Spatial interaction of groundwater and surface topographic using geographically weighted regression in built-up area

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Abstract. Groundwater is a primary water resource for human living. In Indonesia, excessive exploitation of groundwater generally occurs in the built-up area due to over-discharge processes characterized by a cone of depression. This research revealed the spatial interaction between groundwater levels and surface topographic using geographically weighted regression in built-up area. Groundwater levels data are obtained from 72 wells in Cikembang, Bandung Regency, whereas surface topographic based on BIG’s DEMNas data which has 8 meters spatial resolution. This study showed significant spatial interaction between groundwater levels and surface topographic in the built-up area. The interaction has a clustered pattern with p-value less than 0.01. It indicated in the area with flat surface topographic has lower groundwater levels than others. There are several points who indicated the cone of depression in the built-up area with flat topographic. The geographically weighted regression model has high spatial variability and better results than the global regression model to assess groundwater level interaction with surface topographic.

1. Introduction
The need for freshwater always increases with population growth on the earth. Groundwater is primary water resources for human living in many aspects such as household, agricultural and industrial [1,2]. Groundwater is the water found in underground soil and rock cracks, its stored and dynamic in the saturation zone called aquifers [3]. The main source of groundwater comes from rainwater and infiltrated into geological formation following the hydrological cycle [4]. On the earth surface, groundwater covers 1.7 percent entire world’s water and supply about 20 percent the need for freshwater [5]. Groundwater has a dynamic character and depends on various environmental factors such as geological, climatic, land cover and topographic conditions [6].

In the area with uniform geological and climatic conditions, land cover and surface topographic have a dominant role. The surface topographic determines direction and water flow due to differences in hydraulic potential, aquifer thickness and groundwater levels [7,8]. Specifically, surface topographic is formed by land elevation and slope gradient which are able to influence recharge, groundwater flow rates, surface run-off, and others [9-12]. The groundwater exploitation matching with high human activities, urbanization, and land-use change, these happen in the built-up area which has impermeable characteristics and creates a cone of depression phenomenon as an impaired recharge-discharge process [13-15]. Understanding the interaction between groundwater and surface topographic in a built-up area is an appropriate effort which accordance with real-world models in
Indonesia. The country has massive-rapidly urbanization and in some cases give a negative effect on groundwater level. It needs sustainable management to keep the quality and quantity by knowing the water mechanism [16,17].

The interaction between groundwater and surface topographic is spatial studies because location or geographical factor can influence the phenomenon on a multivariate frame when the geographical model has higher significance than conventional model [18,19]. This study aims to reveal the spatial interactions between groundwater and surface topographic using geographically weighted regression in a built-up area which located on Cikembang, Bandung regency. Study of the interaction is needed because Cikembang is an upper area of Citarum watershed. Cikembang occurs land-use change into the built-up area, the process involves a topographic change to support human needs and increase groundwater exploitation thereby disrupting hydrological and environmental systems [20-23]. Furthermore, the interaction model of groundwater and surface topographic is useful not only for water resource management but can implemented in environmental engineering such as run-off, landslides, drainage placing, and waste management [24].

2. Research methods

2.1. Study area
This research was held in Cikembang Village, Kertasari District, Bandung Regency, West Java. Cikembang is located at 107° 41' 31.96" E and 7° 12’ 29.68" S. The study location focuses on a built-up area which located in the western of Cikembang because the region has urbanization tendency and various surface topographic (see Figure 1). Cikembang role as an agrotourism area called Ciwidey-Kertasari agropolitan and the upper area of Citarum watershed which requires attention to against environmental degradation [25].

2.2. Data acquisition and analysis
Groundwater data collected from 72 wells using water level meters and portable GNSS on wet season. Spatial distribution of groundwater levels is created by inverse distance weighting (IDW) technique and validates using geostatistical rules such as mean error and RMSE [26,33]. Meanwhile, surface topographic data based on BIG’s DEMNas (https://www.tides.big.go.id) which have 8 meters spatial
resolution. The data contains terrain elevation values, whereas the gradient information is obtained from slope analysis results [27] (see Table 1).

Spatial interactions between surface topographic and groundwater can be assessed using the geographically weighted regression (GWR) method with fixed Gaussian weighting type. The GWR refers to the first law of geography “everything is related to everything else, but things are more related than distant things” [28]. Spatial effects of the surface topographic into groundwater levels following the GWR equation [29,30], use:

\[ Y_i = \beta_0(u_i,v_i) + \beta_k(u_i,v_i)x_i \]

Where \( Y_i \) observed value of dependent variable in specific location, whereas \( u_i, v_i \) is geographic location of independent phenomenon (i) with regression coefficient (\( \beta \)) and \( \epsilon_i \) is called constant value.

| Variable          | Sources                   |
|-------------------|---------------------------|
| Surface topographic | Terrain elevation         |
|                   | Land gradient / slope     |
| Groundwater       | Groundwater levels        |

| Sources                        |
|--------------------------------|
| BIG’s DEMNas                   |
| Slope analysis                 |
| Field survey based on 72 well  |

3. Results and Discussion

3.1. Groundwater and surface topographic in built-up area

Similar to the development trend in other developing countries, the dynamics of urbanization in Bandung Regency sprawl into suburban and rural areas. This phenomenon causes a recharge-discharge imbalance of groundwater which shown by the existence cone of depression [1,15]. In the built-up area, groundwater levels average reached 1730.22 meters, whereas the average depth of the groundwater was reached 9.76 meters from land surface with decreases pattern (increases in depth) into the east (Figure 2).
Figure 2. Groundwater levels and flow generated using IDW interpolation based on field survey on wet season.

Figure 3. Surface topographic parameters in Cikembang. The terrain elevation generates from DEMNas using bilinear interpolation with hillshade effect, whereas the land gradient reclassify using Van Zuidam’s classification.

There are three cones of depression on the built-up which is located close together. Groundwater levels reduction occurred due to over-exploitation [31] and a high density of wells. In the biggest cone
of depression, well density reaches more than 50,000 units per square km. In other side, the total head in this location has better recharge from around because Cikembang located on valley of the South Bandung mountain complex. The majority of wells are located at 1601 – 1607 meters above sea level with groundwater levels that tend to deep. Unevenly distribution of groundwater wells occurred by limited compatibility for residential land with clustered pattern and the area has many settlements will experience resources over-exploitation [13]. The built-up area occupies in flat area based on Van Zuidam's classification [32]. The built-up of this area has slope gradient between 0 – 15 percent or 0 – 8 degree (Figure 3).

3.2. Spatial interaction of groundwater and surface topographic

This study showed the significant spatial interaction between groundwater levels and surface topographic in the built-up area. The interaction has r-square reach 0.435 and probability value (p-value) less than 0.01 (Figure 4). a the highest interaction has clustered pattern in the northern area, it occurs in flat areas with lower elevation from the surroundings and shallow groundwater levels can be found in there. This condition indicated surface topographic as a determining factor for the availability of shallow groundwater, besides the climatic, geological, vegetation and social-economic factors [2]. In addition, this geographically weighted regression (GWR) model has high spatial variability and better result than global regression (GR) because the GWR r-square (0.435) is higher than GR r-square (0.055) [18, 29, 33], thus the geographical influence of surface topographic on groundwater levels in built-up area of Cikembang was proven. The spatial interaction of groundwater and surface topographic is shown as follows:

\[ Y_i = 0.46(X_1) + 0.38 (X_2) + \]

Based on the equation, terrain elevation (X1) has a higher effect than slope (X2) on groundwater levels (Yi) in the built-up area with a relatively small difference. Besides that, the constant values have greater value than variable coefficients, it indicates there are non-natural factors which also determine the groundwater levels such as well location, water exploitation, and management [9,26] although determination of surface topographic into groundwater levels was reach 28 percent. The high exploitation of groundwater in Cikembang raised a cone of depression. If this phenomenon not managed properly, it will reduce the quantity and availability of groundwater [13,15]. Therefore the exploitation of groundwater must suitable with the surrounding environment, the presence of other wells, drainage, and waste repositories need more attention to maintain water resources.
Figure 4. Spatial interaction of groundwater and surface topographic shows clustered patterns with p-value 0.01. The interaction has risen on the flat and low topographic areas of Cikembang.

4. Conclusions
The surface topographic has significant spatial influence into groundwater levels in the built-up area of Cikembang. The groundwater is affected by topographical conditions, its presence is better in a flat and low area. Spatial analysis of groundwater with surface topographic is very important for water resources management, especially if other factors are constant. The spatial method to understanding the interaction between groundwater and environmental conditions is able to reveal a better mechanism of the local hydrological process, if the interaction model has fulfilled of validity and variability.

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