Reprofiling landscape of rainwater harvesting in supporting Semarang urban water resilience

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Abstract. The uniqueness of the urban physiographic landscape could share advantage as well as constraint for the sake of urban water availability. Physiography landscape of urban area will slightly affect the ability of a city in providing water needs of urban dwellers. An alternative solution to resolve the problem is rainwater harvesting. Semarang is one of secondary cities, faces various problems such as ground water scarcity, land subsidence, flood, and drought. Water resilience problem of Semarang would become more severe when development activities do not pay attention to 2 kinds of landscapes: social and physiography dimension. This study aims to examine the distribution and characteristics of landscape physiography associated with social condition, considering appropriate form of rainwater harvesting application. The basic methods used are spatial analyses and combined with non-parametric statistical technique based on questionnaires. Landscape physiography variables embrace various aspects of altitude, slope, geology, soil, ground water potential, landslide, flood, and land subsidence. While social variables involve several aspects of community attitudes, gender, education and income. The results shows that the application of rainwater harvesting needs to consider physiographic landscape together with social profile to ensure and support water resilience of urban areas.

Keywords: Landscape, Rainwater harvesting, Urban, Water resilience, , Community

1. Introduction

Many countries around the world have been well aware of increasingly critical water resources. This condition encourages various circles to find ways to ensure the availability of water in a sustainable manner. Many cities are faced with critical water problems as a result of population growth and excessive groundwater exploitation. This requires many cities to work to build water resistance so as not to hit the water crisis. Resilience can be defined as "the ability of a system, community or society to be exposed to hazards to resist, absorb, accommodate and recover from the efforts of a hazard in a timely and efficient manner" [1]. The definition of resilience by UNISDR is in line with the water security formulated by UN-Water. Water security is defined as capacity of the population to sustainable livelihoods, human well-being, socio-economic development, as well as for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability [2].

Semarang is an urban area that has a unique physiographic landscape. The uniqueness of physiographic landscape owned by Semarang City, facing this city on water resistance problem. Semarang is one of secondary cities, faces various problems such as ground water scarcity, land subsidence, flood, and drought. An alternative solution to resolve the problem is rainwater harvesting. Unfortunately the implementation of the rainwater harvesting program in Semarang City has not run
as expected. In fact, if you see the potential of annual rainfall of Semarang city ranging from 2,000-2,500 mm/year, the successful application of rainwater harvesting can be a promising solution.

Many studies on rainwater harvesting have been done in different parts of the world [3, 4, 5, 6, 7, 8, 9]. Studies of the application of special rainwater harvesting in urban areas are also widely published [3,4,5,]. Various rainwater harvesting related themes, such as calculating rainwater catchment potential [3, 6, 7, 10], selecting rainwater storage locations [10, 11], calculating cost savings that can be done [9, 12, 13], to quality water [14] as well as utilization of rainwater harvesting [15]. Studies on the social aspects of rainwater harvesting [16, 17] have also been widely practiced, especially regarding the level of public acceptance [16], and the factors that influence [16, 17].

Studies conducted by Mankad et al. in Australia [16] sought to identify key factors affecting people's willingness to apply rainwater harvesting principles. The study states that public attitudes are generally very supportive, but perception change factors play a role in encouraging the realization of community attitudes [16]. Another study by Donohue and Biggs [8] tries to make multi-dimensional spatial approaches to assessing the social environment in Nepal. The results of their study suggest that there is a correlation between social conditions of society with landscape topography factors [8]. This is in line with the results of the study Barthwal et al. [11] which states that social factors of income level are the decisive factor in the application of rainwater harvesting, and the application of rainwater harvesting should adapt the characteristics of the region. The examples of the studies conducted, in part, lead to one thought that the application of rainwater harvesting should pay attention to environmental aspects either social or physical.

Based on the condition of unsuccessful application of rainwater harvesting in Semarang City and based on previous studies, this study is interested to know whether or not the linkage of social condition and landscape physiography with attitude of society in Semarang City, in applying rainwater harvesting. This study aims to examine the distribution and characteristics of landscape physiography associated with rainwater harvesting application.

2. Methods

2.1. Study area

This study was conducted in the administrative area of Semarang City. The city administration is divided into 16 districts and 177 urban villages. The administrative population covers all sub-district administrations and the calculations in this study are conducted according to the sub-district analysis unit. The districts are grouped into 3 physiographic landscape units based on the identification and zoning of the region. An overview of the location of the study and the spatial distribution of administrative regions, presented in Figure 1.

2.2. Type of data

This study uses primary data and secondary data. Primary data used is obtained through the distribution of questionnaires and field observations. Primary data obtained from authorized institutions in accordance with the theme. Secondary data used in this research there are several kinds. Data of population, number of head of household and annual average rainfall of Semarang City obtained from Central Bureau of Statistics (BPS) for publication data year 2012-2016. Data on the distribution of residential areas (2012), high-resolution image data of World View (2012), and 30 m resolution SRTM images obtained from the Geospatial Information Agency. Spatial data of roof cover (2011-2012) and urban household water requirements were obtained from the Ministry of Public Works. Geological map, soil, ground water potential, landslide, flood, and land subsidence are obtained from Spatial Planning of Semarang City 2005-2030 document, Regional Planning and Development Board (BAPPEDA).

2.3. Sampling method

The population of this study is the adult population of Semarang City that can determine the attitude in managing household water needs. The gender of the respondents can be male or female. This study uses combined sampling method. Combined sampling methods are area, and random methods. In the initial stage the number of samples is calculated according to the zone area, then the determination of
the respondents is determined randomly. Based on calculations, each zone of territory should be
represented by a minimum of 100 respondent samples to meet 90% accuracy.

2.4. Variables
The variables in this study are differentiated into independent variables and dependent variables. The
independent variables consist of: physiographic landscape zone, ground water potential, disaster
vulnerability, gender, education, and income. The dependent variable of this study is the attitude of
the community in applying rainwater harvesting. The independent variables tested for their correlation
relationship with dependent variable are: physiographic landscape zone, gender, education, and
income. The variables of ground water potential and disaster vulnerability are only used to look
spatially related to the potential and vulnerability of rainwater harvesting application in Semarang
City.

2.5. Questionnaire
The questionnaire used in this study consists of 2 parts. The first section contains information on
respondents, namely: location of residence zone, gender, education level, and income level. The
second part contains questions relating to the assessment of individual attitudes toward the application
of rainwater harvesting. Questions submitted consist of 8 questions as presented in Table 1.
Assessment of attitude done using Likert scale. Each question can be judged by the numbers 1
through 5, so the value of all the answers to the question can be totaled to the final value. The total
value of all the answers to questions can be a minimum of 8 and a maximum of 40. The average value
of individual attitudes is calculated based on the number of respondents in each analysis group.

2.6. Data analysis method
Some of the analytical methods used in this study are described in the following sections. The
identification and zoning of landscape physiography in this study was done visually and
mathematically using geographic information system (GIS). Determination of the limits of
phonograph landscape zonation using the administrative boundary of the sub-district in Semarang
City. Profiling geology, soil, and ground water potential are done based on thematic data obtained
from the spatial plan document of Semarang City 2005-2030. Calculation and analysis using GIS
tools and software. The same method is used to process and analyze the profile of disaster vulnerability (landslide, flood, and land subsidence). For the analysis of the distribution of societal attitudes by gender, education and income, descriptive statistical methods are used. The respondents' attitudes were derived from the sum of the scores from each question (8 questions with a score of 1-5). The calculation is done to know the average value of respondent attitude on different group of variables. The method used to know the correlation of public attitudes with gender, education and income or correlation between attitude with landscape, is method of crosstab analysis. This method is used to know the value of Pearson Chi-Square and significance value of relationship between variables, so it can be known, there is or not relationship between these variables.

**Table 1. Questions of attitude variable.**

| No. | Questions on attitude variable |
|-----|--------------------------------|
| 1   | Do you agree, if the central/regional government promotes rain harvesting in your area by developing a reservoir/tank to meet sufficiency water needs? |
| 2   | Do you agree, if the government promotes rain harvesting in your area through development of absorption wells and/or biopores to absorb water and reducing flooding risk? |
| 3   | Do you agree, if you are asked to get involved in rain harvesting activities by preparing your own tanks/tubs to collect rainwater in your home? |
| 4   | Do you agree, if you are asked to be involved in rain harvesting activities by making your own absorption well and/or biopores to absorb rainwater in the vicinity of your residential area? |
| 5   | Do you agree, if the government provides equipment and community assistance to provide means and infrastructure of rain harvesting, such as tank, well, and drill? |
| 6   | Do you agree, if the government provides incentives in the form of tax deductions or exemptions on earth and buildings if you apply rain harvesting through applying absorption wells, biopore and/or rainwater reservoirs? |
| 7   | Do you agree if harvesting or collecting rainwater activities in a tub/water tank for sufficient water needs should be managed through community or urban village activities? |
| 8   | Do you agree, if the activities to create and to maintain absorption wells and biopore to absorb water, to reduce flooding and drought risks should become routine joint activities managed by community or urban village? |

Source: setup by author

Analysis of the volume of rainwater and population water needs is done to assess the potential harvesting of rainwater by volume compared to the volume of household water needs. The volume of rainwater that is compared is the volume of rainwater obtained from the capture of the roof of the settlement with the daily household water needs. Calculation of rainfall potential (RWH) potential that can be harvested using average rainfall (P, in mm/year), the width of the roof or the catchment area (A, in m²), and the runoff coefficient (RC, nondimensional) [21] as shown in equation (1). The calculation of the population's water needs, using the reference set by the Ministry of Public Works Indonesian, 150 liters/day/person. The calculation of the community's water needs uses the formula (2) that is, the number of population (P, in person) multiplied by the daily water requirement (Wn, in liters/day/person) multiplied by the number of days (365, in day) in one year.

\[
RWH \text{ potential} = P \cdot A \cdot RC \quad (1)
\]

\[
\text{Annual water needs} = POP \cdot Wn \cdot 365 \quad (2)
\]

The calculation of the population for estimates of 2030 is calculated using population projection formula approach with geometry method. To estimate the 2030 rooftop area the 2030 population projection approximation method is divided by the average number of family members (2012) times the average roof per head of the family in 2012. Calculation of population in 2030 can be estimated by using equation (3):

\[
P_n = P_0 \left(1+r\right)^n \quad (3)
\]

Remarks:
- \(P_n\) = number of population in year \(n\)
- \(P_0\) = number of population in year 0 or base year
- \(n\) = number of years between 0 and \(n\)
- \(r\) = population growth rate per year (in %)
3. Result and Discussion

3.1. Identification and zoning of physiography landscape

Based on altitude and slope, the administrative area of Semarang City is divided into 3 areas according to landscape physiography. The division also refers to the ecosystem and region zones according to the hydrological cycle. The division of the 3 zones is: the lower Semarang zone, middle Semarang and upper Semarang. According to the calculation the distribution of land based on the altitude class, the lower Semarang region has a height of 0-50 meters from sea level. The lower Semarang area covers an area of 20,105 ha. Semarang central zone area has a height ranging from 50-200 meters from sea level with an area of 12,004 ha. The upper Semarang zone area has a height of more than 200 meters from sea level covering an area of 6,735 ha. Based on the slope, the area of Semarang City can be grouped into 5 classes of slopes. The wide distribution for each slope class by zone is presented in Table 2.

Figure 2. Land altitude.
Figure 3. Slope of Semarang City.

Figure source: processing data from document of Semarang City Spatial Planning 2005-2030.
3.2. Profiling geology, soil, and ground water potential

Based on geological map, the lower zone area is dominated by alluvium surface sediment type, which is 12,304 ha. This formation is a coastal plain and river sediment plains. The dominant material of this formation is clay and sand, with a thickness of more than 50 meters. The middle zone of Semarang City is dominated by the basic sedimentary breccia formation, covering an area of 7,440 ha from the total area of 10,237 ha. The upper zone is dominated by geological formation of volcanic breccia sedimentary rocks of 8,803 ha from the total area of the upper zone of 14,626 ha. In general, Semarang City is dominated by surface sediment of 13,725 ha of alluvium and 11,408 ha of basic sedimentary bricks. Based on the geological map it is known that the formation of volcanic formation is more common in the upper zone. While alluvium and marine formations are more in the lower zone.

| Zone   | Area of slope (ha) | 0-2% | 2-15% | 15-25% | 25-40% | > 40% |
|--------|--------------------|------|-------|--------|--------|-------|
| Lower  | 13,128             | 567  | 244   | 43     | 0      |
| Middle | 1,718              | 4572  | 2,925 | 675    | 348    |
| Upper  | 1,763              | 8,094 | 3,064 | 830    | 875    |
| Total area of slope | 16,609 | 13,232 | 6,233 | 1,548 | 1,223 |

Source: processing and calculation by author.

Soil type in Semarang city, dominated by type of reddish brown latosol of 12,931 ha. This type of soil is most often found in the upper zone, an area of 10,604 ha. Another dominant type of soil is the gray alluvial association, most commonly found in the lower zone, covering an area of 7,603 ha of the total area of 9,761 ha. Mediteran brown type most commonly found in the middle zone of 5,353 ha, of the total area of 7,681 ha.

Semarang City groundwater is generally available in limited quantities with moderate productivity (medium productivity, broad distribution or medium productivity, and local productivity) with an area of 22,135 ha. Areas with productive aquifers (productive and productive classes) cover an area of 7,002 ha. Areas with productive aquifers are more common in the lower Semarang zone, while the remainder can be found in the central and upper Semarang zone areas. Areas with rare earth water potentials cover a total area of 5,635 ha and areas with brackish water covering an area of 3,149 ha. Areas with high groundwater potential only cover a very small area of 922 ha only.

3.3. Profiling of disaster vulnerability (landslide, flood, and land subsidence)

Based on the three vulnerabilities of disaster, the most impacted disaster vulnerability in Semarang City area is landslide (medium and high risk) covering 9,479 ha. The second rank is a flood disaster that impacts an area of 7,893 ha. The disaster vulnerability due to the decreasing of the land surface has an impact on the area of 5,309 ha. Some areas of Semarang City are at very low landslide risk, which is 22,696 ha (58.43%) of the total area. The area of the vulnerable zone is the middle and upper zone. Total 3,483 ha area of Semarang City, located at a location with high landslide risk.

| Zone   | Area of landslide risk (ha) | Very low | Low | Medium | High |
|--------|-----------------------------|----------|-----|--------|------|
| Lower  | 13,509                      | 222      | 219 | 32     |
| Middle | 3,655                       | 3,147    | 2,999 | 437 |
| Upper  | 5,532                       | 3,301    | 2,778 | 3,014 |
| Total area | 22,696                  | 6,670    | 5,996 | 3,483 |

Source: processing and calculation by author.

Most of the flood-prone areas are located in the Semarang lower zone, which is 6,682 ha. This condition is related to the position of the area of the Semarang lower zone that is directly adjacent to the sea and potentially affected by rising tide. A small percentage of flood risk areas are found in the Semarang central zone (826 ha) and the Semarang upper zone (385 ha).

Semarang City area that experienced the largest decline in land surface is in the lower zone of Semarang. The zone region of central and upper Semarang, has not decreased ground level. This
condition is understood, because the basic material landscape area of the lower Semarang zone area is alluvial sediment material of lower density than 2 other zone areas.

3.4. Distribution of community attitudes according to gender, education and income

Based on the distribution of the average value of respondents' attitudes in the application of rainwater harvesting presented in Table look some attitude patterns according to gender variables, education level and income. In the gender variables it appears that the attitude of men in the middle zone is much better than other zone areas. This condition is actually inversely proportional to the attitude of women in the middle zone who tend to have the lowest value compared to other zones. Female respondents had relatively uniform attitudinal values for each zone. While male respondents have more fluctuating attitude values in each zone.

Based on educational variables, it is indicated that the average value of respondents' attitudes in the application of rainwater harvesting increases in line with the rising level of education. If it is associated with the location of the zone of the respondents, then only on the group of highly educated respondents whose respondents' attitudes increase as the zone changes from bottom to top. For middle and low education groups tend to form cross pattern.

Based on average earnings in general it appears that the value of attitude increases with increasing levels of income. If it is associated with the zone area it appears that there is a difference in attitude values but the pattern of values formed to form a pattern of crossing/zig zag. To ascertain the relationship between sex variables, education level and income with respondents' attitude values in the application of rainwater harvesting it is necessary to test the correlation which will be discussed in section 3.5.

Table 4. Value distribution of attitude on variable classification.

| Variable | Classification | Zone       |
|----------|----------------|------------|
|          |                | Lower  | Middle | Upper  |
| Gender   | Male           | 28.77  | 30.23  | 29.40  |
|          | Female         | 29.76  | 29.17  | 29.96  |
| Education| Low            | 28.57  | 26.83  | 27.08  |
|          | Midle          | 28.56  | 29.28  | 29.06  |
|          | High           | 30.02  | 30.15  | 31.08  |
| Income   | Low            | 28.73  | 28.31  | 29.09  |
|          | Midle          | 29.10  | 29.87  | 29.90  |
|          | High           | 32.27  | 32.29  | 31.56  |

Source: processing and calculation by author

3.5. Correlation of community attitudes with gender, education and income

The correlation test in this study used crosstab analysis. The calculation results are presented in Table 5. Based on the comparison of the calculated value with the value of the table and the comparison of its significance level at the 0.05 reference in Table 5, it can be concluded the correlation result between the variables. The sex variables were not related to attitudinal values, but the educational level and average income variables were related to community attitudes in applying rainwater harvesting. This is in line with the statement of Barthwal et al. [11] which states that social factors of income level are the decisive factor in the application of rainwater harvesting.

Table 5. Correlation of community attitudes with gender, education and income.

| Respondent characteristics | Pearson Chi-Square attitude |  |
|---------------------------|----------------------------|---|
|                           | Value | df | Table value | Asymp. Sig. (2-sided) | Sig |
| Gender                    | 1.280 | 2  | 5.991       | 0.527                | 0.05 |
| Education                 | 46.001| 10 | 18.307      | 0.000                | 0.05 |
| Income                    | 31.425| 8  | 15.507      | 0.000                | 0.05 |

Source: processing and calculation by author using Crosstab analysis

3.6. Correlation of community attitudes with physiography landscape

The calculation of the correlation between community attitudes in applying rainwater harvesting with physiography landscape is presented in Table 6. Based on the calculation it can be concluded that there is a correlation relationship between the value of community attitudes in applying rainwater harvesting and physiography landscape as presented in Table 6. Based on the distribution of average earnings in general it appears that the value of attitude increases with increasing average earnings in general. In the gender variables it appears that the attitude of men in the middle zone is much better than other zone areas. This condition is actually inversely proportional to the attitude of women in the middle zone who tend to have the lowest value compared to other zones. Female respondents had relatively uniform attitudinal values for each zone. While male respondents have more fluctuating attitude values in each zone.

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harvesting with physiography landscape where they live. This result reinforces Donohue and Biggs’ [8] statement about the results of their study suggesting that there is a correlation between social conditions of society with landscape topography factors. To understand this connection, it is necessary to understand the theory of urban development patterns. The pattern of urban development can be determined by the pattern of transport network which is also influenced by the physiography landscape pattern. In case of Semarang City, the flood vulnerability and the land subsidence in lower zone are predicted to be the factors driving the community to find better settlements in the south zone area. People with higher levels of education and income tend to prefer residence in the middle and upper zone area.

### Table 6. Correlation of community attitudes with physiography landscape.

| Physiography landscape | Pearson Chi-Square attitude | Value | df | Table value | Asymp. Sig. (2-sided) | Sig. Reference |
|------------------------|----------------------------|-------|----|-------------|----------------------|---------------|
| Zone 1, 2 and 3        |                            | 97.348| 50 | 67.505      | 0.000                | 0.05          |

Source: processing and calculation by author using Crosstab analysis

3.7. **Analysis volume of rainwater and water needs of the population.**

The calculation of the potential volume of rainwater that can be captured and the estimated volume of household water demand is presented in Table 6. Based on the approach of the roof area and the number of population can be calculated the need and the possibility of supply for the prediction of 2030. Year 2030 is taken as a reference because that year the spatial plan the area of Semarang City must be rearranged. The calculation results show that the lower and middle zone areas have the potential to catch more rain water because the population density is higher than the upper zone area. Based on the water requirement, the lower zone area tends to require more water than twice that of the other zone. When compared directly between water demand and rainwater harvesting supply potential, the lower zone area is likely to have a water deviation of $20,884.64 \times 10^6$ liters per year, while the middle zone has a water surplus of $2,430.05 \times 10^6$ liters per year, and an upper zone of $1,329 \times 10^6$ liters per year.

If the condition of supply and demand of water occurs as calculated in Table 6, it is necessary to consider the management of rainfall harvesting concerning physical condition (physiography landscape, geology, soil), social condition (education level, income), and disaster vulnerability comprehensively. The composition of the population according to the level of education, income and physiography landscape can be the basis of consideration in planning and design of implementation rainwater harvesting technology. By knowing the interrelationship between variables then it is possible to do better management of rainwater harvesting, so it can support water resilience of urban area.

### Table 7. Analysis volume of rainwater and water needs of the population.

| Zone                        | Lower            | Middle           | Upper            |
|-----------------------------|------------------|------------------|------------------|
| Roof area estimation 2030   | 1,788.40 ha      | 1,758.55 ha      | 1,169.23 ha      |
| Volume estimates rainwater harvest | 34.337.36 (x10^6) litre | 33,764.19 (x10^6) litre | 22,419.30 (x10^6) litre |
| Projected population 2030   | 1,008,621        | 572,313          | 385,759          |
| Volume estimates household water needs | 55,222.00 (x10^6) litre | 31,334.14 (x10^6) litre | 21,120.31 (x10^6) litre |

Source: processing and calculation by author

4. **Conclusion**

Based on the results obtained it can be concluded that the distribution and landscape characteristics have an impact or influence the attitude of the community in the application of rainwater harvesting. These results were obtained through a correlation analysis between community attitudes and their presence in different landscape physiography zones. Communities in higher physiography landscape areas are indicated to have better attitudes than people in lower and flat physiography landscape.
Differences in attitude responses are also related to the level of education and income community. In line with physiography landscape, public attitudes to apply rainwater harvesting are also indicated driven by education and income level factors. Referring to these conditions it can be concluded that the planning application of rainwater harvesting can not only consider the technical aspects only. There needs to be social considerations related to the physiography landscapes. Physiography landscape based social considerations is one of key to successful implementation of rainwater harvesting in urban areas.

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