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STUDY OF HYDROLOGICAL CHARACTERISTICS AND HYDROGEOLOGICAL CONDITIONS FOR MANAGEMENT OF AQUIFER RECHARGE IN NW HANOI AREA

Badanie charakterystyki hydrologicznej i warunków hydrogeologicznych dla gospodarki wodnej w rejonie NW Hanoi

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Treść: Obszar badań o powierzchni około 50 km^2 leży w północnej części Hanoi i obejmuje część Rzeki Czerwonej ze strefą przemysłową Thang Long na południu i fragment rzeki Ca Lo ze strefą przemysłową Quang Minh na północy. Na obszarze badań panuje klimat monsunowy z gorącym, wilgotnym latem i chłodną, suchą zimą. Względna roczna wilgotność wynosi 84% przy maksymalnych opadach 1532 mm i minimalnych 948 mm. Obszar leży na wysokości 5÷10 m n.p.m. Występują tu dwie formacje wodonośne – górna, holoceńska (Qh), wychodząca na powierzchnię. Zwierciadło wody gruntowej znajduje się na głębokości 5÷5.5 m pod powierzchnią. Dolna, plejstoceńska formacja (Qp), ma strop na głębokości 20÷30 m. W obu woda jest słodka. Formacja Qp jest intensywnie eksploatowana jako główne źródło wody pitnej na tym obszarze. Zbiornik ten nie jest bezpośrednio narażony na skażenia, ale substancje zanieczyszczające mogą się przedostawać z formacji holoceńskiej (Qh) przez okna hydrauliczne.

Słowa kluczowe: hydrologia, hydrogeologia, holoceński poziom wodonośny, plejstoceński poziom wodonośny

Key words: hydrology, hydrogeology, Holocene aquifer, Pleistocene aquifer

INTRODUCTION

The study area is about 50 km^2 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 with hot and wet summer and cold and dry winter (Fig. 1). The annual relative humidity is 84% with rainfall of max. 1532 mm and min. 948 mm (Fig. 2). 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 beginning of Quaternary to the end of Pleistocene, with three depositional cycles of Lechi ($Q_1{}^1$lc), Hanoi ($Q_1{}^{2-3}$hn) and Vinhphuc ($Q_1{}^3$vp) formations (An 1996, Dy 1998).

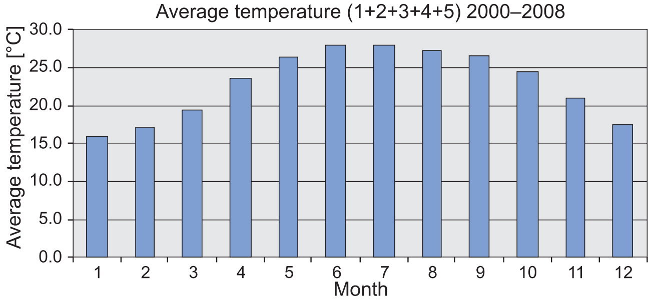

Fig. 1. Distribution of monthly temperature by five meteorological stations in study area and around for period 2000–2008

Fig. 1. Zmiany miesięczne temperatury na obszarze badań i w sąsiedztwie w latach 2000–2008

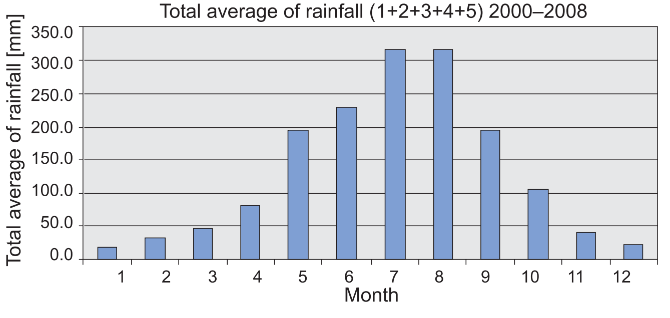

Fig. 2. Distribution of total monthly rainfall by five rainy stations in study area and around for period 2000–2008

Fig. 2. Zmiany miesięczne opadów na obszarze badań i w sąsiedztwie w latach 2000–2008

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 10 m (1.36 m is minimum in 20.02.2006). 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 1 m (An 1996, Nghi & Toan 1991).

The quality of water in Red river and Ca Lo river is generally good. The total dissolved solid content (TDS) is low (<0.2 g/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 changes season by season. In the flood season (August-September) it is usually 4÷6 m higher than the land surface of area. The annual fluctuation of the water level in Red river is 2÷12 m, exceptionally 14.13 m in 1971 (historical flood year). Thus, Hanoi has a dense and diverse hydrographic system, which not only provides abundant water resources but also serves as a water way transportation and drainage of the city and as a tourist attraction. However, so far due to various reasons, the surface water potential has not been exploited appropriately for domestic water supply.

GEOLOGICAL FORMATION

During the Quaternary period the land of study area has been created through transgressions and regressions of the sea in 5 depositional cycles. The first cycle took place in the Early Pleistocene with sediments as pebbles, gravels and coarse sands. This formation varies in thickness 70÷140 m. The second cycle took place in the middle-late Pleistocene (Q_I^{2-3}hn), with coarse grained sediments as well as cobbles, gravels, coarse sand to finer sediments as well as silt sand and clayed silt. The third cycle took place in the Late Pleistocene (Q_I^{3}vp). The fourth cycle took place at the end of Pleistocene and beginning of Holocene with marine genesis, mainly composed of clay and clayed silt of greenish gray color accumulated in the lagoon environment. The fifth depositional cycle took place in the Late Holocene with sediments of various genesis such as alluvial, alluvial-marine sands.

There are different opinions on the subdivision of the Holocene stratigraphy in the Red river delta plain (Nghi & Toan 1991, Hori *et al.* 2004). The main factors considered are 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 year 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 year BP point of time as boundary between Early and Late Holocene.

The paleogeographic situation had also strong changes in the 3 000 year BP point of time. The sea regressed far southeastwards for forming plane and large plain. The weathering surface of motley-colored clay member of the (Q_{III}vp) formation has been regarded as the Pleistocene/Holocene boundary in the confines of Red river delta. Then, we can see from borehole profile sections that this boundary inclines gradually seawards. The subdivision of Holocene sediments and the establishment of stratigraphic units, such as Haihung (Q_{IV}^{1-2} hh) and Thaibinh (Q_{IV}^{3}tb) formations has been mainly based on sedimentary characteristics, geochemistry of the environment and assemblages of forams, diatoms, spores, pollens, etc.

The tectono-structural analysis of Red river fault zone shows that the Pre-Cambrian Convoi mountain metamorphic belt was deformed and became an elongated dome of 10÷15 km in width, the folds of which are gentle in the central part, but very steep near Red river and

Chay river faults. The existence of syndepositional normal faults and gentle folds of mainly NW-SE trend in the Oligocene-Miocene sediments implies that the uplift movement occurred in both Oligocene-Miocene sediments and metamorphic complexes. Neotectonic activities, on one hand caused the uplift of the studied area, forming scattered extensional grabens along the Red river fault zone filled up with the Tertiary sediments from very coarse pebbles to fine claystone and coal-bearing beds; on the other hand gave rise to strong horizontal strike-slip, which appeared vividly in the Oligocene-Miocene sediments along the Red river fault zone. In general, the association of structural features implies that the Red river fault zone had been developed during Meso-Cenozoic period with sinistral-extensional tendency. The extension has been increasing southeastwards (Rangin *et al.* 1995, Hori *et al.* 2004).

The earliest Cenozoic formation (member of conglomerate and gritstone) distributed along the Red river fault zone contains many *in situ* caved in fragments of some to hundreds cm in size from banded metamorphic rocks similar to those of the Convoi range. This fact has been proving that these rocks are considerably older than Cenozoic sediments. During all the development process of the Hanoi graben, from the Eocene to the end of the Miocene, the tectonic stress field of this area was characterized mainly by the extension.

HYDROGEOLOGY

On the basis of stratigraphy of 3 wells – OW1, OW2 and OW3 drilled in study area by the end of July 2008 (Fig. 3) there are two aquifers (Fig. 4). Holocene aquifer (Qh) is exposed on the surface, widely and continuously distributed from Red river to Ca Lo river. The water bearing formations consists of 2 sequences: the upper sequence is composed of sandy clay, clayey sand, with low permeability, with thickness to about 10 m. The lower sequence is composed of sand with various grain sizes, in some place mixed with the gravel at the bottom, with average thickness of 9÷10 m. The depth to the groundwater level is 5÷5.5 m 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 0.5 g/1, mainly of calcium-bicarbonate type. The iron content in the water in most of the area is 0.4 to 10 mg/l. The manganese content is 0.2÷2 mg/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 observed all over studying area. The depth to the top of the aquifer is 20÷30 m. Between two aquifers is one confining layer Q_1^3vp (Fig. 4). The aquifer Qp is of changeable thickness from few to 60 m, increasing from N to S, constructed by coarse sand, gritstone, gravel with low TDS and with water level from few to tenth meters. The source for Qp is mainly rainy water from surrounding region of Red river delta and from hydrogeological windows. Between the aquifers and the rivers, there is the close hydraulic connection, proved by observation of water level in OW1. 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

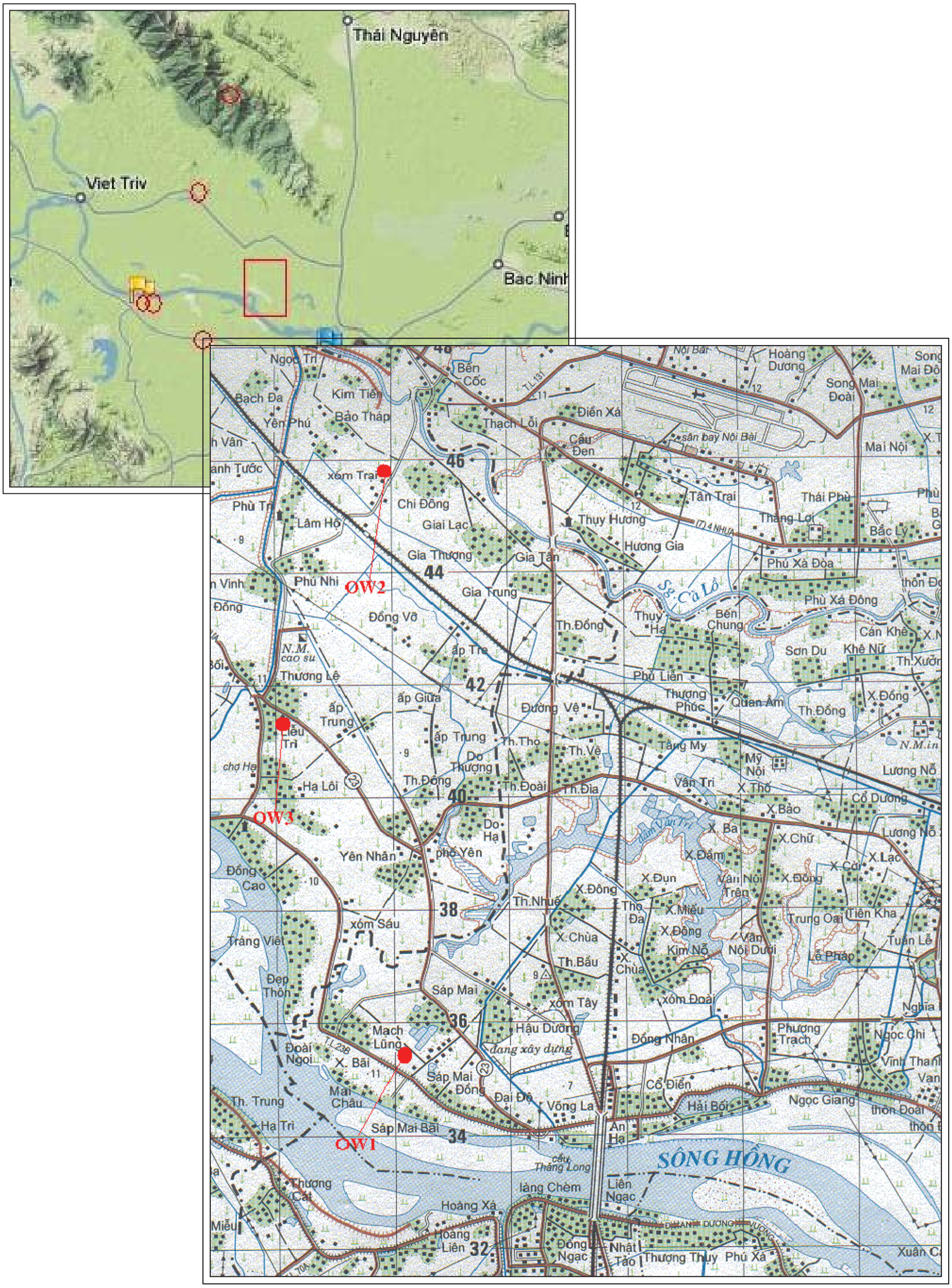

Fig. 3. Location of wells OW1, OW2 and OW3 in the study area

Fig. 3. Położenie otworów OW1, OW2 i OW3 w rejonie badań

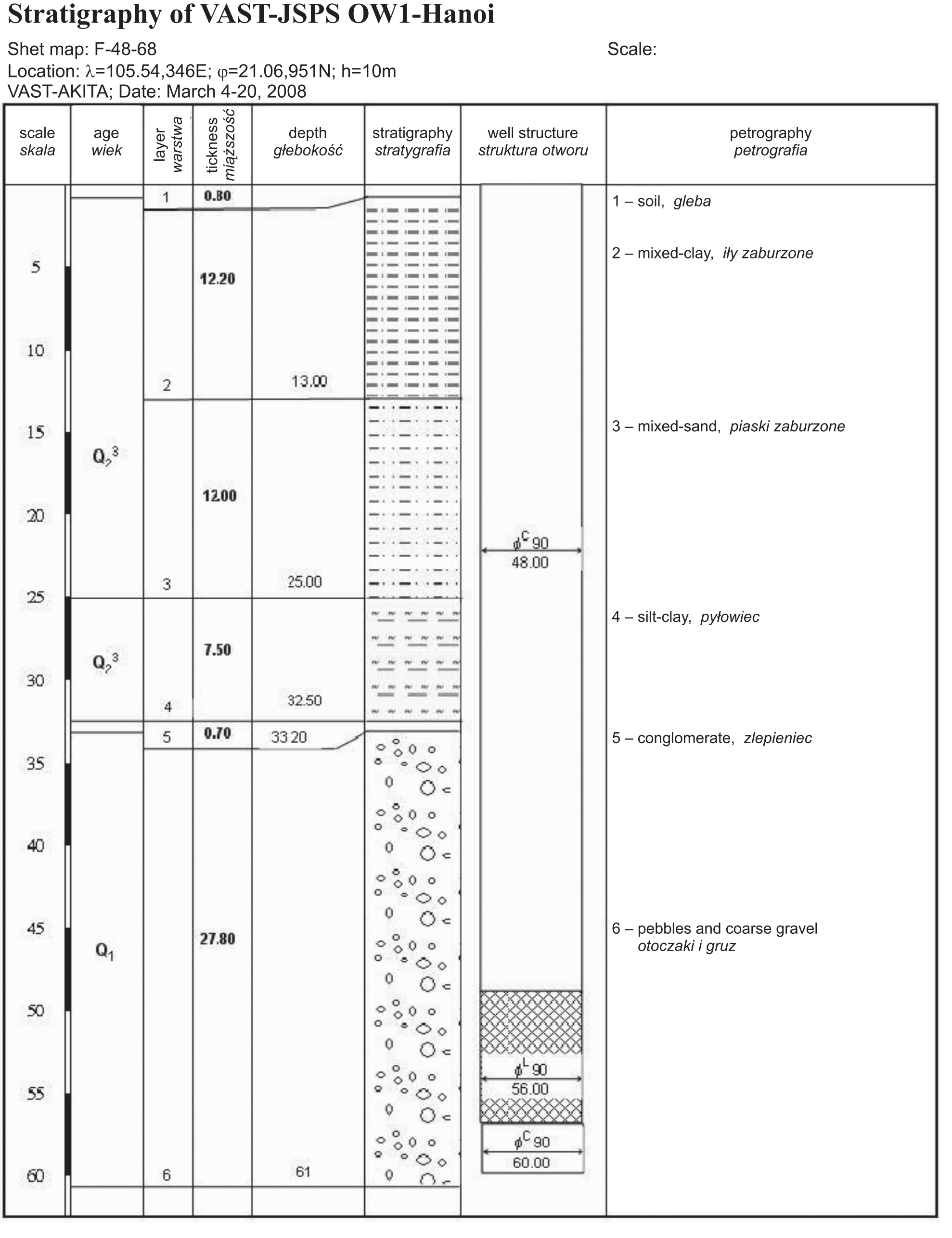

Fig. 4. Stratigraphy of the OW1 well (layer 3 in $Q2^3$ corresponds to Qh aquifer and layer 6 in Q1 corresponds to Qp aquifer)

Fig. 4. Stratygrafia w otworze OW1 (warstwa 3, $Q2^3$ odpowiada warstwie wodonośnej Qh, a warstwa 6, Q1 odpowiada warstwie wodonośnej Qp)

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 and the project continue monitoring of 3 wells for future forecasting.

Regarding hydrogeological conditions in the study area one can take remarkable conclusions to the Red river delta region. The Qp aquifer is the largest in the Red river delta of Vietnam. The study on relation between the rain water, Red river 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, Payne 1983). The existence of T in the all of wells in Qp proved mixing between water from this aquifer and modern water.

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 table 1.

Table (Tabela) 1

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

Zawartość izotopów w wodzie opadowej z kilku stacji (na podstawie raportu Institute of Nuclear Technology – Hanoi)

Station, *Stacja*	T(TU)	$\delta^{18}O$ (% o MOW)	δD (% o SMOW)	Date, *Data*
Hong Kong	1.72 ÷ 3.69	–1.91 ÷ –9.00	–5.3 ÷ –61.0	2002
Kunming	4.4 ÷ 17.7	–0.67 ÷ –17.51	–20 ÷ –90	2002
Hanoi rainy water *woda opadowa w Hanoi*	0.98 ÷ 4.65	–1.4 ÷ –9.8	–6.76 ÷ –77.42	2002–2005
Red river water *woda z Rzeki Czerwonej*	1.78 ÷ 8.50	–7.18 ÷ –9.77	–46.43 ÷ –66.62	
Hanoi aquifer Qh *poziom wodonośny Qh w Hanoi*	< 1.0 ÷ 5.8	–4.21 ÷ –9.10	–41.0 ÷ –66.6	
Hanoi aquifer Qp *poziom wodonośny Qp w Hanoi*	< 1 ÷ 5	–5.14 ÷ –8.90	–41.4 ÷ –56.0	

The content of 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 of T in Hanoi rainy water is lower than in the Red river water. 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 2. 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 (Ca Lo 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 study area. The location of H6 is of well OW1.

Table (Tabela) 2

The location of water samples collected in 2007–2008

Lokalizacja próbek wody pobranych w latach 2007–2008

Station, *Stacja*	Location, *Położenie*	Date, *Data*
H1	Red river right bank – W *prawy brzeg Rzeki Czerwonej – W*	11:00, June 27, 2007
H2	Red river right bank – E *prawy brzeg Rzeki Czerwonej – E*	13:00, January 31, 2008
H3	Ca Lo river left bank – W *lewy brzeg rzeki Ca Lo – W*	12:00, January 31, 2008
H4	Ca Lo river left bank – E *lewy brzeg rzeki Ca Lo – E*	14:30, March 21, 2008
H5	Dai Lai reservoir *zbiornik Dai Lai*	12:30, March 21, 2008
H6	Observation well OW1 *otwór obserwacyjny OW1*	10:20, March 20, 2008
OW1	Observation well OW1 *otwór obserwacyjny OW1*	12:00, July 10, 2008
OW2	Observation well OW2 *otwór obserwacyjny OW2*	15:30, July 10, 2008
OW3	Observation well OW3 *otwór obserwacyjny OW3*	14:00, July 10, 2008

The results of the analysis of water for anion and cation in mg/l is presented in table 3.

Table (Tabela) 3

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

Wyniki badań wody przeprowadzonych przez N. Hida i współpracowników w czerwcu i wrześniu 2008 r.

Station *Stacja*	Cl	NO_3	SO_4	HCO_3	Na	K	Mg	Ca	$\delta^{18}O$ [%o]	δD [%o]
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. 5). It is lower in dry season from March to May and higher in rainy season in 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.

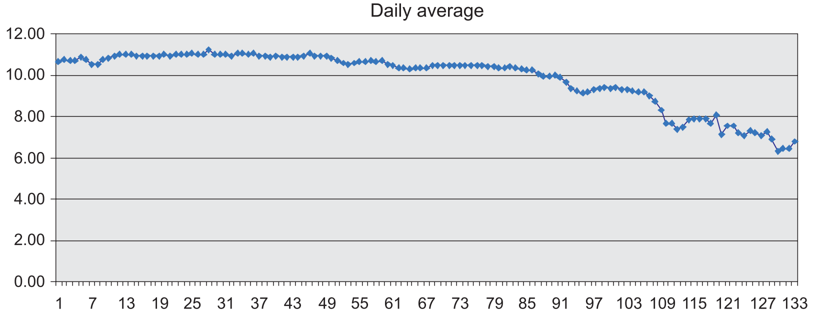

Fig. 5. The groundwater level observation of OW1 from March to July 2008

Fig. 5. Obserwacje zmian poziomu wody w otworze OW1 od marca do lipca 2008 r.

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 connected by hydraulic windows.

The differentiation of geological structure and geochemical characteristics of the sediments causes the difference in hydrological features of the study area.

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

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. The answer will be suitable for the Management of Aquifers Recharge (MAR).

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