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Integrating Green Infrastructure Distribution and Green Corridor Mapping with Proposed Green Trail Area and Wildlife-Human Conflict Using Remote Sensing-GIS Approach

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ABSTRACT

Most people now prefer to live in cities, and the urban population has grown significantly. The decrement of urban green corridors causes an essential need for livability in highly populated areas. The needs of population health and sustainable city development are put under prolonged stress by the shortage of publicly accessible green infrastructure and its placement in inappropriate areas. The inventory of green corridor areas and the distribution of significant infrastructure are not fully understood, thus encouraging conflicts between residents and wildlife and increasing flood risk in their vicinity. Optical satellite images were required to (1) develop a green corridor (GC) map, (2) investigate the green infrastructure (GI) demand with the existing land use, and (3) propose new green trails (GT) in the Kuantan district using a geospatial approach. NDVI and site suitability analysis were carried out on Landsat OLI and Sentinel-2 MSI images, which were integrated with GIS tools to achieve all the objectives. A GC map has been developed, and five new proposed areas for GI development have been identified. Based on the results, 5 proposed green trails (3 long GTs, 2 short GTs) with a total length of 79.3 km are scattered in the Kuantan district at the most suitable site, identified using a geospatial approach. This study supports SDG 15: Life on Land, where green corridors reinforce biological connectivity, provide conducive space for high-populated areas, and minimize the negative impact of urbanization on the designed areas of GC, GI and GT in the developing city of Kuantan.

Keywords: Green corridor, satellite, sustainable city, urban

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INTRODUCTION

The proportion of people living in cities increased from 62.0% in 2000 to 71.0% in 2010 (Department of Statistics Malaysia, 2011), aligning with national rapid growth. The four most urbanized cities in Malaysia are Kuala Lumpur and Putrajaya (100%), Selangor (91.4%) and Pulau Pinang (90.8%). In contrast, the three lowest urbanized states are Perlis (51.4%), Pahang (50.5%) and Kelantan (42.4%). With large-scale land clearance set for economic development and urbanization, fragmented green spaces are decreasing daily. Thus, a green initiative needs to be undertaken to create more sustainable living spaces for people. An increase in deforestation has occurred in Malaysia due to rapid urban development (Botezan et al., 2021; Danjaji & Ariffin, 2017). Shrinkage of green space has triggered slope failures, and many landslides jeopardize the stability of green infrastructure. Green trails should also be selected on non-steep surfaces where no or low landslide risk is infrequent (Zhan et al., 2022). The green corridors are critical for protecting pedestrians from dangerous pollution on open highways and increasing beneficial interactions between urban inhabitants and nature. Meanwhile, green infrastructure can be used with grey infrastructure measures to reduce stormwater runoff into streams and rivers and minimize infrastructure and property damage.

The objectives of this study are (1) to identify existing green infrastructure and green corridor distribution in the Kuantan district, (2) to analyze the spatio-temporal trends of Human-Wildlife conflict using spatial analysis in the Kuantan district, and (3) to propose remote sensing-Geographic Information Systems (GIS) approach for Green Trail in Kuantan district.

Developing cities trigger plenty of human-wildlife conflicts. Human-wildlife conflict (HWC) refers to adverse encounters between humans and wild animals that have ramifications for both humans and their resources, as well as wildlife and their ecosystems (Broekhuis et al., 2017). Meanwhile, deforestation reduced global forest areas lost to other uses such as agricultural croplands, urbanization, or mining (Al-Masri et al., 2019). Deforestation can lead to the direct loss of wildlife habitat and general habitat destruction. Creating a natural network for wildlife to migrate through cities and connecting green places has been demonstrated to promote biodiversity.

Remote sensing data was cost-efficient because satellite images resolved the cost and time-constraint issues in accomplishing field visits for various purposes, including crop estimation (Gallego et al., 2014). Satellites can capture images of large areas, allowing for comprehensive mapping of green corridors and critical habitat linkages for wildlife populations. It could be integrated with spatial analysis tools and techniques, such as GIS, to analyze and model the spatio-temporal trends of human-wildlife conflict. It can provide valuable insights into conflict patterns, drivers, and impacts and support evidence-based decision-making for conservation and management efforts.

This study supports one of the Sustainable Development Goals agenda, SDG15: Life on Land, which initiates minimizing the negative impact of urbanization on the designed area of GC, GI and GT in the developing city of Kuantan. Subsequently, there is a huge possibility of developing and creating an existing GT map and GT initiatives to achieve sustainability in Kuantan. Some parameters needed are accessibility distance, topology, slope and natural features.

METHODOLOGY

Study Area

This study focused on areas in Kuantan with high vegetative coverage, which aligned with the determination of this city to achieve status as a sustainable city according to the SDG. Kuantan is a Pahang state district that faces the South China Sea on the east coast of Peninsular Malaysia. The frequency of HWC, which occasionally increases each year, brings high motivation to conduct this study in Kuantan. Satellite images of Landsat OLI and Sentinel-2 with different spatial resolutions were used for this study to ensure the whole Kuantan district was covered. Moreover, elevation data from Shuttle Radar Topography Mission (SRTM) 1 Arc-second Global is used in conducting this study. Figure 1 illustrates the general workflow of the study.

Data Collection

This study gathers primary data, secondary data, including satellite images, and relevant supportive data for the comprehensive preparation required for this study. Primary data such as coordinates of land use type, green corridor, and existing GI from field visits has been gathered, along with other supportive information, including from newspapers, that is relevant to this topic. The field visit involved an area in Kuantan, Pahang, with various natural features and man-made infrastructures, an undulating topographical surface and a face-off of the South China Sea. Handheld GPS records the location of existing GI and different land use types in Kuantan. The drone system, including its sensor, panel board, and flight planning software, had been utilized to record the overall view and information of the Kuantan area, as well as the distribution of existing GI, land use type, green corridor area, and other relevant information that was used for result verification.

Besides that, the secondary data, which was used in this study is multispectral satellite images with a moderate spatial resolution (30 m) of the Landsat OLI and Sentinel-2 MSI, which has a 10 m spatial resolution that is important for mapping of GI and GT proposed locations in Kuantan, Pahang. Pre-processing of satellite data was performed using a licensed-authorized remote sensing-GIS processing system. Sentinel-2 and Landsat 8 could offer excellent accuracy and reliability for general use of monitoring and observation

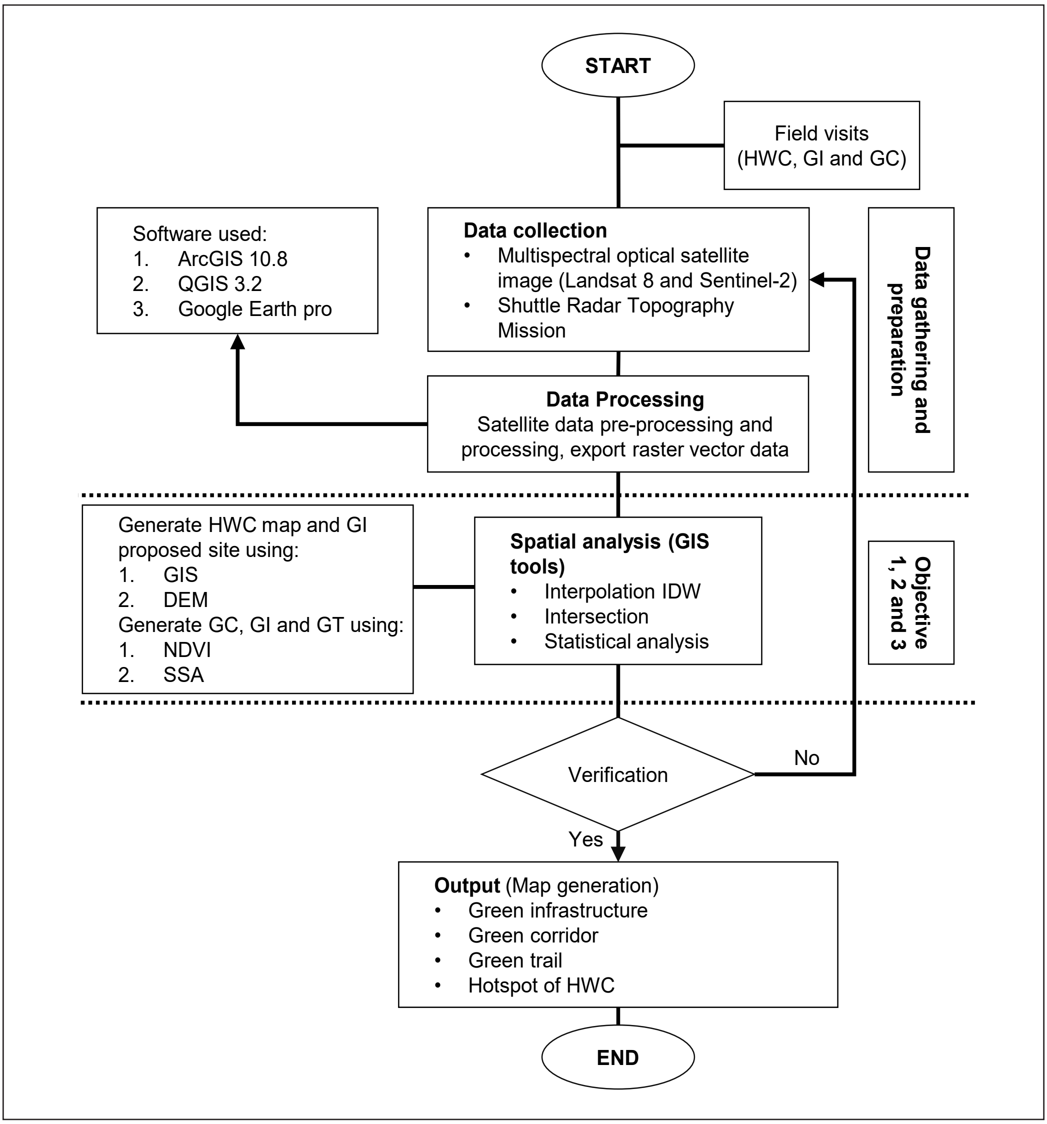

Figure 1. General workflow of the study

in the mapping process, especially for land use and green mapping in huge areas (Rasli & Kanniah, 2018). Sentinel-2 mainly gives specific specifications of the images as it accurately distinguishes different types of natural vegetation and crops in the mapping process (Espinosa & Schroder, 2019; Phelan et al., 2013).

Data Processing

Both primary and secondary data collected for this study were processed to fulfill the study's demands. Raster data format (grid form) of digital data, including optical remote sensing satellite images and vector data format such as existing GI points, was processed using a geospatial processing system with the correct map projection suitable for Pahang state. The raster and vector data attribute was assessed using ArcGIS 10.8 and certain tasks on open-source software, namely Quantum GIS (QGIS) 3.2. Both programs are data interchangeable. Multispectral satellite images have been used to generate a Normalized Difference Vegetation Index (NDVI) map where red and near-infrared spectral bands are processed using the formulae (NIR Band - Red Band)/(NIR Band + Red Band). Before processing, the georeferencing of the images, stacking of band spectral bands, and loading of the spectral layer of bands into the software were performed to ensure its readiness in terms of conforming the coordinates of the satellite image with the real location on the earth's surface, which is very critical for result accuracy after further digital data processing.

Spatial Analysis

Subsequently, after data processing, spatial analysis was performed on the processed spatial data to achieve all the objectives. The characteristics of the acquired green corridor, NDVI, green trails, and their spatial interactions are investigated using spatial analysis. It is a very important task to assess the geographic suitability of specific locations for developing proposed GT based on existing GI and GC, considering the adjacent land use types, characteristics of places, and range of NDVI values, and detecting significant trends concealed within this study. The decision-making process is more convenient with the input information from spatial analysis.

This study performed spatial interpolation using the Inverse Distance Weighted (IDW) interpolation scheme provided in ArcGIS. A set of locational data on animal roadkill accidents, reports of wildlife disturbance from residents, and animal deaths observed during field visits in the Kuantan district was consolidated as the input for spatial analysis. The zoning area with very high, medium, and low HWC occurrences was automatically generated based on the input, which was then overlaid with NDVI, where high NDVI is typically closely related to a high rate of HWC. Besides that, the intersection of the produced map with other geographical features, such as land use type, and statistical analysis have also been performed to assist in interpreting the results obtained from the data processing.

Verification Process and Map Generation

The result verification phase began after conducting field visits and collecting the data using handheld GPS and drone systems (drone, sensor, panel board, and flight planning software). Those data were exported to a geospatial file format to align their compatibility with GIS processing systems. The transfer of data from multiple GIS devices is often undertaken by converting the verification data, operated by a translational program in ArcGIS or Google Earth Pro, from the compact internal storage format to a new raster or vector data format with suitable map projection. This study used the geodetic coordinate reference system, GDM2000, with Well-Known ID (WKID) 3379 and ellipsoid of GRS 1980 as the spatial data projection. The verification process using field-based data is important to indicate the accuracy of the outputs from a satellite-based approach, including land use type GI, map, and HWC map. Data accuracy was checked, and a set of 85% (110 out of 150 points coordinate) of land use types and GI and 92% (18 out of 20 locations) of HWC area collected during the field visits were matched with processed results. The final and reliable existing GI-GC map, proposed GT-GI and HWC mapping were successfully generated using ArcGIS 10.8, QGIS 3.20, and Google Earth Pro software accomplished by all cartographic elements of a map.

RESULTS AND DISCUSSION

Existing GC and GI Map

The study is critical as green corridor mapping provides insightful inputs for the decision-makers of local agencies in projecting development plans for the city where human and man-made features and natural life share equal quality and comfort of livelihoods. This study also identified certain places to preserve and strategic areas for high conservation values. Instead of improving linear relationships between humans and animals, the focus should be reducing the frequency of conflict (Misbari et al., 2017). A green corridor is important to strengthen the ecological connection of the green spaces and reduce fragmentation patches in urban areas. According to Ashikin (2021), Pahang is the third largest Malaysian state, and Kuantan is the most developed city in the East Coast region.

This mapping was identified according to the NDVI and site suitability analysis in the spatial analysis process. The location with the highest vegetation index was selected as a green corridor. Based on Figure 2, the red area indicates the developed area, the blue area indicates the water body, the brown area indicates bare soil and the green area indicates the vegetative area. The green area is the most suitable location to build a green corridor, and the least suitable is the red area.

During the site visit, the coordinates of the existing green infrastructure in the Kuantan district were recorded using handheld GPS. Some of the types of green infrastructure are green streets, rain gardens, urban tree cover, permeable pavements, and recreational parks. After recording all green infrastructures in Kuantan, the coordinates were exported to Google Earth Pro to confirm and verify the data collected through the site visit. In total, over 300 green infrastructures of five different designs of GIs, shown in Figure 2, are mostly located in developed areas because of the low vegetation index. All proposed GI locations are free from slope failures where no or low potential of new landslides will occur.

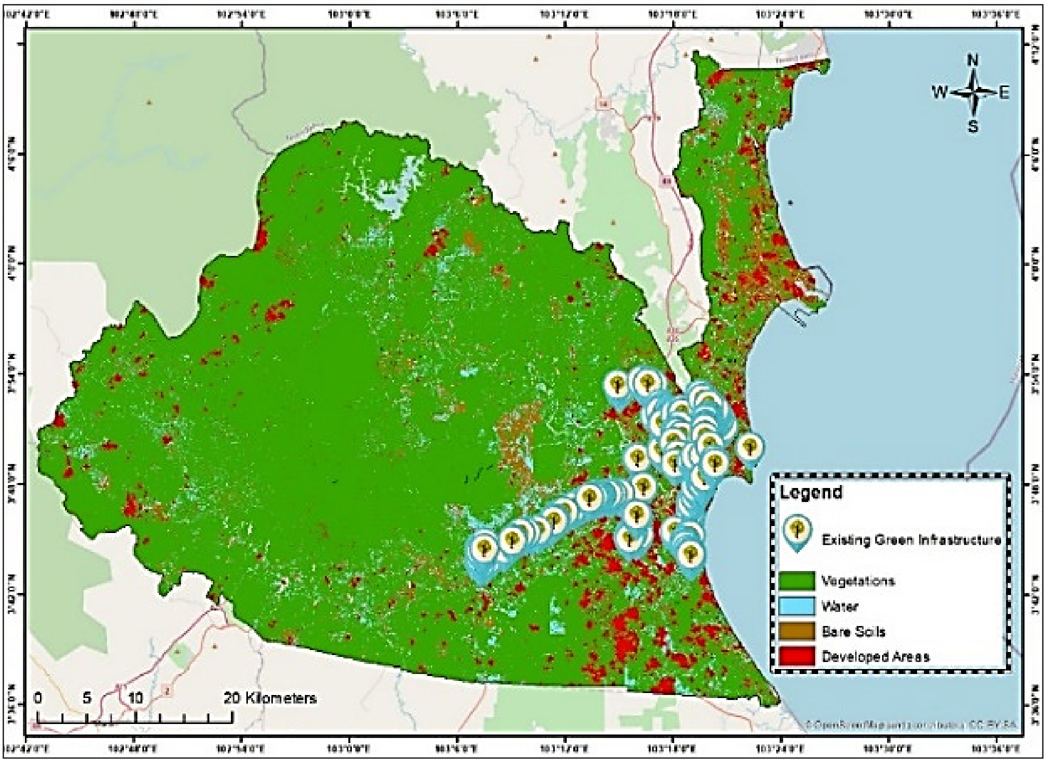

Figure 2. Existing green corridor and green infrastructure in Kuantan district

Proposed GT and GI Map

Site suitability analysis was conducted to generate green trails and proposed new green infrastructure mapping. In the site suitability analysis (SSA) process in ArcGIS for generating green trails, the road, river, slope, soil and NDVI were taken as the variables to obtain a suitable location for building the Green Trail in Kuantan. Most of the input data for SSA is from Kuantan Municipal Council, except slope and NDVI, which are generated from SRTM data and ground data collection. The SSA evaluates and grades places based on numerous weighted criteria to discover potential locations for GT and GI. SSA begins with defining the problem, determining the criteria for solving it, and creating the necessary input datasets.

Raster datasets, including the criteria of slope, river, and road in Kuantan, are used for the SSA. Inputs were ranked based on importance and priority using a common ratio such as 1/2, 1/4, 1/5, or 1/7 to compare the criteria. The author, who was familiar with Kuantan City, determined this rank. After that, the processing system, with the tool of the analytical hierarchy process, determined the weights for the criteria that have been used and combined them to get a score for each potential site. Finally, the scores determine the best feasible placements for the proposed GI. In this case, NDVI scored the highest (0.5381), while road data scored the lowest (0.1026). Thus, the green area is the most suitable for building a green trail. Meanwhile, the red area is not suitable because it is heavily developed. Hence, there are 5 trails generated that can be built in Kuantan district.

As shown in Figure 3, the longest trail (Green Trail 1- green pale) is 41 km long; meanwhile, the shortest trail (Green Trail 5-pale blue) is 2 km long, and the total length of these 5 trails is 79.3 km. All these trails are prohibited from trespassing by any authority or any development. Thus, these trails are named as a reserved and conservation location for natural habitat flora and fauna. Similar to GI, all proposed GT locations have a low risk of landslides or flash flood events, which may cause casualties for the residents in Kuantan City (Sami et al., 2013).

Furthermore, in the SSA process for green infrastructure, the slope, soil and NDVI were taken as the variables to obtain a suitable location for building GI in Kuantan. The location near the waterfall and green trail is the most suitable location for GI because of the natural features, and the most suitable type of GI to build is recreational parks. The GI buildings are green streets, rain gardens, permeable pavements, and urban tree cover (Mustafa, 2011). Besides, after analyzing the existing GI map, we found that these types of green infrastructure are not well distributed in the Kuantan district. Hence, the proposed green infrastructure is needed to stabilize the distribution of green infrastructure and its type according to its suitability. Figure 3 also illustrates five new proposed sites for GI development.

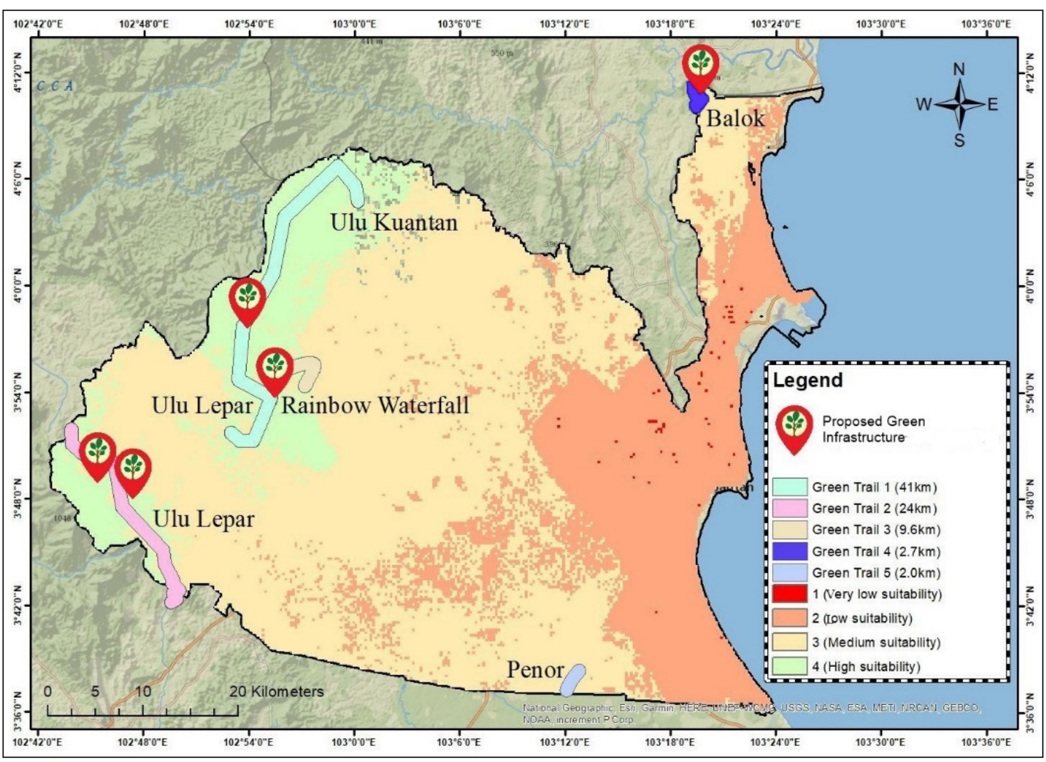

Figure 3. Proposed green trails and green infrastructure in Kuantan district

The proposed GI may benefit the residents' environment and quality of life. However, relevant stakeholders may take into consideration a few potential challenges in implementing the proposed green infrastructure in Kuantan. It may come from the maintenance of the proposed GI for the long term in terms of its operational cost and related tasks, including watering and pruning trees, integration of the proposed GI with existing urban infrastructure such as transportation systems and utilities, and selection of tree species. In addition, public perception may doubt the effectiveness of GI for urban hazards, including floods and heat, that cause low community engagement from residents. Therefore, a comprehensive solution involving collaboration among government agencies such as Kuantan Municipal Council and the Malaysian Public Works Department, community organizations, private stakeholders, and experts in urban planning and environmental research is required to address these challenges and ensure that the public well-accepts proposed and existing GI.

Human-wildlife Conflict Map

Figure 4 reveals hotspots of HWC in the Kuantan district and the types of animals involved in the casualties. The map shows a negative regression between the interpolated area of

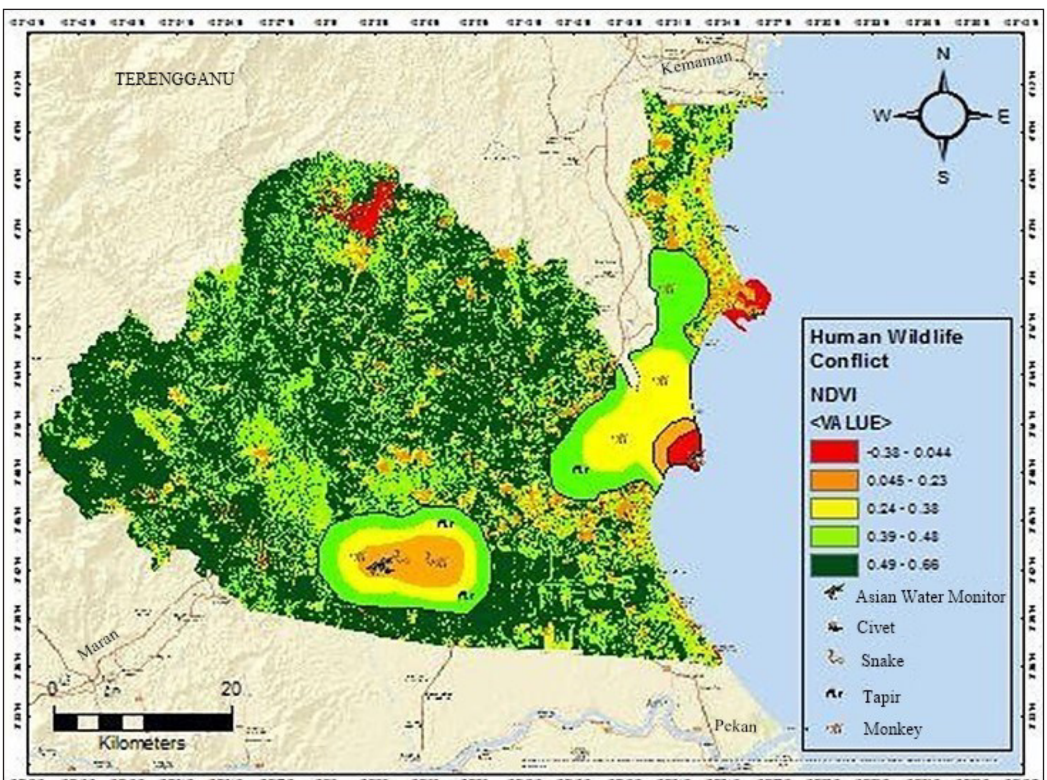

Figure 4. Human-wildlife conflict map in Kuantan district overlaid on NDVI layer

HWC and NDVI values, where HWC increased when the NDVI increased. It indicates low habitat density in low vegetation areas, which triggers conflicts between humans and wildlife. Besides that, the buffer zones were generated by using kernel density tools, and there are 5 categories of HWC hotspots, which consist of very high (red), high (orange), moderate (yellow), low (light green), and very low (dark green).

Furthermore, all recorded animals in the Kuantan district show different sizes, from medium to large mammals or reptiles, such as Asian water monitors, civets, snakes, tapirs, and monkeys. Indirectly, this result was recorded in 2021. Based on the results, the highest hotspot was recorded on the east side of Kuantan district, the Teluk Cempedak area.

CONCLUSION

This study was carried out to identify existing green infrastructure and green corridor distribution in the Kuantan district, analyze the spatiotemporal trends of HWC using spatial analysis, and implement a remote sensing-GIS approach for green trail mapping. Based on the findings, all objectives were achieved. The existing GI in Kuantan is concentrated in the urban area along the easy-accessed corridor. Thus, five locations of new GI are proposed to be built along the proposed GT. Based on the results, 5 proposed green trails (3 long GTs, 2 short GTs) with a total length of 79.3 km are scattered in the Kuantan district at the most suitable site, identified using the RS-GIS-based approach. As shown in Figure 3, two new GIs should be developed along the GT1, 2 new GIs along the GT2 and a new GI along the GT4. By improving GI and preserving the GT area, the rate of HWC could be reduced in the Kuantan district in the long term.

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