Development of ecosystem health index in rural areas of Java Island: Preliminary results

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Abstract. The assessment of ecosystem health in Indonesia is currently being conducted poorly since no national guidance standard. This study aimed to formulate a quantitative system to justify the rural ecosystem quality with six indicators, i.e. air pollution index (API), water pollution index (WPI), forest coverage index (FCI), biodiversity index, public health and environmental health. This research is a type of basic and applied research at the same time, where applied research lies in the implementation part of the ecosystem health index. Environmental conditions at rural areas of Java Island (Regencies of Pandeglang, Bandung, Temanggung, Magetan and Bangkalan) was evaluated. Secondary data collection from local environmental management and health authorities was conducted in March-May 2019. The data is expressed into indices with a value of each components ranging from 0 to 100. The ecosystem quality of Bandung Regency, Temanggung Regency, Bangkalan Regency, Magetan Regency quantitatively showing numbers of 67.03, 80.68, 81.76 and 78.66. The four values exceeded the national standard (IKLH, Indeks Kesehatan Lingkungan Hidup) in 2017, i.e. 66.46. It indicates that the ecosystem quality of these four regencies is generally professionally managed. Meanwhile, Pandeglang Regency shows the number of 65.22, which is below the national standard of IKLH.

1. Introduction

Rural ecosystems reflect the suitability of rural areas with production and rural life activities. It also reflects the characteristics, functions, position, and role of the rural regions, as well as their resources, and environment [1]. The progress of urbanisation and rapid rural development leads to a better rural social and economic conditions but also harms ecosystem health [2].

Ecosystem health is one of the main priorities for scientists, managers, and governments in all parts of the world. There have been more than three decades of scientific studies discussing ecosystem health and approaches to assess it [3]. An ecosystem is healthy if it is stable or respectively resilient [4] and able to provide a series of ecosystem functions in a sustainable manner [5]. Ecosystem health is a combination of services and a balance between adaptability and resistance to the dynamic of environments [6]. Healthy and sustainable ecosystems are the basis for the sustainable development of human society [7].
Ecosystem health itself is a metaphor because health is the property of organisms. Therefore, the possible way to measure ecosystem health is to take several ecosystem properties and unify them into an index [8]. The assessment of ecosystem health in Indonesia is currently being conducted in different ways among ecologists and environmental scientists. It is closely related to the existing conditions where no single guidance can be used as a national reference which is based on a collective agreement. An alternative assessment of ecosystem health is to use the Environmental Quality Index (IKLH, *Indeks Kualitas Lingkungan Hidup*), which is published in a yearly basis, indicated by three (3) criteria, i.e. air quality, water quality, and forest cover.

The three indicators are considered still not able to represent the health of the ecosystem as a whole considering that in general, the ecosystem has not only abiotic components (non-living) but also biotic which also has an impact on the state of the ecosystem [9]. It is variable to evaluate the ecosystem health by only one subject [10]. For example, humans cannot ignore the damage of the environment and nature due to their activities in fulfilling their daily needs [11]. The excessive use of these natural resources often has the potential for the disposal of waste which could damage the ecosystem, affect the quality of the environment, including the quality of human life itself. Sources of drinking water, excellent necessary sanitation facilities will affect the incidence of diarrhoea in the North Semarang sub-district [12].

Furthermore, chemical, and nutrient pollutants, which lead to the sea, could have a massive impact, such as mortality of marine life due to the toxic power of each contaminant [13]. Therefore, in this paper, a more holistic conceptual framework of ecosystem health assessment was constructed. Three additional indicators, namely the biodiversity index, public health index and environmental health index, are added as a complement to the quantitative evaluation of existing ecological quality into an ecosystem health index.

The first objective of the research was to develop a quantitative approach to the rural ecosystem health assessment system that is expressed as REHI (Rural Ecosystem Health Index) and is calculated with six parameters. The second objective of the research was to calculate the ecosystem quality of five regencies in Java Island, i.e. Bandung, Temanggung, Bangkalan, Magetan, and Pandeglang.

2. Methods

2.1. Study area

Rural ecosystem health indices were analysed based on secondary data of five regencies in the Java and Madura islands (Pandeglang, Bandung, Temanggung, Magetan, and Bangkalan Regencies). Determination of the five locations was based on climate classification, according to Schmidt-Ferguson. The five represent a variety of wet to dry climate classifications on Java and Madura islands. The data were collected and analysed from March to May 2019. The research locations are shown in Figure 1.

![Figure 1. Research locations in Java and Madura Islands ( Adopted from DigitalGlobe.com)](image-url)
2.2. Conceptual Framework

The research was conducted by collecting the secondary data of each sampling parameters. Air quality, water quality, forest cover and biodiversity of the regencies were obtained from the Information on Regional Environmental Management Performance (IKPLHD, Informasi Kinerja Pengelolaan Lingkungan Hidup Daerah) publication. Meanwhile, public health and environmental health information was obtained from the Regional Health Profile release. The compiled ecosystem health indices with their parameters are presented in Table 1.

Table 1. Indicators and measurement parameters of the Rural Ecosystem Health Index (REHI)

| REHI Components | Parameters | Assessment method |
|-----------------|------------|-------------------|
| Air quality     | Sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) | EU air pollution index (AQI) |
| Water quality   | Total suspended solids (TSS), dissolved oxygen (DO), chemical oxygen demand (COD) | Pollution index (WQI) |
| Forest coverage | Primary forest area (LHP), secondary forest area (LHS), forest area (LKH) | Forest coverage index (FCI) |
| Biodiversity    | Total individuals of one species, entire species, total individuals, the specific abundance of each species | Shannon-Wiener Index (BI) |
| Public health   | Mortality (infant, toddler, maternal mortality), morbidity, life expectancy and nutritional status | Public health index (PHI) |
| Environmental health | Percentage family that have sanitation facility, health house, access to clean water | Environmental health index (EHI) |

After that, the collected data is then converted into indices. The Rural Ecosystem Health Index (REHI) is calculated as the total of the six parameters involved divided by six as follows:

\[
REHI = \left( \frac{AQI + WQI + FCI + BI + PHI + EHI}{6} \right)
\]  \hspace{1cm} (1)

The equation that used to calculate AQI, WQI, FCI, BI, PHI and EHI is given below:

\[
AQI_{NO_2} = 100 - \left( \frac{50}{0.9} \right) \times (IEU - 0.1)
\]  \hspace{1cm} (2)

Notes:

IEU: air pollution index model EU (Europe)

If the index of NO₂ and SO₂ parameters have been received, then the air pollution index (AQI) can be calculated as the average score between these two equations:

\[
IEU = \frac{IPU_{NO2} + IPU_{SO2}}{2}
\]  \hspace{1cm} (3)

Notes:

AQI = air pollution index [-]
AQI NO₂ = air pollution index of NO₂ parameter [-]
AQI SO₂ = air pollution index of SO₂ parameter [-]
WQI or water pollution index can be calculated by using the notation of PI (pollution index) as declined on the second attachment of the Decree of Forestry Minister 115/2003 about The Guidance on Determining the Water Quality Status.

Based on that calculation principle, it will be calculated by measuring the concentration of water quality parameters, then comparing with the concentration on standards (L) according to its use as written on Government Law 82/2001 about Water Quality Management and Water Pollution Control. Based on the data collected and the calculation that measured, the result is the score of the pollution index (PI). The equation that will be used is given below:

\[
P_I = \left( \frac{\left( \frac{C_i}{L_{ij}} \right)^2 + \left( \frac{C_i}{L_{ij}} \right)_{r}^2}{2} \right)^{1/2}
\]

(4)

\( P_I \) = water pollution index (pollution index) for “j”

\( C_i \) = concentration of water quality parameter “i”

\( L_{ij} \) = concentration of water quality parameter “i” as written on the standard of water “j”. In this case, is the water quality of class II

\((C_i/L_{ij})_{m} = \text{maximum score of } (C_i/L_{ij})\)

\((C_i/L_{ij})_{r} = \text{average score of } (C_i/L_{ij})\)

Forest coverage (TH) is found by calculating the quotient between the total area of primary forest (LHP) and the area of secondary forest (LHS) based on The Decree of Forestry Minister about the area of the province (LWP) as described below:

\[
TH = \frac{LHP + LHS}{LWP}
\]

(5)

Forest coverage index (FCI) is calculated by using the equation below (IKLH 2014):

\[
ITH = 100 - (84.3 - (TH \times 100)) \times \frac{50}{54.3}
\]

(6)

Notes:

TH = forest coverage

LHP = the area of primary forest [Ha]

LHS = the area of secondary forest [Ha]

LWP = area of the province [Ha]

FCI = index of forest coverage [-]

84.3 = the area of forest coverage in Papua in 1982 as the ideal reference.

Quantitative assessment of flora and fauna aspect can be declined as biodiversity indexes such as Simpson Index, Margalef Index or Shannon Index. As an example, the biodiversity index by Shannon [14] is given below:

\[
H' = -\sum_{i=1}^{n} p_i \times \ln p_i
\]

(7)

Notes:

H’ = Shannon-wiener biodiversity index

n = the total species of the sample

p_i = n_i/N

n_i = the total individual of species "i"

N = the total individual species of the sample.

Public health index is the average of morbidity value, mortality value, and life expectancy age (UHH). Morbidity value (prevalence of illness) is the total cases of disease around ten thousand population. Mortality value consists of infant mortality, toddler mortality, and maternal mortality. Life expectancy age (UHH) is the age estimation of a person who lives in an area, and it has been calculated usually in each region in Indonesia. Environment health aspect consists of followed components percentage of a family that have clean water access, percentage of health house, percentage of the family...
that have sanitation facilities. Environmental health index is the percentage average of the three aspects. Figure 2 shows the flowchart of the study.

Figure 2. Research flow chart

3. Result and Discussion

3.1. Ecosystem health assessment
The usage of various parameters will result in a better review with a reliable prediction of how each parameter represent the health of the ecosystem. This ecosystem health indices score could be a recommendation for the government in managing the environment. The final assessment of the ecosystem health of the five regencies is shown in Table 2. By using the new version of the score, local authorities as well as the national could describe the quality of the ecosystem in a more comprehensive way.

Table 2. The final score of ecosystem health in the five regencies

| Parameters of REHI | Pandeglang | Bandung | Temanggung | Magetan | Bangkalan |
|--------------------|------------|---------|------------|---------|-----------|
| AQI\(^a\)          | -          | 72.86   | 83.22      | 91.48   | 89.64     |
| WQI\(^b\)          | 70.00      | 54.08   | 70.00      | 70.00   | 66.00     |
| FCI\(^c\)          | 55.79      | 50.82   | 80.96      | 67.61   | 67.61     |
| BI\(^d\)           | 57.89      | -       | -          | -       | -         |
| PHI\(^e\)          | 81.37      | 88.71   | 92.95      | 92.41   | 91.30     |
| EHI\(^f\)          | 61.06      | 68.66   | 75.93      | 87.33   | 78.76     |
| Average            | 65.22      | 67.03   | 80.68      | 81.76   | 78.66     |
3.2. Air quality index

The ambient air quality in Magetan Regency is considered good with a score of 91.48. At the same time, Bandung Regency shows the worst air quality of the five (5) regencies with air quality index score of 72.86. There are two (2) parameters that are used in the calculation of this pollutant index. Nitrogen dioxide (NO$_2$) represents emissions from motor vehicles using gasoline, while the sulphur dioxide (SO$_2$) represents emissions from industry and diesel vehicles that use diesel fuel and fuel with other sulphur content. Two factors that could cause potential differences in air quality in both regencies are types of industry and the number of motorised vehicles.

The different types of industries that dominated the two regencies could have a disparate impact on air quality conditions. SO$_x$ and NO$_x$ pollution in the air can be caused either by industrial activities [15, 16]. Magetan Regency is dominated by small red brick industries with 3741 out of a total of 15895 companies. The sectors that are considered to have an impact on the environment is the blacksmith industry as many as 118 companies, while 12036 other small companies are engaged in the food industry. As many as 1054 large-scale industries in Bandung Regency play a role in ambient air quality degradation. Ten (10) paper industry, two (2) companies in the base metal industry and three (3) motor vehicle industry companies are considered to have the impact of ambient air quality drop.

The Central Bureau of Statistics counted that the number of motorised vehicles in Magetan Regency was 252,013, while in the same year the number of vehicles in Bandung Regency was 506,802. The difference in motorised vehicle number between both regencies certainly had an impact in decreasing the ambient air quality. NO$_x$ emissions come from motor vehicle fuel combustion [17], and the levels vary throughout the day, depending on the intensity of sunlight and motor vehicle activity [18]. The number of industries and motorised vehicles in the other two (2) regencies is presented in Table 3.

| Regencies     | Number of Industries | Motorised Vehicle |
|---------------|----------------------|-------------------|
| Temanggung    | 16531                | 71,932            |
| Bangkalan     | 701                  | 5,326,317         |

3.3. Water quality index

Bandung Regency had the worst water quality with an index value of 54.08 out of 100. The existence of 574 textile industries could be a factor that caused a decrease in river water quality in Bandung Regency. Wastewater originated from the textile industries has a dense colour, high concentration of TSS and COD [19]. Temanggung and Magetan Regencies which have better river water quality with WQI of 70.00 having less textile industry. The correlation between WQI and the number of textile industries of the regencies is depicted in Figure 3. The higher the number of textile industry, the worst water quality as indicated by water index (WQI).
Figure 3. Correlation between WQI and the number of textile industries in Pandeglang, Bandung, Temanggung and Magetan Regency.

Among 225 river water samples, 96 of them were polluted lightly, 44 samples were intermediately polluted, the other five were heavily polluted, and the rest were meet the water quality threshold. According to the Regional Environment Agency of Bandung Regency, 43% of industrial wastewater was not professionally managed, thereby increasing river pollution load. The use of fertilisers and insecticides in agriculture as well as livestock and poultry farming potentially pollute the river nearby.

3.4. Biodiversity index (BI)
Biodiversity identification is one of the regular activities which is conducted yearly beside the water and air sampling. The report about animal species and plant identification supposed to be published in the Information on Regional Environmental Management Performance (IKPLHD), but in fact, it was not conducted by the authorities of five study regencies. For example, the Regional Environmental Agency of Bangkalan Regency conducted a limited identification for Madura cow (Sapi Madura), endemic plant of Melati Rato Ebuh and black mango in 2014 and 2015. The 72.54 biodiversity index was obtained from the identification carried out by the Magetan Regional Environmental Agency in 2014. Meanwhile, the identification carried out in Pandeglang Regency from 2012 to 2015 result in a biodiversity index of 64.78; 52.10; 56.74 and 57, 89.

Biodiversity records could be a benchmark for good or bad an environment management in a region. For example, various species of birds diminish with reduced trees in East Africa [20]. A decrease in biodiversity is often linked with the decline of ecosystem health and the increase of human disturbance [21]. Conservation of biodiversity could be a way to maintain ecosystem resilience [22].

3.5. Forest cover index (FCI)
The forest index value of Temanggung Regency is 80.96 with the secondary dry land area of 28,093 ha, plantation area of 54921.56 ha and bush area of 740.1 ha of the total area of 87,065 ha. Temanggung Regency has the Sindoro-Sumbing Mountain area which is dominated by mountains and hills with the distribution of land in the form of production forest areas, community forests, and protected forests. Mountainous areas in Indonesia have a significant role in forest cover index. The Bukit Barisan mountain range which stretches in the western region of Jambi Province plays a role in the district FCI value of the area, as shown in Table 4.

Table 4. Forest cover index of municipality and regencies in western Jambi Province 2014

| No. | Municipality/Regencies    | Forest cover index |
|-----|---------------------------|--------------------|
| 1   | Kerinci                   | 79.26              |
| 2   | Kota Sungai Penuh        | 94.35              |
| 3   | Bungo                     | 81.27              |
| 4   | Tebo                      | 78.55              |
Another example, as noted in the Solok Selatan Regency 2014 State of Environment Report, the forest cover index was 75.32. The regency's landscape varies between the lowlands, hills, and highlands which are also a series of Bukit Barisan Mountains. Monitoring the status of forests is necessary since land use and land cover change is one of the drivers of the most critical changes in ecosystems and ecosystem services [23].

3.6. Public health index (PHI)
Health indicators in Indonesia showed a high burden, one of which can be seen from high maternal mortality (359 deaths per 100,000 live births). Stunting also occurs in 31% of the total population of children under five years. One hundred twenty-one million (121) people (47% of the population) did not have access to adequate health care due to fragmented health financing and insurance systems in 2013 [24]. An overview of the public health index's component in the five regencies can be seen in Table 5.

Pandeglang Regency has the lowest number for morbidity, mortality, and life expectancy. The low level of public health in Pandeglang Regency is due to inadequate health facilities such as hospitals and community-based health care facilities. The number of health facilities and health workers in five (5) regencies is shown in Figure 4.

Table 5. Public health index components score in the five regencies

| PHI Component                  | Regencies     |
|-------------------------------|---------------|
|                               | Pandeglang | Bandung   | Temanggung | Magetan | Bangkalan |
| Morbidity                     | 80.20       | 76.75     | 98.62      | 98.60   | 97.91     |
| Mortality                     | 81.80       | 99.80     | 98.41      | 98.09   | 98.09     |
| Life expectancy               | 63.51       | 73.14     | 75.42      | 71.91   | 69.77     |
| Nutritional status indicator  | 99.97       | 99.94     | 99.34      | 100.00  | 99.99     |
| Score                         | 81.37       | 83.51     | 92.95      | 92.41   | 91.30     |

Figure 4. The total number of health facilities and health workers in five regencies

The compliance of primary health service needs can be illustrated by the ratio of PUSKESMAS (community-based health centre) to 30,000 residents. Pandeglang district, which has 36 health centres
has a service ratio of 3.01 for 100,000 residents, which means one (1) PUSKESMAS can serve 33,191 residents. It means that the PUSKESMAS in Pandeglang Regency has not met the target, while Magetan and Temanggung Regencies that have better PHI values, service ratios in the two regencies for 100,000 residents are 3.29 and 3.49. One (1) PUSKESMAS in Temanggung Regency can serve 30,363 residents, while one (1) PUSKESMAS in Magetan Regency can serve 28,573 residents, which means it has met national targets.

3.7. Environmental health index (EHI)

Magetan Regency got the highest environmental health index with the largest population that has access to clean water access and basic sanitation facilities. Among 628,609 residents, as many as 580,554 already have sustainable access to decent clean water, and 611,671 already have healthy latrines. The three (3) EHI indicators in the five (5) regencies are shown in Figure 5.

Clean water and proper sanitation have a significant role in preventing disease. In Indonesia, around 58% of the population has access to adequate drinking water, 50-75% live with proper sanitation, and 12-45% of the population practice open defecation in 2015 [24;25].

![Figure 5. Percentage of clean water access, healthy house and basic sanitation facility owned by families in the five regencies](image)

3.8. Relationship between each parameter

As previously explained, combining several properties of the ecosystem into an index is one of the methods that could be used to measure the health of the ecosystem. The index specified as a parameter must represent the condition of the ecosystem being measured. Relationship between parameters is described in the graph by determination coefficients (R²).

3.9. The relation between EHI and PHI

The relationship between PHI and EHI in the five districts is shown in Figure 6. The coefficient of determination indicates that the relationship between the two values is strongly correlated. For example, in Pandeglang Regency, which has the lowest EHI value, it also shows the worst public health figures among the five regencies.
3.10. The relationship between EHI and WQI

The coefficient of determination of 0.07 in Figure 7 shows low correlation between the parameters of EHI and WQI in five regencies regardless of whether both indices are logically related. More data is required to see the precise correlation between EHI and WQI in rural areas.

3.11. The relationship PHI and WQI

The relationship between PHI and WQI in five regencies is a negative correlation where the value of WQI does not affect the value of PHI. This relationship can be seen in Figure 8.

3.12. The relationship between PHI and AQI.

The R² value of 0.5676 is shown in the relationship between PHI and AQI. In Figure 9, the two parameters show a positive correlation and are related to each other. For example, low air quality in Bandung Regency with an air pollution index value of 72.86 affects the ARI (ISPA) disease with the highest number of sufferers in the same year.
4. Conclusion
The conclusions that can be drawn from this study are:

- The quantitative approach on the rural ecosystem health assessment system is expressed as REHI (Rural Ecosystem Health Index) that is calculated with six parameters. The parameters involved are air pollution index (AQI), water pollution index (WQI), forest cover index (FCI), biodiversity index (BI), health index community (PHI), and environmental health index (EHI) and expressed by the equation:
  \[ REHI = \frac{IPU + IPA + ITH + IKH + IKM + IKL}{6} \]
- The ecosystem quality of Bandung Regency, Temanggung Regency, Bangkalan Regency, Magetan Regency quantitatively showing numbers of 67.03, 80.68, 81.76 and 78.66. The four values exceed the value of National IKLH in 2017, which is 66.46. It indicates that the ecosystem quality of these three regencies is generally professionally managed. Meanwhile, Pandeglang Regency showing numbers of 65.22 which below the National IKLH in 2015

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