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Spatial Dynamics and Drivers of Urban Growth in Thua Thien Hue Province, Vietnam: Insights for Urban Sustainability in the Global South

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Abstract: Investigating the historical patterns of urban growth and their drivers is crucial to informing sustainable urban planning policies, especially in cities of the Global South. In Vietnam, most studies focus primarily on city extents, offering little insight into urban growth across various provinces. This study, therefore, combined categorical land use and land cover change detection, Random Forest classification and expert interviews to quantify the urban growth between 2000 and 2020, assess urban encroachment upon other land uses, and identify key drivers shaping this growth in Thua Thien Hue province. Findings show that the urban land areas were 27.94 km^2, 82.97 km^2, and 209.80 km^2 in 2000, 2010, and 2020, respectively. Urban encroachment upon other land use types, especially cropland, barren land, rice paddies, shrubs, and forests, was observed in these periods. Additionally, accessibility to built-up areas, DEM, proximity to rice paddies, slope, proximity to street roads, accessibility to social areas, and proximity to cropland are the major spatial drivers of urban growth in the province. The study concludes that rapid urban expansion is evident in the province at the expense of other land use types, especially agricultural land use types, which may impact food security and livelihoods in the province.

Keywords: urbanization; urban encroachment; land use land cover; geospatial analysis; Thua Thien Hue province

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1. Introduction

Urbanization is a defining feature of the modern era, with over half of the world's population now living in urban areas [1]. In general, urbanization is a principal indicator of the economic and social development of a country and a major driver of global economic advancement and sustainable development [2]. However, the impact of urbanization differs across different regions [3]. For instance, the urbanization experienced in many Global South countries contrasts with what has been observed in the Global North [4], as urbanization in the former is characterized by several problems. These

problems include rapid urban growth with limited or no economic development, high slum proliferation, increasing crime, increasing diseases and other health issues, transportation problems, pollution, increasing urban inequalities, and urban sprawls [5,6]. Presently, planning systems and public institutions have not been able to deal with these problems [7]. This is of great concern as the larger share of future population growth is expected to be in the developing country regions of Sub-Saharan Africa and Southeast Asia [1], and if major steps are not taken toward improving present urban policies, the aforementioned urban challenges may persist or even increase.

An important step in improving existing urban planning policies and practices is investigating historical pattern of urban expansion and its encroachment upon other land uses [8,9]. This is because urban growth can have different consequences on various aspects of society, economy, and environment. For instance, urban encroachment upon agricultural land can have significant implications for food security and agricultural productivity, while encroachment upon natural habitats can lead to habitat fragmentation and loss of biodiversity [10,11]. It can also lead to loss of green spaces, deforestation, and changes in hydrological processes [12,13]. Furthermore, investigating the historical pattern of urban expansion offers insights into the evolution of urban areas and identifies trends and drivers of urban growth, facilitating improved predictions of future urban development and its impacts on surrounding land uses [14,15]. It can also aid in assessing the efficacy of land-use policies, urban planning strategies, and development interventions in addressing urban encroachment upon various land use classes. Analyzing historical trends and outcomes enables policymakers to make informed decisions that enhance land use planning, foster sustainable development, and reduce the adverse effects of urbanization on both the environment and society [16,17]. The aforementioned advantages underscore the significance of examining historical patterns of urban development. However, research in countries such as Vietnam remains limited [18], and existing studies primarily concentrate on city extent [18,19]. While the geographical extent of cities is significant in urban research, many cities have grown beyond their original boundaries, which thus impacts the neighboring land areas, such as uncontrolled development of urban sprawls, increasing land prices, loss of biodiversity, and carbon pools [9,18,20]. Consequently, studies extending beyond urban boundaries are essential for informing sustainable future urban development policies.

In the same vein, investigating the drivers of urban growth is important for various social, economic, environmental, and policy reasons. A key motivation for examining these drivers is that it provides insight into the underlying factors shaping the urban growth pattern, which can facilitate the prediction of future urban trends and the management of urban sprawl, thereby contributing to sustainable urban development [21]. Similarly, understanding the drivers of urban growth also helps to address the social and economic disparities associated with urbanization through the identification of inequalities in access to urban services, housing, and employment opportunities, thereby informing inclusive urban policies that foster social equity and economic prosperity [22]. Furthermore, analyzing the roles of governance, institutions, and policy frameworks in shaping urban growth reveals opportunities for improving urban governance and policy effectiveness, thereby promoting sustainable urbanization [23,24]. To summarize, studying the drivers of urban development provides critical insights into the complex dynamics of urban growth, its environmental and societal impacts, and supports the formulation of evidence-based policies for sustainable and inclusive urban development.

Earlier studies on drivers of urban growth were loosely based on biophysical/environmental [17,25,26], infrastructural [27,28], socioeconomic [17,29–31], and political [32,33] factors. For example, in the Global North, Guo and Zhang [34] analyzed six drivers of urban growth using spatial cluster analysis and mixed-effect

regression analysis in the Texas Triangle, United States, between 2001 and 2016. It was found that urban expansion is highly influenced by three drivers, which are population, GDP, and highway density. For European cities, Guastella et al. [35] analyzed urban growth between 1990 and 2014 using geospatial data and configural frequency analysis. They observed that urban expansion is caused by five identifiable drivers, comprising shrinking populations, economic shifts, poor land-use policies, fragmented urban areas, and historical development patterns. Similarly, in the Global South, Salem et al. [36] examined eight drivers of urban expansion in the Greater Cairo Region (GCR) in Egypt between 2007 and 2017 using the logistic regression model (LRM). They identified population density and proximity to roads as key drivers in the expansion of the GCR. On the other hand, Gilbert and Shi [37] employed geospatial techniques and Pearson's correlation to analyze 10 drivers of urban spatial evolution in Lagos, Nigeria, between 2000 and 2020. They found population growth, GDP, and sectoral outputs as major drivers in Lagos, with strong positive correlations between population growth and natural habitat decline. In Asia, Li et al. [38] examined 12 drivers of urban expansion and their effects across different regions in China between 1990 and 2010 using a spatial Probit model. They highlighted population, GDP, proximity to water bodies, and developed urban areas as significant drivers in China. Similarly, Siddiqui et al. [39] examined eight drivers of urban growth dynamics in Uttar Pradesh, India, between 1993 and 2013, but used a hybrid model of cellular automata, Markov chain, and logistic regression. They emphasized the importance of proximity to urban centers and major roads in driving growth in Uttar Pradesh, India. Despite the difference in geographical settings and research methods, these studies consistently pointed to the influence of population dynamics, economic development, and infrastructure accessibility. In addition to considering most of the drivers within a spatial context, this study differs by using an integrated remote sensing and qualitative approach to examine 16 drivers of urban growth while also considering a locally specific socioeconomic driver in Vietnam, which has rarely been addressed in other studies.

Within the context of socioeconomic drivers, Carlino and Saiz [40] showed in their study of urban growth in America how urban areas with attractive places for leisure activities tend to grow faster than others. Dolui and Sarkar [41] also posited that commercial areas influence urban growth through business activities. For example, the establishment of coffee shops can lead to increasing housing prices in a neighborhood [42], which can then impact urban development and growth over time [43]. This is because these coffee shops operate as both recreation and commercial outlets. For instance, a qualitative study [44] that evaluated the functions of coffee shops in five English cities revealed that they proliferated because they usually promote community growth, relationships, and enrichment in urban environments. In another study of the impact of the built environment on urban vitality in Chengdu, China, Xu et al. [45] utilized geospatial techniques and statistics. They established that economic vibrancy and urban regeneration are found to be more strongly correlated with the coffee shop index. Hence, the locations and spatial distribution of coffee shops might serve as a critical driver of urban growth and development. In Vietnam, coffeeshop spaces were studied by Duy et al. [46] in Vinh Long City using questionnaire surveys. They found that the majority of locals, regardless of their financial status, view having access to coffee shops as a daily necessity for social interaction and pleasure. This suggests high patronage leading to an increasing area of public spaces that could drive urban expansion. More studies [47,48] have also pointed to the thriving culture of coffee shops in Vietnam, therefore making it imperative to be considered. Generally, in urban growth research, coffee shops are not usually included as a possible sub-driver with other identified socioeconomic drivers of urban growth in many studies. Since commercial and leisure areas like coffee shops are

forms of social capital [49,50], they can impact urban growth and, therefore, should be investigated alongside other drivers of urban development. This study aims to do so, as there are few studies combining all drivers in a single analysis.

While urbanization and its challenges have been widely debated on a global scale, they have also been examined within local contexts. Considering urbanization in Vietnam, significant changes have been documented, especially after the country's shift to a market economy in the 1980s [51]. This transition has resulted in rapid urban expansion in different cities in Vietnam, mirroring the urban growth patterns observed in other Southeast Asian cities [51]. Also, since the 2000s, significant socioeconomic changes due to agricultural land acquisition for urbanization and industrialization have been observed in the country [52]. Additionally, urbanization trends in Vietnam have been linked to the fragmentation of urban spaces, leading to issues such as housing price bubbles and urban fragmentation [53,54]. While urbanization in Vietnam has resulted in noticeable economic development, it has also presented numerous problems for the government to effectively manage the associated challenges related to urban growth [55]. These challenges are also exacerbated by the severe impacts of climate change, such as increasing precipitation and temperature leading to increasing flooding and heat stroke, respectively, especially in Central Vietnam [56].

This study focuses on the province of Thua Thien Hue (TTH), which, like many provinces in Vietnam, has experienced significant urban growth, driven by population growth, economic development, and rural urbanization [57,58]. Conversely, socioeconomic disparities are observed within the province, which is intensified by the province's vulnerability to flooding [56,59]. According to the new master plan of the province, by 2030 the whole province will become a centrally run heritage urban area and one of the largest major centers in Southeast Asia for culture, tourism, and specialized medical care, serving as a high-quality educational center and strong marine economic center with guaranteed national defense and security [60]. One of the implications of the proposed master plan will be urban growth in the province and the possibility of urban encroachment upon other land use and land cover classes. It is, therefore, important to identify these classes, as well as probable locations of new urban development, to support urban planning policies in the province. Furthermore, driving factors of urban expansion tend to vary across regions and urban scales [61], suggesting that analyses at different spatial scales are necessary. This study, therefore, quantifies the historical pattern of urban growth between 2000 and 2020 and assesses the current urban encroachment upon other land uses and the spatial drivers of urban growth in the TTH province.

2. Methodology

2.1. Study Area

The study was carried out in TTH province, located in Central Vietnam (Figure 1). The province has a natural land area of 4947.11 km^2 and lies between the geographical coordinates from 16° to 16.8° North latitude and from 107° to 108.2° East longitude. It shares a boundary in the east with the South China Sea and in the west with Laos and Cambodia. The province is divided into nine districts, of which Hue city is the province-controlled city. The province has a population of 1,160,224 with 612827 people living in urban areas and 547397 people living in rural areas [62]. Like other provinces in Vietnam, Thua Thien Hue is vulnerable to disasters and is considered among the most disaster-prone areas of Vietnam [63].

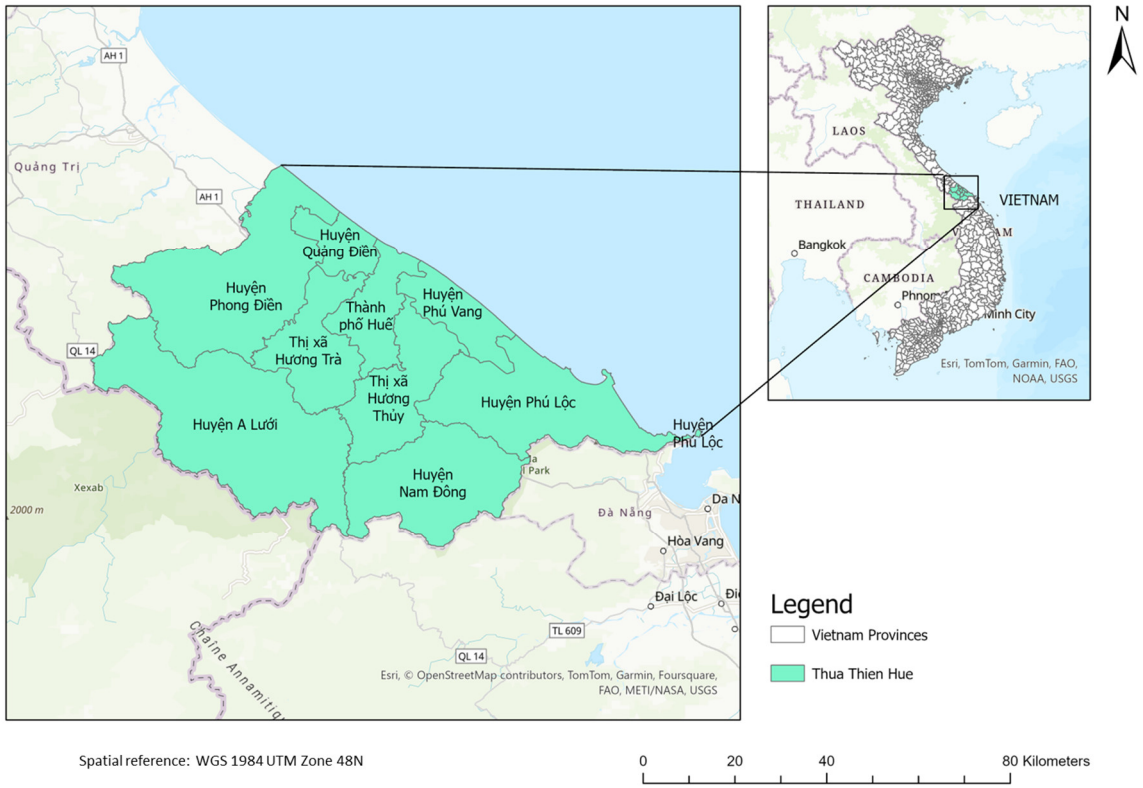


Figure 1. The study area: Thua Thien Hue province.

2.2. Data Collection

The study combined geospatial datasets with interviews to investigate historical trends in urban growth and assess urban encroachment upon other land uses and land cover classes, as well as the drivers of urban development in the study area. In this study, urban is defined as "urban land cover and land use, impervious surfaces, and other manifestations of the built environment" [64]. Land use maps (Figure 2) for the three-time steps were downloaded from the Japan Aerospace Exploration Agency-Level-1 (2000, 2010, and 2020) [65]. The level 1 data sources were selected because of their high overall accuracy (91.6%) and kappa (90.7%) [66]. The closer the years, the better the accuracy; therefore, 2000 was chosen as the initial year [18]. A TanDEM-X-based digital elevation model [67], acquired directly from the German Aerospace Center (DLR) on January 18, 2020, was utilized in this study. Also, other spatial datasets, such as road networks, places of worship, social areas, industrial areas, mining areas, and rail lines, were obtained from OpenStreetMap (OSM) and government agencies (Department of Transport and Department of Natural Resources and Environment) in TTH.

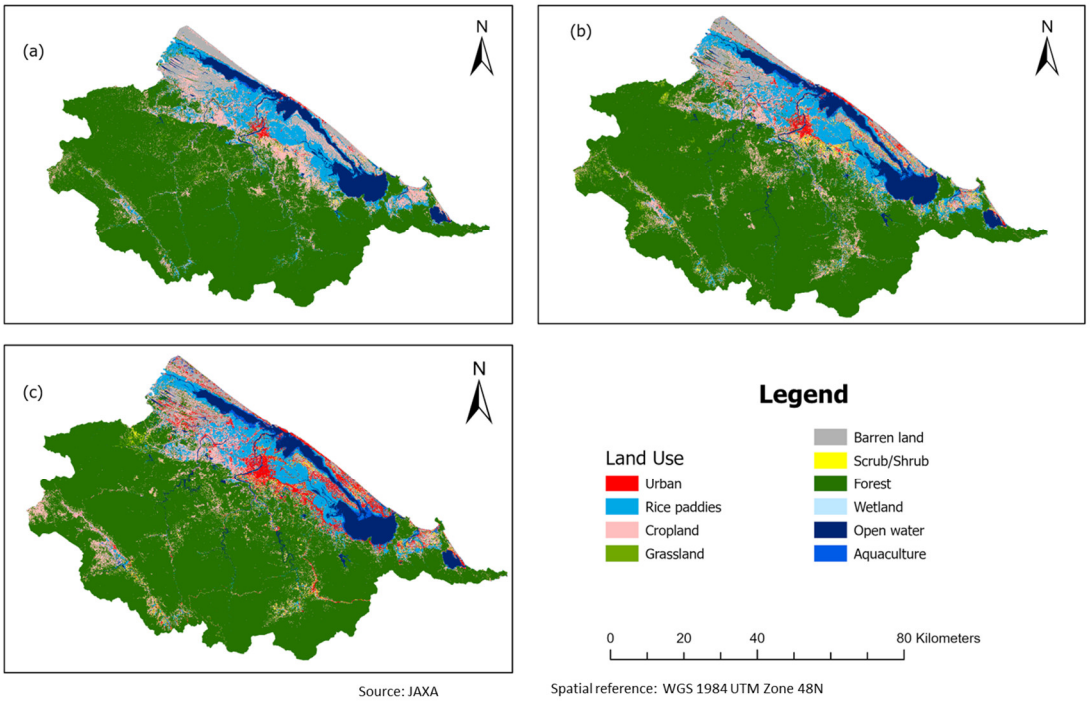


Figure 2. Land use and land cover maps (a=2000, b=2010, and c=2020).

Additionally, key informant interviews (KIIs) were conducted with four experts in TTH at two different times. The purpose of the first round of interviews was to solicit information about the general drivers of urban growth in TTH province, while the second round of interviews was to validate the results of the Random Forest model. Additionally, during the second round of interviews, experts were presented with the results of the change detection to solicit information on the reasons for some of the observed urban encroachment in the study areas. The key informants were selected from academia and government parastatals involved in urban development in the province. A mixed selection of interviewees was chosen to obtain mixed overviews from different perspectives.

2.3. Data Analysis

2.3.1. Change Detection of Urban Growth from 2000 to 2020

The detection of change in urban growth between 2000 and 2020 in the study area was based on the categorical change detection in ArGISPro. This method computes the change between two thematic raster maps and quantifies the pixels that change or are unchanged between two different time periods [68]. The urban area for the three time steps was quantified, as well as the areas of other land uses that the urban area encroached upon during the two time intervals (i.e., 2000–2010 and 2010–2020) in the study area.

2.3.2. Potential Driving Factors of Urban Growth in Thua Thien Hue Province

Potential drivers of urban growth in the province were selected based on previous studies and interviews with experts in the province. The potential drivers were reclassified into site-specific (slope and DEM) and distance-related drivers (distance to industrial areas, urban areas, commercial areas, social areas, proximity to water bodies, rail lines, streets roads and national roads) (Table 1).

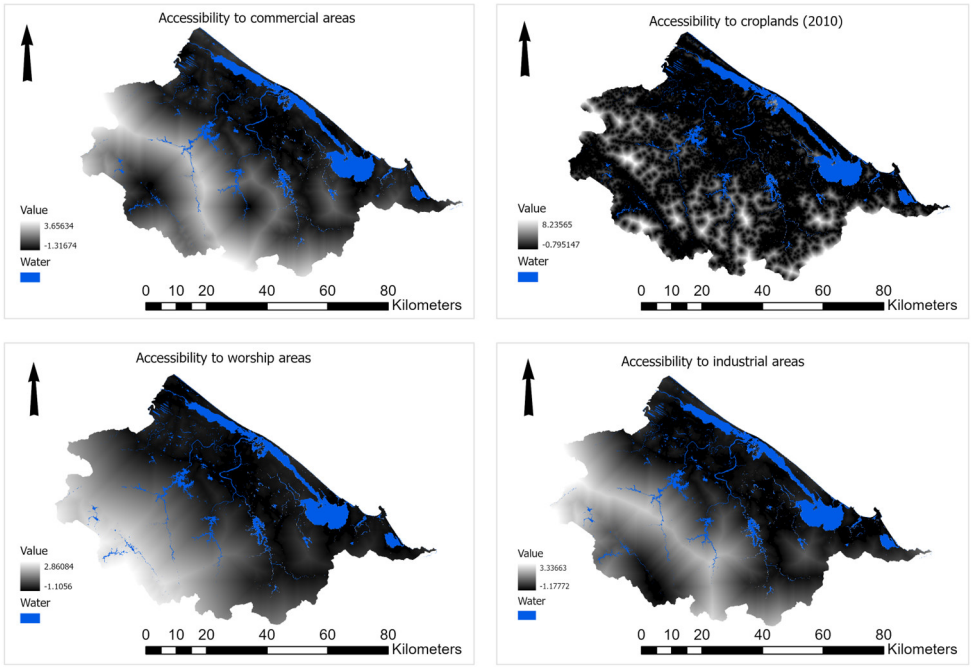
Table 1. Potential drivers of urban growth in TTH province.

Driver Type	Variable Description	Data Type	Justification	Data Source
Target Variable	Urban (1) and non-urban (0)	Binary		
Site-Specific Characteristics	Slope	Continuous	TTH province includes mountains, hills, and plains, which has impacted urban development in the province (Interviews, 2024)	Developed from TanDEM-X
	DEM	Continuous		TanDEM-X
Distance-Related Characteristics	Euclidean distance to streets roads	Continuous	Urban expansion along transportation lines drives pattern of urban development [69]	OSM
	Euclidean distance to national roads	Continuous		
	Euclidean distance to rail lines	Continuous		
	Cost-weighted distance to rice paddies	Continuous	Most croplands are located near urban areas, leading to potential competition between agriculture and urban land use [70]	LULC, JAXA, 2010
	Cost-weighted distance to croplands	Continuous		LULC, JAXA, 2010
	Euclidean distance to water bodies	Continuous	Adoption of water-related activities like fishing and aquaculture can improve livelihoods [71], thus increasing the potential for urban growth closer to water bodies	OSM, Government agencies in TTH
	Cost-weighted distance to mining area	Continuous	Closeness to employment areas drives urban growth [72]; therefore, areas close to mining, commercial, and industrial areas are potential areas for urban development	
	Cost-weighted distance to commercial areas	Continuous		
	Cost-weighted distance to industrial areas	Continuous		
	Cost-weighted distance to worship areas	Continuous	Worship areas can impact changes to the landscape [73]	
	Cost-weighted distance to social areas: tourism areas, restaurants, coffee shops	Continuous	Urban areas with attractive places for leisure, coffee shops, and restaurants tend to grow faster [40,43]	
	Cost-weighted distance to current urban areas, 2013	Continuous	The current urban area is more attractive for new urban development in the province (Interview, 2024)	LULC, JAXA, 2010

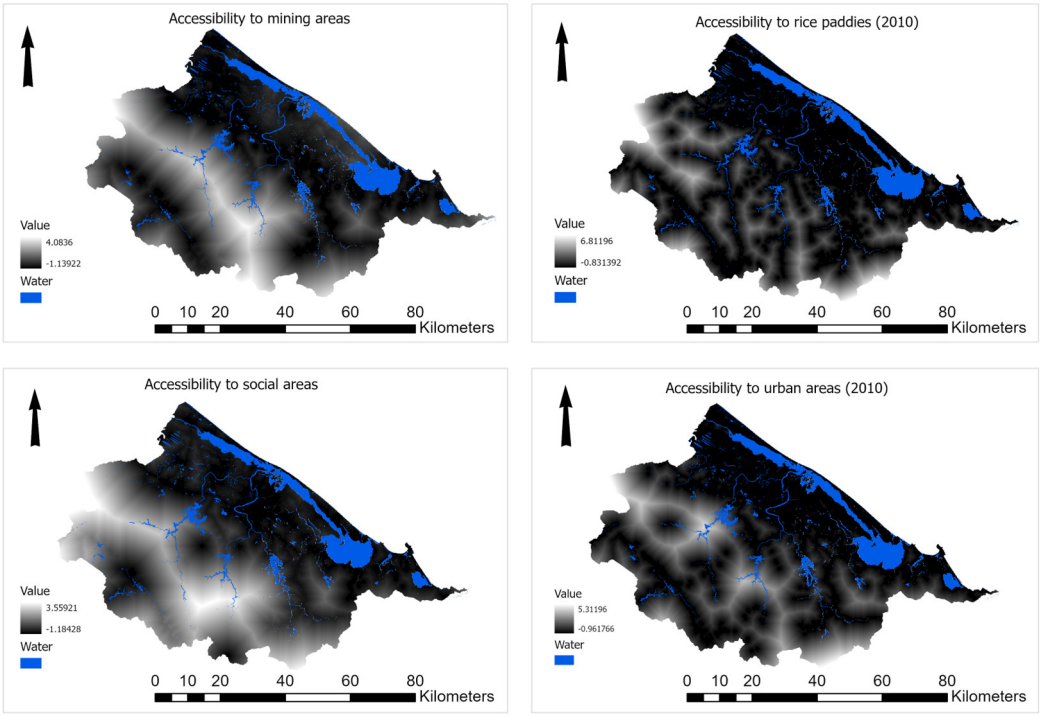
2.3.3. Developing Raster Maps of Potential Drivers of Urban Growth

While the DEM and slopes were already in the raster format (30 m resolution), the other datasets were still in the vector format (obtained from OpenStreetMap and TTH government agencies). Because of the spatial context of this study, we reasoned through the first law of geography posited by Tobler [74], which states that everything is related to everything else, but near things are more related than distant things. This law is highly relevant to studying spatial drivers of urban growth because it provides a foundation for understanding how distance relationships and interactions influence patterns of growth and development in urban areas. Therefore, different distance calculation methods in ArcGIS Pro 3.2 were used to convert the other drivers in vector formats into raster formats (30 m resolution). This distance can be in terms of proximity or accessibility. In this study, proximity is considered to be a physical distance between origin and destination, while

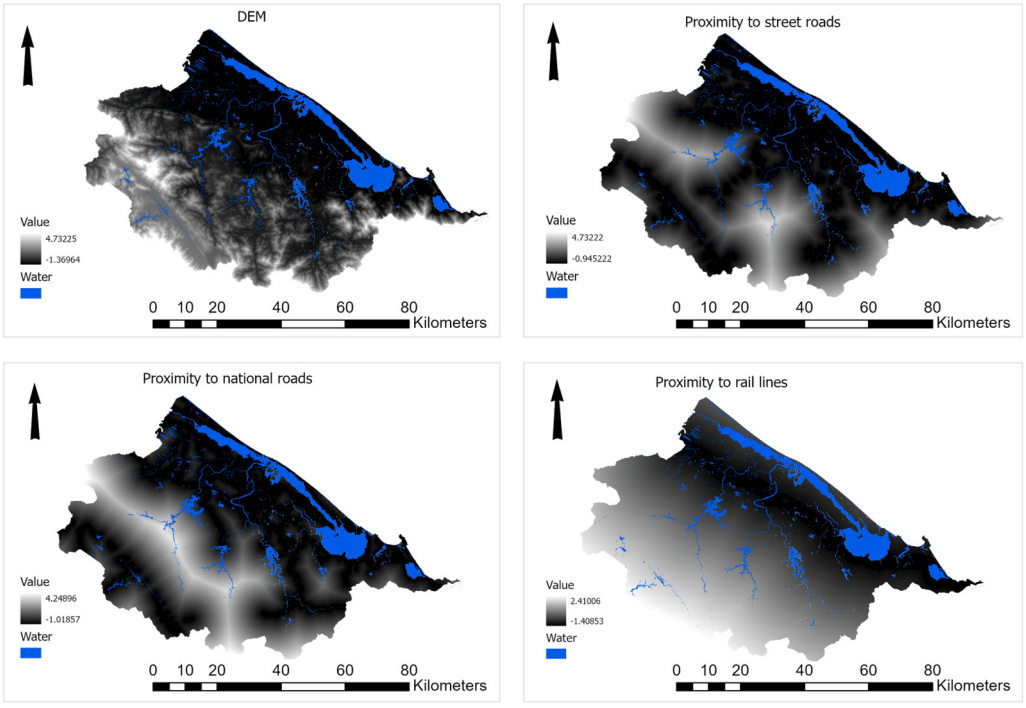
accessibility is not just about the physical distance but also the cost it will take to reach a destination [75]. The cost can be defined in terms of money, time, and preference [75,76]. In this study, cost is defined as the time it will take to reach a destination, for which the different road types are used as proxies (see [76] , for a further discussion). The Euclidean distance function is used to calculate the proximity to roads (access and express), water bodies, and rail lines, while the cost-weighted distance was used to define accessibility to social areas (such as coffee shops and restaurants), mining areas, commercial areas, industrial areas, existing built-up areas, rice paddies, cropland, and places of worship. We used a Python script for the batch processing of all raster maps to standardize them using the standard score (z-score). This transformation ensures that the data are on the same scale by establishing a mean of zero and a standard deviation of one. We ensured that all raster maps had the same grid format (30 m × 30 m), spatial extent, projection, and coordinate system. All processes were computed in ArcGIS Pro 3.2 (Figure 3a–d).



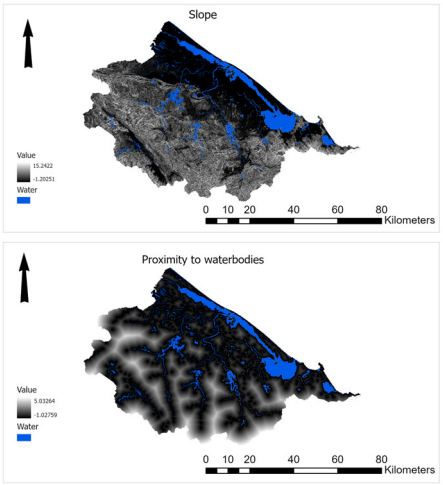
(**a**)


Accessibility to mining areas
Value
4.0836
-1.13922
Water
0 10 20 40 60 80
Kilometers
Accessibility to rice paddies (2010)
Value
6.81196
-0.831392
Water
0 10 20 40 60 80
Kilometers
Accessibility to social areas
Value
3.55921
-1.18428
Water
0 10 20 40 60 80
Kilometers
Accessibility to urban areas (2010)
Value
5.31196
-0.961766
Water
0 10 20 40 60 80
Kilometers

(**b**)


DEM
Value
4.73225
-1.36964
Water
0 10 20 40 60 80
Kilometers
Proximity to street roads
Value
4.73222
-0.945222
Water
0 10 20 40 60 80
Kilometers
Proximity to national roads
Value
4.24896
-1.01857
Water
0 10 20 40 60 80
Kilometers
Proximity to rail lines
Value
2.41006
-1.40853
Water
0 10 20 40 60 80
Kilometers

(**c**)



(**d**)

Figure 3. (**a**–**d**) Standardized potential drivers of urban growth in TTH province.

2.3.4. Random Forest Model

We applied a Random Forest model [77] to identify and analyze the relationship among the drivers of urban growth, as well as to build a probability map of urban growth in 2020, in TTH province. "Random Forest models are an ensemble method of decision trees" [78]. Random Forest models function by training multiple decision trees on randomly selected subsets of a dataset and subsequently averaging the outcomes of these decision trees to produce a final prediction [78]. This approach enables the Random Forest model to achieve high predictive accuracy while avoiding overfitting the data [78,79]. Additionally, Random Forests can manage multicollinearity, handle variables of varying scales, and accommodate high-dimensional datasets [78,79]. Another notable advantage of Random Forests is their ability to assess the importance of variables, providing a score that indicates the significance of each feature (in this context, drivers) to the model's overall performance [78]. While these advantages make it suitable for this study, it is important to acknowledge that the results of a Random Forest model can be challenging to interpret [77]. Nonetheless, in this study, the variable importance scores derived from the model offer insights into the drivers of urban growth in TTH province.

The target variable was binary (new urban: 1; persistent–non-urban: 0), which was derived from the change detection between 2010 and 2020 in the study area. The new urban class was derived from non-urban areas that changed to urban in 2020, while persistent–non-urban classes were non-urban areas that persisted from 2010 to 2020. In the same vein, the predictor variables were the aforementioned driver raster maps. Further, 7000 training points were randomly selected for each target variable class (a total of 14,000), and the function "extract multi-value to points" was used to extract corresponding raster values of the predictor variable for each sample point. The resulting shapefile was exported, and further preprocessing took place in the Python 3.9 environment.

During the preprocessing of data in Python, some missing values were observed, and the rows with missing data were removed. In the end, the new urban class was 6860, while the persistent–non-urban class was 6369. The resulting sample points were used in the Random Forest model. Generally, the accuracy of model predictions largely depend on the values of the hyperparameters; however, it is impossible to know in advance which hyperparameter values will provide the best results [80,81]. Therefore, it is important to try different hyperparameter combinations to determine the best combination through a

process called hyperparameter tuning. In this study, hyperparameter tuning was performed using the grid search method [80,82]. The grid search method systematically works through multiple combinations of parameter values to determine the combination that produces the best performance [80]. We utilized the GridSearchCV function in the Scikit-learn library in Python to perform this task. We developed a dictionary that defines each hyperparameter (n_estimators: the number of trees in the forest; max_depth: the maximum depth of each tree; min_samples_split: the minimum number of samples required to split an internal node; min_samples_leaf: the minimum number of samples required to be at a leaf node; max_features: the number of features to consider when looking for the best split; bootstrap: whether to use bootstrap samples when building trees) and lists possible values for each parameter. GridSearchCV systematically evaluates all possible combinations of the dictionary's values sequentially and subsequently employs the "tenfold cross-validation" technique to assess the model's performance with each combination [81,83]. The tenfold cross-validation method uses nine folds for training and one onefold for validation each time, therefore dividing the information set into ten folds [81]. The outcomes are averaged after 10 iterations to derive a final value.

2.3.5. Validation of Random Forest Model

After running a Random Forest model, the goodness of fit of the model should be determined. The relative operating characteristic (ROC) curve [84] was used to validate the Random Forest model in this study. The ROC curve reflects the sensitivity and specificity of continuous variables [32]. It combines the probability that an event occurs with the existence of an event, in this case urban growth, through plotting sensitivity against specificity [85]. Sensitivity, here, refers to the rate of true positives to positives classified, while specificity refers to the rate of false positives to negatives classified. The ROC curve is measured by the area under the curve (AUC), which ranges from 0 to 1. The higher the value, the better the predictive power of the model.

A total of 60,000 independent samples were used to validate the model, and an AUC value of 0.96 was achieved. Subsequently, drivers of urban growth in the province were computed based on the variable of importance obtained from the Random Forest model. Also, the trained Random Forest model was used to predict on the raster maps to develop a transformation probability of lands changing to urban use in the province in 2020. Further, based on the new master plan, TTH province is considering developing new urban centers in the province, and shapefiles of the proposed areas were overlaid on the probability maps to evaluate how our model considers the probability of those places developing into urban areas.

2.3.6. Analysis of Interviews

The interviews were conducted in the Vietnamese language and translated into the English language. The goal of the interviews was mainly to complement the geospatial data analysis. The interviews were analyzed using narrative analysis to extract how participants provided and presented their expert evaluations on the drivers of urban growth in the province and validate the relative importance of each driver obtained from the Random Forest model. The study employed pseudonyms for all individuals mentioned, adhering strictly to ethical protocols concerning confidentiality and informed consent.

3. Results

3.1. Historical Pattern of Urban Growth in TTH

The results of the land use change analysis for the TTH province in Central Vietnam are presented in Figure 4. The spatial extents of urban land are 27.94 km², 82.97 km², and 209.80 km² in 2000, 2010, and 2020, respectively. We found that the urban land change between 2000 and 2010 amounted to 55.03 km², indicating an increase of 196.93%. Further findings between 2010 and 2020 show that urban land occupied an additional 126.83 km² which amounted to an increase of 152.87%. When aggregated, the urban land change between 2000 and 2020 accounted for 181.86 km², indicating an increase of 650.9% during this period.

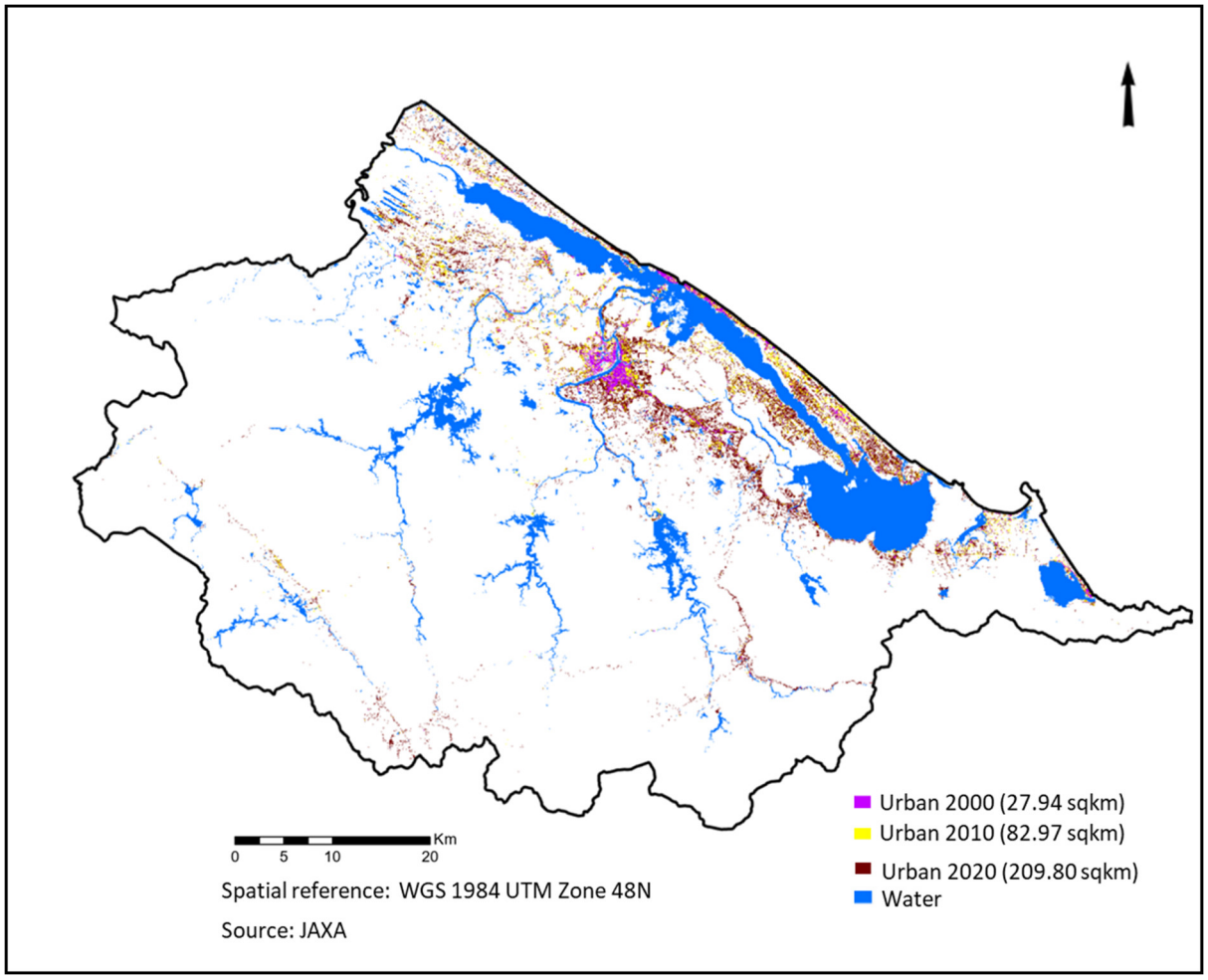


Figure 4. Land use change map of TTH province for 2000, 2010, and 2020.

3.2. Urban Encroachment upon Other Land Use Types (2000–2020) in TTH

Further findings (Figure 5) show evidence of urban land taking over other land use classes. Between 2000 and 2010, urban land occupied 3.94 km² of rice paddies, 28.58 km² of croplands, 0.02 km² of grassland, 7.50 km² of shrubland, and 3.15 km² of forest. Moreover, 0.53 km² of open water was occupied by urban land use, and the area of barren land being occupied accounted for 18.38 km², with no impact on wetland and aquaculture. Between 2010 and 2020, we found that urban land took over more land area from rice paddies (11.07 km²), croplands (56.32 km²), grassland (0.21 km²), barren land (33.09 km²), shrubland (16.3 km²), forest (12.21 km²), and open water (0.44 km²). Summarily, urban encroachments upon croplands and barren land were the highest between 2000 and 2020, followed by shrubland, rice paddies, and forest.

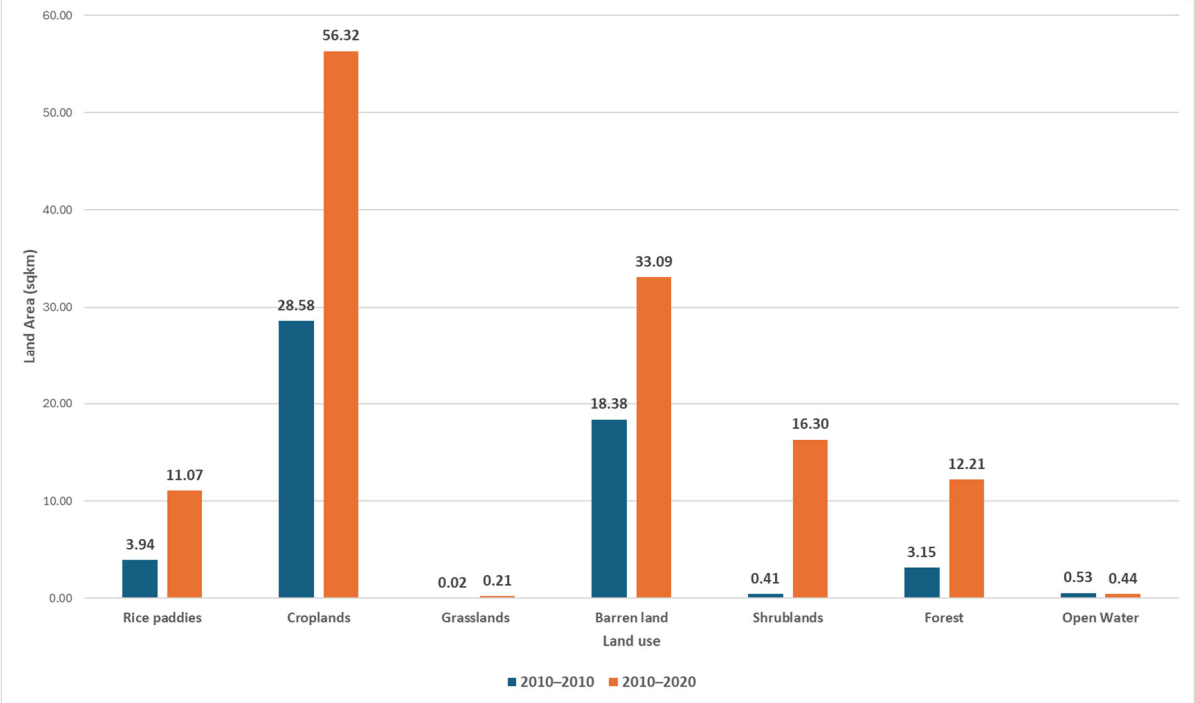
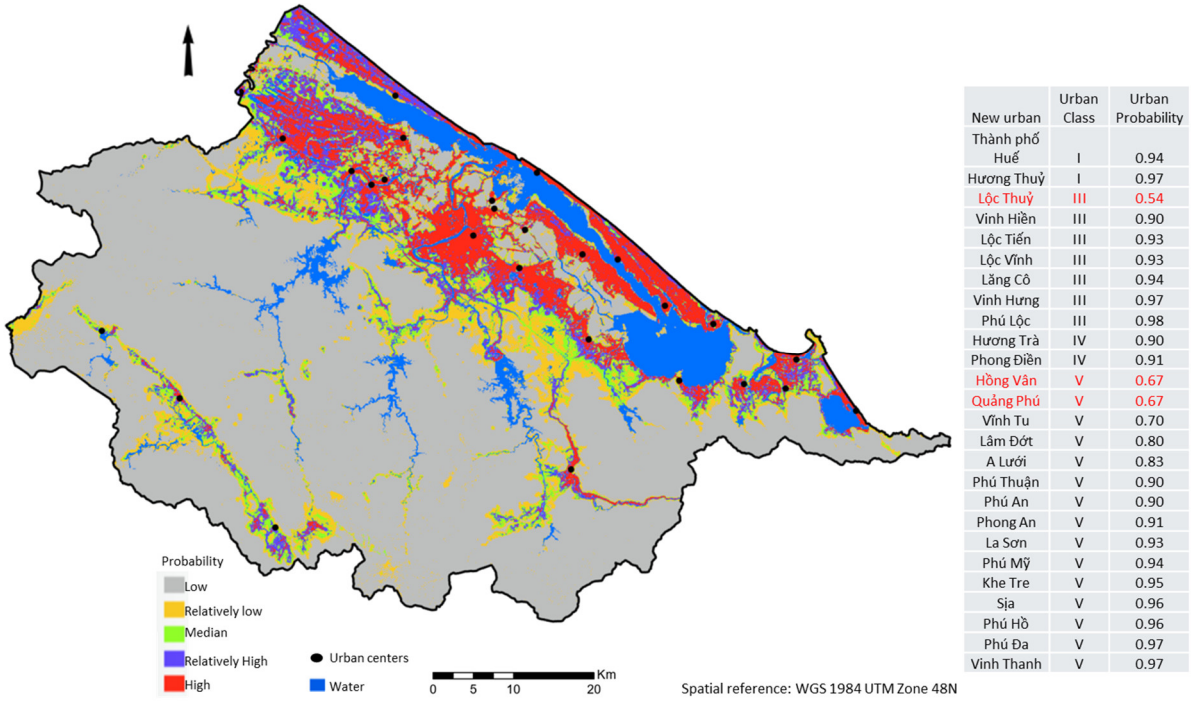


Figure 5. Land use classes encroached on by urban between 2000 and 2010 and 2010 and 2020 in TTH province.

3.3. Urban Probability in TTH Province

The distribution of the transformation probability of land areas in TTH into urban use in 2020 is shown in Figure 6. The aim of the map is to illustrate the probability of the urban transformation process in TTH. Using the natural breakpoint method, the transformation was divided into five levels. A transformation probability less than or equal to 0.10 is defined as low, a transformation probability greater than 0.10 and less than or equal to 0.325 is defined as relatively low, a transformation probability greater than 0.325 and less than or equal to 0.563 is defined as medium, a transition probability greater than 0.563 and less than or equal to 0.829 is defined as relatively high, and a transition probability greater than 0.829 is defined as high. The table within the figure provides the transformation potential for the proposed major urban centers in the new master plan [60].



New urban	Urban Class	Urban Probability
Thành phố Huế	I	0.94
Hương Thuỷ	I	0.97
Lộc Thuỷ	III	0.54
Vinh Hiền	III	0.90
Lộc Tiến	III	0.93
Lộc Vĩnh	III	0.93
Lăng Cô	III	0.94
Vinh Hưng	III	0.97
Phú Lộc	III	0.98
Hương Trà	IV	0.90
Phong Điền	IV	0.91
Hồng Vân	V	0.67
Quảng Phú	V	0.67
Vĩnh Tu	V	0.70
Lâm Đớt	V	0.80
A Lưới	V	0.83
Phú Thuận	V	0.90
Phú An	V	0.90
Phong An	V	0.91
La Sơn	V	0.93
Phú Mỹ	V	0.94
Khe Tre	V	0.95
Sịa	V	0.96
Phú Hồ	V	0.96
Phú Đa	V	0.97
Vinh Thanh	V	0.97

Figure 6. Distribution of the transformation probabilities of land in TTH changing to urban use in 2020.

In terms of the urban spatial distribution, the highest transformation probability of land area changing to urban in the province is around the coastal plain, linearly following water bodies, already established urban centers, and at the western border of the province. Conversely, the mountainous areas show the lowest urban transformation probability compared to other land areas in the province. This was buttressed by an interview participant, who said the following:

> "Urban expansion in mountainous areas does occur but at a much slower rate because the main purposes of these regions are to preserve biodiversity and develop ecosystem services, contributing to climate change mitigation and adaptation". (Participant D, Male, 30 years, Forest manager)

Also, when we overlaid the proposed new urban centers on the probability of urban transformation, we saw that the average probability of the transformation of land areas into urban areas in these locations was also high, i.e., between 0.7 and 1. This may be attributed to the fact that these urban areas are already in existence but still have a high tendency of extending beyond their current borders. However, Lộc Thuỷ, Hồng Vân and Quảng Phú are exceptions. In the case of Lộc Thủy, a commune in Phú Lộc District with attractive sites such as Suối Tiên and Thủy Yên Lake, the local government and community prioritize sustainable tourism development, intentionally limiting large-scale urbanization [86]. Also, the location of Hồng Vân in the mountainous district of A Lưới may have resulted in a lower probability of urban transformation, as a high cost is required for urban infrastructure development in the area. In the same vein, the focus of the local government for the Quảng Phú commune is rural development [87], which, therefore, may have impacted the lower probability of urban transformation in this commune

3.4. Drivers of Urban Growth in TTH

We identified 14 key spatial drivers of urban growth in Thua Thien Hue province and analyzed them based on their importance. These drivers are explained in detail in

Table 1. They are presented as relative variables of importance to indicate their significance to urban growth in the Thua Thien Hue province. The following two results are provided: one based on the Random Forest model and the other on expert opinions resulting from the interviews. From the Random Forest model, the results (Figure 7) indicate the variables of highest importance to be the following: accessibility to built-up areas (2010), DEM, proximity to rice paddies, slope, proximity to streets and roads, accessibility to social areas, and proximity to cropland (2010). Others include accessibility to industrial areas, proximity to national roads, accessibility to mining areas, accessibility to worship areas, proximity to rail lines, accessibility to commercial areas, and proximity to water bodies.

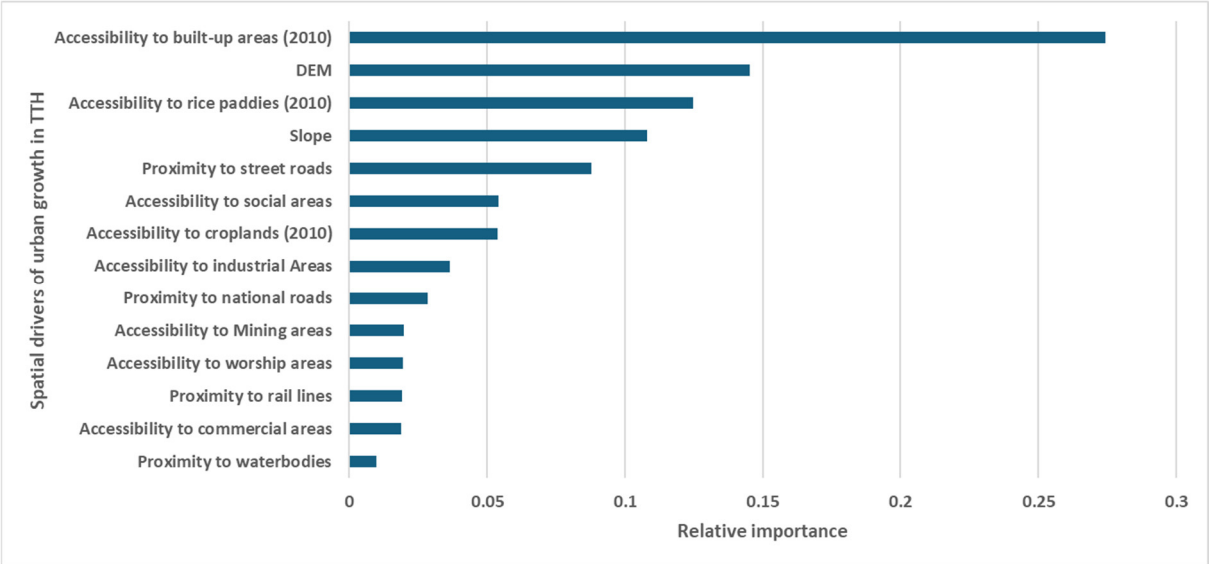


Figure 7. Variables of importance in characterizing spatial drivers of urban growth from the Random Forest model.

The experts that were interviewed also cited proximity to streets, accessibility to old urban areas, proximity to rice paddies, slope, DEM, and accessibility to social areas as more important to urban growth in TTH. For instance, one participant believed the following:

> "The probability of urban expansion near agricultural areas, particularly rice fields, tends to be higher compared to expansion near forests because of the stringent protection of forest land. And that during land acquisition for urban expansion or resettlement area development, agricultural land, especially fields, is often reclaimed for such purposes". (Participant A, Male, 55 years, Town Planner)

This participant explained further, as follows:

> "Old urban areas typically possess established infrastructure, so the expansion of new urban areas can leverage existing infrastructure to its advantage". (Participant A, Male, 55 years, Town Planner)

Another participant also emphasized the driver of accessibility to built-up areas, stating the following:

> "Areas that have been previously built-up benefit from established infrastructure, which reduces the costs and challenges associated with new development, making them prime targets for continued urban growth". (Participant B, Female, 38 years, Town Planner)

Regarding street roads, Participant B explained that residential areas are built near streets roads rather than highways to avoid accidents and noise pollution in the province. Participant B also elaborated that street roads are more conducive to daily activities, such as commuting to work, accessing markets, and interacting with social hubs. In contrast, highways are often associated with high-speed traffic and other disturbances, making them less desirable for residential development.

Finally, with respect to the DEM and slope, Participant A believed that the topography of the province discourages new urban development in the mountainous areas. Participant C also corroborated this when he mentioned the following:

> "In the study area, urban expansion always prioritizes nearby inner city and coastal directions. Meanwhile, urban expansion in mountainous areas does occur but at a much slower rate, because the main purposes of these regions are to preserve biodiversity and develop ecosystem services, contributing to climate change mitigation and adaptation". (Participant C, Male, 33 years, Scientist)

Participant D added further context, explaining the following:

> "While urban expansion is indeed concentrated near inner-city and coastal areas, the topography of the mountainous regions poses significant challenges for large-scale development. These areas are not only less accessible due to steep slopes and rugged terrain, but they are also environmentally sensitive zones. As a result, urban growth in these regions remains limited, as preserving biodiversity and supporting ecosystem services take precedence over new developments. Additionally, the infrastructure costs for building in mountainous regions are far higher, further discouraging urban expansion in these areas". (Participant D, Male, 30 years, Forest manager)

Finally, interviewee C believes that social areas such as tourist areas have influenced urban expansion in the province. He explained the following:

> "Tourist and cultural hubs, like Minh Mang Tomb, play a pivotal role in driving urban expansion in the province. These areas not only attract visitors but also stimulate economic activity, which leads to increased development around them. The frequent use by both residents and tourists makes these locations prime targets for infrastructure and commercial growth". (Participant C, Male, 33 years, Scientist)

4. Discussion

4.1. Historical Pattern of Urban Growth

Urban growth is a dynamic process that significantly shapes the spatial, social, and environmental characters of cities. As time progresses, new studies are evolving to provide more information on its impacts, especially within the local contexts of cities in the Global South. This is because the Global South is stated to experience the majority of the present and future urban growth [1]. Considering this observation, we analyzed urban growth in TTH province starting from the reference year 2000. We found that a relatively small increase in urban land was evident until 2010. However, a huge increase occurred between 2010 and 2020, which largely contributed to the overall significant change experienced over the two decades. It is, therefore, generally evident that TTH province experienced remarkable urban growth between 2000 and 2020. This suggests significant urbanization and urban development activities during this decade, which seems to be a general occurrence in Vietnam [88–90]. In fact, Fan et al. [91] expressed that the country experienced rapid urbanization after the Doi Moi, which is the economic development reform that caused Vietnam's cities that had a population of one million or more to see a

sharp increase in both built-up land density and population size relative to the national average. This experience is more evident in Hue city, which is the administrative seat of the province, whereby urban expansion between 1990 and 2020 increased tremendously over the last decade compared to the previous two decades [18]. Another piece of evidence from Thieu [92] is that urban expansion in Hue city is significantly caused by the development of new residential areas, especially new urban area (NUA) projects. All of these situations are without their associated consequences in the province and Vietnam in general [18,91]; hence, there is the need for sustainable urban growth in the province.

4.2. Urban Encroachment upon Other Land Use Types (2000–2020)

In TTH province, we found that urban land primarily encroached upon agricultural areas between 2000 and 2010. For example, rice paddies and croplands were converted to urban use. Also, urban land infringed upon forests, shrubland, and grassland, which is an indication of encroachment upon natural vegetation. Urban encroachment also occurred upon water bodies with a slight impact on open water areas and none on wetlands or aquaculture areas during this period. The following decade, between 2010 and 2020, experienced a more intense encroachment by urban land upon other land use classes. During this period, more rice paddies and croplands were converted into urban areas, thereby reflecting a further decline in the availability of agricultural land. Encroachment upon natural vegetation also intensified, with forest, shrubland, and grassland substantially taken over by urban land use. Moreover, a large area of barren land was encroached upon, having been converted into urban land.

The high rate of encroachment upon agricultural land can be attributed to the general urban expansion in Vietnam due to agricultural land acquisition for urbanization (ALAFU), which has been government land policy action since the beginning of the millennium [88–90]. According to Phuc [93], the growing lack of available urban land led the Vietnamese government to commit vast amounts of agricultural land in peri-urban areas for urban use through the mechanism of compulsory land acquisition. For instance, it was stated that approximately one million hectares of rural land were converted to urban use between 2001 and 2010, which affected an estimated 2.5 million people within 630,000 households [93]. What is noticeable specifically about TTH province is the spike in non-agricultural land evident between 2001 and 2010 [94]. As reflected throughout Vietnam, such a situation has severe consequences for food security and agricultural livelihoods, as it reduces the availability of land for farming [95]. Moreover, the encroachment upon forests and shrublands has significant environmental consequences, including loss of biodiversity, ecosystem disruption, and increased vulnerability to natural disasters like floods and landslides [92,96].

In line with the new master plan of the province, TTH is expected to be a significant region in Vietnam based on its developmental goals. The specific goals pertaining to urban growth are as follows: (i) the rate of urbanization is about 70%; (ii) the average population growth rate reaches 1.38% per annum; (iii) the population of the province will reach about 1,300,000 people by 2030; and (iv) maintenance of a forest coverage rate of 57% and improvements in its quality. Having related these goals to our findings, it is established that the rapid urban growth, characterized by an over fourfold increase in urban land (between 2000 and 2020), presents significant challenges in relation to the achievement of the master plan's goals. This relates particularly to the goal of maintaining a 57% forest coverage rate. If the increasing trend in urban land continues, there is a chance that the forest reserve might decrease to less than 57% by 2050. In addition, while TTH province aims for a 70% urbanization rate, the substantial encroachment upon forests and other land classes by urban expansion undermines the ecological sustainability targets in the master plan.

4.3. Drivers of Urban Growth

The spatial drivers of urban growth are reflective of the ongoing urbanization and urban development in TTH province of Vietnam. Our findings indicate 14 spatial drivers, which are listed in order of relative importance to urban growth in TTH. They comprise accessibility to built-up areas (2010), DEM, proximity to rice paddies, slope, proximity to streetsroads, accessibility to social areas, and proximity to cropland (2010). Others include accessibility to industrial areas, proximity to national roads, accessibility to mining areas, accessibility to worship areas, proximity to rail lines, accessibility to commercial areas, and proximity to water bodies. The proximity to urban areas demonstrates that urban growth in the province occurred near existing urban centers. The province has 47 urban districts, including the capital city, which are attractive locations for people [97]. This is because, like most urban areas, they are hubs of social and economic activities occupied by government and private investments, industries, businesses, housing, and infrastructure. Hence, many opportunities abound in these areas, ranging from educational and employment to other avenues for quality livelihoods. The proximity to streets roads shows that connectivity and transportation are critical factors that make certain areas in the province more attractive to people and for development. This situation is evident in other urban settlements around the world. For instance, in [98], a significant positive relationship was also established between population growth and road stocks. Other studies [99–101] provide evidence of urban growth and real estate development around transport infrastructure. Our model also shows accessibility to croplands and rice paddies as important drivers of urban growth in the study area. This shows that agricultural areas are prime targets for urban expansion in the province, as suggested by our earlier findings and backed by previous studies on the ALAFU policy in Vietnam. The second and fourth drivers are the following two physical properties: the slope and elevation of different areas within the province. Approximately three-quarters of the total land area in the province is made up of mountains and highland. These two physical properties of the land are prioritized for building and construction, as locations with flat slopes and low elevations are more prone to urban development [102–104].

The findings from our interview with experts emphasize the aforementioned spatial drivers of urban growth in TTH province. Rationales for urban encroachment are provided alongside the spatial drivers in the province. The susceptibility of agricultural land converting to urban encroachment compared to forests is due to stringent protection of the latter by local and national laws, as they are protected areas [105–107]. This implies that agricultural land is not legally protected from urban encroachment. Even the government itself acquires agricultural land for urban development and resettlement purposes, among others, which can also be traced back to the ALAFU policy in Vietnam and the issue of compulsory land acquisition raised by Phuc [93]. Moreover, the inner cities and coastal areas are stated as prime locations for urban expansion because of the existing and continuous socioeconomic activities in these areas. For mountainous regions, large-scale development is less evident because they are nationally dedicated to preserving biodiversity and developing ecosystem services [106]. Aside from this reason, the topography and high infrastructure costs of development also significantly deter urban expansion into these regions. Finally, it was established that tourism plays a pivotal role in urban expansion in the province. This is because the culture and heritage of the people, as well as the ecological landscapes, attract tourists to the province [18,108,109]. Tourism in the province is also promoted by the location and accessibility to social and cultural areas [110,111]. For example, tourist attractions like Hue Citadel and Minh Mang Tomb or popular restaurants tend to flourish when they are easily accessible via well-established road networks. Proximity to major roads increases foot traffic and makes these

locations more convenient for both residents and visitors, thereby enhancing their attractiveness for further commercial and residential development.

As stated earlier, while many studies have examined drivers of urban growth, most have either focused on these factors individually or analyzed only a limited combination. This study advances knowledge by integrating 14 different drivers of urban growth across multiple dimensions while also incorporating the spatial context based on proximity or accessibility to better understand their impacts. Also, many studies tend to lump social areas, such as tourist areas, restaurants, and coffee shops, within commercial areas. While we are not denying the fact that they perform commercial functions, this study shows that when excluded from other commercial areas and treated as individual drivers, they exhibit greater importance to urban growth compared to other commercial areas in the province. Similarly, they show greater relative importance than other drivers such as proximity to national roads, accessibility to industrial areas, proximity to rail lines, proximity to mining areas, accessibility to worship areas, and proximity to water bodies, which has already been identified by previous studies [21,41,69]. This may be attributed to social areas being multifunctional. For instance, Zhang [112] observed in Shanghai that accessibility to restaurants improves the living environment, promotes social interactions, and drives high-intensity development within cities. Also, Zhou [113] echoed this when they demonstrated in four different cities in China that coffee shops constitute one of the major indicators of urban vitality and positively correlate with urban development and growth. In the same vein, the concentration of social areas stimulates economic growth as it attracts visitors and new residents [114]. Lastly, the complementary geospatial and interview results aided in establishing that social areas interact with other spatial drivers (e.g., proximity to transportation or built-up areas) to provide a more comprehensive understanding of their role in urban growth.

4.4. Global Perspective and Insights for Urban Sustainability

We contextualized our findings on TTH province within global and regional studies on urban growth. Over a decade, Seto et al. [64] showed a total change of 58,000 km^2 in global urban land extent between 1970 and 2000. Since then, the increase in urban land area was comparable to 1.3 times the size of Denmark, or roughly 1.56 to 3.89 percent of the total urban land area worldwide in 2000. Liu et al. [115] later showed that the global urban area grew by 9687 km^2 annually. When compared to earlier credible estimates from individual cities around the world, they established that this rate was four times higher, indicating an unprecedented rate of urbanization on a global scale. Both studies evidenced substantial global expansion during these periods. At the country level, total urban area in the United States was found to increase by approximately 20 percent during the period of 1985–2015 [116]. Increasing the expansion of urban land is also established in African and Asian cities, including Nigeria, Mali, Kenya, Indonesia, Malaysia, and the Philippines [117,118].

The urban expansion in TTH province resulted in encroachments particularly upon agricultural lands and forest areas. Similar encroachments by urban land were observed globally, which directly affected natural areas, with approximately 60 percent of endangered species indirectly affected [119]. On a regional level, almost 60 percent of the land converted to urban land between 1970 and 2010 in Africa was also in these natural areas [120]. Studies in Asia offer similar support, pointing to encroachments upon forests and croplands in India and Nepal [121,122]. Lastly, as pointed out in earlier studies [36,38,39], the drivers of urban growth are in terms of proximity and/or accessibility to urban centers, major roads, social areas, and productive lands, as evident in TTH.

At global and local scales, we have been able to establish that cities are faced with rapid urban expansion and urban encroachment, which are determined by spatially

contextualized drivers. While these shared similarities offer support for the general attainment of sustainability through the Sustainable Development Goals (SDGs), caution should be taken by considering regional disparities in urban growth. Odeh ([123], p. 338) posited that "Global North countries are wealthy, technologically advanced, politically stable, and aging as their societies tend toward zero population growth; the opposite is the case with Global South countries". This implies that the Global North has a high comparative advantage over those of the Global South in terms of the planning, governance, finance, technology, and implementation of plans and policies. Hence, they have been at the forefront of the sustainability agenda and have, to a significant extent, been able to address the dual challenges of accommodating urban growth while preserving their ecological systems. This has been achieved through effective enforcement of targeted policies and strategies. For instance, in the United States, Canada, and Western European nations, urban growth boundaries, also known as urban development boundaries, have been established to restrict the rate of fast urban expansion and protect particular geographical regions as natural habitats [124]. Moreover, smart growth policy and principles have been adopted in the United States [125,126], while European cities are currently guided by regional policy, urban agenda, cohesion policy, and territorial cohesion, which are scaled for continental adoption [127].

The urban sustainability measures in the Global North are required in the Global South. They could, however, be adapted based on regional differences. This is where the local context inputs of the Global South come in and should be based on empirical evidence while also geared toward achieving specific SDGs. First, the high urban expansion that implies rapid urbanization suggests the critical need for sustainable urban planning to achieve both SDG 11 on sustainable cities and communities and SDG 9 on industry, innovation, and infrastructure. Available are the compact city, green city, and smart city solutions, among others [128,129], which provide innovative urban forms and resilient infrastructure that can help manage urban growth more sustainably. Second, the encroachment upon agriculture raises concerns about food security, aligning with SDG 2, which aims for zero hunger. Policies to protect agricultural lands from urban encroachment should be framed or enforced to ensure sustainable food production and availability. Third, in alignment with SDG 15 regarding life on land and SDG 13 on climate action, encroachment upon natural lands emphasizes the importance of protecting the forest areas that serve as carbon sinks and play a crucial role in mitigating climate change impacts. This contributes to the overall protection of ecosystems and biodiversity. Lastly, while urban expansion is actively driven by socioeconomic issues, there is the need to slow down its pace through livelihood improvements in alternative settlements like the rural areas.

4.5. Limitation and Implications for Further Studies

We provided empirical-based evidence on urban growth in TTH province; however, our study has its limitations. One, a decadal time measurement was used in the analysis of urban land use change. We were, therefore, unable to account for short-term changes within the decade. This also implies that the urban growth challenges within such a period are not accounted for in our study. Nonetheless, we were still able to establish long-term changes in urban land use for two decades in order to guide land-use policies and decision making in the province. Although we did not include policy-related drivers, such as land use planning and zoning, in this study, the 14 utilized drivers were able to explain the observed urban growth. This shows that openly available data utilized in this study will make easier replicability in other regions possible, especially in data-scarce regions in the Global South. Based on these limitations, the following further areas of research are suggested: (i) analysis of annual trends in land use land cover change alongside its

socioeconomic and ecological implications for TTH province; and the (ii) prediction of urban growth and climate impacts in TTH province.

5. Conclusions

Urban growth phenomena in contemporary towns and cities have been a recurrent subject of research due to continuous global warming and climate change threats. While aggregated sustainable solutions for urban settlements abound on the global scale, different ones are needed at the local scale due to their unique physical, social, economic, environmental, and political characteristics. This emphasizes the need for empirical place-based evidence to address specific urban challenges. In this study, we explored urban growth in TTH province, Central Vietnam, focusing on historical trends, urban encroachment upon other land use classes, and the drivers of urban land use change. Our findings indicate a significant increase in urban land area over the past two decades, often at the expense of other land uses, particularly rice paddies, croplands, shrubs, and forests. Such shifts pose risks to food security, agricultural livelihoods, biodiversity, and ecosystem health, while also increasing the region's vulnerability to natural disasters such as floods. Moreover, the study identified key spatial drivers of urban growth in the province, including proximity to roads and urban areas, distance to rice paddies, DEM, slope, proximity to croplands, and accessibility to social areas. For the TTH, these insights provide valuable guidance for developing locally appropriate urban planning strategies that mitigate the adverse effects of uncontrolled urban expansion, especially those that meet both the urban growth and ecological goals of the master plan. Urban sustainability measures that limit urban growth in accordance with SDGs 2, 9, 11, 13, and 15 are generally recommended as lessons for the Global South.

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