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 products. However, because of urbanization after the high-growth period, the ecological balance has deteriorated because of land development, abandonment of cultivation, automobile dependency, and similar factors. This study assessed an improved method of calculating the ecological footprint (EF) value, which assigns a rating for environmental balance in rural areas. Residents' consumption is calculated based on the environmental load (cultivation, CO_2 emission, and similar loads) 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. Analysis of the case study shows: (1) environmental productivity and consumption capacity differed greatly according to the advancement of urban development, and (2) only a few settlements, located in forested areas, are ecologically balanced. **DOI: 10.1061/(ASCE)UP.1943-5444.0000337.** *© 2016 American Society of Civil Engineers.*

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Introduction

At the Earth Summit (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 had become worse, not better, according to a report from the World Wide Fund for Nature (WWF), meaning that the balance of the environment has been disrupted (WWF 2008).

However, residents in old Japan predominantly based their life and production operations in settlements: basic units of certain residents formed of communities constituting a 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 today. Also, the settlements absorb waste from the surrounding urban areas and provide resources to them by way of 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 restore the balance, it is important for not only the government or corporations, but also the general residents, to change their daily lifestyles to benefit the environment. Understanding the actual conditions in a simple way is essential as a first step to actually performing the changes. Therefore, it is necessary to measure 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 residents' immediate consumption and environmental capacity is needed.

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

As a tool to assess the balance of environment, the ecological footprint (EF) indicator quantifies the environmental impact of human activities. The EF indicator was developed by Wackernagel and Rees (1996) 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 waste is less than or equal to the total available land area.

This study assessed an improved method for calculating the EF value, which assigns a rating for environmental balance in settlements in rural areas. Residents' consumption is calculated based on the environmental load (cultivation, CO_2 emissions, and similar factors) that residents generate during daily life activities. Simultaneously, this study defines a biocapacity (BC) value that quantifies the environmental consumption capacity of cropland, forestland,

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and pastureland. The level of environmental balance is revealed by combining the two values.

Moreover, it is more commonly considered that 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 an extremely biased value, with too high of an EF value in the built-up area and too high of a BC value in the mountains area. Although there are policies towards urban areas for preserving green field and avoiding soil consumption, such as urban regeneration and use of brownfields, these result in insignificant changes 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 areas, 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, such as a household, a district, a city, a region, or humanity as a whole, as 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). On a macroscale, the EF value and BC value have been calculated for 150 countries at a national level by the WWF (WWF 2008) for each given year, and for cities all over the world at a regional level (Chartered Institution of Wastes Management 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) and the Ministry of the Environment provides the EF indicator as an assessment of progress into the Basic Environmental Plan (Ministry of the Environment 2006). Governments also introduced the indicator in the Regional Environmental Plan (Environment Division of Ikayama Prefecture 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 the 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 relationship between the urban model (size of settlement, density, and similar factors) and ecological footprint (Moos et al. 2006). The EF applications described in 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; Browne et al. 2009). For land-use policies, land-use zoning with the guidance of EF and other ecological evaluations has 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, have been developed (Ujihara and Taniguchi 2011; Chen et al. 2013).

There are also studies 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 areas because the target is 16–17-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 easily understandable tool for residents 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 (Browne et al. 2009).

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

1. This study addresses the fact that the environmental load and capacity differ by the type and location of settlements, and proposes a convenient method for residents to assess the environmental balance in a microscale for the locale 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 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 for examining the method for estimating the environmental balance on a microscale. The character of the EF and BC indicator can be clearer in the settlements, where the balance changes sensitively. Also there is too high of an EF value in the built-up area and too high of a BC value in the mountains area; and
4. Calculation of EF is based on statistics bureau data and other official data, which possess 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. Fig. 1 presents the target region location. Fig. 2 shows the positional relationship among settlements, six areas, and Tsukuba Science City area in Tsukuba city. The six areas used to be six cities and were administrative merged into Tsukuba city in 1995. Tsukuba Science City area is a planned area developed in the 1960s, and shows a different character from the others.

Fig. 3 shows the detailed land uses, which are drawn up from the 100 m mesh data from the Digital National Land Information (MLIT 2009). Fig. 3(a) shows that the forestland and cropland are mostly located in the north. Grazing land is not shown in this

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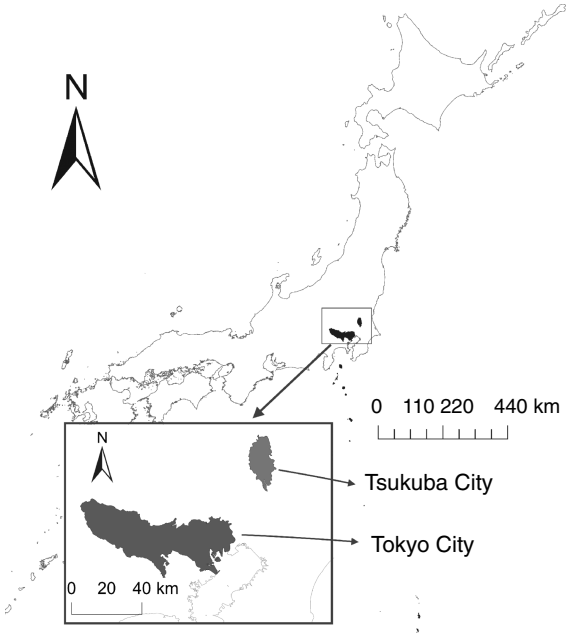

Fig. 1. Location of Tsukuba

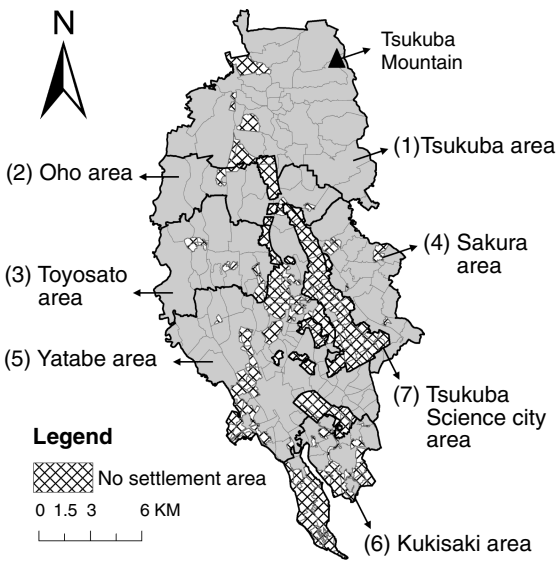

Fig. 2. Districts of Tsukuba

figure because there is little grazing land to be counted in the 100 m mesh map. On the other hand, Fig. 3(b) shows that the urban areas' facilities and buildings in and around Tsukuba Science City area have been developed sequentially from the 1960s through development of Tsukuba Science City. The Tsukuba Science City area has been almost rebuilt into commercial facilities or research institutes and few natural lands remain. Fig. 3(c) presents the river and lake land, and other land use. Moreover, in order to get an image of these areas, Figs. 4(a and b) show two photos of the Tsukuba Science City area, Fig. 4(c) shows a photo of the Yatabe area, and Fig. 4(d) shows an aerial photo of the Tsukuba area.

The object of this study is settlements in Tsukuba city, including both the traditional settlements and the 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 it is built up and developed. In this study, the settlement is where the geographic name and residents existed from 1925, as determined from the oldest map in the Japan Maps Center (JMC 1996). This study documented all 271 settlements in Tsukuba city and confirmed the territories of each settlement using JMC (1996), and adopts the oaza (settlement section) as the territory because it corresponds to land-use data from the Tsukuba Urban Planning Division (2010). In Fig. 2, oazas with settlement are shown as gray, and those with no settlement are shown in crosshatch.

Calculation of the EF Value

Many related researchers have specifically addressed issues of international trade, the consumption of a whole nation, or specific products (Duro and Figueras 2013; Kissinger and Gottlieb 2010; Muniz et al. 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 of 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 as calculated in this study, it shows the unbalance in each settlement and provides 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 obtained from the Ujihara–Taniguchi Model (UT Model) (Ujihara et al. 2010), and comprises the following components linked to land-use planning

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; and
5. Energy footprint: forestland needed to absorb CO_2 from fossil fuels for household and private transport use.

These components were obtained from the compound EF methodology developed by Wackernagel and Rees (1996). However the features of the settlements cannot be clarified by the former methods, so an improved calculation is proposed for application on a settlement scale. The improved calculation is shown in Eqs. (2)–(11).

The EF value is calculated as shown

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

where $EF^k = EF$ value of settlement, k (ha); $EF_i^k = EF$ value of component, i, in settlement, k (ha); k = settlement; and i = component.

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

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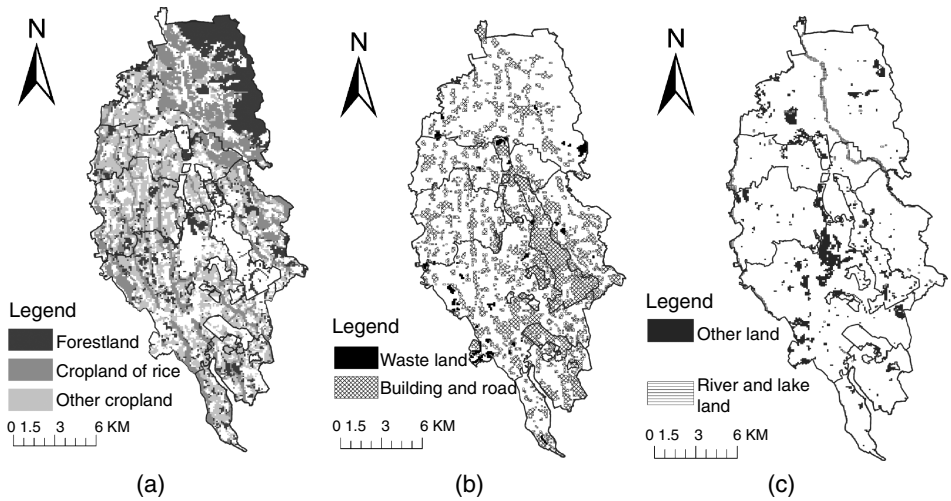

Fig. 3. Land use of Tsukuba

Fig. 4. Tsukuba: (a) Tsukuba Science City area 1 (image courtesy of Hidetaka Mori); (b) Tsukuba Science City area 2 (image courtesy of Hidetaka Mori); (c) Yatabe area (image by He Chen); (d) Tsukuba area (image courtesy of Kayoko Oda)

- Cropland and grazing land footprint

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

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

where EF_{fg}^k = land need for food and grass, in settlement, k (ha); F_j^k = consumption of crop, j, in settlement, k(ton); p_n^k = population of age bracket in settlement, k (person); f_{nj} = consumption of crop, j, in age bracket, n(t/person); and α_j = land productivity of crop, j(t/ha).

- Forestland footprint

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

where EF_p^k = land need for paper, in settlement, k (ha); 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); and r = rate of household consumption (%).

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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 the Urban Planning Baseline Survey 2010 of Tsukuba (Tsukuba Urban Planning Division 2010). This space of all built-up land-use types, including residential land, commercial land, industrial land, common land, railway land roads, and other land types, 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 or not the urban green zone lands are counted.

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. An improved method, shown subsequently, is used to calculate the three sectors because the UT model was unable to give additional information to generate the characters of these respective sectors.

1. Built-up land footprint

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

where EF_b^k = built-up land, in settlement, k (ha); b_i^k = built-up land use, i, in settlement, k (ha).

2. Energy footprint
   - Consumer residential sector

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

$$C_{xy}^k = \delta^{ci} \times E_{xy}^{ci} \tag{7}$$

where EF_h^k = land need for energy in residential house, in settlement, k (ha); C_{xy}^k = CO_2 emissions in tons, y = type of houses, and x = size of households in settlement, k; P_x^k = population x = size of households (person); γ = absorption efficiency of CO_2 (t-CO_2/ha); δ^{ci} = CO_2 conversion factor of energy, $ci(t\text{-}CO_2/\text{kWh})/(t\text{-}CO_2/\text{m}^3)/(t\text{-}CO_2/\text{L})$; E_{xy}^{ci} = consumption of each energy use, y = type of houses, and x = size of households in settlement, $k(\text{kWh}/\text{m}^3/\text{L})$; x = four sections by national population census (single-person, two-person, three-person, more than four-person); y = two sections (detached house, cluster house); and ci = three sections (electricity, gas, heating oil).

   - Consumer transport sector

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

where 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 Transportation Plan Council (2009)]; P_y^k = population; T = hours of automobile per person in Tsukuba; and y = type of houses, in settlement, k (ha).

   - Cargo transport sector

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

$$LS = \sum_{1}^{3} \frac{WS_{Gj}^{Ci}}{\sum_1^3 WS_{Gj}^{Ci}} \times LS^{Ci} \tag{10}$$

$$LA = \sum_{1}^{3} \frac{WA_{Gj}^{Ci}}{\sum_1^3 WA_{Gj}^{Ci}} \times LA^{Ci} \tag{11}$$

where $U_{CO_2(k)}$ = CO_2 emissions intensity of transport method, $k(\text{g-}CO_2/\text{ton}\cdot\text{km})$; W = traffic volume (ton); WS_{Gj}^{Ci} = traffic volume of goods, j, by ship from importing country, Ci (ton); WA_{Gj}^{Ci} = traffic volume of goods, j, by air from country, Ci (ton); LA^{Ci} = transport length by air from country, Ci (km), country; LS^C = transport length by ship from country, C (km); and 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 (Ministry of Internal Affairs and Communications, Government of Japan 2010b). Furthermore, the energy from this sector is calculated using the average energy consumption volume of the eastern Japan area (Ministry of the Environment 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 Ministry of Internal Affairs and Communications, Government of Japan (2010a); then, this land is allocated to each settlement based on hours of automobile per zone, which is recorded in TMTPC (2009), in which the 271 settlements are divided into 16 zones; and
3. For the cargo transport sector, the calculation 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 from the Ministry of Finance (Dept. of the Treasury 2010), and transport length is based on airline mileage (AXSMarine 2014) and sea mileage (Hikaku.com Corp. 2014).

Based on an analysis using the preceding configuration, the environmental load and environmental balance can be quantified and applied easily to other cities. This method demonstrates most of the data available from the local government.

Calculation of the BC Value

BC refers to the capacity of an area to provide resources and absorb waste 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 subsequently.

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

$$BC^k = bc_{fm}^k + bc_f^k + bc_g^k + bc_b^k \tag{12}$$

where BC^k = biocapacity in settlement, k (ha); bc_{fm}^k = cropland area in settlement, k (ha); bc_f^k = forestland area in settlement,

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k (ha); bc_g^k = grazing land area in settlement, k (ha); and 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 outside the settlement. The environmental load excess ratio in settlement $k(r^k)$ is defined as

$$r^k = \frac{EF^k}{BC^k} \tag{13}$$

where EF^k = ecological footprint in settlement, k (ha); and BC^k = biocapacity in settlement, k (ha).

Results and Discussion

Figs. 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 a dark bold line, and those with no settlements are shown as crosshatch in each figure. Conclusions regarding the environmental balance of settlements from these figures demonstrate the following:

1. The detailed environmental load of components in EF value is depicted in Figs. 5(a–c). The cropland footprint ranges from 0.076 to 0.081, and the average value is a little larger than the Japanese average value because 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, and there are higher elderly ratio and

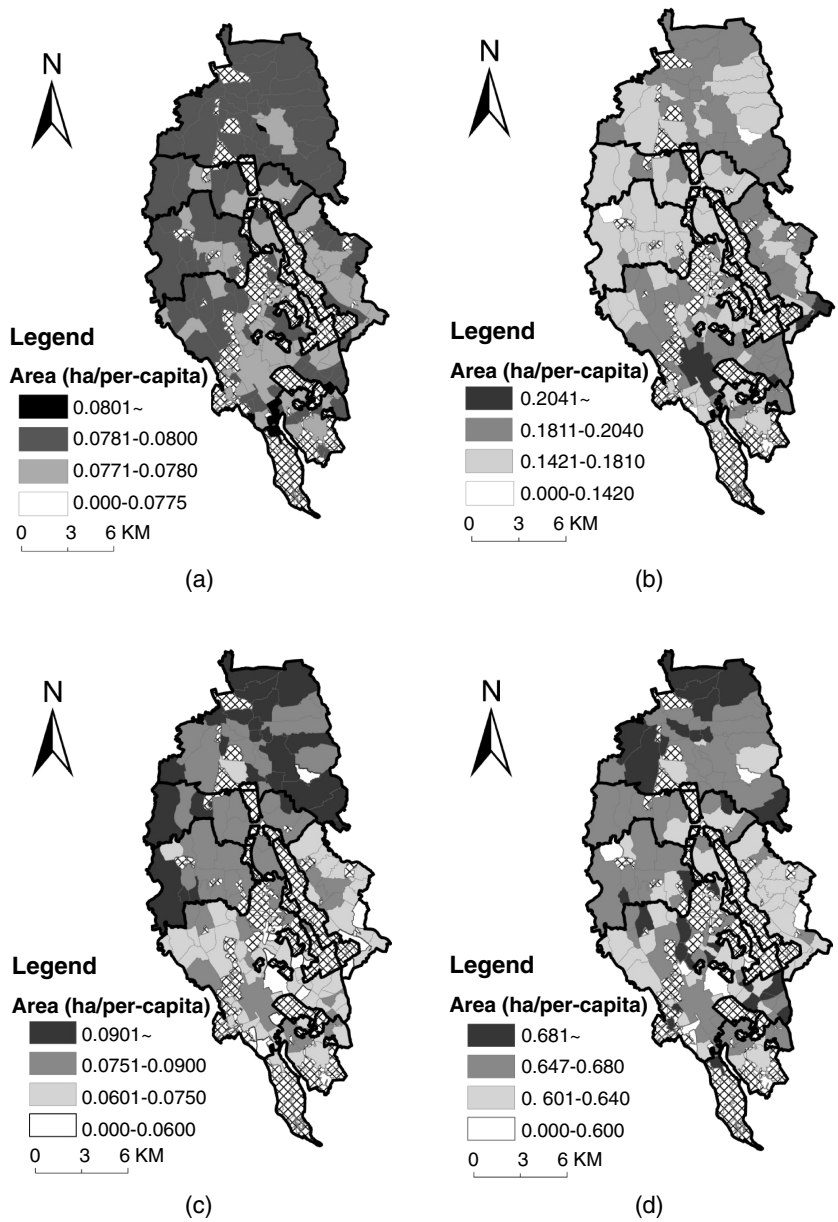

Fig. 5. EF per person in settlements

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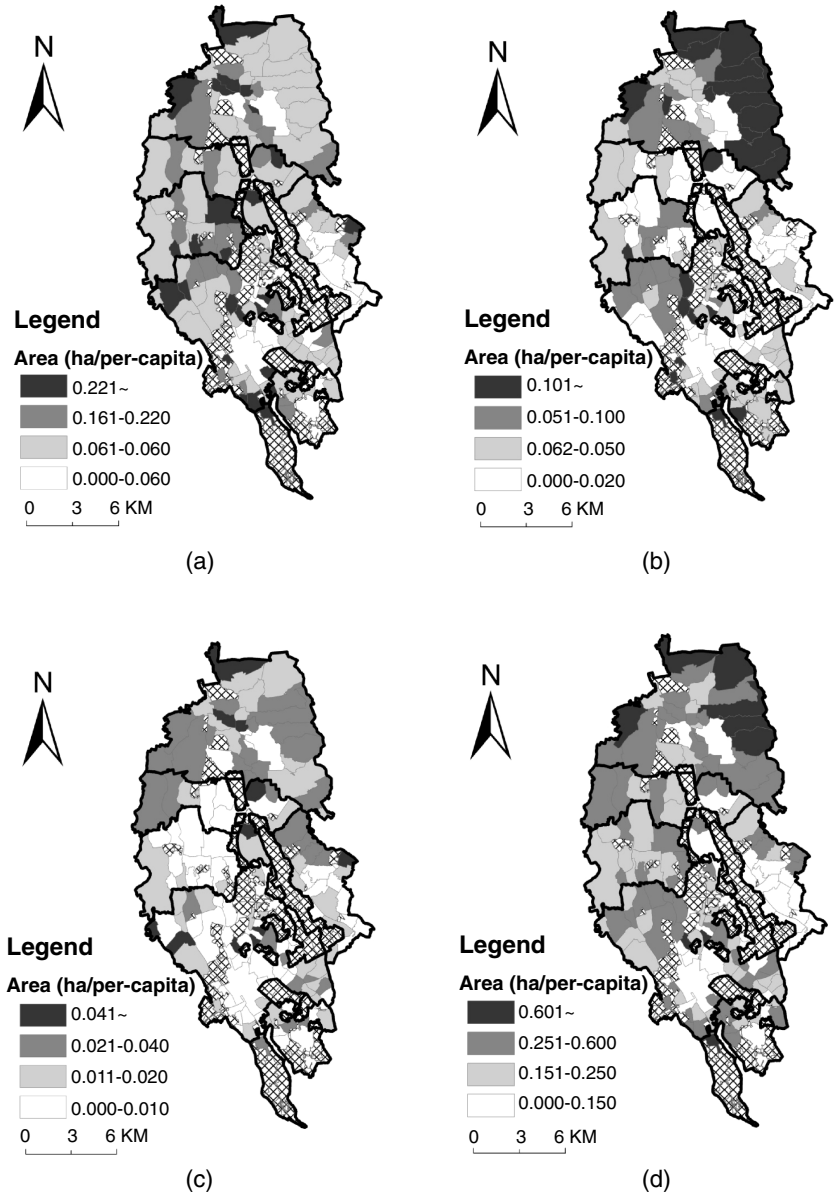

Fig. 6. BC per person in settlements

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 the cargo transport sector only considers land needed for CO_2 emissions from transportation of goods between international trades. The potential for reducing the EF by promoting local production for local consumption is shown because the value of the energy footprint of the cargo transport sector is high. Compared to other consumptions, the energy footprint of the consumer residential sector accounted for the largest proportion, and the value is almost twice that of the transport sector;
3. The consumption capacity per person in Fig. 6 demonstrates how much land the settlements can provide cropland for food, grazing land for livestock, and 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 areas range from 0.00 to 0.5 ha;
4. Comparing the cropland and the cropland footprint, three-quarters of the settlements are balanced in food consumption, and are dispersed around Tsukuba city. The grazing resources are less common in Tsukuba because the livestock industry has no widespread from the ancient times. The forestland is like a city breathing system for absorbing the CO_2 emission from consumer resident and transport, and provides the paper needed. The result from the calculation shows that less than 3% of the settlements can absorb the emission and have the ability to provide respiration function for other regions. Moreover, 55% of the settlements consume 10 times as much as they possess. In Tsukuba, agricultural demand can be local production for local consumption, whereas an extreme lack appeared in grazing and forest;

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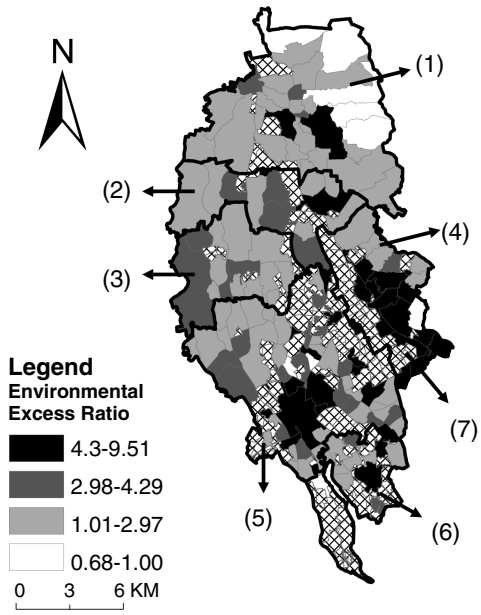

District in Tsukuba
(1) Tsukuba area; (2) Oho area; (3) Toyosato area;
(4) Sakura area; (5) Yatabe area; (6) Kukisaki area;
(7) Tsukuba science area

Fig. 7. Environmental excess ratio of settlements

5. The level of environmental consumption in the place of origin in the settlements is presented in Fig. 7 as the 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 a previous study (Chen et al. 2013). There are settlements for which the r value was higher than the average of Tsukuba in the Sakura area and Yatabe area, items (4) and (5), respectively, in Fig. 7, 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 the Tsukuba area and Kukisaki area, items (1) and (6), respectively, in Fig. 7. This fact demonstrates that urban functions have pread to suburban areas by the EF value;
6. The environmental excess ratios were less than 1.0 in Tsukuba and Toyosato areas, items (1) and (3), respectively, in Fig. 7. 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 that 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 account for the balance actually because only consumptions of residents' daily life are counted in this study; and
7. Compared to existingresearch (Poom et al. 2014), the result is similar because the cropland footprint shows little difference in each of the settlement and the residence energy footprint in settlements near the urban area is higher than the others. However, the energy footprint is different because of different lifestyles in the target regions. Moreover, this study uses official data which possess high reliability and applicability to other areas, whereas the existing research (Poom et al. 2014) used data from a survey of 16- to 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 calculations, three- quarters of the settlements are balanced in food consumption, whereas an extreme lack appeared in grazing land and forest land for absorbing CO_2 emission. The energy footprint of the consumer residential sector accounted for the largest proportion in EF, and the energy footprint of the cargo sector is second. Heat and electric consumption and CO_2 emission from the import product affect the environmental load of residents' daily life the 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 are balanced simply because of their smaller populations.

Further study of precision-improving methods, which 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 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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