Multi-dimensions urban resilience index for sustainable city

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Abstract. In 2030, more than 73% of Indonesia's population is predicted to live in cities. Under that massive population concentration, urban problems are becoming more difficult and complex to deal with. Besides chronic pressures of the existing problems, when disasters occur, urban areas and their population are also more prone to be exposed to shocks, leading to increased vulnerability, uncertainty, and risks of the cities. This situation demands the communities and whole urban systems to develop better urban resilience. This paper describes our quantitative study in Semarang City that aims to build an index using secondary data by considering 5 dimensions: social, economic, infrastructure, institutional, and hazard and shows resilience level in scores from 0 – 1 where 0 representing very low and 1 the best. The results shows here are only 3 sub-districts that are at the level of high resilience (Semarang Selatan, Banyumanik, Semarang Tengah) and the infrastructure dimension is a very influencing factor. The index allows for equal spatial and temporal comparisons of several regions, which is important when it comes to conducting further studies on the regional dynamics and making priorities of which areas should be resilience-increased towards sustainable urban development.

Keywords: Index, Disaster, Semarang City, Urban resilience.

1. Introduction

High physical and population concentrations in urban areas are noticeably correlated with increasing urban challenges in the matter of inequality, uncontrolled population, high demand of service of clean water and energy, housing, transportation, health, food. Without the proper approach, these challenges become more complex to handle [1,2,3,4]. This situation happens in all major cities, and Semarang City in Central Java, is no exception. Semarang is a large metropolitan with a population of 1.73 million [5]. Physically and topographically, its landscape is diverse with the coast, plains, and hilly areas. Combination of both therefore, makes the case of shocks and stresses confronted by it also multifaceted: water scarcity, river pollution, high employment rate, power outage, landslides in upper and hilly areas, flash floods, tidal floods, land subsidence, coastal erosion, sea-level rise, drought [2,6,7,8]. It is also a fact that the incidence of natural disasters as one form of shock that occurred in the city tends to increase. In 2016 there were 155 events. A year after, the number became 179 events. The 2018’s statistics even show an increase of 50% by 268 disaster events [9]. This high risk by disasters and other threatening situations leads to high uncertainty for any affected urban communities [10].

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This uncertainty is often persistent if the urban system is not prepared to deal with any changes caused by the events.

To respond to these conditions and ensure the sustainability of urban development, a flexible and dynamic approach that goes beyond risk mitigation is needed, which is often referred to as the urban resilience concept. Urban resilience is the ability of individuals, communities, businesses, institutions, and systems to be able to survive, adapt and recover from any conditions of chronic stress and acute shocks in a timely and efficient manner [11]. To prepare a city for dealing with disturbances and how adaptation patterns should be carried out it is important to measure the existing resilience in multi-dimensional aspects [12,13,14]. However, before that, to measure resilience we need indicators and parameters that can be measured, so that resilience can be better understood and can also be a benchmarking performance of a community [13]. Therefore, this paper aims to deliver our report of developing resilience variables/indicators (indexing) and also measuring the composite resilience to disasters based on the geographic variability of Semarang City at the subdistrict level (i.e., mapping unit is sub-distRICT), which can be used further as a benchmarking to increase the resilience of Semarang City to ensure its sustainable development.

2. Data and Methods

2.1 Data sources and variable selection

Data in this paper were collected from several agencies in Semarang City, which are Central Agency of Statistics (BPS), Semarang City Health Service (Dinas Kesehatan), Regional Disaster Management Agency (BPBD), and General Elections Commission (KPUD) (table 1). Those secondary data are the most updated data published in 2018, free, and can be accessed through the website of the relevant agencies. This is so that indicators can be easily replicated.

Selecting any relevant, robust and representative variables is very important as the strengths and weaknesses of the indicator were determined by the quality of the selected variable. Criteria for determining the quality of variables have been widely stated in the literature, but there are no set indicators or definite frameworks for measuring the resilience toward disasters [15,12]. This thesis then using the consensus in the research community where resilience is multi-concept covering at least the social, economic, infrastructure, institutional dimensions [10,12]. The measurement of resilience index in this paper adopts the “baseline resilience indicators for communities (BRIC)”, a method developed by Cutter et al. [13]. The variables in the method were modified according to data availability. Another dimension was added: hazard dimension as suggested by [15,16,17,18]. These dimensions were used further for geographic comparison analysis. The approach using variables for comparison is preferable in measuring resilience because it is often difficult to measure resilience in absolute terms [12]. Considerations in selecting variables in this paper are: 1) Empiric justification of the relevance of indicators based on previous research, 2) relevant to local decision-making 3) data are easily accessed and replicated from local/national data sources, and 4) rely on available data.

2.2. Data Processing

Data from the relevant agencies was then processed by transformation, normalization, aggregation, and classification. The transformation process converts raw data with various sizes and characteristics into comparable scales (i.e., percentage, density or ratio). Normalization aims to scale all variables into a consistent and similar measurement scale and thus comparable to each other. The Min-Max method was used for normalization.
Table 1. Indicators to calculate urban resilience index in the 16 sub-districts of Semarang City.

| Dimensions and indicators            | Variables                                                                 | Effect on Resilience | Justification         | Data source                  |
|--------------------------------------|---------------------------------------------------------------------------|----------------------|-----------------------|------------------------------|
| Social resilience                    |                                                                           |                      |                       |                              |
| Educational equality                 | % of population with higher education (graduate from high school)          | Positive             | [12,15,16,17,20]      | BPS 2018                     |
|                                      | % of illiterate population                                                | Positive             | [12,15,17,20]         | BPS 2018                     |
| Demography                           | % of population in productive age                                          | Positive             | [12,13,15]            | BPS 2018                     |
|                                      | % of population aged 65 years and older                                    | Negative             | [16,19]               | BPS 2018                     |
|                                      | % of population living in poverty                                          | Negative             | [14,15,17]            | BPS 2018                     |
| Transportation access                | Number resident/km2                                                        | Negative             | [15,16,17,20]         | BPS 2018                     |
| Economic resilience                  | % of population with a vehicle (% motor)                                   | Positive             | [12,19]               | BPS 2018                     |
| Business size                        | Ratio of large to small business                                           | Positive             | [12,15,20]            | BPS 2018                     |
| Health access                        | Number of physicians per 10,000 population                                 | Positive             | [12,13,16]            | BPS 2018, Dinas Kesehatan 2018|
| Market access                        | Market access                                                              | Positive             | [15]                  | BPS 2018                     |
| Infrastructure resilience            |                                                                           |                      |                       |                              |
| Housing type                         | % of permanent housing                                                     | Positive             | [12,13,20]            | BPS 2018                     |
| Recovery                             | Number of public schools per km2                                           | Positive             | [12,13]               | BPS 2018                     |
| Medical capacity                     | Number of hospital beds per 10,000 residents                                | Positive             | [16,19,20]            | BPS 2018, Dinas Kesehatan 2018|
| Institutional resilience             |                                                                           |                      |                       |                              |
| Mitigation                           | % of Household that trust and know warning system                          | Positive             | [12,16]               | BPBD Kota Semarang 2018       |
|                                      | % of member of cooperatives                                                | Positive             | [15]                  | BPS 2018                     |
| Political engagement                 | % of voting population participating in election                           | Positive             | [13,19]               | KPU Kota Semarang 2018        |
| Hazard Resilience                    |                                                                           |                      |                       |                              |
| Frequency                            | Frequency of disaster                                                      | Negative             | [16,17,19]            | BPBD Kota Semarang 2018       |
| Variety                              | Variety of natural disasters occurred in the area                          | Negative             | [16,17]               | BPBD Kota Semarang 2018       |
In Min-Max normalization, the minimum value would have a value of 0 and the maximum would be 1. All data values were scaled into values from 0 to 1 by subtracting the minimum value and dividing it by the range of data values (maximum-minimum). For some variables that have a negative effect on resilience (i.e., variables with high scores correspond to low resilience), the order of their contributions to the overall resilience index with the inverse of the observation were reserved and rescale. An example of this reverse is “% population living in poverty”. This variable indicates that the bigger the poor population the lower the resilience. To make it functions in the measurement, the values need to be reversed (the highest percentage will be given a value of 0 and the smallest value will be given a value of 1).

After normalization – which was implemented on each sub-district – it was performed aggregation on each dimension/sub-index level by measuring the average of variable scores. Averaging is chosen to reduce the effect of inequality of the total number of variables among dimensions. It will produce 5 mean sub-index scores for each sub-district. The total resilience score is the aggregation of the sub-index scores. The score calculation for both the sub-index and the total resilience score uses the same weighted (equally weighted index), with the consideration that no justification is found related to which variable or which dimension is more important.

To classify the final scores, concerning comparability, 5 classes of resilience were consistently use [15]:

| Score Range | Resilience Class |
|-------------|------------------|
| 0.0 – 0.2   | No or very low resilience |
| > 0.2 – 0.4 | Low resilience |
| > 0.4 – 0.6 | Moderate resilience |
| > 0.6 – 0.8 | Resilient |
| > 0.8 – 1.0 | High Resilience |

With the Min-Max normalization method of comparison and interpretation of a number of resilience variables is done more easily. However, the final score is not an absolute measure of resilience at one location but rather a relative value. The relative estimation using normalization will give the possibility of slight over or underestimation, but it gives an advantage in the ease of understanding the comparison between locations at a time. The use of normalized values will be very useful in benchmarking progress in an effort to increase resilience over time and between locations.

3. Results and Discussion
The resilience score presents the resilience value at the sub-district level which consists of 16 sub-districts in Semarang City. The index measurement results are presented in maps (figure 1 and 2) and resilience score rank (table 2). Spatially, the resilience value is visualized in two models, namely the spatial distribution of the total resilience index and the spatial distribution of sub-indices (social, economic, infrastructure, institutional and hazard (figure 2).

The total resilience score ranged from 1.360 to 3.019 and there are only 2 sub-districts that have a score above 3.0. In accordance with the classification of resilience, there are only 3 sub-districts that are at the level of high resilience (Semarang Selatan, Banyumanik, Semarang Tengah). The results show that high resilience is inclined to be located in the sub-districts with good infrastructure (housing, educational facilities, health facilities) where the social and economic resilience can also be developed suitably. The high resilience is also occurring in the sub-districts with high hazard resilience (low frequency and variety hazards). Geographically, those sub-districts with high resilience are having very good infrastructure and are situated in the center of the city (except Banyumanik) and directed as the service centers in the City Spatial Plan of 2011-2031.
Table 2. Resilience score

| Subdistrict         | Social | Economic | Infrastructure | Institutional | Hazard | Resilience Score | Class Resilience |
|---------------------|--------|----------|----------------|---------------|--------|------------------|-----------------|
| Semarang Selatan    | 0.362  | 0.469    | 0.939          | 0.329         | 0.920  | 3.019            | 1.000           |
| Banyumanik          | 0.637  | 0.500    | 0.705          | 0.288         | 0.875  | 3.005            | 0.991           |
| Semarang Tengah     | 0.634  | 0.576    | 0.461          | 0.391         | 0.789  | 2.851            | 0.892           |
| Tugu                | 0.581  | 0.555    | 0.167          | 0.551         | 0.735  | 2.589            | 0.722           |
| Semarang Timur      | 0.541  | 0.406    | 0.547          | 0.417         | 0.664  | 2.574            | 0.712           |
| Gajah Mungkur       | 0.685  | 0.160    | 0.782          | 0.221         | 0.548  | 2.396            | 0.597           |
| Ngaliyan            | 0.586  | 0.131    | 0.550          | 0.664         | 0.357  | 2.289            | 0.528           |
| Semarang Utara      | 0.445  | 0.554    | 0.295          | 0.214         | 0.780  | 2.289            | 0.528           |
| Mijen               | 0.505  | 0.316    | 0.252          | 0.256         | 0.833  | 2.162            | 0.446           |
| Tembalang           | 0.509  | 0.051    | 0.682          | 0.363         | 0.435  | 2.039            | 0.366           |
| Gunungpati          | 0.736  | 0.122    | 0.008          | 0.430         | 0.717  | 2.014            | 0.350           |
| Candisari           | 0.337  | 0.158    | 0.497          | 0.221         | 0.768  | 1.980            | 0.328           |
| Gayamsari           | 0.505  | 0.188    | 0.235          | 0.258         | 0.699  | 1.886            | 0.268           |
| Pedurungan          | 0.687  | 0.072    | 0.122          | 0.296         | 0.682  | 1.859            | 0.250           |
| Genuk               | 0.508  | 0.090    | 0.265          | 0.371         | 0.333  | 1.566            | 0.061           |
| Semarang Barat      | 0.486  | 0.115    | 0.161          | 0.258         | 0.452  | 1.472            | 0.000           |

Resilience scores are normalized using the Min-Max normalization method and further classified into 5 resilience classes. Spatial visualization of the results of index measurements gives advantages in being able to provide a quick comparative review of which indicators need to be improved and with the resilience sub-index can be identified on the dimensions of what strategies should be applied to increase the total resilience score. For example, in Gunung Pati, Tembalang, Genuk, and Semarang Barat, in order to increase resilience, it is important for the city government to increase economic-related capacities.

It is acknowledged that infrastructure in Semarang plays a key factor in resilience development. A report from the Semarang City Government regarding shock and stress assessment also notified this. However, infrastructure contribution to tackle shock and stresses is considered low [7]. Then, it confirms that the sub-districts that have very low resilience, there is also a tendency that the scores for infrastructure to be relatively low compared to other dimensions (for example, in the sub-district of Genuk and Gunung Pati).
Figure 1. Spatial distribution of total resilience for Semarang City

Figure 2. Sub-index resilience for Semarang City: a) Social, b) economic, c) infrastructure, d) institutional, e) hazard

Compared to the multi-disaster risk map by BNPB [22], we see a pattern where any sub-districts with a high disaster-prone index tend to be resilient and highly resilient, such as Banyumanik, Tugu, and Semarang Timur sub-district. Other sub-districts, Ngaliyan, Semarang Utara, Gajah Mungkur, and Gayamsari that have moderate disaster-prone indexes also have moderate resilience scores. We also noted that further attention is required to Gunung Pati, Tembalang, Genuk, and Semarang Barat sub-districts. They are located in the high multi-disaster-prone area but our study reveals that those areas have low resilience. To search the factors that cause this, we checked back the index of social, economic, infrastructure, institutional and hazard components (figure 2). We then found out that Gunung Pati, Tembalang, Genuk, and Semarang Barat have very low economic resilience (figure 2a
and figure 2b) that contributed to the low total resilience score. Spatial patterns in economic resilience show that high resilience is concentrated in the northern region adjacent to the service center where the area in the spatial plan districts as a trade and service and settlement area, except Banyumanik (Figure 2b).

Although this study demonstrates that the index measurement can provide a steady comparative overview of the resilience of Semarang City among its sub-districts, the study can be enhanced further by conducting the assessment of variables. Regression and validation tests have not been done on used variables, to check their influence on each other, and whether they have a significant influence on the resilience. The study results can be taken as a lesson for multi-dimension measures of urban resilience, which can provide comparability among regions for both spatial and temporal aspects, as an effort to increase resilience to guarantee sustainable cities.

4. Conclusion
This research aims to measure the city’s resilience to disasters using 5 dimensions (social economy, infrastructure, institutional and hazard) with 13 indicators and 18 variables. The results of resilience measurements show the infrastructure dimensions is a very influencing factor where high resilience is found in the sub-districts with good infrastructure and low resilience also tends to occur in the sub-districts with poor infrastructure conditions. The spatial index and distribution presented can also provide an overview of resilience patterns, a quick comparative review of which indicators need to be improved and can be used as a means by stakeholders in determining strategies to improve the resilience of their region.

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**Acknowledgments**

Author would like to gratefully acknowledge the support of the BIG for sponsoring this presentation and *RISTEK-DIKTI* for doctoral fellowship.