THAI NGUYEN UNIVERSITY
UNIVERSITY OF AGRICULTURE AND FORESTRY

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STUDY ON SOIL EROSION ASSESSMENT FOR AGRICULTURAL LAND USE IN THE SONG CONG BASIN, THAI NGUYEN PROVINCE

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LIST OF PUBLISHED WORKS RELATED TO THE THESIS

1. **Nguyen Le Duy**, Le Van Tho, Truong Thanh Nam, Nguyen Hung Cuong (2024). Research on the application of geographic information system (GIS) and universal soil loss equation (RUSLE) to assess potential soil erosion in Song Cong basin, Thai Nguyen province. *Journal of Soil Science,* No. 73/2024, pp. 105-109

2. **Nguyen Le Duy**, Le Van Tho, Phan Thi Thanh Huyen (2025). Application of the universal soil loss model RUSLE to assess soil erosion in the Song Cong basin in Dinh Hoa district, Thai Nguyen province. *Journal of Forestry Science and Technology*, vol. 14, no. 1 (2025), pp. 73-82.

3. **Nguyen Le Duy**, Le Van Tho (2025). Determining the erosion of some types of sloping land use in Dinh Hoa district, Thai Nguyen province. *Vietnam Journal of Agricultural Science and Technology;* No. 05 (2025), pp. 109-116.

INTRODUCTION

1. Urgency of the topic

Soil erosion is a serious global problem, causing soil degradation and declining crop yields. On average, the world loses about 12–15 tons of soil per hectare of cultivated land each year, equivalent to nearly 1 mm of topsoil. In mountainous areas, erosion caused by rainwater and wind is particularly severe, with water erosion being the dominant process (John Boardman et al., 2021). In Vietnam, rainfall-induced erosion is the main cause of soil degradation in mountainous regions, affecting about 40% of the natural landscape. Steep terrain combined with heavy rainfall in many places (e.g., Thua Thien Hue) has led to severe erosion, causing significant economic damage (Nguyen Le Duy et al., 2025).

To minimize erosion in mountainous areas, two aspects need to be studied in parallel: the natural erosion process (erosion caused by natural conditions), including its causes and influencing factors, and erosion caused by human activities (Zakharov, 1981). Studies on soil erosion provide the scientific basis for policymakers and land use planners to formulate appropriate land policies that promote effective land management and improve livelihoods. At the same time, they help identify solutions to prevent soil erosion, aiming to use land more effectively in economic, social, and environmental terms (Pham Gia Tung et al., 2023).

The Song Cong Basin has a favorable geographical location and serves as an important transportation and socio-economic hub of strategic significance linking Thai Nguyen Province with Hanoi and other provinces in the Red River Delta. With its natural advantages—such as scenic landscapes like Nui Coc Lake, and historical relics such as the Viet Bac Safety Zone (ATK), Van Mountain, Vo Mountain, and Tam Dao National Forest—the Song Cong Basin is also one of the major industrial centers of Thai Nguyen Province. It hosts several industrial parks mainly concentrated in Pho Yen City and Song Cong, contributing to the province's economic growth, which averages over 30% per year. The total industrial production value accounts for 93% of the province's industrial output, while exports from the area make up 97% of the province's total export turnover (Thai Nguyen Provincial Statistics Office, 2024).

The Song Cong Basin features complex terrain and a typical tropical monsoon climate, meaning that soil erosion is influenced by both natural causes and human agricultural activities (Le Thi Phuong Quynh et al., 2014). Inappropriate land use practices—such as deforestation and unsustainable farming—have increased soil erosion and nutrient leaching, leading to serious resource degradation in sloping areas. Soil erosion causes numerous negative consequences: it degrades soil and reduces fertility, as eroded topsoil carries away organic matter and nutrients. Research shows that in tea-growing areas of Thai Nguyen, erosion can cause the loss of nearly 188 kg of mineral nutrients and 1,687 kg of organic matter per hectare per year, thereby reducing soil fertility and regeneration capacity (Hoang Thi Lan Anh et al., 2024).

In addition, soil erosion thins the arable layer and depletes nutrients, resulting in lower crop yields over time. Farmers face reduced productivity and incomes, as well as higher fertilizer costs to maintain soil fertility (Pasquale Borrelli et al., 2021). Eroded soil flows into streams and Nui Coc Lake, causing sedimentation, water quality deterioration, and reduced reservoir capacity. This also increases the risk of flooding and negatively affects aquatic ecosystems. Moreover, soil erosion contributes to landslides, threatening roads, dikes, and other infrastructure (Ted M. Zobeck & R. Scott Van Pelt, 2011). In Thai Nguyen, soil erosion is recognized as a factor that adversely impacts various socio-economic sectors—agriculture, transportation, tourism—and disrupts local livelihoods. In areas along the Song Cong, landslides have destroyed hundreds of square meters of agricultural land, reducing arable area and damaging crops. During each rainy season, large portions of riverbank land are washed away, forcing people to abandon their homes for safety (Le Thi Phuong Quynh et al., 2014).

To control and minimize soil erosion, it is essential to measure and assess erosion levels by determining key coefficients such as rainfall erosivity (R), soil erodibility (K), topographic factor (LS), cover management factor (C), and conservation practice factor (P). These coefficients enable the application of empirical models (such as USLE/RUSLE) combined with GIS to estimate annual soil loss and classify erosion intensity across the basin. Consequently, thematic and soil erosion risk maps can be developed to illustrate the spatial extent and severity of erosion, ranging from mild to very severe (Nguyen Thanh Hai et al., 2021).

In the Song Cong Basin, accurately determining these erosion coefficients and constructing corresponding maps are essential for establishing a comprehensive soil erosion database for the area..

2. Topic objectives

To assess the current status and dynamics of land use in the Song Cong basin during the period 2013–2023, including the identification of land use changes, spatial distribution patterns, and an analysis of the characteristics and agricultural production situation in the study area.

To evaluate the extent and spatial distribution of soil erosion caused by annual rainfall in the Song Cong basin by applying remote sensing (RS) and geographic information system (GIS) technologies based on the Revised Universal Soil Loss Equation (RUSLE).

To develop, implement, and monitor soil erosion control models aimed at protecting sloping agricultural land, and to propose practical solutions and recommendations for sustainable agricultural land use and soil conservation in the Song Cong basin.

3. Research Objects and Scope of Research

3.1. Research Objects

Types of sloping land distributed in the Song Cong Basin and the application of the Revised Universal Soil Loss Equation (RUSLE).

Land use models and types of land use on sloping land within the Song Cong Basin.

3.2. Scope of Research

Content: The study focuses on assessing the current status of soil erosion caused by rainfall in order to propose solutions for agricultural land use in the Song Cong Basin.

Spatial scope: The research is conducted within the Song Cong Basin area, covering five administrative units at the district/city level: Thai Nguyen City, Song Cong City, Pho Yen City, Dai Tu District, and Dinh Hoa District.

Time scope: Secondary data on agricultural land management and use, land use status maps, and other relevant information were collected for the period 2013–2023. Primary data collection and model monitoring activities were carried out in 2023.

4. Scientific and practical significance

4.1. Scientific significance

Contributed to systematizing and supplementing the theoretical basis related to the assessment and calculation of soil erosion levels under the specific conditions of the Song Cong Basin. The research results also contributed to enriching the scientific foundation in the field of soil resource protection and utilization.

4.2. Practical significance

The solutions proposed in the thesis can be utilized by management agencies to develop and implement measures that limit soil erosion caused by rainfall, thereby contributing to the promotion of agricultural development in the Song Cong Basin.

The research results also serve as a valuable reference for scientists, managers, lecturers, students, and others interested in soil erosion and the effective use of agricultural land..

5. New contributions of the Thesis

Systematically contributed to determining the characteristic coefficients that reflect the risk of soil erosion on sloping land in the Song Cong Basin through the application of the Revised Universal Soil Loss Equation (RUSLE).

The results and recommendations of the thesis provide a scientific basis for developing land management solutions, contributing to the reduction of soil erosion and the protection of soil resources in the Song Cong Basin in particular, and in other river basins with similar conditions in general.

CHAPTER 1: DOCUMENT OVERVIEW

1.1. Theoretical Basis of Soil Erosion and Sustainable Use of Agricultural Land

The thesis clarifies several key concepts, including land, agricultural land, forestry land, and sustainable use of agricultural land (land use, sustainable land use, and the relationship between soil erosion and sustainable land management). It also defines soil erosion, the classification of soil erosion, and river basins, thereby identifying the factors affecting soil erosion and the relationships among soil erosion, slope, and land use types.

1.2. Scientific Basis of Soil Erosion Assessment and Sustainable Use of Agricultural Land

Based on previous research, the thesis synthesizes various soil erosion assessment methods. In addition to experimental approaches such as soil profile analysis, stake (pile) erosion measurement, plant root analysis, and sediment collection, there are also mathematical models including the USLE model, RUSLE/MUSLE (Revised/Modified Universal Soil Loss Equation) models, the European Soil Erosion Model, the WEPP model, and the SWAT model.

The thesis presents methods for applying technology in assessing soil erosion and identifying soil erosion indicators, thereby proposing solutions for the sustainable use of agricultural land under the impacts of erosion.

1.3. Agricultural Land Use in River Basins Around the World and in Vietnam

1.3.1. Agricultural Land Use in River Basins Around the World

Research on agricultural land use in river basins worldwide shows that the total global natural land area is approximately 14,865 million hectares, of which 3,300 million hectares are suitable for cultivation and 1,474 million hectares are currently in use. Land distribution is uneven across continents, with Asia playing a central role in global food security, while Africa has more limited potential for land exploitation. In Southeast Asia, rapid population growth has placed pressure on agricultural land; however, some potential land remains unused, particularly in Cambodia and Laos. In contrast, the Philippines and Thailand have utilized almost all of their agricultural land, posing significant sustainability challenges.

At river mouths, mangrove areas have been extensively converted to aquaculture, especially shrimp farming, placing great pressure on local ecosystems. In recent years, many countries have revised their land use policies to expand mangrove areas and plan aquaculture more appropriately to balance economic development with environmental protection. Overall, global differences in land use and exploitation reflect the combined impacts of climate, technology, economic conditions, and management policies in each region.

1.3.2. Agricultural Land Use in River Basins in Vietnam

Research in Vietnam indicates that as of 2022, the total natural land area reached 33.13 million hectares, of which agricultural land accounts for the largest share (84.4%), followed by non-agricultural land (11.9%) and unused land (3.7%). Agricultural land is mainly used for annual crops (6.79 million hectares), especially rice (3.94 million hectares) concentrated in the Mekong Delta, along with perennial crops (4.93 million hectares) primarily in the Central Highlands and the Southeast region. Forestry land accounts for 46.5% of the total area, mostly in mountainous and midland regions, playing a crucial role in ecosystem protection.This overall land use pattern not only confirms Vietnam's comparative advantages in agriculture but also highlights the increasing pressures from urbanization and socio-economic development, posing urgent requirements for sustainable land management and utilization..

1.4. Some Studies on Soil Erosion and the Sustainable Use of Agricultural Land in the World and in Vietnam

1.4.1. Studies Worldwide

Research has shown that soil erosion is a complex process simultaneously influenced by multiple natural and human factors. In natural conditions, the physical and chemical properties of soil (Hamanaka et al., 2019), terrain slope (Pampalone et al., 2022; Pathirana et al., 2009), rainfall intensity (Pathirana et al., 2009), and vegetation cover (Carrara & Carroll, 1979; Kázmér et al., 2024) are the main determinants of soil loss. In addition, long-term land use and cultivation practices have a significant impact, as demonstrated by Zakharov (1981) and Falcao-Sobrinho et al. (2023). Urbanization has also been identified as a factor increasing erosion in India (Aswathy & Sindhu, 2013), Nepal (Chhabi Lal Chidi, 2023), and China (Fan et al., 2019), while agricultural expansion in Turkey has shown that 25.7% of the total area is at high risk of erosion (Özsoy & Aksoy, 2015). Overall, the conversion of forest land to built-up or agricultural land reduces natural protection, alters water flow and infiltration, and consequently increases erosion rates. The USLE and RUSLE models, when combined with GIS, have proven effective for quantification and prediction, emphasizing the importance of integrating sustainable land use strategies into development planning.

1.4.2. Studies in Vietnam

Studies in Vietnam indicate that soil erosion is one of the most serious forms of land degradation, particularly in midland, mountainous, and unsustainably cultivated agricultural and forestry areas. Topographic factors—especially slopes over 15°—are identified as rapidly increasing soil loss (Thai Phien & Nguyen Tu Siem, 1999), while heavy rainfall in the Central Highlands can cause hundreds of tons of soil loss per hectare per year (Nguyen Quang My, 1995). Vegetation cover plays a crucial role, as the C coefficient in the USLE/RUSLE model varies significantly by season and crop type (Nguyen Quang My, 1995; Tran Thi Thom et al., 2023; Vo Kien Nguyen et al., 2023; Dao Minh Duc et al., 2023). The characteristics of red basalt soil in the Central Highlands also make it highly susceptible to erosion if cultivation practices are inappropriate (Vu Thi Thuy et al., 2019). Unsustainable land use—such as converting forests into swidden fields or paddy fields into industrial crops—can increase erosion by 30–50% during the rainy season (Nguyen Manh Ha et al., 2013). Applications of the USLE model show that the A Sap Basin loses an average of 10 tons/ha/year, with some areas exceeding 19 tons/ha (Pham Gia Tung et al., 2018). Research using the SWAT model in the Nam Rom, La Buong, and Song Be river basins confirms that both climate change and land use conversion alter water flow, increase sediment yield, and raise erosion risks (Nguyen Van Hung et al., 2020; Ngo Thanh Son et al., 2020; Dao Nguyen Khoi et al., 2019; 2021). Moreover, continuously cultivated land has been shown to have lower nutrient content than forested land, leading to reduced moisture retention capacity and higher erosion risk (Nguyen Phuc Khoi et al., 2024). Overall, researchers agree that soil erosion in Vietnam is driven both by natural factors (slope, rainfall) and by the strong impacts of unsustainable land use and climate change, underscoring the need for sustainable land management, forest protection, and the integration of advanced modeling tools to forecast and mitigate risks..

1.5. Research Orientation of the Topic

1.5.1. Research Gap

International research on soil erosion has established a solid theoretical foundation—from the classic works of Bennett (1960), Zakharov (1981), and Hudson (1981) to more recent studies by Borrelli et al. (2021)—which clarify the mechanisms, causes, and distinctions between natural and human-induced erosion. Mathematical models such as USLE, RUSLE, WEPP, EUROSEM, and SWAT, when combined with remote sensing and GIS technologies, have greatly enhanced the capacity to predict and manage erosion risks. In Vietnam, although numerous studies have been conducted in the Northwest, Central Highlands, and major river basins, medium-sized basins such as the Song Cong have not been comprehensively investigated. Particularly, there is a lack of studies combining modeling with high-resolution spatial data. Many existing studies stop at quantification using USLE or RUSLE models without calibrating or validating them with field data, nor do they integrate factors such as land use change, vegetation cover, or farming practices. This research gap highlights the need for integrated studies that both quantify erosion and propose sustainable agricultural land use solutions tailored to local conditions.

1.5.2. Research Orientation

Based on the theoretical and practical gaps identified in previous studies on soil erosion and sustainable land use, this thesis aims to address both theoretical and practical issues through the implementation of specific research contents and methods to achieve the proposed research objectives. Specifically:

The thesis builds upon the synthesis and evaluation of theoretical and practical studies conducted and published by domestic and international researchers on soil erosion and the sustainable use of agricultural land. It clarifies the theoretical and practical foundations of soil erosion and sustainable land use in river basins.

The study focuses on assessing land use changes during the period 2013–2023 and evaluating the level of soil erosion in the Song Cong Basin, Thai Nguyen Province. The RUSLE model, combined with remote sensing (RS) data and geographic information systems (GIS), was applied to determine key erosion factors, including the rainfall erosivity factor (R), soil erodibility factor (K), topographic factor (LS), cover management factor (C), and conservation practice factor (P), in order to calculate the amount of soil loss.

An experimental model was developed and monitored in Dinh Hoa District to accurately determine the amount of soil lost under different land use types (tea land, cinnamon land, and production forest land). In addition, the study analyzed the relationship between soil erosion, slope, and land use type.

Based on the research findings, the thesis proposes a set of solutions for the sustainable use of agricultural land aimed at minimizing soil erosion and improving land use efficiency in the context of socio-economic development and land resource protection within the study area..

CHAPTER 2: RESEARCH CONTENT AND METHODS

2.1. Research Content

2.1.1. General overview of the Song Cong Basin

2.1.2. Assessment of the current state of soil erosion in the Song Cong Basin

2.1.3. Assessment of the relationship between soil erosion, slope, and land use types in the Song Cong Basin

2.1.4. Assessment of soil erosion under different land use types through experimental models

2.1.5. Proposing solutions for sustainable agricultural land use in the Song Cong Basin

2.2. Research Methods

2.2.1. Data Collection Methods

The study utilizes both secondary and primary data to analyze the current status of soil erosion in the Song Cong Basin (Thai Nguyen Province). Secondary data were collected from district-level People's Committees, Statistical Yearbooks, domestic and international scientific studies, administrative maps, and current land use and land use planning maps up to 2030, as well as Landsat satellite images (2013 and 2023).

Primary data were collected through fieldwork, including experiments measuring soil loss at nine points representing different land use types (monitored during the 2023 rainy season), soil sampling for laboratory analysis at the Institute of Life Sciences – Thai Nguyen University of Agriculture and Forestry, and field surveys on terrain, soil characteristics, cultivation practices, and erosion conditions.

In addition, the study overlaid erosion, slope, and land use maps to create a spatial database containing 5,062 observation points with detailed information on erosion levels (classified into five levels according to TCVN 5299), land use types (10 groups), and slope categories (nine groups according to Shin, 1999). The collected data were processed in three stages: Checking and cleaning, converting qualitative data into quantitative form, and Consistency verification to ensure reliability and accuracy for the analysis of the relationships among soil erosion, slope, and land use.

2.2.2. Experimental Layout Method and Determination of Eroded Nutrient Mass

2.2.2.1. Experimental Layout Method

The study of soil erosion experimental layout in 3 communes of Son Phu, Binh Thanh and Diem Mac (Dinh Hoa district, Thai Nguyen), representing the terrain conditions, climate and common land use types. The three types selected are production forest land (acacia plantation), tea plantation and cinnamon plantation, each with three research points to ensure representativeness. The experimental plots have an area of 50 m², randomly arranged on sloping land, built with soil berms and soil-water collection pits to measure the amount of erosion. Cultivation activities in the plots are carried out according to actual production (soil preparation, fertilization, harvesting...) and recorded in detail. This layout helps to compare between theoretical and experimental models, thereby assessing the level of erosion and proposing solutions for sustainable agricultural land use.

2.2.2.2. Determination of the Amount of Eroded Nutrients

The volume of eroded soil is calculated by the following formula:

$$M = \sum_{1}^{n} M_i * \frac{10.000}{A}$$

In which:

M is the annual soil erosion mass (kg/ha/year)

Mi is the soil erosion mass of the i-th weighing

A is the monitoring area (m2)

To determine the amount of nutrients lost through erosion, the study selected six key indicators: humus content (OM), total nitrogen (N), total phosphorus (P_2O_5), total potassium (K_2O), calcium (Ca^{2+}), and magnesium (Mg^{2+}) contents.

The indicators and analysis methods are based on the following standards: TCVN 8941 – 2011; TCVN 6498 – 1999; TCVN 8940 – 2011; TCVN 8660 – 2011; TCVN 4405 – 1987; TCVN 4406 – 1987.

Determining the amount of eroded nutrients:

$$M_{OM} = \frac{a*M}{100} \qquad M_{N_{ts}} = \frac{x*M}{100}$$

$$M_{P_2O_{5\_ts}} = \frac{y*M}{100} \qquad M_{K_2O_{ts}} = \frac{z*M}{100}$$

$$M_{Ca^{2+}} = \frac{c*M}{100} \qquad M_{Mg^{2+}} = \frac{n*M}{100}$$

2.2.3. Land use change assessment method

The study assessed land use changes in the Song Cong Basin during the period 2013–2023 using spatial analysis in GIS through the overlay of two land use map layers. After being standardized in terms of coordinate system, symbols, and scale, the data were processed using the Intersect tool in ArcGIS to accurately identify the areas of change. The results were presented in the form of a land use change map and a change matrix of land use types, where the diagonal values represent areas that remained unchanged, while the off-diagonal values represent areas converted to other land use types. The data were then exported to Excel for synthesis and detailed analysis of the increase and decrease in the area of each land use type during the study period.

2.2.4. Methods of soil erosion assessment

To assess the level of soil erosion in the Song Cong Basin, Thai Nguyen Province, this study applied the Revised Universal Soil Loss Equation (RUSLE) model in combination with Geographic Information System (GIS) technology. The RUSLE model is a powerful and widely used tool worldwide for estimating the amount of soil eroded by rainfall, and is expressed by the following formula:

A = R*K*LS*C*P to calculate the amount of soil lost due to erosion due to rain.

A is the average amount of soil lost due to erosion during the year (tons/ha/year)

R is the coefficient of erosion due to rain

K is the coefficient of soil erosion resistance

LS is the coefficient of influence of terrain on erosion

C is the coefficient of influence of vegetation cover on soil erosion

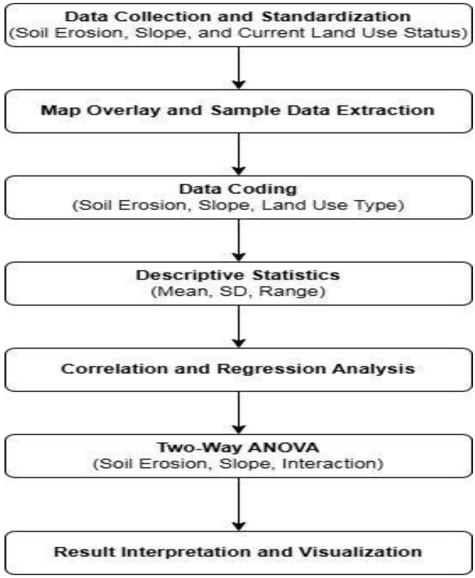
P is the coefficient of influence of farming measures on soil erosion

Interpolation method

2.2.5. Mapping methods and GIS information systems

The study uses the GIS mapping method to analyze land use changes and erosion risks in the Song Cong basin. Component maps (land use, rainfall erosion R, LS coefficient, cover C, slope, hydrology, administrative boundaries, etc.) are standardized in coordinate system, scale and format before being overlaid using ArcGIS. This process allows both determining land use changes in the period 2013–2023 and constructing erosion zoning maps according to the RUSLE model, thereby analyzing the relationship between soil erosion, slope and land use type.

2.2.6. Methods of Analysis, Statistics, and Data Processing



Data analysis, statistics and processing process

CHAPTER 3: RESULTS AND DISCUSSION

3.1. Overview of the Song Cong Basin

3.1.1. Natural Conditions

The Song Cong Basin (with a total area of 93,621 ha, of which 85,487 ha are located in Thai Nguyen Province) is an important tributary of the Cau River, flowing through five administrative units. The terrain is predominantly low to medium elevation, with more than 78% of the area lying below 200 m, which is favorable for agriculture and urban development, while areas above 600 m account for only 5.15%, suitable mainly for protective forests. In terms of slope, areas with slopes of less than 5° account for 28.11%, making them suitable for cultivation, whereas areas with slopes greater than 25° (14.15%) are mostly mountainous regions prone to erosion and in need of forest protection. During the period 2013–2023, the average annual rainfall ranged from 1,200–1,800 mm, showing a decreasing trend—particularly in spring and summer—thereby increasing pressure on irrigation and causing water shortages during the dry season. The basin contains abundant mineral resources (coal, tin, phosphorite), while forest land accounts for 41.87% of the total area, serving an important protective role. In addition, the region possesses rich surface and groundwater resources, although unevenly distributed. The area also has high potential for ecological and cultural tourism (e.g., Nui Coc Lake, ATK Dinh Hoa), requiring development strategies that integrate environmental protection measures.

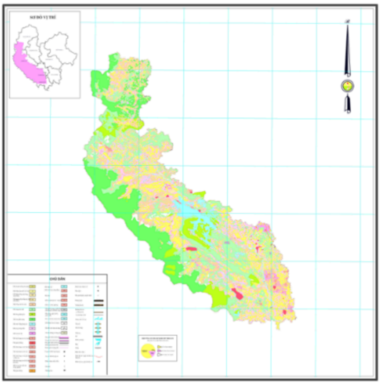
3.1.2. Socio-economic Conditions

The Song Cong Basin has a diversified economic structure with three main sectors: agriculture–forestry–fishery, which increased by 4.23%; industry–construction, which increased by 9.75%; and services, which increased by 7.35% (Thai Nguyen Statistical Office, 2023). The agricultural sector still plays an important role, with food production reaching 458.2 thousand tons, live pigs 214.9 thousand tons, harvested wood 252 thousand m^3, and aquatic products 17.3 thousand tons. During the period 2013–2023, the agricultural land area decreased from 52.3 thousand hectares to 39.4 thousand hectares due to urbanization; however, the productivity of key crops such as rice, corn, potatoes, cassava, and tea all increased thanks to technological advances. Rice still accounts for nearly 45% of the cultivated area, while livestock production continues to increase its share. In terms of population, the entire basin has nearly 789 thousand inhabitants, of which Thai Nguyen City accounts for almost half, resulting in a high population density (1,637 people/km^2) and creating significant pressure on infrastructure and the environment. In contrast, the midland and mountainous districts have low population density, scattered labor resources, and underexploited potential. In general, the region has advantages in land, natural resources, processing industries, and tourism, but faces population–labor imbalances and environmental pressures, requiring sustainable development policies and rational resource allocation.

3.1.3. Current Status and Changes in Land Use in the Song Cong basin

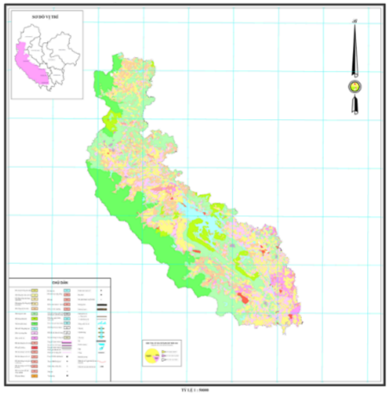
3.1.3.1. Current Status of Land Use in the Song Cong basin

By 2023, the land resources of the Song Cong Basin have been almost fully utilized, with a utilization rate of 99.95%. Of this, agricultural land accounts for 76.13%, playing an important role in the socio-economic development of the region. Agricultural land is mainly composed of rice land (18,940.81 ha) and perennial crop land (13,134.64 ha), with tea being the dominant crop, suitable for local climatic and soil conditions. In addition, non-agricultural land accounts for 23.82%, concentrated in urban areas, residential zones, and infrastructure serving industry and services, reflecting the strong development of the urbanization process. The remaining unused land is very limited, accounting for only 0.05% of the total basin area, indicating that land resources have been almost completely exploited .



Current land use map of the Song Cong basin in 2013

(Collected from the 1:/50.000 scale map)



Current land use map of the Song Cong basin in 2013

((Collected from the 1:/50.000 scale map)

3.1.3.2. Land use changes in the Song Cong basin in the period 2013-2023

During the period 2013–2023, the land use structure in the Song Cong Basin experienced significant fluctuations, characterized by a decrease in agricultural land area and an increase in non-agricultural land. Agricultural land decreased by 7,674.78 ha, of which rice land declined sharply by 11,171.74 ha, as part of the area was converted to residential, industrial, and infrastructure purposes. In contrast, non-agricultural land increased by 8,033.09 ha, reflecting the strong trend of urbanization and industrialization in the region. In addition, there was a structural shift within agricultural land: production forest land increased by 4,951.02 ha and perennial crop land increased by 149.07 ha, demonstrating an orientation toward economic development associated with the cultivation of production forests and high-value perennial trees. However, special-use forest land decreased by 7,221.68 ha, and unused land decreased by 358.31 ha, thereby increasing the risk of natural forest area decline. Overall, the land use change process in the Song Cong Basin reflects the combined impacts of urbanization and industrialization, alongside a trend toward sustainable agricultural exploitation—creating momentum for economic development while simultaneously posing challenges for environmental protection and ecological balance .

3.2. Soil Erosion Assessment in the Song Cong basin

3.2.1. Rain Erosion Coefficient (R)

The study determined the rainfall erosivity coefficient (R) in the Song Cong Basin based on the formula developed by Nguyen Trong Ha (1996), using average annual rainfall data for the period 2013–2023. The IDW interpolation results in ArcGIS showed that R ranged from 657.29 to 748.96 mm/year, mainly concentrated in the rainy season from May to September. Spatial distribution analysis indicated that the North–Northeast areas had low R values due to flat terrain and good vegetation cover, while the South–Southwest areas had high R values as a result of steep terrain and forest loss. Dai Tu and Pho Yen had a large proportion of their area within the high-R group, whereas Dinh Hoa was primarily classified in the low-R group. In general, the spatial differentiation of the R coefficient reflects the relationship between rainfall, topography, and land use in influencing erosion risk across the basin.

3.2.2. Soil Erosion Coefficient

The soil erodibility coefficient (K) in the Song Cong Basin was determined based on the soil map of Thai Nguyen Province and relevant reference documents, reflecting the physical properties, mechanical composition, and structure of the soil. The results showed that the K value ranged from 0.14 to 0.50, indicating a clear difference in erosion resistance among soil types. Within the total area of 85,487.49 ha, non-acid alluvial soil accounted for the largest proportion (25.28%), followed by red-yellow soil developed on clay and metamorphic rocks (20.88%) and red-yellow soil developed on acidic magmatic rocks (18.97%). Some soil types, such as sloping valley soil and light yellow soil on sandstone, also play an important role in agricultural and forestry production. Soil groups such as Dystric Gleysols have high K values and are more susceptible to erosion, whereas Xanthic Ferralsols and Rhodic Ferralsols have lower K values, indicating better erosion resistance.

3.2.3. Terrain oefficient (LS)

The results of the terrain factor (LS) analysis show that the Song Cong Basin exhibits clear slope differentiation, with the proportion of area decreasing as the slope increases. Flat areas (LS < 2) account for the largest share (38.78%), mainly distributed in valleys and river deltas, with low erosion risk. Areas with LS values ranging from 2–12 account for the majority of the basin (over 30%), typical of gently undulating midland terrain, favorable for agricultural production if sustainable farming practices are applied. The LS group ranging from 12–27 accounts for nearly 12%, while areas with LS > 27 make up 7.34%, concentrated in steep mountainous regions with a high risk of erosion. In particular, areas with LS > 65, although covering only 0.37% of the total, often suffer from severe erosion due to shifting cultivation activities. Spatial analysis indicates that the downstream areas (Thai Nguyen City, Song Cong, Pho Yen) are predominantly flat, whereas the upstream regions (Dinh Hoa, Dai Tu) feature more complex terrain, with many zones having high LS values, making them hotspots for soil erosion.

3.2.4. Surface Coating Factor (C)

The land cover coefficient (C) in the RUSLE model reflects the impact of vegetation and human activities on erosion, with values ranging from 0 (maximum erosion protection) to 1 (no protective cover). The C coefficient map is determined from the NDVI index, allowing analysis of differences in vegetation cover in the Song Cong basin. The results show that mountainous and natural forest areas, such as the North of Dinh Hoa, have low C coefficients, demonstrating good soil cover and protection. In contrast, urbanized areas and bare land in Song Cong City, Thai Nguyen City and Pho Yen City have high C coefficients, with a high risk of erosion. Agricultural areas and intercropped forests such as Dai Tu have average C coefficients.

3.2.5. Land Use Cultivation Coefficient (P)

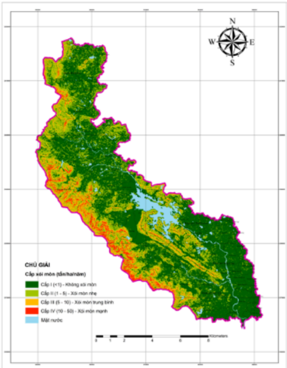
The P factor in the RUSLE model reflects the level of erosion reduction due to farming practices, especially evident in agricultural land, and in this study was calculated according to the formula of Wischmeier & Smith (1978). The results show that the Song Cong basin has 7 land use types, of which natural forests account for 54% of the area, mainly in steep areas with very low P values. Areas with high P factors are concentrated in the plains and key agricultural areas such as Thai Nguyen City, Song Cong and Pho Yen, where land is continuously exploited. In contrast, mountainous and forested areas in Dinh Hoa and Dai Tu have low P factors, reflecting limitations in farming and priority for forest protection. Some areas with medium to high P in Hoang Nong, Yen Lang, and Phu Thanh show diverse land use purposes. This shows the need to apply sustainable agriculture in areas with high P and maintain natural cover in areas with low P to limit erosion.

3.2.6. Building Potential Erosion Maps

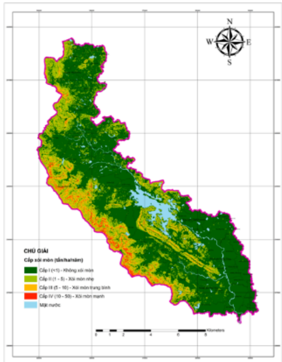
The potential erosion map in the Song Cong basin was developed based on natural factors such as rainfall, soil type and terrain, under the assumption of no vegetation cover or farming practices. The results show that the majority of the area (59.14%) is at level I, no erosion, and 27.71% is at level II (slight erosion), appearing mainly in mountainous zones between the plain and the mountains. Medium erosion (level III) accounts for 10.03%, while the area of strong erosion (level IV) accounts for only 3.12%, appearing mainly in the mountainous areas where vegetation is reduced due to unsustainable exploitation and cultivation. The distribution by administrative unit shows that Dai Tu and Dinh Hoa districts are more strongly affected, while Song Cong and Thai Nguyen are less affected. Approximately 13% of the area is at the level of medium to strong erosion, which are vulnerable areas that need to be prioritized for management. Therefore, combining measures such as agroforestry, protective afforestation, terraced farming and increased vegetation cover is necessary to minimize the risk of land degradation.

3.2.7. Building Soil Erosion Maps

The results of soil erosion analysis in the Song Cong basin show that most of the area is in levels I and II (no erosion and slight erosion), accounting for over 90% of the total area, reflecting relatively stable and favorable natural conditions for agricultural production. Areas with moderate to strong erosion account for a small proportion (about 9%), mainly distributed in mountainous areas with steep slopes, degraded vegetation and impacted by farming activities. In particular, Dai Tu district is the most heavily affected area, with rates of slight, moderate and strong erosion much higher than other localities due to the complex terrain of the Tam Dao range. In contrast, cities such as Song Cong, Thai Nguyen and Pho Yen have a high rate of stable soil thanks to flat terrain and urbanization. Dinh Hoa district has a low to moderate level of erosion, mainly concentrated in low hilly areas.



Potential erosion map of the Song Cong basin
(Collected from 1:/50,000 scale map)



Soil erosion diagram of Song Cong basin
(Collected from 1:/50,000 scale map)

3.3. Assessment of the Relationship between Soil Erosion and Slope and Land Use Types in the Song Cong basin, Thai Nguyen province

3.3.1. Slope Classification of Song Cong basin

The RUSLE model results indicate that soil erosion in the Song Cong Basin is predominantly at the levels of no erosion to slight erosion (82.9%), while about 17.1% of the area experiences moderate to strong erosion, concentrated in regions with steep slopes and degraded land cover. The land use structure in the basin is quite diverse, with production forest land (19.58%) and non-agricultural land (19.42%) accounting for the highest proportions, followed by rice land (15.47%) and perennial crop land (14.76%), reflecting the combination of agricultural development and an expanding urban economy. Special-use and protective forest land also account for a significant share (13.71%), contributing to ecological and environmental protection. Slope analysis shows that most of the area falls within the low to medium slope categories (56.7% and 27.9%, respectively), creating favorable conditions for cultivation and infrastructure development. However, areas with high slopes (>25°) make up about 17.8% of the total, mainly concentrated in mountainous regions, which face a high risk of soil erosion and land degradation. Overall, although the majority of the basin remains stable, high-slope areas continue to be erosion hotspots that should be prioritized in soil management and protection efforts.

3.3.2. Relationship between Erosion level and Slope

The analysis results showed that terrain slope had a strong and statistically significant positive correlation with soil erosion level ($r = 0.587$; $P < 0.001$), in which the slope explained 34.4% of the variation in erosion. The regression equation $Y = 0.0424X + 1.1659$ indicated that when the slope increased by 1°, the average erosion level increased by 0.0424 units. Analysis by slope group revealed a critical threshold at 10°; once this threshold was exceeded, erosion levels increased rapidly—particularly in the slope group >25°, which exhibited moderate to strong erosion levels (2.510–3.500). This finding confirms that slope is the key factor determining the risk of soil erosion, although other factors such as rainfall, soil characteristics, land cover, and human activities also play important roles

3.3.3. Relationship between Erosion level and Land Use Type

The analysis results showed that the average erosion level differed significantly among land use types (ANOVA, $F = 48.29$; $P < 0.001$). Forest land exhibited the highest erosion level (2.086), particularly special-use forest (2.337), whereas agricultural land had a lower level (1.632); this difference was statistically significant ($T = 17.19$; $P < 0.001$). However, the main cause was not soil type but terrain: forest land was often located in areas with steep slopes (average 19.87°), while agricultural land was found in lower-lying terrain (12.15°). When controlling for slope, the effect of land use type on erosion was significantly reduced (R^2 increased slightly, from 0.344 to 0.356). This finding confirms that slope is the primary determinant of erosion, while soil type plays only a secondary role.

3.3.4. Correlation Effects between Land Use Type and Sloping Land

The results of the multivariate regression analysis showed that both slope and land use type significantly affected soil erosion levels, with slope being the main determinant ($R^2 = 0.344$), while the addition of the land use type variable improved the model by only 1.2% ($R^2 = 0.356$). The special-use forest land group had the highest regression coefficient (0.2156), reflecting a higher level of erosion due to its predominant distribution in areas with steep terrain (>25°). In contrast, rice land was concentrated (78.4%) in low-slope areas (<10°), which are suitable for cultivation and water management. Thus, the difference in erosion levels among land use types mainly originated from terrain characteristics rather than from the intrinsic properties of the soil.

3.3.5. Relationship between Soil Erosion, Slope and Land Use ype

The analysis results showed that slope was the main factor influencing soil erosion ($\eta^2 = 0.472$), while land use type explained only 6%, and the interaction between the two factors accounted for 3.4%. As slope increased, erosion rates rose sharply across all soil types—from about 1.4 tons/ha/year at low slopes (<10°) to 2.5–2.9 tons/ha/year at high slopes (>25°). Forest soils exhibited the highest erosion rates on steep terrain, emphasizing the important role of vegetation cover and soil management. This finding confirms the necessity of terrain-appropriate land use planning and the implementation of soil conservation measures in mountainous areas to minimize land degradation.

3.4. Soil Erosion Assessment for Sustainable Land Use in the Song Cong basin, Thai Nguyen province

3.4.1. Soil Erosion Assessment through Experimental models

3.4.1.1. Determining the Amount of Soil Erosion of Different Land Use Types

Monitoring from May to September showed that tea land had the lowest erosion rate (0.83 tons/ha/year, level I – no erosion), thanks to the application of appropriate technical measures. Cinnamon land and forest land had higher erosion rates (2.69 and 3.62 tons/ha/year, level II – slight erosion), particularly during June and July, the period of heavy rainfall. This reflects the important role of land use type and vegetation cover in controlling soil erosion, especially on steep slopes.

Table 3.1. Erosion hierarchy of Land Use types

Land Use Type	Volume (tons/ha)	Erosion Level	Classification
Tea growing land	0.83	Level I	No erosion
Forest land	3.62	Level II	Slight erosion
Cinnamon growing land	2.69	Level II	Slight erosion

3.4.1.2. Determination of Nutrient Availability of Land Use Types

The analysis data showed that the nutrient content of soil in the Song Cong basin was significantly different between the three land use types: forest, tea and cinnamon. Forest soil had the highest humus and nitrogen content (2.41% and 0.421%), while tea soil had the lowest (1.76% and 0.11%), reflecting the impact of the thick forest litter layer and continuous tea cultivation. Total potassium in all three soil types was poor, ranging from 0.42–0.63%, with forest soil still superior to tea and cinnamon. Regarding phosphorus, tea soil had the highest (0.15%) compared to forest (0.14%) and cinnamon (0.13%). Calcium and magnesium varied slightly, with cinnamon soil being richer in Ca^{2+}, while forest soil was richer in Mg^{2+}.

However, the annual loss of nutrients due to erosion was highest in forest soil, especially humus (87.24 kg/ha/year) and potassium (22.81 kg/ha/year), many times higher than in tea soil. Cinnamon soil had an average loss of nutrients, but still higher than tea, especially nitrogen and phosphorus. This result shows the difference in the ability to accumulate and lose nutrients between land use types, and emphasizes the need for appropriate land management to limit fertility decline and ensure sustainable farming.

3.4.2. Comparison of Results between Experimental Model and Theoretical formula

Table 3.2. Comparison between the RUSLE Theoretical Model and the Experimental Model

Criteria	Theoretical Model (RUSLE)	Experimental Model
Evaluation goals	Calculating potential and actual erosion across the basin	Actual measurement of soil erosion at specific land use types
Scope	The entire Song Cong Basin (nearly 85,487 hectares	Three types of land use: tea, forest, cinnamon
Input data	Spatial data (DEM, soil maps, satellite images, meteorology)	Monthly field data on soil erosion
Calculation method	A = R × K × LS × C × P (using GIS software to overlay maps)	Calculate the total soil erosion (tons/ha) from the measured plots over time

Research results in the Song Cong Basin show that the combination of the RUSLE theoretical model and the experimental model is highly effective in assessing soil erosion. The RUSLE model has the advantage of covering the entire basin (85,487 ha), modeled on a GIS platform, indicating that more than 90% of the area is at the level of insignificant to slight erosion (Levels I–II). In contrast, the experimental model deployed at measurement sites (tea, forest, and cinnamon) accurately reflects actual field conditions and provides essential verification data. Experimental results recorded erosion rates of 0.83 tons/ha/year for tea land (Level I), 3.62 tons/ha/year for forest land, and 2.69 tons/ha/year for cinnamon land (Level II), which are consistent with the classification derived from RUSLE. However, the experimental erosion values are higher in absolute terms due to their direct reflection of field conditions. Overall, the empirical model plays a crucial role in calibrating the C and P factors of RUSLE, thereby enhancing the reliability of erosion assessments and supporting the development of sustainable land use solutions.

3.5. Proposing some Solutions for Sustainable Agricultural Land Use in the Song Cong basin

3.5.1. Advantages and Disadvantages of Sustainable Agricultural Land Use in the Song Cong basin

3.5.1.1. Advantages of Sustainable Agricultural Land Use in the Song Cong basin

Favorable Natural Conditions

The Song Cong Basin has a tropical monsoon climate, with an average annual rainfall of 1,200–1,800 mm and an average temperature of 23–25°C, which is highly favorable for the cultivation of various crops. The diverse terrain, ranging from plains to high mountains, creates distinct microclimates suitable for both annual and perennial crops. The fertile soils—including red basalt soil, yellow-brown soil, and forest soil rich in humus and nitrogen—contribute significantly to the potential for sustainable agricultural and forestry development.

Favorable Socio-Economic Conditions

The region has a high economic growth rate (over 30% per year), with industry and services accounting for more than 97% of the economic structure, thereby generating abundant resources for research and environmental protection. The basin serves as a major industrial center of Thai Nguyen Province, increasing the demand for the implementation of sustainable development solutions. At the same time, the region's strength in cultivating Thai Nguyen tea and cinnamon trees creates opportunities to develop high-value agriculture, organic farming, and agroforestry models that are both economically efficient and environmentally sustainable, contributing to the protection of land resources.

3.5.1.2. Difficulties in Sustainable Agricultural Land Use in the Song Cong basin

The Song Cong Basin is under significant pressure from soil erosion and resource degradation: approximately 85% of the area is affected by erosion, of which 22% experiences severe to very severe levels, with an average soil loss of 15.7 tons/ha/year—far exceeding the permissible threshold. Steep terrain (areas with slopes over 25° accounting for 18.4%), combined with unsustainable forest exploitation, slash-and-burn cultivation, and the clear-cutting cycle of production forests, has reduced both forest cover and quality, thereby increasing the risks of flash floods, landslides, and soil degradation.

In terms of land use and management, most land is exploited for agricultural purposes, contributing to food security and providing raw materials for the processing industry, but also exerting considerable pressure on land and forest resources. Land and forest management still shows many limitations and lacks long-term linkage to resource protection. Additionally, industrialization, urbanization, population growth, and economic restructuring are placing increasing pressure on agricultural land and the environment, highlighting the urgent need for more sustainable land use solutions.

3.5.1.3. Synthetic Analysis of the Relationship Between Advantages and Disadvantages

Table 3.3. Analysis of the Relationship Between Advantages and Disadvantages

No.	Favorable	Challenges	Priority Solutions

1	Biodiversity and suitable climate	Severe soil erosion	Solutions to limit erosion at each level
2	Diversity of terrain and soil	Steep and highly dissected terrain; complex land use	Biological and technical solutions
3	Potential for high-value agricultural development	Land exploitation and management; forest resource degradation	Reasonable land management solutions
4	Strong economic growth creates resources	Land use pressure (due to economic and population growth)	Solutions for sustainable agricultural land use in the basin

3.5.2. Proposing some Solutions to Limit Soil Erosion for the Rational Use of Agricultural Land

3.5.2.1. Solutions to Limit Erosion at each level

Level I (no erosion): Protect existing forests and apply reasonable cultivation practices that combine exploitation with conservation.

Level II (slight erosion): Maintain vegetation cover and preserve good soil conditions.

Level III (moderate erosion): Plant trees along contour lines, cultivate in rows, and use pit planting to reduce surface runoff.

Level IV (severe erosion): Enclose and regenerate forests, plant additional native or fast-growing tree species (such as Acacia and Eucalyptus), focus on restoring vegetation along strips and slashes, and prioritize forest rehabilitation.

3.5.2.2. Proposed Biological Solutions

Use vegetation (vetiver grass, wild peanuts, green beans) to retain soil, stabilize slopes, and improve soil fertility.

Plant trees along slopes (Acacia, bamboo, Leucaena) to reduce the impact of surface runoff.

Maintain natural forest vegetation and limit clear-cutting to protect the topsoil.

3.5.2.3. Proposed Technical Solutions

Construct drainage ditches along contour lines to allow gradual water infiltration and maintain soil moisture.

Build stone, wood, or concrete embankments in steep areas to prevent landslides.

Apply terraced cultivation to reduce flow velocity and maintain fertile topsoil.

3.5.2.4. Reasonable Soil Management Solutions

Cultivate along contour lines to reduce nutrient leaching.

Apply organic fertilizers to improve soil structure and fertility.

Reduce exploitation intensity, limit excessive plowing, and apply appropriate crop rotation methods.

3.5.2.5. Solutions for Each Type of Land Use

Tea land: Apply organic fertilizers, limit plowing, plant green manure crops, and maintain ground cover between tea rows.

Forest land: Limit clear-cutting, apply agroforestry models, and maintain natural ground cover.

Cinnamon land: Cultivate along contour lines, use biological soil cover, and add nutrients to maintain soil fertility.

3.5.2.6. Solutions for Agricultural Land Use in the Song Cong Basin

Upstream areas (slope >15°): Construct step terraces, cover the soil with legumes, and prioritize implementation in Dinh Hoa and Dai Tu.

Medium hill areas (10–25°): Convert easily eroded annual cropland to agroforestry models by intercropping fruit and forestry trees.

Steep slopes (>25°) and upstream forests: Enclose and restore protective forests; plant additional native species to retain soil.

Re-plan the cropping system: Limit short-term crops on sloping land and expand tea cultivation in midland areas.

Surface water management: Build contour-aligned drainage ditches, small reservoirs, and dykes to prevent erosion in densely populated areas (Pho Yen, Dai Tu).

CONCLUSION - RECOMMENDATIONS

1. Conclusion

1. The Song Cong basin exhibits diverse natural, socio-economic, and land use characteristics, with a transitional terrain between the midlands and the mountains. The significant variation in elevation and slope creates differences in cultivation potential and soil erosion risk. During the period 2013–2023, the study area experienced substantial land use changes, particularly the conversion of forestry and agricultural land into non-agricultural land. The increase in construction land area and the decrease in natural forest area are key factors contributing to a higher risk of soil erosion in steep terrain regions.

2. The research results show that the level of soil erosion in the basin is unevenly distributed, mainly concentrated in areas with steep slopes, poor land cover, and inappropriate land use. Among these, light erosion (Level II) accounts for the highest proportion, with 24.28% of the total area, followed by moderate erosion (Level III) at 7.74%, and severe erosion (Level IV) at 1.36%. Areas with severe erosion are typically found in the northern and northwestern mountainous regions, where slopes are steep and land use practices are unsuitable.

3. Data from 5,062 survey points across the basin show that the erosion rate increases significantly with slope and is strongly influenced by land use type. Areas with slopes over 25° are mainly concentrated in forest land (12.4%) and tea cultivation land (2.5%), accounting for 18.4% of the area with high erosion. In contrast, flat areas with slopes under 5°, primarily rice paddies and urban land, account for only 1.3% of the high-erosion area. Cultivated areas on sloping land, especially tea and cinnamon plantations, often lack soil protection measures.

4. Research results from the experimental model show that tea land lost an average of 1.99 tons of soil per hectare per year, cinnamon land lost 6.46 tons per hectare per year, while production forests lost about 8.69 tons per hectare per year. Forest land lost 1.73 times more humus than cinnamon land and 5.97 times more than tea land. Cinnamon land lost an average of 50.30 kg of humus per hectare per year, 8.61 kg of N per hectare per year, 11.57 kg of K_2O_5 per hectare

per year, 3.50 kg of P_2O_5 per hectare per year, 12.75 kg of Ca^{2+} per hectare per year, and 3.68 kg of Mg^{2+} per hectare per year. Tea-growing soil had the lowest nutrient loss, with 14.61 kg of humus per hectare per year, 0.91 kg of N per hectare per year, 3.49 kg of K_2O_5 per hectare per year, 1.25 kg of P_2O_5 per hectare per year, 15.53 kg of Ca^{2+} per hectare per year, and 1.31 kg of Mg^{2+} per hectare per year.

5. Based on the research results and practical conditions in the Song Cong basin, the thesis proposes several solutions for sustainable agricultural land use, including measures to reduce erosion at different levels, biological solutions, technical interventions, improved land management strategies, land use–specific solutions, and integrated approaches for sustainable agricultural land use in the Song Cong basin.

2. Recommendations

- Due to time constraints, the thesis only focuses on studying and assessing soil erosion due to rain in the Song Cong basin and arranging experiments at three typical sloping land use types of the basin. Therefore, to have a more complete assessment and a more comprehensive solution for soil erosion, it is necessary to continue studying other issues related to soil erosion such as wind, terrain, soil properties as well as continuing to arrange experiments at some other land use types…
- It is recommended that the relevant authorities responsible for agricultural land use in the Song Cong Basin consider applying the solutions proposed in this thesis to enhance the effective use of agricultural land in localities within the Song Cong Basin, Thai Nguyen Province.