# ECOLOGICAL SUITABILITY ASSESSMENT FOR MOUNTAINOUS AREA DEVELOPMENT AND BIODIVERSITY CONSERVATION IN BAC KAN PROVINCE, VIETNAM

**Trong Dai Ly**



**A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geoinformatics**

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**การประเมินความเหมาะสมทางนิเวศวิทยาสำหรับการพัฒนาพื้นที่ภูเขาและการอนุรักษ์ความหลากหลายทางชีวภาพ จังหวัดบักกาน ประเทศเวียดนาม**

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**วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต**

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ตรอง ดาย ลี : การประเมินความเหมาะสมทางนิเวศวิทยาสำหรับการพัฒนาพื้นที่ภูเขาและการอนุรักษ์ความหลากหลายทางชีวภาพ จังหวัดบักกาน ประเทศเวียดนาม (ECOLOGICAL SUITABILITY ASSESSMENT FOR MOUNTAINOUS AREA DEVELOPMENT AND BIODIVERSITY CONSERVATION IN BAC KAN PROVINCE, VIETNAM) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.สุวิทย์ อ๋องสมหวัง, 199 หน้า.


การประเมินความเหมาะสมทางนิเวศวิทยาเป็นวิธีการสำหรับใช้ในการจำแนกและกำหนดพื้นที่ที่ความเหมาะสมสำหรับการพัฒนาที่มีประสิทธิภาพ เพื่อลดผลกระทบจากกิจกรรมของมนุษย์ต่อระบบนิเวศสำหรับการพัฒนาอย่างยั่งยืน เป้าหมายของการศึกษาคือ การประยุกต์หลักการทางวิทยาศาสตร์ของทฤษฎีนิเวศภูมิทัศน์และการประยุกต์สำหรับการพัฒนาพื้นที่ภูเขาและการอนุรักษ์ความหลากหลายทางชีวภาพในจังหวัดบักกาน ประเทศเวียดนาม วัตถุประสงค์ของการศึกษาคือ (1) เพื่อจำแนกภูมิทัศน์และอธิบายคุณลักษณะหน่วยวัดทางภูมิทัศน์ (2) เพื่อจำแนกปัจจัยสำคัญสำหรับการประเมินความคงทนทางนิเวศสำหรับการก่อสร้าง (3) เพื่อประเมินและจำแนกศักยภาพความคงทนทางระบบนิเวศ (4) เพื่อวิเคราะห์นิเวศภูมิทัศน์สำหรับการอนุรักษ์ความหลากหลายทางชีวภาพ และ (5) เพื่อวิเคราะห์และกำหนดเขตความเหมาะสมทางระบบนิเวศในการวางแผนการพัฒนาพื้นที่ภูเขาและการอนุรักษ์ความหลากหลายทางชีวภาพ วิธีการศึกษาแบ่งออกเป็น 5 ส่วน ประกอบด้วย (1) การจำแนกและการอธิบายคุณลักษณะภูมิทัศน์ (2) การสำรวจปัจจัยสำคัญสำหรับการประเมินความคงทนทางระบบนิเวศสำหรับการก่อสร้าง (3) ประเมินความคงทนทางระบบนิเวศสำหรับการก่อสร้าง (4) การวิเคราะห์ทางนิเวศภูมิทัศน์สำหรับการอนุรักษ์ความหลากหลายทางชีวภาพ และ (5) การกำหนดเขตความเหมาะสมสำหรับการพัฒนาพื้นที่ภูเขาและการอนุรักษ์ความหลากหลายทางชีวภาพ

ผลการศึกษาของวัตถุประสงค์ที่ 1 พบว่า ระบบการจำแนกภูมิทัศน์ของจังหวัดบักกานด้วยเทคนิคการแบ่งส่วนแบบหลายระดับ มีทั้งหมด 4 ระดับ ในระดับที่ 4 ซึ่งเป็นระดับที่แสดงรายละเอียดสูงสุดของรูปแบบทางภูมิทัศน์ที่จำแนกจากข้อมูลธรณีกาล ระดับความสูง ความลึกของดิน และการใช้ประโยชน์ที่ดิน ประกอบด้วยประเภทภูมิทัศน์ 315 ประเภทและหน่วยภูมิทัศน์ 8,472 หน่วย สำหรับผลการศึกษาของวัตถุประสงค์ที่ 2 พบว่า ตัวชี้วัดที่สัมพันธ์กับองค์ประกอบพื้นฐาน ความสำคัญ และความยืดหยุ่นทางนิเวศซึ่งได้จากการสำรวจความคิดเห็นจากผู้เชี่ยวชาญจำนวน 10 รายโดยใช้วิธีการเดลฟี (Delphi) 2 รอบ มีทั้งหมด 12 ตัวชี้วัด สำหรับผลการศึกษาของวัตถุประสงค์ที่ 3 พบว่า คลาสความเหมาะสมทางระบบนิเวศสำหรับการก่อสร้างและการพัฒนาส่วนใหญ่อยู่ใน

ระดับปานกลาง และพบว่า พื้นที่ของคลาสความเหมาะสมมากที่สุดสำหรับการก่อสร้างและการพัฒนาพบอยู่ในบริเวณที่ราบ สำหรับผลการศึกษาของวัตถุประสงค์ที่ 4 พบว่า จากการวิเคราะห์รูปแบบทางภูมิทัศน์โดยอาศัยดัชนี 4 กลุ่ม (ความวิวิธพันธ์ของภูมิทัศน์ รูปร่างของหย่อม ระยะห่างของหย่อมและพื้นที่ของหย่อม) สามารถนำมาแสดงผลลัพธ์เชิงปริมาณของสารสนเทศทางนิเวศวิทยาได้ และสำหรับผลการศึกษาของวัตถุประสงค์ที่ 5 รายงานผลลัพธ์เกี่ยวกับการกำหนดเขตการพัฒนาในระดับจังหวัดที่แบ่งออกเป็น 5 ระดับ และเสนอแนะทิศทางการพัฒนาในอนาคตในระดับอำเภอออกเป็น 3 แนวทาง

จากผลการศึกษาสามารถสรุปได้ว่า ผลลัพธ์ที่ได้รับจากการศึกษาสามารถนำไปใช้เพื่อสนับสนุนผู้ตัดสินใจ ผู้กำหนดนโยบาย นักวางแผนการใช้ประโยชน์ที่ดินและผู้จัดการที่ดินได้ ในขณะเดียวกัน กรอบของวิธีการวิจัยที่ใช้ในการศึกษาสามารถนำไปใช้เป็นแนวทางสำหรับการประเมินความเหมาะสมทางระบบนิเวศของประเทศเวียดนามในอนาคตได้



สาขาวิชาภูมิสารสนเทศ ลายมือชื่อนักศึกษา__________

ปีการศึกษา 2562 ลายมือชื่ออาจารย์ที่ปรึกษา__________

TRONG DAI LY : ECOLOGICAL SUITABILITY ASSESSMENT FOR MOUNTAINOUS AREA DEVELOPMENT AND BIODIVERSITY CONSERVATION IN BAC KAN PROVINCE, VIETNAM. THESIS ADVISOR : ASSOC. PROF. SUWIT ONGSOMWANG, Dr. rer. Nat. 199 PP.

ECOLOGICAL SUITABILITY ASSESSMENT/ ECOLOGICAL DEVELOPMENT ZONE/ LANDSCAPE ECOLOGY/ INTEGRATED ECOLOGICAL RESISTANCE MODEL/ DELPHI METHOD/ BAC KAN PROVINCE/ VIETNAM

Ecological suitability assessment is an effective approach to identify and locate the most suitable territories for future development in order to reduce the negative impacts of human activities on the ecosystem for ensuring sustainable development. The study aims to apply the scientific basis of landscape ecology theory and its applications for mountainous area development and biodiversity conservation in Bac Kan province, Vietnam. The main objectives of the study are (1) to classify landscape and describe landscape unit character, (2) to identify significant factors for ecological resistance evaluation for construction, (3) to evaluate and classify potential ecological resistance for construction, (4) to analyze landscape ecology for biodiversity conservation, and (5) to analyze ecological suitability zonation for mountainous area development and biodiversity conservation plan. The research methodology consisted of five components included (1) landscape classification and characterization, (2) significant factor identification for ecological resistance evaluation to construction, (3) ecological resistance evaluation for construction, (4) landscape ecological analysis for

biodiversity conservation, and (5) ecological suitability zoning for mountainous area development and biodiversity conservation.

Major results of the first objective revealed that the landscape classification of Bac Kan province using a multi-level segmentation technique has 4 hierarchical levels. Level 4, which provided full details of spatial pattern based on geologic period, elevation, soil depth, and land use, had 315 landscape types and 8,427 landscape units. For the second objective, 12 indicators related to ecological elements, importance, and resilience were selected by 10 experts under 2 rounds of Delphi process. For the third objective, the most dominant ecological suitability class for construction and development was the moderately suitable class while the most suitable areas for construction and development located in lowland. For the fourth objective, results of landscape pattern analysis using four groups of metrics (landscape heterogeneity, patch shape, patch distance, and patch area) were quantitatively reported as ecological information. Lastly, the fifth objective reported about the development zonation at the provincial level with 5 classes and 3 future directions at the district level.

In conclusion, the results of this study can be used to support decision-makers, policymakers, land use planners, and land managers. In the meantime, the presented framework of the research methodology can be used as a guideline for ecological suitability assessment in Vietnam.

School of Geoinformatics — Student's Signature_______________

Academic Year 2019 — Advisor's Signature_______________

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AHP | = | Analytic Hierarchy Process |
| BKPC | = | Bac Kan People's Committee |
| DEM | = | Digital Elevation Model |
| ESRI | = | Environmental Systems Research Institute |
| GDP | = | Gross Domestic Product |
| GIS | = | Geographic Information System |
| IER | = | Integrated Ecological Resistance |
| LULC | = | Land Use and Land Cover |
| MCE | = | Multi-criteria Evaluation |
| MCRM | = | Minimum cumulative resistance model |
| NAV | = | National Assembly of Vietnam |
| NDVI | = | Normalized Difference Vegetation Index |
| UN | = | United Nations |
| USLE | = | Universal Soil Loss Equation |
| VAST | = | Vietnam Academy of Science and Technology |

# CHAPTER I

# INTRODUCTION

## 1.1 Background and significance of the study

Sustainable development is one of the most critical tasks in many countries. In Vietnam with three-quarters of the area is hills and mountains, most of them have very diverse ecosystems and provide potential natural resources for economic development. However, sustainable development in Vietnam faces many obstacles due to the difficulty of socio-economic conditions and policies as well as the limitation of qualified managers and lack of awareness from local people. In addition, the pressure of population growth and the exploitation of natural resources for socio-economic development towards industrialization and modernization also affect sustainable development goal.

According to the Food and Agriculture Organization of the United Nations report in 2005, Vietnam has the second-highest rate of deforestation of primary forests (Butler, 2005). Most of the areas after deforestation have been converted to perennial trees or food crops. These kinds of activities have been causing more and more depleted natural resources and polluted environment. These activities do not take into account the suitability with natural conditions. In addition, natural disasters frequently occur more and cause more serious consequences such as soil erosion, landslide, flash floods, etc. (Table 1.1). Therefore, it is necessary to study with an appropriate holistic approach in order to provide direction for efficient production planning in accordance with natural conditions as well as to ensure environmental protection.

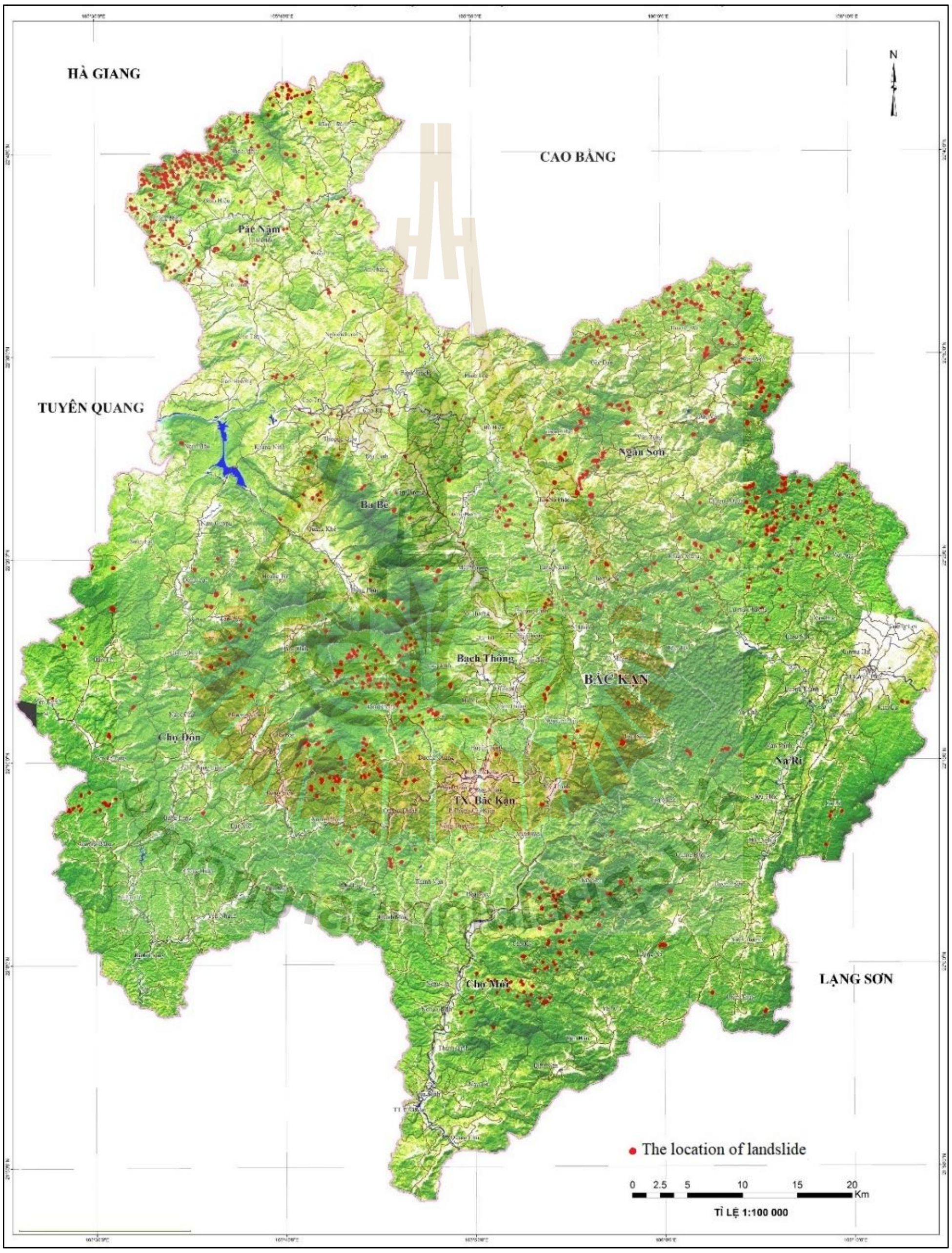
**Table 1.1** The summary of the landslide inventory mapping in the 14 mountainous provinces of Vietnam.

| **No.** | **Province** | **Number of occurrences** | **Volume ($m^3$)** | | | | |
|---|---|---|---|---|---|---|---|
| | | | **< 200** | **200 - 1,000** | **1,000 – 10,000** | **10,000 – 100,000** | **> 100,000** |
| 1 | Lai Chau | 970 | 337 | 325 | 280 | 18 | 0 |
| 2 | Dien Bien | 673 | 335 | 181 | 139 | 12 | 1 |
| 3 | Son La | 1694 | 795 | 622 | 266 | 11 | - |
| 4 | Lao Cai | 534 | 316 | 162 | 53 | 3 | - |
| 5 | Yen Bai | 1165 | 580 | 385 | 187 | 9 | 4 |
| 6 | Ha Giang | 963 | 519 | 289 | 150 | 2 | 3 |
| 7 | Tuyen Quang | 246 | 151 | 94 | 1 | - | - |
| 8 | Cao Bang | 88 | 21 | 42 | 25 | - | - |
| 9 | Bac Kan | 720 | 305 | 282 | 123 | 9 | 1 |
| 10 | Bac Giang | 302 | 192 | 94 | 16 | - | - |
| 11 | Quang Ninh | 374 | 162 | 141 | 67 | 4 | - |
| 12 | Hoa Binh | 184 | 69 | 81 | 34 | - | - |
| 13 | Thanh Hoa | 938 | 630 | 223 | 78 | 7 | - |
| 14 | Nghe An | 1298 | 664 | 425 | 195 | 8 | 6 |

**Source:** (Hung et al., 2017).

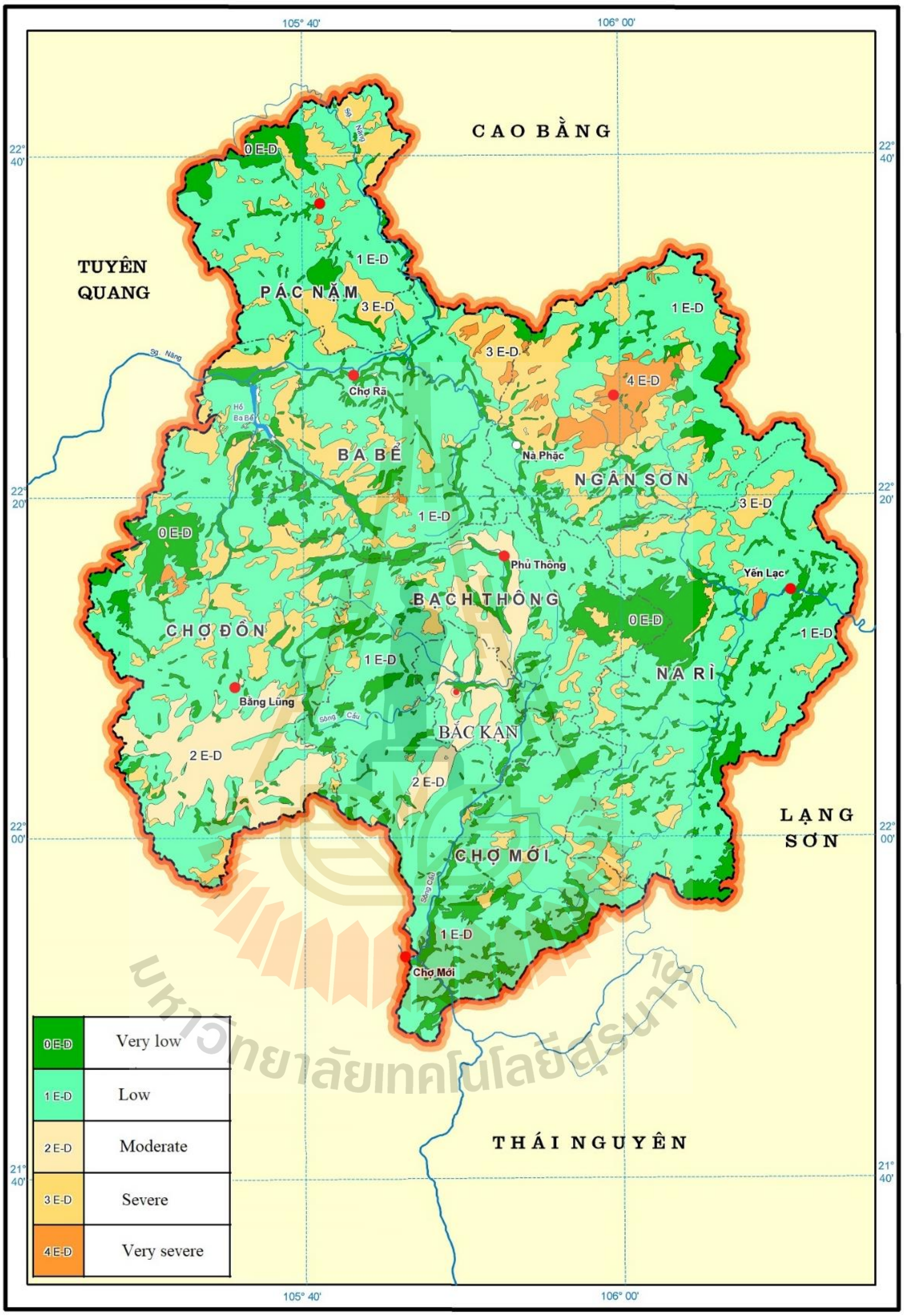
Bac Kan is a mountainous province which locates in the hinterland of the northeastern part of Vietnam, but it has a significant position in terms of economic and national security, particularly tourism and mineral resources. Bac Kan has been developed by industrialization and urbanization process (BKPC, 2016). At the same time, environmental problems (water pollution) and natural disasters (landslide and land degradation) are dramatically increasing in the area, and they threaten the health and property of citizens (Giang, 2011). These issues had been mentioned by many researchers. Ha (2014) stated that if landslide occurred over an area of 1,000 $m^2$ in Bac

Kan capital city, there might be a risk of life loss of 1.7 persons (Figure 1.1) and asset loss would be at approximately 65,000 USD per household. (BKPC, 2015); Vu (2011) reported about land degradation (Figure 1.2). Giang (2011); Ha (2011) and Them (2013) mentioned about water pollution in the area.




**Source:** Ha (2014).

**Figure 1.1** Distribution of the existing landslide in Bac Kan province.




**Source:** Vu (2011).

**Figure 1.2** Land degradation classification of Bac Kan province.

Meanwhile, the new holistic approach which relates to landscape ecology and landscape ecology assessment, has played an important role in solving integrated problems, particularly suitability evaluation for mountainous area development. This is because landscape ecology considers a territory space as a system that consists of both natural elements, namely geology, topography, soil, climate, and vegetation as well as human components, such as residence and land use patterns . In this system, any change of one component may lead to change in other components. Changes in the system may cause an unexpected consequence, for example, flash floods after severe deforestation. However, these changes can be well protected and prevented by conducting studies based on landscape ecology concept. Under these approaches, each territory will be clarified through analyzing its structure, function, and dynamics as the main characteristics of the landscape. These are an essential, solid and reliable scientific basis for sustainable development planning.

Therefore, ecological suitability assessment for mountainous area development and biodiversity conservation in Bac Kan province, Vietnam was chosen to conduct in this study. Because Bac Kan requires a specifically developed plan that provides directions and solutions to organize the space in a suitable way with the specific conditions and circumstances of the province. This study will not only promote socio-economic development but also protect the environment in order to achieve sustainable development goal for Bac Kan province.

## 1.2 Research objectives

The study aims to apply the scientific basis of landscape ecological theory and its applications for mountainous area development and biodiversity conservation. The specific objectives are as follows:

(1) To classify landscape and describe landscape unit character;

(2) To identify significant factors for ecological resistance evaluation for construction;

(3) To evaluate and classify potential ecological resistance for construction;

(4) To analyze landscape ecology for biodiversity conservation;

(5) To analyze ecological suitability zonation for mountainous area development and biodiversity conservation plan.

## 1.3 Scope of the study

(1) Landscape classification and mapping was implemented using the multi-segmentation process under the eCognition software environment. Herein, the selected landscape components for landscape classification are topography, geology, soil, and LULC.

(2) Landscape ecology analysis was performed under the Fragstats software environment. Herein, four groups of landscape metrics using for analysis include landscape heterogeneity, patch shape, patch distance, and landscape context. Additionally, landscape ecology analysis was performed at the landscape level for the purpose of quantitative biodiversity information extraction and comparison.

(3) The selection of indicators of three factors (criteria) including ecological structure resistance, ecological functional resistance, and ecological adaptation for ecological suitability assessment was identified by experts using the Delphi method.

(4) Ecological suitability assessment was performed based on the fundamental theory of structure, function, dynamics of landscape ecology using GIS spatial analysis.

## 1.4 Limitation of the study

(1) The availability of biophysical and socio-economic factors for landscape classification depends on available data from specialized agencies and local authorities.

(2) The criteria and weights using for the ecological suitability assessment process rely on the existing recommendations from relevant papers and experts.

## 1.5 Study area

The study area is Bac Kan (Bắc Kạn) province, Vietnam. It situates in the northeastern part of Vietnam and lies between 21°48'N to 22°44'N and 105°26'E to 106°15'E. It covers an area of 4,859.4 $km^2$ (Figure 1.3). It consists of 8 districts, namely, Pac Nam, Ba Be, Cho Don, Ngan Son, Bach Thong, Na Ri, Cho Moi, and Bac Kan. The elevation varies between 30 and 1,600 m above mean sea level (Figure 1.4).

Nature gives the Bac Kan province with numerous mountains, rivers, and lakes which are very scenic and had become well-known sights, such as Ba Be Lake, Puong Cave, Dau Dang Waterfall. Besides, Bac Kan is a center of plentiful primitive forest resources with the fullness of flora and fauna. In 2011, Ba Be national park located inside Bac Kan has recognized the Ramsar site no. 1938 of the world (Secretariat, 2013). Bac Kan is also as known as a center of mineral resources mainly lead, zinc, iron, and gold which was forming by different geological processes and activities from the Cambrian era through the Quaternary period (BKPC, 2017). Moreover, with seven ethnic groups living together, Bac Kan has a vibrant and diverse culture with a variety of unique customs and habits, as well as modern festivals. The integration of these environmental and social characteristics had formed a richness in the mixture of the Bac Kan landscape.


**Figure 1.3** Location map of the study area.

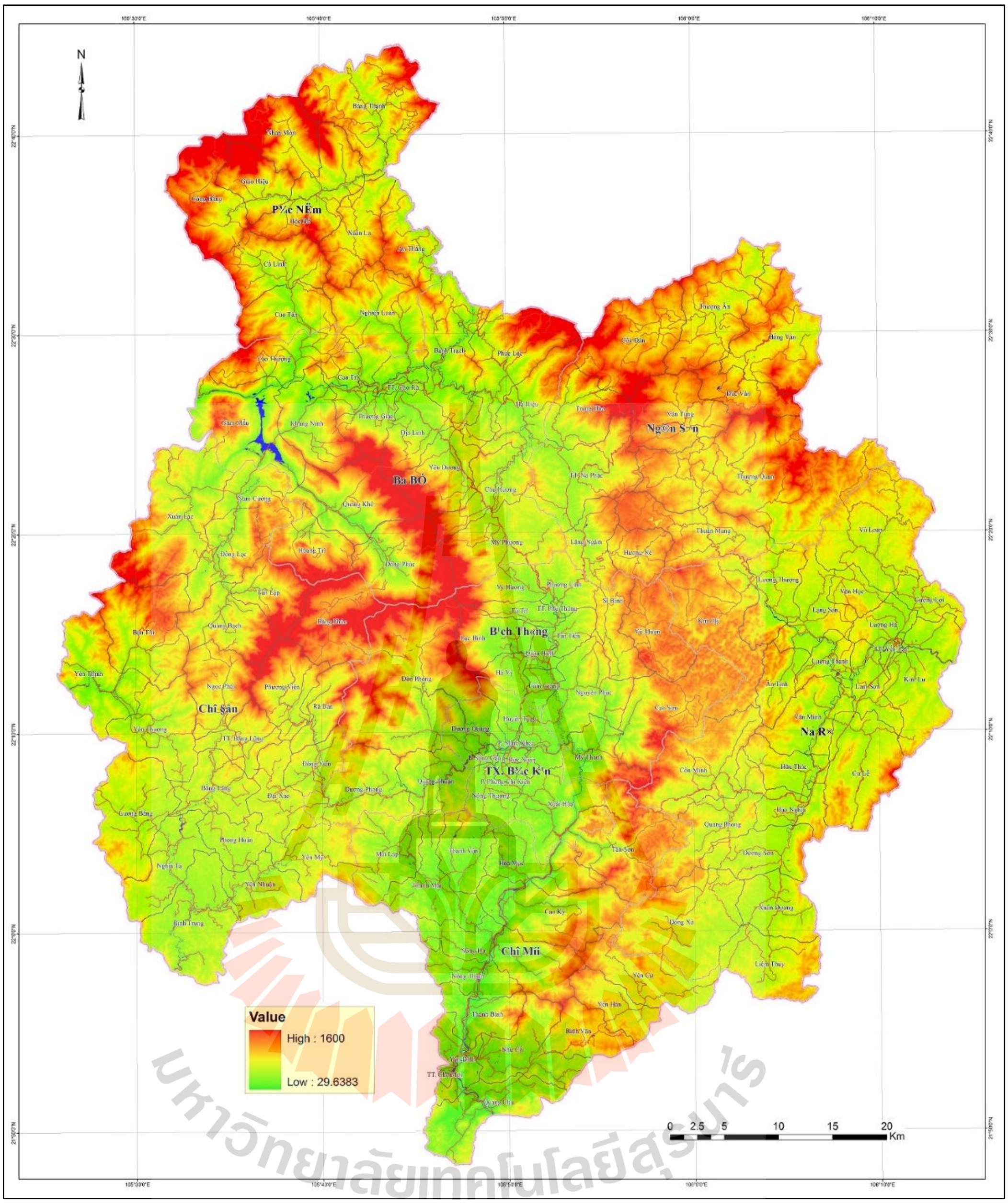



**Figure 1.4** Elevation map of the study area.

## 1.6 Benefit of the study

(1) An understanding of landscape formation and landscape pattern through landscape classifying and landscape analyzing.

(2) An understanding of ecological resistance and its components, consequently, significant factors impact ecological resistance and measure this resistance with regard to construction.

(3) An assessment of ecological suitability based on landscape ecology can be used as a framework for mountainous area development and biodiversity conservation to support planners, managers, and decision-makers. This framework can be applied to other areas.

# CHAPTER II

# RELATED CONCEPTS AND LITERATURE REVIEWS

## 2.1 Basic concepts

### 2.1.1 Landscape ecology

**(a) Definition and main characteristics of landscape ecology**

The term "Landscape ecology" was coined by the German biogeographer Carl Troll toward the end of the 1930s. Troll hoped that a new science could be evolved combining the spatial "horizontal" approach of geographers with the functional "vertical" approach of the ecologists. Landscape ecology deals with the ecology of landscapes. Surprisingly, there are many different interpretations of the term "landscape". The disparity in definitions makes it difficult to communicate clearly, and even more difficult to establish consistent management policies. Definitions of landscape invariably include an area of land containing a mosaic of patches or landscape elements. Forman and Godron (1986) defined the landscape as a heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in similar form throughout.

Mücher, Klijn, Wascher, and Schaminée (2010) stated that landscape is considered to form recognizable parts of the earth's surface, it shows a characteristic ordering of elements, although it is often heterogeneous. Every landscape is also considered as a system of elements connected to each other by energy, matter or information (Farina, 2006). This complex system is formed and maintained by the mutual action of abiotic and biotic forces as well as human action (Zonneveld, 1995). However, this system by itself shows different functions which refer to the broad categories of "services" that consists of production, protection, and regulation (Leitão, Miller, Ahern, and McGarigal, 2012). Therefore, landscape structure, function, and change are fundamental aspects of landscape ecology.

- **Landscape structure**: is a description of the spatial relationships among ecosystems, or more specifically the distribution of energy, materials, and species in relation to the size, number, types, and configurations of ecosystems. There are several principal ways to describe the structure of landscapes, each using different kinds of data. With point data, the property of interest is usually the geographic location of each point, although measured attributes at each location may also be of interest. Linear networks within a landscape may be useful in the study of hydrologic systems (such as rivers and streams), wildlife corridors, or transportation and energy networks. Surficial or continuous surface data is useful to address landscape variability as gradients (McGarigal and Cushman, 2002).

- **Landscape function**: refer to the broad categories of "services" that landscapes provide: production, protection, and regulation. Production services support the human needs for food, wood, recreation, and transport. Landscape protection provides for natural functions, such as rainfall infiltration, oxygen production, and absorption of carbon dioxide, water cleansing by soils and wetlands, nutrient buffering by riparian corridors, and maintenance of biological diversity. Landscape regulation provides negative feedback loops that assure the overall stability of a landscape (Naveh, 1994). Landscape function can also refer specifically to the flows of energy, materials, nutrients, species, people, and ecological processes.

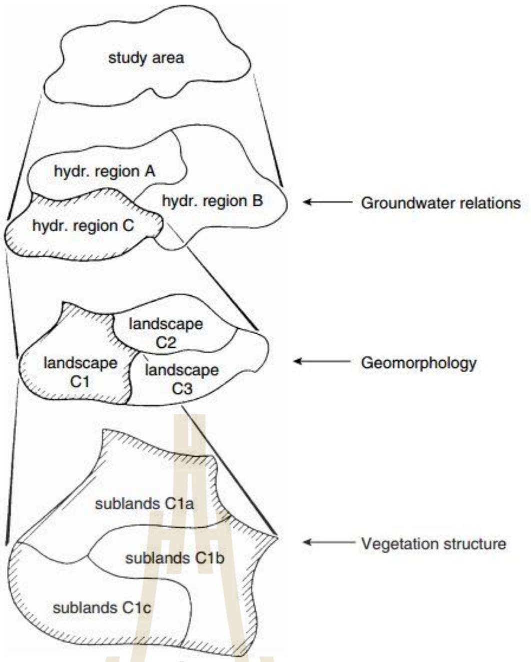
- **Landscape change**: The surface of the earth is constantly undergoing change resulting from the cumulative effect of a variety of disturbances, and the growth and development of ecosystems and human culture. Landscape change can be understood as the alteration of landscape structure and function over time. The most effective manner for landscape planners to deal with landscape change is to develop a basic understanding of it and to understand options and consequences associated with alternative plans for the future.

**(b) Landscape classification**

It is possible to classify a landscape and the component patches using many approaches that can again be anthropocentric or more independent, according to perceptive capacity.

**Structural patch**. It generally composed of a soil type overlapped by associations of vegetation.

**Functional patch**. It is an area homogeneous for a function or a physical descriptor such as altitude, temperature, moisture, and light penetration. In this category, it can include the ecotope, a selection of characters which, when they meet together, determine a unique character at a higher level. Ecotope classification is subjective and finalized to a goal. Often the ecotope classification represents an attempt to find a group of spatially coincident characters to correlate with the distribution of a species, of behavior or, more generally, of a process (Figure 2.1).




**Source:** Canters, den Herder, de Veer, Veelenturf, and de Waal (1991).

**Figure 2.1** Example of landscape classification of the Netherlands based on a hierarchy of hydrological regions, geomorphology, and vegetation structure.

**Resource patch**. It mostly related to animal ecology; a landscape can be described as a combination of resource patches. These patches are considered part of an animal home range in which food or the nesting site or roosting are easily available and part of the home range in which some specific functions are concentrated. It affects individuals and is considered equal to or smaller than an individual home range.

**Habitat patch**. It affects the populations. May be defined as distinct plant community types that are generally larger than an individual home range. Different groups of organisms can share the same habitat patch. (Farina, 2006).

**Corridor patch**. Although the definition of the corridor and their use is controversial, it considers as a corridor patch a portion of the land mosaic that is used by an organism to move, explore, disperse or, migrate. Often, the corridor concept is associated with a narrow strip of land. Generally, we associate corridors with a special feature of an organism that is accomplished outside its “normal” life.

As mentioned earlier, there are many ways to classify a landscape. In this study, a hierarchy approach was applied to classify landscape types of Bac Kan province. They are entities where many components and processes interact. It is accepted that the relatively independent abiotic phenomena (e.g., climate and geology) determine the presence and nature of relatively dependent biotic phenomena, such as vegetation. Changes in these abiotic characteristics generally lead to changes in biotic components (shift in position, shift in composition) (Mücher et al., 2010).

Eq. (2.1) illustrated the formation of the landscape. The sequence of state factors in Eq. (2.1) is ordered by increasing dependency and grouped according to abiotic (C, G, T, H, S), biotic (V, F). Groom (2005) claimed that these factors had an important role in most of the 49 national and regional landscape classifications.

$$\text{Landscape} = f\,(C_t, G_t, T_t, H_t, S_t, V_t, F_t,) \qquad (2.1)$$

Where C is climate, G is geology, T is topography, H is hydrology, S is soil, V is vegetation, F is fauna, and t is time.

Basically, natural processes and man's interference at various levels will be applied to characterize landscape components as present in Eq. 2.1. In practice, it can be used to order and rank various processes and their impacts on dependent variables, and it can support classification and mapping by (i) selecting significant factors, (ii) ranking factors according to its hierarchy and (iii) contributing to the architecture of a classification from factors, and (iv) creating a legend of a map.

However, this procedure is not dictated solely by scientific criteria, the quality and details of classification and maps also depend on user requirements.

In the case of the Bac Kan province, hydrology factor was not used for the delineation of the landscape units, but it was overlaid after mapping landscape units. The climate also was used since Bac Kan province has only a single climate type, namely "humid subtropical" (Cwa) (Peel, Finlayson, and McMahon, 2007). Therefore, geology, topography, and soil that are considered as abiotic factors, and land use and land cover that represents a biotic factor were applied to classify landscape types in Bac Kan province.

### 2.1.2 Delphi method

**(a) Definition of Delphi**

The use of criteria and indicators for sustainable development has been acknowledged and recommended by the United Nations Commission of Sustainable Development as important tools for the use in measuring the status of management of sustainable development. In order to evaluate the past, guide the action of the present, and plan for the future, we need to know what data to collect and what to measure (Sirakaya, Jamal, and Choi, 2001). However, there are no universal techniques are available for determining a set of criteria. It is obvious that the set of criteria depends on the particular system being analyzed. The number of evaluation criteria is dependent on the characteristics of the decision problem. The set of evaluation criteria for a particular decision problem may be developed through an examination of the relevant literature, analytical study, and opinions (Malczewski, 1999). A survey of opinions may be useful in selecting evaluation criteria (Keeney and Raiffa, 1993). People who will be affected by a decision, or a group of experts, can be asked to identify the criteria that should be included in decision analysis. Such methods as the key information approach, nominal group process, and Delphi method, to name a few, can be used to identify a set of criteria for a particular decision problem (Malczewski, 1999).

The Delphi method belongs to the subjective-intuitive methods of foresight. Delphi was developed in the 1950s by the Rand Corporation, Santa Monica, California, in operations research. The Delphi method is based on structural surveys and makes use of the intuitive available information of the participants, who are mainly experts. Therefore, it delivers qualitative as well as quantitative results and has beneath its explorative, predictive even normative elements. There is not one Delphi methodology, but the applications are diverse. There is agreement that Delphi is an expert survey in two or more rounds in which in the second and later rounds of the survey the results of the previous round are given as feedback. Therefore, the experts answer from the second round on under the influence of their colleague's opinions.

Wechsler (1978) characterized a "Standard-Delphi-Method" in the following way: "It is a survey which is steered by a monitor group, comprises several rounds of a group of experts, who are anonymous among each other and for whose subjective-intuitive prognoses a consensus is aimed at. After each survey round, standard feedback about the statistical group judgment calculated from median and quartiles of single prognoses is given and if possible, the arguments and counterarguments of the extreme answers are fed back".

**(b) General steps of the Delphi method**

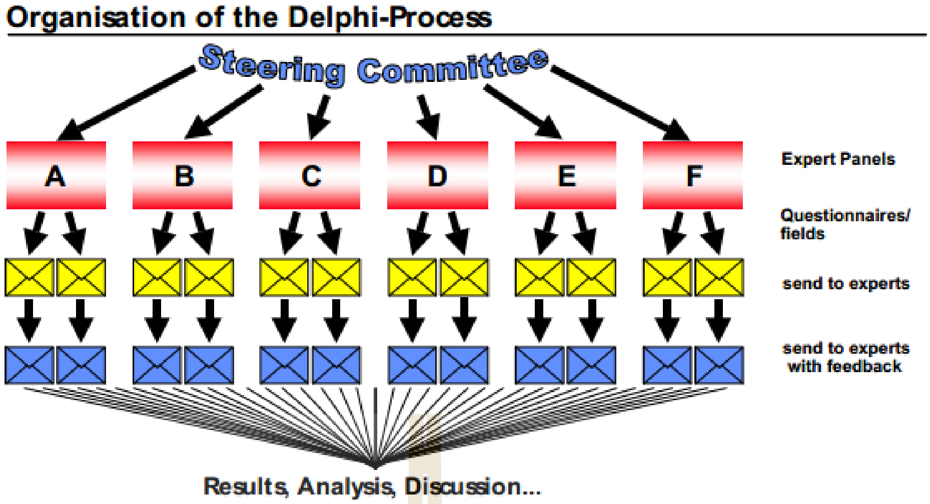
There is not a unique sequence of steps or procedure for the Delphi method, since different situations may benefit from different approaches. However, there are some basic elements that are common to all the applications of the Delphi technique (Linstone and Turoff, 2002). The following is a list of them:

- The participants have feedback on their contributions and an opportunity to revise them,
- There is an assessment of the group view on the problem,
- There is a degree of anonymity for the individual contributions.

The conventional form of Delphi usually works as follows:

- The (small, sometimes a single person) monitor team designs a questionnaire and sends it to the members of the group.
- The members of the group (individually) return the responses to the monitor team.
- The monitor team summarizes the results, designs a new questionnaire based on them (including a synthesis of the responses of the group), and sends it again to the group.
- The members of the group return the responses to the monitor team, possibly revising their initial opinions.
- Based on the revised responses and the degree of consensus, the monitor team decides to go again to the third step or to finally conclude the process.

The number of "rounds" in a Delphi process depends on the nature of the problem. Usually, there is an initial phase of contributions of information on the problem, the second phase of discussion of diverging views of the group members, and a final phase of evaluation. Figure 2.2 illustrates an example of an organization of the Delphi process (Cuhls, Blind, and Grupp, 1998).




**Source:** Cuhls et al. (1998).

**Figure 2.2** Organization of a Delphi survey.

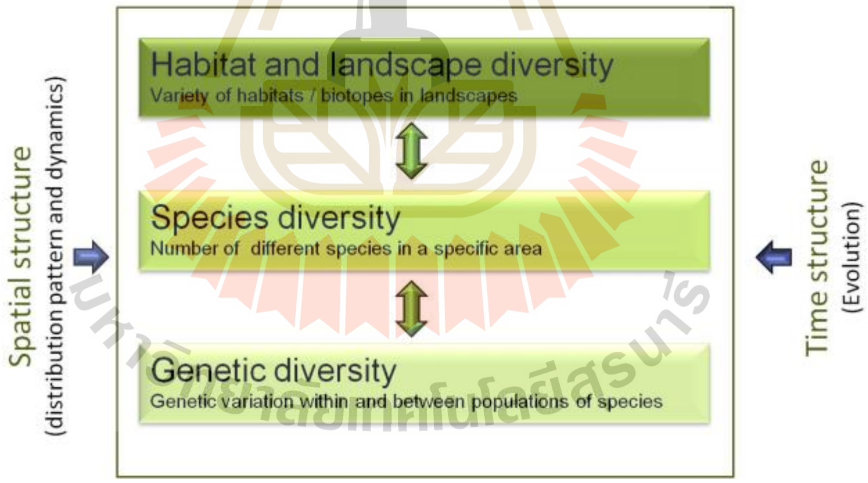
### 2.1.3 Landscape metrics application for planning and biodiversity conservation

#### (a) Definition and main components of biodiversity

The term biodiversity was first coined by Walter G. Rosen in 1986. Biological diversity, abbreviated as biodiversity, represent the sum total of various life forms such as unicellular fungi, protozoa, bacteria, and multicellular organisms such as plants, fishes, and mammals at various biological levels including gens, habitats, and ecosystem

United Nations (1993) defined biodiversity as the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems.

Biodiversity comprises the fields of genetic diversity, species diversity (number of species in certain units of space) and diversity of habitats and ecosystems at the landscape level (Figure 2.3). Thereby, each level is dependent on each other. The dynamics of natural processes, such as the changing distribution patterns of species and habitats in space and over time, are also part of biological diversity (Blab, Klein, and Ssymank, 1995). At each level of biodiversity, three fundamental characteristics of biodiversity can be considered: composition, structure, and function (Noss, 1990; Waldhardt and Otte, 2000). Composition describes the individuality and variety of elements, such as land use units or species within a region. Structure, by contrast, refers to the arrangement or the construction of units, the distribution of elements and their relationship to one another. Function, finally, comprises all processes, such as demographic trends, cycles of material or disturbances (Lipp, 2009). Especially at the landscape level, composition and structure can be described by landscape metrics.




**Source:** Walz (2011).

**Figure 2.3** Levels of biological diversity.

**(b) The relation between landscape structure and biodiversity**

It is often mentioned in very general terms that the spatial pattern of the landscape influences many ecologically relevant processes, e.g., the distribution of materials and nutrients or the persistence and movement of organisms (Turner, 1989). Numerous studies have shown such relationships to be determinants of species diversity (Ricotta, Corona, Marchetti, Chirici, and Innamorati, 2003). There is a relationship between landscape structure and species diversity/patterns of species distribution.

With respect to plants, important preconditions for high biological diversity are the abiotic site conditions and the geomorphology. Habitats with spatially heterogeneous abiotic conditions provide a greater variety of potentially suitable niches for plant species as habitats with homogenous characteristics. Variations in physical structure (e.g., slope direction, soil structure) have proven to be an appropriate factor for the prediction of the richness, diversity, and dominance of plant species (Burnett, August, Brown, and Killingbeck, 1998; Hobbs, 1988; Lapin and Barnes, 1995).

In the study of Burnett et al. (1998), they found that deciduous forests with high geomorphological heterogeneity had the highest plant diversity. The variances in plant abundance and diversity were explained best by slope direction and the water balance. Because of the strong correlation of the abiotic variables and biological diversity, these factors can be used to predict relative levels of biological diversity.

By contrast, in a landscape like the Central European cultural landscape, the composition and diversity of plant species depend on the structure of use affected by people. With respect to area size, Bastian and Haase (1992) found that the relationship between the number of plant species and area size can be described with statistical assurance by means of a logarithmic function. With an increased surface area of shrubs, the proportion of typical forest species in the total number of species also increased.

The shape of habitats can affect the number of species, too. For a greater number of environmental transitions between irregularly shaped habitats, areas can generally include more plant species (Honnay, Hermy, and Coppin, 1999; Honnay, Piessens, Van Landuyt, Hermy, and Gulinck, 2003). Therefore, shape complexity can be used to analyze land cover data as an index for species richness (O'Neill et al., 1988), which improves the accuracy of the prediction of plant richness. Geometric landscape complexity proved to be a sensitive indicator of plant richness, especially in agricultural landscapes (Moser et al., 2002).

In fragmented landscapes, the distance to viable habitats (isolation) also determines the composition and abundance of plant species (Butaye, Jacquemyn, and Hermy, 2001). Less isolated habitats are generally more species-rich because they can be easily settled. The constant influx of new individuals prevents local extinction due to demographic and environmental coincidences (Honnay et al., 2003).

Also, in agricultural landscapes, ecotones, which are linear landscape structures between different habitat types, have significant benefits, mainly because they provide habitats after the harvest and for hibernation. Ecotones with high structural heterogeneity, such as forest fringes and hedgerows, provide an improvement for regional biodiversity, as they do for the richness and diversity of beneficial organisms (Duelli, 1997).

The linkages between wildlife and landscape structure are similar. However, there are differences, in particular, due to the mobility of animals. Thus, species with good ability to spread depend mainly on landscape composition, i.e., the proportion of their preferred habitat type. Landscape structure is less important for these mobile species (Walz, 2011). By contrast, for species with poor dispersal ability, both landscape composition, and landscape structure have an arbitrative influence on the frequency of the species.

The process of fragmentation of landscapes, in the sense of the piece-meal conversion of formerly contiguous habitat, usually primarily affects animals with relatively large territories e.g. birds or large mammals. On the other hand, animals with limited mobility are separated into isolated populations more rapidly by such elements as roads or urban structures (Swenson and Franklin, 2000).

The shape of patches may also play an important role. It was shown for the ruffed grouse that regularly shaped patches are preferred (Fearer and Stauffer, 2003). Overall, it is clear that animals can react differently to habitat diversity.

### 2.1.4 Land-use suitability analysis: A landscape ecological suitability approach

**(a) Defining land use suitability analysis**

Land use suitability analysis is a tool used to identify the most suitable places for locating future land uses. Suitability techniques enable environmental managers and planners to analyze the interactions among three types of factors: location, development actions, and environmental elements. Analysts then are able to map these interactions in a variety of ways (Collins, Steiner, and Rushman, 2001). For example, a map might show (1) which land uses will have the least adverse impact on environmental processes, (2) qualitative predictions of environmental impacts of proposed developments, and (3) the most and least propitious locations for specific development proposals. Public officials and private developers can use these maps to set policies and make decisions regarding the use of land (Collins et al., 2001).

In the context of land suitability analysis, it is important to make distinctions between the site selection problem and the site search problem (Cova and Church, 2000). The aim of site selection analysis is to identify the best site for some activity given the set of potential (feasible) sites. In this type of analysis, all the characteristics (such as location, size, relevant attributes, etc.) of the candidate sites are known. The problem is to rank, or rate alternative sites based on their characteristics so that the best site can be identified. If there is not a pre-determined set of candidate sites, the problem is referred to as site search analysis. The characteristics of the sites (their boundaries) have to be defined by solving the problem. The aim of the site search analysis is to explicitly identify the boundary of the best site (Malczewski, 2004).

Both the site search problem and land suitability analysis assume that there is a given study area and the area is subdivided into a set of basic units of observations such as polygons (areal units) or raster. The land suitability analysis problem involves the classification of the units of observations according to their suitability for a particular activity. The analysis defines an area in which a good site might exist. The explicit site search analysis determines not only the site suitability but also its spatial characteristics such as its shape, contiguity, and/or compactness by aggregating the basic units of observations according to some criteria. The term land-use suitability analysis will be used in a broader sense that includes the site search problem (Malczewski, 2004).

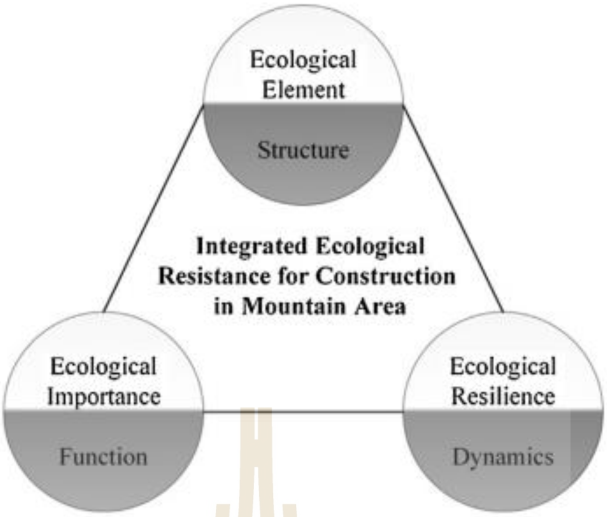
**(b) landscape ecological suitability evaluation for development and construction using ecological resistance approach**

Minimizing the ecological impact of land development is a fundamental principle of sustainable development. Ecological suitability evaluation is the key to realizing sustainability and is also significant for optimizing spatial patterns of territorial development. Especially in mountainous areas where the ecosystem is both vulnerable and important, quantitative evaluation of ecological suitability for land development is particularly important and urgent given the current development strategy of urban construction in mountainous areas (Peng, Ma, Du, Zhang, and Hu, 2016).

The framework of ecological suitability evaluation for land development is an effective tool to identify and locate the most suitable territories for future development and construction (Collins et al., 2001). This tool identifies the location and ecological boundaries of areas suitable for construction and also establishes suitability hierarchies based on ecological planning principles and quantitative evaluations of factors influencing construction, particularly ecological features (Liu, Shu, and Zhang, 2010; Zong, Wang, Wang, Wang, and Zhang, 2007).

The essence of mountainous area development is a process of human activity to overcome the resistance of natural ecosystems. An increase in resistance, on the one hand, means that the ecological or socio-economic cost of land development and construction increases, whereas on the other hand, it means that construction security risks and ecological risks increase (Peng et al., 2016).

Peng et al. (2016) proposed an integrated ecological resistance (IER) for construction in mountainous areas. The IER has a negative correlation with the level of ecological suitability, which means that the higher the former, the lower is the latter. Based on the theory of spatial ecology in landscape ecology, IER had used ecological elements, ecological importance, and ecological resilience to characterize the resistance of ecological structures, ecological functions, and ecological dynamics (Figure 2.4).




**Source:** Peng et al. (2016).

**Figure 2.4** Conceptual framework of integrated ecological resistance to construction in mountainous areas.

**Ecological structure resistance**

Ecological structure resistance is assessed from ecological elements. The ecological environment is an overall system consisting of organisms, soil, water, air, geology, topography, and other natural ecological elements to support the sustainable development of human society and its agricultural production within a certain area. Ecological elements are the basic components of multi-scale ecological patterns, among which ecological site conditions such as geology and topography directly determine the type and spatial configuration of surface ecosystems. Therefore, the basic ecological structure resistance to mountainous area development is determined by both the stability of the geological environment and the flatness of the topography. In other words, the more stable the geology and the flatter the terrain, the lower will be the ecological resistance to mountainous area development (Peng et al., 2016).

**Ecological functional resistance**

Ecological functional resistance is determined from the ecological importance assessment. The ecological function is the integrated characterization of a variety of ecological processes, as well as the external manifestation of the close relationship between natural ecosystems and human demands (Xiao and Chen, 2002). Human activities interfere with normal natural ecological processes and ecosystem services by changing ecological patterns, especially land use or land management patterns (Cotter et al., 2014). Therefore, when developing mountainous areas, maximum protection of the ecological foundation, the ecological environment, and their evolution processes must be ensured (Xie, Yao, and Wang, 2014). An ecological importance assessment is helpful in understanding the spatial differentiation rules of ecosystem services and then dividing the crucial spatial patterns accordingly (Naidoo et al., 2008). The higher the level of ecological importance, the greater will be the ecological risk of mountainous area development; moreover, ecological resistance will also increase proportionately.



**Ecological dynamic resistance**

Ecological dynamic resistance is determined from the ecological resilience assessment. Ecological resilience measures the ability of an ecosystem to resist disturbances and return to a steady-state in the face of eco-destruction resulting from external interference (Alberti and Marzluff, 2004; Gunderson and Holling, 2002; Li, Qian, and Wu, 2014; Wu, 2013). Higher ecological resilience indicates a greater capacity for self-recovery and self-updating to counteract disturbance or damage, as well as less ecological risk and lower ecological resistance to construction in mountainous areas.

## 2.2 Literature reviews

### 2.2.1 Landscape classification

Landscape classifications in the past are based on classifications of geographical regions and are often holistic and generic in nature. Examples are the landscape regions of Estonia by Granö (1929), and the landscape regions of Belgium (Christians and Daels, 1988). More recent typologies are based on GIS-overlay of digital thematic maps, using spatial and statistical analysis to define landscape types (Lioubimtseva and Defourny, 1999; Mücher et al., 2010; Van Eetvelde and Antrop, 2009). In general, landscapes are classified in a typology or chorology, based on the definition of landscape units as landscape types or as spatial units.

A landscape typology is a systematic classification of landscape types based on attributes that describe properties of interest, such as land use, scenic properties, or cultural characteristics or history. Landscape types are defined by unique relations between natural components (such as geology, soil, morphology, land cover) and human components (such as settlement and field patterns, land use, building, and farming styles). Landscape types are generic in nature: they may occur in different areas and in different geographical contexts. They often reflect a specific landscape history or are formed by specific processes. Important examples are an open field and enclosed landscapes, pastoral landscapes, polder land, heathland, and Mediterranean polycultures, such as the montado and dehesa (Meeus, 1995; Pinto-Correia and Vos, 2004).

Landscape chorology focuses on the spatial patterns formed by different landscape types to form unique spatial arrangements with a distinct identity. They are often unique, which is reflected by a proper given name to the area. Landscape chorology is part of defining geographical regions. It is a hierarchical spatial classification at different scale levels. In classical land evaluation, landscape typology and chorology are often combined (Zonneveld, 1994).

Two methodological approaches exist for making landscape classifications: the holistic and the parametric methods.

The principle of the holistic method is to start with a hierarchical chronological subdivision of an area. This approach developed strongly with the use of aerial photographs, introduced in landscape studies by (Troll, 1939), offering a detailed and synoptic view of the landscape in a bird's eye perspective. The procedure is very similar to analog photo interpretation and is highly based on the Gestalt-abilities of our perception in interpreting complex patterns. The holistic method starts with building a spatial framework that becomes gradually filled when more detailed information becomes available. It is typically a process of zooming in on the landscape.

The parametric method starts from overlaying a set of thematic maps, forming a composite map where the overlay polygons define the landscape units or patches and the combined themes describe the landscape types (Mitchell, 1973). This technique becomes very popular when GIS and digital maps are available. The process is rather one of zooming out on the landscape, making aggregations and generalizations.

### 2.2.2 Delphi method for selecting criteria and indicator

Delphi method is widely used to inventory scientific consensus. When used correctly, the method can contribute significantly to broadening knowledge between experts. This method has been shown to be a reliable qualitative research approach with the potential to solve problems to contribute to decision-making and reach a group consensus in a wide variety of areas (Cochran, 1983). This method is widely used and is accepted by many researchers in Vietnam (Hai, Hai, Y, and Hens, 2009).

For monitoring ecotourism sustainability in the Northern forest of Iran, Barzekar, Aziz, Mariapan, and Ismail (2011) had used Delphi method to identify criteria and indicators with the principle goal to ensure the objectives of forest management, and at the same time, maintain processes in a sustainable manner. Indicators covered aspects of social, ecological, cultural, economic and institutional factors affecting the sustainability of ecotourism. Three rounds of meetings were held for discussions and dissemination of research to a panel of local experts. At the end of the second round, a consensus on 9 criteria and 61 indicators had been reached. They included 21 indicators related to ecological aspects, 8 to economic aspects, 21 to social aspects, 6 to cultural aspects and 5 to institutional aspects. The selected indicators would be applied by the Iranian Cultural, Heritage, Handicrafts and Tourism Organization for monitoring ecotourism sustainability in the Northern forest of Iran.

Delphi method was also applied for criteria selection in site survey of oil jetties in Iran (Hasanzadeh, Danehkar, and Pak, 2012). This study was to identify, select, and prioritize the environmental and technical criteria for site evaluation. The results showed that the “Sensitive coastal area” was the criteria with the greatest percentage of importance. After that “Depth”, “Marine meteorology”, and “Possibility of bigger ships berthing” were identified as the most, while “Land value” and “Distance to development foundations” were the least important criteria. On the other hand, “Distance to habitat area”, “Threat for locals” and “Human population density” were given the least percentage of usage among others. Then the “Ecologic” criteria can be introduced as the most and “Social” one as the least crucial criteria in oil jetties’ site survey. All the results revealed the high efficiency of the Delphi method for criteria selection of site survey for oil jetties.

In Vietnam, Hai et al. (2014) applied the Delphi method to select a system of sustainability indicators for the Thai Binh province. These indicators are a basis to measure sustainability and to direct policies that aim to achieve a better quality of life. A two-round questionnaire was organized to use with 32 experts, who acted as participants. 69 indicators were selected from 98 listed indicators: 15 related to economic development, 5 to the sea and coastal zone, 1 to the global economic partnership, 4 to consumption and production patterns, 7 to poverty, 3 to governance, 9 to health, 4 to education, 3 to demographics, 2 to natural hazards, 5 to atmosphere, 7 to land status, and 3 to freshwater. Conversely, 29 other indicators were rejected. In addition, Hai, Hai, Khoa, and Hens (2009) applied the Delphi method to select a system of sustainability indicators for Quang Tri province, 37 indicators were selected from 39 listed indicators. They include 17 related to the social aspects, 12 to the environmental aspects, 3 to the economic aspects, and 5 to institutional aspects. The application of the Delphi method in these studies allows indicator selection for identification of the process of sustainability. The system of indicators, as the first important step of the sustainable development process, provides useful information for decision makers and planners as well sustainability strategy. It is planned that the indicators selected should be applied in these provinces.

In conclusion, the Delphi approach is an effective method to select indicators. It is a research approach for gaining consensus through the utilization of questionnaires and the provision of feedback to participants who have expertise in key areas. While there are many potential applications of the Delphi method, it is obvious that this method has been widely used for generating criteria and indicators.

### 2.2.3 Landscape metrics in planning and biodiversity conservation

The successful protection of biodiversity requires the preservation of adequate habitats and ecosystem functioning in the context of the entire landscape complex at various spatial and temporal scales. Particularly considering future land use changes which will increase further and expected climate change, landscapes with high geomorphological heterogeneity are considered important. Therefore, in planning and nature conservation, landscape metrics have more and more attention. An understanding of the importance of the landscape matrix is important for maintaining diversity.

Indeed, landscape metrics have an important and diverse role in planning through their applications. Landscape metrics can be used to characterize individual landscape elements (e.g., individual patches), collections of landscape elements of the same type (e.g., unique patch types or land cover classes), and entire collections of diverse landscape elements (e.g., entire patch mosaics). Thus, landscape metrics can be used to characterize a wide variety of spatial patterns.

Ongsomwang and Srisuwan (2012) applied landscape metrics (Dominance, Contagion, and Fractal dimension) to assess status and change of forest landscape type at landscape and class levels in Thap Lan national park. The results showed that all three-landscape metrics of Thap Lan national park and its 5 km buffer zone in 1987, 2005 and 2007 had continued to decrease. These results imply that Thap Lan national park and its surroundings became a more fragmented landscape in the past 20 years.

Ongsomwang and Ruamkaew (2013) applied landscape matrices to quantify agricultural and forestry landscape sustainability of Lamtakhong Watershed, Nakhon Ratchasima, Thailand. analyze the landscape pattern of the agricultural and forest landscape of Lamtakhong watershed, Nakhon Ratchasima, Thailand. In this study, the extracted and predicted land use and land cover data from 1993 to 2025 were used to classify landscape types by the majority of land use and land cover. The derived landscape types were then applied for status and change assessment and sustainability evaluation. The results showed that from 1993 to 2025 the most dominant landscape was the agricultural landscape and the least abundant landscape was miscellaneous landscape. Meanwhile, the development of landscape types indicated that urban, agricultural, and miscellaneous landscapes had continued to increase but the forestry landscape had successively decreased. The overall sustainability level of the agricultural and forestry landscape from 1993 to 2025 was moderate. However, the sustainability of agricultural and forestry landscape had continuously declined in terms of gains and losses in the past and would continue to do so into the future.

Likewise, Ongsomwang and Sutthivanich (2014) utilized remotely sensed data and forest landscape pattern analysis with 14 landscape metrics to determine the priority for forest restoration and management plans in Sakaerat Biosphere Reserve (SBR) in Nakhon Ratchasima, Thailand. It was found that SBR landscape pattern change variation occurred with increasing in fragmentation and diversity but decreasing in the core area and shape complexity from 1980 to 2002, and all these indices values were slightly changed from 2002 to 2010. Furthermore, the trends of change in the indices' values of forest landscape types in each SBR management zone (core, buffer, and transition zones) were subsequently used in relation to gains and losses in the context of forest landscape ecology to set up the priority levels of recommendations on a forest restoration and management plan. This evaluation showed that the priority level of natural forest and disturbed forest landscapes was moderate and high in all management zones, respectively, whereas the priority level of forest plantation landscape was high in the core and transition zones, and moderate in the buffer zone.

The studies mentioned above had made a clear view of using landscape metrics to quantify spatial patterns which can affect a wide variety of ecological processes. Because of the relationships between spatial patterns and processes, landscape metrics can inform planners about landscape functions, which are often difficult or impossible to measure directly. In this regard, landscape metrics can help answer questions such as: "Which alternative landscape design results in the least habitat fragmentation, or maintains the greatest degree of habitat connectivity?" Planners often work with qualitative relationships in the form of "is scenario one better than scenario two for species y?" (Jongman, 1999). In such cases, landscape metrics provide quantitative scientific information that can lead to insights about qualitative relationships.

Landscape metrics can also be particularly useful as environmental indicators, and as proxies or surrogates for difficult-to-measure variables needed by complex ecological models. Similarly, due to the high complexity of natural systems, it is very difficult, if not impossible, to assess every aspect of biodiversity (Treweek, 2009). Landscape metrics can provide a measure of the amount and spatial configuration of land cover types (e.g., natural communities), and thereby provide a "coarse-filter" assessment of biodiversity. In addition, landscape metrics can provide insights about the spatial distribution of suitable habitat for individual species of concern, and thereby may also serve as part of a "fine-filter" assessment of biodiversity.

Landscape metrics can also be used for monitoring biodiversity. The monitoring of biodiversity is carried out almost at the level of species diversity. It is obvious that landscape metrics must always be selected for different tasks or problems and in accordance with the available resources. A single index, or always the same set of indices, is not automatically appropriate for all study objects. Similarly, because of their complexity, a combination of indices should generally be preferred to individual indices for the estimation of biodiversity. Nowadays due to sophisticated sensor technology and resolution, as well as better availability of data, remote sensing, in combination with climate and environmental data, could lead to a more precise characterization of landscape diversity, and thus a better assessment of species diversity.

Landscape metrics are used for habitat modeling of individual species or species groups, e.g., by Dormann (2004); Fauth, Gustafson, and Rabenold (2000); and Fernández, Delibes, and Palomares (2007). For example, Steiner and Köhler (2001) were able to show the existence of a clear dependence of the species diversity on landscape structure in model experiments. With a decreasing degree of landscape heterogeneity in the model, both local and regional species diversity also decreased. The importance of considering space, habitat structure and landscape patterns was also illustrated by Dormann (2004).

Moreover, landscape metrics were used for the selection of protected areas (Harrison and Fahrig, 1995; Sundell-Turner and Rodewald, 2008), the evaluation of the landscape (Leitão et al., 2012), the analysis of equipment deficiencies of the landscape, or it was used as an assessment tool in strategic landscape planning (Herbst, 2007).

In summary, landscape metrics can help improve the theoretical foundation of the methods of landscape planning and nature protection, with the goal of sustainability. Examples of the use of landscape metrics in spatial planning can be found in landscape planning, in the design of ecological networks and in nature conservation. The following table shows several landscape metrics that have been used and repeatedly mentioned in the field of biodiversity (Table 2.1).

**Table 2.1** Important landscape metrics in the field of biodiversity.

| Function | Index | Source |
|---|---|---|
| Prediction and assessment of biodiversity | (1) habitat diversity (number of habitat types per unit area), (2) habitat heterogeneity number of habitat patches, lengths of ecotones per landscape unit, (3) portions of natural, semi-natural and intensive land use | Duelli (1997) |
| | Surface area of semi-natural ecosystems | Leitão et al. (2012) |
| | Patch distribution, edge and patch density | Bailey, Billeter, Aviron, Schweiger, and Herzog (2007) |

**Table 2.1** (continued).

| Function | Index | Source |
|---|---|---|
| Prediction of species diversity | Patch Density PD, Largest Patch Index LPI, | Bailey et al. (2007) |
| | Simpson's Diversity Index SIDI, Proximity | Strand (2007) |
| | PROXMN, Patch Richness PR, Edge density ED, Euclidean Nearest Neighbor ENNCV, Circumscribing Circle, CIRCMN, Number of species, population sizes, number of viable populations and habitat area, Landscape diversity, the intensity of agricultural use, frequency weighted absolute species richness of vascular plants | Tasser, Sternbach, and Tappeiner (2008) |
| Planning of biotope network | Proximity Index | Kiel and Albrecht (2004) |
| | Density of landscape elements, indices of connectivity/ isolation | Baguette and Van Dyck (2007) |
| Assessment of protected areas, habitat requirements of species of the core areas and edges | Total Core Area TCA, Total Class Core Area TCCA, Number of Core Areas NCA, Core Area Index CAI | Bock et al. (2005) |
| Landscape fragmentation | Effective mesh size | Jaeger (2000) |
| | Area of unfragmented open spaces | Fuer Naturschutz (2008) |
| Quantification of the floristic diversity (habitat function) | Shannon Diversity SHDI, Number of different classes and their distribution | Herbst (2007) |
| Smallness, shape richness of a landscape (natural spatial diversity) | Edge density ED, Density of patch boundaries or linear elements in a landscape, Length of contour lines per area, the elevation difference between highest and lowest point, river length and area of surface waters | Herbst (2007) |
| Diversity of land use | Diversity of main land use types, length of forest edges, field sizes | Stachow (1995) |
| Floristic species richness (general) | Distance (isolation) to usable habitat, largest patch index LPI, patch size coefficient of variation PSCV | Grashof-Bokdam (1997); (Butaye et al., 2001) |
| Faunal species richness | Road density, forested area, distance to the nearest built-up area, the density of human settlements, degree of soil imperviousness | Sundell-Turner and Rodewald (2008) |

**2.2.4 Landscape ecological suitability evaluation for development and construction using ecological resistance approach**

With the acceleration of urbanization and industrialization, a large amount of farmland and woodland in mountainous areas have been occupied by urban and construction land. Regional development is becoming increasingly disordered, leading to resource overload and ecosystem destruction. The sustainability of regional development is threatened. How to balance economic development and ecological protection is the key to sustainable development (Collin and Melloul, 2001; Zhang, Fu, Zhang, Tao, and Fu, 2014). Scientific and comprehensive ecological suitability evaluation has been recognized as being critical for assessing the land suitability for specific use and planning for future land use and management (e.g. ecological suitability evaluation for land construction model) (Joerin, Thériault, and Musy, 2001). As a result, the process of landscape ecological suitability evaluation using the ecological resistance approach is of great interest to researchers.

To overcome the shortage in traditional methods of land ecological suitability evaluation, Chen-jing, Shi-guang, Si-hui, Guang-hui, and Xin-yi (2011) established a gravity-resistance model based on physical motion principle and applied in Deyang, China. This model simulated two processes - gravity and resistance evaluation to assess land ecological suitability evaluation, factors of gravity and resistance which are crucial to the construction are selected according to the rules of stability, independence, representativeness. The weights of gravity factors were determined by AHP and the scores of resistance factors were determined by the Pessimistic Decision Method. Based on the gravity-resistance model, Deyang was divided into four zones: prohibited, restricted, optimized and key areas, which are 40.45%, 16.23%, 23.77%, and 19.54% respectively.

In a case study in Changzhou, China Li, Ye, Song, and Wang (2015) applied the minimum cumulative resistance model (MCRM) to calculate the amount of ecological land (e.g., arable land, forest, grassland, wetlands) that meets the demand of socioeconomic development and ecological protection considering the source of ecological land and constructed land (e.g., residential, commercial, industrial land), ecosystem services, and the resistance plane. Results showed that the suitable ecological land area is about 1006.9 km2, which is 53.8% of the total urban area of Changzhou and is mainly distributed in Wujin and Xinbei districts. Considering the ecological land space and functional changes in the study area and comparing the current land use status with the model simulation results, three land use types were proposed. For urban ecological land, positive protection measures and prohibiting economic development initiatives are necessary. For ecotones between urban developed land and ecological land, protection should be given priority and economic development activities should be rigidly controlled. For constructed land, measurements and policies should be taken to promote reasonable development and improve land intensity.

Xu, Kong, Li, Zhang, and Wu (2011) had analyzed and compared K-means clustering and BP neural network in a study of evaluation of urban construction land using geo-environmental factors in Hangzhou, China. This study involved a consideration of the geomorphology, geology, engineering geology, geological hazards, and other geological factors. The results showed that the geo-environmental suitability evaluation results of construction land using K-means clustering and BP neural network were similar in terms of the distribution and scale of construction land suitability level. At the same time, the results of the two evaluation methods were consistent with the variability in suitability level, engineering geology, and hydrogeology of Hangzhou. The results also showed that the suitability level of the urban construction land based on the geo-environment in Hangzhou was divided into four construction sites: land for building super high-rise and high-rise buildings, land for building multistory buildings, land for low-rise buildings, and non-building land. This result provided a scientific basis for decision-making in urban development in Hangzhou.

Zong et al. (2007) also conducted ecological suitability assessment in the Dalian city region by developing a domestic widely-used weighted factor-overlay method and extending it to a weighted potential-constrain approach which is originally from a cost-benefit analysis. The main advantage of this approach is to divide the assessment factors into two groups, one contains ecological potential factors, and the other the ecological constraint factors, to choose the factors under the principle intensively of data obtainable, and to determine their weights by choosing exact means. The employment of this approach could help to determine the ecological suitability classes more scientifically and reasonably. The analysis showed:(1) the area that could be intensively developed for urban construction purpose is 850.46 km$^2$ in Dalian city region, being about 6.28% of the total study area; (2) the area that could be developed moderately for construction purpose is 1,835.97 km$^2$, or about 13.56% of the total area; and (3) the area that could not be used or being moderately and lightly suitable for construction is 10,851.92 km$^2$ or about 80.16% of the total area. Furthermore, four planning zones of construction improvement zone, construction emphasized zone, construction restricted zone and construction forbidden zone could be worked out, in which the development strategies and implementations in each zone are suggested.

In conclusion, most previous evaluation systems have placed more emphasis on the number of factors selected, while failing to demonstrate a logical framework for the evaluation model in a complete and clear way. Like traditional suitability evaluation methods, most of these evaluation systems include ecological constraints simply by adding ecological factors into the model, rather than investigating the supporting or limiting role that natural ecological factors play in land development and construction. Meanwhile, existing ecological suitability assessments are all good at the quantitative characterization of ecological components, especially their static spatial patterns. However, from a macro-ecological perspective, components with various ecological functions simultaneously participate in a variety of ecological processes, and the ecological environment is closely associated with human social and economic activities through various mass and energy flows. Therefore, it is necessary to explore an ecological suitability evaluation method including dynamic ecological processes to improve the robustness and reproducibility of the ecological suitability evaluation for the land construction model.

# CHAPTER III

# RESEARCH METHODOLOGY

The overview research methodology framework in this study according to the research objectives consists of data collection and preparation and five main components include (1) landscape classification and characterization, (2) significant factor identification for ecological resistance evaluation to construction, (3) ecological resistance evaluation for construction, (4) landscape ecological analysis for biodiversity conservation, and (5) ecological suitability zoning for mountainous area development and biodiversity conservation (Figure 3.1). Brief information of each component with major tasks are separately summarized in the following sections. Meanwhile, details research methodology of each component were described in the following chapters.

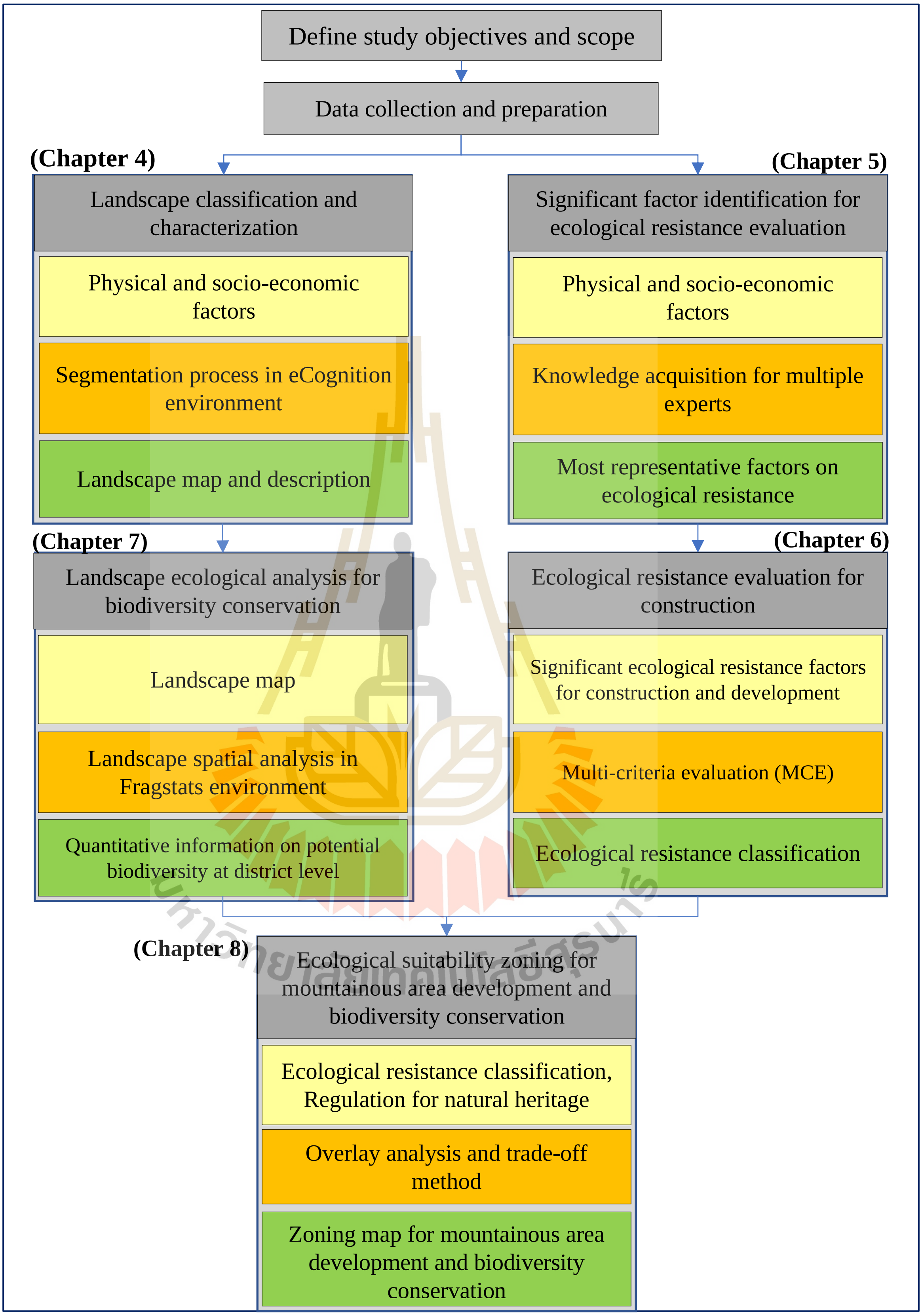



**Figure 3.1** The overview of research methodology framework.

## 3.1 Data collection and preparation

The collected and prepared data which include remotely sensed data and GIS data are summarized in accordance with relevant main components in Table 3.1.

**Table 3.1** Data collection and preparation.

| Data collection | Data preparation | Scale | Source | Component |
|---|---|---|---|---|
| Geology map | Reclassification | 1:100,000 | 1. Bac Kan Department of Natural Resources and Environment<br>2. Institute of Geography (VAST) | 1, 3 |
| DEM | Elevation and slope extraction | 30 m resolution | Department of Surveying and Map | 3 |
| Topography map | Terrain extraction | 1:100,000 | Department of Surveying and Map | 1, 4 |
| Soil type map | Reclassification | 1:100,000 | 1. Soils and Fertilizers Research Institute<br>2. Institute of Geography (VAST) | 1 |
| LULC type map | Reclassification | 1:100,000 | Bac Kan Department of Natural Resources and Environment | 1, 3, 4 |
| Elevation | Extract from DEM | | - | 3 |
| Slope | Extract from DEM | | - | 3 |
| General disaster map | Area extraction | | Bac Kan Department of Natural Resources and Environment | 3 |
| Fracture zones location | Area extraction | | Bac Kan Department of Natural Resources and Environment | 3 |
| NDVI | Extract from Satellite imagery | | | 3 |
| Natural park and reserves map | Area extraction | | Bac Kan Department of Natural Resources and Environment | 3 |

**Table 3.1** (continued).

| Data collection | Data preparation | Scale | Source | Component |
|---|---|---|---|---|
| Population | Extract from Bac Kan provincial office | | People's Committee of Bac Kan Province | 3 |
| GDP per area | Extract from Bac Kan provincial office | | People's Committee of Bac Kan Province | 3 |
| Annual rainfall | Interpolation | | National Centre for Hydro-Meteorological Forecasting | 3 |

## 3.2 Landscape classification and characterization

Under this component, two processes were implemented: landscape classification and landscape characterization.

For landscape classification, multi-level segmentation techniques (Burnett and Blaschke, 2003; Lucas, Rowlands, Brown, Keyworth, and Bunting, 2007) which were successfully applied in LANMAP methodology (Mücher et al., 2010) was used to identify landscape units. Segmentation (object recognition based on spatial characteristics) is the process of identifying spatial units, which are mostly derived from satellite imagery, was implemented using the eCognition software, which is object-oriented image segmentation and classification software for multi-scale analysis (Trimble, 2014).

For landscape characterization, the derived landscape units of Bac Kan were described based on landscape typology which is a hierarchical naming process for every landscape type at four levels by a combination of geology, topography, soil and land use. The first level is geology, followed by the second level with a combination of geology and topography. At the third level, every unit is a combination of geology, topography, and soil and the fourth level, which is the full detail of the classification, is made of all criteria, geology, topography, soil, and land use.

## 3.3 Significant factor identification for ecological resistance evaluation to construction

Based on the conceptual framework of integrated ecological resistance to construction in mountainous areas as suggested by (Peng et al., 2016), this component concerned with the selection of factors (criteria) that describes ecological elements, ecological importance and ecological resilience, which had been successfully applied to characterize the resistance of ecological structures, ecological functions, and ecological dynamics to construction in mountainous areas. The process of factors selection was implemented using the Delphi method. The Delphi method is an iterative process that is designed to achieve a consensus among a group of experts on a specific issue. This method is one of the most effective means for participants (experts) to identify criteria or indicators. It is an excellent way to generate a consensus of expert opinion when solid scientific data is unavailable (Barzekar et al., 2011).

To implement a survey using Delphi method, a variety of factors (criteria) that represent for each group ecological elements, ecological importance, and ecological resilience was firstly reviewed from a wide range of sources, particularly research papers (Table 3.2).

**Table 3.2** Criteria and indicators of ecological resistance for construction and development.

| Criteria | Indicator | Reference |
|---|---|---|
| Ecological elements | 1. Vegetation type | Schutsky, Kaufman, and Signell (2006) |
| | 2. Soil type | Coleman, Callaham, and Crossley (2018) |
| | 3. Soil depth | Coleman et al. (2018) |
| | 4. Elevation | Peng et al. (2016) |
| | 5. Slope | Peng et al. (2016) |
| | 6. Geological hazard frequency | John (2018) |
| | 7. Rock type | DiPietro (2018) |
| | 8. Distance to fracture zones | Indra and Nikhil (2002) |
| Ecological importance | 9. Importance of biodiversity protection | McDonald (2013) |
| | 10. Importance of water retention | Peili, Bo, Genwei, and Ji (2004) |
| | 11. Importance of soil conservation | Peng, Li, and Zhang (2007) |
| Ecological resilience | 12. Vegetation stability | Belov and Sokolova (2008); Gunderson (2000) |
| | 13. Ecological sensitivity | Chi et al. (2019); Gunderson (2000) |
| | 14. Social disturbance intensity | Gunderson (2000); Peng et al. (2016) |

Secondly, 10 experts were invited to identify criteria or indicators using the Delphi method. They are experienced in different fields of their areas of interest. Dalkey and Helmer (1963) mentioned that a Delphi group possesses the largest confidence when the number of experts at least 10.

In this study, the identification process was planned in 2 rounds. For the first round, a formal letter with an enclosed questionnaire was send to experts. The first-round questionnaire is open-ended and designed to select indicators of each factor for ecological resistance evaluation. The questionnaire was presented in a uniform manner to experts to ensure that they can give the rating regarding each initial indicator and suggest other relevant indicators of three factors.

After receiving the first-round response, the information was summarized, collated, categorized and tabulated into the second questionnaire for the second round. Then, the second questionnaire which incorporated a feedback report was redistributed to the first-round respondents. And again, they was asked to give their rating. The goal of the second round and any other subsequent round (if it requires) using questionnaire was to achieve a consensus or stability of expert' response. Once the consensus or stability is reached, the Delphi procedure is completed. The Delphi method ends when all questionnaire items are either accepted or rejected or over 75% questionnaire items have their rating variant values being less than 15%. The rules for employing the Delphi technique are given in Table 3.3.

**Table 3.3** Rules to analyze the ratings from multiple experts using a Delphi approach.

| Round t for Delphi questionnaire | Round t + 1 | Round t + 2 |
|---|---|---|
| Rating mean (qi) ≥ 3.5 | If rating mean (qi) ≥ 3.5 and Q ≤ 0.5 and rating variant (qi) < 15%. Then qi is accepted, and no further discussion concerning qi is needed. | |
| Rating mean(qi) < 3.5 | Rating mean (qi) ≥ 3.5 or rating variant (qi) > 15% | If rating mean (qi) ≥ 3.5 and Q ≤ 0.5 and rating variant (qi) ≤ 15%. Then qi is accepted, and no further discussion concerning qi is needed |
| Rating mean(qi) < 3.5 | IF rating mean (qi) < 3.5 and Q ≤ 0.5 and rating variant (qi) ≤ 15%. Then qi is rejected, and no further discussion concerning qi is needed | |

**Source:** Chu and Hwang (2008).

Where, rating mean (qi) represents the mean of the ratings for questionnaire item qi, rating variant (qi) represents the ratio of experts who change their ratings for qi, and Q is the quartile range.

## 3.4 Ecological resistance evaluation for construction

According to the integrated ecological resistance (IER) for construction in mountainous areas, excellent ecological suitability for construction in mountainous areas implies an IER as low as possible. Given the ecological matrix of the study area, an IER index system for construction in mountainous areas can be generated as follows:

$$IER = \omega S \times S + \omega I \times I + \omega R \times R \quad (3.1)$$

Where, ωS, ωI, ωR are the weights of the indices. Given that structures, functions, and dynamics are interdependent for the entire ecological environment, equal values were given to these three indices, namely ωS = ωI = ωR = 0.33.

S represents the ecological structural resistance characterized by ecological elements,

I refers to the ecological functional resistance represented by ecological importance,

R is the ecological adaptation resistance measured by ecological resilience. Ecological elements, ecological importance, and ecological resilience were evaluated based on the finalized factors using the Delphi method as suggested in Table 3.2.

### 3.4.1 Assessment of ecological elements

Ecological elements constitute the ecological structural resistance to construction in mountainous areas and are determined by elevation, slope, and other terrain conditions including geological disaster frequency, and distance to fracture zones. The weight of each index was determined using the Analytical Hierarchy Process (AHP).

Herein, elevation and slope were both graded into five categories from level one to level five using the natural breaks method. The resistance level goes up with increasing elevation and slope.

Moreover, the kernel method was used to represent the spatial characteristics of the occurrence frequency of general geological disasters. The frequency of these disasters goes up with increasing disaster-site density, as do the risk of construction and resistance to construction in mountainous areas. The development resistance values resulting from general geological disasters was graded into five categories using the natural breaks method.

Furthermore, the distance to fracture zones can be used to estimate the incidence of related disasters. Therefore, the construction resistance caused by this factor was classified on a descending scale from level 5 to level 1, with the levels corresponding to increasing distance to fracture zones (0–200 m, 200–500 m, 500–1000 m, 1,000–2,000 m, and greater than 2,000 m). The distance from 0 to 200 m is given the highest level of resistance since construction is not suitable within 200 m of a fracture zone.

The final evaluation of ecological structural resistance represented by ecological elements is the weighted sum of all the indices described above, which are respectively connected with elevation, slope, occurrence frequencies of general geological disasters, and distance to fracture zones.

### 3.4.2 Assessment of ecological importance

Construction and development must ensure that natural floral and faunal habitats will not shrink, and that habitat quality will not be degraded greatly. Moreover, the study area has experienced serious soil erosion in recent years due to the heavy rain and the denuded mountainous ecological background that has continuously disturbed from human activities. Therefore, considering the actual conditions in Bac Kan province, it is meaningful to identify the spatial distribution pattern of ecological importance using three vital ecological processes: (1) biodiversity protection, (2) water retention, and (3) soil conservation. The higher the level of ecological importance, the greater will be the resistance to mountainous area construction.

Based on the average value per unit area of ecosystem services to maintain biodiversity in China as suggested by (Xie, Zhen, Lu, Xiao, and Chen, 2008), the relative importance of biodiversity protection in different ecosystems is assessed. In this study, the final resistance grade for biodiversity protection is linked with existing ecosystem types of Vietnam and it was classified into 5 levels.

Meanwhile, the relative importance of water retention is also assessed according to vegetation type in Bac Kan province as suggested by Peili et al. (2004) who applied forest vegetation types in the upper Yangtze basin for water retention evaluation. The final resistance grade for water retention is linked with vegetation types as follows:

Level 1 corresponds to non-forested land;

Level 2 includes young afforested land, non-stumpage forests, nurseries, grazing land, agricultural land, and land suitable for afforestation;

Level 3 covers shrubland, economic forests, and thin forests;

Level 4 includes needle forests and;

Level 5 refers to broadleaf forests, bamboo, and water.

In the meantime, to assess the importance of soil conservation, the universal soil loss equation (USLE) was used. Several factors are applied in the USLE model including the soil erodibility factor (K), the rainfall erosivity factor (R), the topographic factor (LS), the soil and water conservation factor (P), and the vegetation coverage factor (C). Then the potential and actual amounts of soil loss were calculated separately, with the difference representing the amount of soil conservation as suggested by (Peng et al., 2007). As the amount of soil conservation grows, the importance of soil conservation increases.

Finally, the ecological functional resistance to mountainous area construction resulting from comprehensive ecological importance can be calculated as an equally weighted sum of such three sub-indicators as the importance of biodiversity protection, water retention, and soil conservation.



### 3.4.3 Assessment of ecological resilience

Using the concept of ecological resilience based on ecological circulation theory and taking great human disturbance into account, representing the temporal dynamic characteristics of a natural ecosystem's self-organization and self-update using the three aspects of resistance, exposure, and interference. These three aspects respectively correspond to detailed indicators include vegetation stability ($S_1$), ecological sensitivity ($S_2$), and social disturbance intensity ($S_3$). Based on the conceptual framework of ecological resilience, the ecological adaptation resistance R can be expressed as:

$$R = \frac{S_1 \times S_2}{S_3} \tag{3.2}$$

Where, $S_1$ is quantified through the variation amplitude of perennial NDVI in the study area and indicates the ability of vegetation to resist interference and maintain its original growth condition in the face of slight environmental fluctuations in temperature, precipitation, and soil properties. By performing a linear regression of NDVI year by year in units of spatial grid cells, the absolute value of the slope, which represents the variation amplitude of vegetation, was determined. Actually, $S_1$ is the reciprocal of the slope. The greater $S_1$ is, the higher will be the resistance stability and the lower the resilience stability, which means higher ecological risk and higher resistance to development activities.

$S_2$ is the reciprocal of distance to the nearest key ecological patch, such as nature reserves. A shorter distance means a greater risk of ecological structural damage or functional degradation when disturbances occur. Therefore, the area in question is more sensitive, and the resistance to construction is greater.

$S_3$ refers to the spatial differentiation in the intensity of human activity in the study area, as expressed by spatial population density. The greater the degree of social disturbance, the lower will be the resistance to construction.

Finally, the integrated ecological resistance framework (IER) for construction was achieved by assessing ecological elements, importance, and resilience using Eq. (3.1).

## 3.5 Landscape ecological analysis for biodiversity conservation

Under this component, the derived landscape map from component (1) was used for the analysis of spatial information using landscape ecological metrics. The basic units for analysis include 8 districts of Bac Kan province. The landscape pattern analysis was performed at landscape levels for the purpose of quantitative biodiversity information extraction and comparison using the Fragstats software.

Four groups of metrics for analysis include landscape heterogeneity, patch shape, patch distance, and patch area. These selected metrics have been demonstrated in many research studies (Baker and Cai, 1992; Cook, 2002; Forman, 2014; Gustafson, 1998; McGarigal, 2014; Romme, 1982; Turner, 1989).

After implementing the process of landscape ecological analysis, a matrix table between 8 districts and 4 landscape metric groups, which are landscape heterogeneity, patch shape, patch distance, and landscape context, was produced to give the ability for comparing potential biodiversity among different districts through the different values. Additionally, the derived index values from landscape ecological analysis were further used to validate the future direction for development and conservation at district level of Bac Kan province.



## 3.6 Ecological suitability zonation for mountainous area development and biodiversity conservation

The ecological suitability classification for construction and development is created based on basis of landscape ecology, it is also necessary to integrate the derived ecological suitability result with the related regulations of the government in order to meet the specific condition of the province for ensuring the sustainable use of natural resources in the future. According to the construction law of Vietnam (NAV, 2014) and the law on the cultural heritage of Vietnam (NAV, 2001), the new construction and development in the protected areas including the national park, nature reserve, and species and habitat conservation areas are prohibited.

In this study, the overlay analysis was applied to assign development zone at the provincial level while the ratio between development and ecological protection areas with the trade-off technique was used to propose a future direction for mountainous area development and biodiversity conservation at the district level in Bac Kan province.

For the validation of spatial arrangement of development at the district level in Bac Kan province, the indices values derived from landscape ecological analysis were used to confirm and assess the reasonableness of the integrated trade-off approach between mountainous area development and biodiversity conservation according to local conditions.

# CHAPTER IV

# LANDSCAPE CLASSIFICATION AND CHARACTERIZATION

The workflow of landscape classification and characterization is schematically displayed in Figure 4.1. Details of two major tasks for landscape classification and characterization were separately described in the following section.

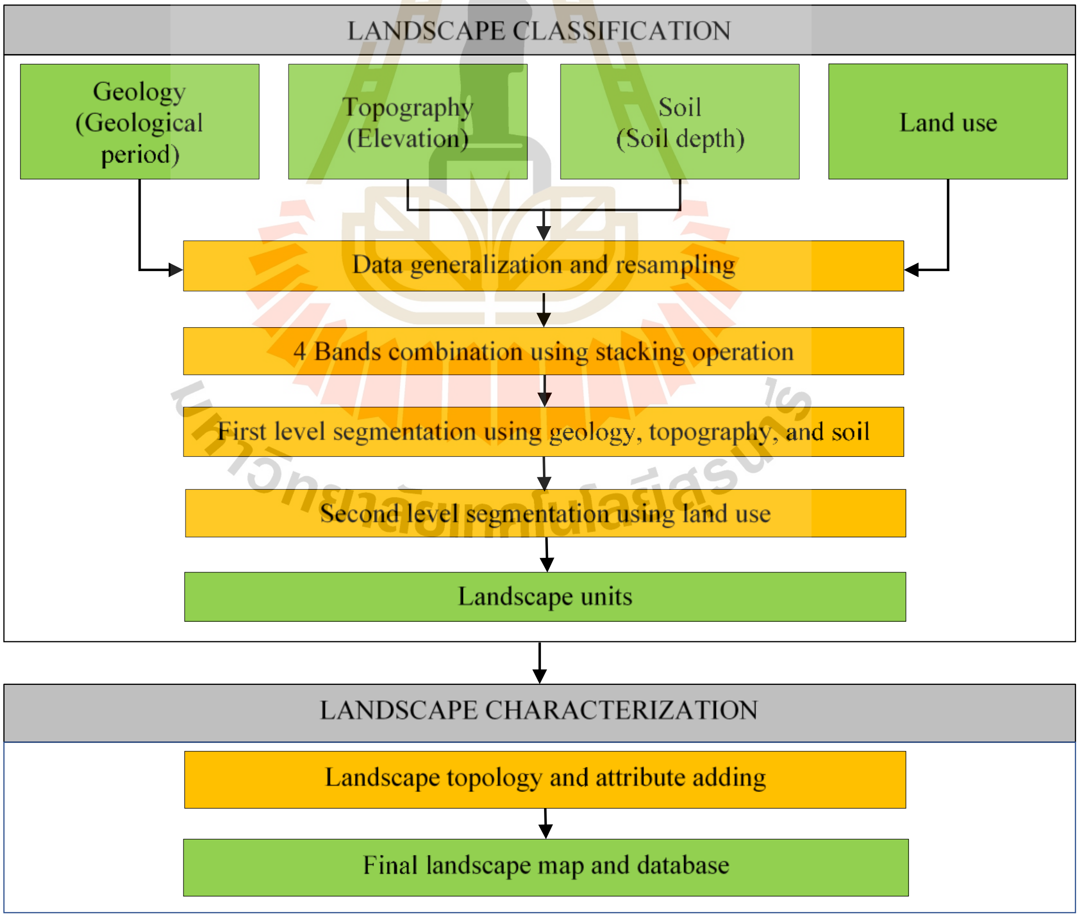



**Figure 4.1** Workflow of landscape classification and landscape unit character.

## 4.1 Physical and socio-economic factors identification

Landscapes are entities where many components and processes interact. It was agreed that landscape is a function of abiotic, biotic and cultural factors (Lipský and Romportl, 2007; Mücher et al., 2003; Mücher et al., 2010) as:

Landscape = Abiotic Components + Biotic Components + Cultural Components (4.1)

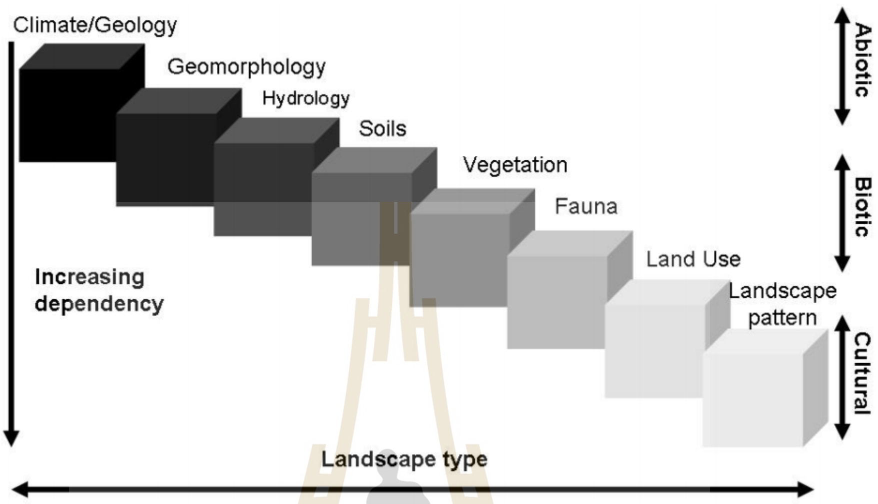
Abiotic components of a landscape are non-living chemical and physical parts of the environment that affect living organisms and the function of the ecosystem, e.g. geology and soil (Hogan, 2010). On the contrary, biotic components include everything that is living, e.g. animals and plants. Finally, cultural components of a landscape include anything that was human-made or influenced, e.g. fences and dams (Schutsky et al., 2006).

Lipský and Romportl (2007) suggested that when characterizing a complex landscape typology based on the synthesis of both natural and cultural features, the use of hierarchical dependency is recommended (Figure 4.2). However, cultural features are too complex to categorize in a simple, comprehensive and internationally accepted way. Thus, how to interpret and classify cultural data have not yet achieved sufficient international consensus and digital data sets of cultural features are rare (Mücher et al., 2010). Therefore, a physico-geographical method which is based on natural features (geology, soils, geomorphology, climate, and potential vegetation) without human activities is the most common for landscape classification and mapping of natural landscapes.

In this study, by considering all the natural (abiotic and biotic) and cultural factors, the equation for landscape formation of Bac Kan province is proposed as shown in Eq. 4.2.

$$\text{Landscape} = f\,(C, G, T, S, LU)\ t \qquad (4.2)$$

Where C is climate, G is geology, T is topography, S is soil, LU is land use, and t is time.




**Source:** Mücher et al. (2003), Lipský and Romportl (2007).

**Figure 4.2** Landscape type as a functional hierarchy of abiotic, biotic and cultural elements.

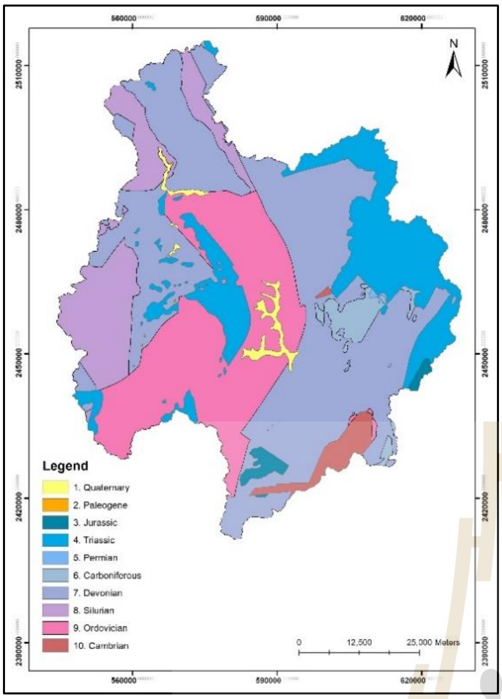
Based on landscape formation equation, climate, geology, topography, and soil is considered as natural factors while land use is here considered as a cultural factor which represents human activity pattern. However, the climate of Bac Kan province only belongs to subtropical-dry winter type (Cwa) which is monsoonal influenced, having the classic dry winter pattern associated with tropical monsoonal climates (Peel et al., 2007), so this factor was not applied for landscape classification. Consequently, Bac Kan landscape classification and mapping were implemented based on geology, topography, soil, and land use factors. Simensen, Halvorsen, and Erikstad (2018) stated that these four criteria were most frequently used to classify landscape units.

The geologic period, which was obtained from the geology map, was here used to represent the continuous process of forming a landscape. In fact, different period affects to rock units and organism development which are the key factors influencing the landscape. Similarly, elevation data, which was obtained from the topography map was applied to classify the landform of the landscape. In the meantime, soil depth, which is a very crucial factor for plant growth, was extracted from the soil map. Likewise, land use, which represents human activities on the landscape, was extracted from the land use map.

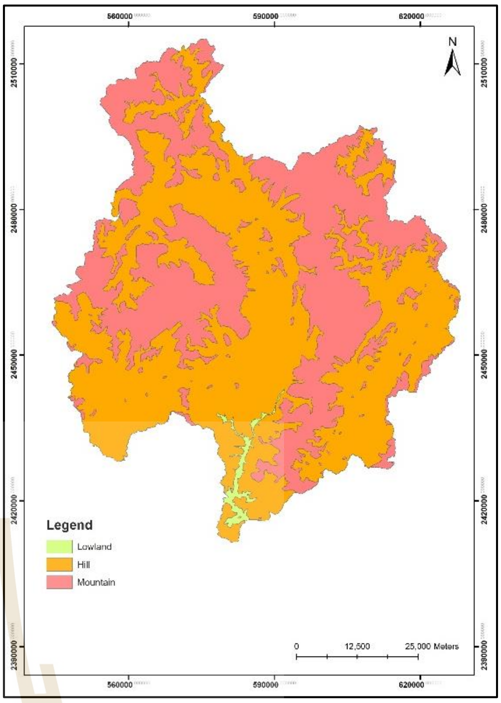
In order to carry out landscape classification process, it was necessary to generalize the original data sources for the integrated segmentation process and also to limit the number of classes that are meaningful for the spatial pattern identification. Therefore, four data layers including geology, topography, soil and land use were here generalized with an acceptable number of classes (Table 4.1). After data generalization, three layers (geology, soil, and land use) were rasterized with 30 m spatial resolution same as the topography layer. Finally, four thematic data layers: geology with 10 classes, topography with 3 classes, soil with 3 classes, and land use with 8 classes, were achieved (Figure 4.3).

**Table 4.1** Basic information after data generalization.

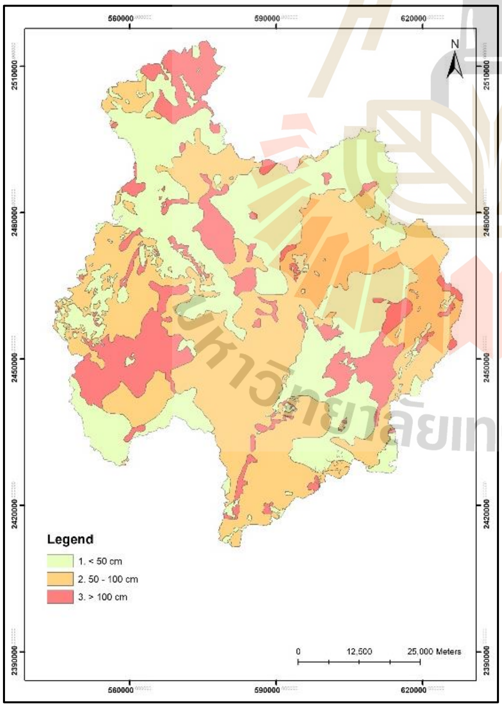
| Geology | | | Topography | | | | Soil | | | | Land use | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *No.* | *Geologic period* | *Code* | *No.* | *Elevation (m)* | *Typology* | *Code* | *No.* | *Soil Depth (cm)* | *Typology* | *Code* | *No.* | *Typology* | *Code* |
| 1 | Quaternary | Q | 1 | 0 - 100 | Lowland | L | 1 | <50 | Shallow | a | 1 | Evergreen broadleaf forest | Ef |
| 2 | Paleogene | Pg | 2 | 100 - 500 | Hill | H | 2 | 50-100 | Moderately deep | b | 2 | Bamboo and wood mixed forest | Bf |
| 3 | Jurassic | J | 3 | > 500 | Mountain | M | 3 | >100 | Deep | c | 3 | Shrub and grassland | Sh |
| 4 | Triassic | Tr | | | | | | | | | 4 | Plantation forest | Pf |
| 5 | Permian | P | | | | | | | | | 5 | Perennial tree and orchard | Po |
| 6 | Carboniferous | C | | | | | | | | | 6 | Paddy field and annual tree | Pa |
| 7 | Devonian | D | | | | | | | | | 7 | Residential area | Ra |
| 8 | Silurian | S | | | | | | | | | 8 | Water surface | Wa |
| 9 | Ordovician | O | | | | | | | | | | | |
| 10 | Cambrian | Ca | | | | | | | | | | | |



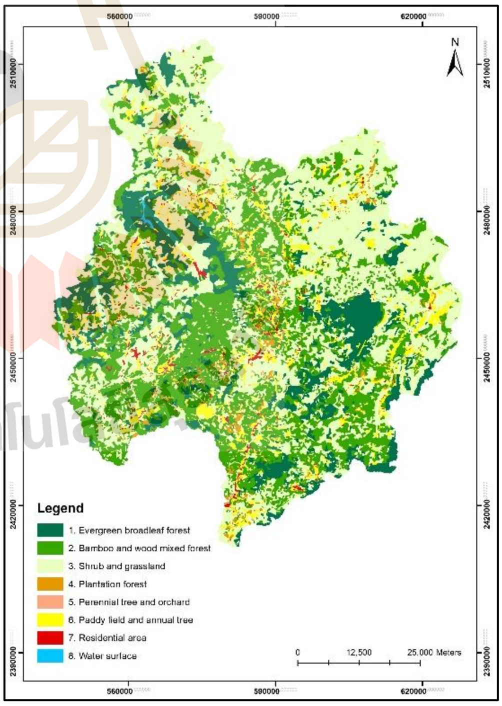

(a) Geology




(b) Topography




(c) Soil




(d) Land use

**Figure 4.3** Input data for landscape classification.

## 4.2 Landscape classification

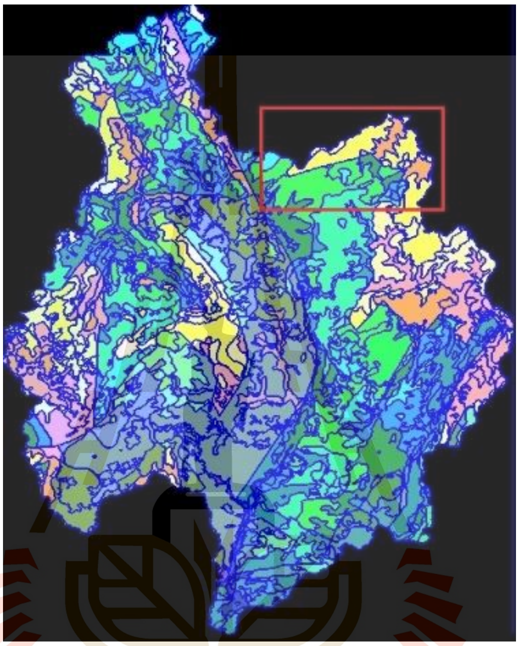
The classification process of the Bac Kan landscape was implemented through the multi-level segmentation technique which is a new approach to build the process on a priori selection of variables based on landscape theory within the applied scientific discipline (Simensen et al., 2018). In this study, a 4-band composite image (i.e. geology, topography, soil, and land use) was built to segment landscape units into two levels.

### 4.2.1 First level segmentation

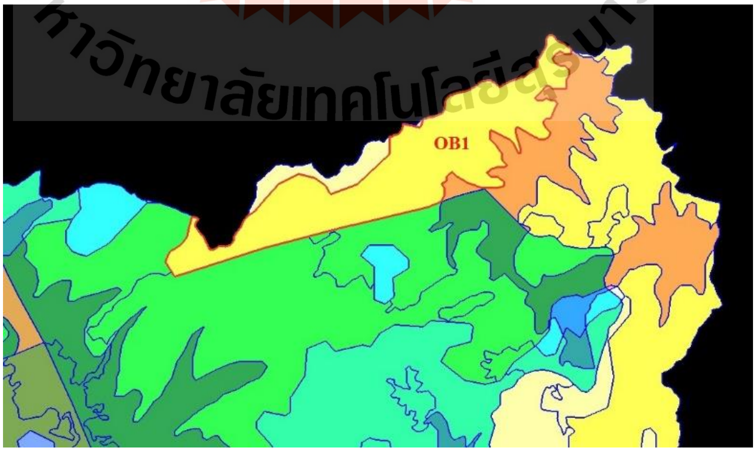
Since three abiotic layers which are geology, topography, and soil have the highest independence of functional hierarchy in the Bac Kan landscape, the image segmentation process at first level was implemented with these three thematic layers by using the multiresolution algorithm. This algorithm is an optimum procedure for minimizing the average heterogeneity and maximizing the respective homogeneity by merging pixels into an image object (Trimble, 2014). Therefore, every created image object contains attributes of thematic layers as related features.

For the first level of image segmentation, only three thematic layers: geology, topography, and soil were applied to segment image object with optimum parameters setting by trial and error. At this level, the scale parameter was set to 30, the shape factor was set to 0, and compactness was set to 0.5. The first level segmentation result was considered to be a fixed matrix since it is based on the relatively static physical data layers. After that, the derived image objects were further segmented at the second level based on the land use data layer which represents cultural factor. At this level, the scale factor was set to 10, the shape factor was set to 0, and compactness was set to 0.5.

The result of image segmentation with a combination of three thematic layers is displayed in Figure 4.4. The number of image objects (landscape units) in the entire study area was 2,710 objects and Table 4.2 shows an example of image object information of object 1 (OB1).



(a) Entire study area




(b) Zoom-in area (red box in a)

**Figure 4.4** Result of segmentation at level 1 using 3 layers (geology, topography, and soil).

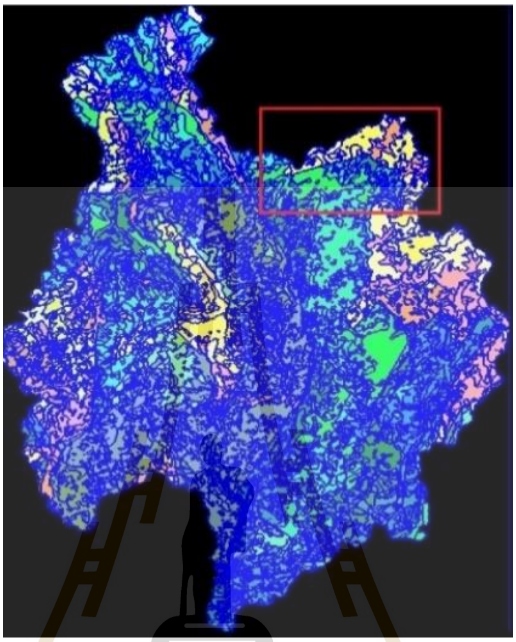
**Table 4.2** Example of image object information of OB1 after segmentation at level 1.

| No | Feature | Value |
|---|---|---|
| | Number of pixels | 48,781 |
| 1 | Thematic object attribute 1 (Code of the geologic period) | Tr (Triassic) |
| 2 | Thematic object attribute 2 (Code of topography) | M (Mountain) |
| 3 | Thematic object attribute 3 (Code of soil depth) | a (Shallow) |

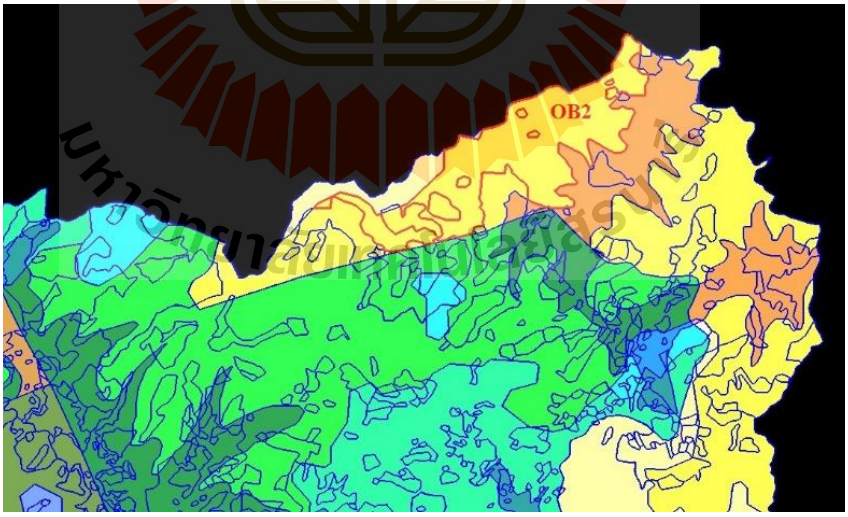
### 4.2.2 Second level segmentation

The second level was considered as the final segmentation result that identified the landscape units based on combination geology, topography, soil, and land use. Then, the final result was exported from the eCognition software to ESRI ArcGIS as shapefile. A last step of post-processing was the removal of small polygons, which were integrated with the (smallest) adjacent polygon. Herein, polygons that are smaller than 0.02 $km^2$ were merged with the adjacent polygon to produce final landscape units according to the minimum mapping unit (Knight and Lunetta, 2003).

In practice, after achieving image objects from Level 1, the segmentation process at Level 2 based on land use thematic layer was carried out. It is obviously observed that the number of image objects dramatically increases at this level. The result shows that a total of 30,633 image objects before data post-processing were segmented for the whole study area (Figure 4.5) because all image objects from segmentation at Level 1 were further segmented with 8 thematic land use classes. Therefore, a significant number of new image objects were created at this level, and a new attribute of land use was added for each image object. Table 4.3 shows an example of image object information of the image object (OB2). In this example, OB2 was defined by the feature of Shrub and grassland (Sh) from land use, other features were adopted from OB1 (Table 4.2).



(a) Entire study area




(b) Zoom-in area (red box in a)

**Figure 4.5** Result of segmentation at level 2 using 4 layers (geology, topography, soil, and land use).

**Table 4.3** Example of image object information of OB2 after segmentation at level 2.

| No | Feature | Value |
|---|---|---|
| | Number of pixels | 29,537 |
| 1 | Thematic object attribute 1 (Code of the geologic period) | Tr (Triassic) |
| 2 | Thematic object attribute 2 (Code of topography) | M (Mountain) |
| 3 | Thematic object attribute 3 (Code of soil depth) | a (Shallow) |
| 4 | Thematic object attribute 4 (Code of land use) | Sh (Shrub and grassland) |

## 4.3 Landscape characterization

After data post-processing, 8,427 landscape units with minimum and maximum areas of 0.02 $km^2$ and 116.63 $km^2$ were approved for landscape typology which was categorized into 4 levels: Level 1, 2, 3 and 4. Figure 4.6 illustrates hierarchical landscape typology with four levels, e.g. "QMb_Ef" represents a combination of Quaternary Mountain with moderate soil depth dominated by Evergreen broadleaf forest. Brief information with highlight classes of each level is summarized below.

**Level 1.** Landscape classification at level 1 is based on the geologic period only, has 10 classes. The largest class at this level is the area forming since Devonian (D) with 2,074.02 $km^2$ and accounts for 42.66% of the whole study area while the smallest class is Paleogene (Pg) with 0.63 $km^2$ and makes up only 0.01%.

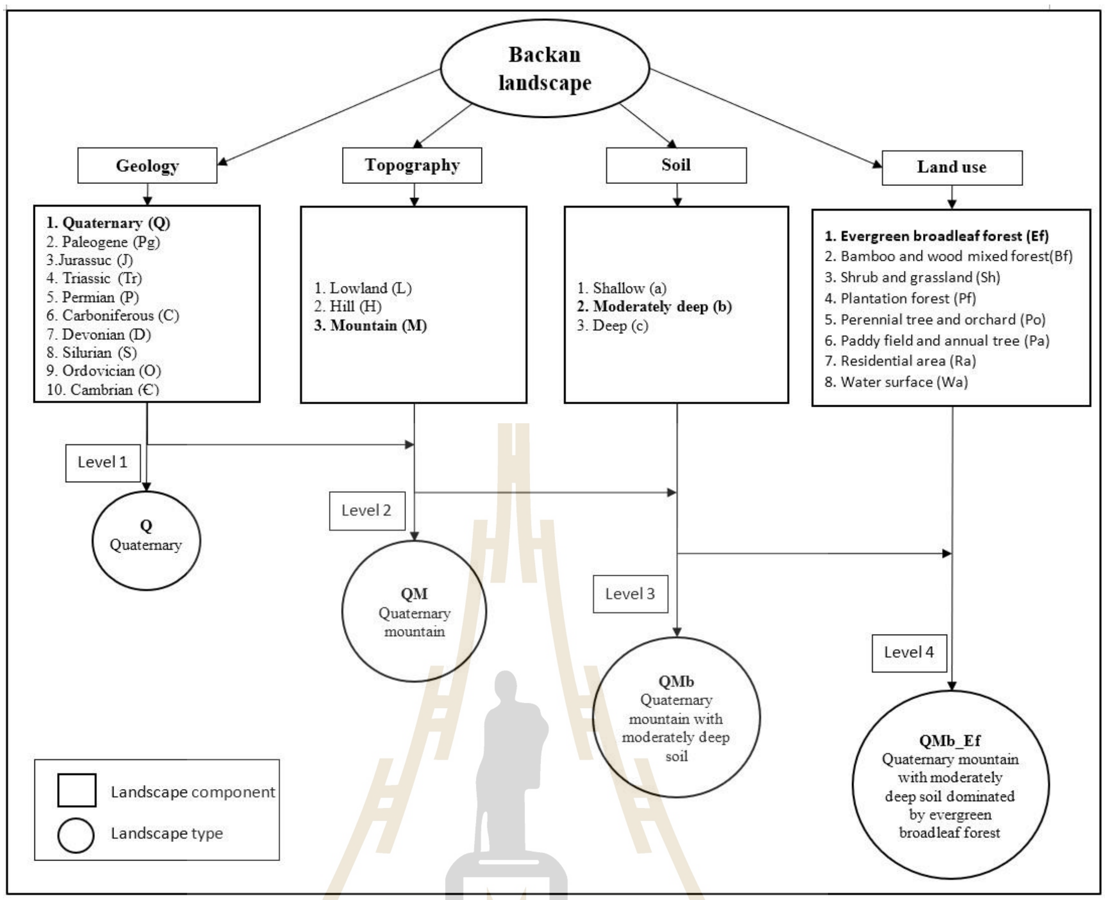



**Figure 4.6** Structure of 4-level hierarchical landscape typology.

**Level 2.** Landscape classification at level 2 is based on geologic period and elevation and has only 23 classes from the total possibility of 30 classes (10 x 3 classes). The largest class in this level is Devonian Mountain (DM) with 1,038.32 km$^2$ and the smallest class is Quaternary Mountain (QM) covering an area of 0.12 km$^2$.

**Level 3.** Landscape classification at level 3 is depended on geologic period, elevation, and soil depth and has 59 classes from the total possibility of 90 classes (10 x 3 x 3). The largest class is Ordovician Hill with moderately soil depth (OHb) with 521.50 km$^2$ and the smallest class is Quaternary Mountain with shallow soil depth (QMa) with 0.12 km$^2$.

**Level 4.** Landscape classification at level 4 which is the last and highest level, based on all four layers (geologic period, elevation, soil depth, and land use). Theoretically, with 10 geology classes, 3 topography classes, 3 soil classes, and 8 land use classes, 720 combinations (10 x 3 x 3 x 8 classes) are possible for landscape types characterization at this level but in fact only 315 combinations were found in the study area, and therefore final landscape map was produced with 315 landscape types. The largest landscape type is the Ordovician hill with moderately soil depth and dominated by bamboo and wood mixed forest (OHb_Bf) and covers a total area of 261.56 $km^2$ with 151 patches. The smallest landscape types which cover the same area of only 0.02 $km^2$ are DLa_Wa, PHc_Bf, and QHb_Wa.

Figure 4.7 displays the Bac Kan landscape map at level 2 while the summary of Bac Kan landscape typology at level 2 is described in Table 4.4. Meanwhile, the structure of the attribute of a landscape unit to describe the landscape of Bac Kan province is displayed in Table 4.5. This attribute table can be selected and easily create a landscape map with spatial data and attribute at various levels. In this study, the classified landscape units were used as the main input data for the next step of landscape ecology analysis which is focused on biodiversity conservation.

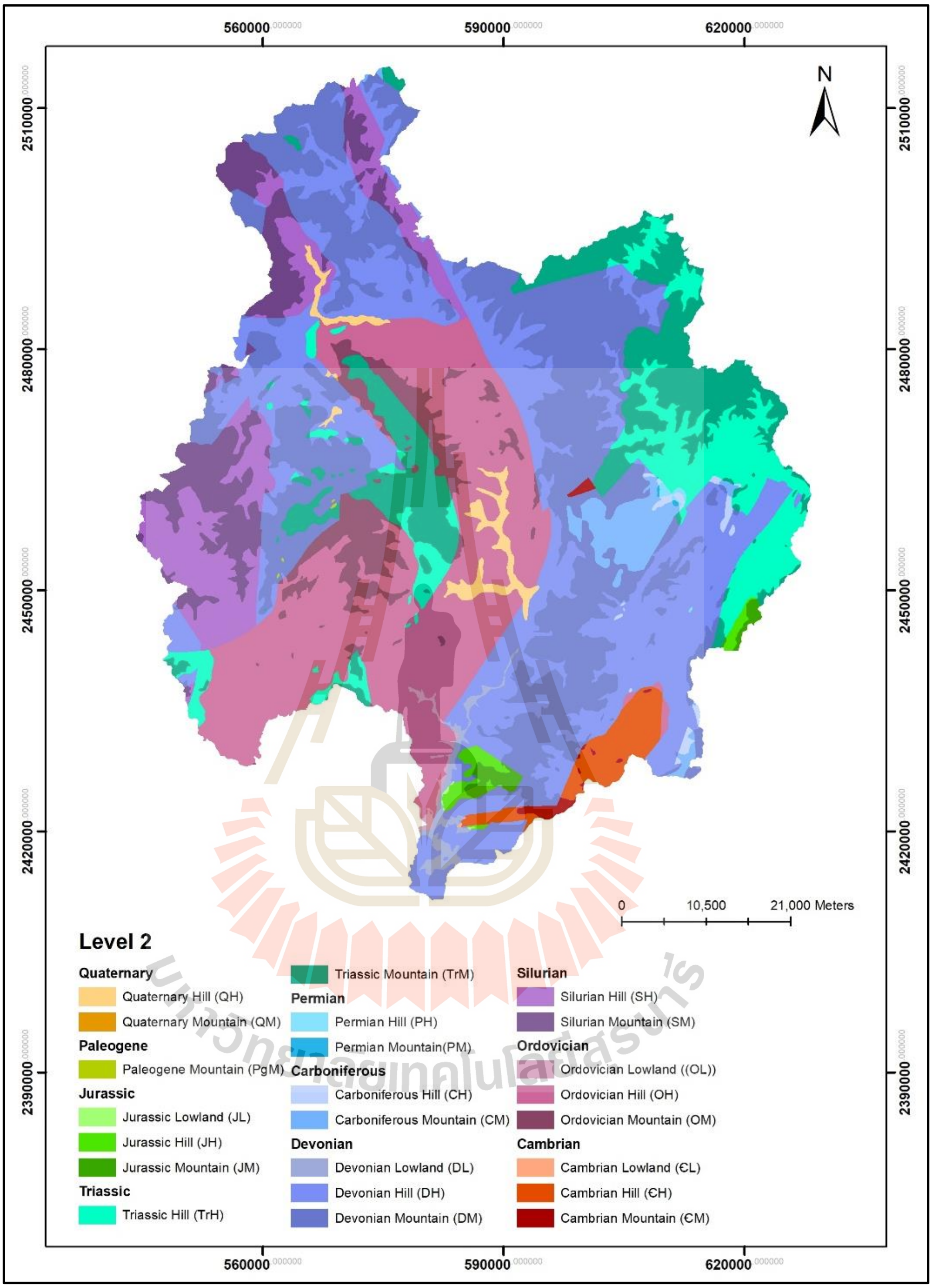



**Figure 4.7** Landscape map at level 2 of Bac Kan province.

**Table 4.4** Area and percentage of Bac Kan Landscape classification at level 2.

| **Level 1** | | | **Level 2** | | |
|---|---|---|---|---|---|
| **Class (10 classes)** | **Area ($km^2$)** | **%** | **Class (23 classes)** | **Area ($km^2$)** | **%** |
| Quaternary (Q) | 59.34 | 1.22 | Quaternary Hill (QH) | 59.22 | 99.80 |
| | | | Quaternary Mountain (QM) | 0.12 | 0.20 |
| Paleogene (Pg) | 0.63 | 0.01 | Paleogene Mountain (PgM) | 0.63 | 100.00 |
| Jurassic (J) | 51.86 | 1.07 | Jurassic Lowland (JL) | 0.83 | 1.60 |
| | | | Jurassic Hill (JH) | 27.74 | 53.49 |
| | | | Jurassic Mountain (JM) | 23.29 | 44.91 |
| Triassic (Tr) | 799.22 | 16.44 | Triassic Hill (TrH) | 338.90 | 42.40 |
| | | | Triassic Mountain (TrM) | 460.32 | 57.60 |
| Permian (P) | 4.34 | 0.09 | Permian Hill (PH) | 3.54 | 81.60 |
| | | | Permian Moutain (PM) | 0.80 | 18.40 |
| Carboniferous (C) | 106.54 | 2.19 | Carboniferous Hill (CH) | 16.08 | 15.09 |
| | | | Carboniferous Mountain (CM) | 90.46 | 84.91 |
| Devonian (D) | 2074.02 | 42.66 | Devonian Lowland (DL) | 32.14 | 1.55 |
| | | | Devonian Hill (DH) | 1003.56 | 48.39 |
| | | | Devonian Mountain (DM) | 1038.32 | 50.06 |
| Silurian (S) | 547.47 | 11.26 | Silurian Hill (SH) | 298.11 | 54.45 |
| | | | Silurian Mountain (SM) | 249.36 | 45.55 |
| Ordovician (O) | 1114.34 | 22.92 | Ordovician Lowland (OL) | 9.98 | 0.90 |
| | | | Ordovician Hill (OH) | 931.07 | 83.55 |
| | | | Ordovician Mountain (OM) | 173.30 | 15.55 |
| Cambrian (Ca) | 103.41 | 2.13 | Cambrian Lowland (CaL) | 0.28 | 0.27 |
| | | | Cambrian Hill (CaH) | 89.07 | 86.13 |
| | | | Cambrian Mountain (CaM) | 14.06 | 13.60 |

**Table 4.5** Structure of attribute of each landscape unit.

| No | Field Name | Explanation |
|---|---|---|
| 1 | OBJECTID | Identity of landscape unit |
| 2 | Area | Area of landscape unit |
| 3 | GP_N | Name of a geologic period |
| 4 | GP_C | Code of a geologic period |
| 5 | Topo_T | Typology of topography |
| 6 | Topo_C | Code of topography |
| 7 | Topo_E | Elevation value |
| 8 | Soil_T | Typology of Soil depth |
| 9 | Soil_D | Soil depth value |
| 10 | Soil_C | Code of soil depth |
| 11 | Land_N | Land use type |
| 12 | Land_C | Land use code |
| 13 | Level 1 | Landscape type at level 1 |
| 14 | Level 2 | Landscape type at level 2 |
| 15 | Level 3 | Landscape type at level 3 |
| 16 | Level 4 | Landscape type at level 4 |

## 4.4 A comparison with existing landscape maps

The thematic accuracy of landscape classification relies on the spatial accuracy of input data (geological formation, elevation, soil depth, and land use data) which were well-prepared with standard procedure by government agencies. In this study, thematic accuracy assessment of landscape type is not performed. Instead, validation of landscape classification was here implemented by comparison with the existing landscape map of Bac Kan province at 1:1,000,000 and 1:100,000. The validation approach was applied by many studies, such as Mücher et al. (2010).

At present, there are only two previous studies relate to landscape classification in Bac Kan province. The oldest map is landscape classification of Vietnam at the scale of 1: 1,000,000 (Hai, Hung, and Khanh, 1997), and the other one is Bac Kan landscape classification at the scale of 1: 100,000 (Giang, Hong, May, Thuy, and Dai, 2014). These two maps were here used to compare for validation the result of a new Bac Kan landscape classification map.

### 4.4.1 Landscape map of Vietnam

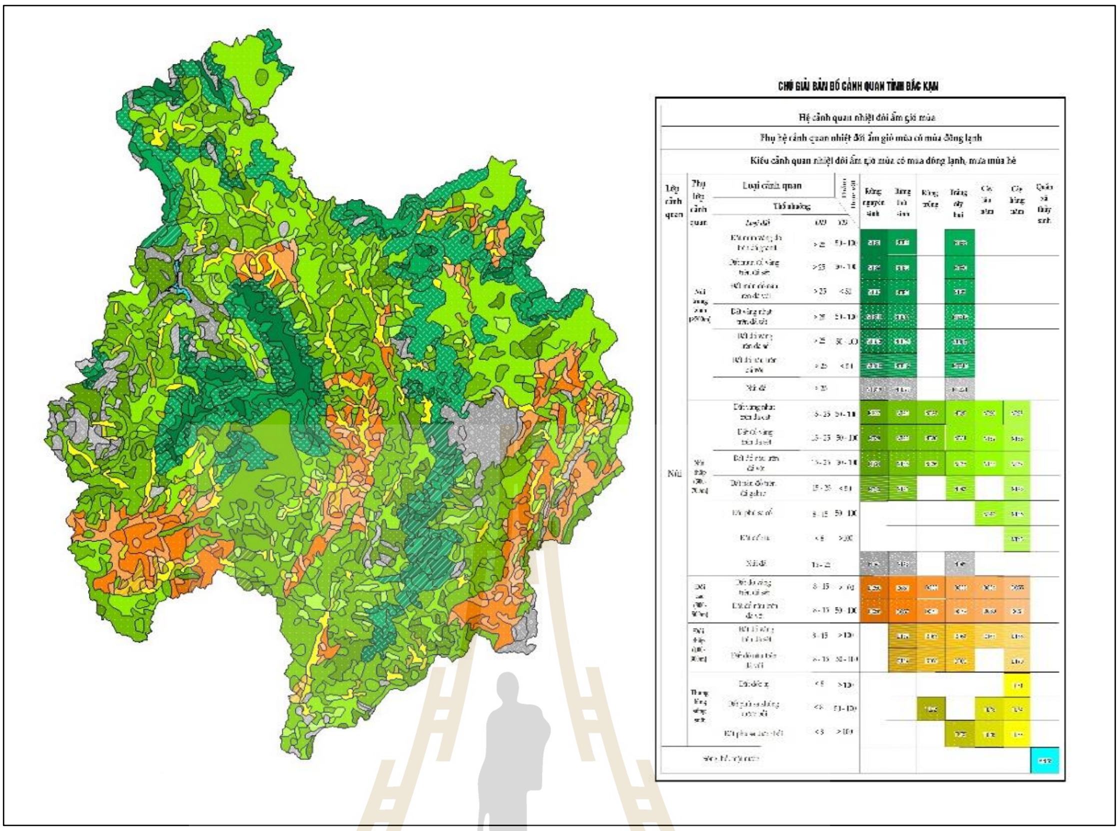
In regard to the landscape map of Vietnam (Hai et al., 1997), it is obviously shown that two different approaches made a struggle in comparing between this map and the new landscape map of Bac Kan. Since, the new landscape classification approach searches for general features distinguishing the landscape from the surroundings and maps landscape unit based on similar features, which can separately occur elsewhere. It consists of a systematization based on similarities and results in landscape typology (Lipský, 1998; Richling, 1989). Meanwhile, the landscape classification approach of Hai et al. (1997) is to highlight unique individual features of the landscapes for distinguishing the given landscape units from others; this way is used to determine and map unique, individual landscapes occurring in unique areas and nowhere else. This approach results in landscape regionalization. As a result, Bac Kan province only belongs to a unique Bac Thai low mountain region, which is classified based on climate condition affected by the monsoon regime. Besides, the landscape map of Vietnam was manually produced without high accurate data and computer support. Therefore, spatial data comparison between these two approaches is limited since the digital map is unavailable at present. Nevertheless, there is a clear resemblance from the perspective of the key factor (climate) between the landscape map of Vietnam and the new landscape map of Bac Kan province.

### 4.4.2 Existing landscape map of Bac Kan province

Under the landscape classification approach of Giang et al. (2014), topography, soil, and vegetation were manually superimposed to produce landscape units and then converted in digital format (digitization) (Figure 4.8). However, the hierarchical structure of landscape classification is from the attribute

On the contrary, the new landscape classification approach used the multi-level segmentation technique under eCognition software to classify image segments as landscape units. The new approach emphasizes the usefulness and convenience of objected-based oriented software, it not only helps to improve spatial accuracy but also reduces time and effort. Additionally, this approach can efficiently handle large data and create a higher number of landscape units in detail. The new landscape map consists of 8,427 units while the existing landscape map of Bac Kan has only 1,377 units (Table 4.6).

In addition, the new landscape classification approach has used geology as an important factor for classification which was absent from the existing landscape map. This factor is considered to play an important role in the Bac Kan landscape. This factor made the new landscape map more detail since it has 4 hierarchical levels compares to 3 levels in the existing map, resulting in the new landscape map of Bac Kan contains 315 landscape types compare to 78 landscape types in the existing one.




**Source:** Giang et al. (2014).

**Figure 4.8** Landscape map of Bac Kan province by Giang et al. (2014).

**Table 4.6** Summary of comparison criteria between new and existing landscape classification.

| **Criteria** | **Item** | **New landscape classification** | **Existing landscape classification** |
|---|---|---|---|
| Approach | Technique | Multi-level segmentation | Manual superimpose and digitization |
| Spatial property | No. of landscape types | 315 | 78 |
| | No. of landscape units | 8,427 | 1,377 |
| | Minimum area of landscape unit ($km^2$) | 0.02 | 0.44 |
| | Maximum area of landscape unit ($km^2$) | 116.63 | 180.17 |
| | Mean area of landscape unit ($km^2$) | 0.57 | 3.53 |
| Classification | Level 1 | Geology (10 classes) | Topography (5 classes) |
| | Level 2 | Geology and topography (23 classes) | Topography and soil (21 classes) |
| | Level 3 | Geology, topography, and soil (59 classes) | Topography, soil, and vegetation (79 classes) |
| | Level 4 | Geology, topography, soil, and land use (315 classes) | - |

# CHAPTER V

# SIGNIFICANT FACTOR IDENTIFICATION FOR ECOLOGICAL RESISTANCE EVALUATION

This chapter presents the results of the second objective relate to the selection of indicators (or sub-criteria) that describes ecological elements, ecological importance, and ecological resilience, which have been used successfully to characterize the resistance of ecological structures, ecological functions, and ecological dynamics to construction in mountainous areas. The process of indicator selection was implemented using the Delphi method. The Delphi method is an iterative process, which is designed to achieve a consensus among a group of experts on the specific issue.

## 5.1 Ecological resistance indicators to construction

Based on the conceptual framework of integrated ecological resistance to construction in mountainous areas as suggested by Peng et al. (2016), 14 indicators that represent for each group of ecological elements, ecological importance, and ecological resilience were selected for the Delphi process. The factors and indicators are illustrated in Table 5.1.

**Table 5.1** Factor (criteria) and its indicator of ecological resistance.

| Factor (Criteria) | Indicators (Sub-criteria) |
|---|---|
| Ecological elements | 1. Vegetation type |
| | 2. Soil type |
| | 3. Soil depth |
| | 4. Elevation |
| | 5. Slope |
| | 6. The occurrence frequency of general geological hazards |
| | 7. Rock type |
| | 8. Distance to fracture zones |
| Ecological importance | 9. Importance of biodiversity protection |
| | 10. Importance of water retention |
| | 11. Importance of soil conservation |
| Ecological resilience | 12. Vegetation stability |
| | 13. Ecological sensitivity |
| | 14. Social disturbance intensity |

After having indicators assignment, 10 experts from the Institute of Geography, VAST and University of Science, VNU, and Thai Nguyen University of Education were invited to participate. They are from different fields, experienced and professional in their areas of interest (Table 5.2). In this study, the identification process on factors (criteria) and its indicator for ecological resistance to construction using the Delphi method was implemented in 2 rounds.

**Table 5.2** List of experts.

| No. | Name | Title | Institution | Address |
|---|---|---|---|---|
| 1 | Pham Hoang Hai | Prof. Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 2 | Nguyen Cao Huan | Prof. Dr. | VNU University of Science | 334 Nguyen Trai, Thanh Xuan, Ha Noi |

**Table 5.2** (continued).

| No. | Name | Title | Institution | Address |
|---|---|---|---|---|
| 3 | Mai Trong Thong | Assoc. Prof. Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 4 | Luu The Anh | Assoc. Prof. Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 5 | Lai Vinh Cam | Assoc. Prof. Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 6 | Vu Anh Tai | Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 7 | Nguyen Thu Nhung | Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 8 | Duong Thi Hong Yen | Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 9 | Nguyen Van Hong | Dr. | IG, VAST | 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam |
| 10 | Pham Thi Huong Giang | Dr. | Thai Nguyen University of Education | 20 Luong Ngoc Quyen, Thai Nguyen |

## 5.2 Questionnaire and expert response after the first round

For the first round, a formal letter with the enclosed questionnaire (Table 5.3) was sent to experts. The first-round questionnaire is open-ended and designed to select indicators of each factor (or criteria) for ecological resistance evaluation. The questionnaire was presented in a uniform manner to experts to ensure that they can give the rating regarding each initial indicator and suggest other relevant indicators of three factors. Each expert was asked to indicate a degree to which they agree with indicators on the scale of 1 to 5 as follows:

1 – Indicator is highly irrelevant to the selected factor,

2 – Indicator is likely irrelevant to the selected factor,

3 – Indicator is more or less relevant to the selected factor,

4 – Indicator is likely relevant to the selected factor,

5 – Indicator is highly relevant to the selected factor.

Basically, the Delphi method ends when all questionnaire items are either accepted or rejected or over 75% questionnaire items have their rating variant values being less than 15%. The rules for employing the Delphi technique are given in Table 3.3.

After receiving the first-round response, the information was summarized as shown in Table 5.4. As a result, it was found that the rating mean of indications is equal or higher than 3.5 except for soil depth. Later on, the second questionnaire was prepared and sent to experts again.

**Table 5.3** Structure of a questionnaire of the first round.

***No:***

## INTERVIEWS – EXPERT

*..............., date......month….year 2018*

**<u>Objective:</u> TO SELECT INDICATORS (SUB-CRITERIA) FOR ECOLOGICAL RESISTANCE EVALUATION IN BAC KAN PROVINCE**

| No. | Factors (Criteria) | Indicators (Sub-criteria) | Degree of relevance | | | | |
|---|---|---|---|---|---|---|---|
| | | | Highly irrelevant (1) | Likely irrelevant (2) | More or less relevant (3) | Likely relevant (4) | Highly relevant (5) |
| 1 | Ecological elements | Vegetation type | | | | | |
| 2 | | Soil type | | | | | |
| 3 | | Soil depth | | | | | |
| 4 | | Elevation | | | | | |
| 5 | | Slope | | | | | |
| 6 | | Occurrence frequency of general geological hazards | | | | | |
| 7 | | Rock type | | | | | |

**Table 5.3** (continued).

| No. | Factors (Criteria) | Indicators (Sub-criteria) | Degree of relevance: Highly irrelevant (1) | Likely irrelevant (2) | More or less relevant (3) | Likely relevant (4) | Highly relevant (5) |
|---|---|---|---|---|---|---|---|
| 8 | Ecological elements | Distance to fracture zones | | | | | |
| 9 | Ecological importance | Importance of biodiversity protection | | | | | |
| 10 | | Importance of water retention | | | | | |
| 11 | | Importance of soil conservation | | | | | |
| 12 | Ecological resilience | Vegetation stability | | | | | |
| 13 | | Ecological sensitivity | | | | | |
| 14 | | Social disturbance intensity | | | | | |

Please fill (x) into only 1 of 5 relevance degrees.

**Other indicators (sub-criteria)**

| No. | Factors (Criteria) | Indicators (Sub-criteria) | Degree of relevance: Highly irrelevant (1) | Likely irrelevant (2) | More or less relevant (3) | Likely relevant (4) | Highly relevant (5) |
|---|---|---|---|---|---|---|---|
| | Ecological elements | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | Ecological importance | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | Ecological resilience | | | | | | |
| | | | | | | | |
| | | | | | | | |

**Other comments:**

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**Table 5.3** (continued).

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……………

**Contact information on person completing the questionnaire:**

| | |
|---|---|
| Title (Dr./Mr./Mrs./Ms.) | |
| Full Name | |
| Designation/Job Title | |
| Organization/Institution | |
| Address | |
| Telephone number | |
| Email address | |

Your opinion is essential for the success of my Ph.D. thesis. Please complete this form within 2 weeks.

**Thank you very much for your cooperation!**

*In case of any questions, please contact:* Mr. Trong Dai Ly*: E-mail:* *lytrongdai@gmail.com*

**Table 5.4** The result of rating analysis after the first round.

| *No.* | *Indicators* | *Rating is given by each expert* | | | | | | | | | | *Rating median* | *Quartile deviation* | *Rating mean* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | | | |
| 1 | Vegetation type | 5 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 0.5 | 4.7 |
| 2 | Soil type | 4 | 5 | 4 | 5 | 5 | 3 | 4 | 4 | 5 | 5 | 4.5 | 0.5 | 4.4 |
| 3 | Soil depth | 3 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 4 | 3 | 0.125 | 3.1 |
| 4 | Elevation | 5 | 5 | 4 | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 0.5 | 4.6 |
| 5 | Slope | 5 | 4 | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 0.5 | 4.7 |
| 6 | Occurrence frequency of general geological hazards | 4 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 5 | 0.5 | 4.6 |
| 7 | Rock type | 4 | 3 | 3 | 4 | 4 | 3 | 4 | 3 | 4 | 3 | 3.5 | 0.5 | 3.5 |

**Table 5.4** (continued).

| *No.* | *Indicators* | *Rating is given by each expert* | | | | | | | | | | *Rating median* | *Quartile deviation* | *Rating mean* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | | | |
| 8 | Distance to fracture zones | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 5 | 0.5 | 4.7 |
| 9 | Importance of biodiversity protection | 4 | 5 | 4 | 5 | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 0.5 | 4.6 |
| 10 | Importance of water retention | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 0 | 4.1 |
| 11 | Importance of soil conservation | 5 | 5 | 5 | 4 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 0.5 | 4.7 |
| 12 | Vegetation stability | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 0.125 | 4.8 |
| 13 | Ecological sensitivity | 5 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 0.5 | 4.7 |
| 14 | Social disturbance intensity | 4 | 3 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 0.5 | 3.7 |

## 5.3 Questionnaire and expert response after the second round

For the second round, the second questionnaire (Table 5.5) which incorporated a feedback report was redistributed to the first-round respondents. And again, they were asked to give their rating. The goal of the second round and any other subsequent round (if it requires) using questionnaire was to achieve a consensus or stability of expert' response. Once the consensus or stability is reached, the Delphi procedure is completed. See the rules for employing the Delphi technique in Table 3.3.

**Table 5.5** Structure of a questionnaire of the second round.

***No:***

**INTERVIEWS – EXPERT**

*..............., date......month ....year 2018*

**<u>Objective:</u> TO SELECT INDICATORS (SUB-CRITERIA) FOR ECOLOGICAL RESISTANCE EVALUATION IN BAC KAN PROVINCE**

| No. | Factors (Criteria) | Indicators (Sub-criteria) | Degree of relevance | | | | |
|---|---|---|---|---|---|---|---|
| | | | Highly irrelevant (1) | Likely irrelevant (2) | More or less relevant (3) | Likely relevant (4) | Highly relevant (5) |
| 1 | Ecological elements | Vegetation type | | | | | |
| 2 | | Soil type | | | | | |
| 3 | | Soil depth | | | | | |
| 4 | | Elevation | | | | | |
| 5 | | Slope | | | | | |
| 6 | | Occurrence frequency of general geological hazards | | | | | |
| 7 | | Rock type | | | | | |
| 8 | | Distance to fracture zones | | | | | |
| 9 | Ecological importance | Importance of biodiversity protection | | | | | |
| 10 | | Importance of water retention | | | | | |
| 11 | | Importance of soil conservation | | | | | |

**Table 5.5** (continued).

| No. | Factors (Criteria) | Indicators (Sub-criteria) | Degree of relevance | | | | |
|---|---|---|---|---|---|---|---|
| | | | Highly irrelevant (1) | Likely irrelevant (2) | More or less relevant (3) | Likely relevant (4) | Highly relevant (5) |
| 12 | Ecological resilience | Vegetation stability | | | | | |
| 13 | | Ecological sensitivity | | | | | |
| 14 | | Social disturbance intensity | | | | | |

Please fill (x) into only 1 of 5 relevance degrees.

**Other indicators (sub-criteria)**

| No. | Factors (Criteria) | Indicators (Sub-criteria) | Degree of relevance | | | | |
|---|---|---|---|---|---|---|---|
| | | | Highly irrelevant (1) | Likely irrelevant (2) | More or less relevant (3) | Likely relevant (4) | Highly relevant (5) |
| | Ecological elements | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | Ecological importance | | | | | | |
| | | | | | | | |
| | Ecological resilience | | | | | | |
| | | | | | | | |
| | | | | | | | |

**Other comments:**

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**Thank you very much for your cooperation!**

*In case of any questions, please contact:* Mr. Trong Dai Ly: *E-mail:* lytrongdai@gmail.com

After receiving the second-round response, the information was summarized as shown in Table 5.6. As result it was found that the rating means of 12 indicators are above 3.5, the quartile deviations (quartile range) are less than or equal to 0.5, and the rating variants are less than 15%. Therefore, these indicators are considered to be relevant for defining ecological elements, ecological importance and ecological resilience which are describing ecological resistance for construction in Bac Kan province. Conversely, the rating means of two indicators which are “Soil depth” and “Rock type” are lower than 3.5, the quartile deviations are less than, or equal to 0.5, and the rating variances are less than 15%. This means that the indicator of “Rock type” is removed in the second round. Consequently, the indicator of “Soil depth” and “Rock type” are rejected. There was also no need to continue the third round because the requirements were met. The result of selection indicators in two rounds is shown in Table 5.7.

This study showed that it is possible to select a set of indicators for characterizing the resistance of ecological structures, ecological functions, and ecological dynamics to construction in the mountainous area using the Delphi approach. The study was implemented with 14 indicators based on 10 experts and a 2-rounds process. During the selection process, two indicators were omitted, and 12 indicators were selected. Among these, 6 indicators relate to ecological elements, 3 indicators relate to ecological importance, and 3 indicators relate to ecological resilience. However, regarding the ecological resistance evaluation for construction, it is more important to evaluate the ability of soil conversation than to assess the soil type. So, to remove the redundant, “soil type” was dropped out of the selected indicators. Similarly, vegetation stability to the construction activities is more important to mind than vegetation type, therefore “vegetation type” was also left out. In other words, the indicators of “soil type” and “vegetation type” are not rejected or solitarily evaluated in the evaluation process but were carefully and completely estimated through the indicator of “the importance of soil conservation” and “vegetation stability”. Finally, 10 indicators, which are used for the next objective of ecological resistance evaluation, are elevation, slope, occurrence frequency of general geological hazards, distance to fracture zones, importance of biodiversity protection, importance of water retention, importance of soil conservation, vegetation stability, ecological sensitivity, and social disturbance intensity.

**Table 5.6** The result of rating analysis in the second rounds.

| *No.* | *Indicators* | *Rating is given by each expert* | | | | | | | | | | *Rating median* | *Quartile deviation* | *Rating mean* | *Rating variant (%)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | | | | |
| 1 | Vegetation type | 5 | 4 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 0.5 | 4.6 | 10 |
| 2 | Soil type | 4 | 5 | 4 | 5 | 4 | 3 | 4 | 4 | 5 | 5 | 4 | 0.5 | 4.3 | 10 |
| 3 | Soil depth | 3 | 2 | 3 | 3 | 4 | 3 | 4 | 3 | 3 | 4 | 3 | 0.5 | 3.2 | 10 |
| 4 | Elevation | 5 | 5 | 4 | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 0.5 | 4.6 | 0 |
| 5 | Slope | 5 | 4 | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 5 | 0.5 | 4.6 | 10 |
| 6 | Occurrence frequency of general geological hazards | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 5 | 0.5 | 4.7 | 10 |
| 7 | Rock type | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 3 | 0.5 | 3.4 | 10 |

**Table 5.6** (continued).

| *No.* | *Indicators* | *Rating is given by each expert* | | | | | | | | | | *Rating median* | *Quartile deviation* | *Rating mean* | *Rating variant (%)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | | | | |
| 8 | Distance to fracture zones | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 5 | 5 | 5 | 0.5 | 4.7 | |
| 9 | Importance of biodiversity protection | 4 | 5 | 4 | 5 | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 0.5 | 4.6 | 0 |
| 10 | Importance of water retention | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 0.125 | 4.2 | 10 |
| 11 | Importance of soil conservation | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 0.125 | 4.8 | 10 |
| 12 | Vegetation stability | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 0.125 | 4.8 | 0 |
| 13 | Ecological sensitivity | 5 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 0.5 | 4.7 | 0 |
| 14 | Social disturbance intensity | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | 0.125 | 3.8 | 10 |

**Table 5.7** The result of selection indicators in two rounds.

| **Round 1** | Rating mean q ≥ 3.5 | Rating mean q < 3.5 |
|---|---|---|
| *The results* | Vegetation type, Soil type, Elevation, Slope, Occurrence frequency of general geological hazards, Rock type, Distance to fracture zones, Importance of biodiversity protection, Importance of water retention, Importance of soil conservation, Vegetation stability, Ecological sensitivity, Social disturbance intensity | Soil depth |
| **Round 2** | Rating mean q ≥ 3.5, Q ≤ 0.5 and rating variant (q) < 15% | Rating mean q < 3.5, Q ≤ 0.5 and rating variant (q) < 15% |
| *The results* | Vegetation type, Soil type, Elevation, Slope, Occurrence frequency of general geological hazards, Distance to fracture zones, Importance of biodiversity protection, Importance of water retention, Importance of soil conservation, Vegetation stability, Ecological sensitivity, Social disturbance intensity | Soil depth, Rock type |

# CHAPTER VI

# ECOLOGICAL RESISTANCE EVALUATION FOR CONSTRUCTION

This chapter presents the results of the third objective focusing on the ecological resistance evaluation for construction (See detail in Section 3.4). The research methodology of ecological resistance evaluation for construction is presented in Figure 6.1 while characteristics of ecological resistance factors and its evaluation were separately described and discussed in the following sections.

## 6.1 Ecological structural resistance

Ecological structural resistance is one of the three factors contribute to ecological resistance against construction in Bac Kan province. This value was evaluated through 4 ecological elements which are (1) elevation, (2) slope, (3) geological hazard frequency, and (4) distance to fracture zones. The weighting process and the evaluation of each element (indicator) are described below.

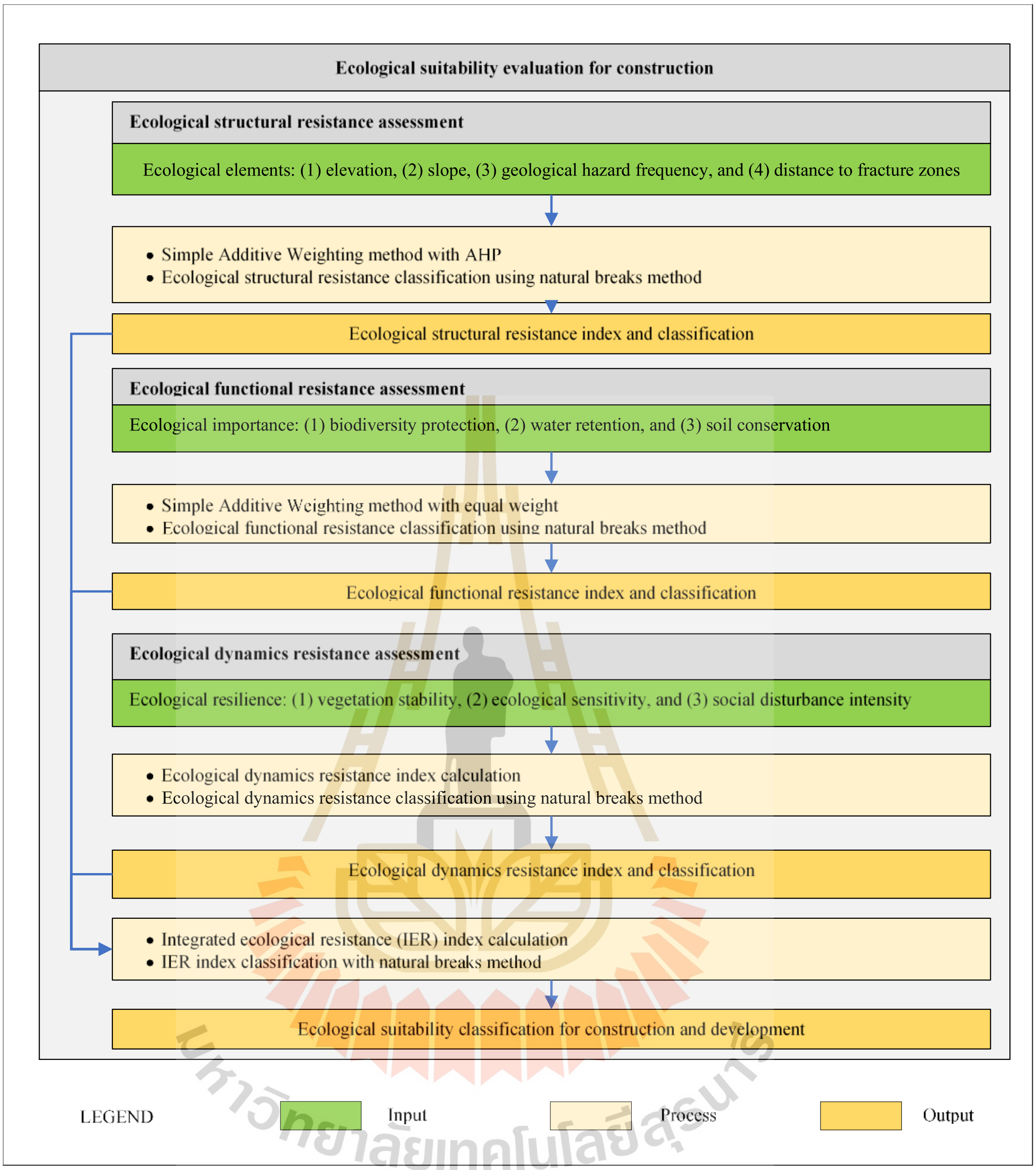



**Figure 6.1** Methodological workflow of ecological resistance evaluation for construction.

### 6.1.1 Indicator weighting

Ecological elements establish the ecological structural resistance are determined by elevation, slope, geological hazard frequency, and distance to fracture zones. The weight of each indicator was determined using Analytical Hierarchy Process (AHP). This method is useful for obtaining a single assessment value based on different indicators or criteria (Benmouss, Laaziri, Khoulji, Kerkeb, and El Yamami, 2019). By using pairwise comparisons, 10 experts from the Institute of Geography, VAST, University of Science, VNU, and Thai Nguyen University of Education were invited to participate in order to establish a priority value for each indicator. The standard numeric scale used for AHP is 1-9 scale which lies between “equal importance” to” extreme importance”, the value 9 indicates that one indicator is extremely important than others, while value 1 indicates equal importance. For analyzing the rating, the Super Decisions software was used with the inconsistency index is 0.029. The inconsistency is less than 0.10 so no correction of judgments is needed (Adams and Saaty, 2003). The comparison matrix of 4 indicators is shown in Table 6.1, and the final weights for the indicator of elevation, slope, geological hazard frequency, and distance to fracture zones are 0.562, 0.227, 0.138, and 0.073, respectively. Among 4 indicators, the elevation is determined as the most important factor to the ecological structural resistance, follows by slope and geological hazard frequency. Distance to fracture is considered to be the least important indicator.

**Table 6.1** Comparison matrix and weight for 4 indicators.

| Indicators | Elevation | Slope | Geological hazard frequency | Distance to fracture zones | Weight |
|---|---|---|---|---|---|
| Elevation | 1 | 3.2 | 4.4 | 5.5 | 0.562 |
| Slope | | 1 | 2 | 3.4 | 0.227 |
| Geological hazard frequency | | | 1 | 2.5 | 0.138 |
| Distance to fracture zones | | | | 1 | 0.073 |

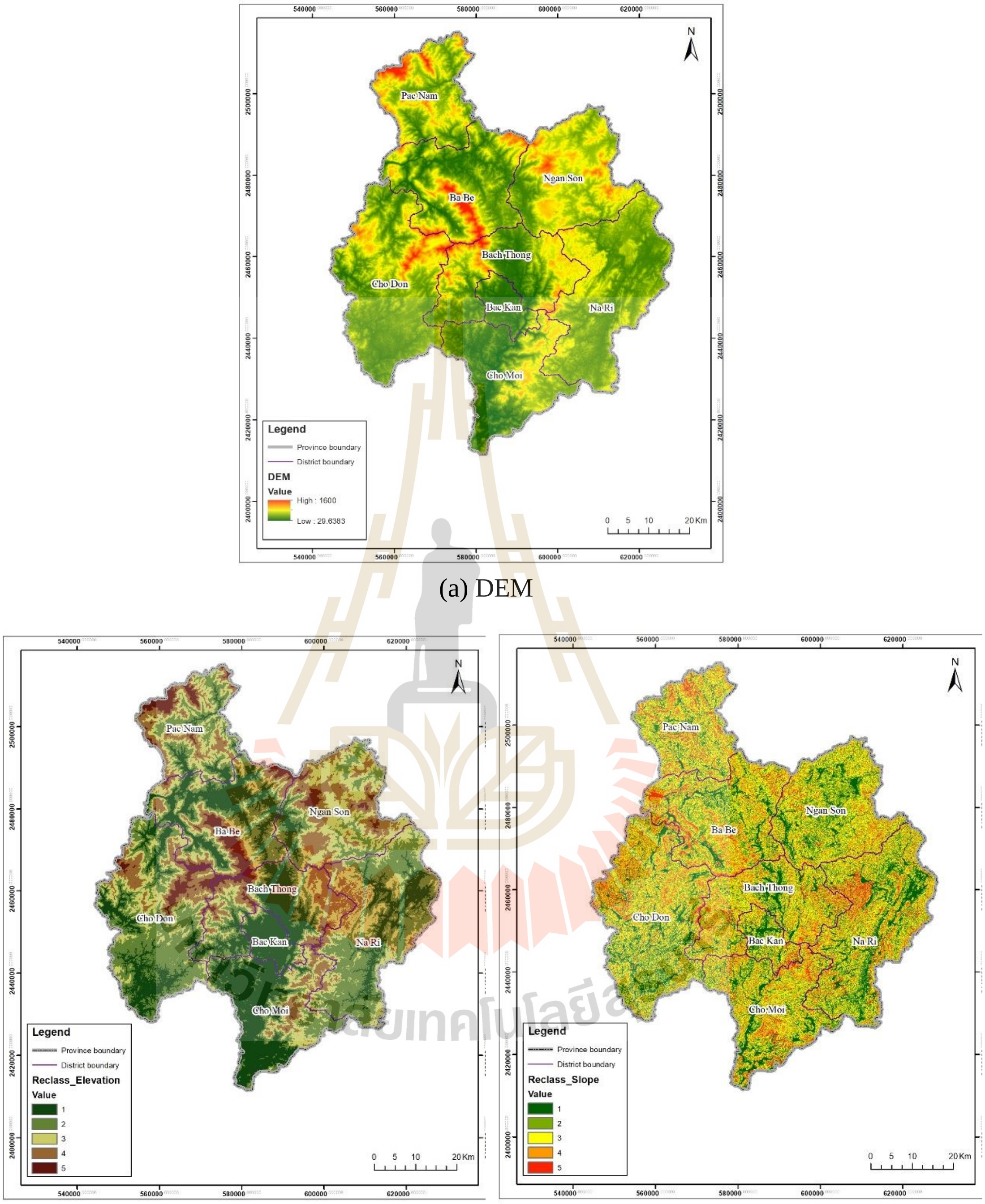
Inconsistency: 0.029

### 6.1.2 Elevation and slope

DEM of the study area was used to compute elevation and slope layers (Figure 6.2a). While the elevation layer was directly reclassified from DEM into 5 classes, the slope layer was generated from DEM using surface toolset and then was also reclassified into 5 classes. The process was performed using reclassify function in ESRI ArcGIS software with the natural breaks method (Table 6.2). The natural breaks method groups similar to values and maximizes the differences between classes (Allen, 2010). The final elevation and slope layers with 5 classes are described in Figure 6.2b and 6.1c. Elevation and slope are directly proportional to the ecological structural resistance. The higher the elevation and slope are, the higher the ecological resistance is.

**Table 6.2** Reclassifying of elevation and slope using natural breaks method.

| **Elevation (meter)** | **Slope (degree)** | **Reclassified classes** |
|---|---|---|
| 29.6 – 309.4 | 0 – 9.4 | 1 |
| 309.4 – 475.4 | 9.4 – 19.8 | 2 |
| 475.4 – 663.4 | 19.8 – 28.8 | 3 |
| 663.4 – 920.5 | 28.8 – 39.9 | 4 |
| 920.5 – 1,600 | 39.9 – 85.5 | 5 |




(a) DEM

(b) Reclassified elevation

(c) Reclassified slope

**Figure 6.2** Indicator of elevation and slope.

### 6.1.3 Geological hazard frequency

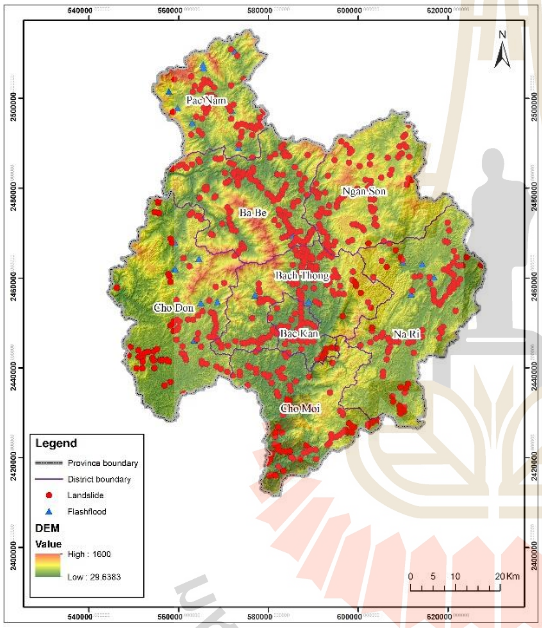
Geological hazard and disaster is critical factor must to fully examine in any development strategy, geological disaster occurs when natural geological processes impact on our activities, either through loss of life or injury or through economic loss, whereas geological hazard are potential disasters, e.g. earthquake, landslide, tsunami, volcano, flood, etc. (Liverman, Batterson, Taylor, and Ryan, 2001). Therefore, in this study, the occurrence frequency of geological hazard is considered to be the indicator of ecological structural resistance to construction in Bac Kan province. And it was accessed through the disaster-site density of landslide and flash flood which are frequently occurred in Bac Kan province. The frequency of these hazards goes up with increasing disaster-site density, as do the risk of construction and resistance to construction in mountainous areas.

**Table 6.3** The number and volume of landslides by the district of Bac Kan province

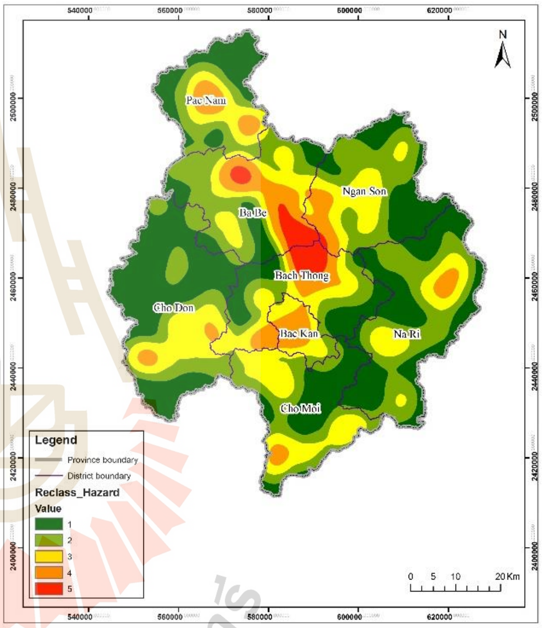
| No. | District | Number of occurrences | Volume ($m^3$) | | | | |
|---|---|---|---|---|---|---|---|
| | | | < 200 | 200 - 1,000 | 1,000 – 20,000 | 20,000 – 100,000 | > 100,000 |
| 1 | Ba Be | 147 | 54 | 52 | 38 | 3 | 0 |
| 2 | Bach Thong and Bac Kan | 152 | 62 | 57 | 31 | 1 | 1 |
| 3 | Cho Don | 88 | 30 | 43 | 13 | 2 | 0 |
| 4 | Cho Moi | 88 | 24 | 39 | 25 | 0 | 0 |
| 5 | Na Ri | 92 | 46 | 41 | 4 | 1 | 0 |
| 6 | Ngan Son | 89 | 57 | 30 | 2 | 0 | 0 |
| 7 | Pac Nam | 64 | 32 | 20 | 10 | 2 | 0 |

**Source:** Hung (2014).

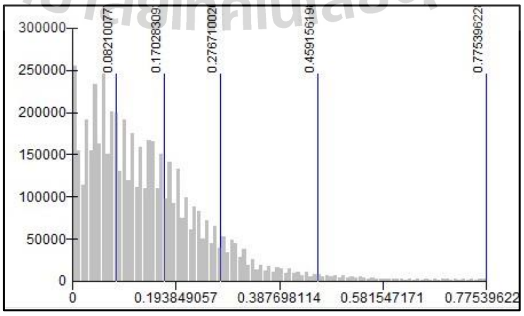
The location of 720 landslides and 26 flash floods, which were extracted from the landslide inventory database (Hung, 2014), were used with the kernel method to produce a geological disaster density map. The density was then grouped into five categories using the natural breaks method. The final distribution of indicator of geological hazard frequency accessed through disaster density as well as the histogram for reclassifying disaster density is shown in Figure 6.3. A summary of the number of landslide occurrences and their volumes by the district is presented in Table 6.3.




(a) Location of geological disaster




(b) Reclassified disaster density



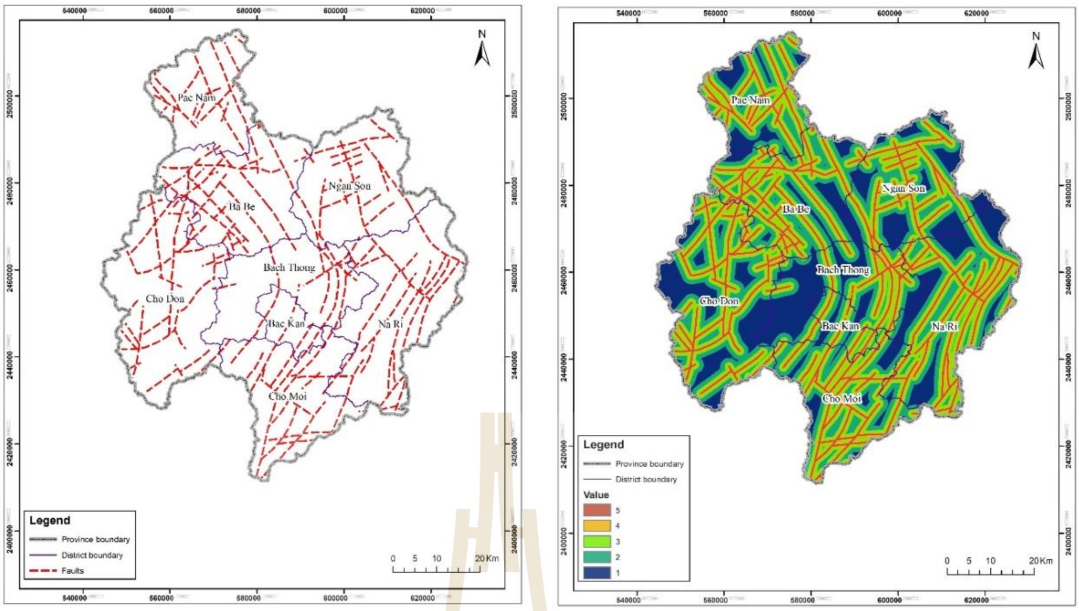

(c) Histogram of natural breaks method for reclassifying disaster density

**Figure 6.3** Indicator of geological hazard frequency accessed through disaster density.

### 6.1.4 Distance to the fracture zone

Fractures zones or faults are in crustal strata along where adjacent rocks have been displaced. Faults may pose problems of settlement, sliding, seepage, and seismicity and also landslides. Therefore, the location and disposition of the fracture zones play an important role in the selection of the engineering site and designing of structures like major buildings, bridges, dams, powerhouses, and tunnels. (Indra and Nikhil, 2002).

The faults were extracted from Bac Kan geological map and their distribution is shown in Figure 6.4a and then a process of Euclidean distance tool in ESRI ArcGIS software was used to create a distance surface. This distance surface layer was then reclassified on a descending scale from level 5 to level 1, with the levels corresponding to the increasing distance to fracture zones (0–200 m, 200–500 m, 500–1,000 m, 1,000–2,000 m, and greater than 2,000 m) (Figure 6.4b). The distance from 0 to 200 m is given the highest level of ecological resistance since construction is not suitable within 200 m of a fracture zone (Peng et al., 2016).




(a) Distribution of fracture zones (faults) (b) Reclassified distance to fracture zones

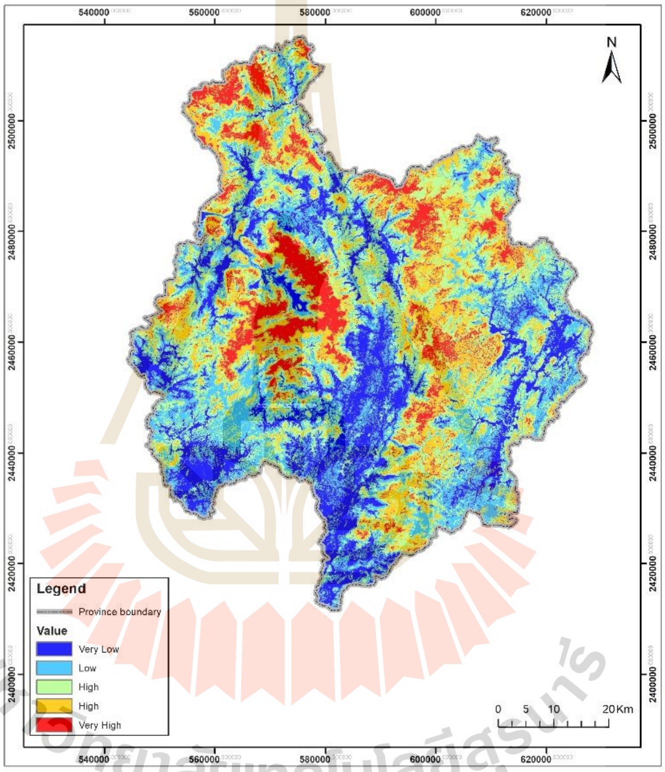
**Figure 6.4** Indicator of distance to fracture zone.

### 6.1.5 Ecological structural resistance evaluation

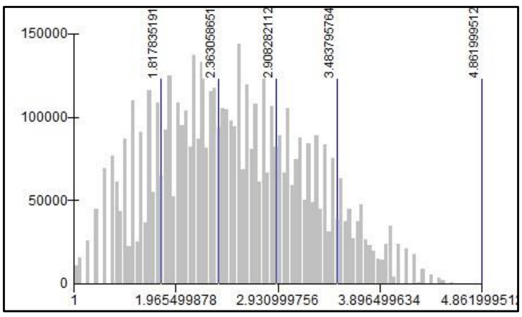
The final evaluation of ecological structural resistance represented by ecological elements is the weighted sum of all the indices described above, which are respectively connected with elevation, slope, occurrence frequencies of general geological disasters, and distance to fracture zones. The spatial pattern of ecological structural resistance is shown in Figure 6.5. It is obviously revealed that the pattern of the ecological structural resistance is considerably affected by elevation because of its high weight. The computed area and percentage for each ecological structural resistance class are presented in Table 6.4. As a result, the spatial pattern of ecological structural resistance for construction is considerably dominated by low and moderate classes that cover an area of about 2,524 $km^2$ or 51.95% of the total area.

**Table 6.4** Percentage and the area of each ecological structural resistance class.

| Resistance class | Description | Resistance value | Area ($Km^2$) | Area (%) |
|---|---|---|---|---|
| 1 | Very low | 1 - 1.817 | 898.219 | 18.49 |
| 2 | Low | 1.817 - 2.363 | 1254.639 | 25.82 |
| 3 | Moderate | 2.363 - 2.908 | 1269.600 | 26.13 |
| 4 | High | 2.908 – 3.483 | 962.158 | 19.80 |
| 5 | Very high | 3.483 – 4.861 | 473.998 | 9.76 |




(a) Ecological structural resistance




(b) Histogram for reclassifying ecological structural resistance

**Figure 6.5** Spatial pattern of ecological structural resistance.

## 6.2 Ecological functional resistance

The ecological function is the integrated characterization of a variety of ecological processes, as well as the external manifestation of the close relationship between natural ecosystems and human demands (Xiao and Chen, 2002). Ecological functional resistance is measured through ecological importance (Eq. 6.1). Construction and development must ensure that natural floral and faunal habitats will not shrink, and that habitat quality will not be degraded greatly. Moreover, the study area has experienced serious soil erosion in recent years due to the heavy rain and the denuded mountainous ecological background that has continuously disturbed by human activities. Therefore, considering the actual conditions in Bac Kan province, it is meaningful to identify the spatial distribution pattern of ecological importance using three vital ecological processes: (1) biodiversity protection, (2) water retention, and (3) soil conservation. The higher the level of the ecological importance is, the greater will be the resistance to mountainous area construction.

### 6.2.1 Biodiversity protection assessment

Ecosystem services can be accessed through ecosystems or land uses. For example, based on the average value per unit area of ecosystem services to maintain biodiversity in China as suggested by Xie et al. (2008), the relative importance of biodiversity protection in different ecosystems is assessed. In Bac Kan province, based on the result of the relationship of land use types and associated ecosystem services, the level of biodiversity in terms of the number of species was identified with different land use types (Simelton and Viet Dam, 2014). The final resistance grade for biodiversity protection is linked with the existing land use types and was classified into

5 levels: level 1 includes construction land and unused land, level 2 corresponds to farmland, level 3 covers shrub and grassland, level 4 is plantation forest, and level 5 refers to natural forest. The spatial distribution pattern of ecological importance for biodiversity protection is shown in Figure 6.6.

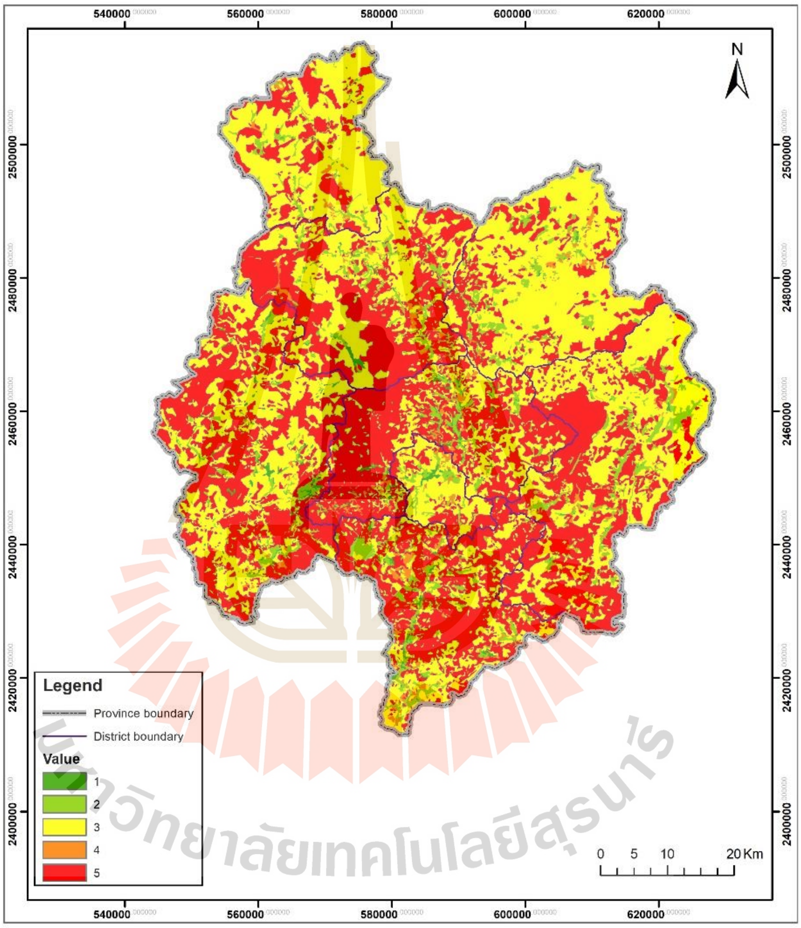



**Figure 6.6** Resistance level for biodiversity protection.

### 6.2.2 Water retention assessment

The interception by vegetation is used to assess the water retention of the study area. The interception by vegetation was used in the study of Vandecasteele et al. (2018) to calculate water retention index (WRI) in a landscape that represents the relative capacity of the landscape to retain water at Pan-European scale. In their study, Leaf Area Index (LAI) which is the green leaf area coverage per unit ground surface area (Watson, 1947) was used to assess water retention in vegetation and LAI ranges from zero (bare ground) to 10 (dense forest). Besides, estimating water retention in vegetation is also implemented by the canopy capacity (Van Dijk and Bruijnzeel, 2001).

In this study, water retention of Bac Kan province was based on the experiment result of Hai (2002), which focused mainly on the ability of water retention of different vegetation types and structures. This ability of water retention was assessed through a variety of criteria, such as humidity at different soil depths (Table 6.5), or canopy capacity (Table 6.6). The final resistance grade for water retention in Bac Kan province is linked with vegetation types as follows:

Level 1 corresponds to non-forested land;

Level 2 includes young afforested land, non-stumpage forests, nurseries, grazing land, agricultural land, and land suitable for afforestation;

Level 3 covers shrubland, economic forests, and thin forests;

Level 4 includes needle forests and;

Level 5 refers to broadleaf forests, bamboo, and water.

The spatial distribution pattern of ecological importance for water retention is shown in Figure 6.7.

**Table 6.5** Variation of soil humidity in a number of vegetation types.

| Vegetation type | Humidity (%) at the soil depth (cm) | | | |
|---|---|---|---|---|
| | 0-5 | 20-25 | 40-45 | 60-65 |
| 1. Bare land | 6.83 | 14.21 | 25.57 | 27.32 |
| 2. Savanna + bushes | 23.52 | 27.59 | 30.86 | 31.16 |
| 3. Rehabilitated forest after slash and-burn cultivation, cover degree 0.7-0.8 | 24.75 | 29.06 | 30.24 | 32.55 |
| 4. Three-stories forest, cover degree 0.7-0.8 | 29.56 | 32.74 | 34.79 | 33.58 |
| 5. One-story forest without ground vegetative, cover degree 0.7-0.8 | 26.21 | 28.19 | 28.61 | 27.42 |
| 6. Three-stories forest, cover degree 0.7-0.8 | 33.79 | 35.94 | 35.98 | 34.37 |
| 7. Two-stories forest, cover degree 0.7-0.8 | 31.98 | 33.59 | 34.12 | 34.21 |
| 8. Bamboo forest, cover degree 0.7-0.8 | 18.82 | 20.20 | 21.78 | 22.60 |
| 9. Imperata cylindrica savanna | 8.16 | 15.22 | 12.83 | 12.98 |

**Source:** Hai (2002).

**Table 6.6** Capability of rainfall interception of natural forest types.

| Forest structural types | Forest cover (%) | Number of stories | Rainfall intercepted by the canopy (%) |
|---|---|---|---|
| 1. Forest after rational selective logging with enough rehabilitation time. | 70-80 | 3 | 11.67 |
| 2. Depleted forest | 30-40 | 3 | 5.72 |
| 3. Young forest with enough rehabilitation time | 70-80 | 2 | 10.34 |
| 4. Young forest after tending by the old way (total clearance of ground vegetation cover) | 70-80 | 1 | 6.91 |
| 5. Forest rehabilitated after slash and burn cultivation | 70-80 | 2 | 9.51 |
| 6. Bamboo forest | 70-80 | 1 | 8.96 |

**Source:** Hai (2002).

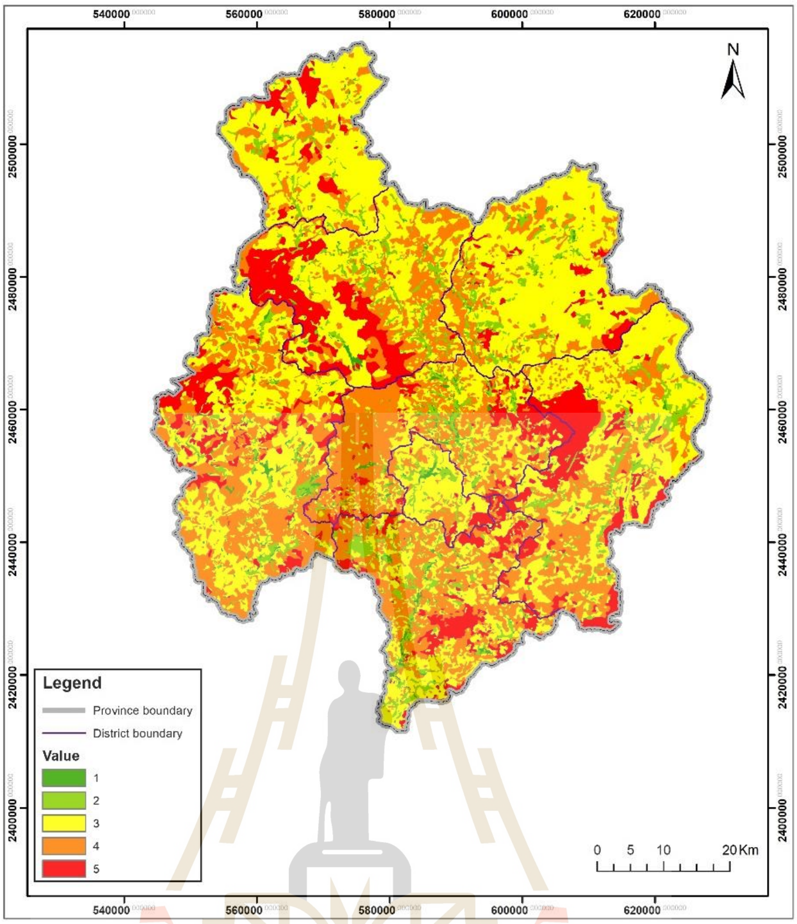



**Figure 6.7** Resistance level for water retention.

### 6.2.3 Soil conservation assessment

In the meantime, to assess the importance of soil conservation, the universal soil loss equation (USLE) was used. Several factors are applied in the USLE model including the soil erodibility factor (K), the rainfall erosivity factor (R), the topographic factor (LS), the soil and water conservation factor (P), and the vegetation coverage factor (C). The potential soil loss of the landscape can be computed as the product of R, K and LS (Vezina, Bonn, and Van, 2006). Then the potential and actual amounts of soil loss were calculated separately, with the difference representing the amount of soil conservation as suggested by (Peng et al., 2007; Peng et al., 2016). As the amount of soil conservation grows, the importance of soil conservation increases.

The basic USLE equation includes six factors: rainfall-runoff erosivity (R), soil erodibility (K), slope length (L), slope gradient (S), crop and management (C) and conservation support practice (P). The USLE is described in IECA (2008) as having the following form:

$$A = R * K * \mathrm{LS} * \mathrm{C} * \mathrm{P} \qquad (6.1)$$

Where:

A is the average annual soil loss (tons $ha^{-1}$ $year^{-1}$),

R is the rainfall erosivity (MJ mm $ha^{-1}$ $h^{-1}$ $year^{-1}$),

K is the soil erodibility factor (tons h $(MJ\ mm)^{-1}$),

LS is the topographic factor (dimensionless),

C is the cropping management factors (dimensionless), and

P is the supporting practice factor (dimensionless)

**Rainfall erosivity (R)** was defined as the product of the total kinetic energy multiplied by the maximum 30 min rainfall intensity (Wischmeier and Smith, 1978). Many methods can be used to calculate the annual rainfall erosivity factor (Gitas, Douros, Minakou, Silleos, and Karydas, 2009; Parveen and Kumar, 2012; Yu and Rosewell, 1996). Calculation of the R factor is a complex process and involves long-term data collection. For conditions in Vietnam, Nguyen (1996) suggested a method to measure R factor based on annual precipitation by analyzing the rainfall data over 54 years from 253 meteorological stations throughout the country:

$$R = 0.548257*P - 59.9 \qquad (6.2)$$

Where P is the annual precipitation (mm).

Spatial interpolation of annual precipitation based on the existing datasets from 1958 to 2018 was carried out using the inverse distance weighted (IDW) technique to generate the rainfall distribution layer for the study area. The derived result was used as the input data to produce rainfall erosivity by applying Eq. 6.2. The average annual rainfall ranges from 1,243 mm to 1,838 mm, and consequently, the calculated rainfall erosivity ranges from 621 MJ mm $ha^{-1}$ $h^{-1}$ $year^{-1}$ to 948 MJ mm $ha^{-1}$ $h^{-1}$ $year^{-1}$. The distribution of rainfall erosivity is shown in Figure 6.8.

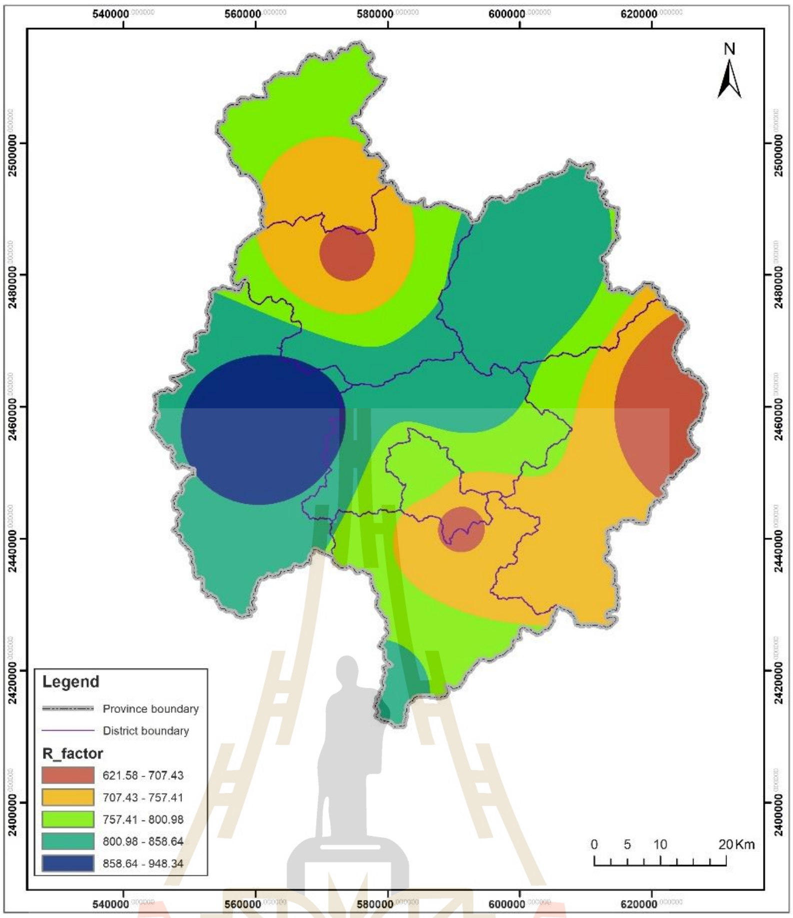



**Figure 6.8** The rainfall erosivity factor (R).

**The soil erodibility factor (K)** represents the effect of soil properties and soil profile characteristics on soil loss. Some soil types are naturally more prone to soil erosion due to their physical structure. Erodibility is a function of soil texture, organic matter content, and permeability (Ranzi, Le, and Rulli, 2012). In this study, K values for different soil types in northern highlands of Vietnam (Vezina et al., 2006) and in Ba Be lake basin (Pham, 2007) as a summary in Table 6.7 were applied to generate the soil erodibility factor map of Bac Kan province (Figure 6.9).

**Table 6.7** Soil erodibility K factor.

| No | Soil type | K factor | Source |
|---|---|---|---|
| 1 | Fluvisols | 0.055 | Vezina et al., 2006 |
| 2 | Regosols | 0.025 | Vezina et al., 2006 |
| 3 | Leptosols | 0.028 | Vezina et al., 2006 |
| 4 | Cambisols | 0.050 | Vezina et al., 2006 |
| 5 | Alisols | 0.045 | Vezina et al., 2006 |
| 6 | Phaozems | 0.065 | Vezina et al., 2006 |
| 7 | Ferralitic humus from limestone | 0.033 | Pham, 2007 |
| 8 | Ferralitic yellow-red from limestone | 0.021 | Pham, 2007 |
| 9 | Ferralitic humus from acid stone | 0.030 | Pham, 2007 |
| 10 | Ferralitic humus yellow-red from granite stone | 0.028 | Pham, 2007 |
| 12 | Ferralitic yellow-red from acid stone | 0.027 | Pham, 2007 |
| 13 | Silt | 0.024 | Pham, 2007 |
| 14 | Ferralitic red-brown from gabbro stone | 0.027 | Pham, 2007 |
| 15 | Ferralitic from typical limestone | 0.026 | Pham, 2007 |

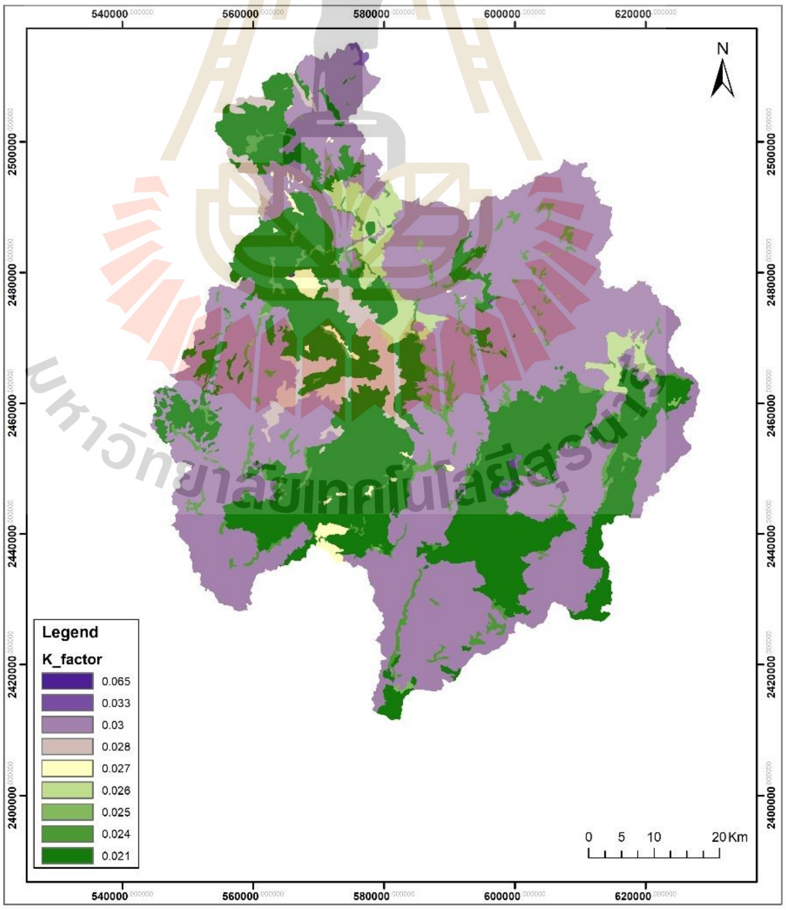



**Figure 6.9** The soil erodibility factor (K).

**Topographic factor (LS)** is the slope length gradient factors comprising L, slope length, and S, slope steepness. The slope has a major effect on the rates of soil erosion. The higher the slope, the higher the velocity of overland flow, thus increasing the shear stresses on the soil particles. As slope length increases, the overland flow and flow velocity also steadily increase, leading to greater erosion forces applied to the soil surface (Ranzi et al., 2012).

In this study, the equation of Moore and Burch (1986), which was adopted and developed by (Mitasova and Mitas, 2001) as Eq. 6.3, was used to calculate the LS factor using the ArcGIS raster calculator tool as shown in Figure 6.10.

$$LS = \left(\frac{FA*Cellsize}{22.13}\right)^m * \left(\frac{\sin(slope\ angle)*0.01745}{0.09}\right)^n \tag{6.3}$$

Where FA is flow accumulation, cell size is the size of the DEM data, slope angle is in degrees (°), and 0.01745 is a parameter to convert degrees to radians. m and n were respectively assigned 0.5 and 1.3 as recommended by (Mitasova and Mitas, 2001).

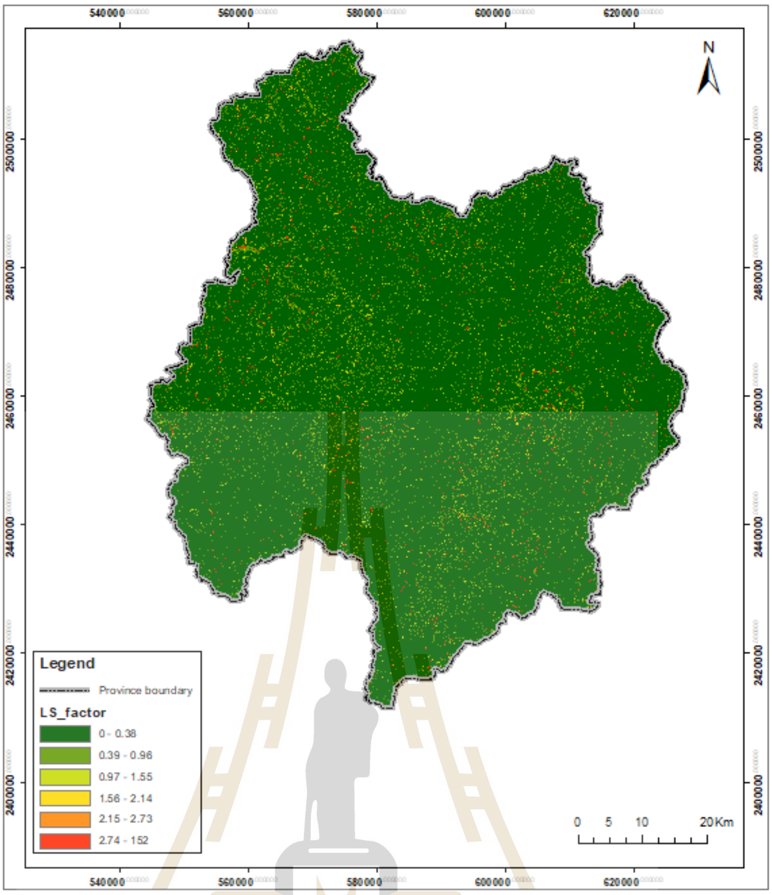



**Figure 6.10** The topographic factor (LS).

**Cropping management factor (C)** is the second most important factor that controls soil erosion risk (Van der Knijff, Jones, and Montanarella, 2000) and it reflects the effect of cropping and management practices on the soil erosion rate (Biesemans, Van Meirvenne, and Gabriels, 2000). Generally, the C factor ranges from 0 to 1. C value equals to 1, it indicates no cover present and the surface is treated as barren land, whereas C value close to zero (0), it indicates very strong cover effects and well-protected soil. The C factor for individual crop in addition to mixed farming systems in Bac Kan province was selected from literature data as adopted for northern Vietnam (Pham, 2007; Ranzi et al., 2012; Vezina et al., 2006). These data were adapted to land use map of Bac Kan, resulting in the cropping factor reported in Table 6.8 and Figure 6.11.

**Table 6.8** Adopted cropping management factor (C) in this study

| Land use | C factor |
|---|---|
| Evergreen broadleaf forest | 0.003 |
| Bamboo and wood mixed forest | 0.003 |
| Shrub and grassland | 0.18 |
| Plantation forest | 0.003 |
| Perennial tree and orchard | 0.5 |
| Paddy field and annual tree | 0.5 |
| Residential area | 0.0 |
| Water surface | 0.0 |

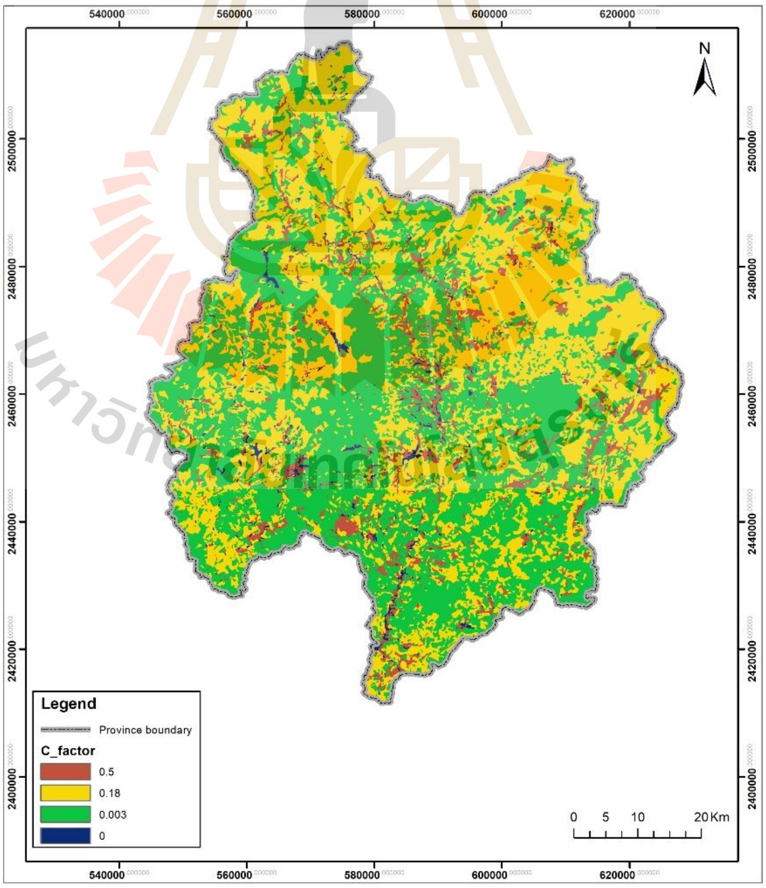



**Figure 6.11** The cropping management factor (C).

**Supporting practice factor (P)** reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduces the amount of erosion, the higher the supporting practice, the lower the value of the P factor. The support practice factor expresses the effect of support practices such as contour cultivation, strip cropping around contours, arable land terrace and bench terrace. In this study, supporting practice factor for A Sap basin (Pham, Degener, and Kappas, 2018) was applied for Bac Kan province, which was calculated by land use type and the slope degrees as suggested by (Shin, 1999) as a summary in Table 6.9 and shown in Figure 6.12.

**Table 6.9** Supporting practice factor (P) for Bac Kan province.

| **Land use type group** | **Slope (Degree)** | | | | |
|---|---|---|---|---|---|
| | 0-5 | 5-8 | 8-10 | 10-15 | >15 |
| Evergreen broadleaf forest, Bamboo and wood mixed forest, Shrub and grassland, and water surface | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Plantation forest, Perennial tree and orchard | 0.55 | 0.60 | 0.80 | 0.90 | 1.00 |
| Paddy field and annual tree | 0.27 | 0.30 | 0.40 | 0.45 | 0.50 |
| Residential area | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |

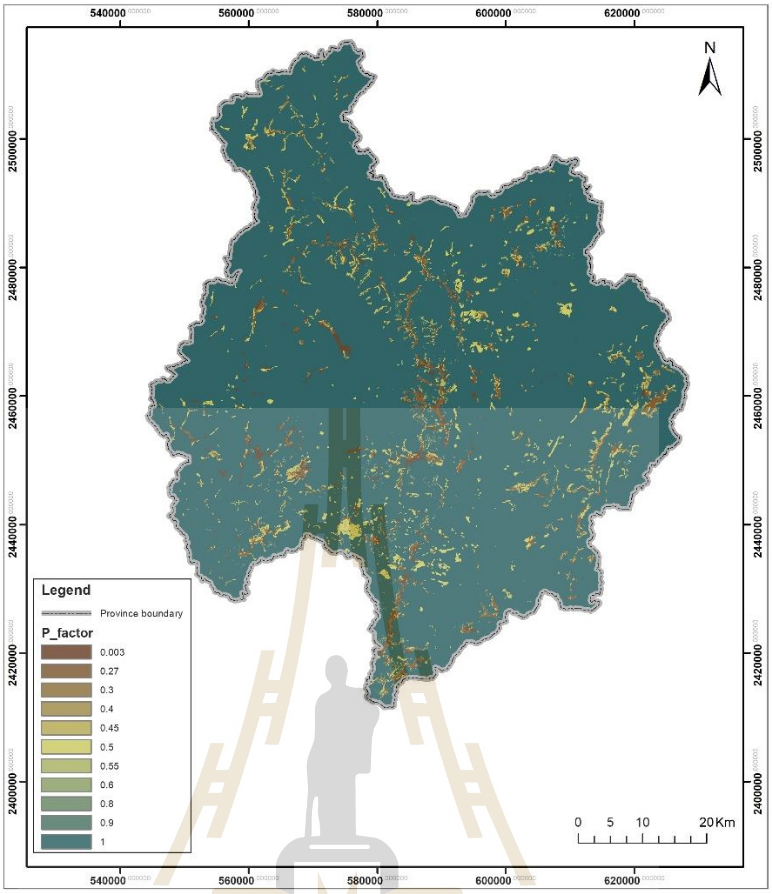



**Figure 6.12** The Supporting practice factor (P).

**Potential soil loss**: Potential soil loss indicates soil erosion rate without considering the C and P factor (Acton, 2013) in the Eq. 6.1. The spatial distribution of potential soil loss in Bac Kan province is shown in Figure 6.13.

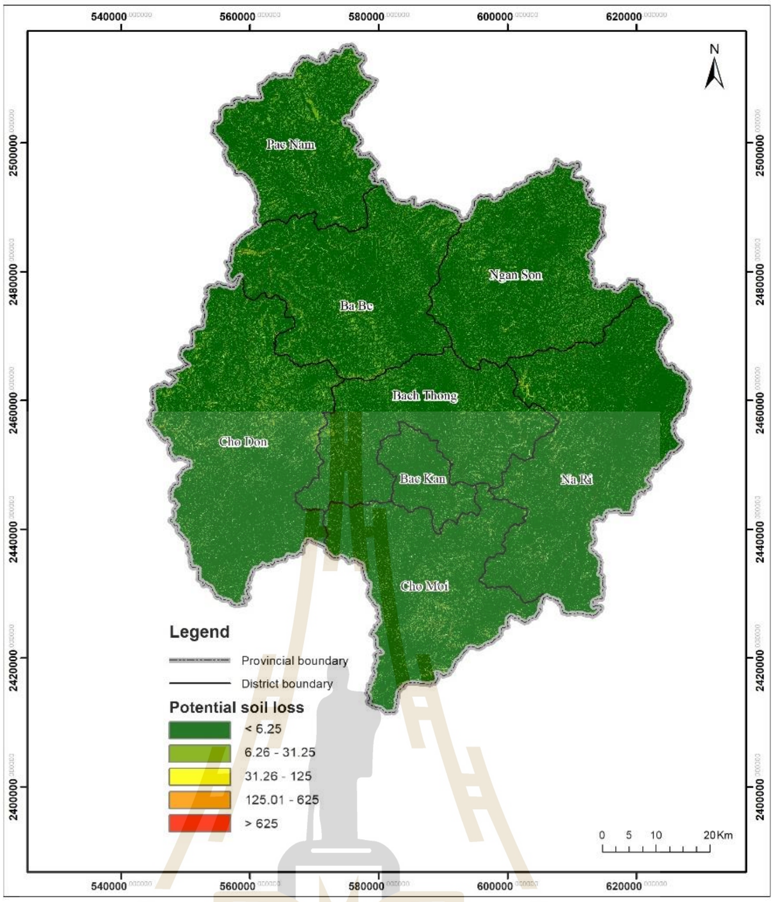



**Figure 6.13** Potential soil loss in Bac Kan province.

**Actual soil loss:** Actual soil loss of the landscape was computed using Eq. 6.1. The spatial distribution of actual soil loss in Bac Kan province is shown in Figure 6.14.

**The importance of soil conservation:** The amount of soil conservation in Bac Kan province was calculated by the subtraction of potential and actual soil loss. The amount of soil conservation was then grouped into five categories using the natural breaks method to represent the importance of soil conservation (Table 6.10). The amount of soil conservation grows, the importance of soil conservation increases. The final distribution of the importance of soil conservation is shown in Figure 6.15.

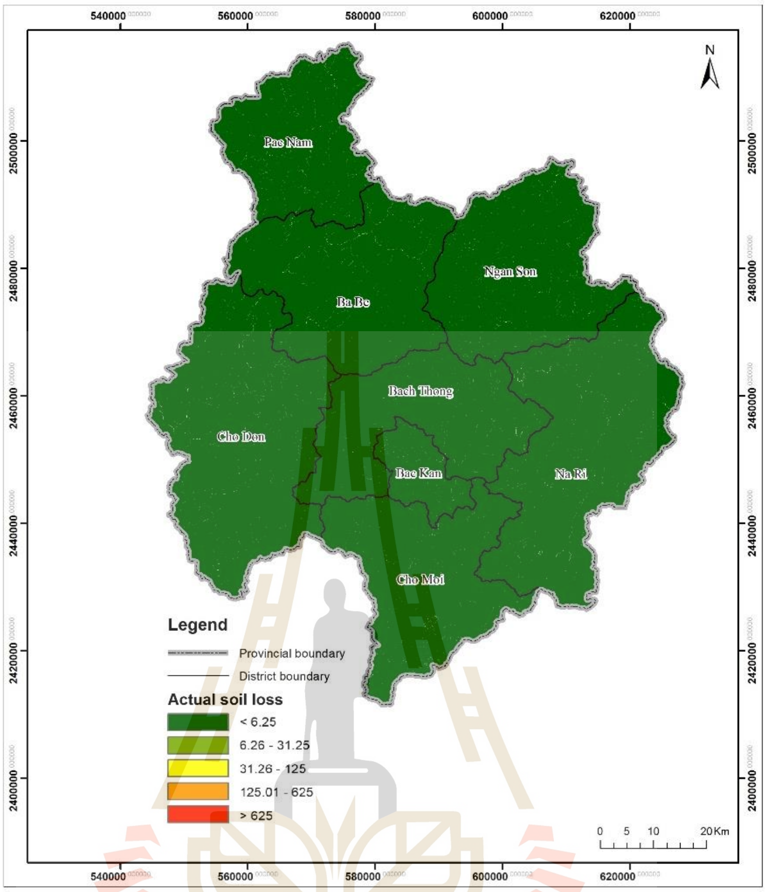



**Figure 6.14** Actual soil loss in Bac Kan province.

**Table 6.10** Reclassifying of soil conservation using natural breaks method.

| No | Soil conservation (tons $ha^{-1}$ $year^{-1}$) | Description |
|---|---|---|
| 1 | 0 – 37.82 | Very low |
| 2 | 37.82 – 189.1 | Low |
| 3 | 189.1 – 520.03 | Moderate |
| 4 | 520.03 – 1,106.24 | High |
| 5 | 1,106.24 – 2,411.04 | Very high |

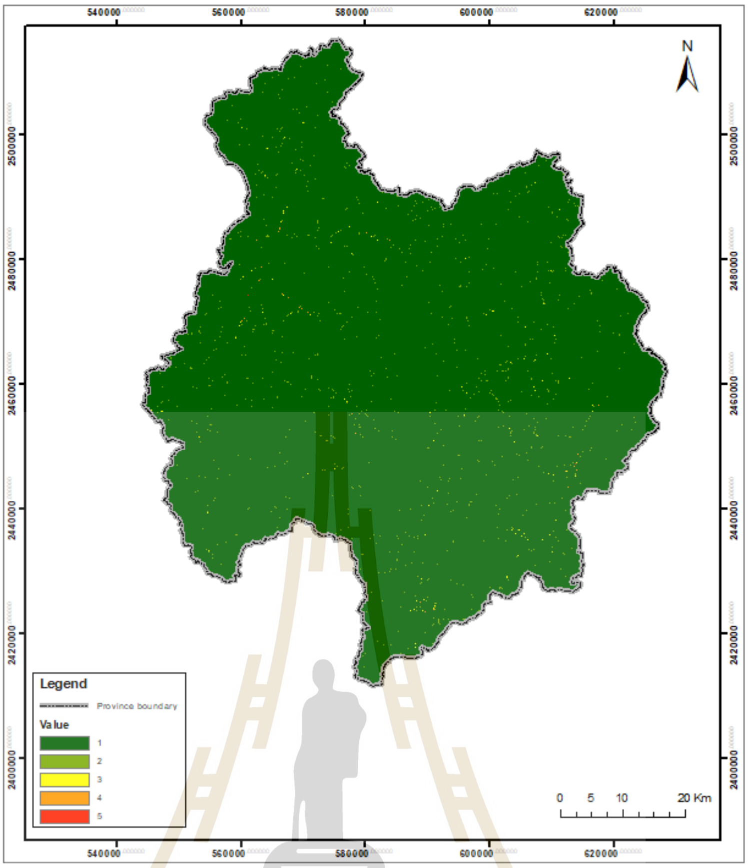



**Figure 6.15** The importance level of soil conservation in Bac Kan province.

### 6.2.4 Ecological functional resistance evaluation

Finally, the ecological functional resistance to mountainous area construction resulting from comprehensive ecological importance was calculated as an equally weighted sum of three sub-indicators as the importance of biodiversity protection, water retention, and soil conservation. The spatial pattern of ecological functional resistance is shown in Figure 6.16 and Table 6.11. As a result, the spatial pattern of ecological functional resistance is considerably dominated by low and moderate classes that cover an area of about 3,785 $km^2$ or 77.91% of the total area.

**Table 6.11** Percentage and the area of each ecological functional resistance class.

| Resistance class | Description | Resistance value | Area ($Km^2$) | Area (%) |
|---|---|---|---|---|
| 1 | Very low | 3 – 5 | 383.677 | 7.90 |
| 2 | Low | 5 – 8 | 2296.990 | 47.27 |
| 3 | Moderate | 8 – 10 | 1488.713 | 30.64 |
| 4 | High | 10 – 11 | 680.149 | 14.00 |
| 5 | Very high | 11 – 15 | 9.081 | 0.19 |

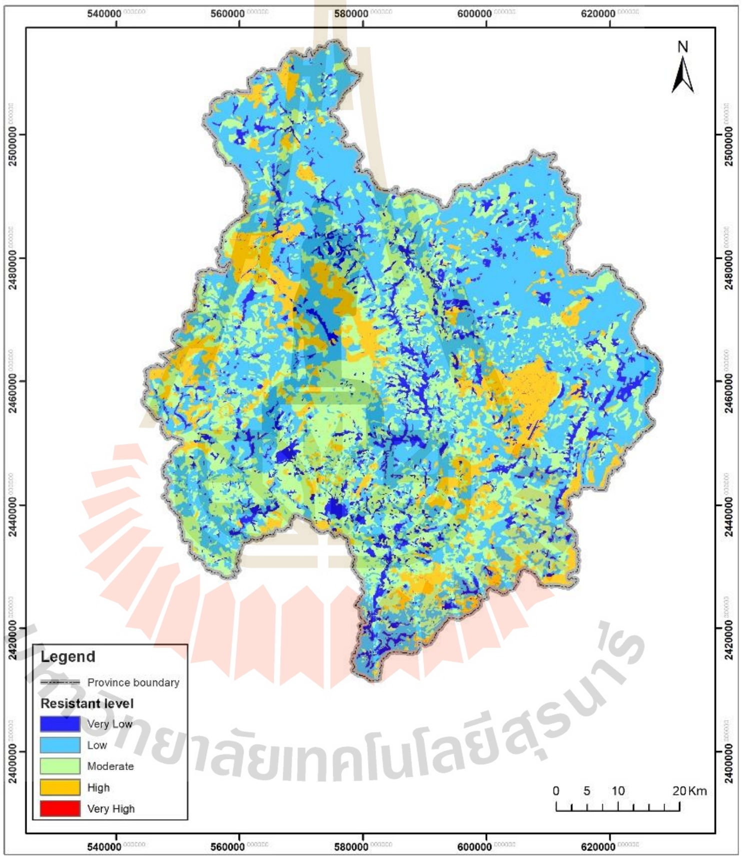



**Figure 6.16** Spatial pattern of ecological functional resistance.

## 6.3 Ecological adaptation resistance

Using the concept of ecological resilience based on ecological circulation theory and taking great human disturbance into account, representing the temporal dynamic characteristics of a natural ecosystem's self-organization and self-update using the three aspects of resistance, exposure, and interference. These three aspects respectively correspond to detailed indicators include vegetation stability ($S_1$), ecological sensitivity ($S_2$), and social disturbance intensity ($S_3$). Based on the conceptual framework of ecological resilience, the ecological adaptation resistance (R) can be assessed using Eq. 3.2.

### 6.3.1 Vegetation stability

Vegetation stability indicates the ability of vegetation to resist interference and maintain its original growth condition with environmental fluctuations in temperature, precipitation, and soil properties. Vegetation stability in this study is quantified through the variation amplitude of vegetation using perennial NDVI from MODIS product (MOD13Q1) with support of TIMESAT 3.3 software. Actually, vegetation stability is the reciprocal of variation amplitude of vegetation. The lower the variation amplitude, the greater the vegetation stability, and therefore the higher the resistance to development activities (Peng et al., 2016).

In this study, an NDVI dataset of 207 scenes (23 scenes/year) between 2009 and 2018 was used to quantify variation amplitude of vegetation. This NDVI dataset was then re-projected and used to extract the study area. Furthermore, the quality of vegetation data is assigned the weights for adjusting NDVI data based on the pixel reliability index (Table 6.12 and Table 6.13).

**Table 6.12** Details of the pixel reliability data.

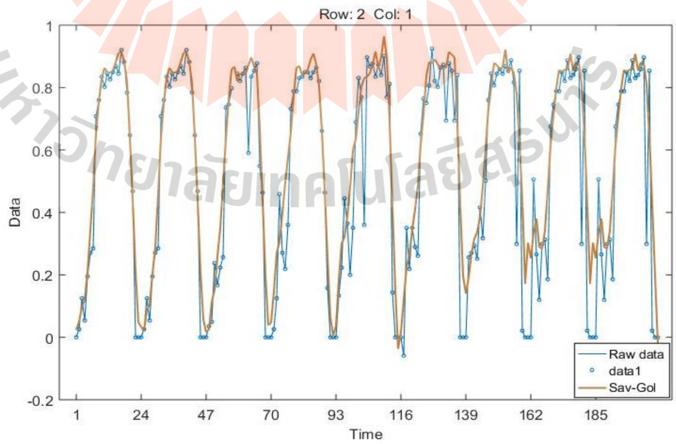
| Rank Key | Summary QA | Description |
|---|---|---|
| 0 | Fill/No Data | Not Processed |
| 1 | Good Data | Use with high confidence |
| 2 | Marginal data | Useful, but look at other QA information |
| 3 | Cloudy | Target not visible, covered with cloud |

**Source**: https://lpdaac.usgs.gov/modis/modis_products_table/mod13q1.

**Table 6.13** Weighting of vegetation data quality (NDVI).

| File Value | Weight |
|---|---|
| 1 | 1.0 |
| 2 | 0.5 |
| 3 | 0.1 |

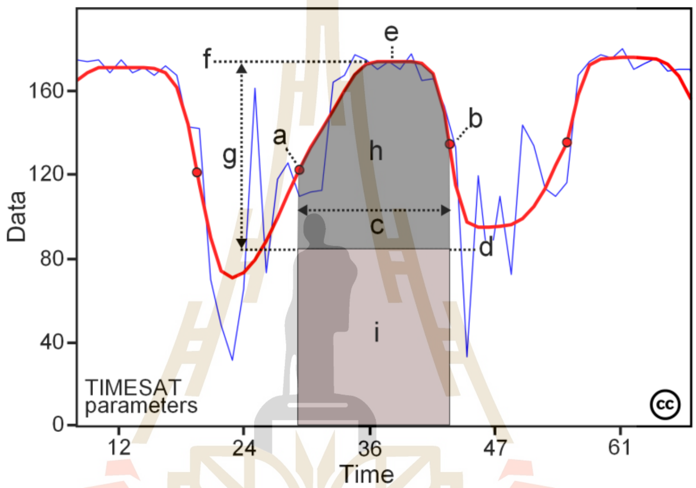
After weighting vegetation data quality, the Savitsky-Golay filtering algorithm was applied to enhance the quality of the NDVI dataset. An example of a characteristic of NDVI before and after filtering of Row 2, Column 1 is displayed in Figure 6.17.




**Source:** Eklundh and Per (2017).

**Figure 6.17** Comparison of time series NDVI data at Row 2, Column 1 before and after filtering.

At the last step, the variation amplitude of vegetation was extracted from seasonality data. Besides, a variety of seasonality parameters can be extracted using TIMESAT 3.3 software is presented in Figure 6.18. The amplitude value was then classified into 5 classes using natural breaks method (Table 6.14). The variation amplitude of vegetation in this study represents vegetation stability. The distribution of vegetation stability is shown in Figure 6.19.




**Source:** Eklundh and Per (2017).

**Figure 6.18** Some of the seasonality parameters generated in TIMESAT: (a) beginning of season, (b) end of season, (c) length of season, (d) base value, (e) time of the middle of the season, (f) maximum value, (g) amplitude, (h) small integrated value, (h+i) large integrated value.

**Table 6.14** Reclassifying of vegetation stability based on variation amplitude of vegetation.

| Amplitude | Vegetation stability | Reclassified classes |
|---|---|---|
| < 0.514 | Very Low | 1 |
| 0.514 – 0.632 | Low | 2 |
| 0.632 – 0.766 | Moderate | 3 |
| 0.766 – 0.896 | High | 4 |
| > 0.896 | Very High | 5 |

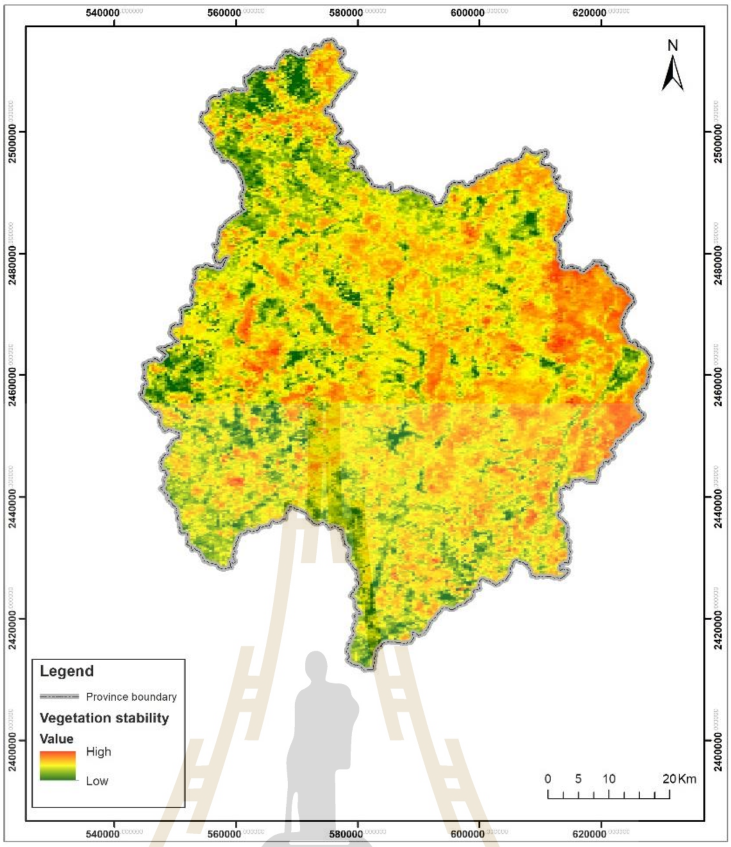



**Figure 6.19** Spatial pattern of vegetation stability.

### 6.3.2 Ecological sensitivity

Ecological sensitivity reflects the degree to which human activities and natural changes reflect on the ecosystem, as well as the degree to which regional ecological and environmental problems can possibly occur (Ouyang Zhi Yun, Ke, and Hong, 2000). Assessing ecological sensitivity was achieved using distance from important ecological functional areas or key ecological patches (Li, Shi, Qureshi, Bruns, and Zhu, 2014). A shorter distance means a greater risk of ecological structural damage or functional degradation when disturbances occur. Therefore, the area in question is more sensitive, and the resistance to construction is greater.

The important ecological functional areas in Bac Kan province include Ba Be National Park, Kim Hy Natural Reserve, and Nam Xuan Lac Species and Habitat Conservation Area. The location and extent of these areas were extracted using data obtained from the Bac Kan Department of Natural Resources and Environment. A distance surface layer was then created using Euclidean distance tool in ESRI ArcGIS. This distance surface layer was then reclassified on a descending scale from level 5 to level 1 using the natural breaks method, with the levels corresponding to the increasing distance to the important ecological functional areas (Table 6.15). This layer represents 5 levels of ecological sensitivity in Bac Kan province with level 5 consist of the most sensitive areas where important ecological functional areas locate. The spatial pattern of ecological sensitivity is shown in Figure 6.20.

**Table 6.15** Reclassifying of ecological sensitivity based on the distance to the important ecological functional areas.

| Distance to the important ecological functional areas (km) | Reclassified classes |
|---|---|
| 0 – 6.171 | 5 |
| 6.171 – 13.250 | 4 |
| 13.250 – 20.147 | 3 |
| 20.147 – 28.315 | 2 |
| 28.315 – 46.284 | 1 |

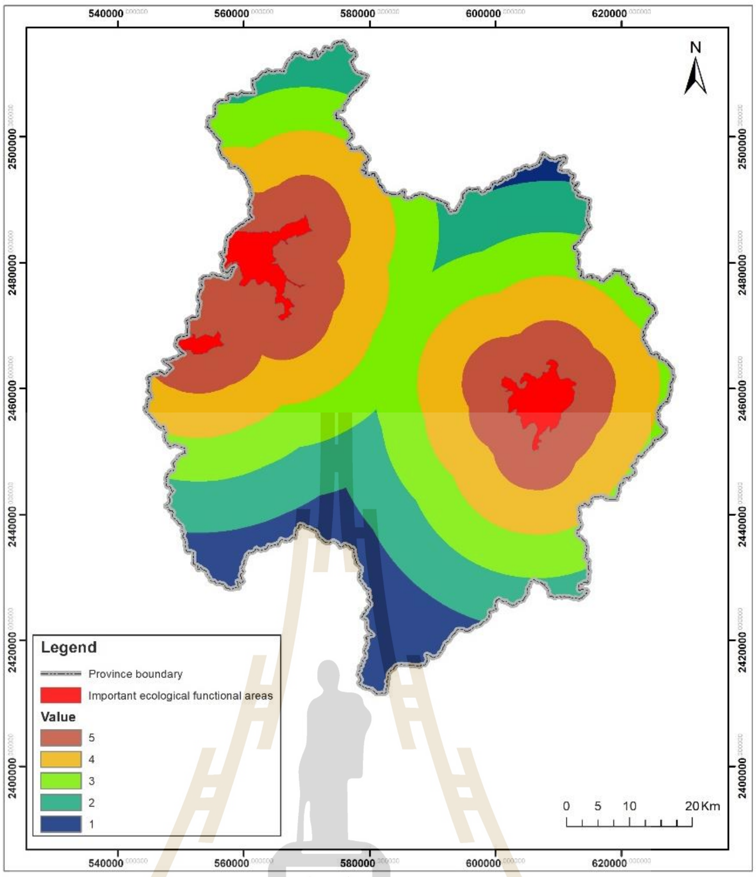



**Figure 6.20** Spatial pattern of ecological sensitivity.

### 6.3.3 Social disturbance intensity

Social disturbance intensity refers to the spatial differentiation in the intensity of human activity in the study area, as expressed by spatial population density. Population density is the proportion of the population divided by area. It is generated at the district level using the population data obtained from the People's Committee of Bac Kan Province of the year 2018. The population density layer was reclassified into 5 classes using the natural breaks method (Table 6.16). These 5 classes represent social disturbance intensity. The greater the degree of social disturbance, the lower will be the resistance to construction. The distribution of social disturbance intensity is shown in Figure 6.21.

**Table 6.16** Reclassifying of population density.

| Population density (person/km$^2$) | Reclassified classes |
|---|---|
| 42 – 44 | 1 |
| 44 – 54 | 2 |
| 54 – 63 | 3 |
| 63 – 67 | 4 |
| 67 – 271 | 5 |

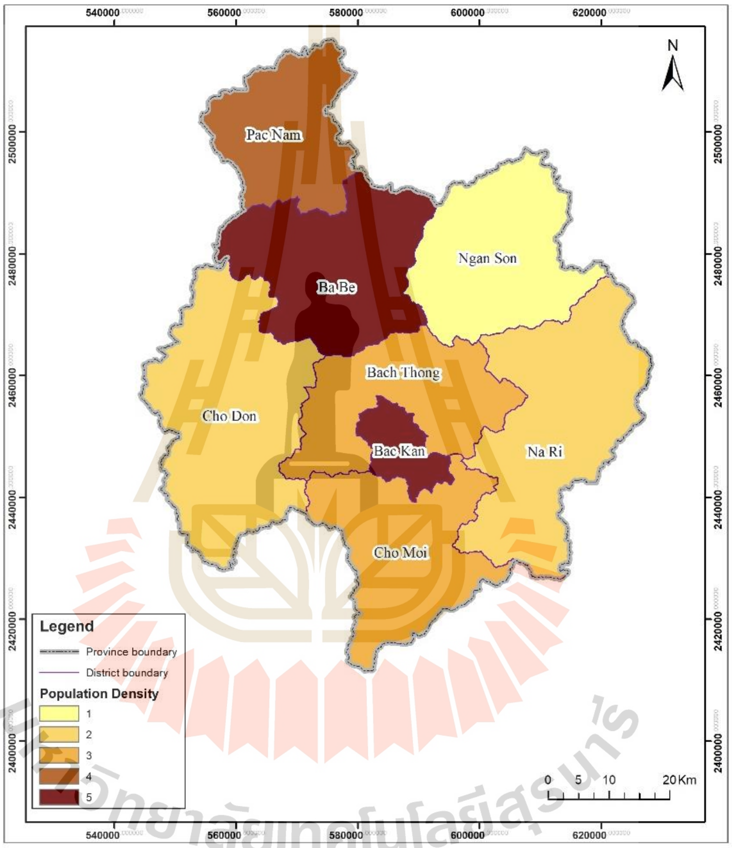



**Figure 6.21** Spatial pattern of social disturbance intensity using population density.

### 6.3.4 Ecological adaptation resistance evaluation

The final evaluation of ecological adaptation resistance represented by ecological resilience is computed using Eq. 3.2, which is connected with vegetation stability, ecological sensitivity, and social disturbance intensity. The spatial pattern of ecological adaptation resistance is shown in Figure 6.22 and Table 6.17. As a result, the spatial pattern of ecological dynamics resistance is considerably dominated by low and moderate classes that cover an area of about 2,604 $km^2$ or 53.85% of the total area.

**Table 6.17** Percentage and the area of each ecological adaptation resistance class.

| Resistance class | Description | Resistance value | Area ($Km^2$) | Area (%) |
|---|---|---|---|---|
| 1 | Very low | 0.333 - 1.592 | 747.591 | 15.46 |
| 2 | Low | 1.592 - 3.332 | 1443.556 | 29.85 |
| 3 | Moderate | 3.332 - 6.621 | 1160.492 | 24.00 |
| 4 | High | 6.621 - 10.027 | 1062.170 | 21.97 |
| 5 | Very high | 10.027 - 25.226 | 421.692 | 8.72 |

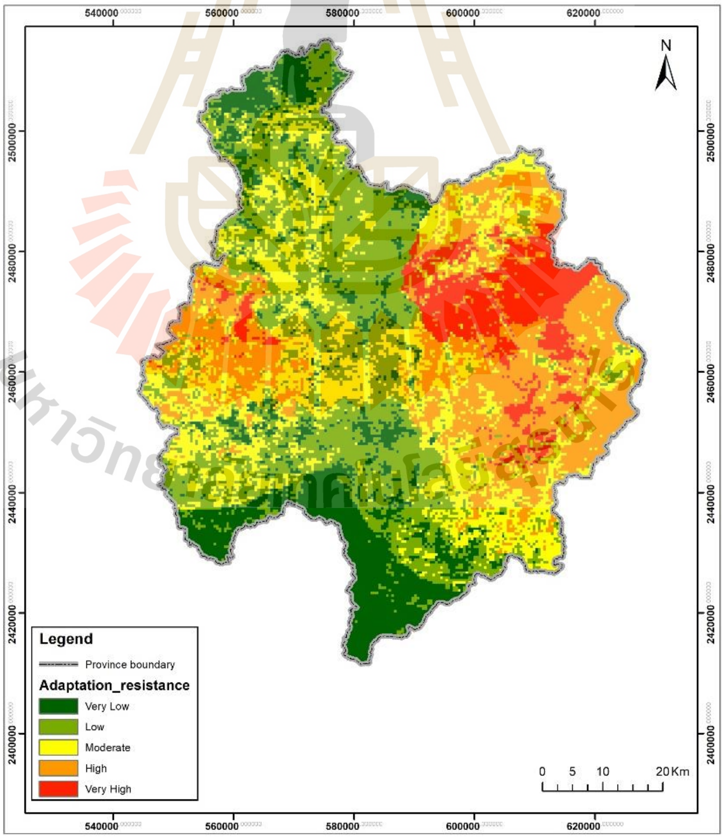



**Figure 6.22** Spatial pattern of ecological adaptation resistance.

## 6.4 Integrated ecological resistance evaluation

By integrating the resistances of ecological structure, function, and adaptation to mountainous area development, the integrated ecological resistance (IER) index for construction in mountainous areas of Bac Kan province was calculated using Eq. 3.1. It can be concluded that the lower the IER index, the less will be the ecological risk in mountainous area development, and the weaker will be its disturbance to the eco-environment, producing lower ecological costs and higher ecological suitability. Based on the IER index values ranging from high to low, this study grades the ecological suitability for construction in Bac Kan province into five categories using the natural breaks method. The classification of the IER index and ecological suitability is shown in Table 6.18. The ecological suitability map for construction is shown in Figure 6.23.

**Table 6.18** The classification of integrated ecological resistance and ecological suitability.

| Class | Suitability | IER Index | Area (Km$^2$) | Area (%) |
|---|---|---|---|---|
| 1 | Not Suitable | 3.63 – 4.95 | 259.863 | 5.37 |
| 2 | Slightly Suitable | 2.98 – 3.63 | 1,338.521 | 27.68 |
| 3 | Moderately Suitable | 2.31 – 2.98 | 1,948.286 | 40.30 |
| 4 | Suitable | 1.64 – 2.31 | 1,022.494 | 21.15 |
| 5 | Very Suitable | 0.99 - 1.64 | 265.719 | 5.50 |

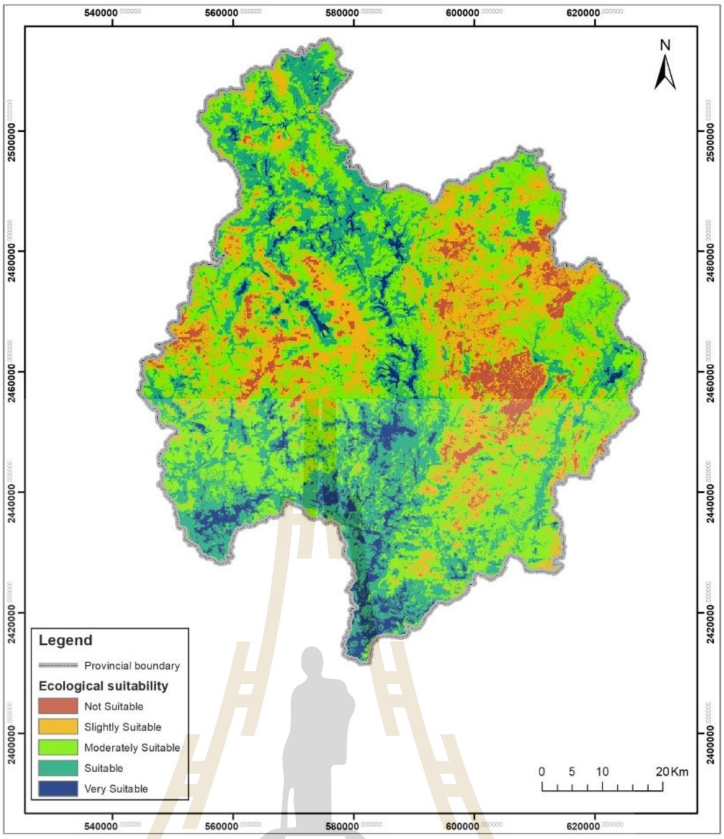



**Figure 6.23** The ecological suitability map for construction in Bac Kan province.

As a result, the most dominant ecological suitability class for construction and development is the moderately suitable class and it accounts for about 1,948 $km^2$ or 40.30% of the total area. In addition, the spatial pattern of the ecological suitability map is considerably similar to the ecological functional resistance map. Meanwhile, the most suitable areas for construction and development in Bac Kan province according to ecological suitability classification locate in lowland areas where are classified as very suitable and suitable classes and they cover an area of about 1,288 $km^2$ or 26.65% of the total area.

In the meantime, at the district level, the suitable and very suitable classes obviously dominate in Bac Kan capital city and Cho Moi district. The two areas have a large area with high suitability for development and construction. General speaking, these areas have a stable geological environment, flat terrain, and ecological importance less than densely vegetated hotspot areas with rich biodiversity, e.g. Ba Be and Na Ri districts. Moreover, from the perspective of dynamic ecosystem adaptation, development and construction in these areas involve less influence on natural ecosystems.

In summary, this study has quantitatively characterized the resistance of the ecological structure, ecological function, and ecological adaptation respectively based on the evaluation of ecological elements, ecological importance, and ecological resilience. Then, the IER index was calculated by integrating these three resistances of ecological structure, function, and adaptation. Furthermore, the ecological suitability map for construction in Bac Kan province was produced with five categories based on the IER index ranging from high to low. This derived ecological suitability map for construction is the crucial data for ecological suitability zonation for mountainous area development and biodiversity conservation in Chapter VIII.

# CHAPTER VII

# LANDSCAPE ECOLOGICAL ANALYSIS FOR BIODIVERSITY CONSERVATION

This chapter presents the results of the fourth objective focusing on analyzing landscape ecology for biodiversity conservation. Herein, the derived landscape map of Bac Kan province with 315 landscape types from Chapter 4 was used to analyze spatial information for biodiversity conservation using landscape ecological metrics.

The formula and description of these metrics are described in Table 7.1. Characteristic of each landscape metric is summarized below:

Firstly, the Shannon diversity index and Shannon's evenness index was used as a measure of landscape heterogeneity. Landscapes that have a great variety of habitat types are assumed to be richer in biodiversity and hence have a higher conservation value than homogeneous ones. The index does not only reflect the richness of habitats but also their relative importance in a given area.

Secondly, the area-weighted mean patch shape and area-weighted mean fractal dimension was applied as a measure of patch shape. Landscape ecological studies suggest that a landscape where complex patch shapes predominate, such as natural woodlands and naturally winding streams, has more species richness and encourages animal migration because of habitat variation on a fine-scale than landscapes influenced by intensive land uses and with straight borders (Moser et al., 2002). However, habitat patches characterized by a high perimeter to area ratio may lack in inner habitat for specific species, for instance, birds and beetles that can only live in inner woodlands. Therefore, the perimeter to area ratio was weighted by patch size in this research.

Thirdly, nearest neighbor distance and mean proximity index were applied as a measure of patch distance. A patch distance index was taken as a measure for the degree of isolation between landscape units within the study areas. Patch isolation explains why fragmented habitats often contain fewer bird species than adjacent habitats (Van Dorp and Opdam, 1987). Well-connected patches may provide essential corridors that enhance species movement between isolated patches. These indices addressed the average connectivity or lack of connectivity between patches in a character area.

Fourthly, number of patches, patch density, total area, and edge density were applied as a measure of the patch area. The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. Most species have minimum area requirements: the minimum area needed to meet all life history requirements. Some of these species require that their minimum area requirements be fulfilled in contiguous habitat patches; in other words, the individual habitat patch must be larger than the specified minimum area requirement for them to occupy the patch. These species are sometimes referred to as "area-sensitive" species. Thus, patch size information alone could be used to model species richness, patch occupancy, and species distribution patterns in a landscape given the appropriate empirical relationships derived from field studies.

**Table 7.1** Landscape metrics for assessing biodiversity values.

| Landscape metric group | Landscape indices | Formula | Description |
|---|---|---|---|
| Landscape heterogeneity | Shannon's diversity index | $SHDI = -\sum_{k=1}^{s} P_i \ln P_i$ | S, m = number of habitat types, $P_i$=proportion of an area in habitat cover k. |
| | Shannon's evenness index | $SHEI = \frac{-\sum_{i=1}^{m} (P_i * \ln P_i)}{\ln m}$ | |
| Patch shape | Area weighted shape index | $AWSI = \frac{\sum_{i=1}^{m} SI_i x a_i}{\sum_{i=1}^{m} a_i}$ | $SI_i$=shape index of patch *I*, *ai* the area of the patch *i*. |
| | Area-weighted mean fractal dimension | $FRAC = \frac{2 \ln (.25 p_{ij})}{\ln a_{ij}}$ | $p_{ij}$ = perimeter (m) of patch ij.<br>$a_{ij}$ = area ($m^2$) of patch ij. |
| Patch distance | Nearest neighbor distance | $NND = d_{jk}$ | NND equals the nearest-neighbor distance from patch j to another patch k of the same type, based on the shortest edge-to-edge distance. |
| | Mean proximity index | $MPI_i = \frac{\sum_{i=1}^{m} PI_i x a_i}{NP}$ | $PI_i$=proximity of patch *i*, NP=number of patches: total number of patches in the landscape, $a_i$ the area of the patch *i*. |
| Patch area | Number of patches | NP = N | N = total number of patches in the landscape. |
| | Patch density | $PD = \frac{N}{A}(10,000)(100)$ | N = total number of patches in the landscape.<br>A = total landscape area ($m^2$). |
| | Total area | $TA = A\left(\frac{1}{10,000}\right)$ | A = total landscape area ($m^2$). |
| | Edge density | $ED = \frac{E}{A}(10,000)$ | E = total length (m) of edge in landscape.<br>A = total landscape area ($m^2$). |

The main results of this chapter derived from the analysis of four group metrics include landscape heterogeneity, patch shape, patch distance, and patch area.

## 7.1 Landscape map preparation for landscape analysis

Before the landscape analysis process, the landscape map of Bac Kan province with 315 landscape types was used to create 8 landscape maps for 8 districts which are Ba Be, Bach Thong, Bac Kan, Cho Don, Cho Moi, Na Ri, Ngan Son, and Pac Nam using the Extract by Mask tool in ArcMap software. These landscape maps are shown in Figure 7.1 to Figure 7.8 with symbology is grouped by land use. While Table 7.2 illustrates the area of land use, Table 7.3 shows a different number of landscape types of these landscapes. These 8 landscape maps were then used as basic units for landscape pattern analysis using Fragstats software. Subsequently, the landscape pattern analysis was performed at the landscape level for the purpose of quantitative biodiversity information extraction and comparison. The result of landscape pattern analysis is presented in detail in the following sections.

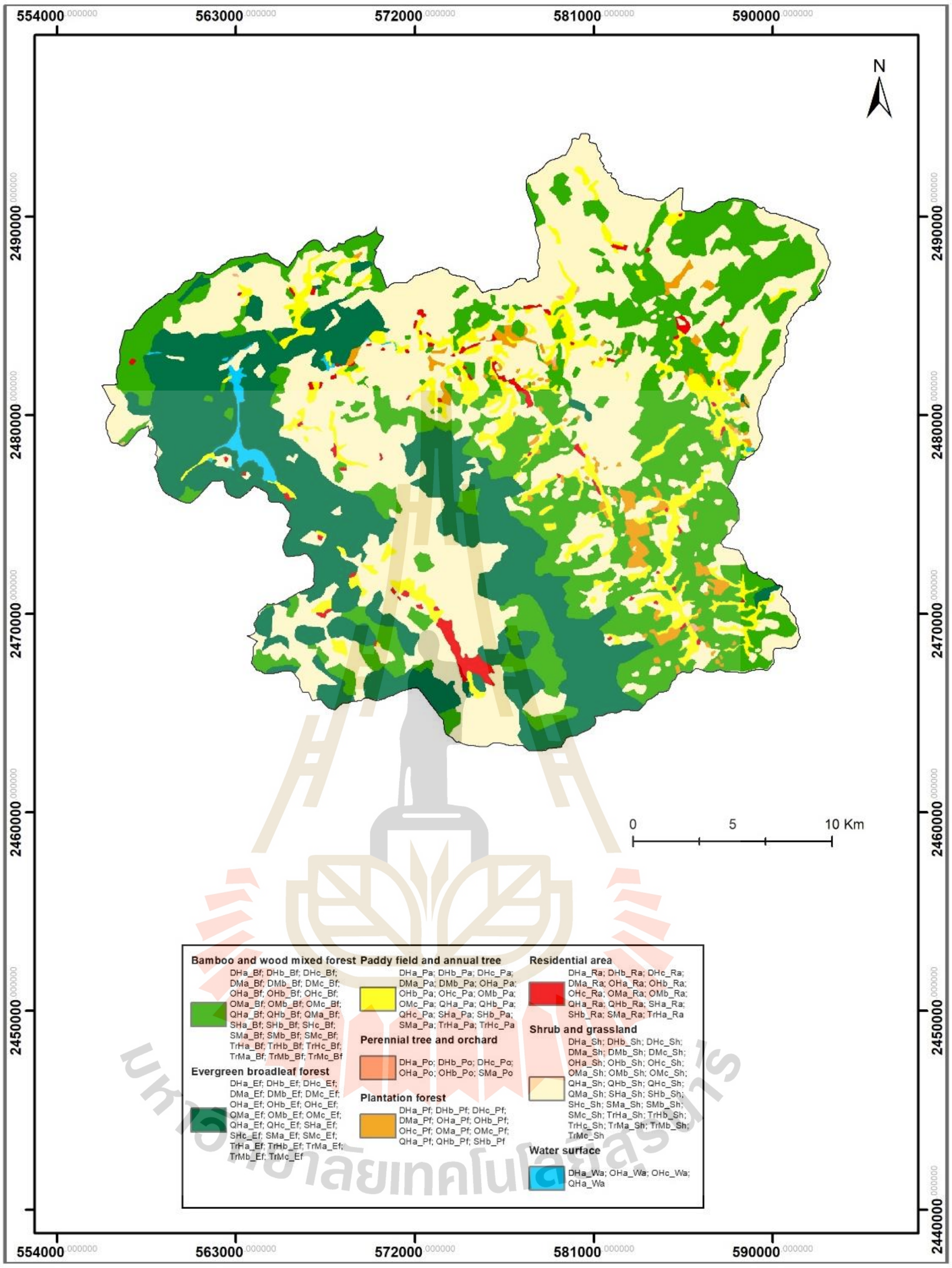



**Figure 7.1** Landscape map of Ba Be district.

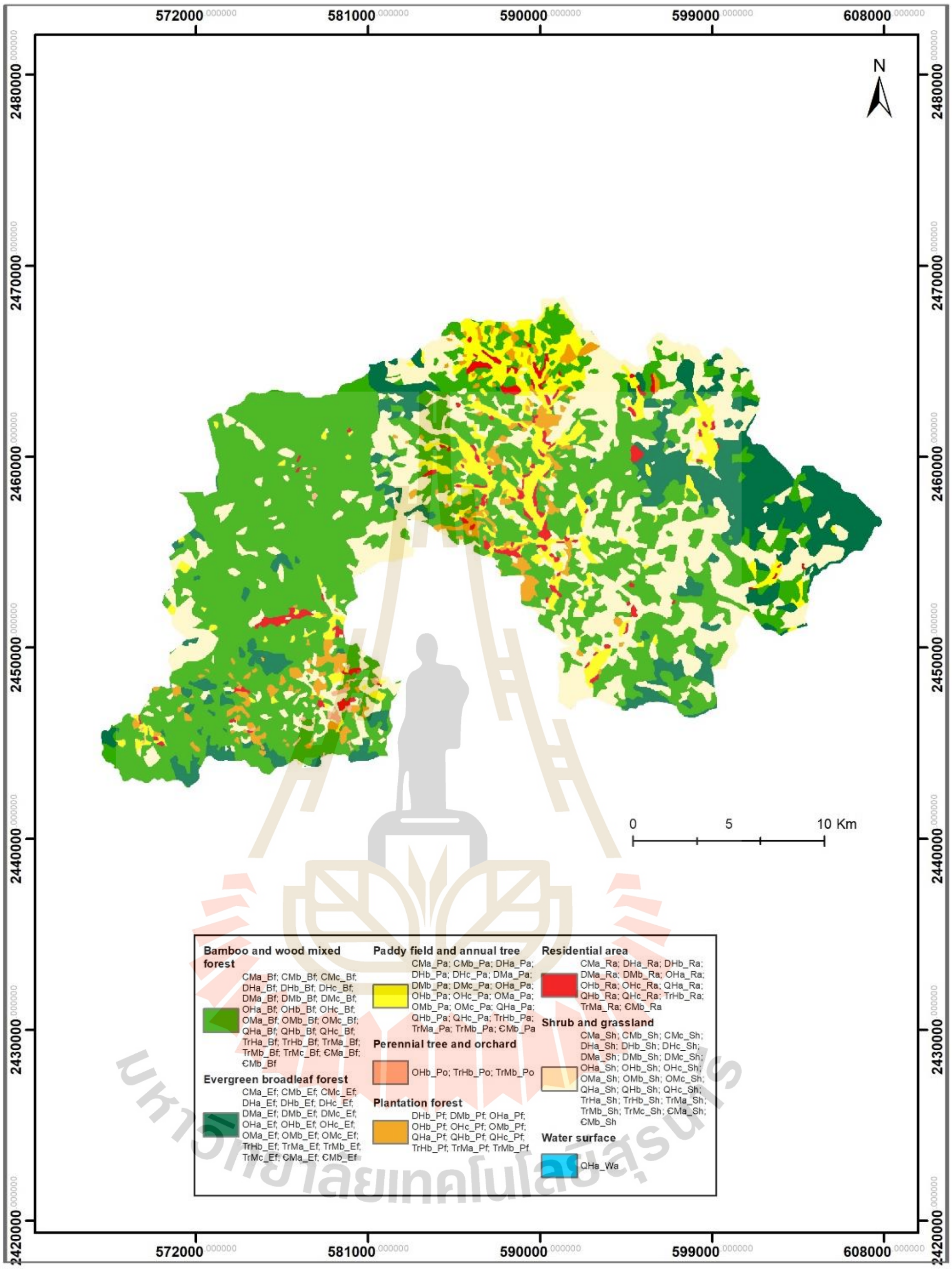



**Figure 7.2** Landscape map of Bach Thong district.

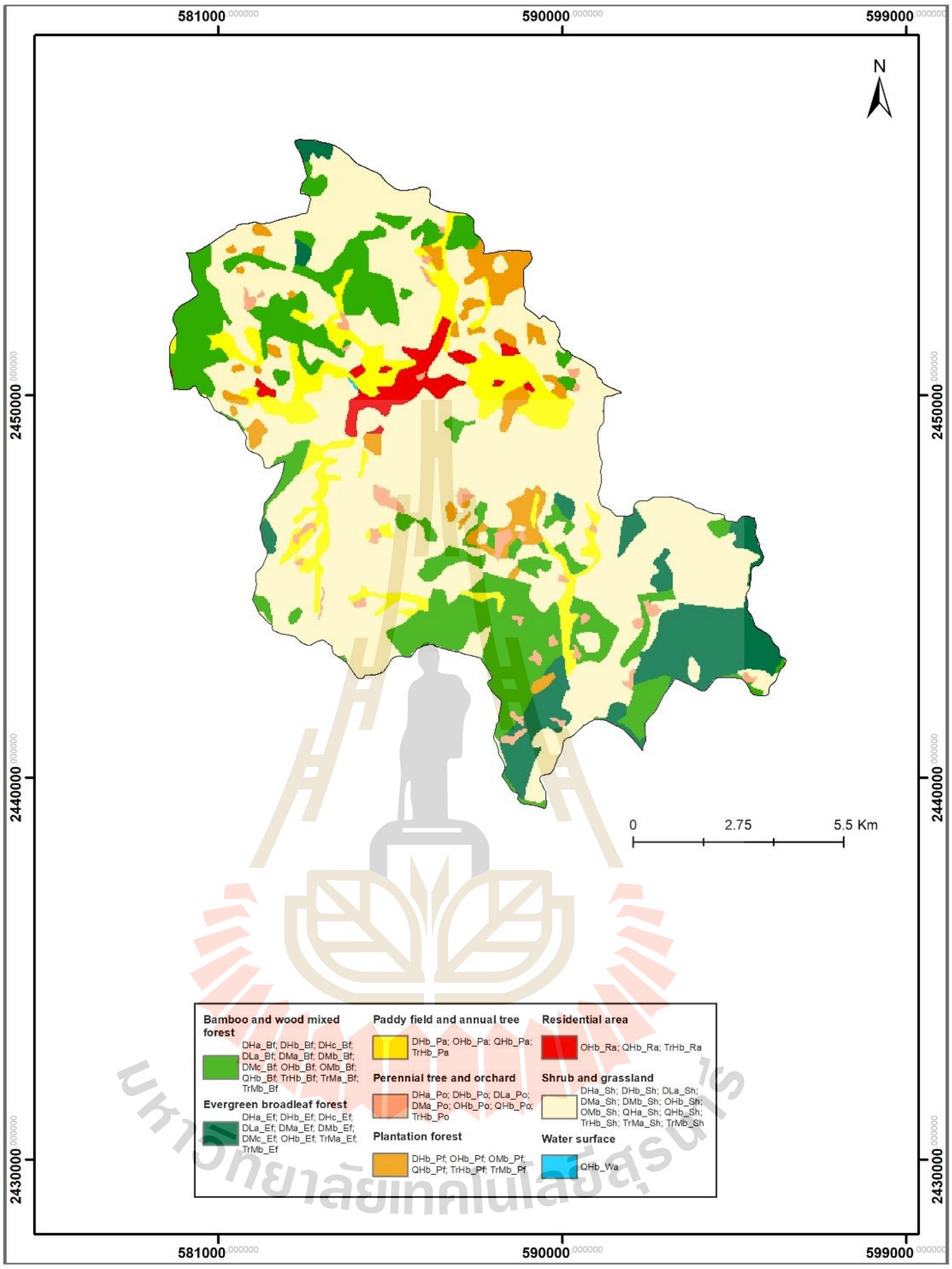



**Figure 7.3** Landscape map of Bac Kan district.

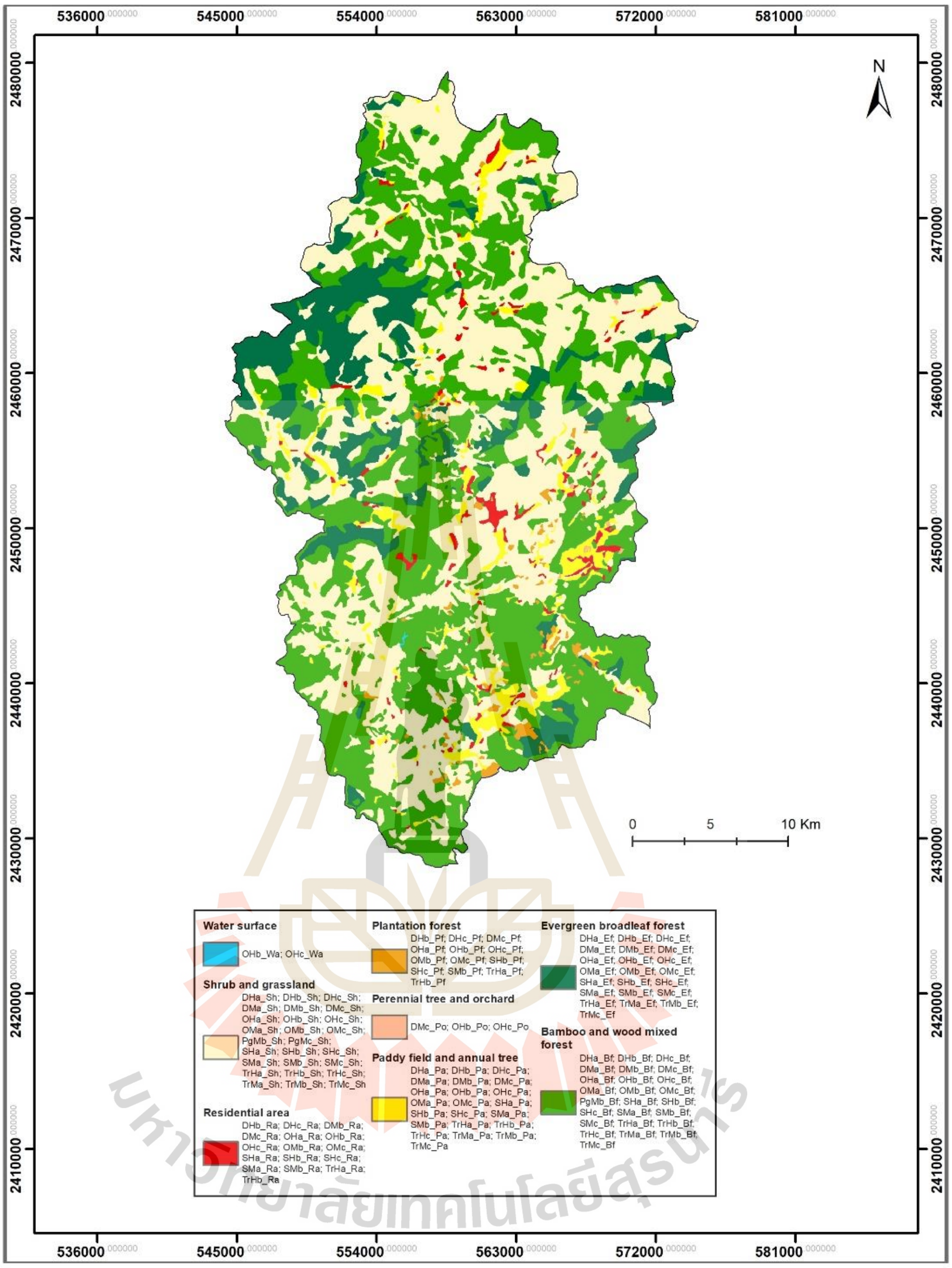



**Figure 7.4** Landscape map of Cho Don district.

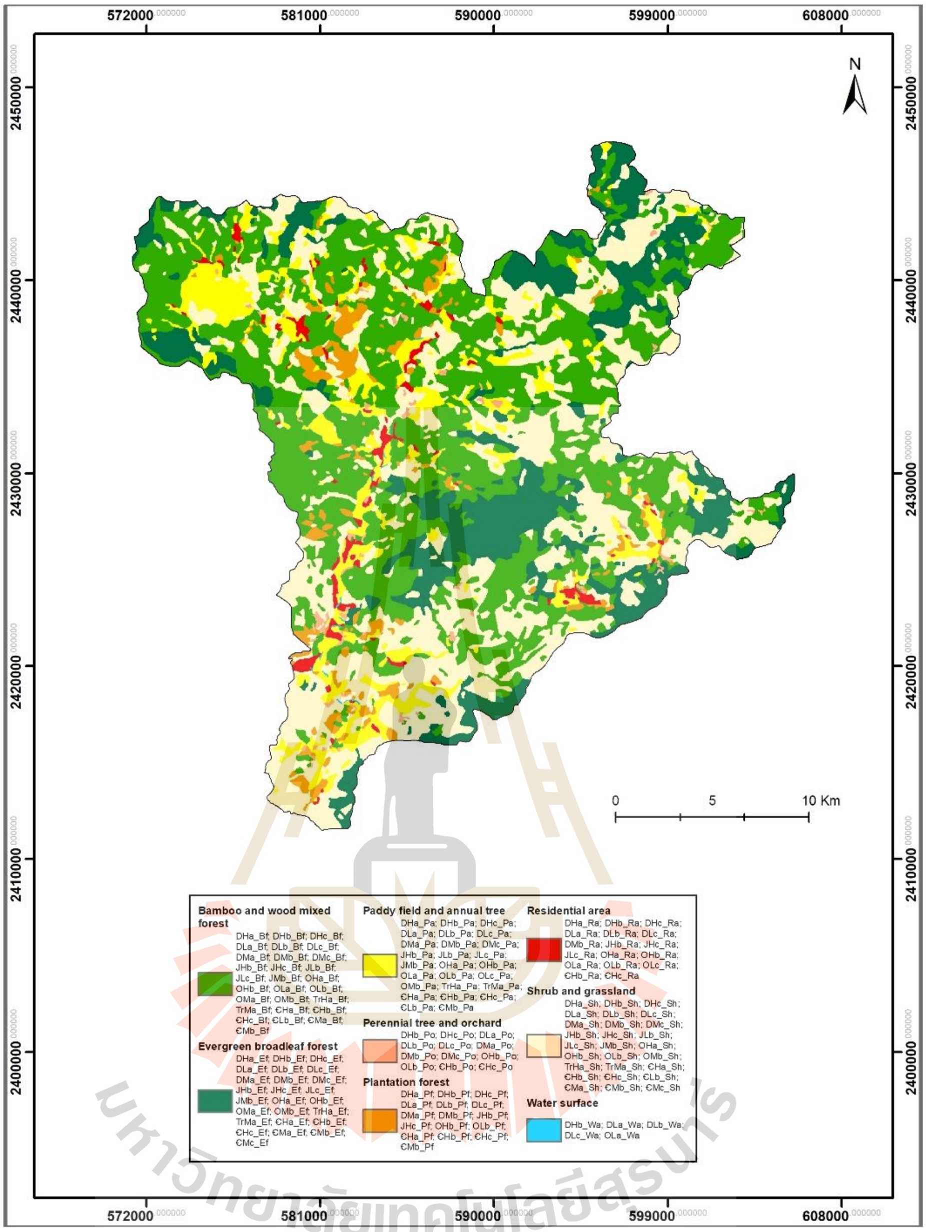



**Figure 7.5** Landscape map of Cho Moi district.

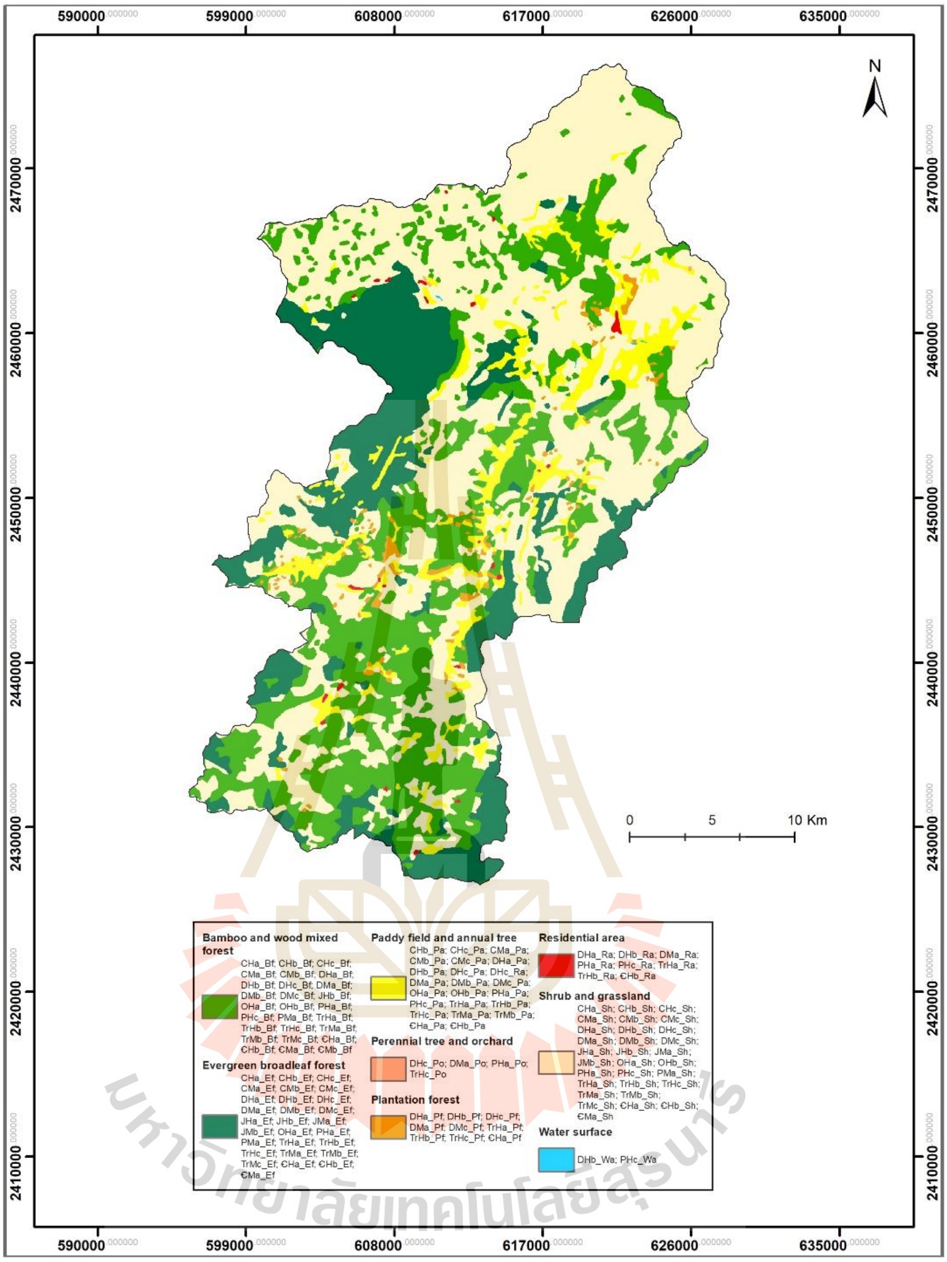



**Figure 7.6** Landscape map of Na Ri district.

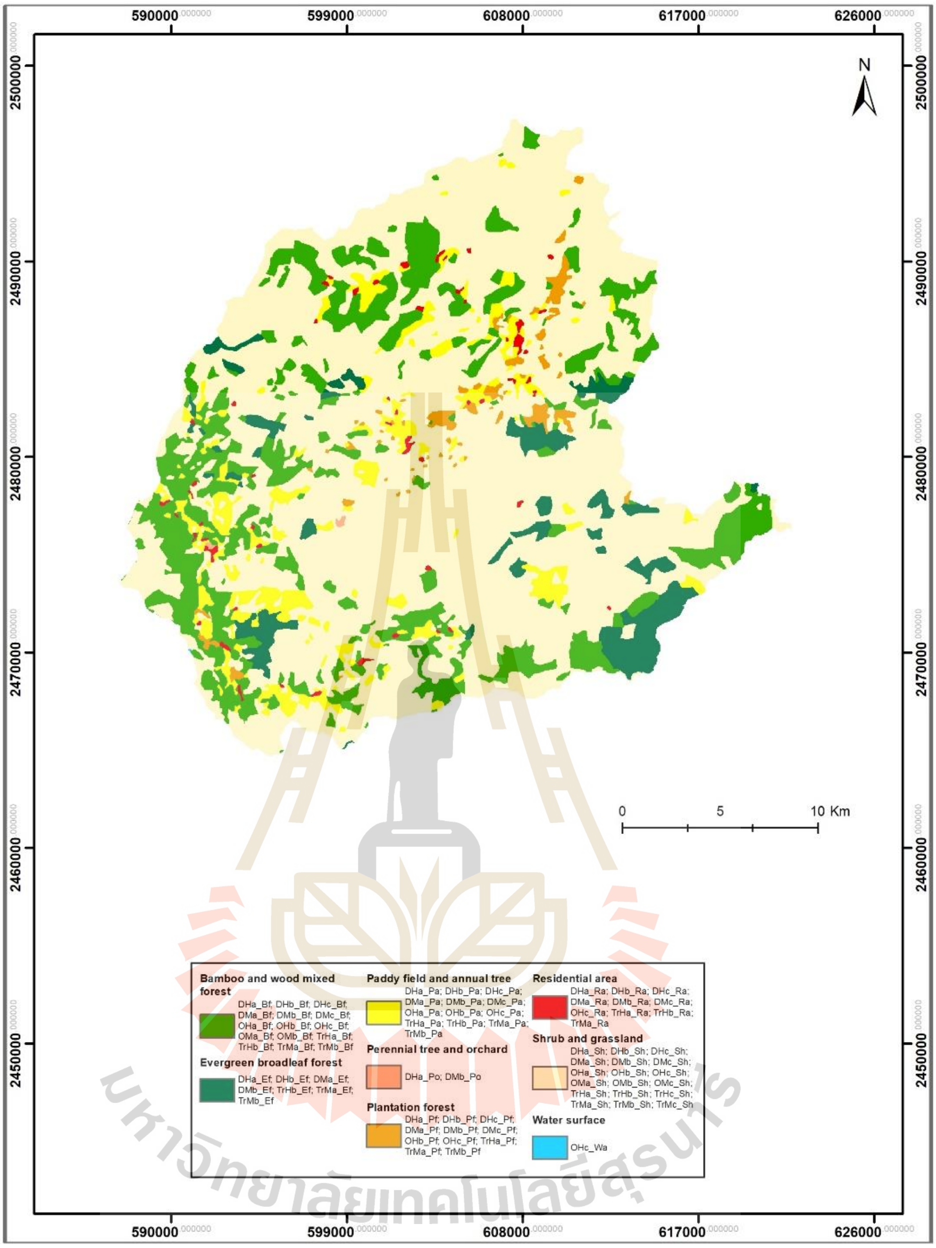



**Figure 7.7** Landscape map of the Ngan Son district.

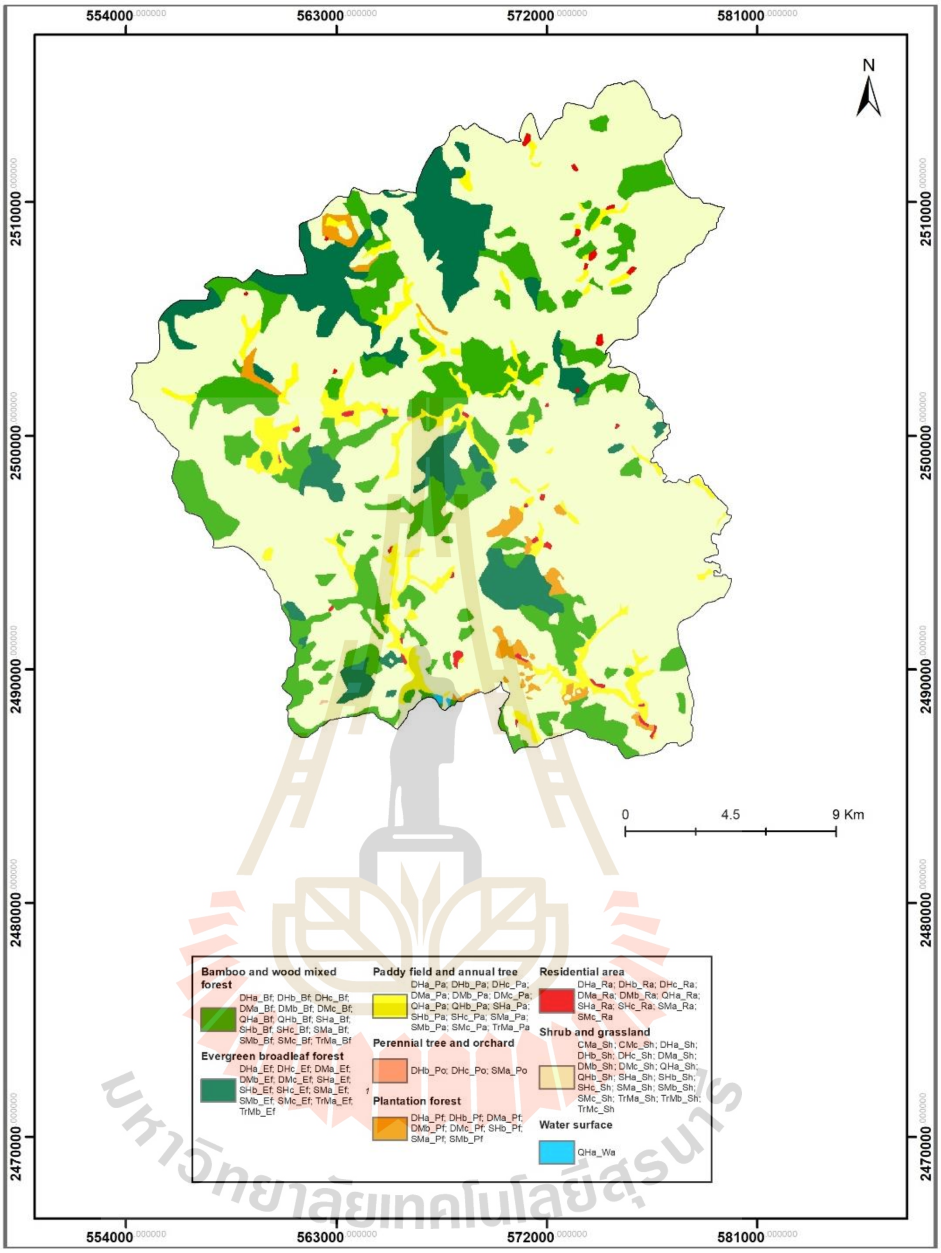



**Figure 7.8** Landscape map of Pac Nam district.

**Table 7.2** The area of land use of 8 districts.

| District | Land use type in ha | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Shrub and grassland | Evergreen broadleaf forest | Paddy field and annual tree | Residential area | Bamboo and wood mixed forest | Plantation forest | Perennial tree and orchard | Water surface |
| Ba Be | 27,414.27 | 15,511.68 | 4,605.93 | 737.73 | 18,471.33 | 1,158.57 | 54.81 | 370.35 |
| Bach Thong | 13,840.20 | 7,046.37 | 3,262.41 | 1,013.67 | 27,501.12 | 1,828.89 | 146.34 | 3.12 |
| Bac Kan | 7,565.94 | 1,109.61 | 1,304.19 | 306.72 | 2,576.16 | 587.52 | 249.66 | 2.43 |
| Cho Don | 37,207.62 | 11,213.73 | 4,028.49 | 1,521.27 | 36,135.63 | 923.4 | 59.4 | 13.77 |
| Cho Moi | 18,153.63 | 9,804.60 | 5,950.44 | 944.64 | 23,050.17 | 2,177.55 | 416.52 | 43.2 |
| Na Ri | 39,602.61 | 15,206.22 | 6,315.39 | 236.52 | 22,757.40 | 1,164.60 | 19.26 | 13.32 |
| Ngan Son | 44,055.99 | 3,294.27 | 4,255.83 | 385.29 | 11,555.19 | 959.13 | 30.51 | 4.03 |
| Pac Nam | 32,121.00 | 4,595.67 | 2,400.21 | 205.65 | 7,653.06 | 687.33 | 9.99 | 2.65 |

**Table 7.3** Number of landscape types of 8 districts of Bac Kan province.

| District | Number of landscape types |
|---|---|
| Ba Be | 133 |
| Bach Thong | 121 |
| Bac Kan | 56 |
| Cho Don | 129 |
| Cho Moi | 156 |
| Na Ri | 131 |
| Ngan Son | 76 |
| Pac Nam | 83 |

## 7.2 Landscape heterogeneity

**(1) Shannon's diversity index (SHDI).** This metric is used as a measure of landscape heterogeneity. Landscapes that have a great variety of habitat types are assumed to be richer in biodiversity and hence have a higher conservation value than homogeneous ones. The index does not only reflect the richness of habitats but also their relative importance in a given area. It is zero when there is only one patch in the landscape and increases as the number of different patch types increases and/or the proportional distribution of area among patch types becomes more equitable. Among 8 districts of Bac Kan province, it is obviously that Cho Don has the highest diversity index with SHDI value of 4.0061, follows by Ba Be, Cho Moi, and Na Ri. This is due to the large portion of primary forest located in these districts. Particularly, Ba Be national park was set up to protect a freshwater lake along with surrounding limestone and lowland evergreen forests. On the contrary, Bac Kan, the capital city of Bac Kan province, has the lowest value of SHDI as the result of urbanization with dominant land use of the built-up area. The status of Shannon's diversity index for 8 districts of Bac Kan province is shown in Table 7.4.

**Table 7.4** Shannon's diversity index value of 8 districts of Bac Kan province.

| District | Shannon's Diversity Index |
|---|---|
| Ba Be | 3.8736 |
| Bach Thong | 3.5982 |
| Bac Kan | 2.6943 |
| Cho Don | 4.0061 |
| Cho Moi | 3.7292 |
| Na Ri | 3.7159 |
| Ngan Son | 3.0547 |
| Pac Nam | 3.3559 |

**(2) Shannon's evenness index (SHEI).** SHEI is another measure of landscape heterogeneity. SHEI measures the other aspect of landscape composition-the distribution of area among patch types. There are numerous ways to quantify evenness and most diversity indices have a corresponding evenness index derived from them. SHEI equals 0 when the landscape contains only 1 patch (i.e., no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven (i.e., dominated by 1 type). SHDI equals 1 when the distribution of area among patch types is perfectly even (i.e., proportional abundances are the same). Overall, there is a consistency between Shannon's evenness index and Shannon's diversity index of 8 districts. The result from SHEI shows that the heterogeneity of 8 landscapes has a similar spatial pattern with the result of SHDI. It also confirms that all 8 districts have the distribution of area among patch types is almost even rather than dominated by 1 type. While the highest evenness index is in Cho Don district account for 0.8243, the lowest is 0.6693 in Bac Kan capital city. The comparison of Shannon's evenness index for 8 districts of Bac Kan province is shown in Table 7.5.

**Table 7.5** Shannon's evenness index value of 8 districts of Bac Kan province.

| District | Shannon's evenness index |
|---|---|
| Ba Be | 0.7921 |
| Bach Thong | 0.7503 |
| Bac Kan | 0.6693 |
| Cho Don | 0.8243 |
| Cho Moi | 0.7385 |
| Na Ri | 0.7622 |
| Ngan Son | 0.7054 |
| Pac Nam | 0.7595 |

## 7.3 Patch shape

**(1) Area-weighted mean patch shape (SHAPE_AM).** This metric is applied as a measure of patch shape. Landscape ecological studies suggest that a landscape where complex patch shapes predominate, such as natural woodlands and naturally winding streams, has more species richness and encourages animal migration because of habitat variation on a fine-scale than landscapes influenced by intensive land uses and with straight borders (Moser et al., 2002). However, habitat patches characterized by a high perimeter to area ratio may lack in inner habitat for specific species, for instance, birds and beetles that can only live in inner woodlands. Therefore, the perimeter to area ratio was weighted by patch size as suggested by Kim and Pauleit (2007). SHAPE_AM equals 1 when all patches of the corresponding patch type are circular (vector) or square (raster), and it increases without limit as the patch shapes become more irregular. It is shown that Bac Kan and Ngan Son has the highest level of complexity patch shape in irregularity as accounts for 3.0577 and 3.8281, respectively. At the same time, the other 6 districts are similar in the complexity of the spatial pattern. The status of the Area-weighted mean patch shape index for 8 districts of Bac Kan province is shown in Table 7.6.

**Table 7.6** Area-weighted mean patch shape index value of 8 districts of Bac Kan province.

| District | Area-weighted mean shape index |
|---|---|
| Ba Be | 2.5926 |
| Bach Thong | 2.8546 |
| Bac Kan | 3.0577 |
| Cho Don | 2.7699 |
| Cho Moi | 2.5961 |
| Na Ri | 2.6230 |
| Ngan Son | 3.8281 |
| Pac Nam | 2.3590 |



**(2) Area-weighted mean fractal dimension (FRAC_AM).** It is another shape index based on perimeter-area relationships. A fractal dimension greater than 1 for a 2-dimensional patch indicates a departure from Euclidean geometry (i.e., an increase in shape complexity). FRAC approaches 1 for shapes with very simple perimeters such as squares and approaches 2 for shapes with highly convoluted, plane-filling perimeters. While the area-weighted mean patch shape shows the difference in the patch complexity of 8 districts, the result from area-weighted mean fractal dimension showed that there is a consistency in shape complexity of patch from 8 districts which is not convoluted. It can be concluded that 8 landscapes have different irregularity level but remain an ordinary shape (Table 7.7).

**Table 7.7** Area-weighted fractal dimension value of 8 districts of Bac Kan province.

| District | Area-weighted mean fractal dimension |
|---|---|
| Ba Be | 1.1159 |
| Bach Thong | 1.1231 |
| Bac Kan | 1.1318 |
| Cho Don | 1.1223 |
| Cho Moi | 1.1173 |
| Na Ri | 1.1181 |
| Ngan Son | 1.1437 |
| Pac Nam | 1.1070 |



## 7.4 Patch distance

**(1) Mean nearest neighbor distance (ENN_MN).** This metric is applied as a measure of patch distance. A patch distance index was taken as a measure for the degree of isolation between landscape units within the study areas. Patch isolation explains why fragmented habitats often contain fewer bird species than adjacent habitats (Van Dorp and Opdam, 1987). Well-connected patches may provide essential corridors that enhance species movement between isolated patches. This index addressed the average connectivity or lack of connectivity between patches in a character area. The result of this metric shows that the patches in Bac Kan district are less isolated than in other districts with the mean nearest distance of the same type is about 655.2 m. Similarly, the ENN_MN of Bach Thong, Cho Moi, and Ngan Son are rather low which means the spatial pattern of patches in these landscapes is well-connected. On the contrary, in the case of Ba Be, Cho Don, Na Ri, and Pac Nam landscape, the nearest distance between patches of the same type are quite high, accounts for 1364.6 m, 1076.4 m, 1329.7 m, and 1166.3 m, respectively. It implies that there is a lack of connectivity between patches in these 4 landscapes. The value of the mean nearest neighbor distance index for 8 districts of Bac Kan province is shown in Table 7.8.

**Table 7.8** Mean nearest neighbor distance index value of 8 districts of Bac Kan province.

| District | Mean nearest neighbor distance index (m) |
|---|---|
| Ba Be | 1364.6705 |
| Bach Thong | 820.7795 |
| Bac Kan | 655.2002 |
| Cho Don | 1076.4568 |
| Cho Moi | 764.9574 |
| Na Ri | 1329.7376 |
| Ngan Son | 888.2005 |
| Pac Nam | 1166.3529 |

(**2) Mean proximity index (PROX_MN).** This metric is another measure of patch distance. Proximity index was developed by Gustafson and Parker (1992) and considers the size and proximity of all patches whose edges are within a specified search radius of the focal patch. The distance between the focal patch and each of the other patches within the search radius is used, rather than the nearest-neighbor distance of each patch within the search radius (which could be to a patch other than the focal patch). PROX equals 0 if a patch has no neighbors of the same patch type within the specified search radius. PROX increases as the neighborhood (defined by the specified search radius) are increasingly occupied by patches of the same type and as those patches become closer and more contiguous (or less fragmented) in distribution. The upper limit of PROX is affected by the search radius and the minimum distance between patches. In this study, a radius of 500 m was applied as suggested by Kim and Pauleit (2007) for calculating the mean proximity index. The analysis result reveals that while the spatial pattern of patches of 7 districts (i.e. Ba Be, Bach Thong, Bac Kan, Cho Don, Cho Moi, Na Ri, Pac Nam) are relatively fragmented with low values of PROX_MN, the distribution of patches in Ngan Son are closer and more contiguous with the PROX_MN value of 80.9. The higher value of proximity enables Ngan Son has more corridors for the disposal of species within this landscape. The status of the mean proximity index for 8 districts of Bac Kan province is shown in Table 7.9.

**Table 7.9** Mean proximity index value of 8 districts of Bac Kan province.

| District | Mean proximity index value |
|---|---|
| Ba Be | 44.0325 |
| Bach Thong | 52.4208 |
| Bac Kan | 46.7337 |
| Cho Don | 47.0616 |
| Cho Moi | 31.5003 |
| Na Ri | 40.4015 |
| Ngan Son | 80.9391 |
| Pac Nam | 26.6326 |

## 7.5 Patch area

**(1) Number of patches (NP).** The number of patches of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. The number of patches in a landscape is fundamentally important to a number of ecological processes. When applied at the class level, the number of patches can be used to measure the degree of fragmentation of the focal patch type. At the landscape level, it measures the graininess of the landscape; i.e., the tendency of the landscape to exhibit a fine- versus coarse-grain texture. The number of patches is probably most valuable and is the basis for computing other metrics. The result shows that a large number of patches are in Ba Be, Bach Thong, Cho Don, Cho Moi, and Na Ri with the highest of 1811 in Cho Don. The high number of patches in these districts is due to their larger area, it also indicates that these landscapes are relatively fragmented. In contrast, the number of patches of Bac Kan, Ngan Son, and Pac Nam is much smaller, especially, there are only 304 patches in Bac Kan district as a result of its smallest natural area. It is also showing that these three districts maintain continuity of habitat. The number of patches of each district is shown in Table 7.10.

**Table 7.10** Number of patches value of 8 districts of Bac Kan province.

| **District** | **Number of patches** |
|---|---|
| Ba Be | 1241 |
| Bach Thong | 1400 |
| Bac Kan | 304 |
| Cho Don | 1811 |

**Table 7.10** (continued).

| District | Number of patches |
|---|---|
| Cho Moi | 1712 |
| Na Ri | 1361 |
| Ngan Son | 807 |
| Pac Nam | 643 |

**(2) Patch density (PD)**. Patch density is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as the number of patches as an index, except that it expresses the number of patches on a per unit area basis that facilitates comparisons among landscapes of varying sizes. However, if the total landscape area is held constant, then patch density and number of patches convey the same information. The choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric. PD equals the number of patches in the landscape divided by total landscape area, multiplied by 10,000 and 100 (to convert to 100 hectares). In general, patch density positively correlated to the number of patches, particularly in the case of Ba Be, Bach Thong, Cho Don, and Cho Moi district, where the PD and NP values are simultaneously high. However, there is a unique case of Bac Kan district in which its PD value is significantly high in opposition to its NP low value. This led to the conclusion that the landscape of Bac Kan district is extremely fragmented. This situation is as a result of urbanization in Bac Kan capital district where development activities (e.g. housing development, road building) are breaking up the landscape or habitat into smaller, disconnected sections. Table 7.11 shows the distribution of patch density of 8 districts in Bac Kan province.

**Table 7.11** Patch density value of 8 districts of Bac Kan province.

| District | Patch density (per 100 ha) |
|---|---|
| Ba Be | 1.8163 |
| Bach Thong | 2.5623 |
| Bac Kan | 2.2186 |
| Cho Don | 1.9879 |
| Cho Moi | 2.8278 |
| Na Ri | 1.5953 |
| Ngan Son | 1.2505 |
| Pac Nam | 1.3488 |

**(3) Total area (TA).** The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. Not only is this information the basis for many of the patch, class, and landscape indices, but the patch area has a great deal of ecological utility in its own right. Most species have minimum area requirements, the minimum area needed to meet all life history requirements. Some of these species require that their minimum area requirements be fulfilled in contiguous habitat patches; in other words, the individual habitat patch must be larger than the species minimum area requirement for them to occupy the patch. These species are sometimes referred to as "area-sensitive" species. Thus, patch size information alone could be used to model species richness, patch occupancy, and species distribution patterns in a landscape given the appropriate empirical relationships derived from field studies. Among 8 districts of Bac Kan province, while, Cho Don district has the highest extent with a total area of around 911 km$^2$, Bac Kan district is the smallest landscape with its natural area of 137 km$^2$. The total area of 8 districts of Bac Kan province is shown in Table 7.12.

**Table 7.12** Total area of 8 districts of Bac Kan province.

| District | Total area (Km$^2$) |
|---|---|
| Ba Be | 683.2467 |
| Bach Thong | 546.3900 |
| Bac Kan | 137.0223 |
| Cho Don | 911.0331 |
| Cho Moi | 605.4075 |
| Na Ri | 853.1532 |
| Ngan Son | 645.3621 |
| Pac Nam | 476.7291 |

**(4) Edge density (ED)**. Edge density (ED) standardizes edge to a per unit area basis that facilitates comparisons among landscapes of varying sizes. ED equals the sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area (ha). The total amount of edge and edge density in a landscape is important to many ecological phenomena. In many landscape ecological investigations, much of the presumed importance of spatial pattern is related to edge effects. For example, one of the most dramatic and well-studied consequences of habitat fragmentation is an increase in the proportional abundance of edge-influenced habitat and its adverse impacts on interior sensitive species. Overall, the result of edge density shows that there is a stable pattern among 8 districts with the minimum value of 28.46 m/ha in Ngan Son districts and the maximum value of 45.06 m/ha in Cho Moi district. The highest edge density of Cho Moi district is due to its highest length of total edge segment in this landscape compared to the other 7 districts, and this is logical when examining its high value of patch density and number of patches. Besides, it is noticeable that the edge density value of Bac Kan district is rather high as a result of its smallest total area, this finding also reconfirms about high fragmentation in Bac Kan district. The distribution of the edge density of 8 districts is shown in Table 7.13.

**Table 7.13** Edge density value of 8 districts of Bac Kan province.

| District | Edge density (m/ha) |
|---|---|
| Ba Be | 36.4717 |
| Bach Thong | 40.9334 |
| Bac Kan | 37.2115 |
| Cho Don | 39.6305 |
| Cho Moi | 45.0688 |
| Na Ri | 33.8848 |
| Ngan Son | 28.4919 |
| Pac Nam | 31.0868 |

In summary, the combination of landscape classification and characterization with landscape ecological analyses allows analyzing the landscape ecological structure in Bac Kan province for biodiversity conservation planning. A major difficulty in Vietnam is the lack of ecological information for this purpose. This study demonstrates the possibility of providing new ecological information by using landscape classification and landscape ecological metrics. The specific goals for biodiversity conservation and enhancement at the district level of Bac Kan province can be formulated on these values. The four metric groups represent different landscape ecological dimensions. The summary of quantifying results of 8 districts in Bac Kan province with different metrics providing the ability for comparing potential biodiversity among different districts through the different values is shown in Table 7.14.

**Table 7.14** The result of landscape pattern analysis in Bac Kan province.

| District | Landscape metric | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shannon's Diversity Index | Shannon's evenness index | Area-weighted mean shape index | Area-weighted mean fractal dimension | Mean nearest neighbor distance index (m) | Mean proximity index value | Number of patches | Patch density (per 100 ha) | Total area ($Km^2$) | Edge density (m/ha) |
| **Ba Be** | 3.8736 | 0.7921 | 2.5926 | 1.1159 | 1364.6705 | 44.0325 | 1241 | 1.8163 | 683.2467 | 36.4717 |
| **Bach Thong** | 3.5982 | 0.7503 | 2.8546 | 1.1231 | 820.7795 | 52.4208 | 1400 | 2.5623 | 546.3900 | 40.9334 |
| **Bac Kan** | 2.6943 | 0.6693 | 3.0577 | 1.1318 | 655.2002 | 46.7337 | 304 | 2.2186 | 137.0223 | 37.2115 |
| **Cho Don** | 4.0061 | 0.8243 | 2.7699 | 1.1223 | 1076.4568 | 47.0616 | 1811 | 1.9879 | 911.0331 | 39.6305 |
| **Cho Moi** | 3.7292 | 0.7385 | 2.5961 | 1.1173 | 764.9574 | 31.5003 | 1712 | 2.8278 | 605.4075 | 45.0688 |
| **Na Ri** | 3.7159 | 0.7622 | 2.6230 | 1.1181 | 1329.7376 | 40.4015 | 1361 | 1.5953 | 853.1532 | 33.8848 |
| **Ngan Son** | 3.0547 | 0.7054 | 3.8281 | 1.1437 | 888.2005 | 80.9391 | 807 | 1.2505 | 645.3621 | 28.4919 |
| **Pac Nam** | 3.3559 | 0.7595 | 2.3590 | 1.1070 | 1166.3529 | 26.6326 | 643 | 1.3488 | 476.7291 | 31.0868 |

# CHAPTER VIII

# ECOLOGICAL SUITABILITY ZONATION FOR MOUNTAINOUS AREA DEVELOPMENT AND BIODIVERSITY CONSERVATION

This chapter presents the results of the fifth objective focusing on ecological suitability zonation for mountainous area development and biodiversity conservation plan. In this study, the spatial analysis was applied to assign development zone at the provincial level while the ratio between development and ecological protection areas with the trade-off technique was used to propose a future direction for mountainous area development and biodiversity conservation at the district level in Bac Kan province. The main results of this chapter include the development zonation map of Bac Kan province and the proposed future direction at the district level in Bac Kan province.



## 8.1 Development zones in Bac Kan province

For development zonation at provincial level, the important ecological function area in Bac Kan province (Ba Be National Park, Kim Hy Nature Reserve, and Nam Xuan Lac Species and Habitat Conservation Areas) was superimposed on the ecological suitability classification map to quantify their relationships using spatial analysis tool of the ESRI ArcMap software and the derived result was applied to define development zone into 5 categories: forbidden development zone, restricted development zone, low priority development zone, moderate priority development zone, and high priority development zone.

The zonation of development at the provincial level is displayed in Figure 8.1 and Table 8.1. As a result, the most dominant zone in Bac Kan province is low priority development and it covers an area of about 1,906 $km^2$ or 39.41% of the total area while the least dominant zone is high priority development zone and it accounts for about 258 $km^2$ or 5.33 % of the total area.

According to zonation and ecological suitability classification, the forbidden development zone is not suitable for construction and development and it also includes the important ecological function areas. Likewise, the restricted development zone is slightly suitable for construction and development while the low priority development zone is moderately suitable for construction and development, so, development and construction activities in these areas should be strictly controlled by the local government. On the contrary, the moderate priority development zone is suitable for construction and development whereas the high priority development zone is very suitable for construction and development. These areas cover an area of about 1,573 $km^2$ or 32.55% of the total area and they mostly allocate in Bac Kan capital city, Cho Moi, and Pac Nam.

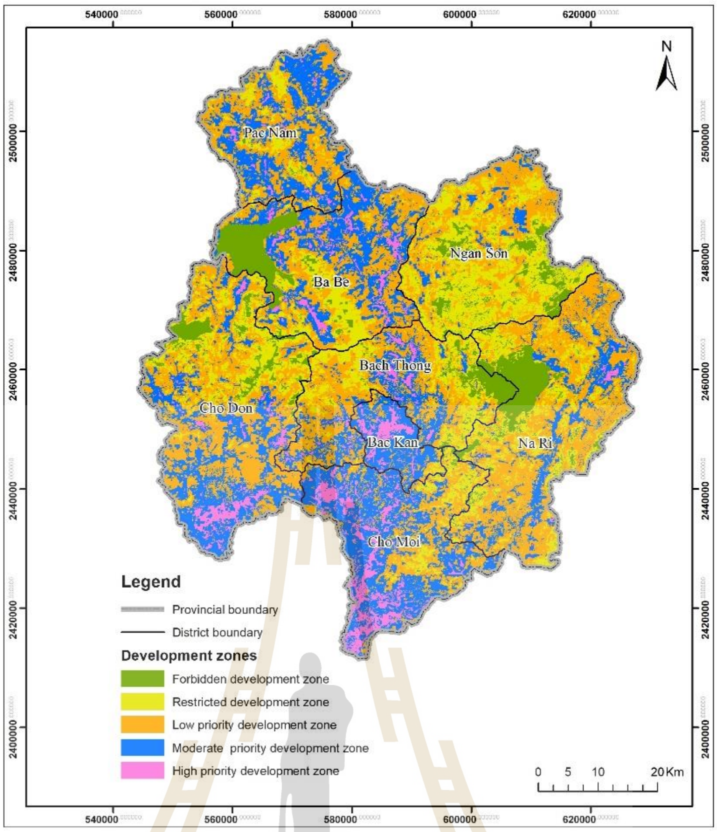



**Figure 8.1** The development zonation map of Bac Kan province.

**Table 8.1** Area and percentage of development zones of Bac Kan province.

| Zone name | Area ($Km^2$) | Area (%) |
|---|---|---|
| Forbidden development zone | 389.67 | 8.06 |
| Restricted development zone | 966.01 | 19.98 |
| Low priority development zone | 1,905.53 | 39.41 |
| Moderate priority development zone | 1,315.95 | 27.22 |
| High priority development zone | 257.53 | 5.33 |

## 8.2 Future direction for mountainous area development and biodiversity conservation at the district level of Bac Kan province

To propose a future direction for mountainous area development and biodiversity conservation at the district level, it is necessary to integrate development zonation with current administrative units. In this study, the moderate and high priority development zone were merged as development area whereas the forbidden and restricted development zone were grouped as ecological protection area. Herein, the low priority development zone was not merged into the development area or ecological protection area since this zone cannot be clearly assigned as a development area or ecological protection area. By using trade-off technique, the percentage of development and ecological protection areas in each district was extracted then ratio between them was calculated to assign the future direction for sustainable use of natural resources of 8 districts into three categories: prior areas for conservation, comprehensive development areas, and prior areas for development. The final result is the proposed future direction at the district level in Bac Kan province.

Table 8.2 showed three future direction categories for sustainable use of natural resources of 8 districts in Bac Kan province according to the ratio between development area and ecological protection area. Herein, any districts with a ratio of less than 2.0 were assigned as prior areas for conservation, and any districts with the ratio between 2.0 and 4.0 were assigned as comprehensive development areas, and whereas, any districts with the ratio more than 4.0 were assigned as prior areas for development. The proposed future direction map at the district level in Bac Kan province is displayed in Figure 8.2.

As a result, the prior areas for conservation in Bac Kan province allocate in Ngan Son, Na Ri, and Bach Thong districts and they account for about 2,045 $km^2$ or 42.09% of the total area. The percentage of ecological protection areas in these districts is obviously higher than the percentage of the development area and the ratios of three districts vary from 0.09 to 1.02.

On the contrary, Bac Kan capital city and Cho Moi district belong to prior areas for development and they cover an area of about 742 $km^2$ or 15.28% of the total area. In fact, the ratio between development area and ecological protection area in Bac Kan capital city and Cho Moi district are 22.73 and 10.17, respectively.

Meanwhile, Ba Be, Cho Don, and Pac Nam districts belong to comprehensive development areas and they cover an area of about 2,071 $km^2$ or 42.63% of the total area. The percentage of the development area in these districts is rather higher than the percentage of the ecological protection area and the ratios of three districts vary from 2.19 to 3.77.

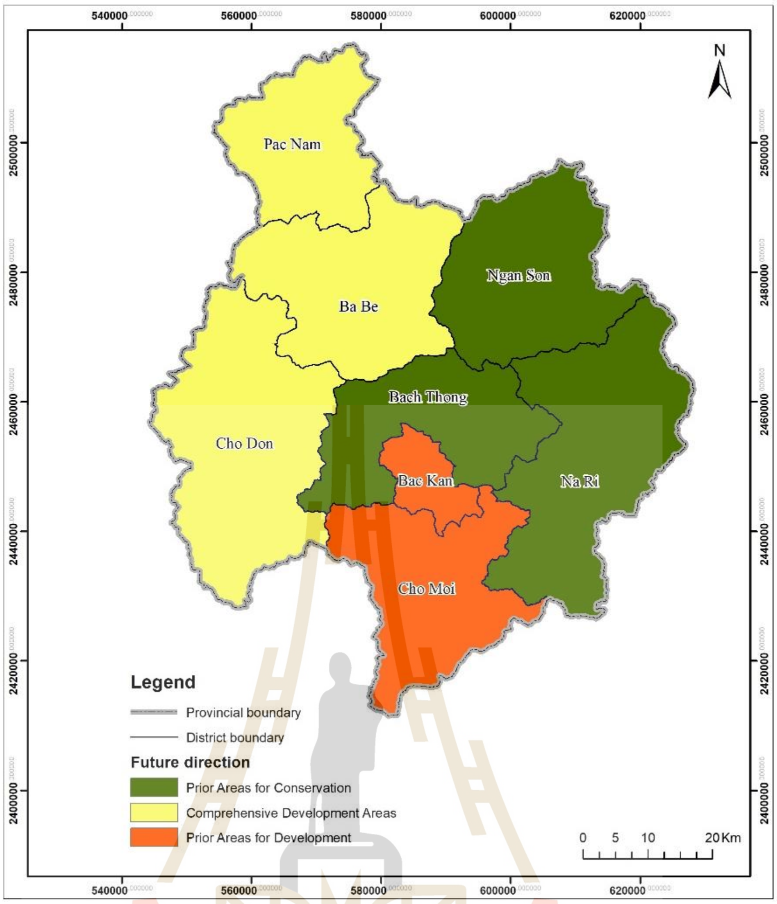



**Figure 8.2** The proposed future direction at the district level in Bac Kan province.

**Table 8.2** Future direction at the district level in Bac Kan province.

| Future direction | District | Area (km²) | Development area (%) | Ecological protection area (%) | Ratio[1] |
|---|---|---|---|---|---|
| Prior areas for conservation | Ngan Son | 645.36 | 5.28 | 58.88 | 0.09 |
| | Na Ri | 853.15 | 16.26 | 30.64 | 0.53 |
| | Bach Thong | 546.39 | 25.98 | 25.36 | 1.02 |
| Comprehensive development areas | Ba Be | 683.24 | 36.19 | 16.51 | 2.19 |
| | Cho Don | 911.03 | 32.86 | 14.53 | 2.26 |
| | Pac Nam | 476.73 | 43.86 | 11.62 | 3.77 |
| Prior areas for development | Cho Moi | 605.41 | 64.81 | 6.37 | 10.17 |
| | Bac Kan | 137.02 | 80.64 | 3.55 | 22.73 |

[1] The ratio of the development area to the ecological protection area.

## 8.3 The validation of spatial arrangement of development at the district level in Bac Kan province

In order to validate the spatial arrangement of the future direction for sustainable use of natural resources of 8 districts in Bac Kan province, the landscape index values derived from landscape ecological analysis was applied to confirm the reasonableness of the integrated trade-off approach between mountainous area development and biodiversity conservation according to local conditions. The discussion of the validation focusses on three future directions of the province includes (1) prior areas for conservation, (2) comprehensive development areas, and (3) prior areas for development with 4 groups of metrics: landscape heterogeneity, patch shape, patch distance, and patch area.

### 8.3.1 Prior areas for conservation

The prior areas for conservation consist of three districts: Ngan Son, Na Ri, and Bach Thong. The results of landscape pattern analysis of both metrics revealed a suggestion for biodiversity conservation as shown in Table 8.3. Firstly, Shannon's diversity indices in these three districts are very high, which are 3.0547, 3.7159, and 3.5982, respectively. Similarly, there is a similar spatial pattern of Shannon's evenness index. These index values of three districts are 0.7054, 0.7622, and 0.7503, respectively. The very high results of diversity and evenness indices are due to the large area of Kim Hy Natural Reserve, which is the important ecological functional area locates in these districts. Secondly, the patch shape metrics show the predominance of complex patch shapes in these areas. Meanwhile, the area-weighted mean fractal dimension indices of three districts are similar, the area-weighted mean shape indices account for 3.8281, 2.6230, and 2.8546, respectively. These index values imply an encouragement of animal migration and the richness of species. Thirdly, the value of the patch distance indices in three districts shows a small degree of isolation among landscape patches within these areas. This implies that these areas can provide essential corridors to enhance species movement. Fourthly, both patch density and edge density indices show these landscapes are less fragmented, therefore it implies that the continuity of habitat in these districts is maintained. In conclusion, these landscape metrics values reflect the richness of habitat and species of these districts and therefore confirm their priority for conservation in the future.

**Table 8.3** The landscape metric values of prior areas for conservation.

| District | Landscape metric | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Shannon's Diversity Index** | **Shannon's evenness index** | **Area-weighted mean shape index** | **Area-weighted mean fractal dimension** | **Mean nearest neighbor distance index (m)** | **Mean proximity index value** | **Number of patches** | **Patch density (per 100 ha)** | **Total area ($Km^2$)** | **Edge density (m/ha)** |
| **Ngan Son** | 3.0547 | 0.7054 | 3.8281 | 1.1437 | 888.2005 | 80.9391 | 807 | 1.2505 | 645.3621 | 28.4919 |
| **Na Ri** | 3.7159 | 0.7622 | 2.6230 | 1.1181 | 1329.7376 | 40.4015 | 1361 | 1.5953 | 853.1532 | 33.8848 |
| **Bach Thong** | 3.5982 | 0.7503 | 2.8546 | 1.1231 | 820.7795 | 52.4208 | 1400 | 2.5623 | 546.3900 | 40.9334 |

### 8.3.2 Comprehensive development areas

The comprehensive development areas consist of three districts: Ba Be, Cho Don, and Pac Nam. The comprehensive development areas will require adequate consideration from local authorities in order not to only promote economic development but also ensure environmental protection and biodiversity conservation. Since 4 landscape metric groups, which are landscape heterogeneity, patch shape, patch distance, and patch area, were selected for quantifying potential biodiversity in the study area, therefore these metric values were only used to confirm the biodiversity potential for the conservation aspect in these districts (Table 8.4). Indeed, the landscape heterogeneity metric values of these districts are very high. Specifically, Shannon's diversity index of Ba Be, Cho Don, and Pac Nam are 3.8736, 4.0061, and 3.3559, respectively, while, Shannon's evenness index of these districts is 0.7921, 0.8243, 0.7595, respectively. This information expresses the rich in biodiversity of these districts. For example, Ba Be National Park in Ba Be district has a variety of ecological systems such as evergreen forest on the limestone mountain, flooded forest ecological system, and river and lake ecological system. Besides, the richness of species and the high possibility of animal migration are also demonstrated through the high values of patch shape metrics. While the area-weighted mean shape index of Ba Be, Cho Don, and Pac Nam are 2.5926, 2.7699, and 2.3590, the area-weighted mean fractal dimension index of these districts accounts for 1.1159, 1.1223, and 1.1070, respectively. In addition, the capacity of these areas to provide essential corridors for species movement is also illustrated through the patch distance metrics, and the continuity of habitat in these districts is proved by both patch density and edge density indices. All in all, the potential of biodiversity in Ba Be, Cho Don, and Pac Nam is obvious for the comprehensive development approach. This approach does not only consider conservation issues but also deals with the socio-economic issues of the landscape through sustainable management of biological resources.

**Table 8.4** The landscape metric values of comprehensive development areas.

| District | Landscape metric | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shannon's Diversity Index | Shannon's evenness index | Area-weighted mean shape index | Area-weighted mean fractal dimension | Mean nearest neighbor distance index (m) | Mean proximity index value | Number of patches | Patch density (per 100 ha) | Total area ($Km^2$) | Edge density (m/ha) |
| **Ba Be** | 3.8736 | 0.7921 | 2.5926 | 1.1159 | 1364.6705 | 44.0325 | 1241 | 1.8163 | 683.2467 | 36.4717 |
| **Cho Don** | 4.0061 | 0.8243 | 2.7699 | 1.1223 | 1076.4568 | 47.0616 | 1811 | 1.9879 | 911.0331 | 39.6305 |
| **Pac Nam** | 3.3559 | 0.7595 | 2.3590 | 1.1070 | 1166.3529 | 26.6326 | 643 | 1.3488 | 476.7291 | 31.0868 |

### 8.3.3 Prior areas for development

The prior areas for development are comprised of Cho Moi district and Bac Kan capital city. These areas are suitable for residential and commercial development. The current spatial pattern analysis showed that these areas have the lowest ecological value (Table 8.5). Certainly, the indices of landscape heterogeneity of these areas are lowest, especially, Shannon's diversity index and Shannon's evenness index of Bac Kan capital city is only 2.6943 and 0.6693, respectively. Also, the patch shape metrics indicate that Cho Moi and Bac Kan dominated by simple shape patches, with the area-weighted mean shape index of 2.5961 and 3.0577, respectively, and the area-weighted mean fractal dimension of 1.1173 and 1.1318, respectively. In contrast, patch distance metrics indicated that patches are less isolated with the mean nearest neighbor distance index of Cho Don and Bac Kan is 764.9574 and 655.2002, respectively, and the mean proximity index value account for 31.5003 and 46.7337, respectively. However, the forest areas in these districts are small, therefore, the possibility of species dispersal is expected to be quite low and there is also a lack of habitat for species. Besides, the high values of patch density and edge density indices indicated that the landscapes of Cho Moi and Bac Kan are extremely fragmented. Overall, the metrics proved that Cho Moi and Bac Kan are prior areas for development in the future.

**Table 8.5** The landscape metric values of prior areas for development.

| District | Landscape metric | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shannon's Diversity Index | Shannon's evenness index | Area-weighted mean shape index | Area-weighted mean fractal dimension | Mean nearest neighbor distance index (m) | Mean proximity index value | Number of patches | Patch density (per 100 ha) | Total area ($Km^2$) | Edge density (m/ha) |
| **Cho Moi** | 3.7292 | 0.7385 | 2.5961 | 1.1173 | 764.9574 | 31.5003 | 1712 | 2.8278 | 605.4075 | 45.0688 |
| **Bac Kan** | 2.6943 | 0.6693 | 3.0577 | 1.1318 | 655.2002 | 46.7337 | 304 | 2.2186 | 137.0223 | 37.2115 |

# CHAPTER IX

# CONCLUSION AND RECOMMENDATION

Ecological suitability assessment is an effective approach to identify and locate the most suitable territories for future development in order to reduce the negative impacts of human activities on the ecosystem for ensuring sustainable development. The study aimed to propose a future direction for sustainable use of natural resources at the district level in Bac Kan province based on the ecological suitability evaluation approach and the trade-off technique. This study had firstly identified significant ecological resistance indicators to characterize ecological elements, importance, and resilience from 10 experts using the Delphi method. Then, an integrated ecological resistance model was applied to classify ecological suitability for construction and development. Moreover, spatial analysis and trade-off techniques were applied to assign development zone and propose future direction at provincial and district levels in Bac Kan province. The conclusion and recommendations of the present study are discussed in this chapter.

## 9.1 Conclusions

### 9.1.1 Landscape classification and characterization

Landscape theory and its application have played an important role in natural resource exploitation and environmental protection. Various classification approaches had been employed worldwide in landscape ecology studies. This study had developed a new hierarchical landscape classification framework for quantifying spatial patterns of Bac Kan province. A landscape formation equation was applied with three natural factors (geology, topography, and soil) and cultural factor (land use). A multi-level segmentation technique with the multiresolution segmentation algorithm was chosen to segment landscape units and to categorize landscape types at different levels. The results revealed that the landscape classification of Bac Kan province has 4 hierarchical levels. Level 4, which provided full details of spatial patterns based on geologic period, elevation, soil depth, and land use, had 315 landscape types. At this level, there are 8,427 landscape units mapped with a minimum and maximum areas of 0.02 $km^2$ and 116.63 $km^2$, respectively. A new Bac Kan landscape map at a scale of 1:100,000 along with 16 different attributes for each landscape unit was also produced. In conclusion, the framework of the research methodology presented in this study can be used as a guideline for landscape classification at provincial and national levels.

### 9.1.2 Significant factor identification for ecological resistance evaluation

This study successfully selected a set of indicators to characterize ecological elements, importance, and resilience using the Delphi method. The Delphi method is a method that the intuitive idea of the participant was used based on a structural survey. This method is an iterative process that is designed to achieve a consensus among a group of experts on a specific issue and it is one of the most effective means for participants (experts) to identify criteria or indicators. It carries quantitative and qualitative results and has underneath its explorative, predictive even normative elements. In this study, a variety of indicators that represent ecological elements, importance, and resilience under three criteria (ecological structural, functional, and dynamics resistance) for construction and development in mountainous areas, was first reviewed from a wide range of sources, particularly research papers and a questionnaire was then prepared for expert interviewing. The Delphi process was implemented in 2 rounds with 10 experts. The results showed that 2 indicators were omitted, and 12 indicators were selected with 6 indicators relate to ecological elements, 3 indicators relate to ecological importance, and 3 indicators relate to ecological resilience.

### 9.1.3 Ecological resistance evaluation for construction

This study had successfully evaluated ecological resistance for construction using the integrated ecological resistance (IER) model. The IER index is comprised of ecological structure, ecological function, and ecological adaptation resistances. These resistances were calculated based on the evaluation of ecological elements, ecological importance, and ecological resilience, respectively. Furthermore, based on the IER index ranging from high to low, the ecological suitability map for construction in Bac Kan province was produced with five categories, which are not suitable, slightly suitable, moderately suitable, suitable, and very suitable. The most dominant ecological suitability class for construction in Bac Kan province is the moderately suitable class and it accounts for about 1,948 $km^2$ or 40.30% of the total area while the most suitable areas for construction and development in Bac Kan province according to ecological suitability classification locate in lowland areas where are classified as very suitable and suitable classes and they cover an area of about 1,288 $km^2$ or 26.65% of the total area. The ecological suitability map for construction is the crucial data for ecological suitability zonation for mountainous area development and biodiversity conservation.

### 9.1.4 Landscape ecological analysis for biodiversity conservation

This study demonstrates the possibility of providing new ecological information by using landscape classification and landscape ecological metrics. Landscape pattern analysis was performed using four groups of metrics: landscape heterogeneity, patch shape, patch distance, and patch area. These four metric groups represent different landscape ecological dimensions. Firstly, the Shannon diversity index and Shannon's evenness index were used as a measure of landscape heterogeneity. It was obvious that Cho Don has the highest diversity index with the SHDI value of 4.0061 and the SHEI value of 0.8243. Secondly, area-weighted mean patch shape and area-weighted mean fractal dimension were applied as a measure of patch shape. It is shown that Bac Kan and Ngan Son has the highest level of complexity patch shape in irregularity as accounts for 3.0577 and 3.8281, respectively. Thirdly, nearest neighbor distance and mean proximity index was used as a measure of patch distance. The result showed that the patches in Bac Kan district are less isolated than in other districts with the mean nearest distance of the same type is about 655.2 m. Finally, the number of patches, patch density, total area, and edge density were applied as a measure of patch area. It is shown that the number of patches in Cho Don district is the highest with 1811 patches. The highest of patch density was found in Cho Moi district with 2.8278 patches per 100 ha, this district also has the highest value of edge density with 45.0688 m per ha. Overall, the specific goals for biodiversity conservation and enhancement at the district level of Bac Kan province can be formulated on these values.

**9.1.5 Ecological suitability zoning for mountainous area development and biodiversity conservation**

Zoning is an instructive and reasonable approach to arrange and guide the land use for regional sustainable development. Zoning can significantly solve the conflict between regional development and environmental protection and therefore forms a safe ecological pattern. Zoning regulation and ordinances are frequently used as the instrument of land use control. In this study, the spatial analysis was applied to classify the whole study area into five zones: high priority development, moderate priority development, low priority development, restricted development, and forbidden development. Besides, the ratio between development and ecological protection areas with the trade-off technique was used to propose a future direction for mountainous area development and biodiversity conservation at the district level in Bac Kan province. As a result, three future directions: prior areas for conservation, comprehensive development areas, and prior areas for development were proposed for future overall planning at the district level. The results of this study can be applied to achieve sustainable development goals.

## 9.2 Recommendations

The current study proposed a comprehensive framework using the landscape ecological theory and its applications to establish a scientific basis for mountainous area development and biodiversity conservation. The study was able to develop a new hierarchical landscape classification framework for quantifying the spatial pattern of the study area. In addition, the significant ecological indicators used to evaluate the ecological resistance and classify the ecological suitability for construction and development were attained. Finally, the zonation of development and future directions at the provincial and district level were achieved. However, for enhancing the results in order to meet the specific condition of the study, the recommendations are necessary.

Firstly, three fundamentals of landscape ecology, namely, structure, function, and dynamics applied in the IER model are considered to be sufficient for studying landscape ecology, however, the indicators for characterizing them have not been yet given with common agreement among researchers. Therefore, this IER model needs to focus more on using different factors and indicators.

Secondly, in this study, population density at the district level was applied to characterize social disturbance intensity in the whole study area. Future researches are also recommended to consider other factors, such as gross domestic product (GDP), which is another important indicator for describing social disturbance intensity. These factors will be useful for improving the result.

Thirdly, the spatial resolution of the collected data is not totally consistent since these data are usually produced for different purposes. However, to minimize the effect of the difference of spatial resolution, the resampling technique is applied to standardize the input data with a cell size of 30 m. The study recommends the full comparison of obtained results using different spatial resolutions of input data.

Fourthly, the weight assignment might introduce uncertainty into the results, since the evaluation itself was a subjective process. However, this quantitative evaluation provides a relatively objective with scientific visualization to understand the ecological impact of construction and development and their constraints. In the future, the weight settings should be adjusted in different scenarios to obtain the optimum choice for the objective of the development plan for decision-makers or policymakers.

Fifthly, the biodiversity conservation approach in this study is a landscape-level conservation approach, however, other traditional biodiversity conservation approaches, such as payment for ecosystem services and protected area establishment are also recommended in future studies. Additionally, landscape pattern analysis for conservation should be examined at class level for specific landscape unit, e.g. evergreen broadleaf forest, and bamboo forest and wood mixed forest with core area metrics measurement.

Finally, the results of this study can be used to support decision-makers, policymakers, land use planners, and land managers. In the meantime, the presented framework of the research methodology can be used as a guideline for ecological suitability evaluation in Vietnam. Therefore, the current research methodology framework is recommended to be examined in other provinces in Vietnam.

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