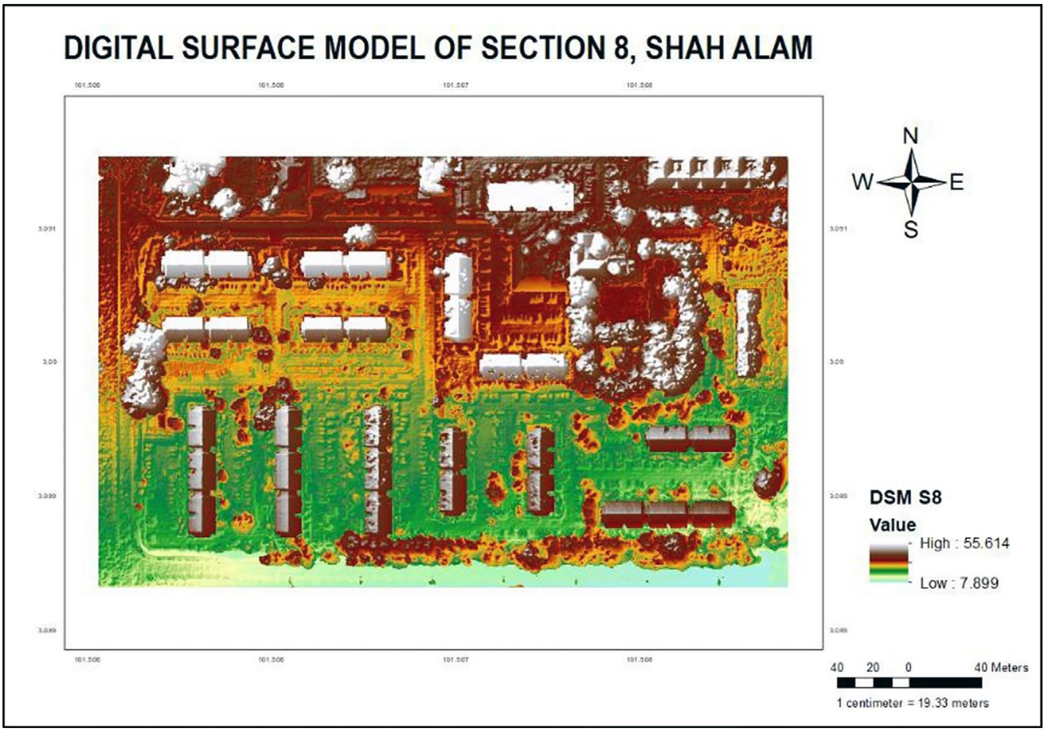

Figure 6. Digital surface model

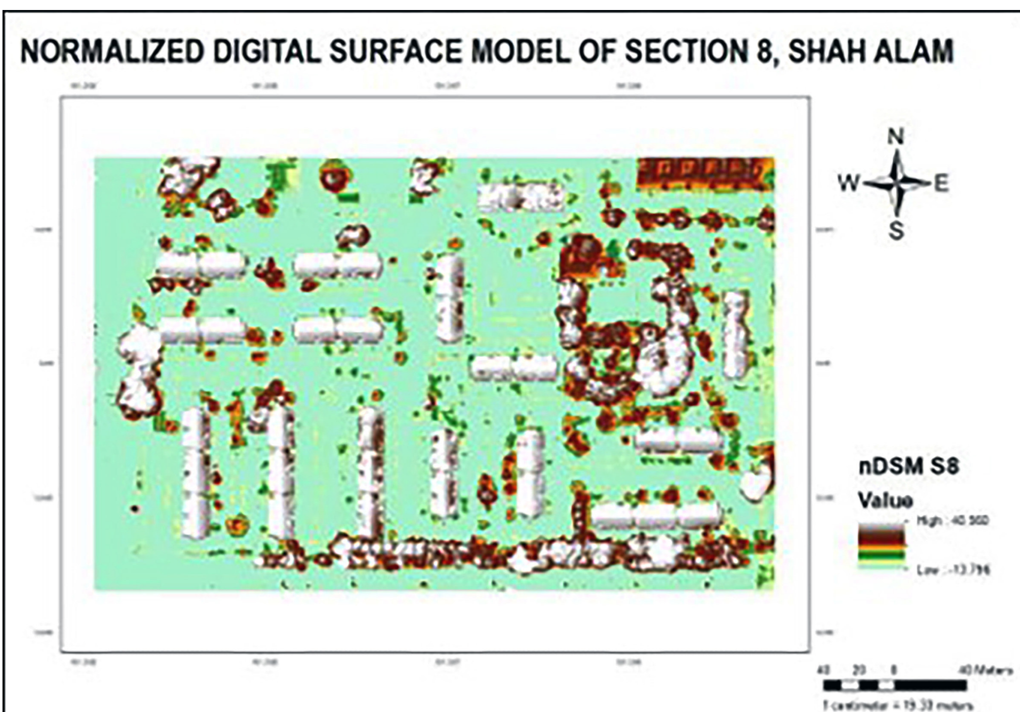

Figure 7. Normalized digital surface model

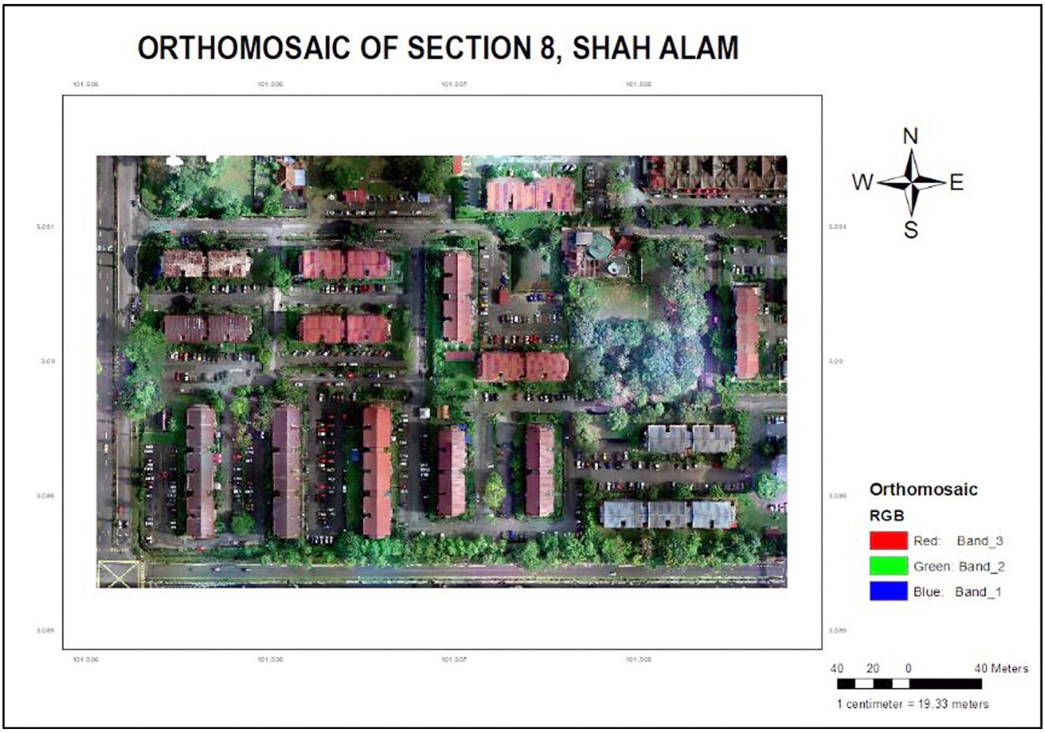

Figure 8. Orthomosaic

Extraction of Tree Parameters

Individual Tree Crown Extraction

Delineating individual trees is one of the crucial parts since many trees overlap with each other. Individual tree crown diameter was then calculated from the tree polygon. Table 1 provides descriptive statistics for individual crown diameters.

Table 1
Descriptive statistics of tree crown diameter

	N	Minimum	Maximum	Mean	Std. Deviation
Crown Diameter	317	1.863	24.039	7.318	3.916
Valid N (listwise)	317				

Altogether, 317 trees were extracted, ranging from 1.863 m to 24.039 m. The distribution of the crown diameter maps of the study area is portrayed in Figure 9. The green colour represents a crown diameter below 6 m. Yellow represents 6 m to 17.99 m, and orange represents 18 m to 29.99 m crown diameter.

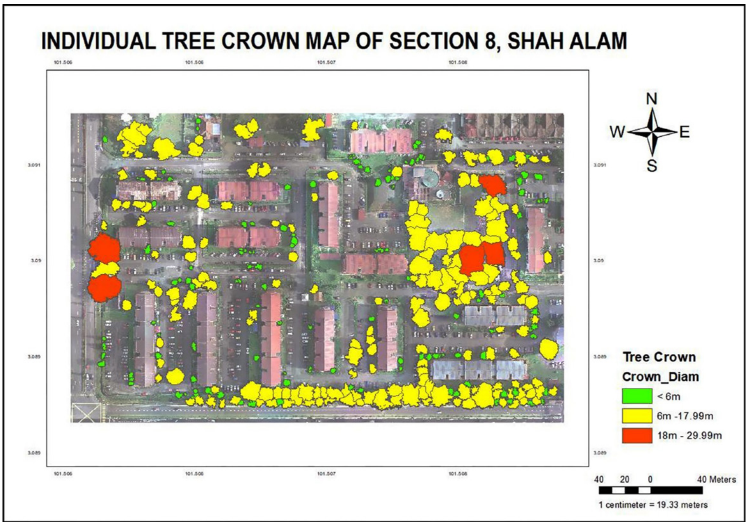

Figure 9. Individual tree crown map

Individual Tree Height Extraction

Table 2 indicates the descriptive statistics of tree height. The range of tree height is between 0.641 m and 23.771 m. Figure 10 illustrates the individual tree height map where tree heights below 9.99 m are labelled with green colour, 10 m to 14.99 m are labelled in yellow, and 15 m to 24.99 m with orange.

Table 2
Descriptive statistics of tree height

	N	Minimum	Maximum	Mean	Std. Deviation
Tree Height	317	0.641	23.771	9.914	4.671
Valid N (listwise)	317				

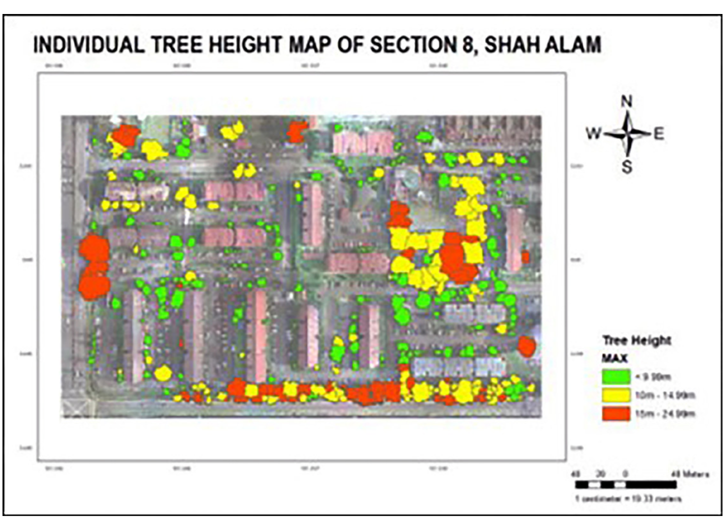

Figure 10. Individual tree height map

Individual Tree Health Assessment

Mean tree health calculates tree hazard ratings using zonal statistics. The tree health was assessed based on NDVI values as explained by Cherlinka (2024). Value -1 to 1 is classified into four (4) classes in which 1 to 0.66 is very healthy, labelled green on the map as depicted in Figure 11. Values of 0.66 to 0.33 are moderately healthy in yellow, 0.33 to 0 are unhealthy in orange, and 0 to -1 are dead trees labelled in red. Based on the results, 177 trees were classified as very healthy, 130 trees were classified as moderately healthy, nine trees were classified as unhealthy, and one dead tree.

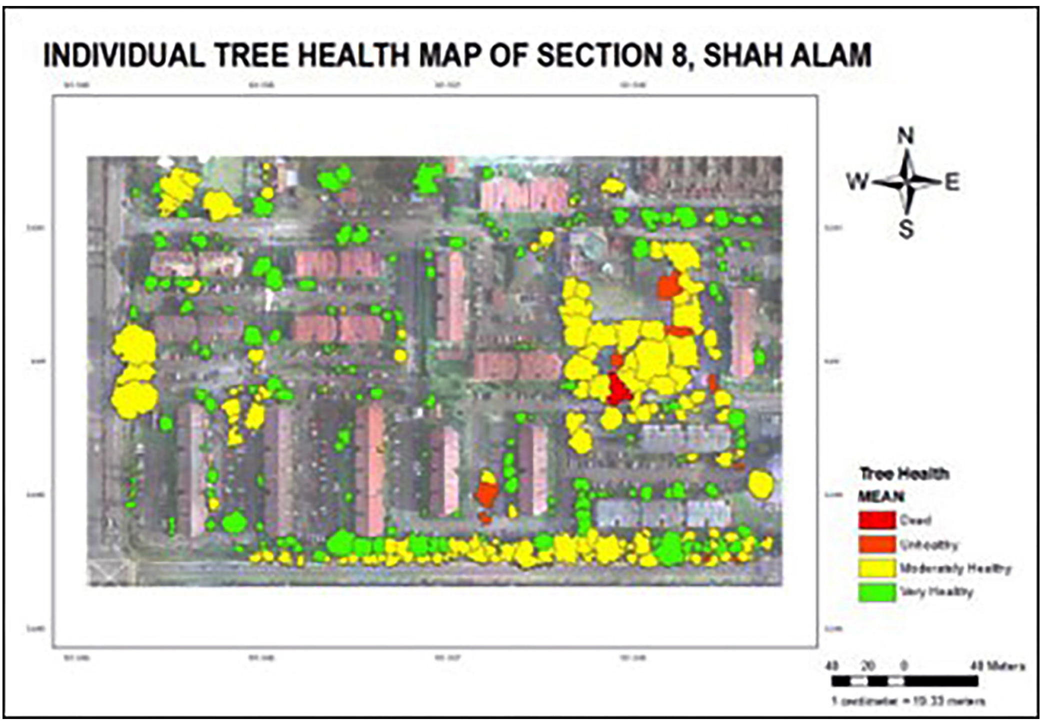

Figure 11. Individual tree health map

Spatial Distribution of Hazardous Tree

Hazard ratings are classified into four classes: low, medium, high, and severe. The ratings are calculated by adding all the parameter classes of tree height, tree health, and crown diameter. Figure 12 illustrates low-rating trees in green colour, medium-rating in yellow, and high-rating in orange.

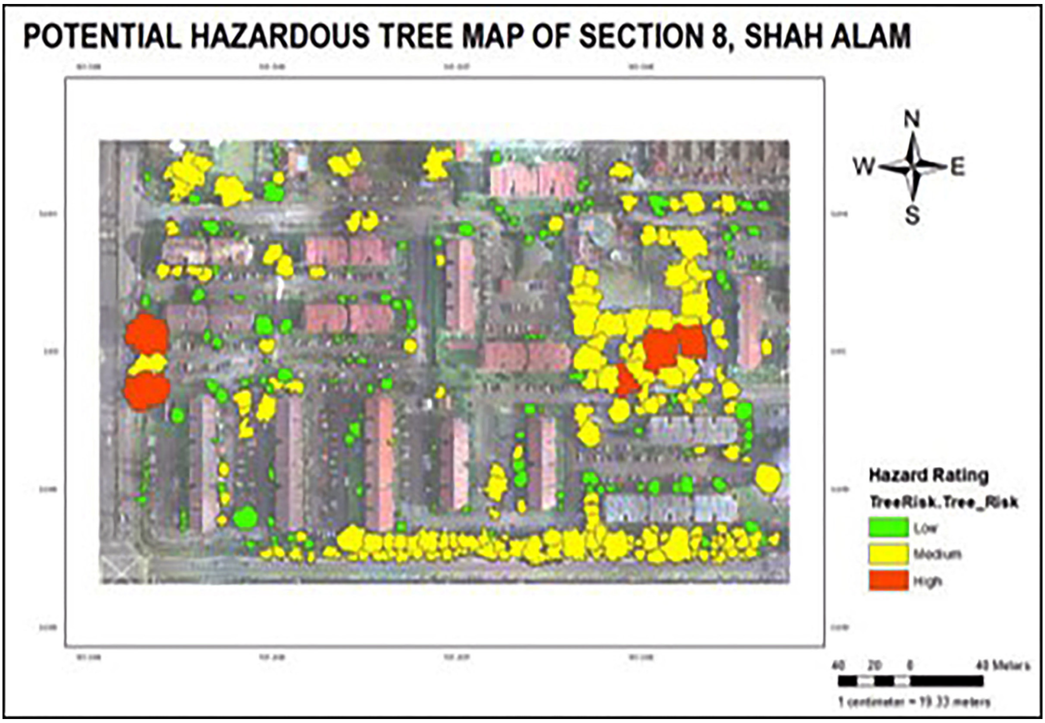

Figure 12. Potential hazardous trees map

Accordingly, 152 trees were categorized with low ratings, 160 trees were categorized with medium ratings and 5 trees were categorized with high ratings. As the findings show, trees with large crowns and tall stature receive high ratings due to their potential harmful impact on residents and road users.

Verification of Hazardous Tree

Data verification using VTA was done with the supervision of a certified arborist. Selected trees are examined based on several criteria, as in the VTA form. A total of 20 trees in Section 8 were examined for three (3) dominant tree species in the study area which are *Samanea saman, Tabebuia rosea,* and *Mimusops elengi*. The verifications are conducted based on the tree species, diameter, breast height, crown spread, wind exposure, cracks, parasitizing trees, and tree vandalisms. Based on the VTA, two trees were assessed with a low rating, 15 trees were assessed with a medium rating, and three trees were assessed with a high rating. Compared to the results extracted from UAV-based multispectral imagery, 18 out of 20 tree ratings are accurate with 90% accuracy.

In addition, verification of tree crown diameter is also done by comparing the processed imagery results with in situ data collection using Root Mean Square Error (RMSE). The RMSE of the crown diameter is ±0.407 m. The RMSE for tree height is ±0.065 m.

CONCLUSION

This study explored the potential of assessing tree risk using tree parameters extracted from UAV-based multispectral imageries. A total of 317 individual tree polygons were identified. Three (3) main parameters were extracted to produce hazard rating tree height, health, and crown diameter.

Accordingly, 152 trees were classified with low hazard ratings, 160 trees were classified with medium hazard ratings and 5 trees were classified with high hazard ratings.

VTA is done to verify and identify the potential tree hazard using extracted parameters from the UAV multispectral imagery. The accuracy of 90% achieved for this study shows that findings could benefit the local authority in identifying the hazardous trees in efficient and accurate manners.

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