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Supply and demand of ecosystem service provision in relation to dynamics land-cover changes: a remote sensing and geospatial analysis in Sukabumi Regency

Ananda Fitriani, Muhammad Dimyati, Faris Zulkarnain
Department of Geography, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok, Indonesia

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ABSTRACT

The rate of population growth in Sukabumi Regency continues to grow, along with the increasing need for food. This population growth, combined with the constant changes in land cover can reduce the productivity of environment in providing natural capital for food availability. Therefore, this study aimed to examine the condition of ecosystem service provision for a decade in Sukabumi Regency due to changes in land cover. In general, the efficient use of remote sensing method and geographic information systems to monitor ecosystem services had received widespread recognition. Following this scenario, the current study used geospatial analysis with dasymetric method which was integrated with supply and demand formulas for ecosystem services provision, food availability, and remote sensing. Geographic information system was also used for land cover interpretation data. The results showed that three districts in Sukabumi Regency, namely Cicurug, Cibadak, and Cicantayan, had “exceeded” condition when the environmental condition already passed the threshold or were unable to support population's needs. Meanwhile, the other districts have “not exceeded” condition, when the environmental conditions were still able to fulfill the needs of population. Finally, the changes in agricultural land cover had a significant influence on the condition of ecosystem services.

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Corresponding Author:

Ananda Fitriani
Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia
Margonda Raya Street, Pondok Cina, Beji, Depok, West Java, 16424, Indonesia
Email: anandaftrani@gmail.com

1. INTRODUCTION

Humans are dependent on the services provided by biosphere and ecosystem to sustain their lives [1]. In general, ecosystem provides many important services that benefit human welfare. To ensure sustainable development, environmental management needs to be given attention. This is because life support system depends on good ecosystem and natural capital stock [2]. Moreover, it is crucial to be aware that natural ecosystem and their modification do not play significant role in supporting human life through ecosystem services [3]. The function of ecosystem is to provide materials and services that can be used directly or indirectly by humans, thereby contributing to human welfare. However, the relationship between natural resources or the environment and human needs is inversely proportional. For example, the increase in population growth, along with demand and spatial changes, leads to resource exploitation and environmental degradation, which eventually affects sustainability.

The increase in social demand can be influenced by growing population and urban expansion, thereby causing ecosystem degradation [4]. In other words, the rate of population growth and development is proportional to the continuous decrease in environmental capacity [1]. It is important to be aware that changes occurring in spatial areas can cause positive or negative changes in environmental quality [5], such as variations in supply and value of ecosystem services [6], as well as its integrity [7]. Specifically, the changes affect productivity in agricultural and forestry, resulting in a shortage of food supply. Also, demand for ecosystem services may no longer be fulfilled when supply of ecosystem services changes [7].

The use of natural resources needs to be optimized by properly communicating the carrying capacity of the environment and how it can be improved [5]. Typically, natural resources have the capacity to provide resources for society and reflects the level or quantity that can be explored [8]. Therefore, to protect and manage the resources, there is a need to calculate and compare aspects of supply and demand [9]. When determining the ability of ecological system, the crucial factors to consider are the nature and condition of ecosystem. A side from the nature and ecosystem condition, human input or activities also contribute to establishing the capacity of social-ecological systems and services [10].

Assessment method focusing on quantifying ecosystem services and defining the main drivers of supply and demand are urgently needed to support ecosystem management [7], [11], [12]. An important factor influencing the evaluation of ecosystem services is land use or land cover. This is because the changes in land use have complicated implications on ecosystem patterns and processes [11], [13]. Consequently, assessment of ecosystem services can be used to examine the effects of land cover or land use change on various types of natural capital [14]. This assessment contains both positive and negative effects, as well as provides evidence for policy decisions and measures that encourage favorable outcomes [15]–[17]. Human welfare, including economic and social, is dependent on the consumption of ecosystem services, which can lead to imbalance between supply and demand [11]. Similarly, the provision of ecosystem services depends on the interaction and feedback from ecological and socio-economic factors. This scenario signifies that both supply and demand need to be considered in the assessment of ecosystem services [18], [19].

Several recent studies have examined the processes of supply and demand on ecosystem services [7], [11], [15], [20]–[22]. In Indonesia, supply-demand of ecosystem services was used as one of the methods to calculate environmental carrying capacity based on Law of The Republic Indonesia No. 32 Year 2009 on Environmental Protection and Management [23]. According to various sources, carrying capacity is the maximum population that can be sustained by the resources and services available in ecosystem [24]. It also includes availability of environment to provide for the needs of humans and other living things [5]. The carrying capacity can be understood through ecosystem services, as it represents the capacity of ecosystem functions and services to support human life and other living things.

This study aimed to examine supply and demand conditions of ecosystem services provision over a decade and determine the effect of land cover changes on these conditions. Specifically, the dynamic changes in land cover were analyzed using land cover database from Ministry of Forest and Environment between 2009 and 2019. Following this process, a quantitative assessment was conducted by mapping ecosystem services and prioritizing food provision. This study was carried out in Sukabumi Regency, West Java Province, consisting of 47 districts and is one of the largest regencies in Java Island, with a leading agricultural sector.

2. STUDY AREA

The study area is located in Sukabumi Regency, West Java Province, consisting of 47 districts with 404 villages as shown in Figure 1. Furthermore, this area is geographically located at 06°57' - 07°25' LS and 106°49' - 107°00' BT with an area of 4.162 km². In the north, the topography ranges from mountainous terrain to high hills with steep slopes and ramps. Meanwhile, in the south, the landscape comprises hills fields, and lowlands with sloppy slopes and flat areas. The opportunities for the agricultural sector in Sukabumi Regency are quite great for the economy of the community. Typically, the area has high agricultural productivity, making it one of the food-growing bases in West Java. Between 2009 to 2019, population increased from 2,274,028 to 2,585,848 people [25]. Population density is higher in the northern areas near the border and along national road lines, while the central and southern areas have lower population density with more scattered settlements. Consequently, the agricultural sector was considered the largest percentage area, which amounted to approximately 65% in 2009 and declined to 60% in 2019.

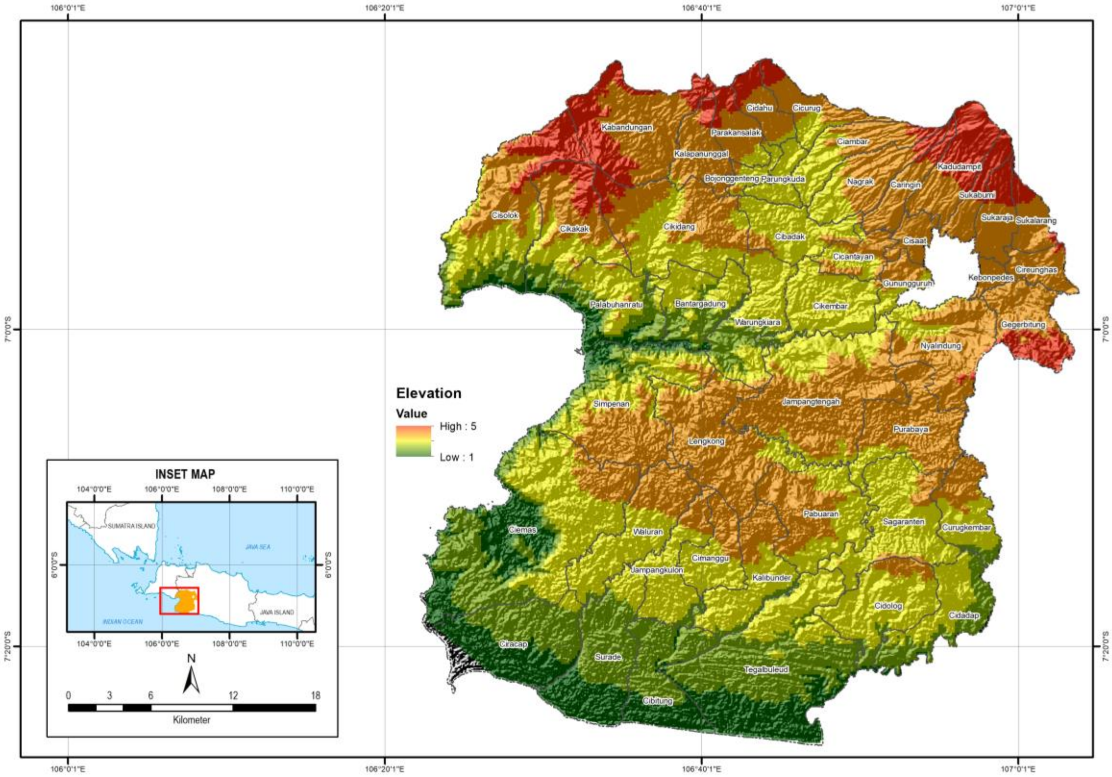

Figure 1. Study area of Sukabumi Regency

3. DATA AND METHOD

This study used the ecosystem services method, as the relationship between supply and demand can be represented by ecosystem functions and services, reflecting the environmental capacity to support life in a specific location. In the assessment of ecosystem services, both supply and demand of food provision were considered. Specifically, supply was determined by the capacity of cultivated fields to produce food services [21], related to physical, social, and ecological conditions in a particular area for a certain period. Meanwhile, demand was based on consumption or usage in certain areas for a certain period, without considering the actual sources of ecosystem services [7], [9], [19]. The available data used for assessing supply and demand of ecosystem can be seen in Table 1. It should be acknowledged that each province and regency had the authority to establish ecoregions and carry out environmental inventories, with the mapping of ecoregional information being one of the tasks [23].

Table 1. Data used to quantify supply and demand of ecosystem service provision

Data	Time steps, time series stand	Scale	Sources
Administrative	2020	Regency	Geospatial Information Agency 2020
Landcover (Landsat 5 and 7)	2009–2019	1:250.000	Ministry of Environmental and Forestry, 2009–2019
Ecosystem services index	2018	1:250.000	Ministry of Environmental and Forestry, 2019
Population	2009–2019	Regency	Statistics Indonesia, 2009–2019
Food Production	2009–2019	Regency	Department of Agriculture of Sukabumi Regency, 2009–2019

3.1. Land cover change analysis

Land cover datasets used were sourced from Ministry of Forestry and Environmental in Inventory and Monitoring of Forest Resources (IPSDH) field, with a classification grade scale of 1:250,000 through interpretation of Landsat thematic mapper (TM) or enhanced thematic mapper (ETM) images. Typically, the accuracy of data was tested for 5,000 sample points on the classification of forest and non-forest. Consequently, the result showed 91.0% and 95.30% in 2009 and 2019, respectively. A total of 16 different classes of land cover were identified as shown in Figure 2, namely i) primary dryland forest, ii) secondary dryland forest, iii) secondary mangrove forest, iv) mixed dry agriculture, v) dryland agricultural, vi) plantation forest, vii) plantation, viii) settlement area, ix) mining area, x) bare soil, xi) paddy field, xii) dry-shrub, xiii) open water, xiv) open swamp, xv) fishpond, and xvi) swampy-shrub. The analysis of changes in land cover focused on changes in agricultural classification, namely paddy field, dryland, and mixed dryland agriculture.

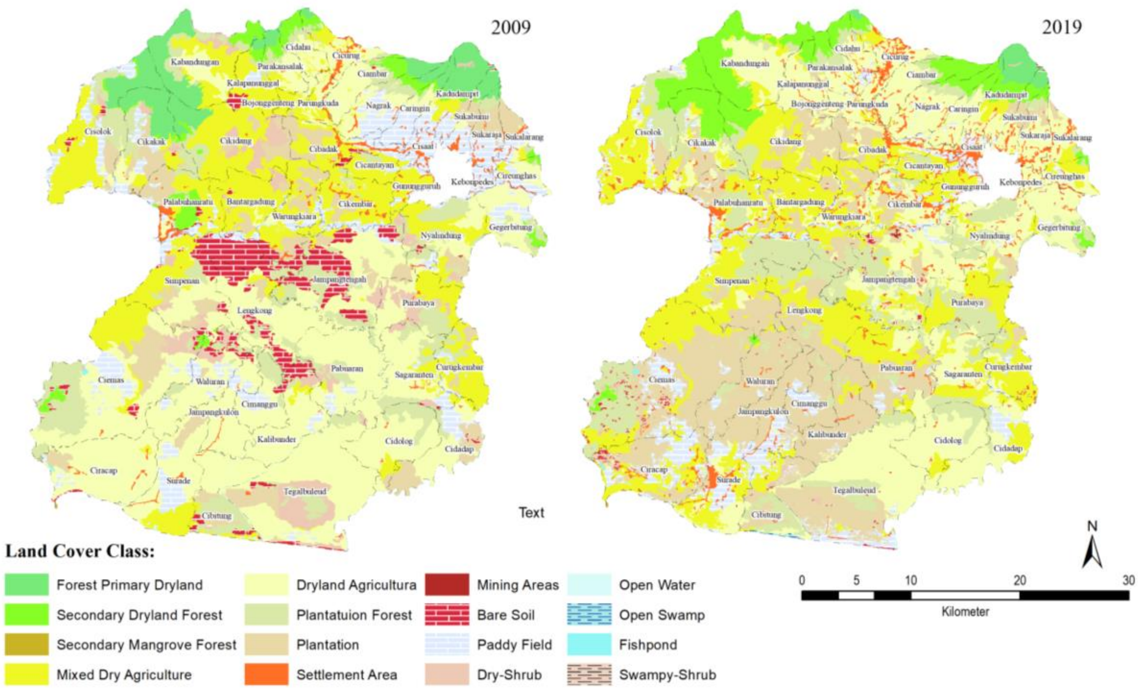

Figure 2. Land cover of Sukabumi Regency from 2009–2019

According to Figure 2, agricultural land cover dominated the area of Sukabumi Regency. Between 2009 and 2019, land cover types were dominated by dryland agriculture, followed by mixed dry agriculture, and plantations. Paddy fields were spread across the northern area, near Mount Pangorango, and around western and southern coast. Settlement density was quite high in the north, around the borders of Sukabumi City and Bogor Regency, as well as the western and southern coast.

3.2. Mapping demand of provisioning ecosystem services

Demand aspects of food-providing ecosystem services in this study were described in terms of ecological footprint. This measured the amount of natural food production by individuals for consumption [5]. The distribution of food demand services used population distribution data [21], considering dasymetric model based on grid 30×30 m grid cells. This value was the calculated using recommended dietary allowances (RDA) for Indonesian citizens, with a value of 2,100 kcal/person/day. In This study focused only on carbohydrate energy needs for food demand, as the food supply was quantified majorly from staple food, containing high carbohydrate.

Population distribution was carried out using dasymetric model, which allocated statistical data to the unit area [26]. This method could improve the accuracy of traditional choropleth maps used for population distribution mapping [27]. Specifically, population distribution model divided space based on actual surface characteristics, using land cover data. The implementation of dasymetric method in calculating population of each land cover cell (pixel) used (1) [26]:

$$P = \frac{(R_n A_n) \times N}{E} \quad (1)$$

where P is population of a cell, R_n is relative density of the mapping unit population with land-cover, A_n is area of mapping unit, N is actual population of enumeration unit, and E is the expected population of enumeration unit calculated using relative density.

Relative density used in this study was based on previous explorations [26], with weights adjusted to the conditions in the study area in Table 2. Additionally, relative density values were obtained using calculation tools for each land cover class. This process produced density weightings for each land cover class, adjusted to the possibility of being inhabited by humans.

Table 2. Relative density [26], [28]

Code	Land cover	Relative Density (%)
1	High-low density residential	62
2	Agricultural area	28
3	Industrial area	6
4	Forest area	3
5	Road and rail network	1
6	Uninhabited area	0

3.3. Mapping supply of provisioning ecosystem services

To map food supply, the capacity of cultivated fields was used to provide food services [21], [29]. Supply referred to the capacity of resources in an area to provide goods or services. In this study, supply was obtained by processing the amount of food production from cultivated fields in each regency. The amounts were converted into kilocalories, representing the energy content of each food type. Data was then distributed based on the physical conditions of the area, using ecosystem services index (ESI) through geospatial analysis.

The ecosystem services index (ESI) of food provision was a value reflecting the quality or extent of ecosystem services resulting from food provision in an area. In this study, ESI score was obtained through calculations, assessments, and weightings of land cover and ecoregion. Typically, these results had been established by previous studies on Java Island, using ecological expert judgment as shown in Table 3 [30]. The equation (1) was used to calculate land cover and ecoregion values for evaluating ESI [30]:

$$\mathrm{ESI} = (W_{eco} \times S_{eco}) + (W_{lc} \times S_{lc}) \quad (2)$$

Where ESI is ecosystem services index, W_{eco} is weight value of ecoregions (40%), S_{eco} is assessment score of each ecoregion, W_{lc} is weight value of land cover (60%), and S_{lc} is assessment score of each land cover.

Table 3. Assessment scoring of ESI value for each ecoregion and land cover [30]

Ecoregions	Value	Land Cover	Value
Volcanic Plain (A)	0.48	Paddy Field (A)	0.91
Volcanic Hills (B)	0.29	Fields/Moors/Huma (B)	0.71
Volcanic Mountains (C)	0.28	Dry Land Forest (C)	0.32
Structural Plain (D)	0.20	Wet Land Forest (D)	0.16
Structural Hills (E)	0.13	Shrubs (E)	0.23
Structural Mountains (F)	0.16	Grassland/Savanna (F)	0.08
Fluvial Plain (G)	1.00	Marsh Grass (G)	0.11
Karst Plain (H)	0.25	Open Field (H)	0.04
Karst Hills (I)	0.16	Built-Up Land (I)	0.04
Denudation Plain (J)	0.30	Unbuilt-Up Land (J)	0.16
Denudation Hills (K)	0.14	Body Water (K)	0.32
Aeolian (L)	0.05		
Marine Plain (M)	0.30		
Glacial Mountain (N)	0.05		
Lowland Peatland (O)	0.19		
Karst Wetland (P)	0.13		
Karst Hilly Coast (Q)	0.11		
Coral Organic (R)	0.04		

4. RESULTS AND DISCUSSION

The results were classified into performance and comparative analysis. In the performance analysis, the efficiency of the classifier was evaluated, along with the efficacy of the optimization algorithm and the proposed method. On the other hand, comparative analysis assessed the performance of the proposed method against existing ones.

4.1. Analysis agricultural land cover changes

Agricultural land cover classes are crucial in providing food resources both directly and indirectly for humans. Moreover, land cover area experienced both a decrease and an increase in the area from 2009 to 2019. Significant changes occurred in dryland and rice field as shown in Figure 3.

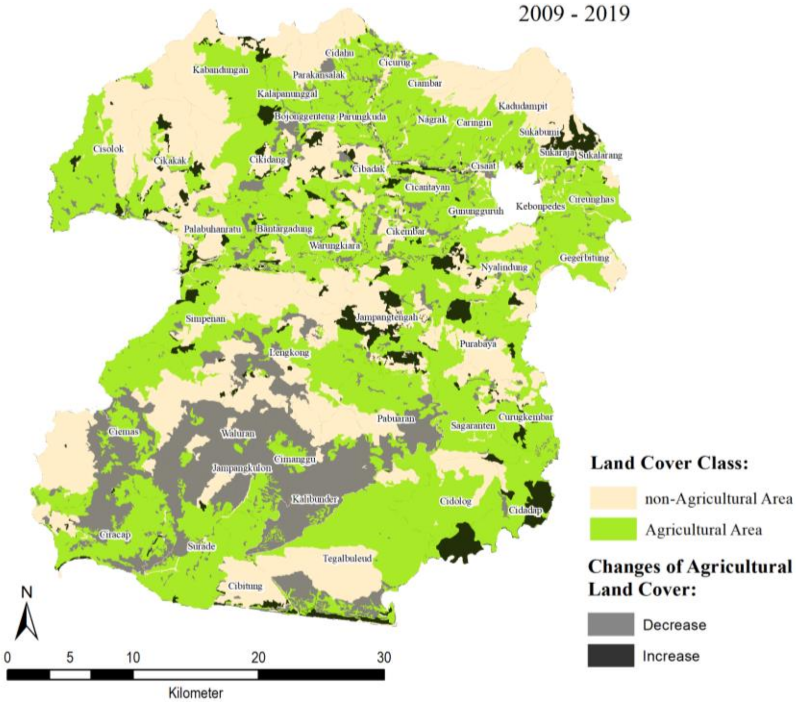

Figure 3. Agricultural land cover changes from 2009 – 2019 in Sukabumi Regency

Several land cover classes increased and decreased. In particular, the decrease was recorded in the southern part, while there was an increase in the southeast near Sukabumi, Cianjur Regency border. Between 2009 and 2019, substantial changes were recorded in the south, where dryland agriculture was converted into plantations. In the context of this study, dryland agriculture and rice field also changed due to land conversion but remain in agricultural land category. A substantial increase in area was observed in the southern area, with additional expansion occurring in the southeastern part near the border as well as central and northern areas. The highest change recorded was the conversion of dryland agriculture into plantations, affecting 58,187.62 hectares. This was followed by the conversion of land to settlements, impacting 3,748.35 hectares. Based on Table 4, there was a 16% decrease in agricultural land cover between 2009 and 2019, amounting to approximately 42,304.19 hectares. Moreover, non-agricultural land cover increased by 28%, or around 42,304.20 hectares.

Table 4. Area of agricultural land cover changes in Sukabumi Regency from 2009 to 2019

Regency	Year 2009		Year 2019	
	Agricultural Area (Ha)	Non-Agricultural Area (Ha)	Agricultural Area (Ha)	Non-Agricultural Area (Ha)
Sukabumi Regency	264,537.65	151,719.14	222,233.46	194,023.34

4.2. Demand of ecosystem services in food provision

Food needs were determined based on population distribution, which was multiplied by energy requirement for carbohydrates. In general, energy requirement was set at 65% or 300 grams/day of the total energy requirement for the average Indonesian population, as stipulated in the Regulation of Minister of Health of Indonesia Number 28 of 2019. This value amounted to 1,365 kcal/person/day out of a total value of 2,100 kcal/person/day. The distribution of food energy demand in 2009, 2014, and 2019 had the same pattern as population distribution pattern. According to Figure 4, demand was higher near the borders of Sukabumi City and Bogor. This correlation represented the principle that areas with higher population had higher food demand. Palabuhanratu Sub-Regency also had a high level of food energy demand, consistent with the population density as the Central Government of Sukabumi Regency. The middle to the south area had a low value of food energy demand. This was influenced by a less dense population, spreading across multiple areas. In addition, physical conditions such as morphology with moderately steep slopes favored land use types such as agriculture, plantations, fields, and forests.

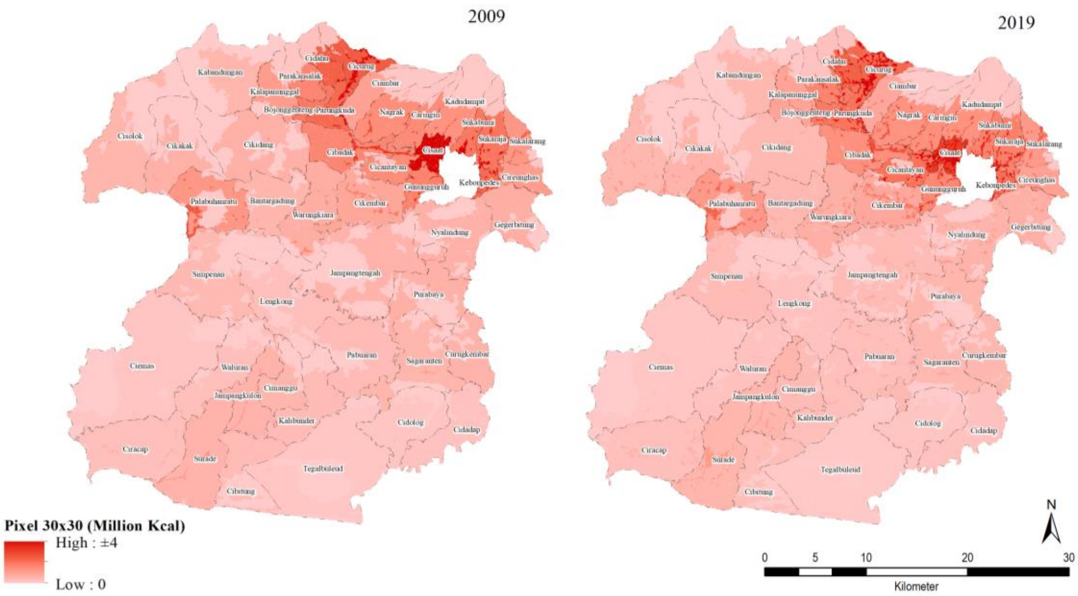

Figure 4. Food Demand in 2009 - 2019 Sukabumi Regency

4.3. Supply of ecosystem services in food provision

Supply of food provision services in 2009 had the highest staple food energy value in Ciemas District, with a total of approximately 210 billion kcal, followed by Surade and Ciracap District. In 2019, the highest energy-value materials were found in Jampang Tengah Regency, with a total of 199 billion kilocalories, representing a significant increase of 53.51% from 2014. Between 2009 and 2019, food supply was high across northern area, particularly near the foot of Mount Salak, Mount Gede, and Mount Pangrango. The coastal parts of northwest and south tended to have varied food supply, as shown in Figure 5. The changing distribution of food energy supply levels every year was influenced by several factors. These factors included changes in the types of food considered in this study, as well as the condition of land cover and ecoregions affecting ESI of food provision. Specifically, this index was used to distribute food energy across the various regencies. Physical conditions, such as ecoregions, dominated volcanic hills and mountains with relatively fertile soil types. Meanwhile, southern part of Sukabumi was characterized by structural hill ecoregions with less fertile soil types.

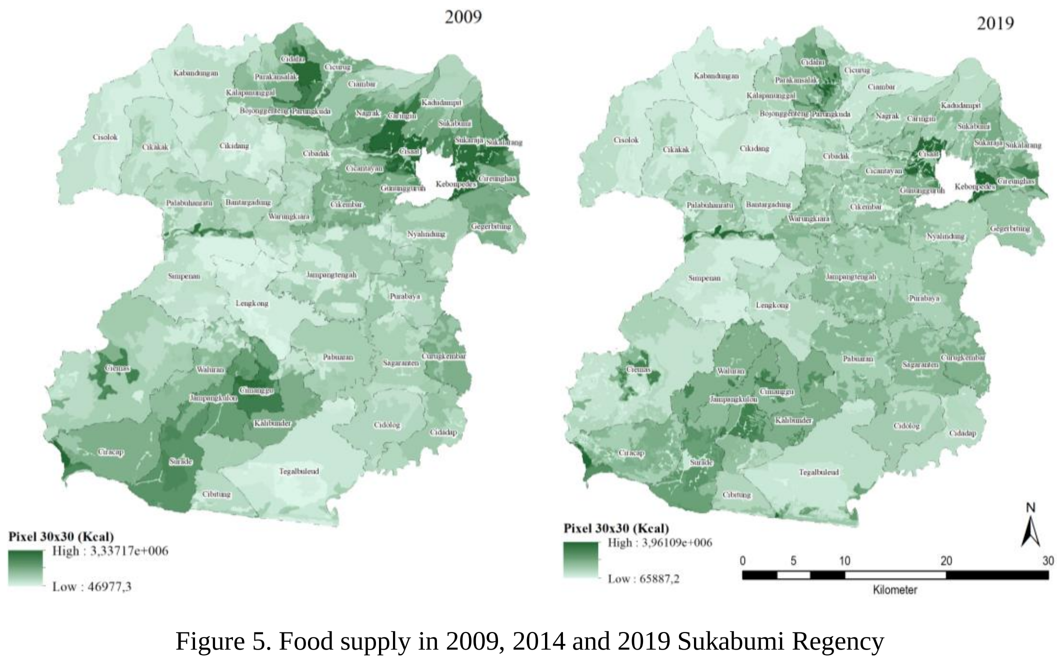

Figure 5. Food supply in 2009, 2014 and 2019 Sukabumi Regency

4.4. Analysis status of ecosystem services in food provision

The status of ecosystem services was determined using a threshold value comparison with population distribution. Typically, the threshold was obtained by dividing the availability of foodstuffs by the individual energy needs measured in kilocalories per year. According to Figure 6, the status "has exceeded" was dominant in northern and northwest areas, while southern part tended to "has not exceeded" status. It should be acknowledged that the physical condition of the areas influenced this distribution. For example, northern part was predominantly characterized by volcanic mountains with hilly topography. Soil conditions were mainly podsolics, latosol, and andosol, which were generally fertile. Meanwhile, southern part consisted of hills and structural mountains with hilly and mountainous topography. In this context, soil types included latosol, podsolic, and latosol. Land cover conditions in north varied but included high-density residential class. Southern area was primarily used for agricultural land, plantations, and others. Another important information to acknowledge was that social conditions also varied across area. This location had high population density, particularly around the border of Sukabumi City, Bogor Regency, and near national roads. The central government was located in northern part, in Cibadak and Palabuhanratu. Meanwhile, in the southern part, population was more spread out and not too dense, with a concentration found in Surade Regency. In northwestern part, such as Cisolok Regency, experienced a decrease in the “has exceeded” status. This change could be attributed to a 37% increase in food productivity from 2009 to 2019.

Changes in the status of ecosystem services were recorded from 2009 to 2019, with both increase and decrease in extent. Table 5 shows the extent of ecosystem services status of regency. Over one decade, the area with status of "has exceeded" experienced a fluctuating but experienced an increase from 2009 to 2019. This increase in "has exceeded" status amounted to approximately 12,643.29 hectares or increase of 3.04%.

In the context of this study, statistical analysis was used to determine whether agricultural land cover had a significant influence on the carrying capacity of food providers. The regression equation was tested for normality, and the result showed positive regression coefficient. This signified that agricultural land cover had a positive influence on population threshold value or the status of food providers. The analysis of regression equation showed that an increase in agricultural land area would increase the carrying capacity of ecosystem services for food provision. Specifically, a rise in agricultural land area would increase the possibility of a "has not exceeded".

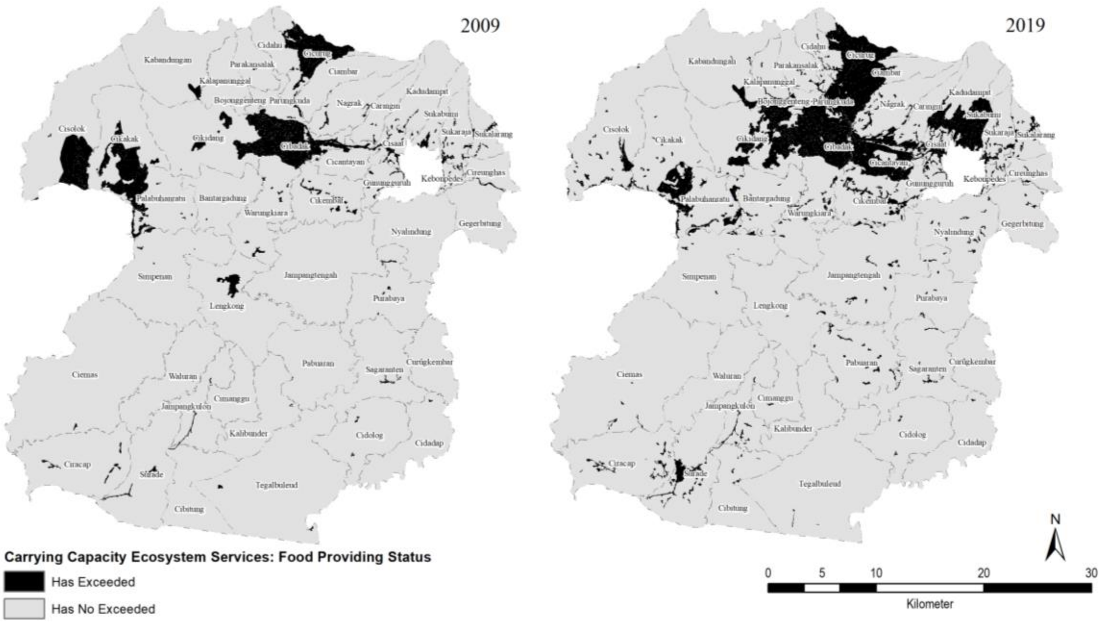

Figure 6. Carrying capacity of ecosystem services in food provision from 2009 – 2019 in Sukabumi Regency

Table 5. Percentage and size of ecosystem services in food provision from 2009–2019 in Sukabumi Regency

Ecosystem services in food provision status	Year 2009		Year 2019	
	Broad (Ha)	Percentage (%)	Broad (Ha)	Percentage (%)
Has exceeded	27,568.080	6.62%	40,211.370	9.66%
Has no exceeded	388,691.730	93.38%	376,048.440	90.34%

5. CONCLUSION

In conclusion, the status of dynamic condition of food-providing ecosystem services in Sukabumi Regency over one decade from 2009 to 2019 produced different values and patterns in each area. During this period, Cicurug, Cibadak, and Cicantayan Regencies had “has exceeded” status, implying that the environment had exceeded the threshold level and was unable to support or fulfill the needs of population. Other districts maintained a status of "has not exceeded", suggesting that the environment had not exceeded the threshold and was still able to meet the needs of population. The distribution of areas with "has exceeded" status was concentrated in the northern part, with densely populated areas and high intensity of undeveloped land. Despite the area being dominated by mountains and volcanic hills, with sufficiently fertile soil conditions, the productivity of environment was still insufficient to meet the needs of population.

Changes in agricultural land cover from 2009 to 2019 significantly influenced the condition or status of ecosystem services in food provision. The 16% decrease in agricultural land cover led to a reduction of "has no exceeded" status area and a 3% increase in "has exceeded" status. This relationship was confirmed through statistical analysis with a significance value of less than 0.05, signifying that agricultural land cover had an influence on population threshold or the condition/status of ecosystem services in food provision. Finally, the relationship between agricultural land cover and ecosystem services status was described by an equation. This equation showed that an increase in agricultural land cover area would raise the threshold value, thereby influencing the condition or status of ecosystem services in food provision.

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BIOGRAPHIES OF AUTHORS

Ananda Fitriani received the B.Sc. degree in geography from University of Indonesia, in 2021. From 2021 – 2023, she had work as an intern GIS analyst at Ministry of Agrarian Affairs and Spatial Planning and a surveyor at PT. PAM Lyonnaise Jaya (PALYJA). Currently, she is a mapping tax surveyor in Regional Revenue Agency (BAPENDA) of DKI Jakarta from 2023. Her research interests include environmental assessment, ecosystem services, spatial planning, and remote sensing with GIS technology. She can be contacted at email: anandaftrani@gmail.com.

Muhammad Dimyati was born in Solo. He obtained his BSc (1982) from Faculty of Geography, Department of Remote Sensing, Gadjah Mada University, and a master (1990) and doctoral degree (1997) of agricultural science, Lab of Regional Planning, Tropical Agriculture Division, Faculty of Agriculture, Kyoto University, Japan. Since 1983-2005, he has been working for the Ministry of Public Works, in the field of remote sensing, geographic information systems, and spatial planning. He was the deputy assistant of large-scale area development, then deputy assistant of integrated infrastructure, then deputy assistant of cooperation and partnerships, then deputy assistant of formal housing planning of the Ministry of Housings (2005-2014). He was the deputy of resources for science and technology of the Ministry of Science and Technology (2014-2015). He was a director general of strengthening for research and development, Ministry of Research, Technology, and Higher Education (2015-2019). Currently he is professor of Department Geography, Universitas Indonesia. He can be contacted at email: m.dimyati@sci.ui.ac.id.

Faris Zulkarnain was obtained S.Si. (Equals to Bachelor of Science) from Geography, Universitas Indonesia in 2013 and M.T. (equals to Master of Engineering) from civil engineering, Universitas Indonesia in 2017. Working as the lecturer for several undergraduate courses at Department of Geography, Universitas Indonesia since 2018. Has done research and project in the field of water resources, GIS, remote sensing, and urban environment. He can be contacted at email: faris.zulkarnain@sci.ui.ac.id. His research can be access on https://www.researchgate.net/profile/Faris_Zulkarnain.