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Local Sustainability Performance and Its Spatial Interdependency in Urbanizing Java Island: The Case of Jakarta-Bandung Mega Urban Region

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Abstract: Jakarta–Bandung Mega Urban Region (JBMUR), located in the western part of Java Island, Indonesia, is experiencing rapid regional development which can be observed from its increase in population density, massive changes of land-use from agricultural land into built-up area, rapid development of infrastructure and facilities, and advances in economic activities. Unfortunately, problems related to sustainability emerge along with this rapid regional development, primarily in decrease in environmental quality and social performance, leading to unsustainable development. This study aims: (1) to develop indicators promoting sustainable development at the subdistrict level, named the local sustainability index (LSI), utilizing factor analysis; (2) to observe local-scale spatial interdependency by employing local indicator of spatial association (LISA) statistics; and (3) to identify regional clusters based on LSI scores using K-means clustering method. Our LISA results show that spatial interdependency of local sustainability performances exists between local-scale spatial units: the LSI of a subdistrict is influenced by the sustainability state of the surrounding areas. Meanwhile, the clustering results show that most subdistricts in JBMUR are categorized as members of cluster 1 with low LSI values in economic and social dimensions but moderate in environmental dimensions.

Keywords: factor analysis; k-means clustering; local sustainability index; spatial association

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1. Introduction

Sustainability has been a general perspective in regional development [1]. This perspective recognizes that human's social and economic needs are constrained by environment and technology [2]. The term "sustainable development" is popular in current development discourses driven by limited natural resources and increased environmental damage [3,4]. There have been a lot of definitions of sustainable development. The well-known definition is that provided by the Brundtland Commission in 1987 [1,5–8]: a development that seeks to meet the needs of the present generation without reducing the ability to meet future needs [9–11]. Afterwards, various concepts have followed to comply with this terminology, including value change, moral development, social reorganization, and transformational process towards a better world in the future.

There are three pillars in the construction of sustainable development: economy, society, and ecology [12–16]. More precisely, the sustainable paradigm guides public policy to be formulated based on the selection of development alternatives that are not only economically feasible, but also ecologically friendly, and socially acceptable [17]. This paradigm emphasizes equity principles between the three pillars [9,18].

Although the theoretical concept of sustainability is widely accepted, measures to quantify a sustainable state are yet to be developed continuously [19,20]. Policymakers require timely information to build measures that demonstrates whether the current system is heading to a sustainable state or not [21]. Such measure can be represented by indicators quantitatively able [22–25] to assess policies [17], infrastructures [26], socioeconomic factors [27], resource uses [28], emissions [29], and other attributes contributing to and profit from the region's metabolism, prosperity, and quality of life [30–32].

An indicator is a variable that may describe one characteristic of the state of a system. It is commonly presented through observed or estimated data [33]. Sustainable development indicators are needed to guide policies and decisions at all levels, whether at the village, city, district, state, region, nation, continent, or worldwide level [34,35]. Previously, The Compendium of Sustainable Development Indicator Initiatives, hosted and managed by the International Institute for Sustainable Development, lists over 500 sustainability indicators, of which 67 indicators are for global scope, 103 are for national scope, 72 are for state or provincial scope, and 289 are for local or metropolitan scope [36].

The ability to estimate the relationship between environmental conditions and human wellbeing [37,38] is a fundamental factor of a good indicator. An indicator does not necessarily include all sustainability aspects since they often become subjective and meaningless [21]. In addition to indicators, indices are also needed to quantify sustainability and supervise several aspects of development subsequently. In general, "indices" are statistical indicators that provide appropriate quantitative information that simplifies analysis of the phenomenon under study. An "index" is a quantitative aggregation of many indicators. It can provide a view of a multidimensional, simplified, and coherent system [39]. Indices normally give a static overview of a system [40]. When calculated occasionally, indices can indicate the tendency of the system whether it becomes more sustainable or not and highlight the driving factors that are most responsible. Sets of indicators and their aggregation into indices are increasingly used to drive policy decisions [35,39].

Indicators and indices for sustainable development have been widely discussed at the regional, national, and global levels [41,42] but still discussed very limitedly at the local level [43–47]. Some argue that studies at the regional, national, and global levels tend to be economically biased. Meanwhile limited studies at the local level do not only focus on economic, but also on environmental and social indicators [48]. Specifically, spatial dependency between locations is stronger at the local level rather than national or global level. The sustainability performance of a location is influenced by sustainability conditions of its surrounding [49]. The enactment of the Law on Village Autonomy in Indonesia requires a formulation of sustainable development indicators at the village level [50,51]. These indicators are expected to be used as measuring tools and guidance for local authority policymakers in implementing development programs.

In Java Island of Indonesia, the establishment of the sustainability index and indicators has become crucial. Java Island covers merely 6.7 percent of Indonesia's land [52] and is where built-up areas are concentrated, housing approximately 43% of Indonesia's population [53]. The island is experiencing rapid urban development, followed by many social and environmental problems, such as poverty and natural disasters [54]. Among the regions in Java Island, Jakarta-Bandung Mega Urban Region (JBMUR) has experienced the most rapid growth, urbanization, social problems, and environmental destruction [55]. JBMUR is formed as a result of urban area expansion of two metropolitan areas, namely Jakarta metropolitan area and Bandung metropolitan area. Jabodetabek's expansion is more dominant [56]. Its contribution to the national gross domestic product (GDP) reaches

more than 25% [57]. The region's development has focused less on sustainability aspects, where several parts of the region have low sustainability index [49,58].

The aims of this research are: (1) to develop indicators promoting sustainable development in JBMUR at the subdistrict level, named the local sustainability index (LSI) utilizing factor analysis; (2) to observe local-scale spatial interdependency of LSI by employing local indicator of spatial association (LISA) statistics; and (3) to identify regional clusters based on the LSI value of the three sustainability dimensions using the K-means clustering method.

2. Materials and Methods

2.1. Study Area

This study focuses on building sustainability indicators and indexes at JBMUR [50,59]. Geographically, this region is located between 5°55′ to 7°30′ South latitude and 106°20′ to 107°55′ East longitude, with a total area of 16,607.29 km^2. JBMUR is formed as a result of urban area expansion of the Jakarta metropolitan area (also known as Jabodetabek) and the Bandung metropolitan area (also known as Bandung Raya). Jakarta is the capital of Indonesia and Bandung is the capital of West Java province. In total, JBMUR covers 8 regencies and 12 municipalities. The regencies are Bogor, Purwakarta, Cianjur, Bandung Barat, Bandung, Karawang, Bekasi, and Tangerang. Meanwhile, the municipalities are West Jakarta, North Jakarta, East Jakarta, South Jakarta, Center Jakarta, South Tangerang, Tangerang, Bogor, Bekasi, Depok, Cimahi, and Bandung (Figure 1). JBMUR consists of 335 *kecamatan* (subdistricts) and 2954 *desa* (villages). Our analysis is at subdistrict level.

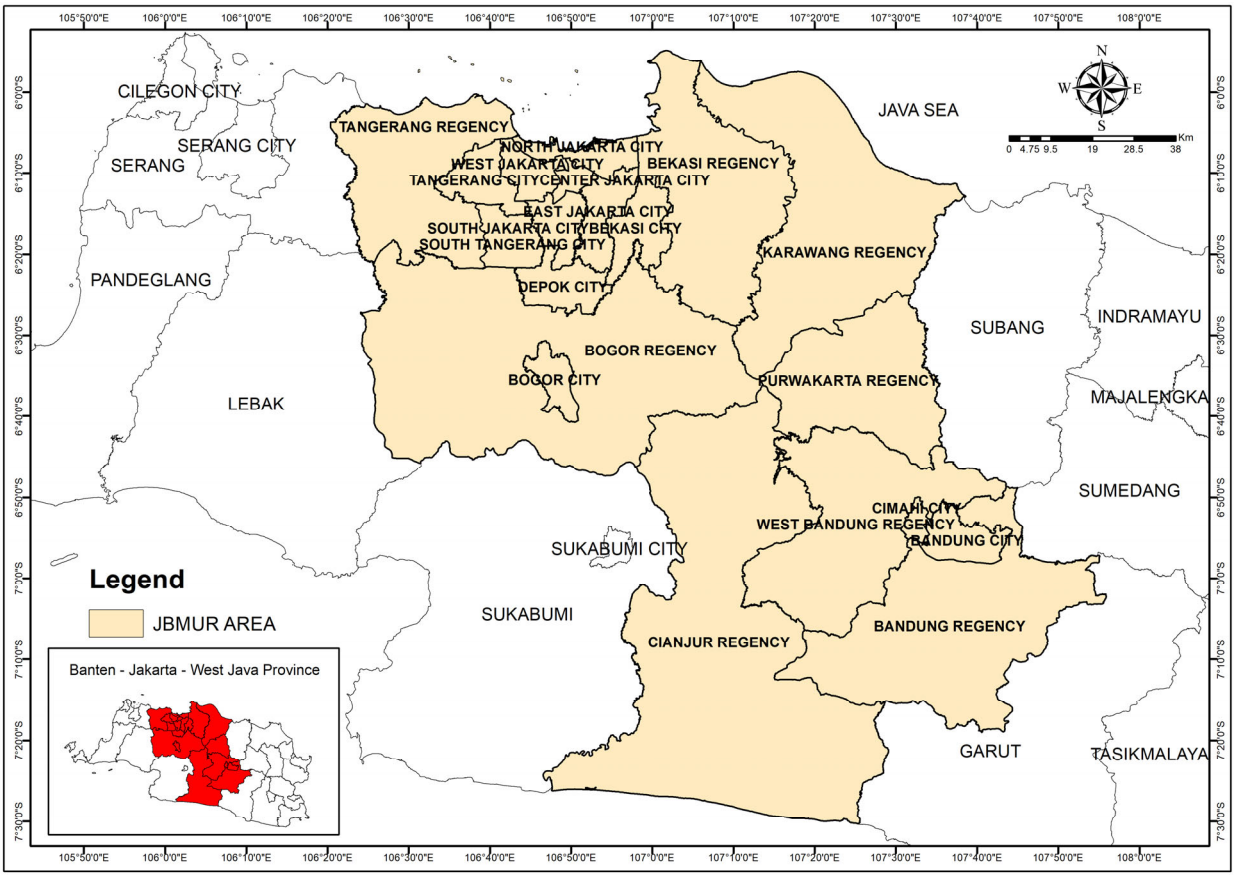

Figure 1. The administration map of the JBMUR.

2.2. Methods

One of the challenges faced in developing local sustainability variables in this research is the availability of data at the local level. In this research, we strongly depend on

Data Potensi Desa or *Data Podes*, literally translated as Village Potential data, collected by Statistics Indonesia. Village Potential data are collected routinely 3 times in a period of 10 years to support the Population Census, Agricultural Census, or Economic Census activities. Statistics Indonesia has carried out Village Potential data census 2018 in all regencies/municipalities, subdistricts, and village level government administration areas. The results of this census are data concerning availability of infrastructure, social and economic potential owned by villages, subdistricts, regencies/municipalities throughout Indonesia. Thus, important facts related to the availability of infrastructure and the potential possessed by each region can be monitored on a regular basis and continuously [50,59]. The Village Potential data used in this research are the latest data available, collected in 2018.

LSI is a development sustainability index at the local level which was first developed by the author in 2016 within the study area in the Greater Jakarta Metropolitan Area (Jabodetabek) with a unit of analysis per village (desa). After being tested in the Jabodetabek metropolitan area, this index has also begun to be tested in several other areas that have various characteristics with different units of analysis using several modified variables or indicators.

From Village Potential data, the local sustainability index (LSI) was developed based on 50 variables (indicators) which were grouped according to the three sustainability dimensions: economy (17 variables), social (19 variables), and environment (14 variables). We filtered and selected relevant variables to describe sustainability. Village Potential data provides data at village level, but then, in this research, data are aggregated and adjusted to subdistrict level.

LSI was developed by employing factor analysis (FA) to select the variables/indicators [49,60]. FA is a statistical method that aims to describe the variability between observed variables and correlated variables. The potential unobserved (underlying) variables are referred to as factors, which are lesser in number than the observed variables. FA looks for combined variation in response to unobserved latent variables [49,60]. Factor loading of a variable measures the extent to which a variable is related to a particular factor [49,60]. The general rationale behind FA is that the information obtained about the interdependencies between the observed variables can be used later to reduce the set of variables in the data set.

FA is used to develop a composite index of each dimension based on factor scores and factor loadings [60,61]. The number of factors is determined by eigenvalues > 1. This method is suitable in our case due to the variability of data measurement unit. The 50 variables included in factor analysis (FA) model are listed in Table 1.

Table 1. List of variables included in Factor Analysis (FA) model.

Code	Variables
	Economic dimension (k = 1)
V1	Average distance to railway station (km)
V2	Length to the nearest bank (km)
V3	Length to the nearest market (km)
V4	Length to the central business district (CBD) (km)
V5	Length to the nearest city (km)
V6	Number of restaurants and food stalls (per 1000 population)
V7	Number of hotels and lodgings (per 1000 population)
V8	Percentage of built-up area (%)
V9	Infrastructure index
V10	Average distance to toll road (km)
V11	Number of industries other than retails (per 1000 population)
V12	Households using electricity (%)
V13	Average distance to shopping center (km)
V14	Average distance to the village head office center (km)
V15	Number of minimarkets, shops, and markets (per 1000 population)
V16	Cooperatives and banks (per 1000 population)
V17	Regional revenue (PAD) (million rupiahs)

Table 1. *Cont.*

Code	Variables
	Social dimension (*k* = 2)
V18	Mean length to formal education facilities (from kindergarten to university) (km)
V19	Health facilities (hospitals, doctors, pharmacies, clinics, health centers) (per 1000 population)
V20	Mean length to health facilities (hospitals, pharmacies, clinics, health centers) (km)
V21	Medical personnel (per 1000 population)
V22	Diarrhea and vomiting sufferer (per 1000 population)
V23	Dengue fever sufferer (per 1000 population)
V24	Respiratory tract infection sufferer (per 1000 population)
V25	Toddler deaths (per 1000 population)
V26	Maternal mortalities (per 1000 population)
V27	Indonesian labor forces (TKI) (%)
V28	Poor people (%)
V29	Formal education facilities (from kindergarten to university) (per 1000 population)
V30	Measles sufferer (per 1000 population)
V31	Malaria sufferer (per 1000 population)
V32	Tuberculosis sufferer (per 1000 population)
V33	Malnutrition sufferer (per 1000 population)
V34	Mortalities (per 1000 population)
V35	Criminalities (evidence)
V36	Population density (people/km^2)
	Environmental dimension (k = 3)
V37	Forest (%)
V38	Plantation (%)
V39	Swamp, ponds, and water body (%)
V40	Percentage of rice field (%)
V41	Percentage of other agricultural area (%)
V42	Rice-field land conversion into non-agricultural land (ha)
V43	Non-rice-field land conversion into non-agricultural land (ha)
V44	Percentage of households living in riparian river (%)
V45	Landslide events (evidence)
V46	Floods events (evidence)
V47	Flash floods events (evidence)
V48	Earthquakes events (evidence)
V49	Whirlwind events (evidence)
V50	Forest fire events (evidence)

The FA model is as follows:

$$LSI_{ki} = \sum_{m=1}^{n_k} E_{km}.S_{kmi} \quad (1)$$

where:

LSI_{ki} is LSI for kth dimension on ith subdistrict;
k is dimension (1 for economy; 2 for social; 3 for environment);
E_{km} is eigenvalue for kth dimension on mth factor;
S_{kmi} is factor score for kth dimension, mth factor on ith subdistrict;
and i is 1, 2, 3, . . . , n.

To standardize LSI value on a scale of 0–100, we used the following formulation to produce standardized LSI value on a 0–100 scale (LSI_{ki} (std)):

$$LSI_{ki}(std) = (LSI_{ki} - LSI_{ki}(min))\left(\frac{100}{LSI_{ki}(max) - LSI_{ki}(min)}\right) \quad (2)$$

Then, after LSI is obtained, a weight or contiguity matrix based on shapefiles' polygon proximity is employed to impose a neighborhood structure of the data. It is to assess the

degree of similarity among locations and values. The methods used were Global and Local Moran's *I* (LISA statistics) with the formula as follows:

$$I = \frac{\sum_{i=1}^{n} W_{ij}\left(LSI_{ki} - \overline{LSI_k}\right)\left(LSI_{kj} - \overline{LSI_k}\right)}{Z_{LSI_k}^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \quad (3)$$

$$I_i = \frac{\sum_{i=1}^{n} W_{ij}\left(LSI_{ki} - \overline{LSI_k}\right)\left(LSI_{kj} - \overline{LSI_k}\right)}{Z_{LSI_k}^2 \sum_{j=1}^{n} W_{ij}} \quad (4)$$

where:

I is Global Moran's Index; I_i is Local Moran's I;
LSI_{ki} is the value of LSI for kth dimension on ith subdistrict;
LSI_k is the mean of LSI_k;
W_{ij} is contiguity matrix reflecting the proximity of subdistrict i's and subdistrict j's locations;
n is the number of subdistricts;
and $Z_{LSI_k}^2$ is the LSI_k's variance.

After calculating the value of the local sustainability index (LSI) of economy (LSIeco), social (LSIsoc), and environment (LSIenv), cluster analysis was employed in this study to identify the typologies of subdistricts in JBMUR based on local sustainability performance. Clustering is one of the most common exploratory data analysis techniques used to get an intuition about the structure of the data. It can be defined as the task of identifying subgroups in the data such that data points in the same subgroup (cluster) are very similar while data points in different clusters are very different (minimizing variance within group/cluster and maximizing variance between groups/clusters). Cluster analysis is a tool or technique to group similar observation into a number of clusters based on the observed values of several variables for each individual. In cluster analysis, a large number of methods are available for classifying objects on the basis of their (dis)similarities. Several well-performed methods in cluster analysis include Ward's minimum variance method and average linkage cluster analysis (two hierarchical methods), and k-means relocation analysis based on a reasonable start classification [62]. Cluster analysis can be a powerful statistical tool to classify or to create regional typologies based on their similar characteristics as shown in some research [63–73].

In this research, we employed multivariate analysis using the K-means clustering method, a non-hierarchical method. This technique is commonly used when clustering a large data rather than clustering using a hierarchical one. The K means clustering algorithm divides a set of n observations into k clusters. K means clustering forms the groups in a manner that minimizes the variances between the data points and the cluster's centroid. In this study, the distance measure used in clustering analysis is Euclidean distance. Data used were values resulted from LSI in each three dimensions (LSIeco, LSIsoc, and LSIenv). Cluster analysis in this study was run in Statistica 8.0 (Statsoft, Tulsa, OK, USA). The clusters members were displayed spatially using ArcGIS 10.3 (ESRI, Redlands, CA, USA). The number of clusters is determined by silhouette method [74].

3. Results and Discussion

3.1. Local Sustainability Index

To assess the sustainability performance of the region, appropriate indicators are often developed for the use of analysis and decision makers [75]. In this research, we develop the local sustainability index to identify sustainability performance at the subdistrict level of JBMUR. Factor analysis (FA) was used to select key performance indicators/variables of economy (LSIeco), social (LSIsoc), and environment (LSIenv) to form the local sustainability index (LSI). Factor analysis is a technique or statistical method that is used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. FA can reduce a large number of variables into fewer

numbers of factors. In this research, FA which was conducted to determine a composite index for each dimension resulted in a different number of factors. Each factor captures a certain amount of the overall variance in the observed variables, and the factors are always listed in order of how much variation they explain [76–78].

Every factor has their own eigenvalue. The eigenvalue is a measure of how much of the common variance of the observed variables a factor explains. Any factor with an eigenvalue ≥ 1 explains more variance than a single observed variable. Eigenvalues measure the amount of variation in the total sample accounted for by each factor. The ratio of eigenvalues is the ratio of explanatory importance of the factors with respect to the variables. If a factor has a low eigenvalue, then it is contributing little to the explanation of variances in the variables and may be ignored as less important than the factors with higher eigenvalues [76,79]. The factors that explain the least amount of variance are generally discarded. Variables representing each factor of the three dimensions are shown on Tables 2–4, respectively, marked in red.

Table 2. Factor loading of economic factor analysis.

Var	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
V1	−0.003	−0.073	−0.026	0.876	−0.103
V2	0.803	−0.125	0.103	−0.055	−0.021
V3	0.623	0.046	−0.092	0.017	−0.118
V4	0.814	−0.148	−0.027	0.228	0.132
V5	0.765	−0.197	0.134	0.197	0.208
V6	−0.082	0.126	0.758	0.250	0.062
V7	0.185	−0.075	0.336	−0.281	−0.321
V8	−0.109	0.880	−0.134	0.028	−0.189
V9	−0.119	0.650	0.069	−0.145	0.530
V10	0.141	−0.170	0.103	0.830	0.051
V11	0.233	−0.108	0.016	−0.015	0.880
V12	−0.027	0.893	0.078	−0.113	0.009
V13	0.769	−0.052	0.060	−0.009	0.223
V14	0.837	0.059	0.020	0.100	−0.084
V15	0.346	0.026	0.749	0.063	0.038
V16	−0.184	−0.165	0.668	−0.273	−0.063
V17	0.215	0.044	−0.021	0.268	0.033
Expl.Var	3.916	2.177	1.776	1.887	1.349
Prp.Totl	0.230	0.128	0.104	0.111	0.079
Eigenvalue	4.339	2.119	1.769	1.619	1.259
% total	25.524	12.465	10.405	9.522	7.406
Cumulative	25.524	37.989	48.394	57.916	65.322

Table 3. Factor loading of social factor analysis.

Var	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
V18	0.197	−0.044	0.277	0.023	0.619	0.081
V19	0.807	0.001	0.069	−0.030	0.019	−0.122
V20	0.268	0.076	−0.094	−0.009	0.136	0.727
V21	0.731	0.026	0.101	−0.008	0.025	0.282
V22	0.030	0.935	−0.002	0.070	−0.037	−0.014
V23	0.097	0.541	−0.121	0.459	−0.228	0.185
V24	−0.033	0.910	−0.040	−0.041	0.060	−0.095
V25	0.526	0.030	0.075	0.082	0.272	−0.187
V26	0.324	−0.059	−0.071	0.008	0.352	−0.239
V27	0.149	−0.050	−0.079	0.100	0.733	0.001
V28	0.022	0.048	−0.808	0.018	−0.095	0.109
V29	0.881	0.054	0.007	0.035	−0.005	0.051
V30	0.052	0.080	0.010	0.868	0.013	−0.035
V31	0.000	−0.036	0.040	0.802	0.175	0.057
V32	0.187	0.260	0.049	0.370	−0.275	−0.358

Table 3. *Cont.*

Var	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
V33	0.195	0.086	0.075	−0.063	0.129	−0.622
V34	0.616	−0.035	−0.132	0.179	0.346	−0.034
V35	0.098	−0.118	−0.346	0.072	−0.364	−0.022
V36	−0.162	0.078	−0.818	−0.089	0.040	0.065
Expl.Var	2.979	2.120	1.602	1.819	1.581	1.305
Prp.Totl	0.157	0.112	0.084	0.096	0.083	0.069
Eigenvalue	3.381	2.429	1.710	1.527	1.231	1.128
% total	17.795	12.787	8.999	8.035	6.477	5.939
Cumulative	17.795	30.582	39.581	47.616	54.093	60.033

Table 4. Factor loading of environmental factor analysis.

Var	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
V37	0.698	−0.032	0.048	−0.035	0.066
V38	0.866	0.041	−0.034	0.093	−0.032
V39	−0.180	−0.043	0.041	0.741	−0.042
V40	0.440	−0.069	0.145	0.715	0.062
V41	0.566	0.202	−0.097	0.353	0.148
V42	0.018	0.877	0.073	0.009	0.015
V43	0.104	0.874	0.039	−0.087	−0.017
V44	0.159	0.046	0.026	−0.040	−0.875
V45	0.674	0.109	0.399	−0.135	−0.034
V46	−0.046	−0.023	0.724	0.301	−0.157
V47	0.227	−0.091	0.762	−0.099	0.058
V48	0.592	0.020	0.488	−0.129	0.078
V49	−0.011	0.305	0.652	0.073	0.025
V50	0.243	0.038	0.001	−0.028	0.476
Expl.Var	2.738	1.701	1.970	1.346	1.061
Prp.Totl	0.196	0.122	0.141	0.096	0.076
Eigenvalue	3.281	1.678	1.570	1.263	1.024
% Total	23.436	11.984	11.212	9.023	7.317
Cumulative	23.436	35.420	46.632	55.654	62.971

Based on FA results for economic dimension, FA determined five factors from seventeen variables representing LSIeco. Variables representing each factor are shown on Table 2, marked in red. According to the factor loading's values, factor 1 is represented by distance to the nearest bank (V2), distance to CBD (V4), length to the nearest city (V5), the average distance to the shopping center (V13), and average distance to the village head office center (V14). These indicators were related to accessibility to economic facilities. Factor 2 is represented by built-up area (V8) and households using electricity (V12). Factor 3 is proxied by the number of food stalls and restaurants (V6) and the number of markets, minimarkets, and shops per 1000 population (V15). Factor 4 is composed of the average distance to railways station (V1) and the average distance to toll road (V10). Factor 5 is represented by the number of industries (V11). The eigenvalue of factor 1 is higher than the eigenvalue of factor 2. The eigenvalue of factor 2 is higher than the eigenvalue of factor 3, etc. In this case, the eigenvalue of factor 1 is the highest (4.339), while the eigenvalue of factor 5 is the lowest (1.259). It means that factor 1 has highest contribution to the explanation of variances in the variables representing the local sustainability index for economic dimension (LSIeco). Table 2 below show the factor loading of economic factor analysis. Factor loading itself is basically the correlation coefficient for the variable and factor. Factor loading shows the variance explained by the variable on that particular factor. Regarding the social dimension, FA established six factors representing LSIsoc, as shown in Table 3. Factor 1 is represented by health facilities (V19), medical personnel (V21), and the number of formal education facilities (V29). Factor 2 is represented by people

suffering from diarrhea and vomiting (V22), and people suffering from respiratory tract infection (V24), which reflected the local communities' health. Factor 3 is represented by poverty (V28) and population density (V36). Factor 4 is represented by people suffering from measles per 1000 population (V30) and people suffering from malaria (V31). Factor 5 is represented by Indonesian labor forces (TKI) (V27), while factor 6 is represented by the mean distance to health facilities (V20). Based on Table 3, it can be seen that the eigenvalue of factor 1 is the highest (3.381), while the eigenvalue of factor 6 is the lowest (1.128). This means that factor 1 has highest contribution to the explanation of variances in the variables representing the local sustainability index for social dimension (LSIsoc). Table 3 below show the factor loading of social factor analysis.

Related to the environmental dimension/aspects, based on the factor analysis results, five factors from ten variables represent LSIenv, as shown in Table 4. Factor 1 is represented by plantation area (V38). Factor 2 is composed of rice-field-to-non-agricultural land conversion (V42) and non-rice-field-to-non-agricultural land conversion (V43). Factor 3 is represented by the floods events (V46) and flash floods events (V47). Factor 4 is represented by the swamps, ponds and water bodies (V39), and rice fields (V40). Factor 5 is represented by households living in the riparian river (V44). Based on Table 4, it can be seen that the eigenvalue of factor 1 (3.281) > factor 2 (1.678) > factor 3 (1.570) > factor 4 (1.263) > factor 5 (1.024). In this FA result for LSIenv, factor 1 has highest contribution to the explanation of variances in the variables representing the local sustainability index for environmental dimension (LSIenv). Table 4 below show the factor loading of environmental factor analysis.

Figure 2 shows the spatial distribution values of LSIeco, LSIsoc, and LSIenv in the Jakarta-Bandung Mega Urban Region (JBMUR). As shown in Figure 2, higher values of the LSIeco are concentrated in the municipalities of Jakarta Province. Some high values appeared as well in several subdistricts in Bandung City and its surrounding region. This pattern indicates that these regions enjoyed better economic performance compared to others. The diagram in Figure 2 displays that only 4% of the total subdistricts in JBMUR have high LSIeco value (between 75.01–100.00), and 71% of subdistricts have moderate values (between 25.01–50.00). As for LSIsoc, 77% of subdistricts have low values (between 25.01–50.00), and only 1% have high values (75.01–100.00). The opposite condition applies for LSIenv, where most subdistricts have high values (14% of subdistricts have index scores between 50.01–75.00 and 62% subdistricts have index between 25.01–50.00). Most subdistricts in Jakarta Province have low values of LSIenv, while on the other hand, many subdistricts in Bogor, Cianjur, and Bandung Regency have high values of LSIenv.

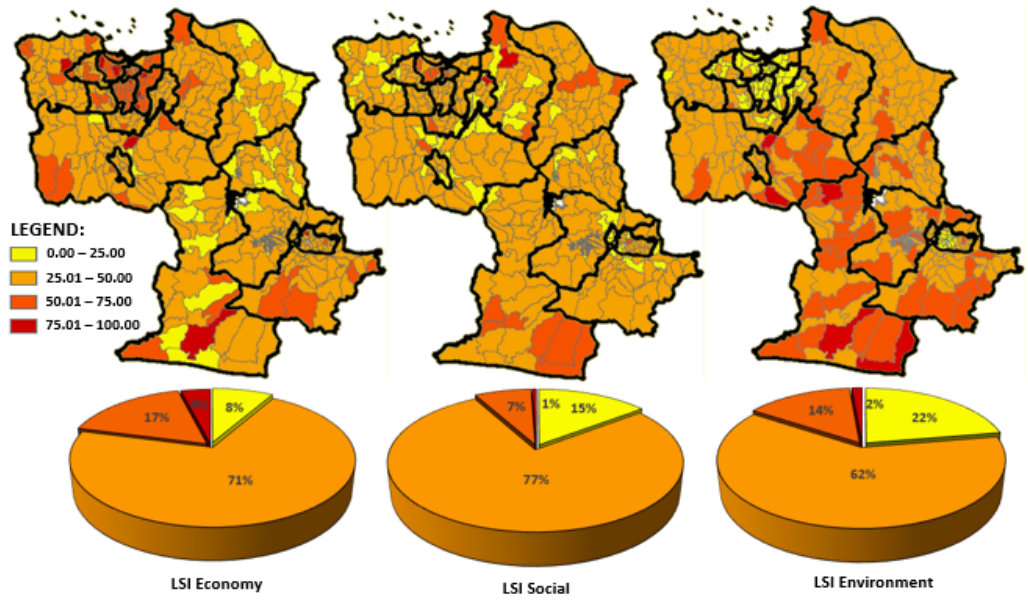

Figure 2. Spatial distribution of the local sustainability index (LSI): economy, social, and environment.

3.2. Local-Scale Spatial Interdependency of LSI

Figure 3 shows the Moran scatter plot and LISA cluster map for each LSI. The Moran scatters plot shows that the spatial autocorrelation value or global Moran index for LSIeco, LSIsoc, and LSIenv are 0.33, 0.18, and 0.45, respectively. It shows that all the LSI have a clustered pattern since the value is positive and more than 0. The result of the local Moran index may help to identify local spatial autocorrelation of LSI value in JBMUR. As for LSIeco, High-High (HH, high values surrounded by high values) category subdistricts are in Jakarta, Tangerang, Bekasi, and Depok (in the LISA cluster map, the HH subdistricts are shown in red). This pattern means that LSIeco is concentrated and clustered in the center area of Jabodetabek, or mainly in the subdistricts of Jakarta Province and its surrounding area.

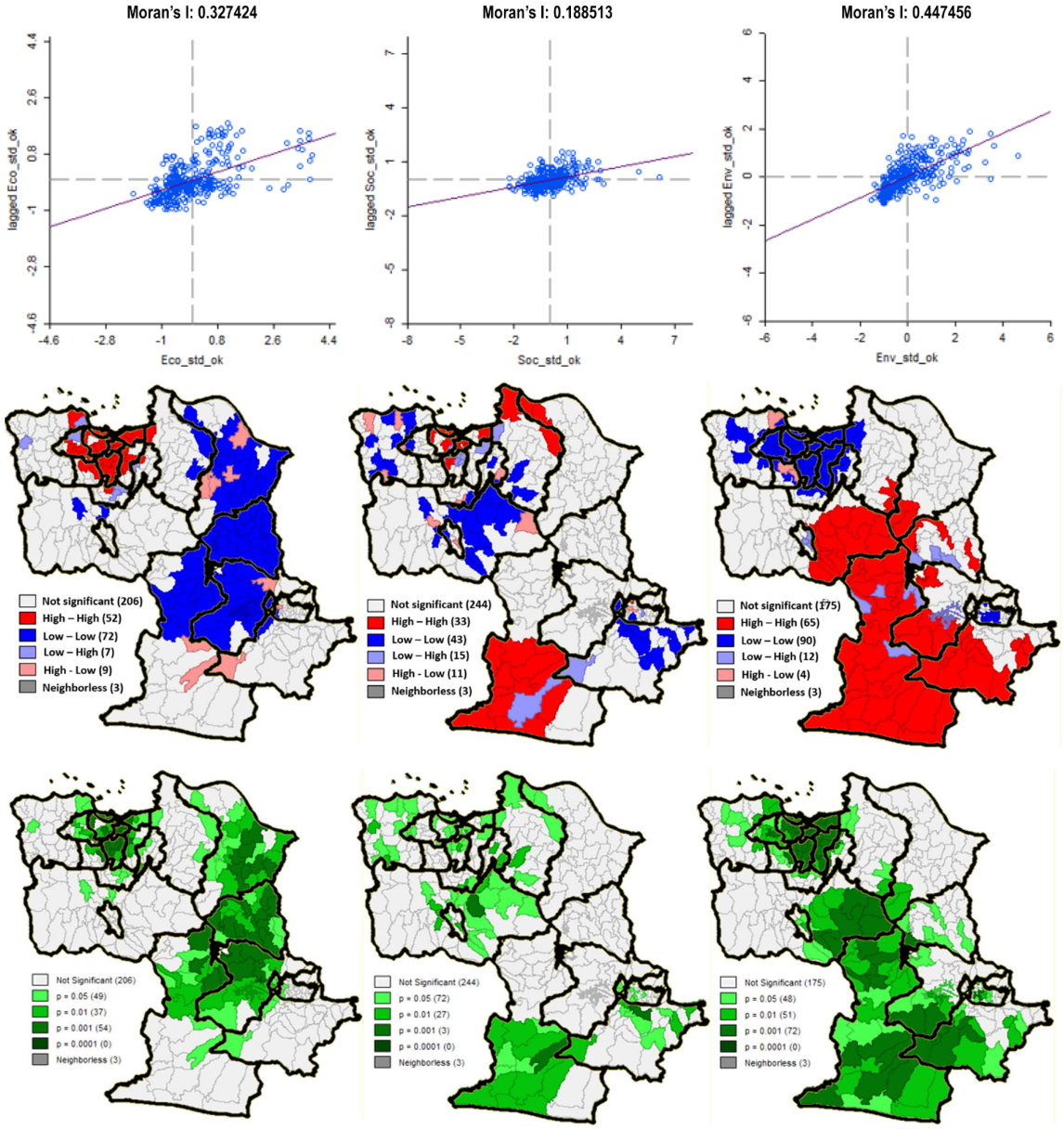

Figure 3. Global and local Moran's index (LISA) for LSI economy, social, and environment and its statistical significance values.

As for LISA value of LSIsoc, HH category subdistricts are concentrated in the southern side of Cianjur Regency and in the northern side of Karawang Regency. Regarding LISA value of LSIenv, HH category subdistricts are concentrated in Cianjur Regency, the eastern side of Bogor Regency, the western side of Bandung, and Bandung Barat Regency. LL

category subdistricts are concentrated in the Jakarta Province, Tangerang, Bekasi, and Depok. Most subdistricts in Jakarta Province with high LISA values of LSIeco, have low LISA values of LSIenv. These results aligned with Pravitasari et al. [49,80] which mentioned a trade-off between economy and environmental conditions in Jakarta Province and its surrounding area.

3.3. LSI-Based Clusters

The last result of this study is a cluster map of subdistricts based on the characteristics of local sustainability performance or LSI value (LSI_1, LSI_2, and LSI_3). According to the result, there are three clusters produced by the K-means clustering method. The distribution member of each cluster can be seen in Figure 4. There are 74 subdistricts (21%) categorized as cluster 3, and most of those subdistricts are in Jakarta Province. Their characteristics are high sustainability in the economy and social dimension but low in environmental dimension. This condition also occurs in other cities in the world [81,82]. There are 96 subdistricts (28%) categorized as cluster 2: moderate scores in economic and social dimension but high values in environmental dimension. Most subdistricts in JBMUR are categorized in cluster 1 (179 subdistricts or 51%), i.e., having low values in economy and social dimension but moderate value in environmental dimension. Subdistricts of Cluster 2 and Cluster 1 are scattered across JBMUR.

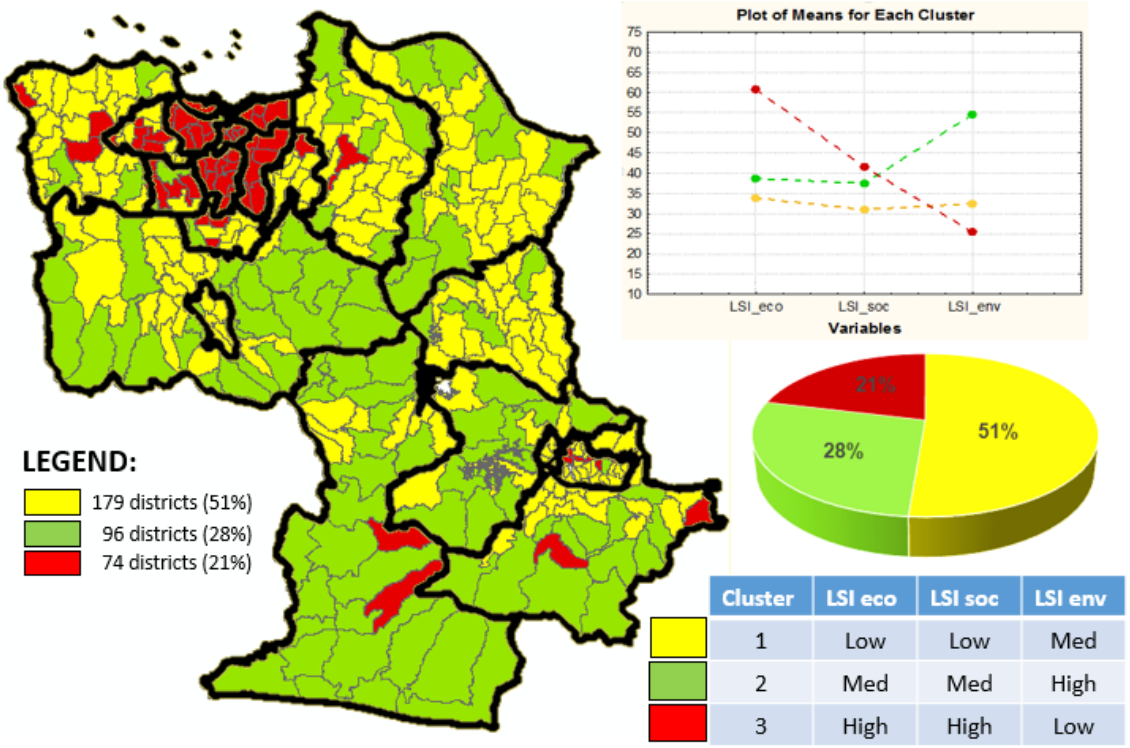

Figure 4. Typology of subdistricts in JBMUR based on the characteristics of LSI.

This study's results strengthen the previous study's conclusion, especially regarding the metropolitan core of Jakarta and Bandung in terms of their sustainability status [83–85]. Metropolitan cores, especially Jakarta and Bandung in our case tend to have low environmental sustainability and high economic sustainability. High economic sustainability in urban centers is driven by completeness of facilities and variety of sources of income. However, in general, JBMUR metropolitan centers often experience environmental problems such as floods. Therefore, metropolitan centers tend to have low environmental sustainability.

In Jakarta, the core of JBMUR, rapid urbanization has led to environmental degradation and food production [85–87]. Environmental degradation is marked by land subsidence, saltwater intrusion, polluted water sources, and air pollution [83,84]. Furthermore, several

studies have also stated that Jakarta development has exceeded the carrying capacity [58,88], indicated by the frequent flooding, because the riverbank is used for settlements, and the lack of water catchment areas (limited green space) [85,89]. In social aspects, the continuing in-migration to Jakarta presents the problems such as slum areas, unemployment, crimes, and disparity [56]. However, regardless the inconvenience of social and environmental condition, metropolitan centers such as Jakarta remain attractive for migrants because they are vital economic centers and hubs in Indonesia, and even in Southeast Asia [90,91].

4. Conclusions

The local sustainability index (LSI) which was developed in this research can be used as indicators to promote sustainable development in JBMUR at the subdistrict level. By utilizing factor analysis, we could create a composite index of LSI for each dimension. Characteristic variables that make up the local sustainability index (LSI) in the economic dimension include factors of accessibility to economic facilities and infrastructure; accessibility to megacity cores; and high industrial activity. Characteristic variables that make up LSI in the social dimension include factors of accessibility to public facilities and health; public health conditions; poverty rates and access to employment; and population density. Meanwhile, the indicators that make up the LSI on the environmental dimension include the presence of green areas; disaster aspects; and the geographic physical characteristics of the region.

In general, subdistricts with high LSIeco are concentrated in subdistricts of Jakarta Province, and several subdistricts in Bandung City and its surroundings. However, high LSIeco values are generally not followed by a high LSIenv value. This phenomenon is found in most subdistricts in Jakarta Province, where this region has a very high percentage of built-up areas. On the other hand, some subdistricts in Bogor, Cianjur, and Bandung Regency have higher LSIenv values, where these regions have a moderate or low percentage of built-up area. As for LSIsoc values, there is no significant pattern found. A total of 77% of the subdistricts in JBMUR are categorized as having low LSIsoc values.

Spatial interdependency of local sustainability performance exists in subdistricts —the local-scale spatial units. The LSI in each subdistrict is strongly influenced by the sustainability condition of its surrounding areas. Then, based on the subdistrict clustering, most subdistricts in JBMUR are categorized in cluster 1 (179 subdistricts or 51% from the total number of subdistricts), which have low values in economy and the social dimension but moderate values in the environmental dimension. In addition, nearly all subdistricts of Jakarta Province (21% of the total number of subdistricts) are categorized in cluster 3, characterized by high values in the economic and social dimension but low values in environmental dimension.

The combination of LISA, LSI, and cluster analysis techniques in this study can capture a regional typology that highlight the characteristics of each region based on their sustainability condition. From the results of the cluster analysis, it can be seen that the sub-regions falling into the category of cluster 3 (red areas) are dominated by core megacity areas which have a high level of sustainability in the economic and social aspects, but their sustainability for the environmental dimension is low. Areas falling into the cluster 2 category (green area) are areas with rural characteristics that have a fairly good sustainability performance, especially seen from the value of the sustainability index for the environmental dimension. Meanwhile, the areas included in the cluster 1 category (yellow area) are areas with suburban characteristics and are areas in the JBMUR conurbation corridor. The areas in this cluster are the worst in terms of the conditions of sustainable development. They are dominant in number—51% of the total subdistricts in JBMUR. This shows that there are still many areas in suburban areas that have quite serious problems, especially in socio-economic aspects. Those problems are the poverty rate, which is still quite high, difficulties in terms of accessibility to economic facilities and infrastructure, access to public and health facilities, and access to the job market.

The results of this study further strengthen the tradeoff between socio-economic and environmental aspects. Areas with a high level of development tend to have a good development sustainability performance in the economic and social dimensions. On the contrary, their sustainability for the environmental dimension is low. The LSI as a composite index can be utilized to indicate locations of the sustainable state. Combined with cluster analysis, the LSI can identify typologies of subdistricts in JBMUR to capture the general sustainability state among subdistricts.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data indeed can be accessed on the website of Statistics Indonesia–precisely on provincial, regency, and municipality Statistics Agencies' websites. To obtain individual case data, e.g., a subdistrict of Cianjur Regency, someone may search on https://cianjurkab.bps.go.id (accessed on 17 August 2022) (Statistics Agency of Cianjur Regency). Our data are not publicly available because it is obtained by agreement between the Department of Soil Science and Land Resource (IPB University) and Statistics Indonesia.

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