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Sustainable management of groundwater

title: **Efficient groundwater management approach for North ThangLong and Quang Minh Industrial zones — Hanoi, Vietnam**

author(s): **Nguyen Van Giang**
Institute of Geophysics — VAST, Vietnam, nvgiang189@yahoo.com

Noboru Hida
Akita University, Japan, art_re6@gipc.akita-u.ac.jp

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INTRODUCTION

The study area is about 50 square km and is located on northern part of Hanoi, Vietnam. The area covers a segment of Red river with Thang Long industrial zone in south and a segment of Ca Lo river with Quang Minh industrial zone in north. The climate of area is humid tropical monsoon by hot and wet summer (from June to October) and cold and dry winter (from November to May). The annual relative humidity is 84% by rainfall of max 1532 mm and min. 948mm. The area is elevated of 5-10 m above sea level. The topographic and geomorphologic evolution of this area has been performed in the period from the end of Pleistocene to the Holocene, corresponding with 5 depositional cycles of sedimentary formations (An 1996, Dy 1998).

HYDROLOGY

Major rivers flowing in the area include the Red river in south and Ca Lo river in north. These rivers have very large discharge which varies by seasons in the year. The content of alluvium *terra-rossa* in Red river is 1.5 kg/m^3 of water, it does mean about 100 mln ton/year of transport. The water level is changing between dry season and rainy season about 10m. The Red river in Hanoi is blocked by two dikes on both sides. Within the space of 60 years the water level of Red river in Hanoi rised up of 1m (An, 1996; Nghi, Toan, 1991).

The quality of water in the Red river and Ca Lo river is generally good up to now. The total dissolved solid content (TDS) is low (<0.2g/l). The water is of calcium bicarbonate type, with pH equaled 7–7.5. The electrical conductivity EC is equal to 15–20 mS/m. The water level sensibility changes season by season. In the flood season (August-September) it is usually 4–6 m higher than the land surface of area.. Thus, Hanoi has a dense and diverse hydrographic system, which not only provides abundant water resources but also serves well as a water way transportation and drainage of the city as well as is a tourist attraction. However, so far due to various reasons, the surface water potential has not been exploited appropriately for domestic water supply. On the other hand, due to large amount of wastewater discharged to them, the small rivers and lakes are being more and more polluted.

GEOLOGICAL FORMATION

During the Quaternary period, the land of studying area has been created through transgressions and regressions of the sea in 5 depositional cycles from the Early Pleistocene to the Late Holocene (see tab. 1).

Table 1. The depositional cycles of Quaternary.

Cycle	Age	Sedimentary materials
5	Late Holocene	Various genesis such as alluvial, alluvial-marine sands
4	End of Pleistocene and beginning of Holocene	Marine genesis, mainly composed of clay and clayed silt of greenish gray
3	Late Pleistocene (Q_1^3vp)	fine sediments as well as silt sand, clayed silt
2	middle-late Pleistocene (Q_1^{2-3}hn)	coarse grained sediments as well as cobble, gravel, coarse sand to finer sand
1	Early Pleistocene	Pebbles, gravel coarse sand (thickness 70-140 m)

There are different opinions on the subdivision of the Holocene stratigraphy in the Red river delta plain (Hori et al., 2004, Nghi, Toan, 1991). The bases consist of the oscillation of the sea-water levels and the stages of cultural development during Holocene. But the fluctuation of sea-water levels is one of important factors playing the main role in the process of development history of Holocene. According to the research results of many authors the Flandrian marine transgression is the highest one at the approximate time of 6,000 yr. BP (Dy, 1998). After this event, the marine regression began to happen. After that, the shoreline began to remove seawards, and the sedimentary environment transformed from lagoon-estuarine to deltaic one. This is the reason for considering the 6,000 yr. BP point of time as boundary between Early and Late Holocene.

HYDROGEOLOGY

On the basis of stratigraphy of 3 wells — OW1, OW2 and OW3 made in studying area by the end of July 2008 (Fig.1b) there are two aquifers (Fig. 2). Holocene aquifer (Qh) is exposed on the surface, widely and continuously distributed from Red river to Ca Lo river.

a) b)

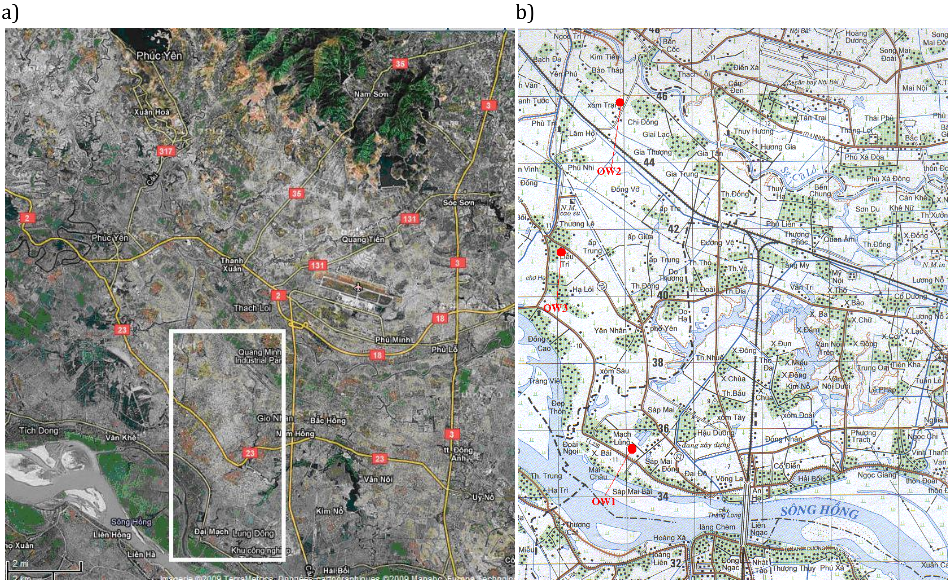

Figure 1. (a) Location of studying area in NW Hanoi, Vietnam. (b) Location of wells OW1, OW2 and OW3 in the studying area.

The water bearing formations consists of 2 sequences: the upper sequence is composed of sandy clay, clayey sand, with low permeability, by thickness to about 10m. The lower sequence is composed of sand with various grain sizes, in some place mixed with the gravel at the bottom, by average thickness of 9-10m. The depth to the groundwater level is 5-5.5m below the surface. It does mean that mainly rainwater, irrigation water and river water recharge to the aquifer during the rainy season. But, during the dry season, groundwater from this aquifer will be discharged to the river and to the underlying aquifers. The groundwater in the Qh aquifer is fresh, with TDS usually below 0.5g/1, mainly of calcium- bicarbonate type. The iron content in the water in most of the area is 0.4 to 10mg/l. The manganese content is 0.2- 2mg/l, the ammonium content is ranging tens of mg/l. The electrical conductivity is 40 mS/m. This aquifer is significant for small-scale water supply (for domestic using). The rural people usually dig wells and drill shallow and small diameter boreholes for extracting the groundwater from this aquifer.

Pleistocene aquifer (Qp*)* is the lower aquifer which distributed all over studying area. The depth to the top of the aquifer is 20-30m. Between two aquifers is one confining layer Q_1^3vp (Fig. 2).

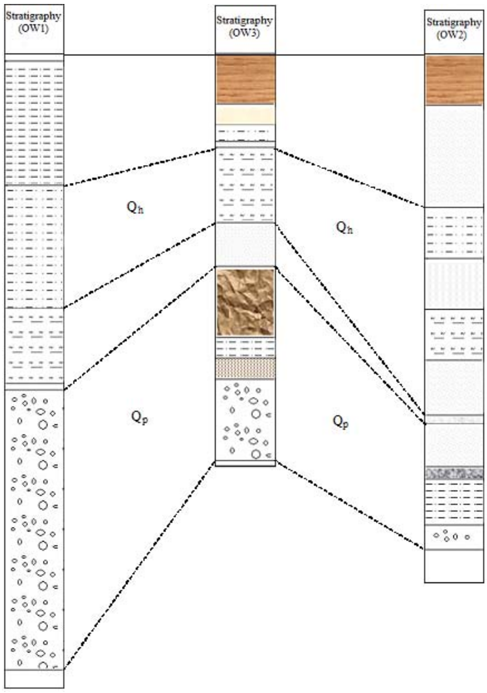

Figure 2. The location of Holocene aquifer, Qh and Pleistocene aquifer, Qp by 3 wells stratigraphy OW1, OW2 and OW3 in the studying area.

The aquifer Qp is pressure with thickness from few m to 60 m and increasing from N to S by coarse sand, gritstone, gravel with low TDS and with water level from few to tenth m. The source for Qp mainly from rainy water from surrounding region Red river delta and from hydrogeological windows. Between the aquifers and the rivers, there is the close hydraulic connection by the observation water level from OW1, recently. The water bearing formation is composed of sand mixed with cobble and gravel of the thickness of 25–35 m. The groundwater in the Qp aquifer is fresh, with TDS 0.3 g/l, mainly of calcium-bicarbonate type. The iron content in the water is 10 mg/l and manganese content is 2 mg/l. Due to its high productivity the Qp aquifer is being intensively abstracted and is the main source of water supply for the area. This aquifer is not much exposed to direct pollution but pollutants can move from the Holocene aquifer (Qh) into it through hydraulic windows. Our project continue monitoring of 3 wells for future forecasting.

Regarding on hydrogeological conditions in the studying area, one can take remarkable conclusions to the Red river delta region, in general. The Qp aquifer is the largest in the Red river delta of Vietnam. The study on relation between the rain water, Red river water (surface water) and groundwater in Hanoi area, through isotope data from 2002 to 2005 year shows interesting information about the recharge of water from Qp aquifer to the Red river. The $\delta^{18}O$, δD and tritium T values were proved to the surface water (Red river) being the result a mixing of precipitation and groundwater (Bono et al., 2004). The existence of T in the all of wells in Qp proved mixing between water from this aquifer and modern water. As we know that tritium's symbol is T or ^3H, also known as Hydrogen-3 which is a radioactive isotope of hydrogen which contains one proton and two neutrons. Tritium is a naturally occurring radioactive form of hydrogen that is produced in the atmosphere when cosmic rays collide with air molecules, but tritium radiation does not travel very far in air.

Isotope data from Hanoi rainy water, Red river water, Hanoi groundwater and rainy water from Hong Kong and Kunming rainy stations in southern part of China are presented in (Tab. 2).

Table 2. Isotope content in rainy water for some stations (annual) after report of the Institute of Nuclear Technology – Hanoi.

Station	TritiumT(TU)	$\delta^{18}O$ (‰ MOW)	δD (‰ SMOW)	Date
Hong Kong	1.72 ÷ 3.69	-1.91 ÷ -9.0	-5.3 ÷ -61	2002
Kunming	4.4 ÷ 17.7	-0.67 ÷ -17.51	-20 ÷ -90	2002
Hanoi rainy water	0.98 ÷ 4.65	-1.4 ÷ -9.8	-6.76 ÷ -77.42	2002-2005
Red river water	1.78 ÷ 8.5	-7.18 ÷ -9.77	-46.43 ÷ -66.62	
Hanoi aquifer Qh	<1 ÷ 5.8	-4.21 ÷ -9.1	-41.0 ÷ -66.60	
Hanoi aquifer Qp	<1 ÷ 5	-5.14 ÷ -8.9	-41.4 ÷ -56.0	

The content T in Hong Kong and Hanoi is ranging from 1.0 to 10.0 TU, but T is higher in Kunming (south China). The content T of Hanoi rainy water is lower than in the Red river water and the phase is lower about 1 month (depend of changeable of season N to S from rainy to dry 1 month) and the T content in rainy water and in the Red river water is increasing by time.

As we know, the flow of Red river water begins from the South China, where T content of rainy water is 2 or 3 times higher than in Hanoi. On the way to Hanoi the Red river water is supplied by rainy and groundwater and it is why in the Red river water in Hanoi T content is lower. The age of water from aquifer Qp is about 10,000 years.

During 2007-2008 we collected 6 samples of water from 6 stations in our study area and around which are presented in table 3. The distance between location of H1 (Red river right bank –W) and H2 (Red river right bank-E) is 5 km and the location between H3 (Calo river left bank-W) and H4 (Ca Lo river left bank-E) is also 5 km. The location of H5 (Dai Lai reservoir) is about 25 km north of studying area. The location of H6 is located of well OW1.The result of the analysis of water for anion and cation in mg/l is presented in table 3.

Table 3. The results of analysis for water by N. Hida and his collaborators in June and September 2008.

Station	Cl	NO_3	SO_4	HCO_3	Na	K	Mg	Ca	$\delta^{18}O$ (‰)	δD (‰)
H1	1.865	3.072	9.038	96.894	3.057	1.606	4.841	29.376	-8.1	-54.6
H2	2.761	2.933	11.939	118.971	4.526	1.686	6.068	32.629	-8.8	-61.7
H3	12.496	5.417	23.537	110.385	8.897	7.000	6.318	34.710	-6.5	-32.1
H4	10.795	10.118	23.277	121.424	7.152	6.905	6.698	39.775	-5.1	-35.7
H5	3.257	1.311	6.258	15.945	2.363	0.920	1.448	4.713	-2.4	-28.3
H6	4.671	3.826	2.806	160.672	15.842	1.913	5.542	36.949	-7.3	-51.0
OW1	1.510	2.650	0.252	112.838	8.206	3.970	4.346	21.654	-7.2	-49.5
OW2	1.835	0.151	1.882	63.778	6.917	2.640	2.807	10.640	-6.5	-47.6
OW3	—	—	4.720	—	—	8.095	—	—	-5.8	-42.0

The groundwater level is changing by time (Fig. 3). It is lower in dry season from March to May and higher in rainy season on July. The time of observation is short, but influence of surface water to groundwater can be observed by OW1 well in the study area. The groundwater level of OW1, OW2 and OW3 wells is changing by time. The values of conductivity of OW3 well water are higher than OW1 and OW2 in the same time. The temperature of groundwater from all wells is approximately constant.

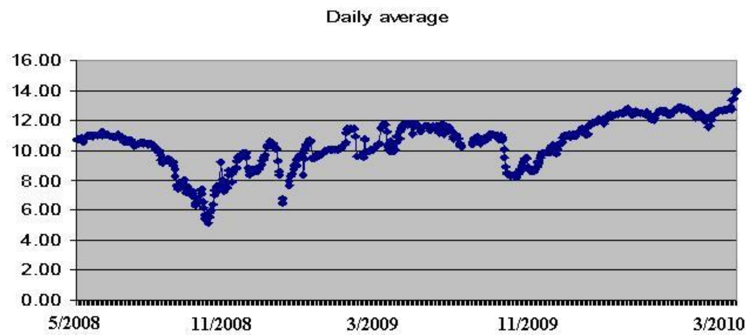

Figure 3. The groundwater level observation of OW1 from May 1, 2008 to March 15, 2010.

CONCLUSIONS

There are two aquifers in the study area on the basis of geological section of wells OW1, OW2 and OW3 stratigraphy. Holocene aquifer (Qh) is shallow and highly polluted but Pleistocene aquifer can be considered as potential groundwater aquifer. They are connecting by hydraulic windows.

The differentiation of geological structure and geochemical characteristics of the sediments causes the difference in hydrological features of the study area. The relationship between geochemical characteristics of the sediments and groundwater quality in the study area is rather close and there is relationship between groundwater and surface water from Red river and Ca Lo river.

Because of rapid development of the industrial zones in the study area the monitoring of groundwater changing is necessary in nearest future.

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