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Research Plan For Managing Groundwater Resources Of The Coastal Cities In The Central North Of Java Island

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Abstract

Semarang, as one of the coastal cities in the central north of Java Island, is growing fast, in particular in the industrial and commercial sectors. From a regional development perspective, the position of Semarang is of high strategic value for the economic activities not only for the central of north Java Island, but also for Jakarta as the capital city of Indonesia.The dynamic condition in Semarang is triggering the increase of economic development for surrounding areas such as from Pekalongan in the west to Demak in the east. It then leads the demand for clean water primarily from groundwater for domestic and industrial purposes, increasing continually in line with the population growth. The increasing exploitation of groundwater affects some environmental problems such as declining groundwater levels, land subsidence, seawater intrusion, and flooding.Thus, there is an urgent need to give quantitative and qualitative assessments to the actual situation of groundwater at the coastal cities in the central north of Java Island. This will be a platform as a tool in order to manage groundwater in the coastal cities for more than one groundwater basins. This three years project aims at:

a. *Calculating groundwater recharge modelling based on GROWA model, empirical methods, and environmental isotopes.*
b. *Defining groundwater age and hydrochemistry analyses.*
c. *Simulating current conditions on groundwater flow and sea water intrusion and future impacts.*

Keywords: *Groundwater recharge, GROWA model, Environmental isotopes, Numerical modelling, Semarang.*

Introduction

One of the current transformations in Indonesia is about urbanization. The rapid urban population and coinciding decline in rural growth rates are summarized in Fig. 1. The proportion of people living in urban areas exceeds 50% by 2010 and is predicted to reach up to 60% by 2025. Statistics Indonesia/BPS (2011) stated that the increasing population has been unevenly distributed in Indonesia. Java Island is the most populated with an annual growth rate of the population around 0.37-1.9% in the years 2000-2010. The highest percentage of urban growth in Java Island occurs in the coastal cities.

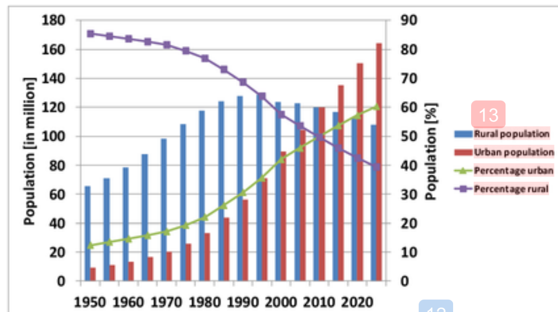


Figure 1. Trends in urban and rural population in Indonesia (United Nations Population Division, 2012)

Unfortunately, the increasing population in the coastal cities affects an enormous stress on the natural resources – groundwater, in particularly. Groundwater represents the most valuable drinking water resource. Urban and industrial development can enforce major stress on this resources by increasing water demand via deep wells (on quantity) and or by releasing contaminants into groundwater (on quality). Moreover, urbanization and industrial development can fundamentally alter the entire water balance of an area (Lerner et al., 1990) by modifying essential hydrological components such as evapotranspiration, runoff, aquifer recharge, and can introduce a new artificial recharge as net urban recharge. This net urban recharge covers total domestic use, local abstraction, consumptive use, leakage from sewers and water mains (Putranto, 2013). Nowadays, groundwater protection and its management programs are in force at the coastal cities in Indonesia due to raising several environmental problems.

Semarang, as one of the coastal cities in the central north of Java Island, is growing fast, in particular in the industrial and commercial sectors. From a regional development perspective, the position of Semarang is of high strategic value for the economic activities not only for the central of north Java Island, but also for Jakarta as the capital city of Indonesia. This area is supported by an international seaport and a national scale airport. The dynamic condition in Semarang is triggering the increasing of economic development for surrounding areas such as from Pekalongan in the west to Demak in the east. It then leads the demand for clean water primarily from groundwater for domestic and industrial purposes increases continually in line with the population growth. The increasing exploitation of groundwater affects some environmental problems such as declining groundwater levels, land subsidence, seawater intrusion, and flooding in the central north of Java Island as the latest happened in the early 2014 (Semarang di bawah ancaman rob (2): Akibat pengambilan air bawah tanah tak terkendali, 2004; Prihantoro, 2011; Parwito, 2014). In the concept of groundwater basin management, these areas are across several groundwater basins (UU No. 7/2004; PP No. 43/2008). Thus, there is an urgent need to give quantitative and qualitative assessments to the actual situation of groundwater at the coastal cities in the central north of Java Island. This will be a platform as a tool in order to manage groundwater in the coastal cities for more than one groundwater basins.

The main objectives of this project are:

a. Calculating groundwater recharge modelling based on GROWA model, empirical methods, and environmental isotopes.
b. Defining groundwater age and hydrochemistry analyses.
c. Simulating current conditions on groundwater flow and sea water intrusion and future impacts.

Intended results of the project can lead to better methods of impact prediction and groundwater protection will provide major benefits and supports to the local planners and decision makers in issuing better strategies for managing groundwater at the coastal cities.

Geological and hydrogeological setting of the study area

The study area is located at the four groundwater basins along the central north of Java Island which are Pemalang-Pekalongan, Subah, Kendal, and Semarang-Demak. All basins are 4,012 km^2 wide crossing several administrative boundaries as shown in Fig. 2.

Figure 2. Groundwater basin boundaries including their volume in MCM yr^{-1} of the unconfined (Q1) and confined aquifers (Q2) in the study area (Setiadi, 2004).

Based on the physiography of Java (van Bemmelen, 1949), the study area contains the alluvial plain of northern Java and quaternary volcanoes. In the north, lithology consists of surficial deposit from coast, river, and deltaic. Meanwhile, volcanic rocks such as tuffaceous sand, breccia, and lahar deposits are dominant in the south.

Ground water flows from the mountainous area in the south towards the coastal plain in the north. Groundwater flows predominantly in an inter granular system which consists of sedimentary deposits while volcanic rocks form an aquifer system of minor importance. They are fissures, interstices and fractures aquifer system. There are two aquifer systems in the study area: unconfined/shallow and confined/deep aquifers, respectively. Based on the regional groundwater basin map of Central Java and Yogyakarta Province (Fig. 2), Setiadi (2004) stated that the volume of the unconfined aquifer (Q1) is varying from 400-800 million cubic meter per year [MCM yr^{-1}] while at confined aquifer (Q2) has a range from 2 to 20 MCM yr^{-1}. Groundwater is abstracted by numerous dug wells from the unconfined aquifer, mostly for domestic water supply, whereas groundwater exploitation via deep wells concentrates on the confined aquifer. The fluctuation of water tables depends on the season, which is high and low levels in the rainy and dry seasons, respectively (Susana and Harnandi, 2007). The piezometric levels have substantially declined due to increasing abstraction as well as the number of deep wells into the confined aquifer since 1980s especially in Semarang, where groundwater is the main water resource for the commercial sector.

Methods

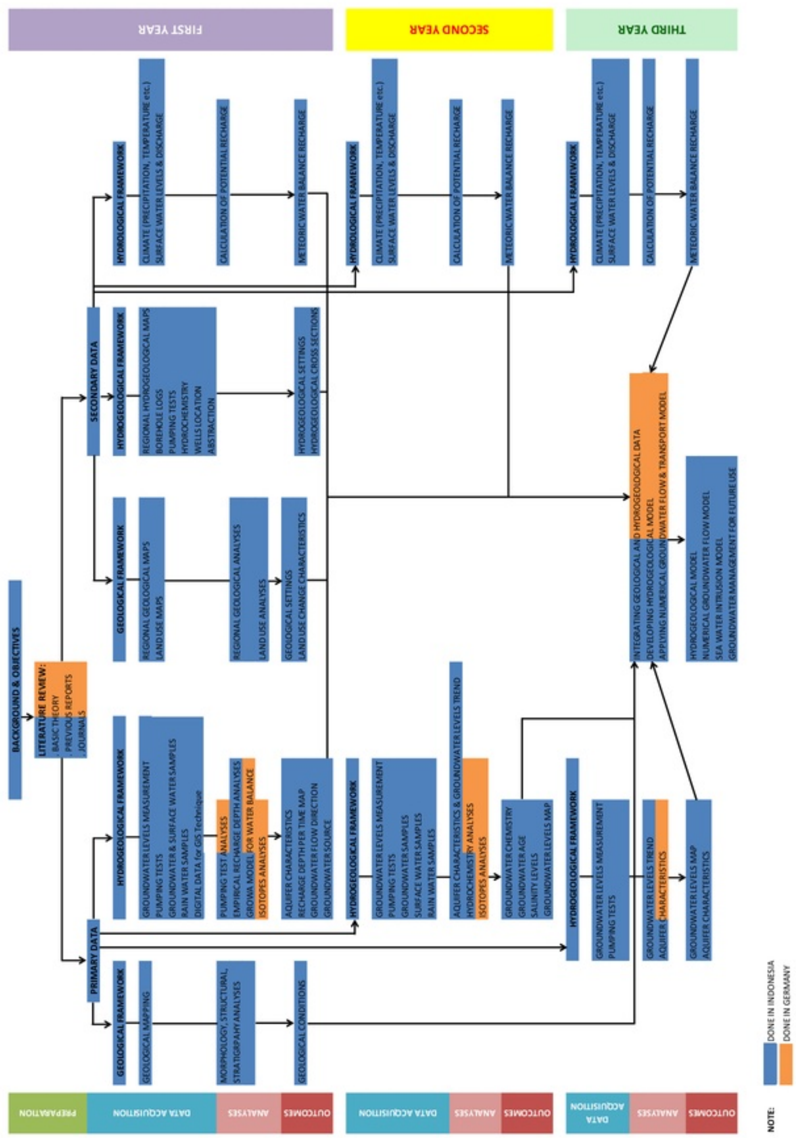
This research will focus on the integrated data of groundwater resources at the coastal cities in the central north of Java Island. Figure 3 illustrates the details of research framework for three years. It divides into four steps: preparation, data acquisition, analyses, and outcomes.

First year concerns on build up the geological and hydrogeological database based on geological, hydrogeological, and hydrological frameworks. Field campaign will focus on data acquisition of geology and hydrogeology. Geological framework describes the geological setting of the study area from the mapping results. Furthermore, the hydrogeological framework concentrates on groundwater quantity. Groundwater level measurements and pumping tests are implemented on deep wells twice in a year (summer and rain seasons) to identify the characteristics of aquifer (e.g. water levels, hydraulic conductivity, discharge etc.). Moreover, water samples from groundwater, surface water (e.g. river), and rain water are analyzed by using environmental isotopes (^{2}H, ^{13}C, and ^{18}O) for defining the origin of groundwater. Furthermore, an application of the GROWA model based GIS technique is applied.

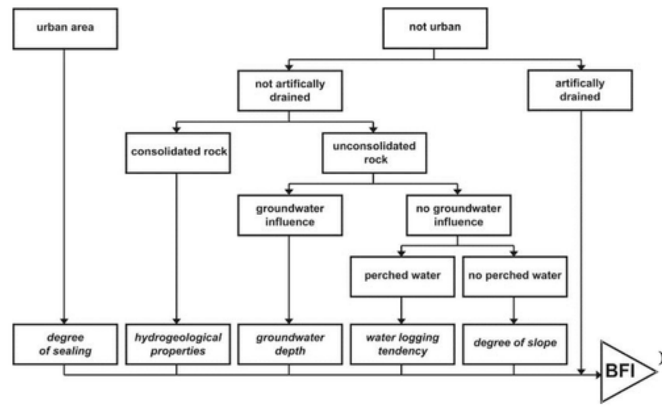
The GROWA model consists of several modules for quantifying the real evapotranspiration, total runoff, direct runoff and groundwater recharge in the basin scale. The results then are compared with the calculation of potential recharge from empirical methods by using hydrological data. Basin scale climate, hydrology, soil, hydrogeology, topography and land use data are required to be applied in the data preparation and regionalization for GROWA model. As GROWA is a GIS-based spatially distributed model, all these datasets will be prepared into a digital platform as far as needed for further analyses.

The hierarchical approach for determining groundwater recharge in the GROWA model is shown in Fig. 4 The groundwater recharge depth is verified in the GROWA model by separating the calculated total runoff into components of direct runoff and baseflow so-called "baseflow indices/BFI" (Karpuzcu & Wendland, 2008). The groundwater recharge is expressed as a relative fraction of the total runoff, Q_{total}:

$$GW\ recharge = BFI \cdot Q_{total} \qquad (Eq\ 1)$$



The BFI values are dependent on specific site conditions and are assumed to be nearly constant on a long-term average. The application of the GROWA model to the Lower Saxony area has shown that the use of BFI values from literature leads to realistic groundwater recharge depth in unconsolidated rock regions.



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The second year is mainly focused on monitoring, evaluating, and assessing groundwater quality. Thirty samples are analysed by using a carbon isotope (^{14}C) to define the groundwater age. Indeed, the hydrochemistry analyses of total 100 samples from groundwater (deep wells, shallow wells, and springs) as well as surface water are performed to define water type based on the major cations and anions also general physical parameters (e.g pH, TDS, eC) content. Furthermore, the salinity levels, as one of the impacts of groundwater overexploitation in the coastal cities, are performed in this period to monitor the current situation of seawater intrusion. All findings in this period are combined with the present hydrological data (i.e. climate) to perform a complete analysis of groundwater quality in the basins.

Expected Outcomes

It has been shown in case of the Semarang sub-basin (Putranto 2013) that a systematic, GIS-based database can give new insights into an aquifer system and that a numerical model is suitable to derive better numbers on groundwater extraction and to predict changes of recharge also due to prognoses of climate changes. Figure 5 shows the effect of abstraction and climate change to the potential loss of groundwater resources based on prognoses results in the future. Keeping abstractions to a constant amount in number is unreasonable due to the future city development. The process of abstraction and climate change will lead to high potential loss of groundwater resources in the future. The best solution is achieved by decreasing abstraction. It affects groundwater storage increase. Thus, it causes a low in potential loss of groundwater resources in the future. This should be a critical point for the decision makers at the local government (Semarang municipality) in order to manage groundwater use in the future.These numbers allow for an improved and solid groundwater management. Yet, dealing on the scale of a sub-basin needs some assumptions on groundwater inflow into the model area from the surroundings. Purpose of this project is to set these values to zero working on the full basin scale. The contribution of the project about managing groundwater resources at the coastal cities in the central north of Java Island expresses the desired state of the groundwater basin both in quantitative and qualitative terms.It provides the essential for more specific basin groundwater management goals:

a. Determine groundwater supply reliability for present and future beneficial uses
b. Maintain groundwater quality to meet present and future beneficial uses based on drinking water standard from Ministry of Health the government of the Republic of Indonesia (Permenkes RI No. 492/2010)
c. Prevent unfavourable environmental impacts due to groundwater usage and urbanization

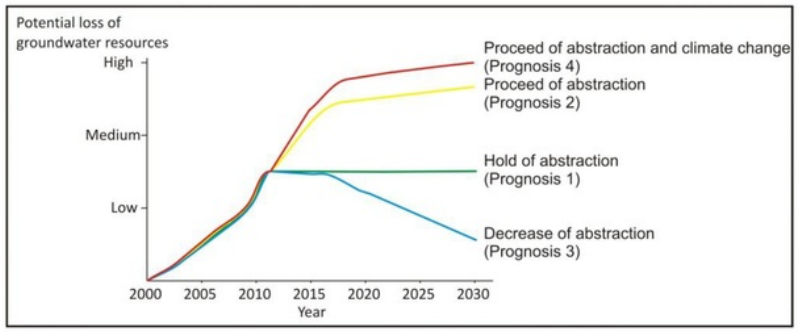

Figure5.The impacts of abstraction and climate change to the potential loss of groundwater resources (Putranto, 2013).

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