Measuring sustainability for rural settlement development: Environmental balance assessment based on the ecological footprint

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Abstract

Rural areas support urban areas by preserving natural environments such as forests and agricultural food product. However, because of urbanization after the high-growth period, the ecological balance has deteriorated because of land development, abandonment of cultivation, automobile dependency, etc. This study assessed an improved method to calculate the Ecological Footprint (EF) value, which assigns a rating for environmental balance in rural areas. Residents' consumption is calculated based on the environment load (cultivation, CO_2 emission, etc.) that residents generate during daily life activities. A case study of Tsukuba city in Ibaraki prefecture reveals a wide distribution of traditional settlements for which this system can determine the environmental balance. Those analyses show that: 1) environmental productivity and consumption capacity differed greatly according to the advancement of urban development; 2) only a few settlements, located in forested areas, are ecologically balanced.

Introduction

At the Rio Summit held in 1992, many countries discussed issues related to the environment. In 2012, the United Nations Conference on Sustainable Development (Rio+20) was also held in Rio as a 20-year follow-up to the 1992 Rio Summit. An astonishing finding was that, 20 years after the Rio Earth summit, the environment of the planet has become worse, not better, according to a report from WWF (LPR, 2008), meaning that the balance of the environment has been disrupted.

However, residents in old Japan predominantly based their life and production operations in settlements: basic units of certain residents formed of communities constituting society. Residents subsist through mutual cooperation in their settlements or with surrounding settlements (NRPB, 2009). Before modernization, residents had a recycling life with a low impact on the environment in those settlements and possessed more natural resources than we do. Also, the settlements absorb wastes from the surrounding urban areas and provide resources to them with the forests, rivers, soils and various species. However, along with urbanization during and after the high-growth period, environmental balance has collapsed in those settlements. Although many green and environmental resources are apparent in the rural settlements, environmental problems are increasing because of land development, abandonment of cultivation, automobile dependence, and other factors. In order to retrieve the balance, it is important for not only the government or corporation, but also the general residents to change their daily lifestyle to benefit the environment. As a first step to actually perform the changing, understanding the actual conditions in a simple way is imminent. Therefore, it is necessary to measure that how much environmental consumption can be accepted, and how much environmental consumption is actually required in each settlement. In other words, a simple tool for evaluating the balance in the immediately residents' consumption and environmental capacity is needed.

In addition, attempts to calculate the environmental balance at a macro scale, such as that between nations or metropolises, have been document in the later reviews. There is no problem to take balance in such macro scale area. On the other hand, the residents' consumption and associated environmental load differed in settlements or neighborhoods, which is the micro scale, a scope that directly related to the residents' life and reflect the differences in consuming patterns. In this paper, settlement is used as the local scale.

As a tool to assess the balance of environment, the ecological footprint indicator (EF indicator) quantifies environmental impact of human activities. The EF indicator was developed by Wackernagel and Rees in the early 1990s. It has been applied since by many researchers. As explained by its creators, the "ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area" (Wackernagel and Rees, 1996). As a measure of carrying capacity, the EF indicator provides an unambiguous standard for quantifying sustainability: sustainable communities are those for which the area of land consumed in the production of resources and assimilation of wastes is less than or equal to the total available land area.

This study assessed an improved method to calculate the EF value, which assigns a rating for environmental balance in settlement in rural areas. Residents' consumption is calculated based on the environmental load (cultivation, CO_2 emissions, etc.) that residents generate during daily life activities. Simultaneously this study defines a bio-capacity (BC value) that quantifies the environmental consumption capacity of cropland, forestland, and pastureland. The level of environmental balance is reveal by combining the two values.

Moreover, it is considered that more commonly new settlements nearby the urban areas are unsustainable, and the policies towards urban areas are more valid. However, this assessment tool does not deny the application in other areas, where the environmental balance is considered to be extremely biased value, too high EF value in the built-up area and too high BC value in the mountains area. Although the policies towards urban areas preserving green field and avoiding soil consumption, such as urban regeneration and use of brownfields, these measure changes insignificant in EF and BC value. In order to facilitate comparison and understanding the environmental balance, this paper specifically examined the settlements located between the built-up areas and the mountain areas where the balance changes sensitively by counter-measures. As an effort toward establishing a sustainable society, the first and realistic measure is to set settlements located in rural areas, not urban area, as a target to improve environmental balance.

Previous study

The EF indicator measures the space needed to provide the resources and absorb the waste that comes with our model of life for one year (Wackernagel and Rees, 1996). Calculation of the ecological footprint can be adapted to a given population—a household, a district, a city, a region or humanity as a whole—the area of biologically productive land and sea necessary to produce the renewable resources this population consumes and assimilate the waste it generates, using prevailing technology. In other words, EF indicates the extent to which human economies stay within the regenerative capacity of the biosphere (Wackernagel et al, 2006). Since the EF indicator was introduced, many researchers have improved the method (Aronsson and Lofgren, 2010). In a macro scale, the EF value and BC value have been calculated for 150 countries at a national level by the WWF (LPR, 2008) for each given year, and for cities all over the world at regional level (BFF, 2004; Regional Progress, 2014). The EF indicator has been used as a proactive approach in England, such as environmental evaluation of project and tourism (Barrett et al, 2002; Collins et al, 2007). In Japan, the EF value has been calculated (Fukuda et al, 2001; Wada, 1995) and the Ministry of the Environment provides the EF indicator as an assessment of progress into the Basic Environmental Plan (EBP, 2006). Governments also introduced the indicator in the Regional Environmental Plan (NOEBP, 2008). In addition, as a part with the highest percentage of EF value, the EF of vehicle travel was estimated for future years (Chi and Stone, 2005).

Recently, several studies have specifically addressed issues of disproportionate share of resources and the relation between economy and resource consumption through international trade (Duro and Figueras, 2013). Furthermore, studies have shown how large of an EF a given country exerts inside the borders of its trading partners (Kissinger and Gottlieb, 2010). Studies have used the ecological footprint to analyze the relation between the urban model (size of settlement, density, etc.) and ecological footprint (Moos et al, 2006). The EF applications described in reports of the literature are growing in number and diversity, such as explorations and the determinants of the ecological footprint of commuting municipal variation by comparing urban form and transportation, or environmental load reduction by technological innovation and lifestyle improvement (Muniz et al, 2013; Brown et al, 2008). For land-use policies, land-use zoning with the guidance of EF and other ecological evaluations have been applied to form and optimize the proper land use and ordered development pattern (Yong et al, 2010). Moreover, a mechanism for securing financial resources based on an interregional cap and trade system, and a concept of environmental balanced area to devote environment management of local government using EF has been developed (Ujihara and Taniguchi, 2010; Chen et al, 2013).

There is also study from the perspective of residents' life in a microscale. The influences of type and location of settlements have been addressed (Poom et al, 2014), but the method cannot be applied to other regions because the target is 16 or 17 year-old high school students by means of a questionnaire.

However, EF has also received a considerable amount of criticism concerning the assumptions underlying the methodology (McManus and Haughton, 2006; Bergh and Grazi, 2010). The ongoing debate has helped to improve the methodology continuously (Kitzes et al, 2009) while retaining its strengths to detect net effects due to the aggregate approach. Also, this method provides an easy understandable tool for resident by combining the environmental load of different types of final consumption into a single-value. Moreover, by improving the calculation, the EF can more accurately represent the resident's consumption, which is considered to depend on the settlement type and location (Brown et al, 2009).

Compared to the previous studies, the present study accomplishes the following.

1) This study addresses that the environmental load and capacity are differed by the type and location of settlements, and proposes a convenient method for residents to assess the environmental balance in a microscale for the local in which they live. This method can be used as residents' self-evaluation, and assist communication in regional and environmental planning.
2) This paper presents a readily useful method to grasp the environmental balance by comprehending the EF indicator and bio-capacity (BC), which generalizes the total capacity for resource consumption and absorbing the waste. Environmental policy effects of both environmental load and consumption capacity can be shown by this method.
3) Moreover, the settlement is the optimum approach to examine the method for estimating the environmental balance on a micro-scale. The character of the EF and BC indicator can be clearer in the settlements, where the balance changes sensitively. While there is too high EF value in the built-up area and too high BC value in the mountains area.
4) Calculation of EF is based on Statistics Bureau data and other official data, which possesses high reliability and applicability to other areas. In addition, detailed data at a microscale are useful for detailed discussion of the EF and BC values.

Case study

This study uses a case study approach in Tsukuba city. Tsukuba city, with a population of 0.2 million, is located in Ibaraki Prefecture, Japan. Although urbanization has increased rapidly in Tsukuba, there are numerous traditional settlements existing in the suburb area. Figure 1 presents the target region location. Figure 2 shows the positional relationship of settlements and six areas and Tsukuba science city area in Tsukuba city. The six areas are used to be six cities, and administrative merged into Tsukuba city from 1995. Tsukuba Science City area is a planned area developed in the 1960s, shows a different character with the others.

Figure 3 shows the detail land use, which are drawn up from the 100 meters mesh data from the Digital National Land Information (MDN, 2009). Figure 3-(a) shows that the forestland and cropland are mostly located in the north part. Grazing land is not shown in this figure because there is few grazing land to be counted in the 100 meters mesh map. On the other hands, figure 3-(b) shows that the urban area's facilities and buildings near and in Tsukuba Science City area have been developed sequentially from the 1960s through development of Tsukuba Science City. Tsukuba Science City area has been almost rebuilt in to commercial facilities or research institutes and few natural lands remained. Figure 3-(c) presents the river and lake land, and other land use. Moreover, in order to get an image of these areas, figure 4-(a) and 4-(b) show two photo of Tsukuba Science City area, while figure 4-(c) shows a photo of Yatabe area, and 4-(d) show an airborne photo of Tsukuba area.

The object of this study is settlements in Tsukuba city, including both the traditional settlements and indirect impact of urban development received in a region. The settlement is where residents predominantly based their life and practiced agriculture and forestry from the olden times. It is different from the city in a more limited sense, especially where is built-up and developed. In this study, the settlement is where geographic name and residents existed from 1925 (the most old map in the 'Change of Tsukuba from Maps'). This study documented all 271 settlements in Tsukuba city and confirmed the territories of each settlement using 'Change of Tsukuba from Maps' (JMS, 1996), and adopts the oaza (settlement section) as the territory because it corresponds to land use data from Urban Panning Baseline Survey. In figure 2, Oazas with settlement are presented by gray, and those with no settlement are shown in grid line.

Calculation of the EF value

Many related researches have specifically addressed issues of international trade, the consumption of a whole nation, or specific products (Duro, 2013; Kissinger, 2010; Muniz, 2013). Those are all important for raising better understanding of the load on the environment. However, this study majorly emphasized the consumption of the daily life from the residents, because the scale is local. The residents' consumption is calculated using this tool based on the environmental load generated during the daily life activities of residents. Other activities, such as industry, business, service, and travel are not included. Even the BC is greater than the EF value in a settlement. It does not mean that the entire environmental load was absorbed inside the area. Although the EF value is less counted in this study, it shows the unbalance in each settlements and provide a self–assessment for the residents.

This study quantifies environmental loads existing inside the settlements by calculating the EF value. The EF value components were referred from the Ujihara–Taniguchi Model (EF-Calc) (Ujihara et al, 2010), and comprises the following components linked to land-use planning. These components were referred from the compound EF methodology developed by Wackernagel and Rees (Wackernagel and Rees, 1996). However the features of the settlements cannot be clarified by the former methods, so an improve calculation is proposed for application on a settlement scale. The improved calculation is shown in parameters (2)-(11).

(1) Cropland footprint: cropland necessary to grow crops for food and feed
(2) Grazing land footprint: grazing land necessary to graze animals for meat and milk
(3) Forestland footprint: forestland necessary to obtain materials for use in paper production
(4) Built-up land footprint: built-up land necessary to conduct urban activities
(5) Energy footprint: forestland needed to absorb CO_2 from fossil fuels for household and private transport use

The *EF* value is calculated as shown below.

$$EF^k = \sum EF_i^k \tag{1}$$

That equation uses the following variables and notation.
EF^k: EF value of settlement k (ha)
EF_i^k: EF value of component i in settlement k (ha)
k: settlement
i: component

First, for components (1)–(3), age-based population in each settlement (JNPC, 2010) was used to calculate cropland, grazing and forestland for paper with the aid of the UT model. The consumption of each crop in cropland footprint was using the average value of the prefecture, while those in grazing land footprint was using average value of Japan. The calculation formulas are defined as shown below.

(1) and (2): Cropland and grazing land footprint

$$F_j^k = \sum_{n=1}^{10} p_n^k \times f_{nj} \tag{2}$$

$$EF_{fg}^{k} = \sum_{j=1}^{10} \frac{F_j^k}{\alpha_j} \tag{3}$$

F_j^k: consumption of crop j in settlement k (t)

p_n^k: population of age bracket in settlement k (person)

f_{nj}: consumption of crop j in age bracket n (t/person)

α_j : land productivity of crop j (t/ha)

(3) Forestland footprint

$$EF_p^k = \frac{p_n^k}{p} \times r \times \sum_{m=1}^{3} \frac{w_m}{\beta_m} \tag{4}$$

w_m : wood pulp and chip demanded for import m (m^3)

β_m : growing stock amount of forest of each destination for import m (m^3/ha)

p: population in Japan (person)

r: rate of household consumption (%)

Then, improved parameters of components (4)–(5) are used. Component (4) stands for infrastructure for housing, transportation, and industrial land. This study calculates built-up land in each settlement using land-use database from Urban Panning Baseline Survey 2010 of Tsukuba (BUPS, 2010). This space of all built-up land use types, including residential land, commercial land, industrial land, common land, railway land roads, etc., is documented. The urban green zone lands are included in the built-up land, and considered as plentiful carbon sinks. However, the BC value changes less whether count the urban green zone lands or not.

The energy footprint is calculated by estimating the biologically productive area necessary to assimilate CO_2 produced by human economic activities. It consists mostly of the EF value. To analyze the energy footprint more accurately, this footprint can be divided into three sectors: consumer residential, consumer transport, and international transport. The method used to calculate the three sectors improved by the authors was shown below because the UT model was unable to give additional information to generate the characters of these respective sectors.

(4) Built-up land footprint

$$EF_b^k = \sum_{i=1}^{3} b_i^k \tag{5}$$

b_i^k : Built-up land use i in settlement k (ha)

(5) Energy footprint

(5)-1 Consumer residential sector

$$EF_h^k = \sum_{x=1}^{2}\sum_{y=1}^{4}\frac{P_x^k \times C_{xy}^k}{\gamma} \quad (6)$$

$$\mathrm{C}_{xy}^{\mathrm{k}} = \delta^{ci} \times E_{xy}^{ci} \quad (7)$$

$C_{xy}{}^{k}$: CO_2 emissions, type *y* of houses and size x of households in settlement *k* (ton)

$P_x{}^{k}$: population, size *x* of households (person)

γ: Absorption efficiency of CO_2 (*t*-CO_2/ha)

δ^{ci}: CO_2 conversion factor of energy ci (*t*-CO_2/kWh)/ (*t*-CO_2/m^3)/ (*t*-CO_2/L)

E_{xy}^{ci}: consumption of each energy use, type *y* of houses and size x of households in settlement *k* (kWh/m^3/L)

x: 4 sections by national population census (single-person, two-person, three-person, more than four-person)

y: 2 sections (detached house, cluster house)

ci: 3 sections (electricity, gas, heating oil)

(5)-2 Consumer transport sector

$$EF_t^k = \frac{p_n^k}{p}\sum\frac{P_y^k \times C^k \times k_c \times (t/T)}{\gamma} \quad (8)$$

C^k: automobile fuel consumption in settlement *k* (CC/person)

k_c: conversion factor

t: hours of automobile per person per zone (16 zones divided by Tokyo Metropolitan Person Trip Survey)

T: hours of automobile per person in Tsukuba

(5)-3 Cargo transport sector

$$EF_T^k = \frac{p_n^k}{p}\sum U_{CO_2(k)} \times k_c \times (WS_{Gj}^{Ci} \times LS + WA_{Gj}^{Ci} \times LA) \quad (9)$$

$$\mathrm{LS} = \sum_1^3 \frac{WS_{Gj}^{Ci}}{\sum_1^3 WS_{Gj}^{Ci}} \times LS^C i \quad (10)$$

$$\mathrm{LA} = \sum_1^3 \frac{WA_{Gj}^{Ci}}{\sum_1^3 WA_{Gj}^{Ci}} \times LA^{Ci} \quad (11)$$

$U_{CO2(k)}$: CO_2 emissions intensity of transport method *k* (g-CO_2/ton·km)

W: traffic volume (ton)

WS_{Gj}^{Ci}: traffic volume of good j by ship from importing country Ci (ton)

WA_{Gj}^{Ci}: traffic volume of good j by air from country Ci (ton)

LA^C: transport length by air from country C (km), country

LS^C: transport length by ship from country C (km)

Ci: importing country range by the traffic volume

1) For the consumer residential sector, population per house and population per family of each settlement were used, based on the database of national population census: sub-region survey (JNPC, 2010). Furthermore, the energy from this sector is calculated using the average energy consumption volume of the eastern Japan area, published in 'Aim of the Nation Action for the achievement of reduction promise of the Kyoto Protocol' by the Ministry of Economy, Trade & Industry (METI, 2010).
2) For the consumer transport sector, land needed for absorbing CO_2 emissions is calculated first based on average gasoline purchases per family per year in the eastern Japan area, as derived from the Family Income and Expenditure Survey from the Ministry of Internal Affairs and Communication (FIES, 2010). Then, allocate this land to each settlement based on hours of automobile per zone, which is recorded in the Tokyo Metropolitan Person Trip Survey 2009 (TMPTS, 2009). The 271 settlements are divided into 16 zones in the TMPTS.
3) For the cargo transport sector, it is using the average value of Japan. Moreover, it only figures land needed for CO_2 emissions from transportation of goods between international trades, which affects this sector much more than internal trade does. CO_2 emissions of this sector are calculated by multiplying CO_2 emissions intensity on traffic volume and transport length. Traffic volume is calculated based on trade statistics (Ministry of Finance) (Trade Statistics, 2010), and transport length is based on airline mileage (AAXSMARINE, 2014) and sea mileage (MC, 2014).

In analysis using the configuration presented above, the environmental load and environmental balance can be quantified and applied easily to other cities. This method demonstrates most of the data available by local government.

Calculation of the BC value

Bio-capacity (BC) refers to the capacity of an area to provide resources and absorb wastes of each component in EF (such as productive land for farmland). Therefore, corresponding to the five components in EF, BC quantified the land for environmental load in a settlement. The formula is defined as presented below.

This study calculates the BC value using a land-use database from the Urban Planning Baseline Survey 2010 of Tsukuba. This space documented all land use types in settlements, including built-up land use, which stands for land to absorb the built-up land.

$$BC^k = bc_{fm}^k + bc_f^k + bc_g^k + bc_b^k \quad (12)$$

BC^k: bio-capacity in settlement k (ha)

bc_{fm}^k: cropland area in settlement k (ha)

bc_f^k: forestland area in settlement k (ha)

bc_g^k: grazing land area in settlement k (ha)

bc_b^k: built-up land area in settlement k (ha)

How to measure the environmental balance

For this study, r is defined as the environmental excess ratio based on the EF value associated with residents' consumption. The environmental balance in each area, which signifies how much the environmental load overshoots the consumption capacity, is evaluated using r. A settlement with an r value lower than 1.0 means that this settlement takes the burden of environmental load from the outside. The environmental load excess ratio in settlement "k" (r^k) is defined as presented below.

$$r^k = \frac{EF^k}{BC^k} \quad (13)$$

EF^k: ecological footprint in settlement k (ha)

BC^k: bio-capacity in settlement k (ha)

Results and discussion

Figures 5–7 respectively portray the environmental load per capita, the consumption capacity per capita, and the environmental load excess ratio. The six areas and Tsukuba Science City area are surrounded by dark bold line, and that with no settlements are shown as a grid line in each figure. Conclusions about the environmental balance of settlements from these figures demonstrate the following.

1) The detailed environmental load of components in EF value is depicted in Figures 5(a)–5(c). The cropland footprint range from 0.076 to 0.081, and the average value is a little lager than the Japanese average value as there is more young population. Although no profound difference is apparent among the cropland EF of each settlement, settlements in the south show a high value in consumer residential EF because the number of persons per household in the detached houses is lower. The settlements with the lowest footprint in consumer residential are shown in white color, and there are higher elderly

ratio and single-person household ratio than others. The consumer transport EF is higher in the settlements located in the north, where the travel distance to the urban area is long with no railways.

2) Grazing land footprint, forestland footprint and energy footprint of cargo transport sector are not shown in the figure because these value are calculated in Japanese average. Grazing land footprint is 0.011 ha per person, forestland footprint is 0.074 ha per person, and cargo transport is 0.16 ha per person. The energy footprint of cargo transport sector only figures land needed for CO_2 emissions from transportation of goods between international trades. Potential of reducing the EF by promoting local production for local consumption is shown because the value of energy footprint of cargo transport sector is high. Compare to other consumptions, the energy footprint of consumer residential sector accounted for the largest proportion, and the value is almost twice as the transport sector.

3) The consumption capacity per person in figure 6 demonstrates how many lands the settlements can provide the cropland for food, the grazing land for livestock, and the forestland for paper and CO_2 emission. In whole, the general BC value (environmental capacity) is smaller near the Tsukuba Science city area. However, settlements located in southern areas have extensive lowland forests and agricultural land; settlements located in the north have rich forest resources. Grazing land is recognizable here and there and the area range from 0.00 to 0.5 hectare.

4) Compare the cropland and the cropland footprint, it is obviously that three quarter of the settlements balanced in food consumption, and they dispersed around Tsukuba city. The grazing resources are less common in Tsukuba as the agricultural life widespread from the ancient times. The forestland is as a city breathing system to absorb the CO_2 emission from consumer resident and transport, and provide the paper needed. The result from the calculation shown that less than 3% settlements can absorb the emission and have the ability to provide respiration function for other regions. Moreover, there are 55% settlements consumes 10 times as they possessed. In Tsukuba, agricultural demand can be local production for local consumption, while an extreme lack appeared in grazing and forest.

5) The level of environmental consumption in the place of origin in the settlements is presented in figure 7 as environmental load excess radio (r value). The average r value of Tsukuba is 4.29. The average r value of Ibaraki prefecture is 2.97 from the former study by our research group (Chen, 2013). There are settlements for which the r value was higher than the average of Tsukuba in (4) Sakura area and (5) Yatabe area because these areas are near the Tsukuba Science city area and urban activities are concentrated there. Moreover, settlements exist for which the r value is higher than the average of Ibaraki prefecture in (1) Tsukuba area and (6) Kukisaki area. This fact demonstrates that urban functions have been spread to suburban areas by the EF value.

6) The environmental excess ratios were less than 1.0 in (1) Tsukuba and (3) Toyosato areas. There are many settlements for which the EF value does not overshoot the BC value, and for which the consumption capacity covers the environmental load. However, by examining the EF per person and the BC per person, it is readily apparent that even if the r value is less than 1.0, the environmental load

related with residents' daily activities is not always lower than those of people in other areas. These settlements might be environmentally balanced simply because of their smaller populations. Moreover, even if the *r* value is less than 1.0, it does not mean that EF and BC take the balance actually because only consumptions of residents' daily life are counted in this study.

7) Compare to the existed research (Poom et al, 2014), the result is similar as the cropland footprint show little difference in each settlements, and the residence energy footprint in settlements near the urban area is higher than the others. However, the result of energy footprint is different because of different lifestyle in the target regions. Moreover, this study uses official data that possesses high reliability and applicability to other areas, while the existed research (Poom et al, 2014) used data from survey of 16–17-year-old high school students.

Conclusions

In order to better compare and understand the environmental balance, this paper examined the settlements located between the built-up areas and the mountain areas. This study proposed and assessed an environmental balance assessment tool that estimates the environmental load of residents' daily life from food, clothing, housing, and commuting by combining the respective components of the EF value and BC value. Using a case study approach for examining Tsukuba in Japan, this study estimated the environmental balance of all settlements. It is possible to explain how the concept promotes understanding of ecological productivity and consumption. From the results of the calculation, there is three quarter of the settlements balanced in food consumption, while an extreme lack appeared in grazing land and forest land for absorb CO_2 emission. The energy footprint of consumer residential sector accounted for the largest proportion in EF, and the energy footprint of cargo sector is the second. Heat and electric consumption and CO_2 emission from the import product affect the environmental load of residents' daily life most. Moreover, there are many settlements where the EF value does not overshoot the BC value. However, by examining the EF per person and the BC per person, some of them are being balanced simply because of their smaller populations.

Further study of precision-improving methods that propose a better examination for locally grown and locally consumed products by detailed compositing among subjects is expected. Moreover, the consumptions coming from outside should be taken into consideration. By application of this tool to studies of individual behaviors that interact and which affect the environment, additional useful suggestions will be provided for the way of life in settlements or for environmental management there.

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Figure captions

Fig. 1. Location of Tsukuba

Fig. 2. Districts of Tsukuba

Fig. 3. Land use of Tsukuba

Fig. 4. Photo of Tsukuba

Fig. 5. EF per person in settlements

Fig. 6. BC per person in settlements

Fig. 7. Environmental excess ratio of settlements

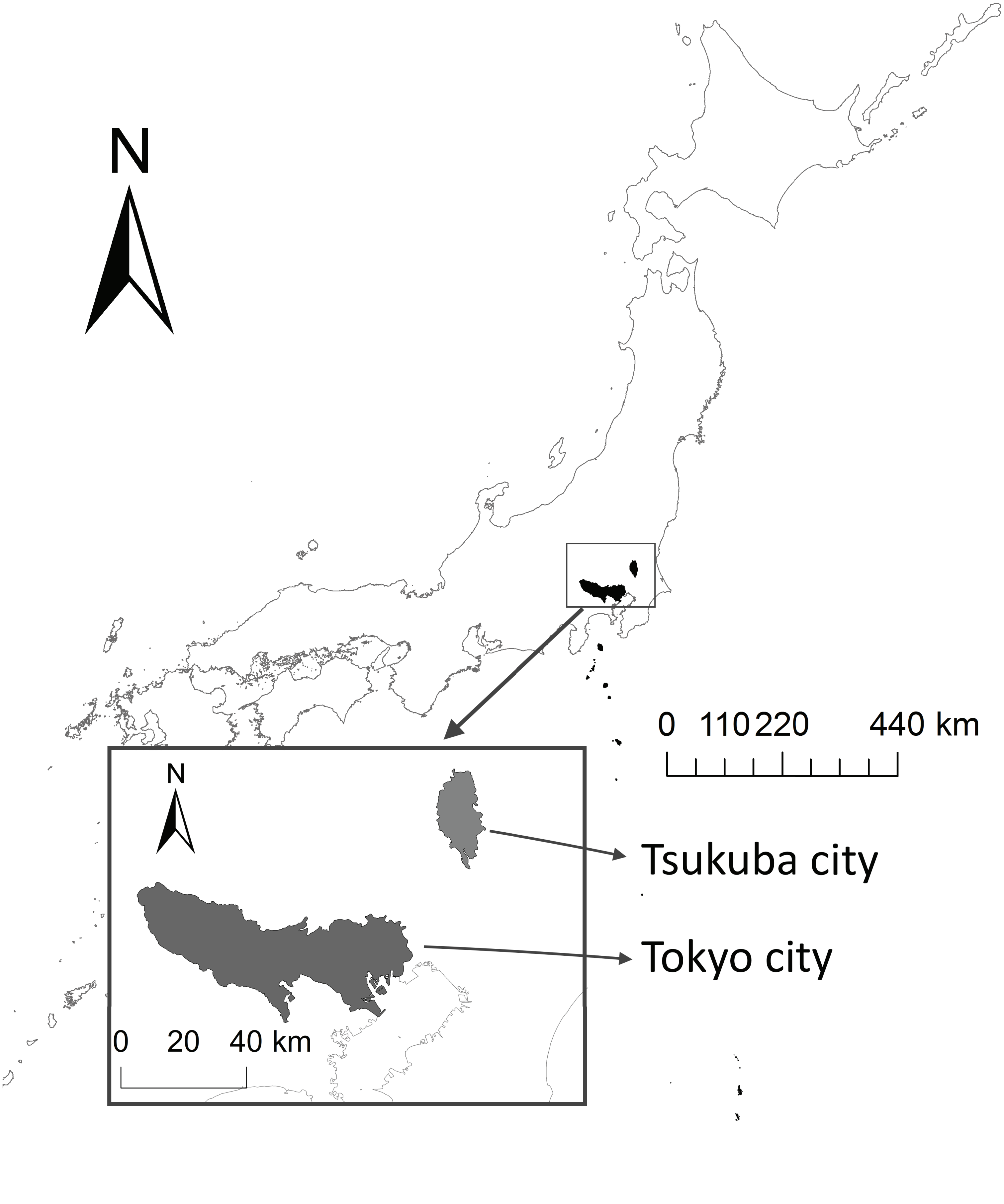


Fig.1

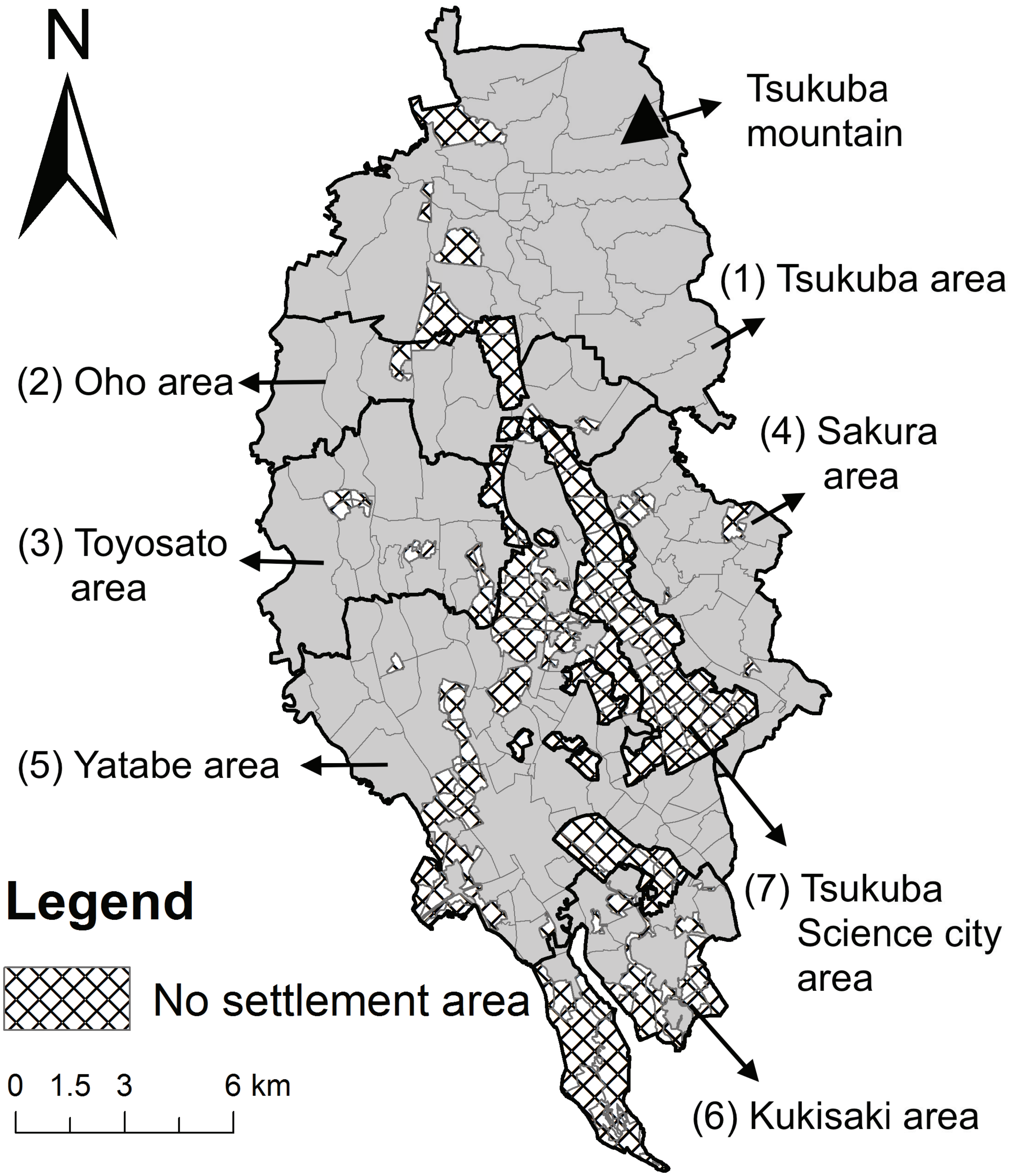

N
Tsukuba mountain
(1) Tsukuba area
(2) Oho area
(3) Toyosato area
(4) Sakura area
(5) Yatabe area
(6) Kukisaki area
(7) Tsukuba Science city area
Legend
No settlement area
0 1.5 3 6 km

Fig.2

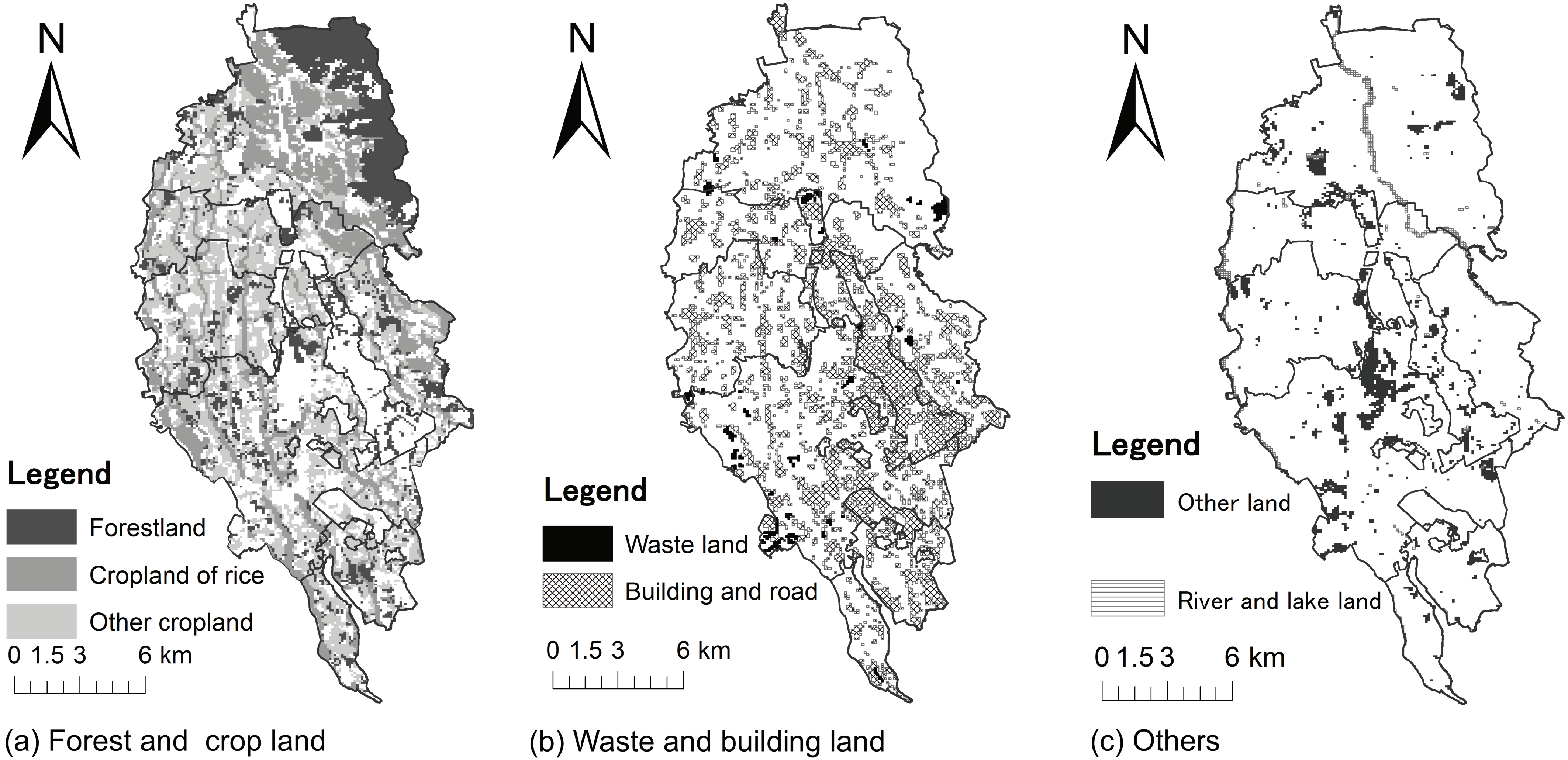

N
Legend
Forestland
Cropland of rice
Other cropland
0 1.5 3 6 km
(a) Forest and crop land
N
Legend
Waste land
Building and road
0 1.5 3 6 km
(b) Waste and building land
N
Legend
Other land
River and lake land
0 1.5 3 6 km
(c) Others

Fig.3

(a) Photo of Tsukuba science city area 1

(b) Photo of Tsukuba science city area 2

(c) Photo of Yatabe area

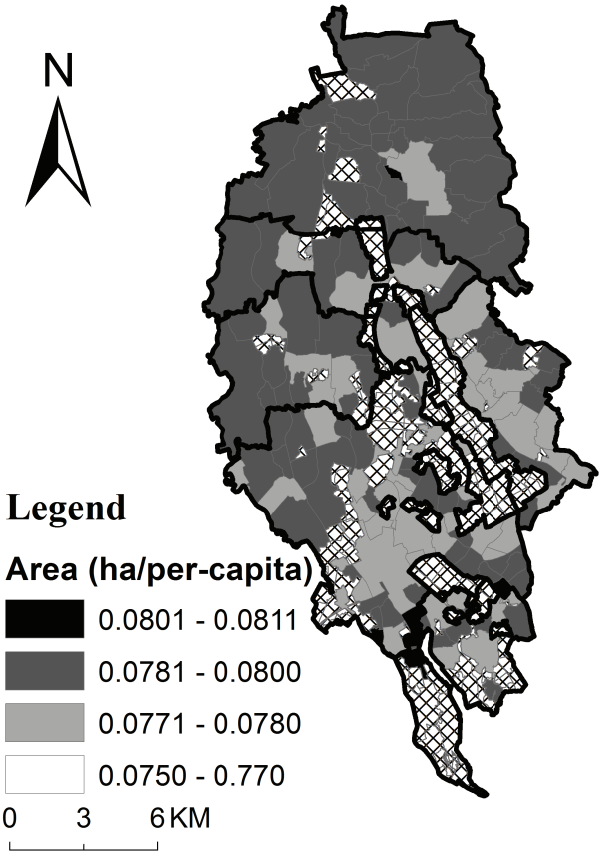
(d) Photo of Tsukuba area

(a) Photo of Tsukuba science city area 1

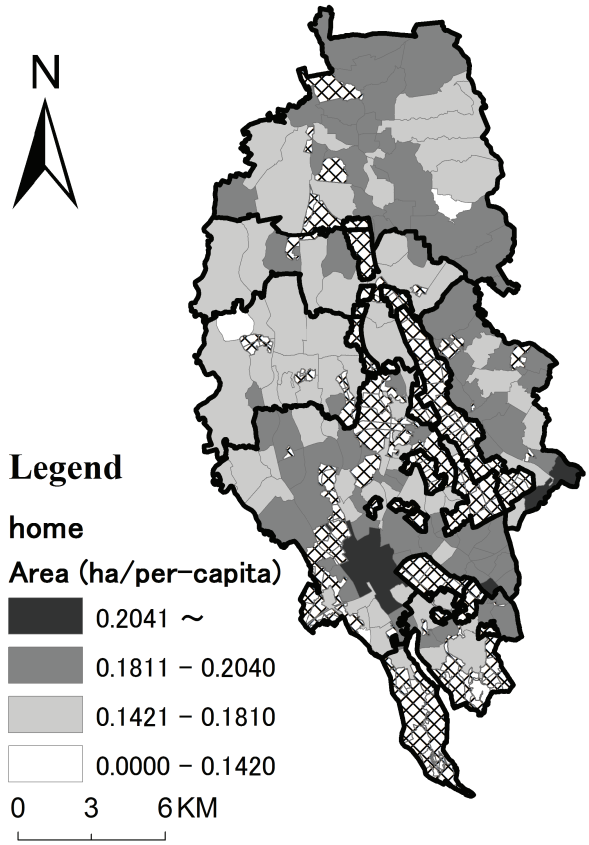
(b) Photo of Tsukuba science city area 2

(c) Photo of Yatabe area

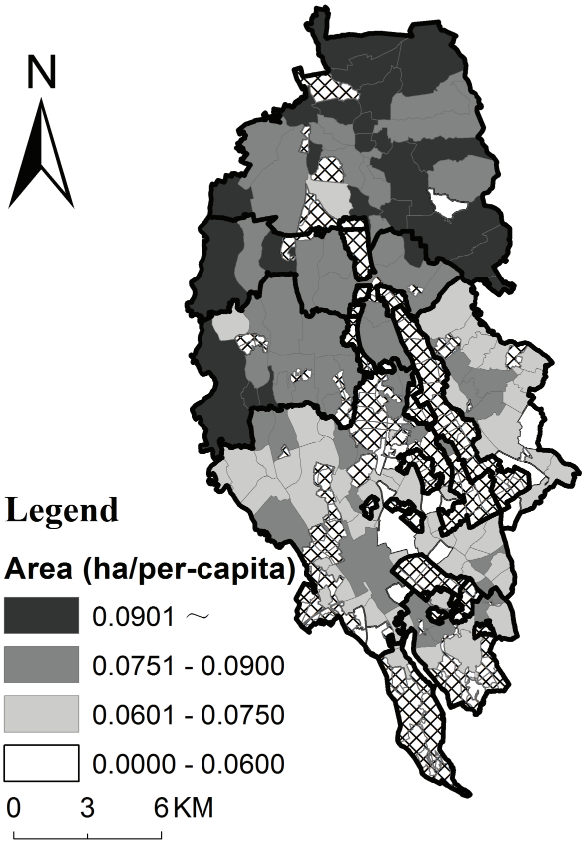
(d) Photo of Tsukuba area



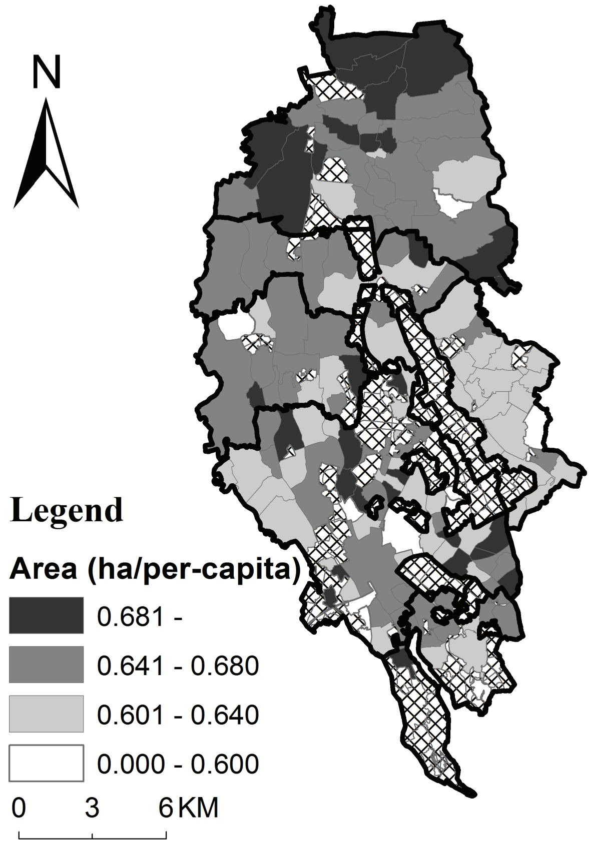
(a) Cropland footprint



(b) Energy footprint:consumer residential sector

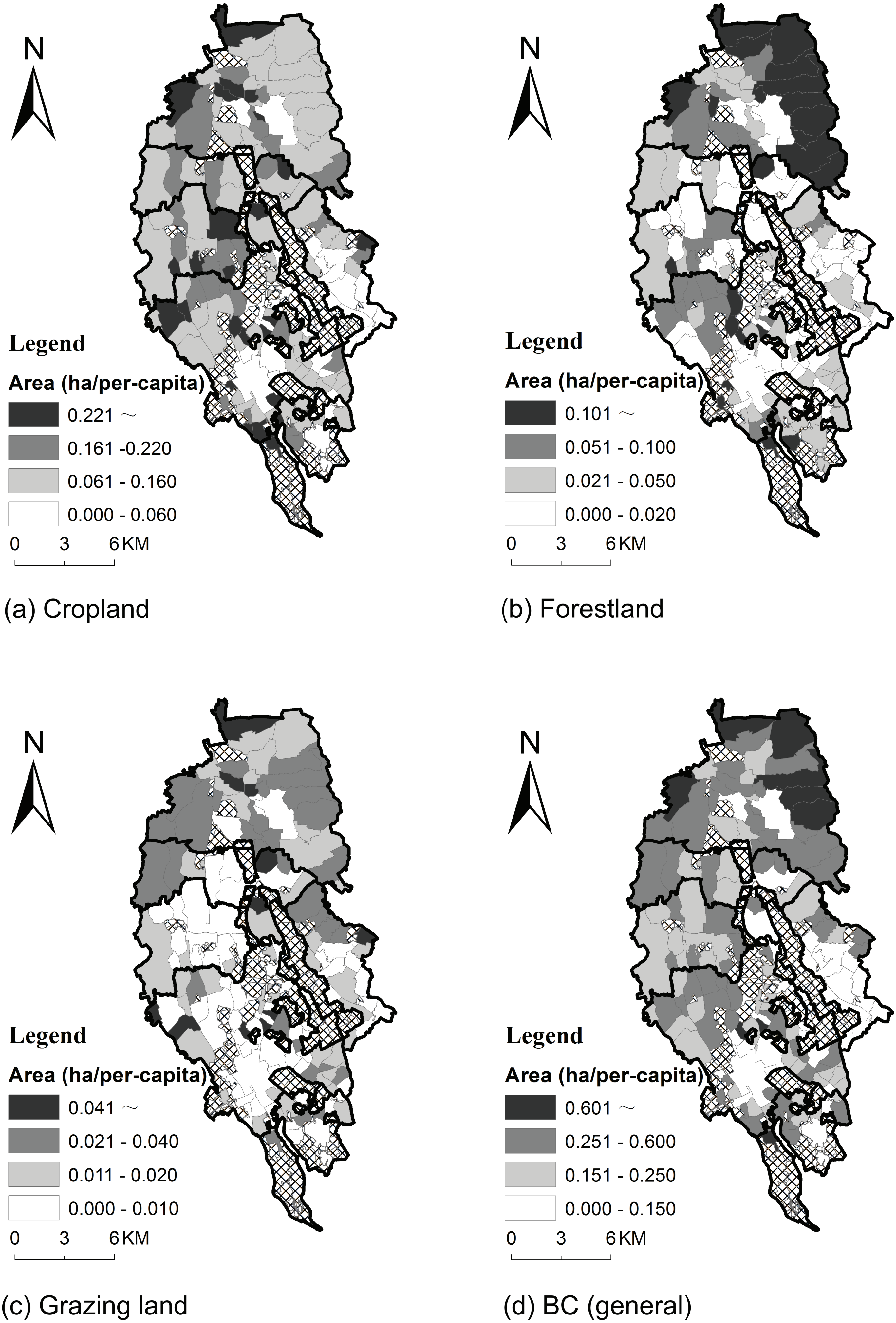


(c) Energy footprint: consumer transport sector



(d) EF (gerenal)

Fig.5



(a) Cropland

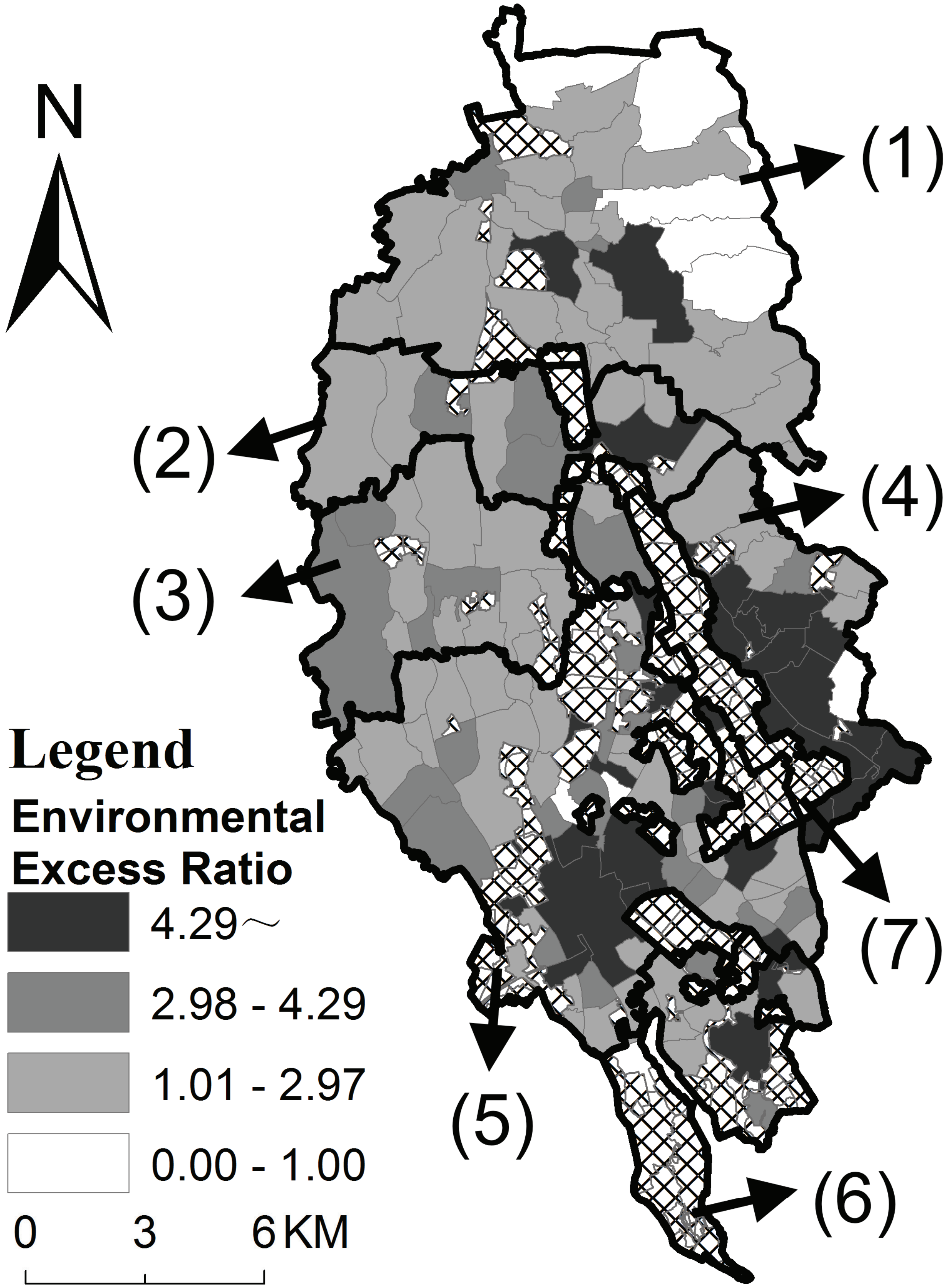
(b) Forestland

(c) Grazing land

(d) BC (general)

Fig.6

Fig.7



Districts in Tsukuba
(1) Tsukuba rea; (2) Oho area; (3) Toyosato area
(4) Sakura area; (5) Yatabe area; (6) Kukisaki area;
(7) Tsukuba science city area