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UTILIZING GIS AND REMOTE SENSING FOR MODELING THE SPATIAL DISTRIBUTION OF WILD ORCHID SPECIES IN PHU FAEK FOREST PARK

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Abstract: Thailand's wild orchids, cherished for their beauty, face threats from habitat loss and over-collection. Urgent conservation is needed, with efforts including protected areas and sustainable practices. This study aims to model the distribution of wild orchids through the utilization of remote sensing and GIS techniques. The methodology involves comprehensive surveys of wild orchid species within Phu Faek forest park. Spatial regression analysis explores intricate relationships between wild orchid density and environmental factors such as NDWI, forest type, elevation, basin density, and aspect. The results of field surveys identified 28 orchid species with diverse distribution patterns, including dominant species like *Aerides falcata Lindl. & Paxton*, *Aerides falcata Lindl.*, and *Cleisostoma fuerstenbergianum F.Kranzl*. The spatial regression model revealed distribution patterns, with higher density in central and north regions. The NDWI indicator, which reflects moisture content, provided additional insights into the distribution of orchids

Key words: Wild orchids, Geographic Information System (GIS), Spatial Regression, Conservation, Environmental Factors, Habitat Preferences.

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INTRODUCTION

Wild orchids are one of the largest and most diverse groups of flowering plants, with over 25,000 species found in almost every region of the world (Pridgeon et al., 2014). These striking plants are known for their intricate and often beautiful flowers, which come in a wide range of shapes, sizes, and colors Wild orchids are one of the largest and most diverse groups of flowering plants, with over 25,000 species found in almost every region of the world (Pridgeon et al., 2014). These striking plants are known for their intricate and often beautiful flowers, which come in a wide range of shapes, sizes, and colors. Orchids, as a diverse group of plants, hold significant importance in the realm of plant conservation due to their extensive species count and the numerous challenges presented by their complex life histories, which often involve various obligate or facultative biotic interactions (Liu et al., 2020).

Thailand is home to a rich diversity of wild orchids, with over 1300 species and 180-190 genera found throughout the country (Thammasiri, 2016). These orchids can be found in a range of habitats, from lowland rainforests to high-altitude mountain forests. While Thailand serves as a natural habitat for a wide range of orchid species, there is a growing interest in cultivating orchid cultivars due to their economic value (Thammasiri, 2016). Thailand's wild orchids are particularly known for their beauty and diversity, with many species prized for their ornamental value. Unfortunately, like many wild orchids around the world, Thailand's orchids face numerous threats, including habitat loss and over-collection (Thammasiri, 2015). Efforts to protect and conserve Thailand's wild orchids have included the establishment of protected areas, the promotion of sustainable harvesting practices, and the development of ex-situ conservation programs (Prasongsom et al., 2020).

Geographic information system (GIS) is a powerful tool for mapping and analyzing the distribution and habitats of wild orchids. GIS technology can help conservationists to identify key areas for conservation, monitor habitat changes, and assess the effectiveness of conservation measures. In addition to mapping and analyzing the distribution and habitats of wild orchids, remote sensing and GIS can also be used to estimate the density and richness of wild orchid (Zhan et al., 2022). Remote sensing data, such as satellite images and aerial photographs, can provide information on vegetation cover and topography, which can be used to predict suitable habitats for orchids. This information can then be combined with ground surveys to estimate the density and abundance of wild orchids in a given area. The examination of orchid richness and density in conjunction with various environmental factors extended to an analysis of these relationships across multiple nature reserves. Notably, environmental variables encompassing soil quality, climate conditions, vegetation types, and topographical characteristics emerged as closely intertwined with the levels of orchid richness and density (Zhan et al., 2022; Smallwood and Trapnell, 2022; Akbulut et al., 2021). To estimate the distribution and identification of suitable habitats for wild orchids, researchers employed remote sensing techniques, leveraging indicators such as the normalized

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difference vegetation index (NDVI). This approach facilitated the creation of a robust model for illustrating the distribution of suitable orchid habitats. The model's foundation lies in the association between wild orchid density and NDVI values, effectively delineating areas conducive to wild orchid growth and habitation (Rahayu and Yusri, 2022).

Regression models are widely used in the field of remote sensing to estimate various vegetation parameters such as biomass, leaf area index, and vegetation cover using satellite imagery data (Aroonsri and Sangpradid, 2021). These models can help to provide valuable information for forest and orchid conservation by allowing the accurate estimation of key parameters. The spatial regression model has gained considerable popularity in recent years. This model enables the detection of spatially diverse relationships between the dependent and independent variables, contributing to enhanced precision within the regression framework (Sangpradid et al., 2022). By considering spatial autocorrelation within the data, the spatial regression model accommodates intricate spatial arrangements and facilitates the representation of intricate spatial structures (Sangpradid, 2023). A spatial regression model, specifically geographically weighted regression (GWR), was then applied to evaluate the potential influence of different environmental factors on the spatial distribution of orchid flora (Ye et al., 2022). This analysis illuminated the complex relationships between environmental factors, spatial variables, and the patterns of orchid distribution. It underscored the pivotal role of spatial variables in shaping the distribution of wild orchid species richness.

A spatial regression model should be applied, taking into account the results of statistical tests (Aristizábal, 2023), to effectively analyze and estimate the relationship between wild orchid distribution and various environmental factors. The objective of this study aimed to investigate the distribution of orchids species within Phu Faek forest park and employ a spatial regression model to estimate the distribution of wild orchid based on remote sensing data and GIS analysis.

MATERIALS AND METHODS

Study Area

Phu Faek forest park situated within the geographic coordinates of 16.690695 N latitude and 103.939065 E longitude. Phu Faek forest park is characterized by its alternating mountainous and hilly topography. The park is adorned with a captivating deciduous dipterocarp forest, showcasing a rich variety of flora including the majestic Makha Mong *(Afzelia xylocarpa)*, Teng (*Shorea optusa*), Rang (*Shorea siamensis*), and rosewood species. This lush forest provides a picturesque backdrop for the park's diverse ecosystem. The study area as shown in Figure 1.

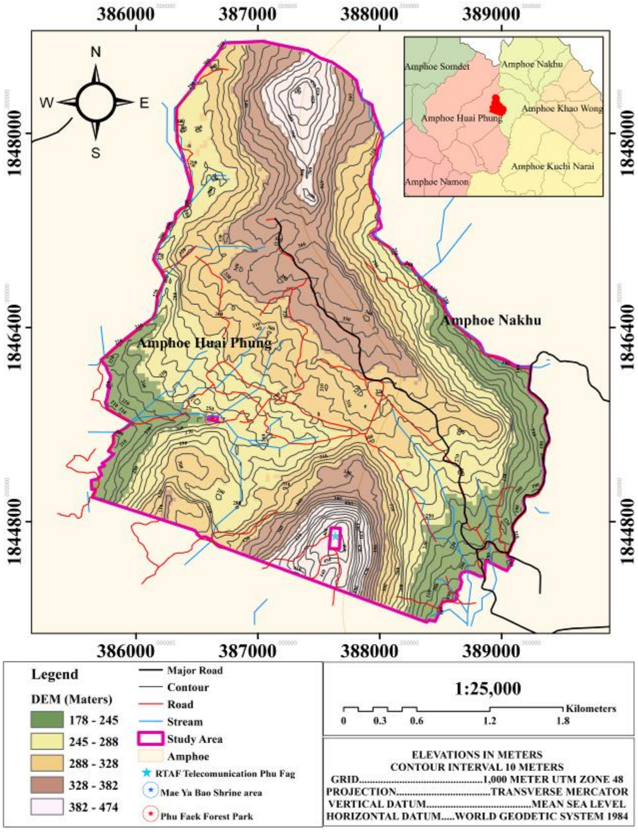


Figure 1. Map of the study area location in Phu Faek forest park, Kalasin province, Thailand (Source: authors)

Data collection

Data collection efforts were meticulously undertaken to comprehensively document the diverse array of wild orchids species encountered during extensive field surveys. Noteworthy locations, including the esteemed Mae Ya Bao Shrine area, captivating nature study trails, footpaths frequently traversed by local communities to access the forest, and the enchanting waterways, served as the primary sites for data collection. An extensive set of data collection tools were adroitly employed to ensure precision and accuracy, including Global Positioning System (GPS) devices for precise location identification, meticulously designed data recording forms, high-resolution cameras to visually document the captivating findings, satellite imagery maps, and topographic maps for detailed spatial representation. Sophisticated data analysis tools played a pivotal role in the meticulous examination of the collected information. These cutting-edge tools encompassed computers, printers, and state-of-the-art geographical information system (GIS) software. Moreover, data recording programs proved instrumental in seamlessly importing the recorded data into spreadsheets for further comprehensive analysis. The data sets compiled essential parameters, such as precise X and Y coordinates, distinct species names, quantities, heights, and distinctive visual characteristics, offering profound insights into the unique traits of each observed wild orchids species. Moreover, during the analysis, crucial factors such as forest type, humidity levels, height distribution, and water flow density were taken into account. This multi-dimensional approach enriched the assessment of the present status and extraordinary biodiversity of wild orchids species within the breathtaking confines of Phu Faek forest park.

The data utilized for this research focused on examining the physical factors that correlate with the growth of wild orchids. These key factors included the elevation, the moisture difference as indicated by the Normalized Difference Water Index (NDWI), basin density, forest type, elevation, and the slope direction (Aspect). Through meticulous data analysis and correlation studies, this research sought to unravel the intricate relationships between these physical variables and the flourishing growth of wild orchids species within the study area. By understanding these correlations, valuable insights were gained, contributing to a deeper comprehension of the ecological requirements and habitat preferences that influence the growth and distribution of wild orchid in their natural environment.

METHODOLOGY

The methodology proposed for conducting this study is outlined in Figure 2, with a detailed description of each stage provided below. This study utilized the following methods: (1) Conducted field surveys to gather information on the presence and locations of various wild orchid species within the study area. Recorded species names and corresponding geographical coordinates (X, Y) of observed wild orchid occurrences. (2) Utilized the collected data to analyze and visualize the spatial distribution of wild orchid species across the study area. Created a preliminary map or representation showcasing the general occurrence and abundance patterns of different orchid species. (3) Obtained satellite imagery, specifically Sentinel imagery, to derive spectral information. Calculated the Normalized Difference Water Index (NDWI) using Near-Infrared (NIR) and Short Wave Infrared (SWIR) bands of the imagery. NDWI values were used to infer the moisture content and water availability in the vegetation canopies, aiding in understanding the environmental conditions relevant to wild orchid growth. (4) Employed remote sensing data and GIS techniques to classify and map basin density, forest type, elevation, and the slope direction (Aspect) within the study area. (5) Conducted a spatial regression analysis to explore the relationships between orchid density and the variables derived from previous steps: NDWI, basin density, forest type, and aspect.

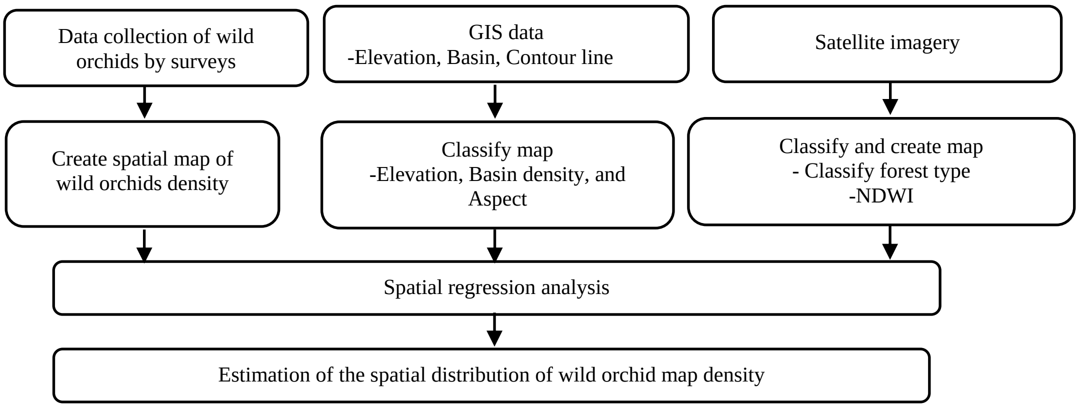


Figure 2. Methodology proposed (Source: authors)

Spatial distribution of wild orchids species

The spatial distribution map, also known as a density map or spatial pattern map, is a graphical representation that illustrates the arrangement and abundance of a specific geographic phenomenon or variable across a study area. It provides valuable insights into the spatial pattern, concentration, and dispersion of the phenomenon of interest. In the context of ecological studies or biodiversity research, a spatial distribution map visually depicts the occurrence, density, or abundance of species, habitats, or other natural features within a given geographic region. Spatial distribution maps are created using geographic information systems (GIS) and spatial interpolation techniques, which estimate values at unmeasured locations based on known data points. These techniques allow researchers to visualize how the phenomenon is distributed across the study area and identify potential hotspots or areas of high concentration.

Normalized Difference Water Index (NDWI)

The NDWI is a satellite-derived metric obtained from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. The SWIR reflectance captures changes in both vegetation water content and the spongy mesophyll structure within vegetation canopies. In contrast, the NIR reflectance is influenced by leaf internal structure and leaf dry matter content but remains unaffected by water content. The combination of NIR and SWIR in the NDWI effectively mitigates variations induced by leaf internal structure and dry matter content, resulting in improved accuracy when quantifying and retrieving vegetation water content. The NDWI assumes a paramount significance in elucidating the moisture status of vegetation, particularly for wild orchids species (Theobald et al., 2015). Its diverse applications span across ecological studies, agricultural practices, and environmental monitoring, with a pronounced focus on wild orchid growth and well-being (Marusig et al., 2020). By furnishing invaluable insights into vegetation water content, NDWI plays a pivotal role in evaluating the health and vigor of wild orchid populations. Additionally, it proves instrumental in identifying areas vulnerable to drought stress or excessive moisture, thereby aiding in targeted conservation and management efforts.

Spatial regression analysis

Spatial analysis is a fundamental technique used to predict or estimate values of a geographic variable at locations where the variable is known, in order to infer values at unknown locations. Spatial techniques play a pivotal role in modeling and decision-making processes, enabling the determination of unknown values both at local and global scales. Among these techniques, statistical regression models stand out as a powerful tool for estimating proposed values using variables from the parameters (Sangpradid et al., 2022). A general specification for a spatial regression model is given by equation (Moscone and Tosetti, 2014).

$$Y=\beta_0+ \beta_1 X_1+ \beta_2 X_2 +...+ \beta_k X_k$$

Where Y represents the estimated value of wild orchid density; β_0 is the intercept; β_k is the coefficient of independent variable; X_k is independent variable.

Spatial regression analysis was conducted to explore the relationships between wild orchids distribution and various key parameters, including elevation, NDWI, basin density, forest type, and aspect. The objective was to gain a comprehensive understanding of how these environmental factors influenced the occurrence and abundance of wild orchids populations within the study area (Ye et al., 2022; Martinis et al., 2018). In the analysis, spatial regression analysis was accounted for to capture the inherent spatial dependencies among the wild orchids data points (Aroonsri and Sangpradid, 2021).

Assessment of Spatial Regression Model

The predictive accuracy of the wild orchid density spatial regression model was evaluated using statistical comparison metrics, including Mean Absolute Error (MAE), and Root Mean Square Error (RMSE), which are presented as follows: (Sahragard et al., 2019).

$$RMSE = \sqrt{\frac{1}{n}\sum\nolimits_{i=1}^{n}(y_i - p_i)^2}$$

$$MAE = \frac{1}{n}\sum\nolimits_{i=1}^{n}|y_i - p_i|$$

Where $\mathbf{y_i}$ **is** the estimated value of wild orchid density of the i value; $\boldsymbol{p_i}$ is the observed wild orchid density value of the i value.

RESULTS AND DISCUSSION

Wild orchid results

The results of the data collection for wild orchid species, which encompass a total of 28 different orchid species, are summarized in the following Table 1. The table provides a comprehensive overview of the different wild orchid species observed during data collection, along with the corresponding number of recordings for each species. These recordings represent the instances of observing the particular orchid species within the study area. The total number of recordings across all species is 3,399. Table 1 illustrates the presence of a diverse spectrum of observations across distinct orchid species, indicating notable variability in recorded occurrences. Notably, certain species, such as *Aerides falcata Lindl. & Paxton* exhibit a significantly higher frequency (605 times), while others, including *Calanthe rosea (Lindl.) Benth.* and *Vandopsis lissochiloides (Gaudich.) Pfitzer* manifest fewer instances (1 or 2 times).

In Table 1, it is evident that orchid species such as *Aerides falcata Lindl. & Paxton, Aerides falcata Lindl.*, and *Cleisostoma fuerstenbergianum F. Kranzl.*, demonstrate relatively elevated recording numbers, indicative of their potential dominance or wide distribution within the study area. Table 1 further reveals that orchid species characterized by fewer recorded instances (e.g., *Calanthe rosea* with 1 recording) signify their infrequent presence within the study area. Notably, species such as *Vandopsis lissochiloides*, and *Bulbophyllum lasiochilum* were observed on only a limited number of occasions.

The results of the wild orchid survey in Phu Faek forest park were presented using a counting method to determine the number of orchids found at each survey point. Figure 3 illustrates the spatial

Table 1. The presence of wild orchid species in Phu Faek forest park

no	Orchid species	number of recordings
1	*Cymbidium aloifolium* (L.) Sw.	48
2	*Nervilia aragoana* Gaudich	97
3	*Nervilia aragoana* Gaudich	73
4	*Dendrobium bilobulatum* Seidenf	75
5	*Cleisostoma fuerstenbergianum* F.Kranzl.	139
6	*Aerides falcata* Lindl.	570
7	*Aerides falcata* Lindl. & Paxton	605
8	*Aerides multiflora* Roxb.	102
9	*Aerides houlettiana* Rchb. f	293
10	*Calanthe rosea* (Lindl.) Benth.	1
11	*Vanda lilacina* Teijsm. & Binn	197
12	*Rhynchostylis coelestsis* Rchb.f.	104
13	*Vandopsis lissochiloides* (Gaudich.) Pfitzer	2
14	*Cleisostoma arietinum* (Rchb.f.) Garay	270
15	*Dendrobium cariniferum* Rchb.f.	3
16	*Dendrobium pulchellum* Roxb. ex Lindl.	40
17	*Pholidota imbricata* Hook	3
18	*Dendrobium delacourii* Guillaumin	423
19	*Coelogyne trinervis* Lindl	22
20	*Pinalia bractescens* (Lindl.) Kuntze.	15
21	*Doritis pulcherrima* Lindl.	61
22	*Luisia thailandica* Seidenf.	34
23	*Habenaria rhodocheila* Hance	27
24	*Vanda denisoniana*.	13
25	*Vanda bensonii* Batem	76
26	*Bulbophyllum lasiochilum* C.S.P.Parish & Rchb.f.	3
27	*Bulbophyllum morphologorum* F.Kranzl.	96
28	*Bulbophyllum blepharistes* Rchb.f.	7
Total		3,399

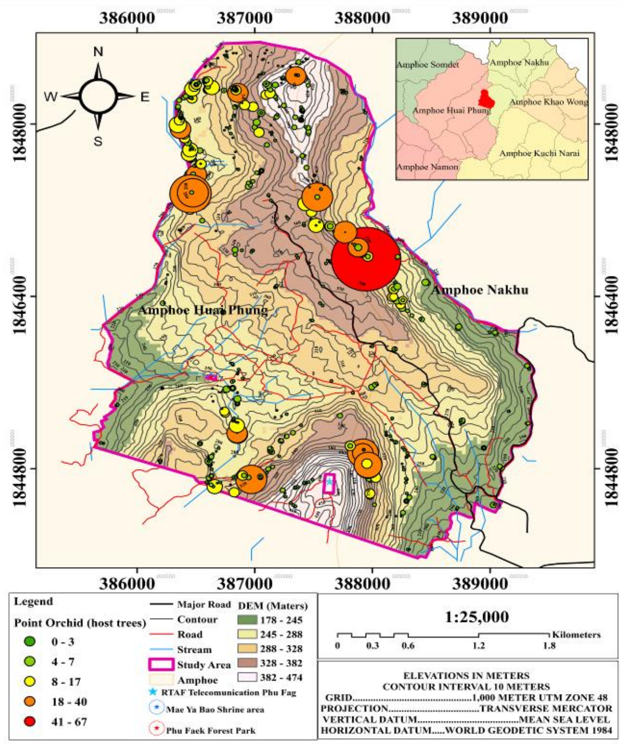


Figure 3. The distribution of wild orchids density map from data collection

distribution of wild orchids by displaying their positions on the map. The size of each circle in the figure represents the quantity of orchids observed at each location. By comparing the sizes of the circles among survey points, we were able to visualize the distribution and density of orchids in the park. In the figure, larger circles indicate higher orchid density, while smaller circles represent lower orchid density. The use of different colors for the circles could further highlight variations in orchid density across the area. This visualization of the orchid survey results in Figure 3 provides valuable insights into the distribution and density patterns of orchids within Phu Faek forest park.

Spatial map results

The map depicting the spatial distribution of wild orchid density has been generated with a spatial resolution of 10 by 10 meters, showcasing the relative occurrences of these orchid densities, as illustrated in Figure 4(a). The outcomes from the spatial orchid density map, illustrated in Figure 4(a), indicate that areas marked by the color red represent high plant density, predominantly concentrated in the central region of the study area.

Conversely, the southern area, represented by the dark green color on the map, exhibits the lowest orchid density. The variable maps for NDWI, forest type, basin density, elevation, and aspect have been generated using advanced GIS techniques. Each map depicts the distribution and attributes of its corresponding variable across the study area, while maintaining a uniform cell size of 10 by 10 meters. These maps are visualized in Figure 4(b), 5, and 6.

The distribution of wild orchid species in relation to NDWI, forest type, basin density, elevation, and aspect is depicted in Tables 2 through 6. Table 2 illustrates the dispersion of wild orchid species across distinct Normalized Difference Water Index (NDWI) values. Notably, both the "Moderate" and "High" NDWI ranges unveil a heightened presence of recorded orchid species, with 25 species each. This implies that locales characterized by moderate to high NDWI values, indicative of flourishing vegetation and ample water content, likely foster a conducive environment for a diverse array of orchids. In Table 3, the findings underscore the variable levels of orchid species diversity exhibited across different forest types within the study region. The Dry Deciduous Dipterocarp and Mixed Deciduous Forests emerge as hosts to a richer assortment of orchid species compared to the Stone Platform, suggesting a more favorable habitat for orchid proliferation.

Table 2. Wild orchid species distribution across NDWI

NDWI	number of species found
Very low	16
Low	6
Moderate	25
High	25
Very High	19

Table 3. Wild orchid species distribution across forest types

Forest Type	number of species found
Stone Platform	8
Dry deciduous dipterocarp forest	24
Mixed Deciduous Forest	25

Table 4. Wild orchid species distribution across basin density

Basin density	number of species found
Very low	22
Low	8
Moderate	18
High	22
Very High	20

Table 5. Wild orchid species distribution across elevation

Elevation	number of species found
175 - 237	7
237 - 287	18
287 - 328	18
328 - 378	25
378 - 474	18

Table 6. Wild orchid species distribution across aspect

Aspect	number of species found
East	23
North	20
South	21
West	21

Table 4 provides valuable insights into the correlation between basin density variations and the distribution of wild orchid species. Notably, higher Basin Density Categories, indicative of areas with intensified basin density, display a comparable number of orchid species (22 and 20 species, respectively). This observation suggests that the presence of more extensive basins or watersheds may indeed influence the distribution and diversity of orchid species.

The data presented in Table 5 reveals intriguing trends in orchid species diversity concerning different elevation ranges. Elevation within the range of 175 to 237 meters demonstrates a lesser variety of orchid species, with 7 distinct species documented. On the contrary, elevations surpassing 237 meters reveal an elevated count of orchid species, with 25 and 18 species recorded, respectively. This implies that higher elevations potentially provide more conducive conditions for a diverse range of orchids to flourish. Lastly, Table 6 delves into the spatial distribution of wild orchid species in relation to varying cardinal directions within the study area. The "North," "South," and "West" aspects present a similar number of recorded orchid species, each featuring 20 or 21 species. Remarkably, the "East" aspect emerges as a hotspot of orchid diversity, boasting the highest count of recorded species at 23. This observation intimates that areas facing eastward may offer a hospitable environment conducive to the thriving presence of diverse orchid species.

Spatial regression analysis result

The spatial regression model results, as depicted in Figure 7, offer valuable insights into the distribution patterns of wild orchid species within Phu Faek forest park. The model, which incorporates factors such as NDWI, forest type, elevation, basin density, and aspect, contributes to a comprehensive understanding of the factors influencing orchid density across the landscape. Figure 7 illustrates the spatial distribution of predicted wild orchid density values across the study area. The color gradient represents varying levels of orchid density, with warmer colors indicating higher predicted density and cooler colors indicating lower predicted density. The model's predictions highlight distinct spatial patterns, showcasing areas of both higher and lower orchid density. Areas with elevated orchid density are prominently visible in the central and north region of the study area, depicted by the red color tones. This central and north zone exhibits a concentration of high predicted orchid density, suggesting favorable ecological conditions for the proliferation of these species. Conversely, the southern area reveals lower predicted orchid density, represented by green color tones, indicating relatively fewer occurrences of orchid species.

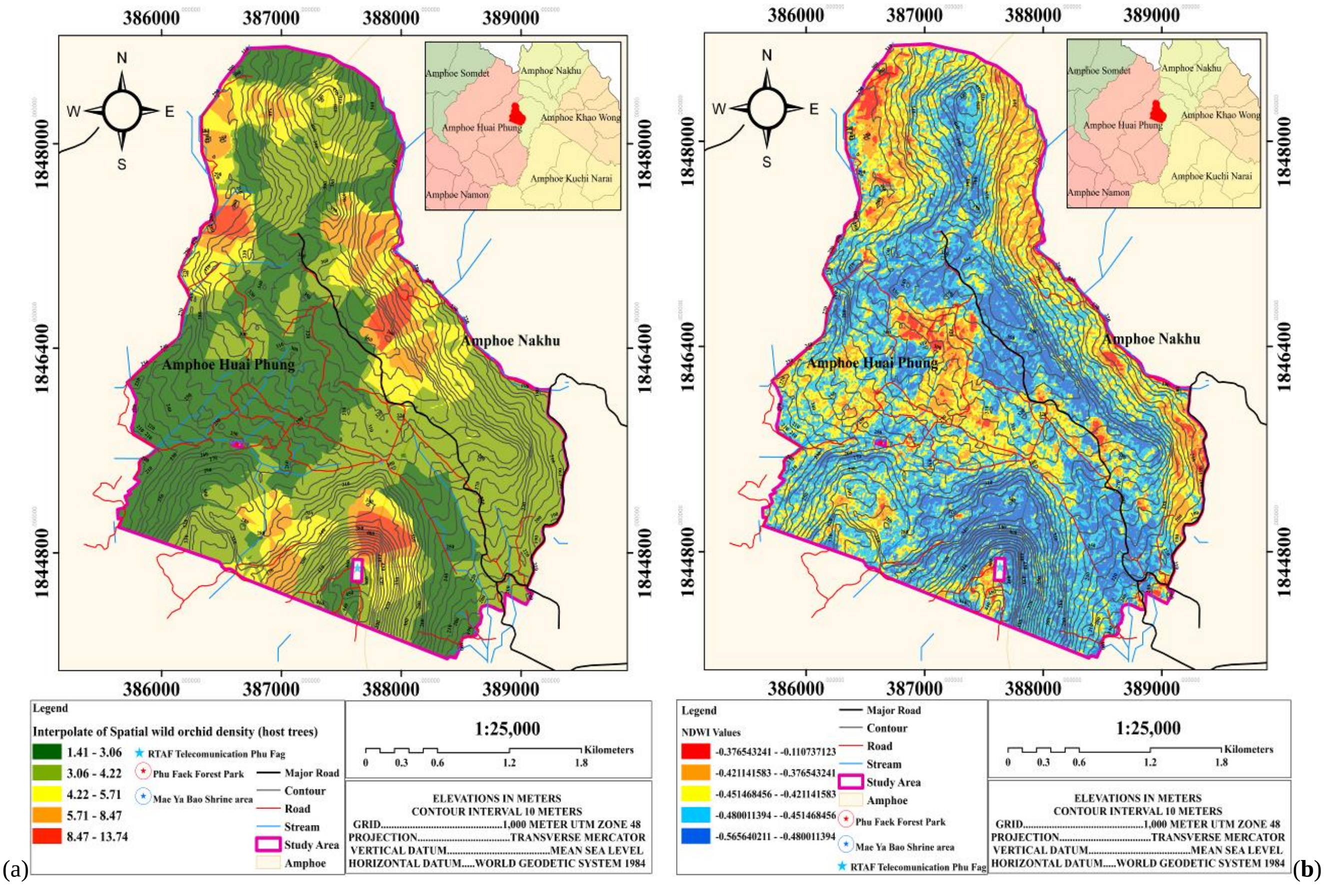


Figure 4. (a) Spatial distribution of wild orchid density map and (b) NDWI map (Source: authors).

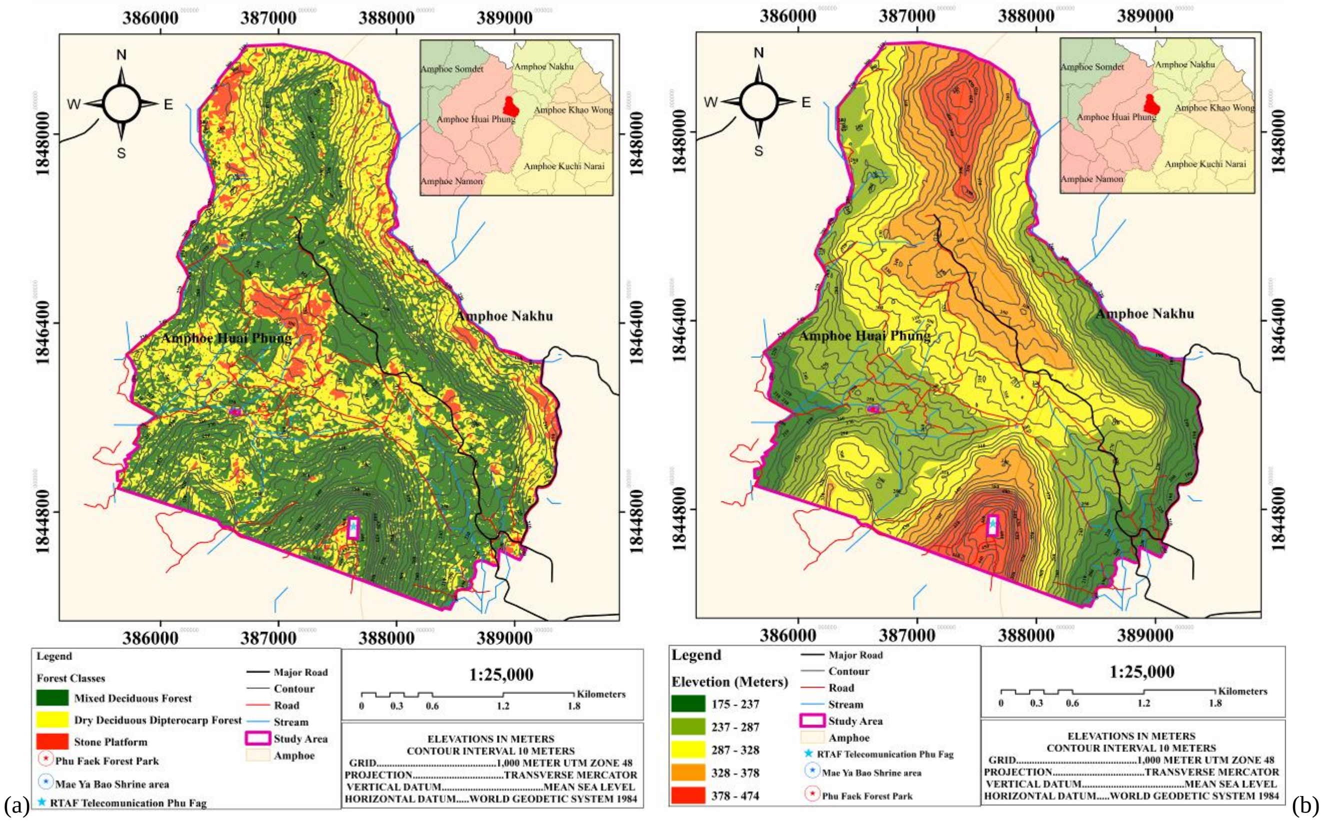
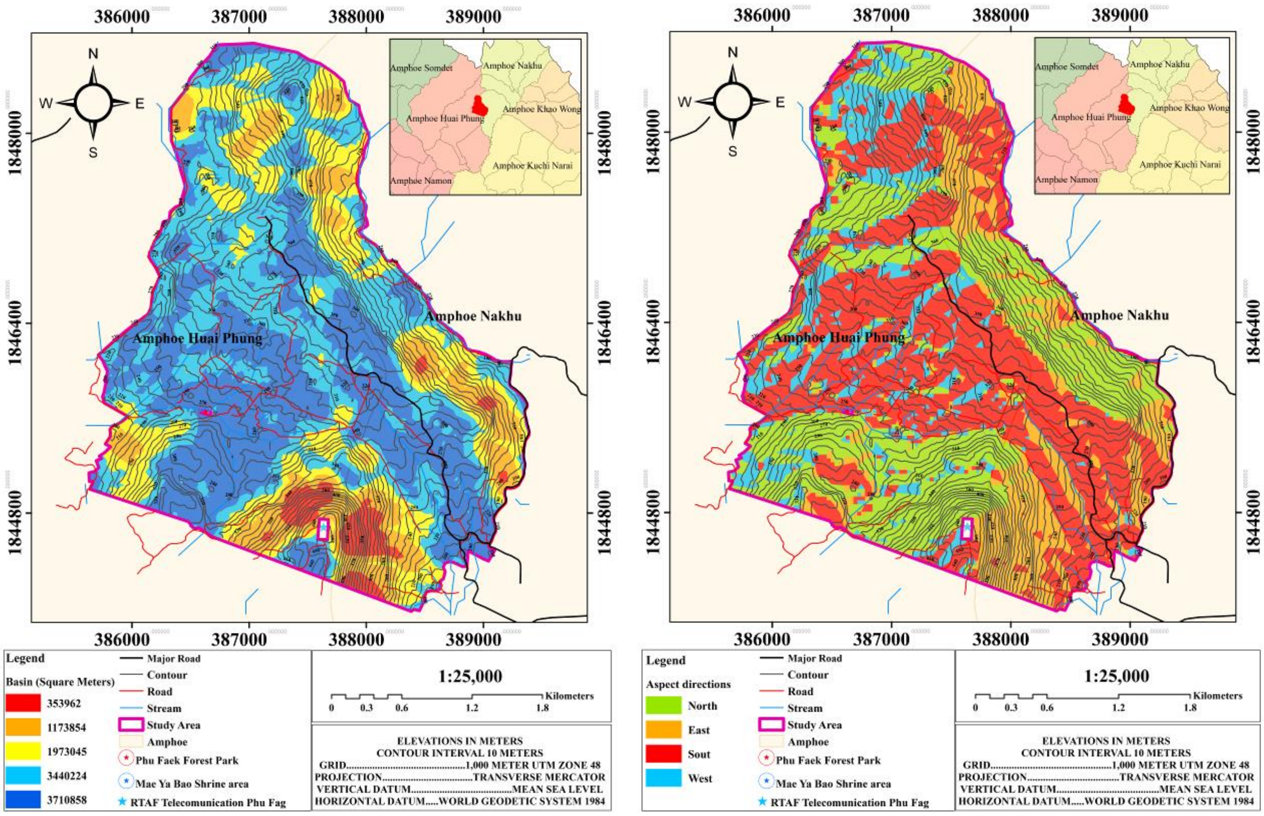


Figure 5. The variable map (a) Forest type and (b) Elevation (Source: authors)



a) b)

Figure 6. The variable map (a) Basin density, and (b) Aspect (Source: authors)

Table 7 presents the coefficients obtained from the spatial regression model, along with their corresponding standard errors and p-values. The coefficients represent the estimated effects of the predictor variables on the wild orchid density in the study area. The intercept coefficient is 5.217, with a standard error of 2.700. The *p*-value associated with the intercept is 0.054. The intercept represents the estimated wild orchid density when all other predictor variables in the model are zero.

Table 7. The coefficients result of spatial regression model

	Coefficients	Standard Error	P-value
Intercept	5.217	2.700	0.054
NDWI	14.550	21.925	0.507
Forest type	8.122	17.257	0.638
Elevation	0.002	0.003	0.476
Basin	0.000	0.000	0.085
Aspect	-0.002	0.002	0.378

The *p*-value indicates that the intercept's effect on wild orchid density is borderline statistically significant. The p-value for NDWI, forest type, elevation and aspect were 0.507, 0.638, 0.476 and 0.378, respectively. The p-value suggests that the effect of these variable on orchid density is not statistically significant. The *p*-value associated with basin density is 0.085. This coefficient suggests the expected change in wild orchid density for a one-unit change in basin density. The *p*-value indicates that the effect of basin density on orchid density is borderline statistically significant.

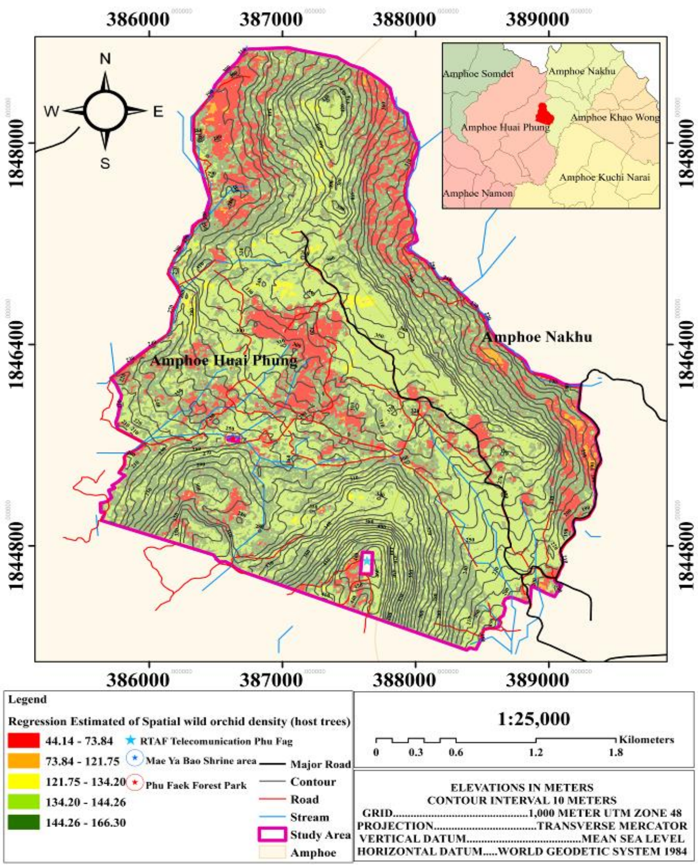


Figure 7. The spatial distribution of estimated wild orchid density resulting from the spatial regression model (Source: authors)

Table 8 provides a comprehensive overview of the comparative error statistics associated with the wild orchid density spatial regression model. These statistics play a critical role in evaluating the precision and appropriateness of the model's forecasts. The RMSE value, shown as 4.686, plays a pivotal role in assessing the spatial regression model's effectiveness.

RMSE is the square root of the mean of the squared disparities between predicted and observed values. Conversely, the MAE value, indicated as 2.502, provides an additional insightful measure of the spatial regression model's precision. Both RMSE and MAE values serve as indicators of predictive performance, reflecting the model's ability to closely approximate actual observed orchid density values. Importantly, these values are within an acceptable range, indicating satisfactory model performance for meaningful interpretation.

Table 8. Comparative error statistics of the wild orchid density spatial regression model

Model	statistics	
	RMSE	MAE
Spatial regression model	4.686	2.502

CONCLUSION

In conclusion, this study employed a comprehensive approach that integrated remote sensing data, GIS techniques, and spatial regression analysis to investigate the spatial distribution and factors influencing the density of wild orchid species within Phu Faek forest park. A total of 28 different orchid species were recorded during the field surveys, highlighting the area's significance as a habitat for these enchanting plants. The variability in observations of wild orchid species, as evidenced by the frequency of recordings, portrays a mosaic of distribution patterns across the study area. Dominant species such as *Aerides falcata Lindl. & Paxton*, *Aerides falcata Lindl.*, and *Cleisostoma fuerstenbergianum F.Kranzl.*, emerge with higher recording numbers, suggesting their potential dominance or wide distribution within Phu Faek forest park. Conversely, rarer and unique species, represented by lower numbers of recordings, provide crucial information about their rarity and conservation significance. Orchid species like *Calanthe rosea (Lindl.) Benth*., *Vandopsis lissochiloides (Gaudich.) Pfitzer*, and *Bulbophyllum lasiochilum C.S.P.Parish & Rchb.f.*, were observed only a few times, underscoring the importance of preserving these delicate and less common flora.

The data collection efforts yielded a diverse set of orchid species, with varying levels of occurrence across different forest types, elevations, aspects, and basin densities. This diversity underscores the importance of maintaining heterogeneous habitats to support the coexistence of numerous orchid species within the park. The analysis of NDWI, a key indicator of vegetation health and moisture content, provided further context for orchid distribution, highlighting the significance of suitable water availability for their growth. The spatial regression model proved to be a robust tool in elucidating the relationships between orchid density and environmental variables. The model's coefficients shed light on the specific influence of each factor, such as NDWI, forest type, elevation, basin density, and aspect, on orchid density.

The evaluation of the model's performance through error statistics demonstrated its ability to predict orchid density with reasonable accuracy. This study's results collectively emphasize the intricate interplay between environmental factors and the distribution of wild orchid species. The spatial distribution maps, along with the regression analysis, contribute to a more comprehensive understanding of the ecological dynamics within Phu Faek forest park.

These findings can serve as a foundation for informed conservation efforts, land management strategies, and future research endeavors aimed at preserving the rich biodiversity and unique ecosystems within the park. In essence, this study underscores the importance of employing advanced spatial analysis techniques to unravel the complex relationships between species distribution and environmental variables. By merging scientific knowledge with cutting-edge technology, we can enhance our ability to conserve and protect fragile ecosystems, such as those harboring the diverse and captivating world of wild orchids**.**

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