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Mapping Potential Habitat Characteristics and Identification of Migratory Raptor Species in the Sabang City

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Abstract: This study aims to identify raptor species, map ideal habitat characteristics, and estimate potential habitat areas in Sabang City. The method includes field exploration to collect data on raptor species and spatial analysis using ArcMap 10.8 and Google Earth Engine to download environmental variable data. This study found seven identified species namely: *Pernis ptilorhynchus*, *Accipiter soloensis*, *Accipiter gularis*, *Butastur indicus*, *Halieentus leucogaster*, *Ichtyophaga ichtyaetus*, and *Falco peregrinus* where five species are migratory and two species are residential. Ideal habitat characteristics include surface temperature of 26–30 °C, NDVI values between 0.43 and 1.00, land slope of 0–2 %, 0–200 m above sea level, and rainfall of 1.500–2.000 mm/year. The total area of potential habitat identified was 674 hectares or 5.51% of the total area of Sabang City. These findings can support sustainable habitat management and raptor conservation, and provide valuable information on management policies to protect migratory birds in the area.

Keywords: Conservation; Habitat; Raptor; Sabang city; Spatial analysis

Introduction

Migration, from the Latin word 'migrate,' is the seasonal movement of animals caused by changes in environmental conditions such as temperature and food availability (Caesar et al., 2021). Birds of prey, commonly known as raptors, are among the migratory species that play a crucial role as apex predators, holding a vital position in maintaining the balance of ecosystems (Cho et al., 2019). Every year, thousands of migratory birds, including these apex predators, travel to Indonesia in search of food (Khairunisak et al., 2022). Notably, the movement of Chinese sparrowhawks (*Accipiter soloensis*) stops in the Sabang area, highlighting its significance as a critical stopover before these birds continue their journey to the Andaman Islands (Pierce et al., 2021).

Raptor migration in Indonesia, particularly in Sabang City, is an interesting and important phenomenon to study (Putri et al., 2021). Sabang, located in the far west of Indonesia, is known to be a migratory route for various raptor species moving between summer and winter habitats (Pierce et al., 2021). Although the presence of migratory raptors in this region is recognized, the urgent need for information on the species present and the habitat characteristics that support them is still minimal (Ramlah et al., 2017). This study aimed to identify raptor species, map ideal habitat characteristics, and estimate potential habitat areas in Sabang City.

This study is important because it highlights the need to know the population dynamics of migratory raptors in Sabang (Dénes et al., 2017). The species faces threats from land use change, urbanization, and other human activities (Achmad et al., 2019). In the face of increasing pressures on natural ecosystems, there is a need to know about raptor species and habitats.

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Therefore, the findings derived from this study will form a solid platform for developing effective conservation policies (O'Bryan et al., 2022). Besides, this research seeks to address a key knowledge gap established in earlier literature because most previous studies concentrated on raptor species in other parts of Indonesia, thereby overlooking the distinctive conditions and problems typical of Sabang (Buechley et al., 2019).

This research provides valuable information on natural resource management and conservation at the local level. By identifying the optimal habitat features for migratory raptors, the research is likely to improve the development of more successful protective measures for these birds and their habitats (Limiñana et al., 2015). The research also seeks to promote awareness at the local community level of the importance of conserving biodiversity in the region and foster involvement in conservation efforts (Ma et al., 2022).

Therefore, this study aims not only to identify species and habitat characteristics, but also to significantly contribute to the conservation of migratory birds of prey in Sabang City, an essential part of the broader ecosystem in Indonesia and Southeast Asia.

Method

This research was conducted in the Sabang City area. The method used is the cruise method, which involves exploring the research area to find the meeting point of the coordinates of the presence of birds of prey (raptors). Birds of prey found will be analyzed descriptively. In contrast, habitat characteristics will be analyzed spatially by downloading environmental variable data from the Google Earth Engine cloud system, reclassifying, and compiling maps using ArcMap 10.8 software.

Collection of Primary Data

Primary data collected were coordinates of raptor presence and raptor species found during the study, which coincided with spring migration in May 2024 and autumn migration in October 2024 (Tyas et al., 2020). Observations were made at specific times, such as morning and evening, to maximize the chances of seeing birds of prey.

Collection of Secondary Data

Secondary data used in this study include raster data of land surface temperature, vegetation density (NDVI), slope, elevation, and rainfall based on research. Table 1 below shows the types of secondary data used and their sources.

Table 1. Secondary Data

Data	Type	Source
Administrative Boundary of Sabang City	SHP	Tanahair.Indonesia
Land Surface Temperature	Tiff	MOD11A1.061
Vegetation Density (NDVI)	Tiff	Citra Sentinel-2A
Slope	Tiff	NASA SRTM 30m
Elevation	Tiff	NASA SRTM 30m
Rainfall (mm/year)	Tiff	CHIRPS Daily

Data Processing

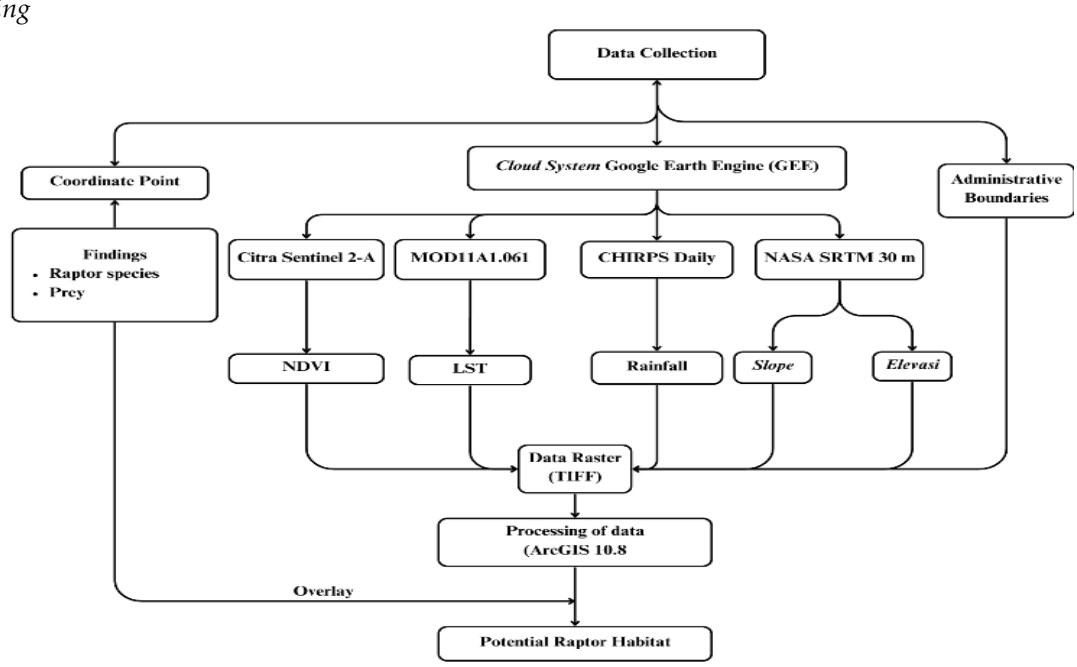

Figure 1. Research flow chart

Environmental factor data were spatially analyzed using ArcMap 10.8. Data from Google Earth Engine was converted to raster format, exported to Google Drive, and reclassified based on relevant criteria. The dissolved vector data were combined with the intersect method to identify the distribution of raptor habitat. For quantitative information, the area identified was calculated in hectares (ha). A map layout was prepared to visualize potential raptor areas. The data processing process can be seen in Figure 1.

Tools and Materials

The researchers employed stationery to record bird identifications in the field, according to Nisa' et al. (2021); the characteristics used to identify birds include body shape and size, beak shape, feather patterns, and bird calls. GPS is used to record locations, tally sheets are used to record observation data, binoculars are used to watch birds from a distance, and ArcMap 10.8 and Google Earth Engine software are used to interpret satellite data.

Result and Discussion

Types of Raptors

Based on research conducted in Sabang City, 7 raptor species from 2 families Accipitridae and Falconidae were found from 19 coordinate points of raptor presence in the Sabang City area. The dominating raptor species are the Accipitridae family including *Pernis ptilorhynchus*, *Accipiter soloensis*, *Accipiter gularis*, *Butastur indicus*, *Halieentus leucogaster*, *Ichtyophaga ichtyaetus*. In addition, *Falco peregrinus* species from the Falconidae family were also found in the Sabang City area. Raptor species found in the Sabang City area can be seen in Table 2.

Tabel 2. Types of Raptors

Famili	Species		Migrant/ Resident
	Local Name	Scientific Name	
Accipitridae	Oriental honey-Buzzard	*Pernis ptilorynchus*	Migrant
	Chinese Sparrowhawk	*Accipiter soloensis*	Migrant
	Japanese Sparrowhawk	*Accipiter gularis*	Migrant
	Grey-faced Buzzard	*Butastur indicus*	Migrant
	White belied Sea-Eagle	*Haliaeentus leucogaster*	Resident
	Grey Headed Fish-Eagle	*Ichthyophaga ichtyaetus*	Resident
Falconidae	Peregrine Falcon	*Falco peregrinus*	Migrant

The table above shows that 5 of the 7 raptor species found were identified as migrant raptor species. This indicates that the Andaman Passage is actively used as a migratory route by raptors when traveling long distances during spring migration and autumn migration. The discovery of Peregrine Falcon, Grey-face Buzzard and Japanese Sparrowhawk in October 2024 proves the existence of an inflow (autumn migration) where raptors move out of breeding sites to stopover sites to get warm temperatures and also the availability of prey for survival (AlAli et al., 2024).

The migratory raptor species found in this study have similarities with species obtained in previous studies. Research conducted by Tyas et al. (2020) in the Mount Sega area, Karangasem, Bali, found 7 raptor species including 5 species of migrant raptors and 2 other species of resident raptors. In addition, research conducted in the Bukit 76 Kaliurang area, Yogyakarta by Putri et al. (2021) found 3 species of migratory raptors and 3 species of resident raptors.

Both studies recorded the same 2 migrant raptor species and 1 resident raptor species, namely Oriental-honey Buzzard (*Pernis ptilorhymchus*), Chinese Sparrowhawak (*Accipiter soloensis*), and Crested Serpent Eagle (*Spilornis cheela*). The discovery of several species of migratory raptors in the Sabang City Region also proves that the Andaman route is actively crossed by migratory raptors during the autumn migration and spring migration seasons (Pierce et al., 2021).

Raptor species frequently perform flying activities during observations. Flight behavior in raptors includes a variety of complex maneuvers that serve different purposes, including hunting, territorial defense, and migration (Donázar et al., 2016). These behaviors are influenced by the specific traits of each species and environmental conditions, indicating raptors' adaptability and survival strategies (Chiatante et al., 2023).

Raptor flight behaviors are profoundly determined by different environmental aspects of their habitat, such as the presence of prey (Álvarez et al., 2024), plant community composition (Zagorski & Swihart, 2021), and climatic factors (Schueck & Marzluff, 1995). These factors are the basic rationale behind an optimal raptor habitat that allows raptors effortless foraging and migration (Aumann, 2001).

Spatial Characteristics of Migratory Raptor Habitat

Spatial analysis was conducted using remote sensing methods through the Google Earth Engine platform and Geographic Information Systems (GIS) using ArcMap 10.8 software (Purwanto & Paiman, 2023). This analysis aims to identify the spatial characteristics of raptor habitat by considering environmental factors such as temperature, rainfall, elevation, slope, and vegetation density. In this process, the Spatial Join method in ArcMap 10.8 integrates the coordinates of

raptor presence in Sabang City. The analysis results will identify the most dominant environmental factor class based on the findings of the most coordinates of raptor presence points and provide an overview of the habitat distribution area in hectares.

Table 3. Preference for Environmental Factors in Migratory Raptor Resting Sites

Environmental Factor	Value Range	Join Count	Preference
NDVI	-1.00 < NDVI < 0.32	0	
	0.33 < NDVI < 0.42	0	
	0.43 < NDVI < 1.00	19	0.43–1.00
Temperature	20–25 ^{0}C	0	
	26–30 ^{0}C	11	26–30 ^{0}C
	30–35 ^{0}C	0	
Rainfall	1.000–1.500 mm	0	
	1.500–2.000 mm	14	1.500–2.000 mm
	2.000 ≥ 2.500 mm	5	
Slope	0–2 %	9	0–2 %
	2–15 %	4	
	15–40 %	5	
	> 40 %	1	
Elevation	0–200 m	18	0–200 m
	200–400 m	1	
	400–500 m	0	
	> 500 m	0	

Table 3 shows each environmental factor's class generated through ArcGIS reclassification. Sentinel-2A image data was processed to calculate NDVI (Normalized Difference Vegetation Index) as an indicator of vegetation (Purwanto & Sulha, 2024). NDVI is a mathematical combination of band 4 (Red) and band 8 (NIR), which has long been used to assess the presence and condition of vegetation (Fitasari et al., 2017). NDVI values range from -1, which indicates unvegetated land, to +1, which indicates dense vegetation (Fadlillah et al., 2018). Processing NDVI using Red and NIR bands produces representative values for the area under study. In addition, Junianto et al. (2023) and Silitonga et al. (2018) state that NDVI values can be classified into three classes (Table 3), which facilitates the interpretation of vegetation conditions.

Surface temperature raster data were obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery with MOD11A1.061 Terra Land Surface Temperature and Emissivity Daily Global 1 km product, accessed through Google Earth Engine (GEE) (Souza et al., 2023). According to Rakuasa (2023), this satellite image product developed by NASA provides information on the Earth's surface temperature and emissions with a spatial resolution of 1 km. After the surface temperature analysis is downloaded to Google Drive, the raster data will be analyzed and classified into three classes (Table 3) using ArcMap 10.8 software.

Rainfall data was obtained from the Climate Hazard Group InfraRed Precipitation with Station (CHIRPS) (Soares et al., 2024). According to Dewi et al. (2022), the CHIRPS rainfall database consists of three main components: global climatological data, satellite-based rainfall estimates, and field measurement results. Additionally, CHIRPS aims to provide a complete, accurate, and up-to-date data set that can be used for various purposes (Virgota et al., 2024). The downloaded raster data were then classified into three classes, as shown in Table 3.

Slope and elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) Digital Elevation 30-meter (Orme, 2019). According to Muin & Rakuasa (2023), this dataset uses radar interferometry techniques to provide elevation information of the Earth's surface, covering almost the entire surface except the polar regions. Land elevation is important for predicting habitat suitability, where higher elevations offer cooler temperatures and reduced human (Zhang et al., 2019). Slope and elevation also influence raptor presence regionally (Tapia et al., 2018). These data were classified into four classes (Table 3) based on the Regional Spatial Plan (RTRW) of Sabang City and Aceh Besar 2012-2032.

The reclassified environmental factor data was overlaid with the coordinates of raptor discovery points using the Spatial Join method. This process aims to obtain a join count value, which results from a spatial merge between the rows of combined feature values and target feature values based on their relative spatial location (Lei & Lei, 2022). In this way, we can more easily determine the target class that will be used as a factor in making potential habitat maps. The join count results can be seen in Table 3.

Figure 2 shows the preference for environmental factors most frequently encountered by raptors. Factors frequently found in raptor habitats are suitable indicators for their habitats. Based on spatial analysis, suitable factors include NDVI in the value range of 0.43–1.00, indicating dense vegetation density; temperature between 26–30 ℃, which is categorized as moderate; rainfall between 1.500–2.000 mm/year, also in the moderate category; slope between 0–2 %, which is categorized as flat; and elevation between 0–200 m, which is categorized as low. These findings are related to the dominance of raptor species from the Accipitridae family.

The Accipitridae family is often found in various habitats, directly affecting prey availability and hunting methods (Redondo et al., 2019). The family Accipitridae is very adaptable, allowing it to live in varied ecosystems such as forests, grasslands, and wetlands. This adaptability benefits the family, allowing it to occupy

numerous ecological niches within its range and attain greater prevalence and dominance (Cho et al., 2019). Environmental factors influence habitat selection by the Accipitridae family. Suitable habitats for these raptors usually have dense vegetation, which is important for nesting and hunting. Moderate temperatures and rainfall levels are preferred for their survival. In addition, flat slopes and low elevations facilitate access to hunting grounds, thus favoring the dominance of Accipitridae in such environments (Monsalvo, 2018).

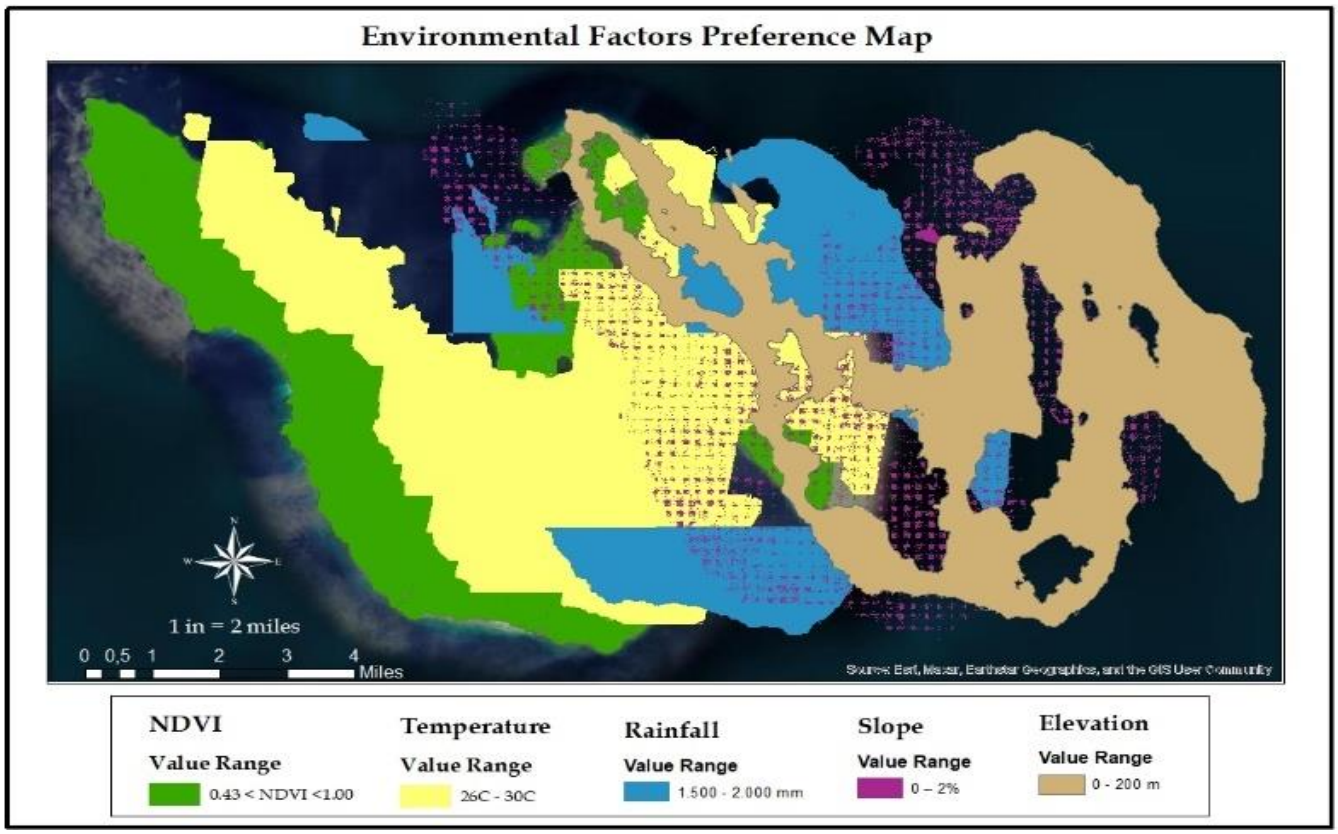

Figure 2. Environmental factors preference map

Figure 2 presents the environmental feature classes where most raptor coordinate points fall. While there are points in other classes (Table 3), this study is concerned with the most dominant class. Sabang is mainly homogeneous, consisting of moderate temperature, low topography, and gentle slopes. Dense vegetation within the center and east regions harbors several wildlife species, including raptors. Moderate rainfall supports water availability and vegetation cover, rendering Sabang a suitable habitat for raptors, especially where cover is dense and at low altitudes.

The spatial analysis result in this study agrees with a recent study by Park et al. (2025), who used MaxEnt modeling to identify the habitat preferences of the raptor species. They modeled NDVI, temperature, rainfall, slope, and elevation variables, which produced microclimates and influenced raptor distribution. The study revealed that NDVI is a significant factor in habitat suitability, especially in species such as *Accipiter gentilis* and *Falco subbuteo*, where tall vegetation is linked to better habitat. Temperatures of 26 to 30 °C suit most raptor species adapted to hot environments. Rainfall influences habitat suitability, with species such as *Accipiter soloensis* being influenced by this aspect in prey distribution. Slope of 0–2 % are typically associated with the diversity of the prey population, and raptors such as *Falco subbuteo* prefer open habitats. Altitude also interacts with temperature and rainfall to influence microhabitats, with birds such as *Falco subbuteo* and *Accipiter soloensis* preferring low elevations.

Modeling of raptor habitat in Sabang shows that this top predator highly depends on environmental factors such as NDVI, temperature, rainfall, slope, and elevation. Therefore, conservation should focus on maintaining and restoring mature forest habitats with high NDVI. It is also important to maintain stable temperature and humidity, and ensure connectivity between elevations so raptors can move and forage well. This study also shows the distribution of raptor habitat, which can be seen in Figure 3 below. Improving monitoring technology and integrating climate resilience into conservation planning are essential to deal with human activities and rapid climate change pressures.

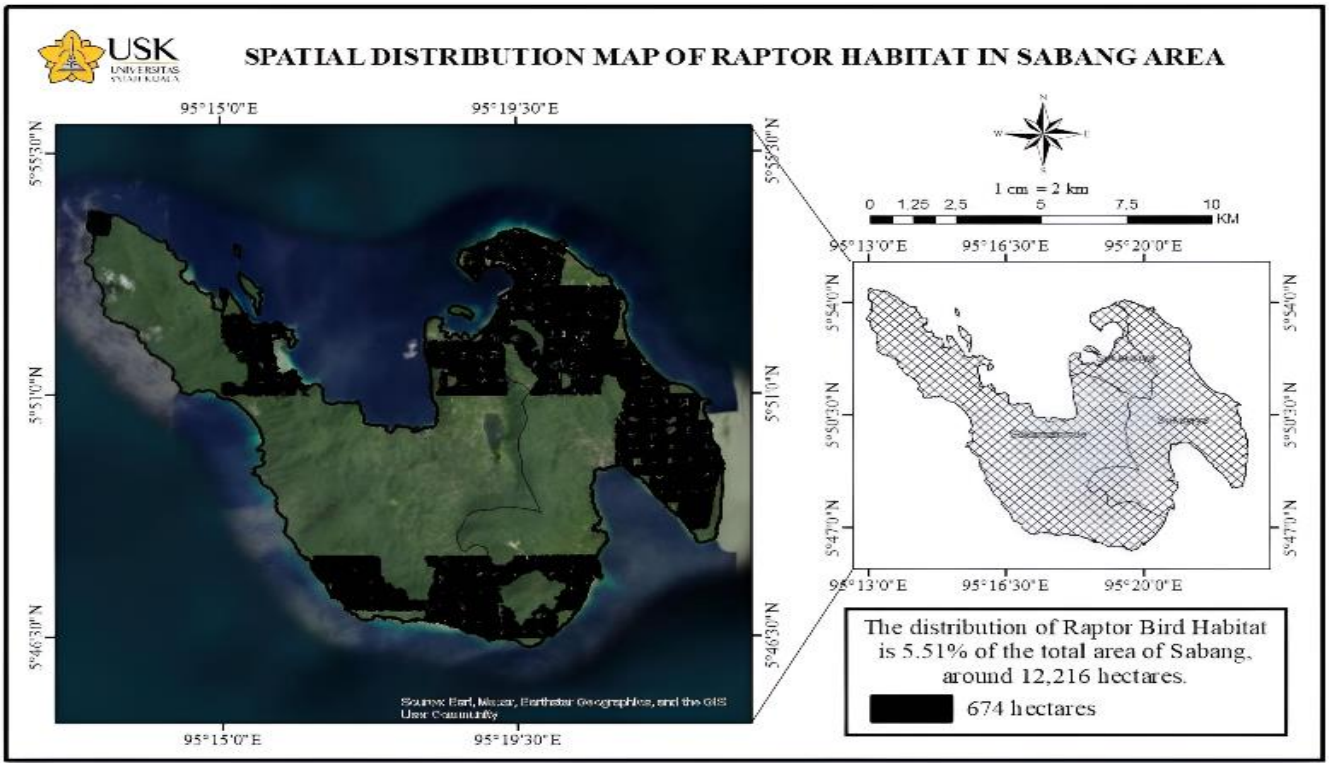

Figure 3. Map of potential habitat area

Figure 3 presents the results of overlaying all the preferences for environmental factors. The overlay method constitutes a spatial analysis method that creates new data from overlapping regions between two or more spatial data layers (Nogoro et al., 2019). The resultant overlay will have only the attributes common to both input layers, thus creating a new layer covering just the overlap areas (Anselin & Getis, 2010). In the present research, this technique was applied to identify potential habitat sites for raptors by investigating the interaction between their preferred environmental variables.

Figure 3 shows the potential area of 674 hectares of raptor habitat, which roughly covers 5.51% of the total area of Sabang city, amounting to 12,216 hectares. The overlapped area indicates where all the classes of environmental factors overlap. The unevenness of habitat distribution mirrors that the ideal combination of environmental factors is not regularly distributed throughout the area of Sabang City.

Ground observations have substantiated the results of Sabang raptor habitat distribution modeling. Haliaeetus leucogaster, or the white-bellied sea eagle, has been successfully identified within the identified coastal area as its habitat throughout the research, thereby testing the model's validity as a determinant for the species' location. Besides, the Oriental honey buzzard (*Pernis ptilorhynchus*), Chinese sparrowhawk (*Accipiter soloensis*), Grey-faced Buzzard (*Butastur indicus*) were observed in open forested and agricultural fields known to be their habitat. Further, the Peregrine falcon (*Falco peregrinus*) was observed flying over the Malacca Strait towards Breuh Island. These findings indicate that the model has significant accuracy in predicting the habitats of various species of raptors in Sabang.

Conclusion

This study identified seven species of raptors in the Sabang area, namely Oriental Honey-Buzzard (*Pernis ptilorhynchus*), Chinese Sparrowhawk (*Accipiter soloensis*), Japanese Sparrowhawk (*Accipiter gularis*), Grey-faced Buzzard (*Butastur indicus*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Grey-headed Fish-Eagle (*Ichthyophaga ichtyaetus*), and Peregrine Falcon (*Falco peregrinus*). The spatial analysis results found that habitats that support these species are characterized by dense vegetation, a moderate temperature range between 26 and 30 °C, total annual rainfall between 1,500 and 2,000 mm, flat slopes between 0 and 2%, and low elevations between 0 and 200 meters. The total area of potential habitat identified was 674 hectares or 5.51% of the total area of Sabang City.

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Author Contributions
Conceptualization, investigation, D.R. and H.T.; methodology, W.D.; software, formal analysis, data curation, writing—original draft preparation, writing—review and editing, visualization, D.R.; validation, A.F. and W.D.; resources, H.T. and D.R.

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Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this article.

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