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Original Research Article

Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad, India

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ABSTRACT

Groundwater recharge processes in an urban area are different than in non-urban areas. There are various new components that must be considered in the case of urban groundwater recharge in addition to the natural recharge from precipitation. These various components are estimated in this study based on the water balance equation for the Hyderabad city of India. Initially, urban recharge components including leakages from water supply network and sewage networks were calculated. To estimate the natural recharge from precipitation, actual evapotranspiration and surface runoff were estimated using remote sensing and GIS techniques. Results indicated that the urban recharge component of groundwater was more than ten times greater than the natural recharge. The net urban recharge component of groundwater was estimated to be approximately 568 mm yr^{-1} and the natural recharge component was observed to be 53 mm yr^{-1}. Water inflow and outflow components were also estimated to provide the complete scenario of the total urban water balance of Hyderabad. This analysis has provided the information regarding the extent and intensity of percolation of urban contaminants into the aquifer.

1. Introduction

Most of the Earth's liquid freshwater is found as stored underground in aquifers and not in the lakes and rivers. The aquifers are also the source of base flow water for the rivers in the absence of rainfall. Groundwater plays an important role in terms of the economic and social health of the urban population of the developing world. Cities need to supply water in various combinations as per demands of their private, public, industrial and commercial users. And the urbanization process has always altered the quality and quantity of the local aquifer systems in various ways. Considering the changes in the hydrological cycle due to urbanization, it is important to study the effect of urbanization on local water resources and especially, on easily available groundwater source in the vicinity. Urbanization, in general, has four immediate repercussions on the hydrological cycle: flooding (e.g. as a result of increased soil sealing), water shortage (e.g. due to rising consumption), changes in the river and groundwater regimes as well as water pollution (Rogers, 1994; Strohschon et al., 2013). Urban areas generate both nonpoint and point sources of contaminants. Point sources that affect groundwater quality include leaking underground storage facilities, as well as miscellaneous accidental spills of organic or inorganic contaminants (Jha, Singh, & Vatsa, 2008). The rapid growth of urban area has two basic effects on groundwater resources such as: effects on natural recharge of aquifers due to sealing of ground with concrete and pollution of groundwater due to leakage from drainage and, industrial wastage and effluents (Baier, Schmitz, Azzam, & Strohschon, 2014). The water balancing of an urban aquifer is a complex process due to the additional sources of groundwater recharge and widely distributed new abstraction points in the urbanized region. It is often believed that with the urban growth, the impermeabilization and ground sealing effect might contribute to decrease in groundwater recharge. But it has been widely discredited by many case-studies about urban groundwater recharge in cities worldwide. Now, most hydro-geologists accept that the infrastructure for water supply and storm drainage generates large amounts of recharge through leaks (Foster, 1990; Lerner, 2002). In many cases, the increasing demand for water due to urban growth forces the authorities to import the large volumes of water from outside the city. The expanded cities later then also produce large volumes of wastewater. Even though the land sealing effect of paving and building prevents natural recharge from precipitation, the enormous volume of

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water circulating through the underground water-wastewater infrastructure under high pressure and loss due to leakages of pipes or from soak-ways draining the built-up area causes a rise in the total volume of recharge in urban areas (Lerner, 2002). The contamination of groundwater in the aquifers beneath the city may also result in abandonment of wells and groundwater abstraction in some places within the cities. It can lead to rise in water table beneath the city due to lack of pumping of contaminated water and high urban recharge from leakages. Several city case-studies show that the effect is most pronounced in cities where on-site sanitation is important and in arid and semiarid climates where the new sources may increase the total infiltration several times over the pre-urban situation (Morris et al., 2003). As cities import bulk amount of water, the flow pressure with which the water is transported and distributed through pipe network is always higher than the flow pressure in sewage network. So, any leakages in these networks can contribute to the huge amount of recharge in that region. In the case of urban recharge process, leakages from sewer network are less significant compared to water supply mains, but it can be major sources of contaminants.

The study area selected for this analysis is one of the megacity in India named Hyderabad. Hyderabad is the capital and largest city of the newly formed southern Indian state of Telangana (separated from the state of Andhra Pradesh in 2014). Hyderabad has 6,809,970 inhabitants and spread along the banks of the Musi River. It has a metropolitan population of 7.75 million, which makes it the fourth most populous city and sixth most populous urban agglomeration in India (Census of India, 2011a, 2011b). In the global ranking for 2025, it will be at a 31st place with the population of 11.6 million due to high population growth rate (United Nations, 2012; Wakode, Baier, Jha & Azzam, 2013). The study area for this analysis is bound by 17°16′35″N to 17°34′5″N latitudes and 78°17′27″E to 78°36′57″E longitudes, covering a total area of 671.62 km^2.

This analysis is another step in the overall study about the impact of urbanization process on the water resources of the Hyderabad city of India. The rapid and unregulated or partially regulated urban growth of Hyderabad city have produced tremendous stress on the natural resources and environment (Wakode, Baier, Jha, & Azzam, 2013). In the previous work by Wakode, Baier, Jha, Ahmed, and Azzam (2014), analysis of groundwater level and quality established the presence of contaminants in the aquifer of Hyderabad. Therefore, it has created a necessity of information about exactly how much wastewater has been percolated into the aquifer. There are three major objectives of this study: first, to estimate the amount of actual urban groundwater recharge due to leakages from water supply and wastewater network, which will provide insight into the extent and intensity of aquifer contamination. After that, the component of natural recharge from precipitation is estimated. Finally, the inflow and outflow components of urban water balance are estimated to find out the movement of water in and out of urban domain. This analysis will provide the foundation to formulate the policies to prevent degradation of groundwater and will be helpful in sustainable development of Hyderabad.

2. Method and materials

Apart from precipitation, the groundwater recharge sources include surface water bodies and the sources located in the subsurface of an urban area such as water supply network, leaking drainage pipes and septic tanks. In the urbanized area, the source of groundwater recharge can be differentiated into two sources: natural recharge from precipitation and urban recharge (Lerner, 2002; Putra & Baier, 2008). As Hyderabad is mostly covered with granitic terrain and have hard rock aquifers, so natural recharge can be only 7–8% of precipitation (Sukhija et al., 2005). In average, only 35% of the population is covered by sewerage network in Hyderabad urban and suburban area (HMWSSB, 2009). It can be expected that water from surface reservoirs probably containing urban wastewater, on-site sanitation, latrines, soak ways and leakages from the water supply and sewage network are the major sources of urban groundwater recharge in this region.

Estimation of various components of groundwater recharge in an urban area is very complex and tedious process. It can be accomplished by estimating the natural recharge from precipitation and recharge from water supply and wastewater systems separately and then by combining those two to obtain overall recharge in the region. Recharge from precipitation can be calculated using the simplest level of water balance Eq. (1) for urban recharge from precipitation as:

$$U_N = P - ET_a - Q_u \tag{1}$$

Where; U_N=Natural groundwater recharge, P=Precipitation, ET_a=Actual evapotranspiration, Q_u=Runoff which considers the effect of impermeabilization

There are also other more sophisticated methods available such as numerical groundwater modelling, solute balances and piezometry or water table fluctuation method. However, developing countries like India are either lacking the data set or are available in poor quality. These constraints for quantity and quality; limit the use of sophisticated methods in any context (Van Rooijen, 2011).

2.1. Estimation of components of urban groundwater recharge

For the estimation of recharge from water supply and wastewater networks, there are many factors which are needed to be considered. Water balances on the water-supply and sewage network at various points are the usual way to estimate losses. The complexity of urban-recharge processes and the insufficient data about many aspects due to lack of monitoring make it difficult to reliably estimate all the components of urban recharge in the developing country like India. Considering all the recharge components individually and with their associated errors can lead to a large accumulated error in the final recharge estimate. So, to reduce errors, it is preferable to consider the overall balance of the network and estimate net recharge as mentioned in Eq. (2) (Lerner, Issar, & Simmers, 1990):

$$Net recharge = W_i + GW_a - CU - S_l \tag{2}$$

Where; W_i = Imports of water, GW_a = Local abstractions of groundwater, CU = Consumptive use, S_l = Effluent leaving area

To calculate the actual urban groundwater recharge from the imported water, it is important to know the exact amount of water that has been introduced into the system and amount of water that has been reached to end users. For this purpose, it was necessary to know that how much water is normally used by the urban residents in India. Bureau of Indian Standards has created the standard for basic requirement of water supply and mentioned it as Indian Standard IS 1172:1993, reaffirmed in 1998. According to this standard, 150–200 l of water per capita per day (LPCD) for urban communities like Hyderabad with a population of over 100,000 is recommended (Bureau of Indian Standards, 2011). From the data provided by Hyderabad Municipal Water Supply and Sewerage Board (HMWSSB), the per capita water supply has been calculated based on the total quantity of water drawn in 2011, losses in transmission and distribution, and the population of Hyderabad.

HMWSSB supplied water through various means such as water supply network, operating mobile tankers, public tap water posts,