Impact of Urbanization on Groundwater Recharge – The Example of the Indonesian Million City Yogyakarta

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1 Introduction

Urbanization refers to a process in which an increasing proportion of an entire population lives in cities and the suburbs of cities and/or change of land use from agriculture to human settlements, commercial sectors and industries.Urbaniziation and population pressure are two main challenges to water ressource management, especially in cities of developing countries. Regarding the groundwater resources it has te be mentioned that urbanization affects both the quantity and quality of underlaying groundwater systems. In order to recognize the issues of groundwater deterioration due to the improper urbanization condition in Yogyakarta City, studies of urban groundwater recharge, groundwater vulnerability, potential contaminant load and groundwater quality are carried out and new predictive relationship is derived for the assessment of the groundwater contamination hazard. This paper will describe the influences of urbanization on groundwater recharge.

2 Urbanization and groundwater

One of the most important issues of the growing city is the interaction between urban development and groundwater, especially on cities located above shallow unconfirmed aquifer. The interaction between urban development and groundwater may be explained in the relation with the pattern and stage of city evolution on affecting the quantity and quality of groundwater (see Figure 1). The changes of quantity and quality are caused commonly by the increase of groundwater abstraction and the existing of new sources of recharge. Two important previous studies of the effect of urbanized area on groundwater are given by Foster et al. (1993) and Morris et a. (1994). Two main issues can be concluded from both studies; 1) urbanized area changes groundwater recharge or cycle, with modification to the existing recharge and the introduction of the new sources, 2) the introduction of new sources of recharge in urbanized area causes extensive but essentially diffuse groundwater contamination. Due to those above pressure, there are at least three main problems related with groundwater under growing cities; (1) fluctuations in groundwater levels, (2) severe groundwater contamination and (3) impact on engineering structure (Vasquez-Sune et al., 2005).

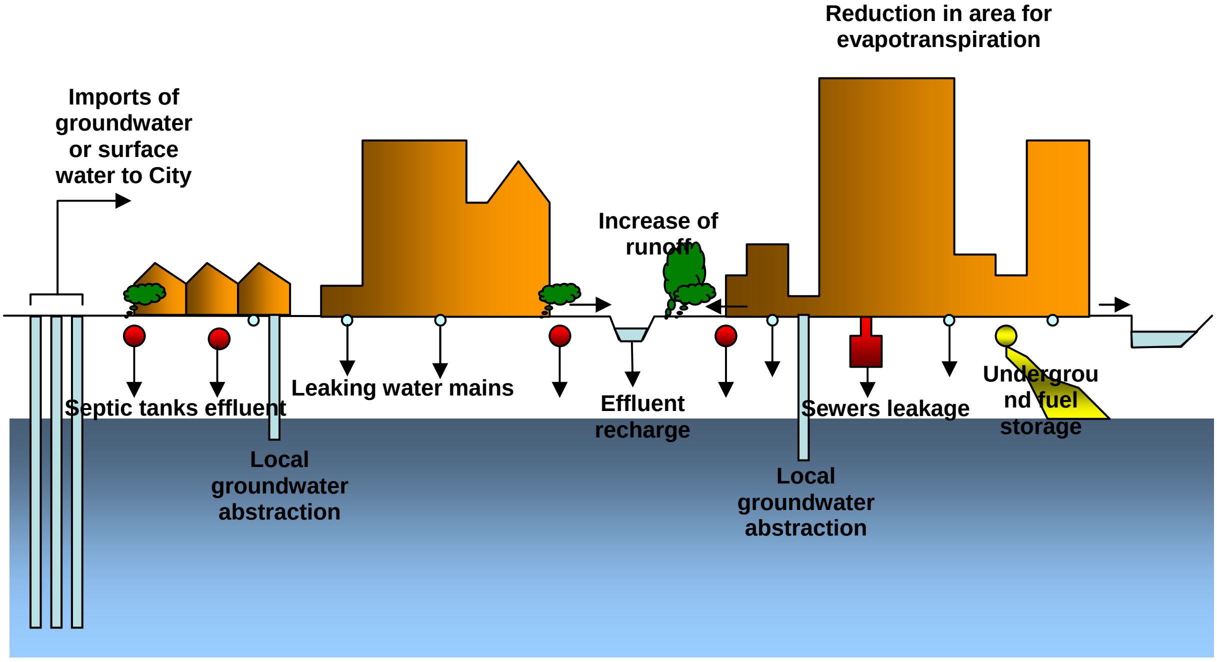

Fig. 1: Urban effects on groundwater

It is often thought that urbanization reduces infiltration to groundwater due to the impermeabilization of the catchment by paved areas, buildings and roads. However, the reverse is often true and recharge beneath cities is usually substantially greater than the pre-urban values (Foster et al., 1993, Lerner, 2000). The sources and pathways for groundwater recharge in urbanized area are more numerous and complex than in rural environments. But nevertheless, the increase of groundwater recharge in this area is known to be closely related to three main sources: rainwater, wastewater and main leakage from water supply networks. In cities where waste water is not exported (cities without sewers for waste water transport), as mush as 90 % of abstracted and/or imported water may return as groundwater recharge (Lerner et al., 1990). In these cities, the most important recharge source would be the infiltration of waste water from large numbers of septic tanks, latrines and soakaways (Lerner, 2002). According to Lerner et al. (1990), the effect of urban recharge sources will be always significantly larger than precipitation recharge in semi arid and arid regions. But in humid areas, urban recharge may only balance the loss of precipitation recharge caused by the impermeable areas, and the overall effect of urbanization will be small. On the other hand, cities which use the local groundwater for their water supply, the effects of urbanization on recharge are in general smaller than in cities that import water. The effect of urban process on infiltration to groundwater can be relatively classified based on its rate, area and time. Cities with on-site sanitation system have potentially major effect on increasing groundwater recharge than cities with sewerage system. On the other hand, it can be also concluded that almost all urbanization processes can potentially increase the rate of infiltration to groundwater. In contrast to the effect of urbanization on the quantity of recharge, the net effect of urbanization on the quality of recharge is generally adverse, especially if waste water is an important component. The quality of recharge water from waste water (e.g. on site sanitations, leakage sewers, etc) is commonly poor. This table also shows that the causes of groundwater quality deterioration in urbanized area are complex, involving a combination of contaminants.

Investigation or studies of contaminated groundwater in urbanized area of developed and developing countries can be reviewed in many previous studies. But good comprehensive reports of this problem can he found on Morris et al. (1994), Lerner & Barrett (1996), Massone et al. (1998), Chilton (1999), and Wakida & Lerner (2005). The issue of groundwater contamination of wastewater disposal is a more serious problem in cities of developing countries where, generally, there are many high dense populated and unsewered areas created by high rates of migration into cities (high population pressure). These areas are unplanned and located in the outskirts of the cities forming shanty towns (typically between 30 and 60 percent of the overall urban population) where pit latrines or septic tanks are common. In some cities, septic tanks and pit latrines are the only way to dispose of sewage (unintegrated planned provision of sanitation), while groundwater is the main water drinking source (unintegrated planned provision of water supply). As result, the worst contaminated groundwater commonly found in cities sited on unconfined or semi-confined aquifers. However, it should be realized that human activities in urbanized areas threaten the groundwater not only due diffuse contaminant loading from urban recharge system, but also due to point contaminant loading from landfill leakage, industrial leaks and many other ways. Furthermore, one should also consider, that the occurrence of contaminants in groundwater does not only depends on the characteristics of contaminant loading as a result of human activity, but also depends on the inherent attenuation capacity of the intervening strata between contaminant source and water table (Morris et al., 2003). This inherent attenuation capacity of the intervening strata depends on its geological, hydrological and hydrogeological condition (Daly et al., 2002).

3 Yogyakarta

Yogyakarta City is located in the central part of Java Island (see Fig. 2). In the 1930s, Yogyakarta was just a small town in the interior of Java with a population of approximately 60.000 inhabitants (Baiquni 2004). In the last two decades, urbanisation has transformed the structures of Yogyakarta City and it grew beyond its administrative boundary with about 1.000.000 inhabitants (Subanu 2004). Urbanisation has transformed rural dwellings to become urban settlements and generated an urban agglomeration area. The Yogyakarta urban agglomeration area consists of the Yogyakarta City municipality and two regencies i.e. Sleman and Bantul. Percentage of urban population in the Yogyakarta Province has significantly increased from 22% in 1980 to 58% in 2000. This increase has simultaneously occured with the growth of the urban area. The population density in the Yogyakarta City municipality area varies between 10.000 – 30.000 persons/km^2, while the population density in its agglomeration area ranges between 1.000 – 3.000 persons/km^2.

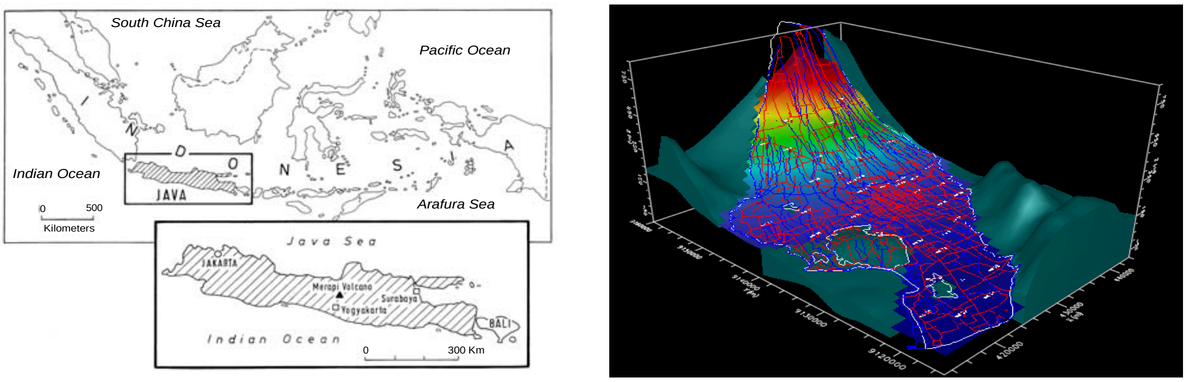

Fig. 2: Location of the investigation area

Since the 1970s, the settlement pattern of Yogyakarta-City was shifting to many directions defined by main road networks and service centres. This shifting has been accelerated by urbanisation activities. Until now, new business centres, education centres and tourism centres are growing hand in hand with new settlements (formal or informal) without proper provision of water supply and sanitation system. The old supply and sanitation system was supplemented by a new network in 1998. However, the sewage system with the new network can serve only 9 % of the city populations (Sukarma & Pollard 2002). As a result, more than 90 % of the population are using on-site sanitation system. The other characteristics of urbanisation in Yogyakarta City are the wide shallow infiltration wells. Shallow infiltration wells are used as alternative way to dispose domestic wastewater direct into groundwater.

4 Groundwater recharge in Yogyakarta

Infiltration of contaminant to the groundwater generally related to the recharge process of groundwater. In the urbanized area, the source of recharge can be differentiated into two sources; natural recharge from precipitation and urban recharge (Lerner, 2002). Because only 9% of the population in the Yogyakarta City are served by sewage system, it can be assumed that wastewater from on-site sanitation, latrines, soakaways and main leakage from the water supply become the major source of groundwater recharge. Based on those factors, the calculation of the rate of urban recharge is conducted and reveals that net urban infiltration in the study area is about 45.6 million mm/a (Table 1). Considering that the width of the study area is about 226.4 km², the average urban recharge of the groundwater within the study area would be about 201mm/a.

To estimate the urban groundwater recharge, the equation below can be used:

Net urban groundwater recharge: $U_u = L_I + L_S + L_W + L_{nd}$

L_I = Leakage from water supply system

L_S = Leakage from sewer system

L_W = not exported domestic waste water

L_{nd} = non domestic wastewater

No.	Component of urban recharge	Q (million m^3/a)
1	[a]Total domestic use (Q_D); about 70% demand is fulfilled by local shallow groundwater abstraction and less than 30% of demand can be supplied from the existing water supply system	51.17
2	[a]Domestic consumptive use (Q_c)	6.92
3	Potential domestic waste water ($W_P = Q_D - Q_c$)	44.25
4	[a]Domestic waste water exported via existing sewer system (W_S)	2.56
5	Domestic waste water not exported ($W_{NE} = W_P – W_S$)	41.69
6	[b]Leakage from water supply system (L_I)	5.76
7	[a]Leakage from sewer system (L_S)	0.37
8	[c]90 % not exported domestic waste water ($L_W = 0.9 \times W_{NE}$)	37.5
9	[c,d]90 % non domestic wastewater (L_{nd})	1.95
10	Net urban groundwater recharge ($U_U = L_I + L_S + L_W + L_{nd}$)	45.6

Tab. 1: Urban groundwater recharge in Yogyakarta

The total groundwater recharge (natural and urban recharge) of the study area is found to be about 434 mm/a. Lerner et al., (1990) stated that in humid areas urban recharge may balance the loss of precipitation recharge caused by impermeable areas, and the overall effect of urbanization on recharge will be small. Since the study area is located in the tropical humid area, thus it is reasonable to estimate the groundwater recharge in the study area based on the precipitation recharge of natural - rural land use condition.

5 Conclusion

It was shown that urban groundwater recharge can drastically affect local aquifer systems in terms of quantity and quality. In regard to land use urban areas quality problems often span multipoint source contamination. Finally, it can be concluded that the impacts of improper urbanization are evident in shallow groundwater of Yogyakarta and its agglomeration area. It seems to be necessary that Yogyakarta needs a low cost water resource management system and a low cost decentralized water treatment system which is accepted by the population.

List of references

Baiquni, M. (2004), Urbanization and Urban Settlement Dualism: A case study and research of Yogyakarta, Indonesia, Proceeding of International Workshop on Asian Approach Toward Sustainable Urban Regeneration, September 2004, The University of Tokyo, Japan. http://csur.t.u-tokyo.ac.jp/ws2004/papers/B1-Baiquni.pdf.

Chilton, J., (1999), (ed), Groundwater in the urban environment, International Contributions to Hydrogeology Vol. 21, 342 p, IAH, A.A. Balkema, Rotterdam.

Daly, D., Dassargues, A., Drew, D., Dunne, S., Goldscheider, N., Neale, S., Popescu, I.C., Zwahlen, F. (2002), Main Concepts of the European Approach to Karst Groundwater Vulnerability Assessment and Mapping, Hydrogeology Journal, Vol. 10, p. 340 – 345, Springer-Verlag.

Foster S.S.D., Morris B.L., and Lawrence A.R. (1993), Effects of Urbanization on groundwater recharge, in Wilkinson, W.B., (ed), Groundwater Problems in Urban Areas, Proceeding of Institution of Civil Engineers, June 1993, London, p. 43 – 63.

Lerner D.N. (2000), Guidelines for estimating urban loads of nitrogen to groundwater, Project NT1845, Groundwater Protection and Restoration Group, Dept. Of Civil and Structural Engineering, University of Sheffield, Mappin St.

Lerner D.N. (2002), Identifying and quantifying urban recharge: a review, Hydrogeology Journal, Volume 10, p. 143 – 152, Springer-Verlag.

Lerner, D.N., Issar, A.S., and Simmers. I. (1990), Groundwater Recharge: A Guide to Understanding and Estimating Natural Recharge, International Contributions to Hydrogeology Vol. 8, IAH, Verlag Heinz Heise, Hannover, Germany.

Lerner, D.N, and Barret, M.H. (1996), Urban Groundwater Issues in The United Kingdom, Hydrogeology Journal, Vol.4, No.1, p. 80 – 89, Springer-Verlag.

Massone H.E., Martinez D.E., Cionchi J.L., and Bocanegra E. (1998), Suburban areas in developing countries and their relationships to groundwater pollution: A case study of Mar del Pata, Argentina, Environmental Management Journal, p.245 – 254, Springer-Verlag New York Inc.

Morris B.L., Lawrence A.R., and Stuart M.E. (1994), The Impact of Urbanization on Groundwater Quality (Project Summary Report), Technical Report WC/94/56, British Geological Survey.

Morris, B.L., Lawrence, A.R., Chilton, P.J.C., Adams, B., Calow, R.C., and Klinck, B.A. 2003), Groundwater and its susceptibility to degradation: A global assesment of the

problem and options for management. Early Warning and Assesment Report Series, RS.03-3. United Nations Environment Programme, Nairobi, Kenya.
Subanu, L.P. (2004), Urban dualism in Asian cities: the case study Yogyakarta, Proceeding of International Workshop on Asian Approach Toward Sustainable Urban Regeneration, September 2004, The University of Tokyo, Japan. http://csur.t.u-tokyo.ac.jp/ws2004/papers/A-Subanu.pdf.
Sukarma, R., and Pollard, R. (2002), Overview of Sanitation and Sewerage Experience and Policy Options, Urban Development Sector Unit, Indonesia Country Management Unit, East Asia and Pacific Region, World Bank.
Vazquez-Sune, S., Sanchez-Vila, X., and Carrera, J. (2005), Introductory review of specific factors influencing urban groundwater, an emerging branch of hydrogeology, with reference to Barcelona, Spain, Hydrogeology Journal, Volume 13, p.522 – 533, Springer-Verlag.
Wakida, F. T. and Lerner, D.N. (2005), Non-agricultural Sources of Groundwater Nitrate: A Review and Case Study, Water Research, Vol. 39, p. 3 – 16, Elsevier Ltd.

Comment of the Authors:

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