EFFECT OF URBANIZATION ON NATURAL GROUNDWATER RECHARGE WITHIN HANOI CITY - A CASE STUDY OF LONG BIEN DISTRICT

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Abstract: *Extensive groundwater withdrawal in Hanoi during the last decades resulted in significant depletion of aquifer storages, which has been recorded at various locations in the Hanoi city. In conditions of rapid decrease of subsurface water resources efficient groundwater management is critical. This implies the necessity of precise evaluation of natural recharge as well as its sensitivity to various factors caused by area urbanization and prediction of its response to future land cover and land use changes. The study area is Long Bien - the district of Hanoi which is supposed to experience a significant development in near future. In this study, an instrument for numerical simulations that provided a possibility to account for various surface as well as subsurface characteristics of the territory in simulations, the GSFLOW model has been used. Scenarios of the Long Bien area development have been built according to the city development master plans and considered changes in land surface parameters that have been expected to affect on runoff formation and infiltration factors. The results of the study showed that recharge from the surface is a minor component in the groundwater budget of the area as it covers only a quarter of groundwater abstraction. Application of land cover change scenarios showed an important role of surface factors on the groundwater recharge, which can be reduced significantly. However absolute values of the reduction are negligibly small in comparison with total inflows and outflow to the adjacent aquifer. The study results confirmed unimportant effect of land cover changes on the groundwater balance within the district of Long Bien, however the estimated values can be significant for other areas in Hanoi that not located in vicinity of large river channels and should be considered in water resources management of the city.*

Keywords: *Urbanization, Precipitation-Runoff modeling, Modular Groundwater Flow, Hanoi City.*

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1. Introduction

The city of Hanoi is the capital and the second largest city of Vietnam, with total area of about 3344km^2 and population of more than 6.3 million people. Domestic and industrial water consumption in the city is covered by groundwater to approximately 80% [1]. Exploitation of groundwater for domestic water supply started in 1909 and initially was 20,000m^3 per day [3]. During the last century the initial water extraction rate was increased approximately 50 times and in accordance with assessment results of water resources approved by the National Committee for Assessment of Water Resources in 2008 total explicated volume of water in the whole Hanoi area was 837,600m^3 per day [3]. which is approximately 158 liters per capita per day and was expected to grow to more than 1,000,000m^3 per day by 2010 [1]. According to the Hanoi Government, water supply master plan to 2030 and vision to 2050, water demand in the area is expected to increase to 1,560,000m^3/day, 2,360,000m^3/day and 3,150,000m^3/day by the years 2020, 2030 and 2050 respectively [1]. As a result of increasing groundwater withdrawals on the territory, significant depletion of the water table has been recorded at various locations in the city of Hanoi. Measured depths and horizontal extension of the cones of depression beneath the area vary depending on location (distance to the rivers or large lakes) and pumping rates of the influencing wells. The maximum lowering of the groundwater table elevations has been recorded in the observation wells located in the eastern and southeastern part of the city, where the depth of depression reaches -32 meters [3]. Major negative consequences of overexploitation of the groundwater resources of the studied area are: land subsidence and water quality deterioration. To estimate the effect of

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groundwater depletion on land subsidence, a number of researches including geodesy surveys and computer modeling has been conducted. Results of the geodetical measurements conducted by various companies (Hydrogeological abd Engineering Geological Division, Institute for Technical Science and Construction and others) in period from 1988 to present time show strongest land subsidence are in the central and southern parts of the city where it reaches over 10mm per year with recorded maximum in Giang Vo-Thanh Cong and Phap Van districts of 20-44mm per year [2]. Results of the subsidence modeling study conducted by. A recent studey on the relationship between groundwer exploitation confirmed that there is a risk of further land subsidence in the area of Hanoi mainly due to high compressibility of porous materials that compose the upper underground layer and continuing groundwater depletion, however regression between rates of groundwater withdrawals and land lowering and hence, expected subsidence range remained highly uncertain [4].

The Long Bien district of Hanoi is located in the northeastern part of the city and separated from the centre by the Red river. There were two major reasons of choosing this territory as the study area: (1) unlike the central and western parts of Hanoi, detailed hydrogeological model of the Long Bien has not yet been developed; (2) in contrast to the city centre, the studied area is characterized by: relatively low population density-72 person/hectare against 225 person/hectare in central part, high fraction of non-residential agricultural and low-density residential lands. However, according to the city development master plan, Long Bien belongs to the areas of Hanoi City that are expected to experience significant urban development in the near future including population growth and infrastructure development which can cause changes in hydrological fluxes within the area that can have a significant effect on the local groundwater balance. This issue that should be considered in further research studies as well as in decision making in the sector of waters resources management.

The objectives of this study are to evaluate the role of land surface, soils and climate characteristics on the groundwater balance within the area of Long Bien district of Hanoi and to answer the question if the expected land cover and land use changes in the near future are critical for sustainable management of groundwater resources in the area. To either confirm or disprove the declared assumption, it has been decided to make following research objectives: i) Set up a numerical model of the area that simulates both surface and underground movement of water; ii) Analyze the simulated groundwater budgets and evaluate contribution of the recharge from the surface in the total water balance; iii) Build scenarios of areal development considering changes in land cover characteristics due to urbanization and use the model with new sets of parameters; and iv) Analyze the effect of scenarios application on the simulated groundwater balance.

2. Methodology

2.1 Study area and land cover changes

The Long Bien district is surrounded by two rivers: Red river on southwest and its tributary Duong river on northeast. The Cau Thanh Tri Street was chosen as the southeast boundary that separates Long Bien from the Hung Yen Province. Since the objective of the research was to analyze changes of groundwater recharge caused by urbanization, analysis of a current state of land use and land cover in the area as well as developing the scenarios of their expected and hypothetical change was one of the key topics of the study. The area of the studied territory is 52.2 square kilometres. In Long Bien, urban areas characterized by high buildings density, developed infrastructure and low fraction of areas covered by vegetation (<20%); Urban areas with low infrastructure and buildings density, fraction of vegetated areas: 30-50%; and Green areas-lands occupied by large parks, agricultural lands, flood plains. Portion of areas covered by vegetation is >50%;

2.2 Model concept

The applied methodology in this research that allowed achieving the desired results was utilizing the modeling software for groundwater simulations and applying geostatistical algorithms for scenarios development. Since the objective of the research takes into consideration many parameters that characterize the processes that could have an effect on the quantitative characteristics of the aquifers underlying the studied area, the model, that describes the hydrological processes taking place both on the surface and in the subsurface of the catchment had to be utilized. Another important choice criteri was the free availability of a software, accessibility of documentations and instructions and proven efficiency. As the model that satisfies the named criteria, GSFlow-a model developed by USGS (United States Geological Survey) organization has been chosen. The GSFlow itself is not an independently developed model, but is a linkage between earlier issued widely used models PRMS (Precipitation-Runoff Modeling System) and Modflow (Modular Groundwater Flow), which is a finite-elements quasi-3D groundwater model. The concept of the model and the modules used in this study are described below (Fig. 1).

2.3 Hydrological response units (HRU)

Elementary spatial units of the PRMS model, that are assumed to be homogenious in climate, land cover and soil cover characteristics. Being deliniated by intersection leads to the distribution of the soil textural classes and classified land cover. Total ammount of created HRU is of 98, with area varying from 29712m^2 to 4525872m^2. Further used in application of area developement scenarios.

2.4 Scenarios development

With regard to the area developing concept changes to the model should consider aspects of changes in groundwater recharge due to changing land cover characteristics. The urban development was simulated by alteration of land surface characterstics of the preliminarily deliniated spatial elements of the model-hydrological response units, including: plant cover density, fraction of impervious areas and available surface water storage. The effect is assessed by alteration of characteristics of HRU in the way of imitating real urban development of the area. It has been simulated in form of changing HRU classes from “Green” to U2 and U2 to U1 in three consequential steps: during the first iteration involved area was limited to radius of 2 km from the district center, then it was increased to 3 km and 4 km in the last iteration, which allowed to affect the whole area. The HRU parameters to be changed included fraction of impervious area, plant cover density and maximum land surface depression depth available for water storage, expressed by increasing the soil saturation threshold values. The procedure has been applied iteratively, which allowed to produce four maps imitating growth of the district (see Fig. 2).

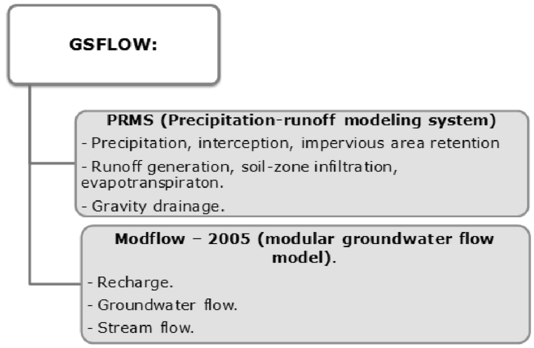

Figure 1. *Modelling concept*

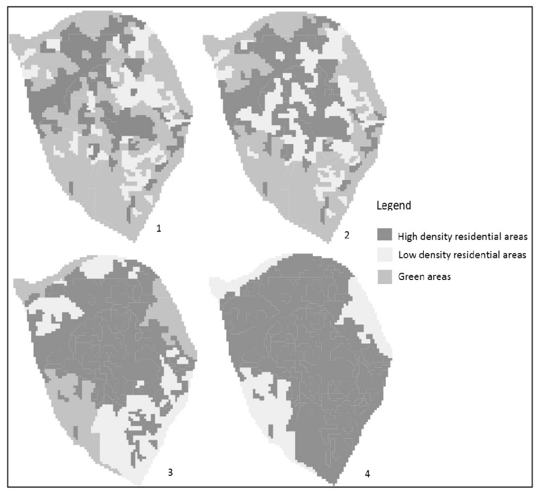

Figure 2. *Stages of the simulated area urbanization*

According to the simulated areal distribution of the land cover, composition of each class in the total area of the territory is changed as presented on the Table 1 and Table 2.

3. Results and discussions

3.1 Groundwater recharge

Resulting groundwater recharge from the land surface for the simulation period of four years is 1.6*107m^3, which is 4*106m^3 or 7.7*10^{-2}m (77mm) for year and is approximately 5.5 % of total precipitation. Simulated

Table 1. *Fraction of different land cover classes*

Land cover types	Fraction of the land class to the total area, %			
	Base state	State 1	State 2	State 3
U1	28	34	56	81
U2	16	22	25	19
Green	56	44	19	0

Table 2. *Parameters affected due to changes of HRUs properties*

Parameters	Base state	State 1	State 2	State 3
Average plant cover density	0.23	0.21	0.16	0.12
Average surface depression depth available for water storage, m	0.069	0.062	0.043	0.026
Total pervious area, %	74.3	56.5	44.4	33.7

monthly average flux components of precipitation including groundwater recharge are presented on the Fig. 3.

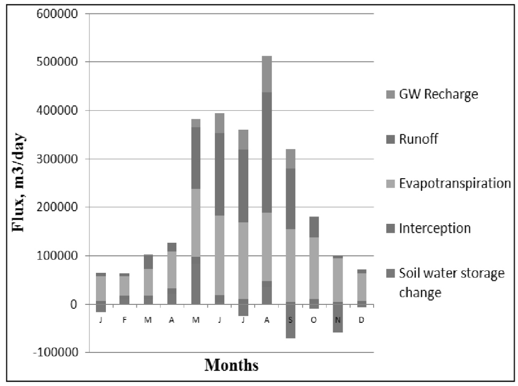

Figure 3. *Simulated water balance components*

3.2 Groundwater heads

Simulated groundwater heads of the top unconfined aquifer within the area vary in range +10 to -3 m (see Fig. 4). The minimum water table elevation is in the central part of the Long Bien district where the cone of depression is formed due to extensive groundwater pumping. As shown in Fig. 5, the depression reaches its maximum in April each year when it gets to the point -3 m below Mean Sea Level (MSL), which is 13 meters below the land surface. In October of the each simulated year, the groundwater table reaches its maximum elevation.

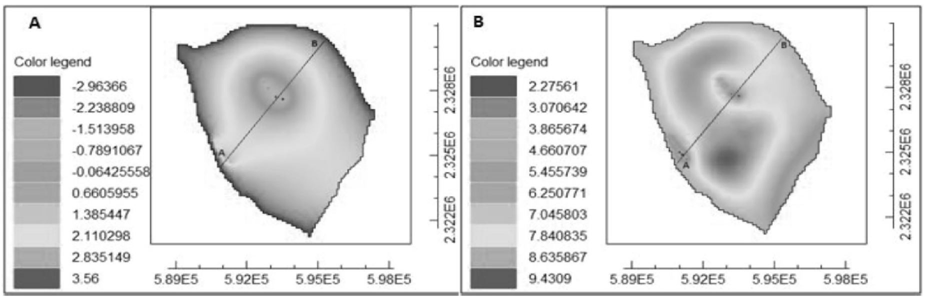

Figure 4. *Simulated groundwater heads within the top unconfined aquifer (Holocene aquifer) for two dates: A) 01 April 2001; B) 01 October 2001*

The presented results of the simulations allow to conclude about several important characteristics of the studied aquifer: (1) the effect of the municipal water pumping wells located in the central part of the area is significant; (2) the direction of water exchange between the aquifer and Red and Duong rivers changes during the year: water from the river discharges to the aquifer most part of the year, but flow in opposite direction occurs after the rain season for the period from September to November; (3) groundwater table heads rise up to the land surface in local depression areas during rainy seasons, which means that groundwater can be discharged to the surface water bodies as well as to the urban sewage system and open drainage channels. The last two phenomena tell about the importance of the surface recharge for the local groundwater system dynamics.

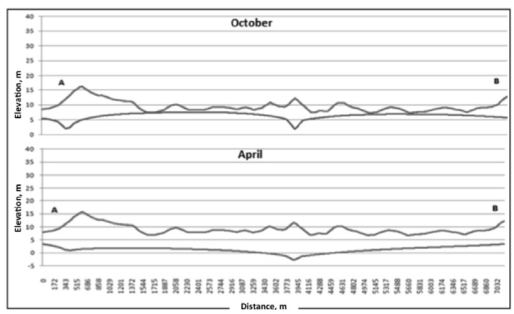

Figure 5. *Profiles of the simulated groundwater heads within the top unconfined aquifer (Holocene aquifer) and land surface elevation for two dates: Top-01 October 2001, Bottom-01 April 2001. Position of the profiles show on the Figure 4*

3.3 Application of the land cover change scenarios

Application of the land cover changes caused by urbanization scenarios showed that the relative decrease of the groundwater recharge can be significant: its estimated values reduced from 77mm per year for the base condition to 71, 58, and 42mm per year after applying three area development scenarios, which are in relative values 92%, 75% and 54% respectively. The recharge reduction however is negligibly small in overall groundwater balance. The groundwater abstraction within the area is mainly compensated by the boundary inflow from Red and Duong rivers-to 76% and to 24% from the surface recharge (Fig. 6).

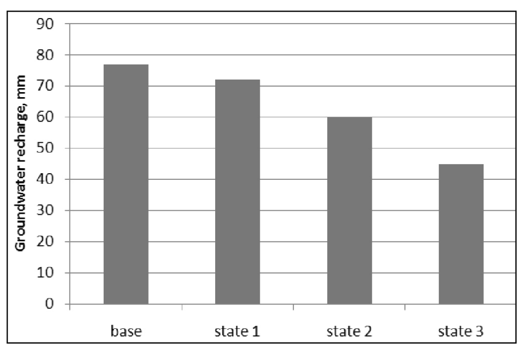

Figure 6. *Simulated GW recharge values (mm) for different stages of imitated area developemen*

Changes of the land cover properties due to urban development in the area can decrease the groundwater recharge from the surface significantly. However, these changes are not considerable for groundwater balance since the portion of the recharge in total water inflow to the aquifer is relatively small and the deficit is covered by the boundary inflow. The expected land cover and land use changes are not critical for the groundwater balance in Long Bien.

4. Conclusion

This study has investigated the role of various land surface characteristics on the groundwater recharge within area of the Long Bien district of the city of Hanoi by applying the coupled surface-groundwater numerical model and considering the effect of land cover changes caused by urban development of the area on groundwater balance. The most important results can be summarized as the following:

- The groundwater recharge from the land surface to the adjacent Holocene aquifer is relatively small as compared to precipitation-only about 5% or 77mm.

- The groundwater abstraction within the area is mainly compensated by the boundary inflow from the Red and Duong rivers-to 76% and to 24% from the surface recharge.

- Groundwater table elevation reaches the surface at the depression areas at the end and after the rainy season, which means that the water stored in lakes and ponds does not contribute to groundwater recharge during this period and is lost for evaporation. This fact should be considered in planning the artificial recharge.

- Changes of the land cover properties due to urban development in the area can decrease the groundwater recharge from the surface significantly, however these changes are not considerable for groundwater balance since the portion of the recharge in total water inflow to the aquifer is relatively small and the deficit is covered by the other sources.

The results of the study should not be considered as the exact estimations of the groundwater balance components and should be validated either by field measuremental data or by applying more sophisticated model. However, they can be used as good initial approximations for the further investigations and should be considered in decision-making activities in the field of water resources management.

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References

1. Duc L.V. (2012), *Sanitation of Water Source and Treatment of Garbage and Wastes in Hanoi,* Statement at the East Asian and Middle-South American Conference on Environmental Industry.

2. Nguyen T.Q., Helm D.C. (1996), "Land Subsidence due to Groundwater Withdrawal in Hanoi, Vietnam", *International Journal of Rock Mechanics and Mining Science and Geomechanics*, 33(7):72-84.

3. Dan N.V. (2002), "Overall Management of Underground Water Resource in Hanoi Area for Satisfying Water-consumed Demand of the of the City", *Procedding of International Conference on Sustainable Architectural Design and Urban Planning*, 52.

4. Trinh M.T., Delwyn G.F. (2000), "Modeling subsidence in the Hanoi City Area, Vietnam", *Canadian Geotechnical Journal*, 34.