Groundwater Problems in Semarang Demak Urban Area, Java/Indonesia

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Abstract

The Semarang Demak urban area is growing fast, in particular in the industrial and commercial sectors. Increasing groundwater withdrawals as an impact of rapid growth induce some environmental problems. Descriptive analysis based on a field campaign and other scientific data was used to give an integrated view of some groundwater problems related to the use of groundwater. Increasing population and land use changes require water resources to fulfill the need. Groundwater representing one of the water resources in the study area is used for many purposes. Groundwater overexploitation in the research area causes a drawdown of groundwater level and land subsidence in the northern part of Semarang, Java/Indonesia. There are three kinds of flooding which are local flooding, river flooding and tidal flooding (rob). Local flooding and river flooding are caused by excessive rainfall, upstream land use changes as well as decreased ability to accommodate the water capacity of the river, while tidal flooding is supported by flat morphology, sea level rise, land subsidence due to overexploitation of groundwater, and human’s socio-economic activities.

Keywords: groundwater, land subsidence, flooding, Java

1. Introduction

Demographic conditions in Indonesia, which is number four in total population size by world population prospects (United Nations, 2004), are characterized by rapid urban population growth and simultaneous decline in rural growth rates as summarized in figure 1. The highest percentage of urbanization takes part in coastal cities. Population statistics show for the first time that urban population reached 50.5 % of total population in 2008 (Setioko, 2010). Indonesian Statistics Board, namely BPS, (2010) stated that the increase of population in Indonesia has been unevenly distributed regionally. Java Island is the most populated with an annual population growth rate of around 0.70-2.03 % in the years 1990-2000. At this time, there are nine cities in Indonesia classified as metropolitan cities with a population of more than one million inhabitants. Most metropolitan cities are located in Java Island such as Jakarta, Bandung, Surabaya, Bekasi, Tangerang and Semarang. Semarang city, as one of the metropolitan cities in Java Island, is growing fast, in particular in the industrial and commercial sectors. From a regional development perspective, the position of Semarang Demak urban area is of high strategic value. Semarang Demak urban area is supported by an international seaport and a national scale airport. The land use in Semarang city has changed from agriculture to non-agriculture during the development process. The widest land use in Semarang city is for housing (33.12 %), plantation (23.81 %) and paddy fields (11.68 %). Nevertheless, there has been a significant change of land use in the last five years. Agricultural use as many as 77 ha have been converted to non-agricultural use in 4 years, i.e. around 20 ha per year. The area used for paddy fields diminished during the last five years from 3,980 ha in 2001 to 3,898 ha in 2005 (Bappeda, 2007). However, the suburban areas (Demak, Grobogan and Kendal) are still dominated by agricultural areas which accounts for 60-70% of the total area. Converting area and city development processes have an impact on total
population. In 2005, the total population in Semarang urban and its suburban areas was 2.7 million inhabitants. Related with the city development process, the population in 2010 increased to above 3 million inhabitants with a growth rate of 1.85% in 2009 (BPS Provinsi Jawa Tengah, 2010). Related with the increasing population and land use changes, there are some environmental problems, especially in relation to groundwater use. This paper will briefly discuss environmental problems related with groundwater use in Semarang Demak urban area such as declining groundwater level, land subsidence, and flooding.

![Figure 1: Indonesia urban population vs. rural population trend (Setioko, 2010).](image)

2. Study Area

Semarang Demak urban area is located at the northern coast of Java Island, Indonesia (fig. 2). Geographically, the study area is located 419500 to 480250 in East Longitude and 9212850 to 9258190 in South Latitude. Total study area covers about 1,386 km² including 321 km² in Semarang city, 864 km² in Demak regency, 190 km² in Grobogan regency and 11 km² in Kendal regency. Topographically, Semarang Demak urban area consists of two major morphologies which are lowland and coastal area in the north and hilly area in the south. The northern part is relatively flat with an altitude of less than 10 m above sea level. It is a centre of residential, transportation facilities (such as harbor, airport and railway), economic and administrative activities with a denser population compared to the southern part. The south is a slopy to hilly area with an altitude between 10 m to 350 m above sea level and residential areas, public grounds and open spaces.

Semarang Demak urban area, like the other regions of Indonesia, has a tropical climate with two distinct seasons; monsoon wet and dry. The rainy season with rainfall > 150 mm/month, is usually from November to April. It is controlled by west monsoon winds that blow from Asia to the continent of Australia and bring abundant moisture from the Java Sea and Indian Ocean. Otherwise, the east monsoon (from May to October) brings much drier air from Australia. In this period, Indonesia will experience a dry season, which has rainfall less than 150 mm/month,. The average annual rainfall in Semarang Demak urban area can be estimated as about 174 mm/month or 2091 mm/year (BMKG, 2008). Groundwater recharge based on the calculation of meteoric water balance, which is concerning some factors such as rainfall, real evapotranspiration, runoff, and also net urban recharge, is about 316 mm/year (Putranto & Rüde, 2011).
3. Geology & Hydrogeology Setting

Geologically, Semarang Demak urban area consists of two main rock types, which are sedimentary rocks and surficial deposits (fig. 3). Sedimentary rocks in stratigraphical order are Kerek Formation (Tmk), Kalibeng Formation (Tmpk), Damar Formation (QTd) and Kaligetas Formation (Qpkg), while surficial deposits consist of unconsolidated alluvium (Qa). Thanden et al. (1996) stated that Kerek and Kalibeng formations consist of alternation of claystone, marl and limestone. Claystones are partly interlayered with siltstone or sandstone, and locally contain forams, molluscs and coral colonies. Conglomerate layers occur in claystone and sandstone. Limestone is commonly bedded and sandy with a total thickness of more than 400 m. The unit is of Middle Miocene age. While Kalibeng Formation consists of massive marl in its upper part, it locally contains marls intercalated with tuffaceous sandstone and limestone. The unit is late Miocene to Pliocene. Outcrops of both formations occur at the lower to intermediate slopes. The Damar Formation, which is located at intermediate slopes, consists of tuffaceous sandstone, conglomerate and volcanic breccia. Volcanic breccia is represented as a laharic deposit in the centre of the Semarang area. This unit is partly nonmarine, containing molluscs and remains of vertebrates. The Kaligetas Formation represents a volcanic product in the intermediate to upper slope consisting of breccia, lava flows, tuffaceous sandstone and claystone. Mathon (1975) stated that the coastal plain of Semarang-Demak is formed by basin sediments (Holocene, Lower Pleistocene) deposited in a marine environment. The bulk of the basin sediments contain alluvium and are made of thick layers of calcareous and shell-bearing clay, with thin intercalations of sand, and occasionally gravel or cemented gravel.

Tectonic activity took place in Early Tertiary, evidenced by basaltic and andesitic intrusions in the southern part of Semarang, and followed by uplifting and erosion. This erosion formed turbidites of the Kerek Formation (the oldest lithology in study area) in a neritic environment which is subsequently followed by the Kalibeng Formation in a bathyal environment and basin filling of the Damar Formation in a transitional to terrestrial environment. Then, the Plio-Pleistocene tectonic activity reactivated the result of Early Tertiary deformation, forming dominantly faults. The occurring fractures form a weak zone for the rise of young Quaternary volcanic rocks.
Groundwater flows from the mountainous area in the south to the coastal area in the northern part (Said & Sukrisno 1988). The recharge area is in the Ungaran Mountain area, whereas discharge area is along the coast. The regional hydrogeological map of Semarang (fig. 4) indicates that the occurrence of groundwater in Semarang Demak basin flows dominantly in an intergranular system, while both fissures and interstices systems spread in some areas, and locally unexploitable groundwater.

2. Groundwater problems in Semarang Demak Urban Area

2.1 Declining groundwater level

Groundwater use in Semarang Demak basin started since the first deep wells were drilled in 1841 at Fort Wilhelm I (Dahrin, 2007). The numbers of registered deep wells and total groundwater withdrawals are shown in figure 5, and also groundwater level in selected wells. The number of registered deep wells increased sharply in
In 1900, the total number of deep wells was 16, became 260 in the 1990ies and in the first decade of the new millennium, it went up to 1,194 wells with a total groundwater withdrawal of around 45 MCM/a (DEG, 2003). Increasing groundwater withdrawals as an impact of rapid growth in housing development and the industrial sector induced a quantitative impact such as declining groundwater level in the research area. Intensive groundwater abstraction in the Semarang area, as shown in piezometric heads of some observation wells (observation wells in Wotgandul, STM Perkapalan, PRPP and LIK), caused a drawdown of the groundwater level from 10 m to 35 m below sea level. In contrast, the drawdown of groundwater level vary from 0.4 m to 7 m below sea level in Demak region. Moreover, groundwater abstraction in Semarang area also made the cone of depression extend over a wide area of Semarang town (Schmidt, 2002). Figure 6 shows the increasing drawdown of the deep aquifer since 1989 in the research area as the result of a rapid increase of groundwater production.

![Figure 5: Development of registered deep wells and groundwater abstraction (a) and piezometric heads of some observation wells in Semarang Demak urban area (b).](image)

![Figure 6: Groundwater level in the deep aquifer 1989 to 1998 (Schmidt, 2002).](image)
2.2 Land subsidence

The increasing exploitation of groundwater, especially in basins filled with unconsolidated alluvial, lacustrine, or shallow marine deposits, has as one of its consequences the sinking of settlements on subsiding ground. The occurrence of major land subsidence due to the withdrawal of groundwater is relatively common in highly developed areas (Poland, 1984). Several investigations for the prediction and modelling of land subsidence in Semarang have been done by researchers using various methods and approaches, e.g., based on models incorporating geological and hydrological parameters (Tobing et al., 1999), one dimension consolidation model (1-D) from Terzaghi (Marsudi, 2000), leveling and Global Positioning System (GPS) survey (Abidin, 2005; Marfai & King, 2007, Abidin et al., 2010), Persistent Scatterer Interferometry/PSI using Stable Points Network/SPN (Kuehn et al., 2009a & b). Most of the researchers stated that land subsidence in Semarang is supposed to be resulting chiefly from compaction in alluvial clayey sediments. Compaction is a natural process but can also be caused by uncontrolled usage and overexploitation of groundwater (Kuehn et al., 2009b). Land subsidence causes many problems in Semarang which are (1) damage to infrastructure such as roads, drains, canals, railroads, sanitary sewers; (2) damage to public and private buildings such as industrial buildings, school buildings, government offices, and houses; (3) changes in elevation and slope of streams, canals, and drains; (4) extra costs of pumping storm water and sewage out to flood canal; (5) subsidence also has resulted in tides moving into low-lying areas that were previously above high-tide level as illustrated in figure 7 (Marfai & King, 2007).

Figure 7: Examples of problems due to land subsidence in Semarang (a) a building damage, (b) remaining dwelling unit after several fillings in the yard, (c) tidal inundation in main road (Marfai & King, 2007).

Based on the Synthetic Aperture Radar (SAR) data recorded from 2002 to 2006 by the German Federal Institute of Geosciences and Natural Resources (BGR) and the Indonesian Geological Agency, the measurement of land subsidence using PSI on stable points which are persistently reflecting the radar radiation during each period of interest, land subsidence is most severe in northern part of the city especially among the harbour area and railway station, and towards the southeast and the east, in accordance with the drawdown of groundwater level (see fig. 6) also expanding into housing and industrial areas (Kuehn et. al 2009a). The highest rate of land subsidence is in the northern part of Semarang which is about 8-9 cm/year while in the southern part, it is around 0-1 cm/year. The rate of land subsidence using PSI observation in Semarang is shown in figure 8. Marfai & King (2007) stated that the area affected by land subsidence in Semarang will gradually increase from 362 ha in the year 2010 to 1,377.5 ha in the year 2015 and up to 2,227 ha in the year 2020 as shown in table 1. The prediction of sinking area was calculated based on digital elevation model data in 2003 and 38 points of bench mark data to monitor land subsidence in Semarang.
2.3 Flooding

Semarang Demak urban area faces three types of flooding which are local inundations, river flooding and tidal flooding. There are several factors contributing to flooding which are meteorological factors, hydrological factors and human factors. Local inundations and river flooding occur during the rainy season in low land and the coastal area. Excess rainfall, lowering capacity of stream channels and changes of upstream land use of the watershed generate higher runoff downstream causing local inundations and river flooding (fig. 9). There are nine surface watersheds in Semarang Demak urban area, as shown in table 2. Flooding often occurs around the river and in the northern part of the lowland area. A potential flood area is generally the coastal area, because the ground surface is lower or equal with mean sea level and became the estuary of most rivers and also in the flood plain zone on the left and right river banks where their slopes are very gentle or flat. Another factor that makes flooding occurring recently in Semarang Demak urban area (especially in Garang, East flood way and Tuntang and also Serang river) is siltation of river beds that caused them to be unable to sufficiently accommodate water discharge from upstream.

Table 1: Sinking area caused by land subsidence in Semarang and its prediction (in ha).

<table>
<thead>
<tr>
<th>Year</th>
<th>Elevation below sea level (cm)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-50</td>
<td>50-100</td>
</tr>
<tr>
<td>2010</td>
<td>328</td>
<td>315</td>
</tr>
<tr>
<td>2015</td>
<td>1,162</td>
<td>187</td>
</tr>
<tr>
<td>2020</td>
<td>1,464</td>
<td>607</td>
</tr>
</tbody>
</table>

Source: Marfai & King, 2007.
Unlike local inundations and river flooding, tidal flooding occurs almost daily depending on the tidal oscillation in the coastal area (Marfai & King, 2007). Tidal flooding, locally named “Rob” inundation, is a special phenomenon which does not commonly happen in the other coastal cities in Indonesia. Rob inundation is caused by the topographical factor, increasing volume of sea water triggering the rise of sea level, land subsidence due to overexploitation of groundwater and human’s socio-economic activities (Rahmatullah, 2010).

### Table 2: Watershed in Semarang Demak urban area.

<table>
<thead>
<tr>
<th>No.</th>
<th>Watershed &amp; Main River</th>
<th>Catchment Area (ha)</th>
<th>Rainfall (mm/year)</th>
<th>Length of Stream (km)</th>
<th>Annual Average Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Blorong</td>
<td>66,797</td>
<td>2,092</td>
<td>56.05</td>
<td>5.9 – 15.3</td>
</tr>
<tr>
<td>2.</td>
<td>Mangkang Barat</td>
<td>10,352</td>
<td>2,064</td>
<td>15.13</td>
<td>0.9 – 1.6</td>
</tr>
<tr>
<td>3.</td>
<td>Mangkang Timur</td>
<td>4,782</td>
<td>2,106</td>
<td>9.6</td>
<td>0.3 – 1</td>
</tr>
<tr>
<td>4.</td>
<td>Garang</td>
<td>42,554</td>
<td>2,152</td>
<td>40.53</td>
<td>28.0 – 46.9</td>
</tr>
<tr>
<td>5.</td>
<td>East Floodway</td>
<td>15,716</td>
<td>2,080</td>
<td>12.66</td>
<td>0.8 – 2.42</td>
</tr>
<tr>
<td>6.</td>
<td>Babon</td>
<td>24,583</td>
<td>2,162</td>
<td>33.76</td>
<td>1.0 – 1.9</td>
</tr>
<tr>
<td>7.</td>
<td>Jragung</td>
<td>59,018</td>
<td>2,156</td>
<td>72.44</td>
<td>2.5 - 9.8</td>
</tr>
<tr>
<td>8.</td>
<td>Tuntang</td>
<td>118,036</td>
<td>2,171</td>
<td>113.52</td>
<td>9.7 – 18.1</td>
</tr>
<tr>
<td>9.</td>
<td>Serang</td>
<td>802,476</td>
<td>2,066</td>
<td>238.55</td>
<td>31.4 – 65.8</td>
</tr>
</tbody>
</table>

Source: PSDA (2009), JICA (1993)

Figure 9: Map of flooding caused by tidal inundation in northern Semarang (a); river flooding caused by excessive rainfall and lowering capacity of Tuntang River, courtesy of Suara Merdeka, photo 31 January 2009 (b); increasing housing development in hilly (upstream) area trigger increasing runoff that caused flooding downstream (c).

### 3. Conclusions and Outlook

Based on all of the problems in Semarang city and its suburban mentioned above, groundwater becomes a major problem related to the increasing population and converting land used. There is an urgent need to give a
quantitative assessment of the actual situation and to facilitate simulations of the groundwater level in response to social and economic demands. Groundwater modelling is one of the main tools used in the hydrogeological sciences for the assessment of the resource potential and prediction of future impact under different circumstances/stresses to be conducted including a scientific approach in order to have more insight into the correlation of groundwater overexploitation as one of the main factors causing land subsidence in Semarang Demak urban area.

References


