Studies on restructuring for sustainable regional ecosystems in the humid tropics

（湿潤熱帯における持続可能な地域生態系の再構築に関する研究）

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Abstract

The productivity of vegetation is naturally high in Southeast Asia because of the warm and humid climate. However, once the vegetation cover has been destroyed, land degradation occurs very easily because the high rainfall results in rapid soil erosion. Traditional agricultural and forestry systems were in harmony with the natural ecosystem. A number of traditional land-use systems in the humid tropics have been extensively evaluated as examples of agroforestry systems that allow sustainable biological production without generating environmental degradation. It has been reported, however, that the structure and function of these traditional land-use systems have been changing as a result of agricultural development, rapid population growth, urbanization, and expansion of the market economy, raising concerns about the deterioration of its sustainability. Intensification of agricultural systems and the promotion of cash crop production and livestock raising have contributed to increased food production, however, the heavy use of chemical fertilizers and the improper utilization of large amounts of livestock waste are causing environmental contamination. Furthermore, deforestation due to the illegal cutting of trees and the clearing, burning and cultivation of sloping lands in mountainous areas, especially since the economic crisis of 1997, has been generating major soil erosion problems.

To solve these problems and to establish sustainable regional ecosystems in the rural humid tropics, it is essential that we reevaluate traditional agricultural and forestry systems and create a new, recycling society appropriate to the current socioeconomic conditions. We need to restructure regional ecosystems in such a way that bioresource recycling occurs on a larger spatial scale than that in a traditional rural society. This aim of this restructuring is to solve the current environmental problems without reducing agricultural productivity under existing conditions. Toward this end, it is primarily important that we elucidate the current condition of material flows within a given region.

The ultimate goal of this study is to provide useful information and to present a

conceptual proposal toward restructuring for sustainable regional ecosystems. We integrated landscape ecological methods and fieldwork (mainly by interview) to determine the typical material flows in the region at a hamlet scale. We then examined the feasibility of restructuring these material flows to establish sustainable regional ecosystems based on bioresource recycling at a watershed scale.

This study was carried out in the Cianjur-Cisokan watershed, which is located in the central part of West Java. This area has a typical rural landscape of the volcanic footslopes that are frequently found in Java. Landscape structure of the study area was investigated based on land condition and land use to sample typical rural hamlets. Topographic maps and aerial photographs were used to construct a Geographic Information System (GIS) of the study area. The landscape structure of the study area was visualized by presenting the relationships among elevation, slope, and land use, which showed a typical arrangement of land-use composition along a catenary sequence of landform expressed by elevation and slope. Three hamlets, hamlets G, M, and S, were sampled as typical examples from each of three areas that had typical land-use compositions, including rural settlements. Hamlet G was located in an upland-field-dominant landscape, hamlet M at an ecotone between upland-field-dominant and paddy-field-dominant landscapes, and hamlet S in a paddy-field-dominant landscape.

We conducted interviews in 60 randomly sampled households in each hamlet to determine: 1) socioeconomic characteristics, such as occupation, cash income, and land ownership; 2) status of biological production and bioresource utilization; and 3) items related to the status of artificial material flows, such as fertilizer input and quantities of food purchased.

In the investigation of biological production and bioresource utilization we focused on food, fertilizers, and livestock feed. The degree of self-sufficiency (DSS) with regard to food was estimated by kilo-joule-based calculations, which showed that only hamlet S was totally self-sufficient in food. However, the DSS for each food item suggested that although hamlets G and M were far from self-sufficient in rice, all hamlets were almost self-sufficient in vegetables and fruits, with the exception of fruits in hamlet G. On the whole, the percentage of food consumed that was derived from local production differed vastly from the DSS of food, reflecting the high percentage of food sold to the market. Livestock manure and crop residue were highly utilized as organic fertilizer in all hamlets. However, the percentage of nitrogen derived from local organic fertilizer in the total nitrogen input to arable lands was extremely low. This suggests that the amount of locally produced organic matter would be insufficient in all hamlets if the current nitrogen input were to be maintained. Sheep, goats, and rabbits were fed with grass collected from within the hamlet or its surroundings, and no commercial feeds were used for these animals. Poultry were fed with kitchen leftovers and rice bran, most of which were purchased from the market. Comparison between the estimated production and consumption of rice bran suggested that only hamlet S was self-sufficient in this commodity.

In estimating the material flow in each hamlet, we divided the rural ecosystems into 9 components: human, home garden, fishpond, livestock, mixed garden, forest garden/bamboo forest, paddy field, upland field, and dump. Material transfers between components due to human activity were estimated from data obtained through interviews and were converted to quantities of nitrogen. Material flow due to the removal of mud accumulated at the bottom of fishponds was calculated from estimates of the annual quantity of mud accumulated, as determined by one-month measurement during both the rainy and dry seasons. The nitrogen content of livestock feeds such as rice bran and grass, manure, fuel wood, and mud were obtained by chemical analysis.

By using the above-mentioned methods, we constructed a component model of nitrogen flow in each hamlet. The model showed that all of the hamlets had formed open systems whereby external inflows in the form of chemical fertilizer and purchased foods played a major role. In particular, nitrogen inputs via chemical fertilizer to the upland fields in hamlet G and the paddy fields in hamlet S showed up as an overwhelmingly large flow in the component model. The nitrogen flow in hamlet M was complex, with a large number of flow channels. This finding was probably related to the complex landscape structure of this hamlet. Nitrogen flow via human excrement played a major role in the internal nitrogen flow of all three hamlets, and nitrogen flow from/to livestock also played a major role in hamlets G and M. In addition, nitrogen flows via mud removed from fishponds were not a negligible part of the total nitrogen flow.

The estimated total nitrogen balance of each hamlet was positive: +290 kg N ha^{-1} $year^{-1}$ in hamlet G, +217 kg N ha^{-1} $year^{-1}$ in hamlet M, and +121 kg N ha^{-1} $year^{-1}$ in hamlet S. The large nitrogen surplus in hamlet G can be attributed to the heavy use of chemical fertilizers and purchased chicken manure in the upland fields, which may have caused ground or surface water pollution in the lower part of the watershed.

Application of unused local resources as substitutes for purchased fertilizers may improve the current status of nitrogen flow in the hamlets. We estimated that application of all of the mud from the fishponds and all of the human excrement could reduce the nitrogen surplus in each of the three hamlets by 48 to 87 kg N ha^{-1} $year^{-1}$, and could reduce the cost of fertilizer by US$ 122 to US$ 346. However, after complete utilization of these resources, hamlet G would still have a high nitrogen surplus, suggesting the need for fundamental improvement of fertilizer management in the upland fields. Our results also suggested that complete use of locally produced organic fertilizers combined with complete use of unused local resources could not provide enough nitrogen to maintain the present status of nitrogen input to arable lands in hamlets G and S.

Our estimations of potential bioresource supply and material flow suggested that restructuring to create a closed bioresource recycling system would be difficult at a hamlet scale under the existing conditions, and that restructuring at the larger scale of the regional ecosystem should be evaluated. In the light of these findings, we evaluated the feasibility of restructuring to establish a closed bioresource recycling system at a watershed scale. From the land-use map and statistical data on population and number of livestock, we estimated the potential supply and consumption of bioresources, food, fertilizers, and livestock feed in 63 municipalities within the Cianjur-Cisokan watershed.

The evaluation of food resources was focused on rice. Rice production within the area was estimated as the total area (ha) of paddy field multiplied by the annual yield per hectare. The estimated rice production was compared with rice consumption, as estimated by the population of multiplied by the rice consumption per person per year in Indonesia; the result indicated that the watershed was self-sufficient in rice. The potential supply of organic fertilizer was evaluated by focusing on livestock manure production, estimated as the number of livestock multiplied by the quantity excreted per head per year. The estimation indicated that complete use of livestock manure would provide only 18% of the total nitrogen input to the arable lands in the watershed. However, incorporating unused resources, such as garbage and human excrement, locally produced organic fertilizers could provide 46% of the total N input. Rice bran, which is the most popular feed for poultry in this area, was assessed in our estimation of the local animal-feed supply. Estimates of rice bran production and consumption showed that it would be self-sufficient for roaming chickens and local ducks. After these animals had been fed, the surplus rice bran would provide 51% of the feed for broiler chickens and laying hens usually fed with commercial pellets at poultry farms, assuming that these animals consumed rice bran at the same rate as the roaming chickens.

From the above results we drew the following conclusions.

1. The methodology used in this study enabled us to rapidly elucidate the artificial material flows in rural ecosystems by first evaluating landscape structure at a watershed scale and then evaluating landscape function in detail by focusing on bioresource production/utilization and material flow at a hamlet scale. This method would be particularly applicable to developing countries, where statistical data has not been well developed.
2. By applying this methodology, we determined the landscape structure of the watershed and the orientation of the hamlets sampled hamlets were clarified. The results of landscape function analysis suggested that the material flows in all hamlets formed open systems with a high dependency on the market. In addition, considering the insufficiency of the potential supply of

bioresources, it would be difficult to restructure a regional ecosystem at a hamlet scale to create a closed bioresource-recycling system. However, estimates at a watershed scale suggested that successful restructuring would be feasible with the utilization of unused local resources such garbage and human excrement.

3. A large nitrogen surplus was recorded in hamlet G, located in the upper reaches of the watershed. This surplus has the potential to cause ground or surface water pollution in the lower reaches. Further studies are needed to determine the material flows due to natural processes and to evaluate the ecological functional linkages between the upper and lower reaches of the watershed.

Japanese abstract / 要 旨

東南アジアの湿潤熱帯では，高温多湿な気候に恵まれて植物生産性は高いが，一度植生が破壊され裸地になると土壌侵食により土地荒廃が引き起こされることから，伝統的に自然生態系と調和した農林業が営まれてきた。湿潤熱帯の各地でみられる伝統的土地利用システムは，アグロフォレストリーの一形態としてその持続性が再評価されている。しかし，農業生産の拡大，人口増加，都市化および市場経済の浸透などの影響によって，こうした伝統的な土地利用システムの構造および機能が変容し，その持続性の低下が危惧されている。農業の集約化や畜産の振興は食糧増産に寄与したが，大量の化学肥料使用や畜産廃棄物によって環境汚染が引き起こされている。さらに，とくに経済危機以降，傾斜地における森林の伐採および違法耕作が進行し，著しい土壌侵食が顕在化している。

持続可能な農村社会を目指すには，伝統的な農林業システムを再評価しながら，環境の変化をふまえた現代社会にふさわしい循環型社会を形成する必要がある。とくに現在引き起こされている環境問題を解決しつつ，農業生産の生産性を維持するには，より高次のレベルにおける地域資源依存型，生物資源循環型の地域生態系の再構築が必要であるが，これを実現するためには，まず地域の物質フローを明らかにすることが重要である。

そこで，本研究では持続可能な地域生態系の再構築のための基礎的知見を得ることを目的として，景観生態学的手法と聞き取りによるフィールドワークを統合し，それを適用することで地域の典型的な物質フローを集落スケールにおいて解明し，流域スケールにおいて生物資源循環型の地域生態系再構築の可能性について検討を行った。

研究対象地は，西ジャワ中央部に位置するチアンジュール川－チソカン川流域とした。本地域はジャワ島に多く存在する火山山麓の典型的な農村景観をもつ地域である。まず，ここから対象集落の抽出を目的として，土地利用と地形条件をベースとした景観構造の把握をおこなった。地形図と空中写真から地理情報システムを構築し，標高－傾斜－土地利用の対応関係を図化することによって景観構造を表現した。その結果，標高－傾斜で表現される地形配列に沿って，典型的な土地利用構成の配列が認められたが，このうち集落の分布がみられる３つの地域から，それぞれG集落，M集落，S集落を典型例として抽出した。G集落は畑が優占する地域，M集落は畑と水田が混在する地域，S集落は水田が優占する地域に立地する。

各集落において，社会・経済的背景，生物生産および生物資源の利用状況，物質フローに関する調査を行った。それぞれ60世帯を対象として聞き取り調査を行い，１）職業，収入および土地所有形態などの社会・経済的背景，２）生物生産およびその利用，および３）肥料投入量，食物購入量など人為的な物質フローに関連した項目について情報収集を行った。

生物資源の利用状況については，食料，肥料，飼料について検討を行った。3集落における食料自給率をカロリーベースで試算したところ，食料全体で自給率が100%を超えているのはS集落のみであった。しかし，食料を項目ごとにみると，米ではG集落とM集落で自給率が非常に低いが，野菜と果物に

関しては，G 集落の果物を除くと，おおむね自給可能であることが明らかになった。さらに，消費される食料のうち自給生産によるものの割合を求めたところ，概して自給率との差が大きく，集落で生産されるものの商品化率が高いことを反映していた。有機肥料についてはいずれの集落についても，最大限に近く利用されていることが明らかになった。しかし，農地への全窒素投入量における自給有機肥料の割合は低く，現状の窒素投入量を維持するには，集落内の有機物を全て利用したとしても不足することが明らかになった。ヒツジ，ヤギ，ウサギの飼料については，集落およびその周辺で採集してきた草を利用しており，外部からの購入はされていなかった。家禽類の飼料は残飯と米糠であり，米糠はその大部分が購入されていた。M 集落と S 集落における米生産量から米糠生産量を推定し，利用量と比較したところ，S 集落では自給可能だが M 集落では利用量の 19%しか供給できないことがわかった。

各集落における物質フローの推定においては，人間，家畜，養魚池，ホームガーデン，畑，水田，ミックスガーデン，タルン，および廃棄場の 9 つのコンポーネントに分割し，コンポーネント間の年間物質移動量を聞き取り調査の結果から推定したうえで窒素量に換算した。養魚池に堆積した泥の除去にかかわる物質フロー量については，雨期と乾期にそれぞれ 1 ヶ月間の堆積量を測定し，年間の堆積量を推定した。米糠や草などの飼料，家畜糞，燃料木，泥などについては，化学分析を行って窒素含量を測定したうえで，窒素量に換算した。

3 集落の物質フローを窒素に換算してコンポーネントモデルを構築した結果，いずれの集落においても化学肥料や食物購入による外部とのフローが大きく，開放系となっていることが明らかになった。とくに G 集落と S 集落においては，それぞれ，畑と水田への化学肥料による投入量が圧倒的に大きいことがわかった。M 集落の物質フローは，他集落と比較して複雑な形態を持っており，複雑な景観構造との関連性が示唆された。集落内のフローとしては，人間のし尿によるものが大きく，G 集落と M 集落では家畜の給餌および糞利用にかかわるものも大きかった。さらに，養魚池の泥の除去にかかわる物質フローも全体の中で無視できないことが明らかになった。

集落全体としての窒素収支では，いずれの集落においてもインプットのほうが大きく，G 集落では+290 kg N ha^{-1} $year^{-1}$，M 集落で+217 kg N ha^{-1} $year^{-1}$，S 集落で+121 kg N ha^{-1} $year^{-1}$ であった。とくに G 集落における大量の窒素過多は，畑への化学肥料および購入された鶏糞の大量投入に起因しており，系外に流出した窒素分による水質汚濁など下流部への影響が危惧される。

養魚池に堆積した泥と人間のし尿を肥料として利用可能な未利用資源としてとりあげ，それらによる窒素投入で，化学肥料を代替した場合に，窒素過多がどれだけ緩和されるのかについて試算を行った。その結果，最大 48 ～87 kg N ha^{-1} $year^{-1}$ の窒素過多が緩和され，これらによって US$122～346 の肥料購入費を削減できることがわかった。しかし，G 集落では依然として窒素過多が大きく，根本的な施肥管理の改善が必要であることが示唆された。また，現況の有機肥料に加えて，これらの未利用資源を最大限に利用しても，G 集落と S 集落では，現況の窒素投入量を維持するには足らず，外部からの購入

が必要であることが明らかになった。

以上の集落スケールにおける生物資源の供給量および物質フローの検討から，集落を単位として閉鎖的な生物資源循環系を構築することは困難であることが明らかになり，より上位の空間単位での再構築の可能性について検討する必要性が示唆された。そこで，チアンジュール川ーチソカン川流域の63市町村を対象範囲として，人口，家畜頭数などの統計資料と作成した土地利用図を用いて，食料，肥料，飼料について検討を行った。

食料としては，米について検討を行った。水田面積と平均年間単収から米の生産量を推定し，インドネシア人１人当たりの平均米消費量から計算した需要と比較したところ，地域内で米を自給することは可能であると推定された。肥料としては，まず家畜糞をとりあげ，家畜頭数と家畜１頭あたりの糞排泄量から，肥料供給量を推定した。その結果，家畜糞を全て利用しても現況の窒素投入量の18%しか供給できないことがわかった。しかし，これに生ゴミと人間のし尿も加えると46%まで供給可能であると推定された。飼料については米糠をとりあげ，生産量を推定したところ，集落内のニワトリとアヒルについては自給可能であることがわかった。養鶏場で飼養されているブロイラーに対しては，配合飼料が用いられているが，集落内のニワトリと同じ米糠消費量を仮定した場合，集落内のニワトリとアヒルに利用した米糠の余剰分を用いて，必要量の51%を供給可能であることが明らかになった。

以上要するに，本研究では以下の結論が得られた。

1） 本研究の手法は，まず地域スケールでの景観構造の評価を行い，抽出された集落において生物生産および物質フローの点から詳細な機能評価を行うものであり，これによって地域における人為的な物質フローを迅速に把握することが可能となった。本手法は，統計情報の整備が遅れている途上国において，とくに有効な手法であると考えられた。

2） 本手法の適用により，流域スケールでの景観構造が解明され，対象とする集落の位置付けが明確にされた。物質フローの推定結果からは，全ての集落において外部に依存した開放系となっており，生物資源の現存量からも集落を単位とした生物資源循環系を構築することは困難であることが明らかになった。しかし，流域を単位として考えた場合，未利用資源の有効利用まで考慮すると，ある程度は実現可能であることが示唆された。

3） 対象流域では，とくに上流部（G集落）における窒素過多が問題であり，下流域への水質などの影響が危惧される。今後は，人為的な物質フローだけでなく，自然のプロセスによる物質フローについても定量的な評価を行い地域生態系の全体像を解明していく必要がある。

Chapter 1
Introduction

1.1. Background of the study

1.1.1. Agricultural development and its influence on environment in Southeast Asia

The productivity of vegetation is naturally high in Southeast Asia because of the warm and humid climate. However, once the vegetation cover has been destroyed, land degradation occurs very easily resulting from concomitant soil erosion due to high rainfall occurrences. Traditional agriculture and forestry systems were in harmony with the natural ecosystem. A number of traditional land use systems in the humid tropics have been extensively evaluated as agroforestry (Nair, 1985) that allow sustainable biological production without generating environmental degradation.

The Southeast Asian countries in humid tropics had experienced rapid population growth in the last several decades and still are continuously experiencing such at present, which required food production increase. Economic growth in these countries during the 1970s and 1980s allowed introduction of modern high-input intensive agricultural systems that may cause environmental degradation. The expansion of agricultural production, rapid population growth, and urbanization, however, have changed the traditional agricultural systems in Southeast Asia and consequently have diminished the sustainability of these systems. The modernization of agricultural systems and the promotion of cash crop production and livestock raising have contributed to increased food production and have somehow improved farm economy, however, the heavy use of chemical fertilizers (e.g. excessive input of nitrogen: more than 200 kg N ha^{-1} $year^{-1}$) and the large amount of improperly utilized livestock wastes are causing environmental contamination. The decrease in

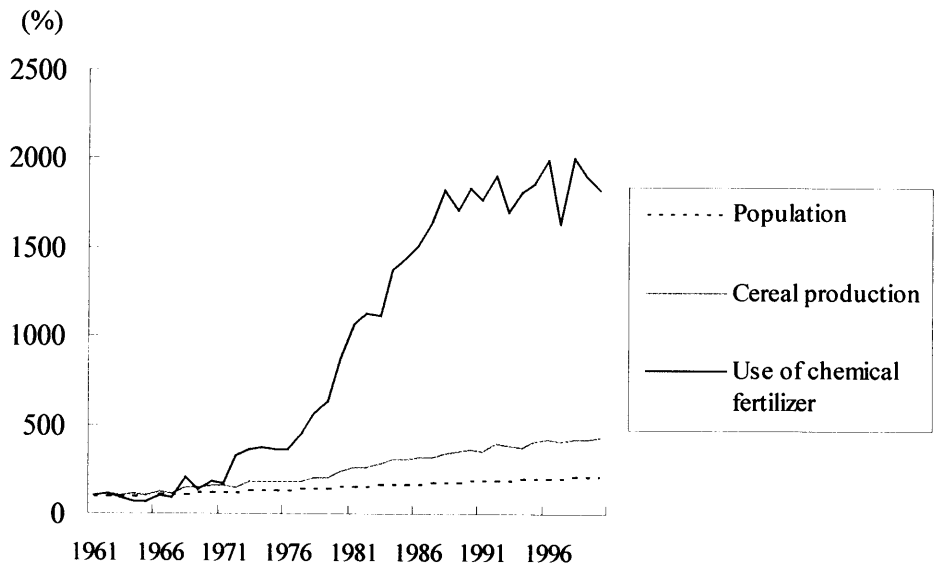

Figure 1-1. Population growth in relation to increase in cereal production and use of chemical fertilizers in Indonesia. (Data source: FAOSTAT, http://apps.fao.org)

the area of paddy fields due to urbanization is increasing and flooding in lowland areas.

Based on FAOSTAT (http://apps.fao.org), it was reported that the population of Asia has doubled and cereal production has tripled in the last 40 years, the amount of fertilizer use has increased to 20 times of the previous utilization. In the case of Indonesia, the population has doubled, cereal production has quadrupled, and fertilizer use is 20 times of what it was 40 years ago (Figure 1-1). Such excessive use of fertilizer may have caused soil/ground- and surface-water pollution. Moreover, increasing population pressure and shortage of lands are forcing peasants to cultivate steeper slopes that were formerly covered with forests, causing major erosion problems, reduced fertility and productivity henceforth giving only small, short-term returns. Deforestation due to illegal cutting of trees, clearing, burning and cultivation of sloping land in mountainous areas in the upper Citarum watershed especially after the economic crisis of 1997 has been generating major soil erosion problems. The Institute of Ecology of Padjadjaran University in Indonesia has reported that the amount of soil erosion on illegally cultivated land is approximately 200 t ha^{-1} $year^{-1}$, which is more than 10 times of what would be expected from a well-managed agro-forestry system (Chay Asdak, personal communication). In addition, this soil erosion is causing soil sedimentation problem in the Sagling reservoir located at the down stream of the upper Citarum watershed.

Cognizant of these problems, search of measures to mitigate such and to establish sustainable regional ecosystems in the rural humid tropics become inevitable. Toward this end, it is deemed essential to re-evaluate the traditional agriculture and forestry systems and to create a new recycling society based on local bioresource utilization appropriate to the current socio-economic conditions. Considering the continuing economic development and changes in social condition, it becomes very necessary to restructure the recycling system at a larger spatial scale than that of a traditional rural society so as to solve the current environmental problems without reducing agricultural productivities under existing conditions. For instance, effective use of livestock dung and human excrement would contribute to a recycling society.

1.1.2. Transformation of the rural landscape in West Java

Java is approximately 130,000 km^2 in area, which accounts for only about 7% of the total area of Indonesia with a total area of approximately 1,900,000 km^2. However, it is a densely populated being occupied by about 60% of total population of Indonesia. The high population density has put a large pressure on land resources for a long time and consequently has been a highly cultivated island.

Land-use change and population growth from 1880 to 1995 is shown in Figure 1-2. According to Verburg *et al.* (1999), agricultural development of Java can be divided into 3 stages. The first stage is from 1880 to 1920, which shows several of the classic features of a period of rapid agricultural extensification. The area of arable land was growing just fast enough to keep up with population growth, where expansion of arable land mainly occurred in upland fields. The second stage began in 1920, by which the frontiers of land extension were almost reached. The colonial

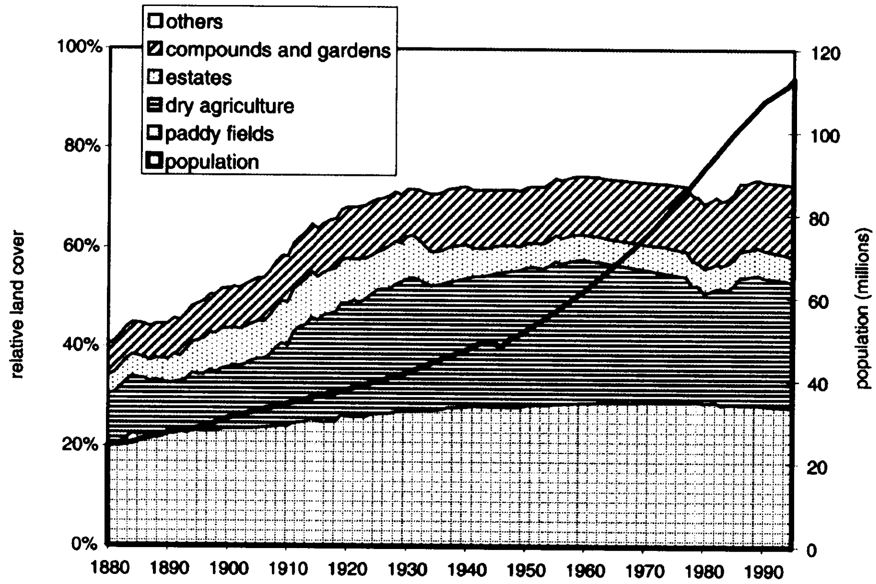

Figure 1-2. Relative cover of different land use types in Java
(Verburg *et al.*, 1999; Data source: Van der Eng, 1993)

authorities discouraged further extension, since it was likely to affect the hydrological situation in the upland forest reserves, and indirectly the supply of irrigation water in the lowlands. Further increases in demand for food caused by population growth were satisfied by agricultural intensification, where intensification is defined as an increase in the cropping ratio. The third stage in agricultural development of Java started after 1970, when very rapid growth in food production can be observed, largely due to yield increase that accelerated throughout the period, particularly in the years after 1979. In recent years, Java is moving increasingly towards labor-intensive manufacturing and services as a means of employing a higher proportion of its population. Together with continuing population growth and large demands for recreational facilities (e.g. golf courses), this will lead to a decrease in the area of prime agricultural land as shown in Figure 1-2 for the most recent years.

Agriculture in Indonesia, which developed as a primary exporting country in the colonial period, consists of 2 sectors: estate agriculture for primary exports, and farm agriculture for food production. Farm agriculture in Java, where the staple crop is rice, is characterized by smallhold farmers and landless households. Development of the rural economy has also been supported by non-rice crop production, effective use of land within house compounds, and nonagricultural activities (Kano, 1988).

Traditional land-use systems in West Java can be regarded as one of the factors that have supported the farm economy of smallhold farmers and landless households. The Javanese home garden (*Pekarangan*) and the annual–perennial rotation cropping system (*Kebun-Talun* system) are examples of these traditional land-use systems (Christanty *et al.*, 1985; Fernandes and Nair, 1986). The *Pekarangan* is an area of land with a definite boundary surrounding a house in which several annual and perennial crops are cultivated, and it often includes small livestock or a fishpond (Karyono, 1990). The *Kebun-Talun* system is a rotation-cropping system, in which the forests are cleared and cultivated as upland fields, generally for 2 years, followed by a 4- to 5-year fallow period during which the forests are restored (Christanty *et al.*, 1985; Christanty *et al.*, 1997). Both are considered sustainable land-use systems because they have been carried out for hundreds of years without causing soil fertility to deteriorate, even on sloping land (Christanty *et al.*, 1985).

However, the structure and function of those traditional land-use systems has been changing because of rapid population growth, urbanization, and the expansion of the market economy (Abdoellah, 1990; Michon and Mary, 1990; Michon and Mary, 1994). Home gardens, for instance, have undergone a decrease in area and plant species, a simplification of the vegetation structure, and a decrease in garbage composting, and they are less likely to function for subsistence food production (Arifin *et al.*, 1997; Arifin *et al.*, 1998a; Arifin *et al.*, 1998b). Shortening of the fallow period and intensification of the *Kebun-Talun* system have also been reported (Christanty *et al.*, 1996, 1997). The transformation of traditional land-use systems raises concerns regarding the deterioration of ecological sustainability accompanied with economic risks, and in addition, destruction of traditional village community institutions (Abdoellah, 1990). However, in the face of continuing rapid population growth and economic development, intensification in these land uses and market-oriented crop production necessarily take precedence. Thus, at issue is how to restructure these systems in order to fulfill overall people welfare, not only in economic aspects but also cultural and ecological aspects (Abdoellah, 1990). Taking account of environmental problems as described in the previous section and economic development that has enlarged the spatial scale of communications and human activities, not only restructuring of individual land use, but of total regional ecosystem is required to achieve ecological, social, and economic sustainability.

1.2. Objectives of the study

The ultimate goal of this study is to provide useful information and to present a conceptual proposal toward restructuring for sustainable regional ecosystems. In order to achieve sustainable regional ecosystems, it is primarily important to elucidate its current status since this could help in extracting trouble spot or potential source of problem. Likewise, this could provide useful information contributory to the improvement of its current state. Aiming at restructuring a new recycling society based on bioresource utilization, clarification of present state of material flow would be powerful tool to provide basic information. On the other hand, landscape structure is important factor that regulates its principal function, i.e. material flow within the landscape.

The followings were the main objectives of this study:

1) To elucidate landscape structure of rural area in West Java, Indonesia, in terms of land use and topographic conditions, to clarify orientation of the study hamlets that were sampled based on the watershed-scale landscape structure, and to examine in detail the landscape structure of the each selected study hamlet.

2) To clarify current status of bioresource utilization and artificial material flow of each study hamlet in order to examine feasibility of restructuring to create a closed recycling system based on bioresource utilization at hamlet scale, and to evaluate sustainability of each hamlet in terms of total

nitrogen balance.

3) To examine feasibility of restructuring in order to establish a sustainable regional ecosystem based on bioresource recycling at watershed scale.

1.3. Research flow

Figure 1-3 shows research flow. More specifically, this chapter reviewed changes of rural ecosystem in the humid tropics with special reference to transformation of rural landscape in West Java, Indonesia. This was aimed at answering the question, "Why is restructuring of regional ecosystems needed?" Apart from this introductory chapter and the final chapter (Conclusion and Recommendations), this study consists of 3 parts.

Landscape structure of rural area in West Java was investigated in Chapter 2. Specifically, this chapter consisted of watershed-scale analysis and hamlet-scale analysis. Firstly, landscape structure of whole watershed area was examined in terms of relationship between land use and topographic conditions: landform, elevation, and slope. Based on landform and land-use ordination clarified by landscape structure analysis at watershed scale, 3 typical hamlets were sampled for detailed investigation of landscape structure and function. The landscape structure of each hamlet was clarified in detail and the results were used as basic information for the study of the landscape functions presented in Chapter 3.

Thus, in Chapter 3, landscape function was investigated for each hamlet focusing on bioresource production/utilization and material flow. In addition, socio-economic characteristics of each hamlet were also clarified as basic information to enhance understanding of current status of the hamlets. Bioresource analysis was conducted to evaluate the feasibility of restructuring rural ecosystems to create closed and self-sustained bioresource recycling system in terms of food, fertilizers, and livestock feeds. Material flow of each hamlet was described as component model of nitrogen flow. Sustainability in terms of nitrogen balance of total hamlets was estimated based

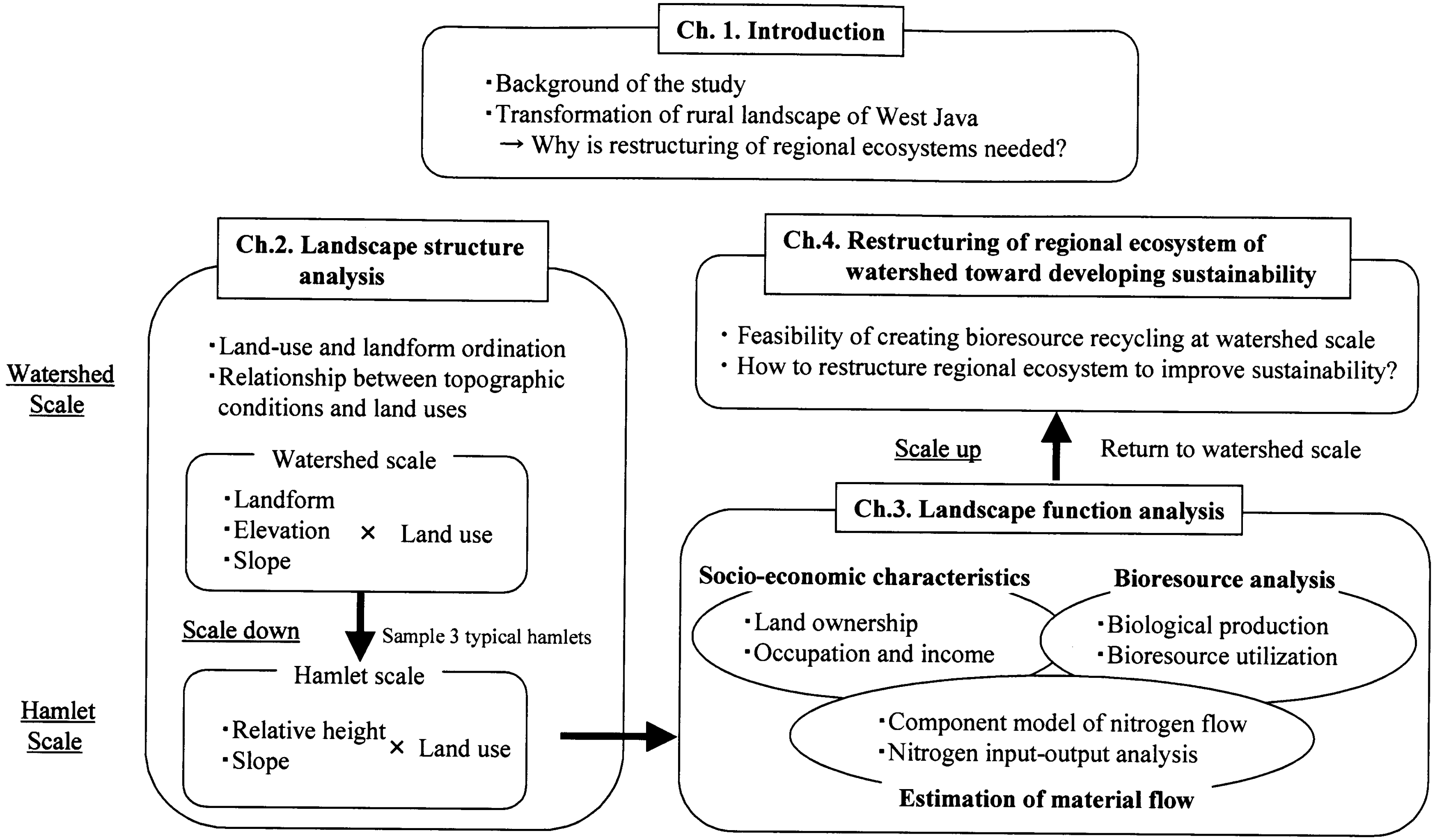

Figure 1-3. Research flow of this thesis.

on results of the investigation conducted on material flow.

Chapter 4 was based on the results of Chapter 3. It delved on the feasibility of restructuring to create closed and self-sustained bioresource recycling at watershed scale in terms of food, fertilizers, and livestock feeds, using available statistical data. Finally, the issue of restructuring regional ecosystems aimed at improving sustainability was conceptually discussed by integrating the results of all the studies.

1.4. Significance of the study

In order to achieve a sustainable regional ecosystem through restructuring, elucidation of material flow within a given regional ecosystem would be essential. This would provide important information that is needed to evaluate the current state of the regional ecosystem and the improvement that is required toward sustainability. For instance, Kobayashi and Zaitsu (2000) demonstrated the significance of material flow analysis toward sustainable development. They estimated the current status of material flow related to livestock farming system and its linkage to other sectors in the regional ecosystem. In this study, they were able to predict the future status of material flow according to several local bioresource utilization scenarios. They pointed out that this approach is important especially in developing countries whose long-maintained social systems are now in transition and are moving into an age of reformation.

Soil nutrient balance being essential part of material flow has been frequently discussed in nutrient cycle and plant nutrition researches and has been used to evaluate the sustainability of agricultural systems in relation to land degradation. De Koning *et al.* (1997) pointed out that a highly positive soil nutrient balance can result in the pollution of ground water and surface water, while a negative soil nutrient balance may lead to mining of the soil nutrient stock and to the subsequent loss of soil fertility. Some researchers have estimated soil nutrient balance in several spatial scales: supra-national scale (Stoorvogel *et al.*, 1993), sub-national scale (De Koning *et al.*, 1997), district scale (Smaling *et al.*, 1993), village, and field scale (Krogh, 1997) in Africa and South America. In addition, Smaling and Fresco (1993) not only estimated current status but also predicted the future level of soil nutrient balance according to several scenarios of future land-use changes and also to human interventions aimed to improve the present state.

For the traditional land use systems in Indonesia, both the nutrient balance and nutrient cycling were estimated through field scale surveys of home gardens (Jensen, 1993a; Jensen, 1993b) and *talun-kebun* system (Christanty *et al.*, 1997; Mailly *et al.*, 1997). Their sustainability was assessed and the factors that support such sustainability were evaluated. Though it was suggested that the spatial scale at which estimations were made is significant (Krogh, 1997), estimation of material flow or material balance at larger spatial scale has not been carried out yet in Indonesia.

The rural landscape of West Java, Indonesia is a mosaic of agroecosystems, usually consisting of several interacting components. In evaluating the bioresource recycling system, not only land uses but also human and livestock should be included because they are important components of the system that are similarly and equally playing major roles in material flows in the regional ecosystems. Thus, estimation at larger spatial scales should comprise these components. Moreover, a comprehensive framework is needed to evaluate material flow of the whole region.

Currently however, only limited studies on material flow with comprehensive and holistic scope have been conducted (Matsumoto *et al.*, 1990). A series of study in Japan (Matsumoto *et al.*, 1990; Matsumoto and Hakamata, 1994; Matsumoto *et al.*, 1995; Mishima *et al.*, 1995) have contributed to the development of methodology for the estimation of material flow especially focusing on nitrogen in rural area at regional scale using census and statistical data. This method, however, is not applicable in general for developing countries where statistical information is not sufficiently available. In such case, the data related to material flow is mainly obtained from interviews.

Several studies have estimated material flow of villages in China (e.g. Abe *et al.*, 1999; Kobayashi, 1999). Each study was focused on only one village as a representative of a human-dominated landscape of the regional ecosystem because the villages were located in remote areas. On the other hand, West Java, as mentioned previously, is densely populated. Its rural landscape is a mosaic of agroecosystems consisting of several interacting components. Moreover, the area is characterized by several bio-climatic zones along vertical section of the watershed. Thus, the single-village framework is not enough to elucidate the current status of whole regional ecosystem of this study area. Very few studies on material flow involving several villages have been conducted. An example is the study of Tripathi and Sah (2001) on material and energy flows in three villages that were characterized by typical agro-ecological situations in Himalaya. At present, however, no study covering the regional ecosystem of the watershed has been carried out yet.

In this study, landscape structure of the study area (regional ecosystem at watersheds scale) was primarily examined to extract the sample hamlets. This process is essential for selecting appropriate hamlets to represent typical rural ecosystems that show typical pattern of material flow. Subsequently, each selected hamlet having several types of land-uses, livestock and human was defined as a unit of rural ecosystem for the estimation of material flow.

In order to evaluate the rural ecosystem holistically, focus was given on "artificial" nitrogen flows due to human activities such as management of biological production system and food consumption. These artificial nitrogen flows can be easily estimated through interview.

Artificial nitrogen flow was defined as nitrogen flow due directly to human-induced material transfer processes such as fertilizing arable lands, harvesting crops, purchasing food, collecting/feeding fodder grass, exporting livestock, etc. Nitrogen flows related to soil nutrient balance as shown in a series of study (Smaling *et al.*, 1993; Smaling and Fresco, 1993; Stoorvogel *et al.*, 1993; De Koning *et al.*, 1997; Krogh, 1997) were summarized in Table 1, from which Mineral fertilizer (IN1), Organic fertilizer (IN2), Harvest products (OUT1), and Removed crop residues (OUT2) were taken into account in this study as artificial nitrogen flows to/from the land-use components. Natural processes of nitrogen flow (atmospheric deposition,

Table 1-1. Processes and its magnitude of nitrogen flows

Process			Type[a]	Magnitude of nitrogen flows[b] (kg N $year^{-1}$ ha^{-1})
Inputs				
	Artificial	IN1	Mineral fertilizer	0 - 30 (95[c])
		IN2	Organic fertilizer	0 - 40
	Natural	IN3	Atmospheric deposition	0 - 10
		IN4	Biological N fixation	0 - 20
		IN5	Sedimentation	0 - 4
Outputs				
	Artificial	OUT1	Harvest products	0 - 80
		OUT2	Removed crop residues	0 - 20
	Natural	OUT3	Leaching	0 - 40
		OUT4	Gaseous losses	0 - 30
		OUT5	Erosion	0 - 40

[a] After Smaling (1993, cited in De Koning , 1997)

[b] Summarized from Stroorvogel *et al.* (1993), Smaling *et al*. (1993), Jensen (1993), De Koning *et al.* (1997), Krogh (1997), and Mailly *et al.* (1997)

[c] Average mineral fertilizer input to arable lands in Indonesia in 2000 based on the data from FAOSTAT (URL: http://apps.fao.org)

IN3; biological fixation, IN4; sedimentation, IN5; leaching, OUT3; gaseous losses, OUT4; and erosion, OUT5) are also important. Nevertheless, an approach taking into account only the artificial nitrogen flows would provide significant insight, since generally, artificial nitrogen inputs (IN1 and IN2) in agricultural lands play major role more than that of the natural process in terms of quantity of nitrogen (Table 1). Moreover, nitrogen losses due to OUT3 and OUT4 from agricultural lands are closely related to nitrogen input through fertilizing (IN1 and IN2). For instance, (IN1+IN2) was used as an important parameter in the transfer function for calculating OUT3 and OUT4 (Stoorvogel *et al.*, 1993; Smaling *et al.,* 1993; De Koning, 1997). In addition, nitrogen losses from paddy fields are generally described as percentage of nitrogen input through fertilizers (e.g. Buresh *et al*., 1991; De Datta, 1995). Nitrogen output through erosion (OUT5) is important only where soil erosion occurs frequently, and often omitted from consideration (e.g. Jensen, 1993; Mailly *et* *al*., 1997). No obvious signs of erosion were observed in the study hamlets. Thus, we would be able to guess OUT3 and OUT4 indirectly from artificial nitrogen flows to a certain extent.

The results of the study provides significant contribution toward restructuring for sustainable regional ecosystems through understanding and assessing the present status of the regional ecosystem holistically in terms of material flow. Likewise, information generated by predicting future status of the regional ecosystems according to several scenarios of bioresource utilization would provide useful insights for regional and local planning to establish sound material cycling systems. In addition, the methodology applied in this study would be powerful tool for assessment of the regional ecosystems especially in developing countries.

Chapter 2
Landscape structure analysis of the study area

2.1. Introduction

It is primarily important to understand landscape structure of a given area before looking at the sustainability of the regional ecosystem since the functions of the landscape are closely related to its structure. Moreover, assessment of the natural conditions of the land is essential in the implementation of sustainable land use, especially in humid tropics where soil erosion occurs frequently due to heavy rain.

In this chapter, land conditions and land uses and their relationships were investigated as factors to determine landscape structure. The objective of this chapter is to specifically clarify the landscape structure of rural area in West Java, Indonesia. First, the landform- and land-use-ordination were examined and the relationships between land conditions and land uses at watershed scale were analyzed. Second, 3 typical rural hamlets were sampled and field surveys were conducted to clarify more detailed landscape structure at hamlet scale.

2.2. Landscape structure at watershed scale

2.2.1. Study area

The study was carried out in the Cianjur-Cisokan watershed in West Java (Figure. 2-1). The Cianjur and Cisokan rivers are tributaries of the Citarum River, which has the largest catchment area (6,000 km^2) in Wes Java Province. The Cianjur-Cisokan watershed is situated in the middle part of the Citarum drainage basin on the east-facing slope of Mount Gede (2,958 m), which is an active stratovolcano with a broad footslope formed by a volcanic debris flow ("lahar") (Figure 2-2). The elevation of the study area ranges from 200 to 2,500 m. The Tertiary hills north of the

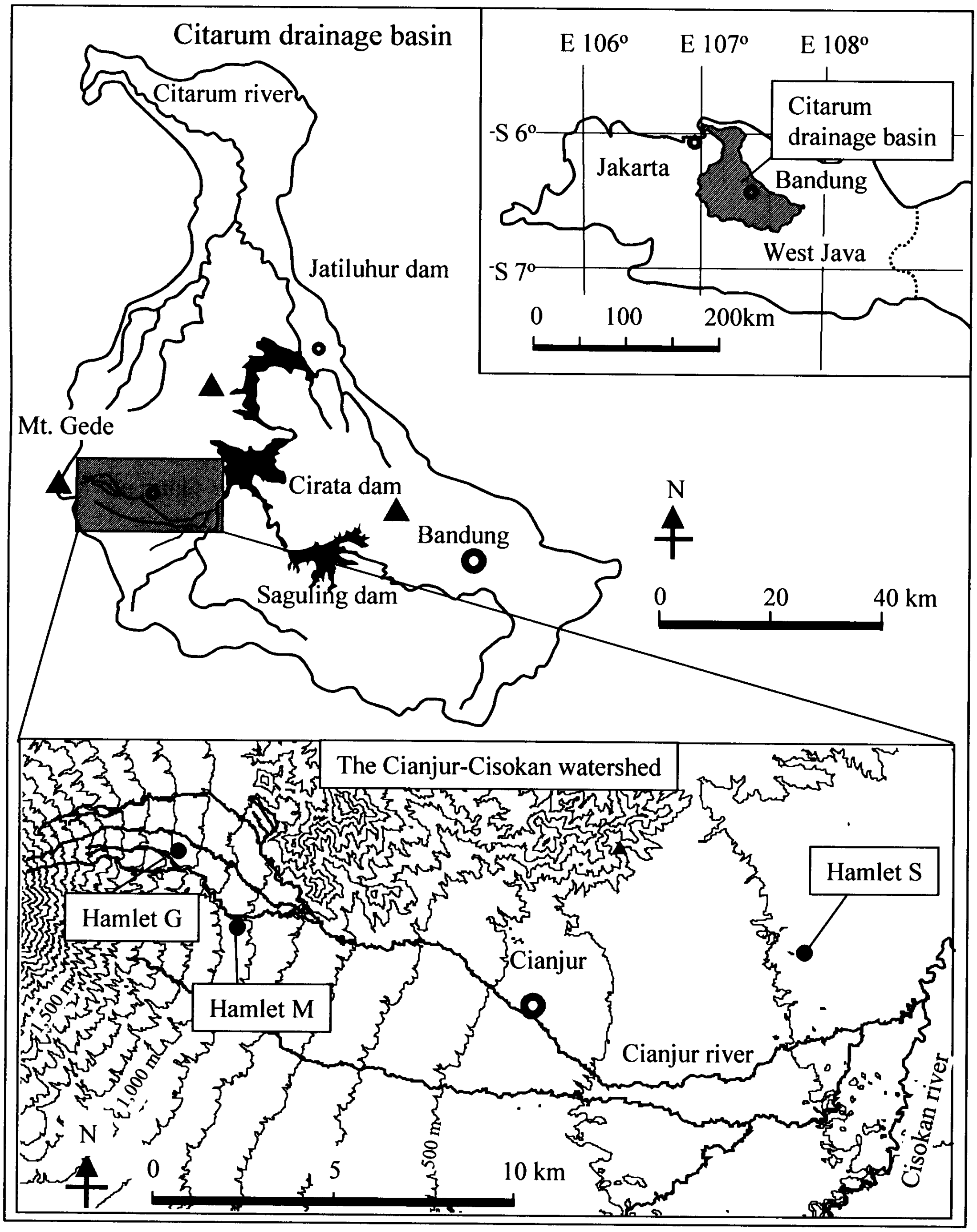

Figure 2-1. Map of the study area.

Cianjur River (Figure 2-2) were excluded from the analysis.

The Cianjur-Cisokan watershed is a typical rural landscape of the volcanic footslopes that are frequently found in Java (see Fig. 2-7). The landscape of the study area contains areas of both estate agriculture and farm agriculture. A vast tea plantation is located on the side of Mt. Gede. Upland fields are dominant on the upper part, and paddy fields on the lower part, of the volcanic footslope. Cianjur City, a major urban center with a population of 140,000, is located in the central part of the watershed. The study area is experiencing rapid population growth. For instance, the population of the 8 counties (*Kecamatan*) included in Figure 2-1 increased by 20% between 1992 and 2000. This is a typical example of an area that is experiencing rapid urbanization and land development more particularly for resort villas because it is easily accessible from the big cities of Jakarta and Bandung by a highway running through the area.

2.2.2. Materials and methods

The land conditions, landform classification, elevation, and slope were considered in conjunction with the land-use data. A landform classification map and a land-use map were prepared as vector format GIS data, and subsequently were converted into raster format data to facilitate statistical analysis through an overlay process. All these raster-format GIS data have 279 rows and 554 columns with a cell size of 50 m × 50 m. Digitizing and data conversion process were conducted using a GIS-software package (ESRI-ArcInfo ver.8.0.2). Description of data source and data-preparation process are stated as follows:

(1) Landform classification map

The landform classification map of Tamura and Kitamura (2001) was partly revised and supplemented by additional data. Landform units were determined by interpretation of aerial photographs with a scale of 1: 50,000 taken by the National Coordination Agency for Surveys and Mapping (*BAKOSURTANAL*) in 1993 (sheet

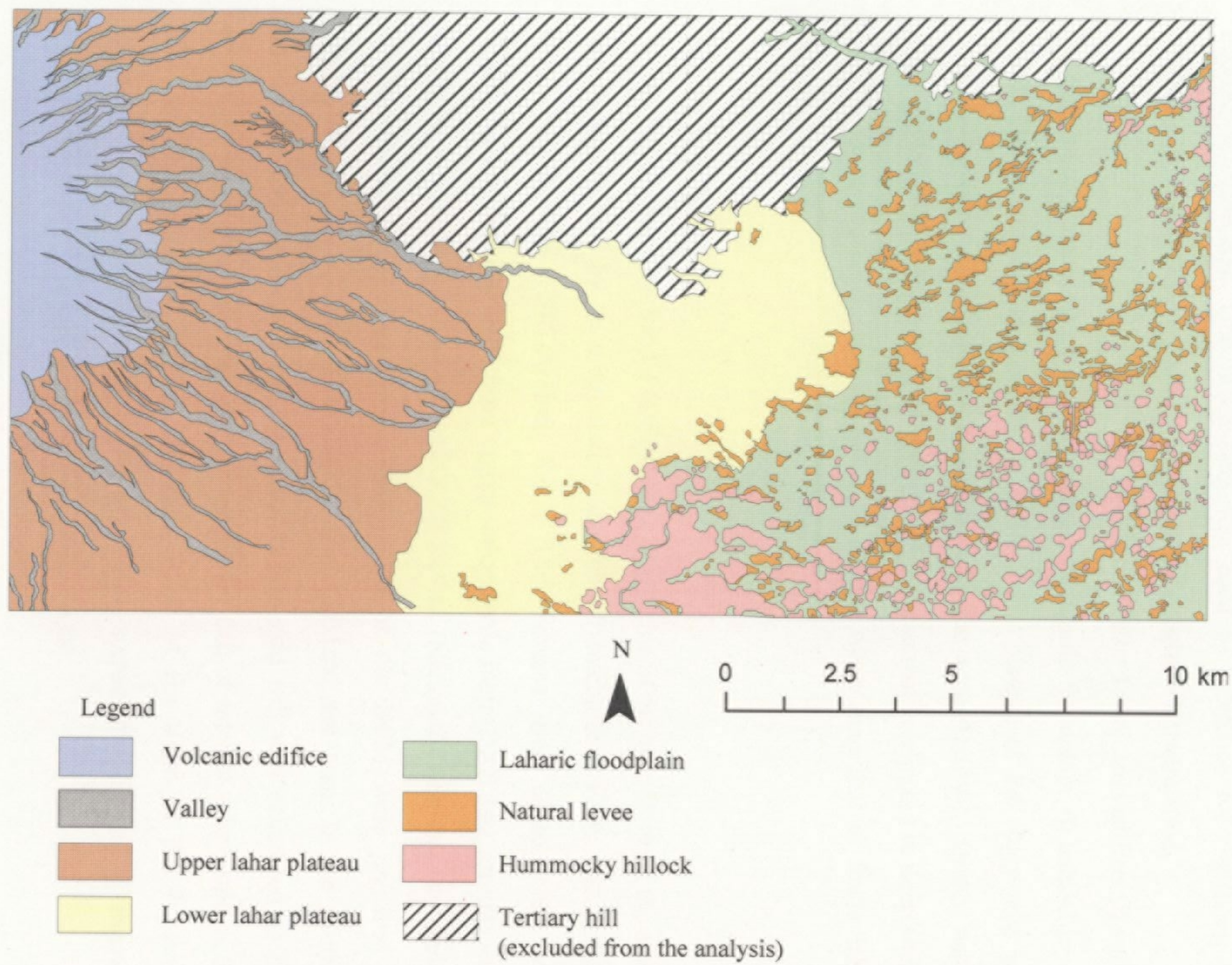

Figure 2-2. Landform classification map of the study area.

no.: NY28W13, 8-14; NY37W12, 23-28).

Geo-coded images of scanned 13 aerial-photographs after geometric correction process (polynomial, 2nd order) were put together by mosaicking process using ERDAS-Imagine 8.4. This image-data was used as reference for digitizing the boundary of landform classification over aerial photograph interpretation.

The study area was classified into 7 landform units: 1) volcanic edifice, 2) valley, 3) upper lahar plateau, 4) lower lahar plateau, 5) laharic floodplain, 6) natural levee, and 7) hummocky hillock (Figure. 2-2). The lahar plateau of the study area was divided into upper and lower parts according to the accessibility to stream water. Agricultural land on the surface of upper lahar plateau that is adjacent to deep valley (30-100 m in depth) is less accessible to stream water than that of lower lahar plateau.

(2) Elevation and slope

A Digital Elevation Model (DEM) with a cell size of 50 m × 50 m of the study area was generated by an interpolation algorithm (Hutchinson, 1988; Hutchinson, 1999) provided by ESRI-ArcInfo 8.0.2. This process used contour line and elevation-point data extracted from digital topographic map (DXF data format) with a scale of 1: 25,000 provided by *BAKOSURTANAL* (National Coordination Agency for Surveys and Mapping, 1999). Grid points of the DEM were prepared to correspond to that of land classification map and land use map. In the overlay process with other spatial data, the value of the grid cell was calculated as the average value of the 4 grid points surrounding the cell of interest. The slope of the grid cell was calculated as the maximum value of the slope of the 4 planes determined by 3 points sampled from 4 grid points surrounding the cell of interest. For instance, slope of "plane 1" (Figure 2-3) is given as:

$$S = (S_x^2 + S_y^2)^{1/2}$$

where

S = Slope calculated for the plane of interest,

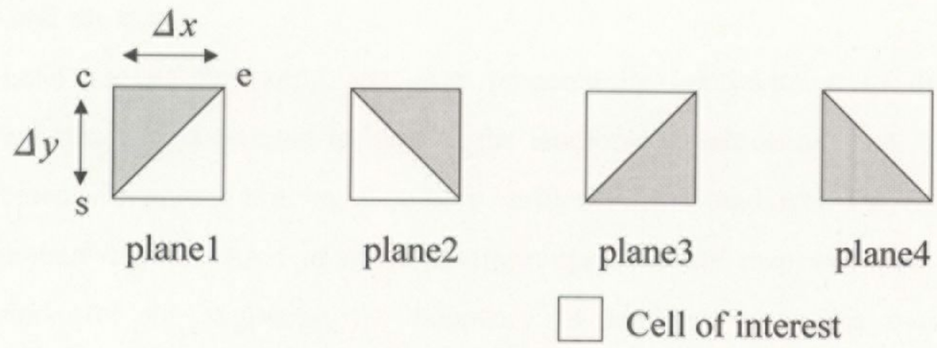

Figure 2-3. Calculation of slope.

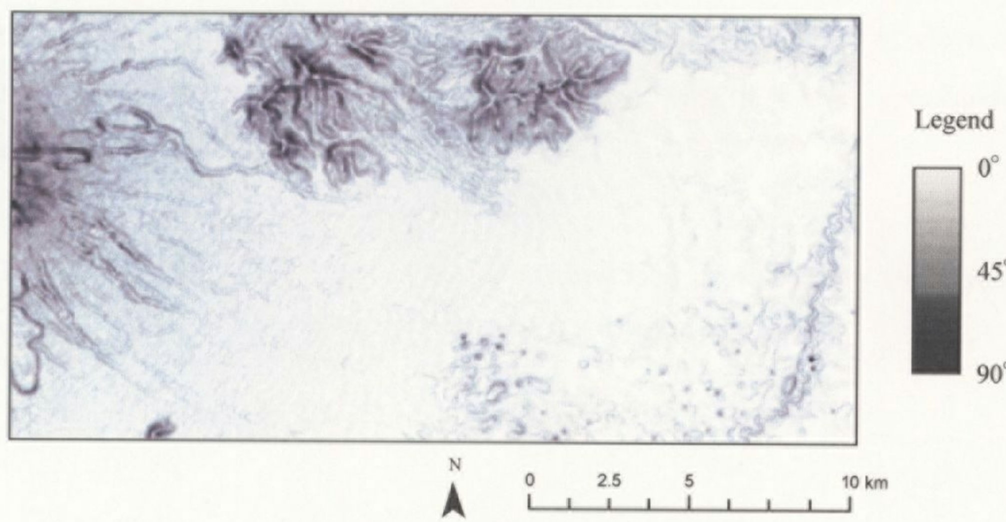

Figure 2-4. Slope map of the study area.

$S_x = (Z_e - Z_c) / \Delta x$,

$S_y = (Z_s - Z_c) / \Delta y$,

Z_i = elevation of the grid point i,

Δx = grid interval (east-west), and

Δy = grid interval (north-south).

In this study, $\Delta x = \Delta y = 50$ m. The value of slope was converted to degree. A slope map of the study area is shown in Figure 2-4.

(3) Land use map

Land use of the study area was prepared by interpretation of the aerial photographs that were used in making the landform classification map. This was combined with ground truthing in order to verify the actual land uses. The Geo-coded image-data that was used to make landform classification map was also used as reference for the digitizing the boundary of land-use categories over aerial photograph interpretation. Land uses of the study area (Figure 2-5) were classified into 8 categories: 1) forest, 2) agroforestry, 3) tea plantation, 4) upland field, 5) paddy field, 6) residential area, 7) river, and 8)others. "Agroforestry" includes mixed gardens (*Kebun Campuran*) and intermediate land-use types composed of clove or rubber plantations and tea plantations or upland fields. "Others" include grasslands, bare lands, and stopes.

Three-dimensional (3D) maps of landforms and land uses made by overlaying them with DEM were shown in Figure 2-6 and Figure 2-7, respectively.

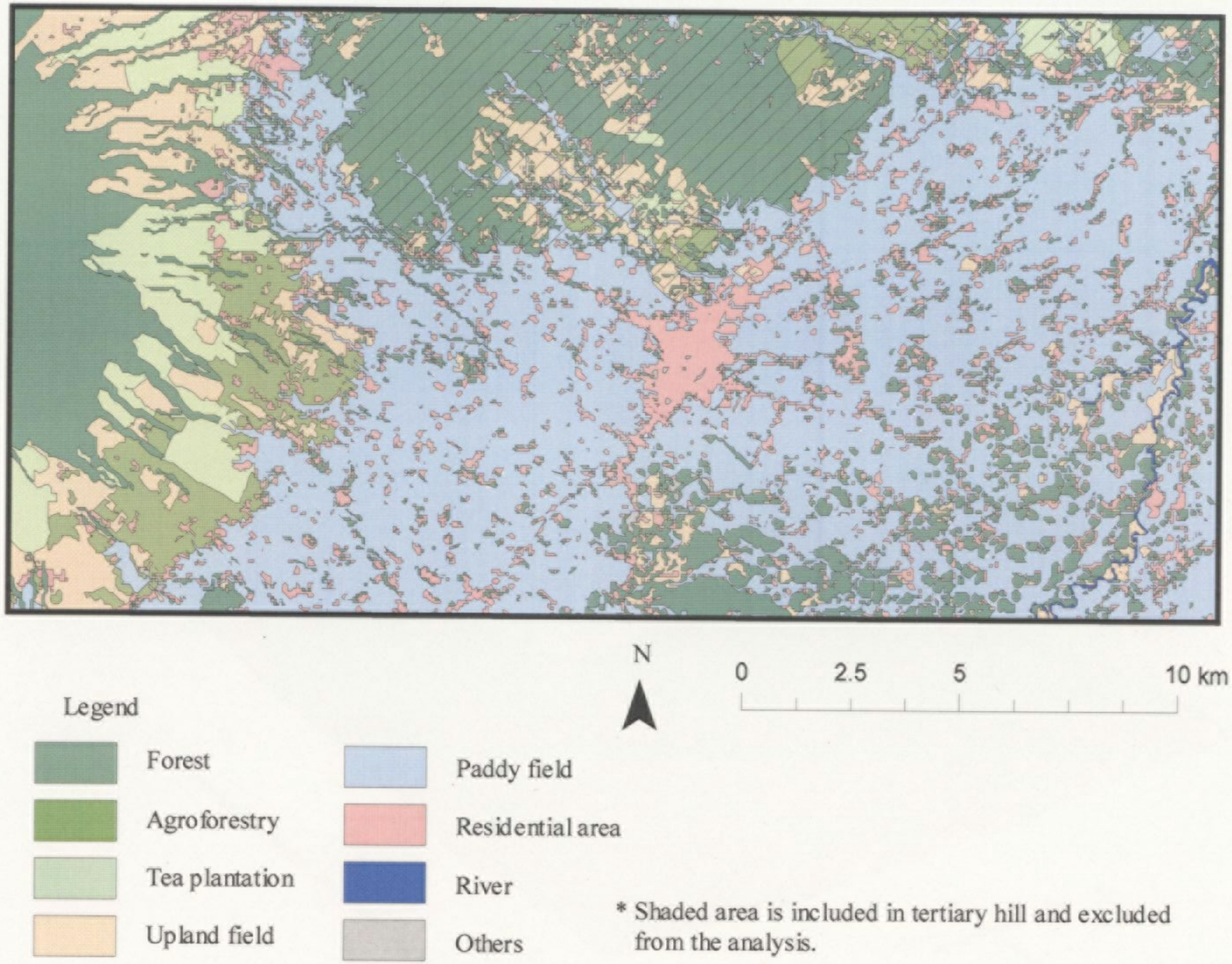

Figure 2-5. Land-use map of the study area.

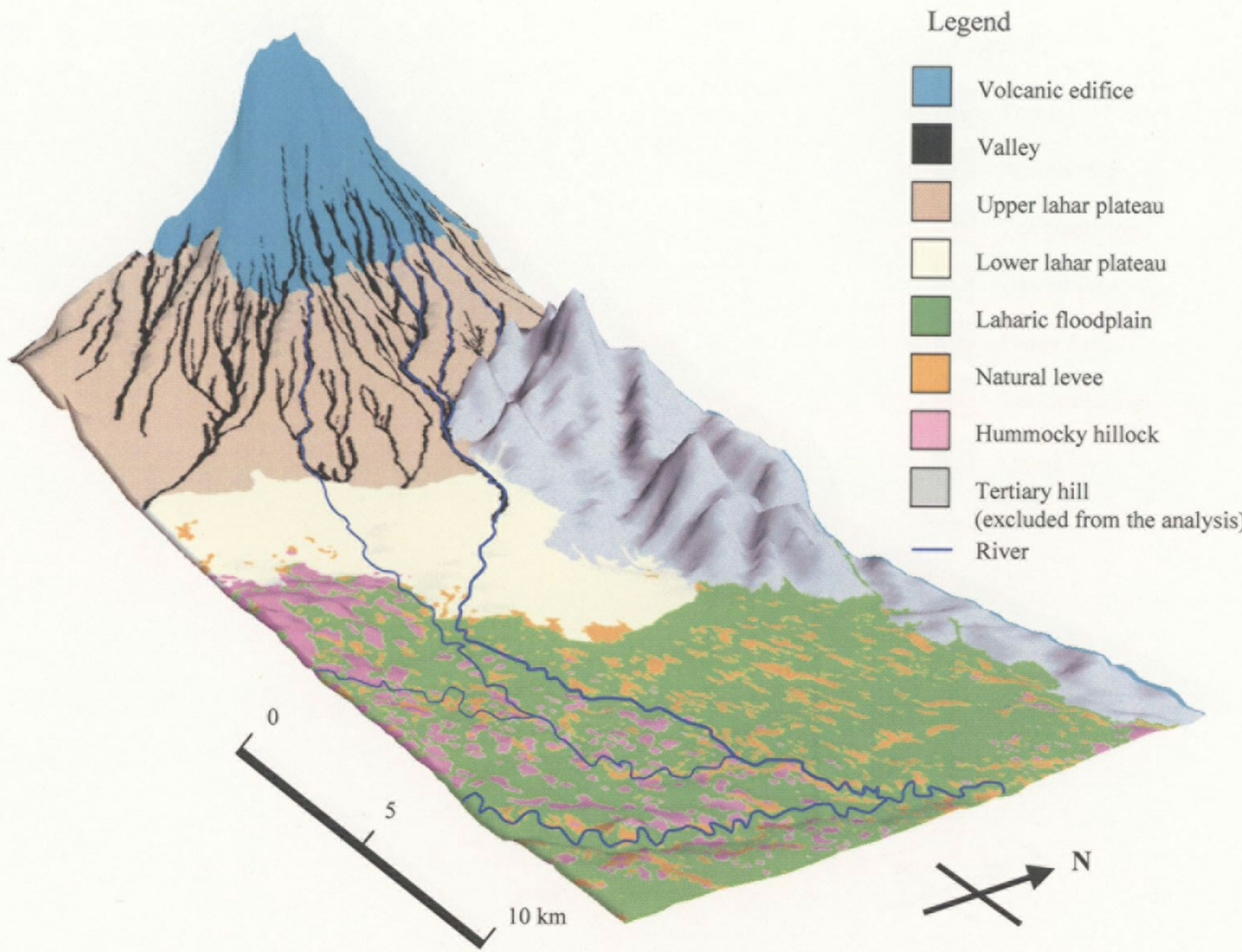

Figure 2-6 . 3D landform classification map of the study area.

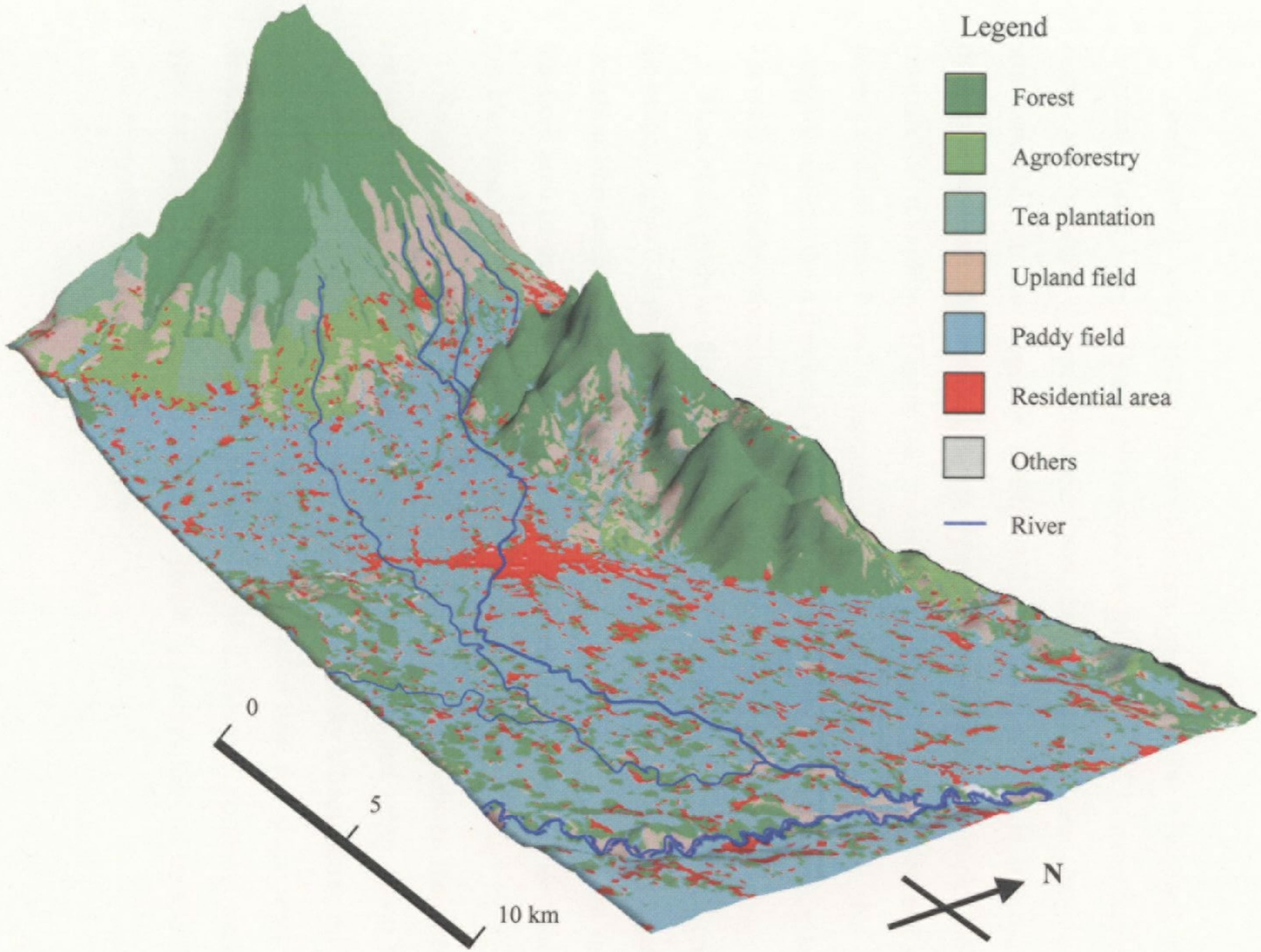

Figure 2-7 . 3D land-use map of the study area.