The spatial ecology dynamics of groundwater quality: a case study of the urban environment, Yogyakarta City, Indonesia

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Abstract. Ecological vulnerability assessment is essential to environmental degradation and resource management, particularly in the urban environment that given recent global warming concerns. In this study, we propose to evaluate the spatial ecology dynamics of groundwater quality with a typical ecology in the urban environment, Yogyakarta city, as a case study. The proposed method is based on the definition of the Intergovernmental Panel on Climate Change and Water (IPCC VI) using software GeoDA 10.4. The results of the research study indicated the ecological spatial dynamics of quality groundwater in Yogyakarta City had variations in spatial correlation distribution. The overall result is 19% of the High-High (HH) classification areas appeared mainly between high concentration and the high population densities, where the economic activities have been developing rapidly. As well, 27% of the Low-Low (LL) classification areas appeared mainly between low concentration and the low population densities. The applied analysis indicates a spatial correlation between groundwater quality index and population densities index in the urban environment with positive autocorrelation. Based on result research that indicates the urgency of applying the sanitation facilities to convince local society for anticipating climate change regarding groundwater quality.

1. Introduction

These Yogyakarta city is an urban environment area in Indonesia, the population growth will increase from 422,732 people to 500,000 in 2030 with an average population growth of 1.04% [1]. In addition, the pressure of population factors from tourism activities where a number of tourist visits recorded in 2017 there were 3.89 million tourists with a proportion of foreign tourists (11.20%) and domestic tourists (88.80%) and an average length of stay is two days. Based on population and number of tourists, that can be implied that the number of people reached 1 million for the average mobility of people for a month. This number given the significant development of urban developments in the city of Yogyakarta, it is necessary to evaluate comprehensive the changes in the urban environment in Yogyakarta City and ensure the sustainability, especially the quality of groundwater.

In principle, the sustainability of an urban area can be seen from the adaptation process in maintaining a balance between ecosystem services and human well-being inside area. Sustainability includes three components of the environment, namely abiotic, biotic and cultural components. Environmental quality has a fundamental role in influencing the sustainability and sustainability of environmental quality degradation and vulnerability [2]. Therefore, to see the extent to which environmental changes or
dynamics can be evaluated through an index to measure changes in urban environments, such as the sustainable development index (UNCSD), ecological trace index (EF), green city index (GCI), and environmental performance index (EPI) [3]. In this study, we propose to evaluate the spatial ecology dynamics of groundwater quality with a typical ecologically in the urban environment, Yogyakarta city, as a case study. The proposed method is based on the definition of the Intergovernmental Panel on Climate Change (IPCC) regarding the concepts of the impact and adaptation of climate change using software GeoDA 10.4.

2. Material and method

2.1. Research area description
The location research area in regional administration is located in Yogyakarta City, shown in figure 1. This area has a total area of ± 32.53 km². The population in Yogyakarta City is one of the most densely populated around 13,007 inhabitants/km² in DIY Province. The city consists of 14 districts and has a border with Sleman and Bantul regency.

![Figure 1. Location of the research area.](image)

2.2. Data description
Data requirements for a research study are divided into the three-steps method, including: (1) Spatial distribution data of population density and sanitation facility, from the Data Cloud Platform
3. Methods
The research study was conducted using analysis method: (1) groundwater quality assessment method (GSs); (2) urbanization assessment method (USs); (3) analysis the spatial ecology of groundwater quality (GSs) and the urbanization assessment (USs)

2.3.1. Groundwater quality assessment. The above mentioned groundwater quality assessment (GSs) is a direct method for evaluating groundwater pollution risk by index. We collected and measured groundwater quality by 100 samples were taken from the shallow well. We selected parameters E. coli, Nitrate, and chloride concentrations in groundwater as a proxy since anthropogenic activities by urban development in Yogyakarta City.

2.3.2. Urbanization assessment. The above mentioned urbanization assessment (USs) is an indirect method for evaluating of development of the urban environment by index. Urbanization patterns in terms of population growth, urban land expansion, economic growth, and changes in social structure [4][5]. We used indicators of population density to identify as impact population growth due to groundwater quality.

2.3.3. Analysis of spatial correlations. The above mentioned spatial correlations between GSs and USs is an indirect method for evaluating groundwater pollution risk with the urban environment. We applied bivariate Moran's I to explore spatial correlation clustering between GSs and USs (bivariate LISA). The bivariate LISA method provides visualization of spatial correlation in local units by producing the appropriate Moran scatter plots, cluster maps, and significance maps [5][6]. The correlation spatial clustering between GSs and USs by bivariate LISA to illustrate the relationship between the value of GSs and the value of USs at neighboring locations at a certain significance level [6].

3. Result and discussion
The research study was analyzed the spatial ecology dynamics of groundwater quality by interactions spatial correlation between GSs and USs. The spatial ecology dynamics of groundwater quality were positive spatially correlated with urbanization assessment, as indicated by bivariate Global Moran's I with patterns of spatial correlations (i.e., HH, HL, LH, and LL)

3.1. Analysis of Groundwater quality assessment (GSs)
The above mentioned groundwater quality assessment (GSs) is a direct method for evaluating groundwater pollution risk. We collected and measured groundwater quality by 100 samples show in table 1 and table 2.

E. coli as an indicator of groundwater pollution whereas E. Coli was divided into four categories based on guidelines from The Regulation of the Health Minister (Permenkes) Number 32/2017 for sanitation and hygiene. Based on collected data E. coli concentration as an indicator of groundwater pollution, can be indicated that groundwater in research area has been polluted by E. coli which 85% of total samples has exceeded the quality standard. The concentration of E. Coli parameter came from feces in the settlement since anthropogenic activities by urban development in Yogyakarta City [7][8][9][10][11]. Based on evaluating groundwater quality dynamics in the research area shown in figure 2 and figure 3, it can be concluded that inferred the consistency between the previous research and groundwater quality assessment.
Table 1. The result of groundwater E. coli concentration.

| No | E. coli concentration (MPN/100 ml) | Total Sample | Category |
|----|----------------------------------|--------------|----------|
| 1  | 0                                | 15           | 15.00    | Suitable |
| 2  | 1–50                             | 53           | 53.00    | Exceed   |
| 3  | 50–100                           | 10           | 10.00    | Exceed   |
| 4  | >100 (TNCT)                      | 22           | 22.00    | Exceed   |
| Total                          | 100          | 100        |          |

Table 2. The result of groundwater Nitrate concentration.

| No | Nitrate concentration (mg/L) | Total Sample | Category |
|----|-----------------------------|--------------|----------|
| 1  | ≤10                         | 58           | 58.00    | Suitable |
| 2  | 11–20                       | 32           | 32.00    | Exceed   |
| 3  | 21–30                       | 10           | 10.00    | Exceed   |
| 4  | 31–40                       | 0            | 0.00     | Exceed   |
| 5  | >40                         | 0            | 0.00     | Exceed   |
| Total|                            | 100          | 100      |          |

Figure 2. Dynamics of groundwater quality in research area (1991-2019).

Based on the data research previously, during periods in 1985, nitrate was not a problem in water wells in Yogyakarta City [7]. Twenty years later, the concentration of nitrate increased in water wells was found in Yogyakarta, and its agglomeration that became more than 10-fold since reported. The
current study reported that the median of the concentration of nitrate in water wells in Yogyakarta City increased almost 20 times compared to the results obtained, consecutively 2.8 and 31.5 mg/L. The result parameters value N:Cl ratios (N = 100) ranged from 0 to 400 with a mean ratio was 1.9, lower than the values of 2–2.5 but still indicating excess nitrate from the fecal origin, while Chloride values measured in the study were low, Nitrate values in excess were observed.\(^9\)

The point result of the study during periods in 2017, nitrate showed that the median of nitrate in water wells in Yogyakarta City was 56.6 mg/L\(^{10}\). The Nitrate values in excess were more likely in urban areas and in households using a shared/communal latrine compared to households using a private latrine. This suggests a linkage between higher density sanitation areas and elevated nitrate levels, as suggested by others and that may be quantified by the N:Cl ratio \(^{9}\)[10]. The conclusion studies suggested rapid urbanization and lack of sanitation systems resulted in elevated nitrate and chloride levels in the city due to on-site sanitation \(^{11}\). The results of previous studies show a similar trend to the results obtained which revealed an increase in nitrate concentrations in water wells in Yogyakarta City over time, that studies conducted by several researchers indicated that an increase of nitrate is correlated with the development of urban areas in Yogyakarta City which was not followed by adequate the sanitation facilities.

3.2. Analysis of urbanization assessment (USs)

Population density is often used as a proxy for pollution pressure at the soil surface and groundwater plays a crucial role in an urban environment as around 70% of the population are using shallow wells \(^{1}\). However, groundwater quality has been tremendously threatened by using on-site sanitation systems. We selected indicators from the aspects of population density to the characterize urban environment as impact population growth due to groundwater quality that be concluded show in table 3.

**Table 3. Distribution of population density in the research area.**

| No | District      | Parameter | Distribution (%) | Density (habitants /km\(^2\)) | Category |
|----|---------------|-----------|------------------|-------------------------------|----------|
| 1  | Danurejan     |           | 4.52             | 17.389                        | Moderate |
| 2  | Gedongtengen  |           | 4.35             | 19.154                        | High     |
| 3  | Gondokusuman  |           | 11.23            | 11.895                        | Low      |
| 4  | Gondomanan    |           | 3.24             | 12.229                        | Moderate |
| 5  | Jetis         |           | 5.67             | 14.108                        | High     |
| 6  | Kotagede      |           | 8.77             | 12.070                        | High     |
| 7  | Kraton        |           | 4.16             | 12.554                        | Moderate |
| 8  | Mantrijeron   |           | 7.90             | 12.799                        | Moderate |
| 9  | Mergangsan    |           | 7.25             | 13.275                        | Moderate |
| 10 | Ngampilan     |           | 4.03             | 20.770                        | High     |
| 11 | Pakualaman    |           | 2.21             | 14.827                        | High     |
| 12 | Tegalrejo     |           | 9.04             | 13.139                        | Moderate |
| 13 | Umbulharjo    |           | 21.47            | 11.179                        | Low      |
| 14 | Wirobrajan    |           | 6.15             | 14.768                        | High     |

The population density in this research found 31.18% of high population density and 32.70% of low population density. It is apparent, that improved water source definition of the Intergovernmental Panel on Climate Change (IPCC) regarding the concepts of the impact and adaptation of climate change and water is not sufficient for ensuring safe water while improved sanitation coverage and safely managed sanitation coverage was 70.90% by using on-site sanitation systems \(^{12}\).
3.3. Analysis of spatial correlations

The results of the research study indicated the ecological spatial dynamics of quality groundwater in Yogyakarta City had variations in spatial correlation distribution. The overall result is 19% of the High-High (HH) classification areas appeared mainly between high concentration and the high population densities, where the economic activities have been developing rapidly, as well, 27% of the Low-Low (LL) classification areas appeared mainly between low concentration and the low population densities. Additionally, 29% of the Low-High (LH) classification areas appeared mainly between low concentration and the high population densities with good sanitation facilities, shown in table 4. The point of view of the research results is urgency applying the sanitation facilities which gives an interpretation of how the sanitation facilities function works based on distribution spatial correlation in the research area, shown in figure 4.
### Table 4. Patterns of distribution spatial correlations in the research area

| No | Class                  | Total Area (ha) | Percentage (%) |
|----|------------------------|-----------------|----------------|
| 1  | Not significant        | 536             | 16             |
| 2  | High-High (HH)         | 637             | 19             |
| 3  | Low-low (LL)           | 905             | 27             |
| 4  | Low-High (LH)          | 972             | 29             |
| 5  | High-Low (HL)          | 301             | 9              |

**Figure 4.** The distribution spatial correlation of groundwater quality assessment (GSs) and urbanization assessment (USs)
The applied analysis indicates a spatial correlation between groundwater quality assessment (GSs) and urbanization assessment (USs) (groundwater quality index and population densities index) with positive autocorrelation particularly with value Moran’s I 0.171641 (Moran's I > 0) shown in Figure 5. The ecological spatial correlation mainly distributed between low concentration and the high population densities with good sanitation facilities, that correlation can be indicated to evaluate the relationship between one other variable using spatial correlation, in this case an analysis evaluating the relationship between one variable with several other variables with gives spatial effect on other location units by sanitation facilities [13].

Figure 5. The spatial correlation between GSs and USs (Moran’s Index).

The applied analysis indicates a spatial correlation between groundwater quality index and population densities index in the urban environment with positive autocorrelation. Based on result research that indicates the urgency of applying the sanitation facilities to convince local society for anticipating climate change regarding groundwater quality.
4. Conclusion
The ecological spatial dynamics of quality groundwater in Yogyakarta City were successfully applied and indicated into an existing urban environment, as a case study. The results of the research study indicated the ecological spatial dynamics of quality groundwater in Yogyakarta City had variations in spatial correlation distribution. The overall result is 19% of the High-High (HH) classification areas appeared mainly between high concentration and the high population densities, where the economic activities have been developing rapidly. As well, 27% of the Low-Low (LL) classification areas appeared mainly between low concentration and the low population densities. The applied analysis indicates a spatial correlation between groundwater quality index and population densities index in the urban environment with positive autocorrelation.

Acknowledgments
This research was supported by The Ministry of Education and Culture. We express sincere appreciation to them. Thanks are also due to Dr. Sigit Heru Murti B.S., M.Si. and Dr. Sudaryatno, M.Si., as examiner in the preparation of this manuscript.

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