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Salt intrusion in Coastal and Lowland areas of Semarang City

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SUMMARY

Over a long term, Semarang Coastal and Lowland areas have experienced salt water intrusion. This condition is accelerated due to land subsidence, sea level rise and groundwater exploitation. The purposes of this research paper were to highlight the salt water intrusion from 1995 until 2108 based on well log measurement and MODFOW numerical modeling in Coastal and Lowland of Semarang City. Sea level rise projection also was considered for salt intrusion projection in the future. MODFLOW was used to compute the groundwater flow field, MT3D for the salt transport, and ArcGIS Environments for coherent geographic visualization. A calibration of the model was conducted based on observation best match. The results obtained illustrate the development of a forward onshore sea salt water intrusion since 1995. It also showed the 2008 recorded sea water intrusion and provide groundwater sea water contamination projection for the years 2018 until 2108. Moreover, fresh water distribution near the coast in previous years developed into brackish water then into saline groundwater. Result showed the movement of saline groundwater from coastline to landward years by years from 2018, 2028, 2048, 2068, 2088 and 2108 following high hydraulic conductivity area. Salt intrusion was also driven by future sea level rise which result to the increase of the fresh water front forward move.

1. Introduction

1.1. Background

The transitional zone between the fresh and salt water in coastal groundwater aquifer can be modeled based on evolution of water quality distribution influenced by a range of effect like tidal, morphology of shore, and groundwater reservoir, geological type (Vandenbohede and Lebbe, 2006). Since this transition zone movement is very dynamic as the result of aquifer stresses changes (Young Kim et al., 2009), this movement depends on factors such as aquifer withdrawal, hydraulic properties, and confining unit of coastal area (Rotzoll et al., 2010). Hydraulic gradient is one of the considered factors to evaluate dynamic density distribution sea water lens (Vandenbohede and Lebbe, 2006). Increase of discharge and piezometric head will result to the decrease of the concentration of ion in saline water (Celico et al., 2008). The mixing of local infiltration from discharge and groundwater rise will conduct the decrease of ion concentration. Most of salinity content in groundwater is due to the influence of seawater and hydrogeochemical process (Bahar and Mezbaul., 2010).

The increase of population, the extensive water use, the interbasin water transfer, and the climate change effect have and will impact the groundwater level change (Tillman and Leake, 2010). It has been showed that groundwater overexploitation leads to salt water intrusion in coastal area (Pousa et al., 2007). And, long-term groundwater abstraction pushes land subsidence occurrence (Seiler and Gat, 2007; Qing-hai et al., 2007). Furthermore, land subsidence may contributes to sea level rise that will lead to increase concentration of chloride as salinity plume forward to the inland (Todd and Mays, 2005; Nguyen et al., 2006).

The main risk in the coastal community of Semarang City, Indonesia is the severe coastal inundation because of the increase of land subsidence (Marfai et al., 2008a; Kuehn et al., 2010). This city is one of the largest areas in Central Java Province that experience coastal inundation from local flood inundation, river flood and sea water tide flood (Marfai and King, 2008). The main factor leading to the land subsidence in Semarang is the groundwater withdrawal to meet water demands (Rahmawati, 2010; Soedarsono, 2011). As population growth and urban development in Semarang City increase, the water stress rises significantly on groundwater. Moreover, the city experiences long-term salt water intrusion (Nugroho, 1989; Purnama, 2005). As a waterfront city, along the coast of Semarang City, the erosion process from 1937 to 1972

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especially has changes shoreline-wide pattern (Marfai et al., 2008b). Those active conditions of land subsidence rate and shoreline changes increases further potential development of salt intrusion in Semarang City. Based on this background and a MODFLOW model, this paper will investigate different scenario of salt intrusion development in the future and its impact for environment based on recent condition (land subsidence) and sea level rise.

1.2. Site description

The Semarang City is located on one of small deltas in the world (Snead, 1980 in Viles and Spencer (1995)), and experiences an important urban growth (in Kodya Semarang). According to history, urban growth in Semarang City starts with due to Chinese visitors for trading purpose. The development of the city has origin with the market center development from Western European as Netherlands Colonies (Wilonoyudho, 2011). This developing city has experienced groundwater overexploitation, salt intrusion, land subsidence, and coastal inundation due to urban growth. Today population density in Semarang City reached 764,487 (Indonesian Statistical Bureau, 2010). The focus of study area is located in Coastal and Lowland of Semarang City area where the center of urban growth occurs. The study area is about 8592.96 ha that one fourth of Semarang City area. Administratively, there are 16 Districts included in focus of the study: Kaliwungu, Mijen, Gajahmungkur, Semarang Selatan, Banyumanik, Genuk, Padurungan, Gayamsari, Candisari, Semarang Timur, Tembalang, Semarang Utara, Semarang Tengah, Semarang Barat, Tugu and Ngaliyan. The boundary in the East area is called Demak Regency, the South is called Semarang Regency, and Kendal is called West part. Fig. 1 shows focus of study area in Semarang City.

The yearly precipitation, the yearly temperature and the annual evapotranspiration are respectively evaluated to 2511.45 mm/year; 27.5 °C; and 182.78 mm/year (Rahmawati, 2010). The study area is approximately flat and the highest elevation level is about 50 m asl. The located Semarang City Coastal Lowland exhibits mainly volcanic terrain as background (Datema, 1989). Other geological deposit in this area includes alluvial and marine sediment, volcanic breccias and tuffs. Soil types in this area are generally alluvial as result of fluvial sedimentation. Spatial and temporal land subsidence occurs in Semarang City. In Coastal Lowlands area, the subsidence is about 3–8 mm/years (Kuehn et al., 2010). The average sea level rises published in the secondary data from Ministry of Ocean and Fishery is approximately evaluated to 6 mm/year. Groundwater abstraction is evaluated more than 81,546 m^3/months and it is attributed mainly to seven industrial and commercial activities on an area of 8.01 km^2 surrounding Tanjung Mas Harbor, Semarang City (Ministry of Public Works, 2008). Faster land subsidence result to a faster groundwater level drop (Qiyan et al., 2008). Moreover, land subsidence is connected to sea level rise because of sinking of its original ground level base (Nguyen et al., 2006). Rise of sea level creates groundwater level drop (Rotzoll et al., 2010). Those conditions were confirmed in the Coastal and Lowland area of Semarang City. For example, groundwater level in Tanjung Mas Harbour dropped from 5.6 m asl in 2004 to 2 m asl in 2008 due to sea level rise and land subsidence.

1.3. Past salt intrusion development observation

Salt water intrusion in Semarang City develops particularly in the Coastal Lowlands. There was a significant change of saline groundwater development in 1995–2004. In 1995, no saline water was recorded in this area. But, starting in 2004, saline groundwater intrusion was observed close to the beach. From 1995 to 2000, most of the area included brackish water that total dissolved solids content in groundwater was measured with less than 2274 mg/l. Salt intrusion development in Coastal and Lowland areas of Semarang City was observed. Saline groundwater was observed sur-

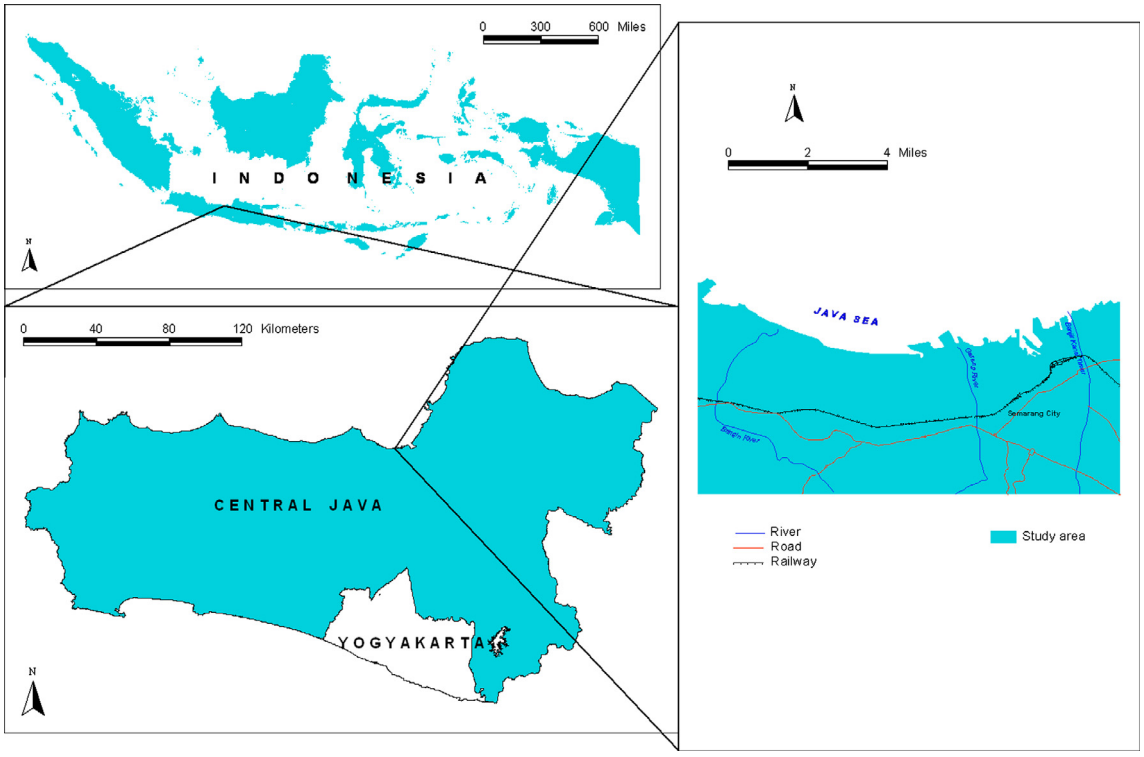

Fig. 1. Illustration of the study area. Central Java Province is illustrated and more specific place like the Coastal Lowlands of Semarang City is identified.