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title: **Groundwater table fluctuations types in urban area, Wroclaw, SW Poland**

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INTRODUCTION

The following report shows only small part of final results of tests performed in the first aquifer (quaternary formation) in Wroclaw between 2002–2006, which was partially financed by Ministry of Science and Higher Education – No 4 T12B 031 27. Complete study was done by Worsa-Kozak in doctoral thesis (2006).

The first systematic hydrogeological observations in Wroclaw are dated on April 9, 1987 (Jacobi, 1877) and lasted until 1922. All the results were published in municipal yearbooks (Breslauer Statistic, 1877–1922). Observations of groundwater table in Wroclaw with various interruptions and in variable research network are carried out today (Kowalski, 1977; Worsa-Kozak, 2006; Kotowski , Worsa-Kozak, 2009). The purpose of previous researches was to analyze and evaluate the characteristics of the ground and waters conditions in the city and point dependence between groundwater table and the urban factors. This article is the first in its kind and treats about classification of the groundwater table fluctuation in the City of Wroclaw.

STUDY AREA

General information

Wroclaw, the main city of the region and administrative province of Lower Silesia, is situated in south-western Poland (Fig. 1). Sudety Foreland on the southwest, Silesian Highland on the east, and Trzebnickie Hills on the North of the Silesian Lowland, outline the borders of Silesian Lowland where city of Wroclaw is located (Kondracki, 2002). The axis of the Lowland goes through Odra ice-marginal valley and it cuts the city in the northwest – southeast direction.

Wroclaw occupies 293km^2, 40% of which is dense of urban development. Surface waters are also a big part of the area (total 9.55 km^2), 8.26 km^2 includes flowing waters. In terms of hydrography Wroclaw is situated in the Middle Odra Basin. The length of Odra River within the city border is 26 km, and the width of its valley can measure even a few kilometers. Widawa River (length 20 km within the city border) is the major right tributary of the Odra River and the left tributaries include Olawa (8 km), Sleza (16 km), Bystrzyca (15 km) and Lugowina. The total length of the watercourses within the city limit is 280 km.

Geology

Wroclaw is situated on the southwest perimeter of the Fore-Sudetic Monocline, close to its border with the Fore-Sudetic Block. Pre Cenozoic foundation (metamorphic schists and granitogneisses of Middle Odra Metamorphic Complex, in some places rocks of Carboniferous, deposits of Triassic and Permian) is covered with Cenozoic deposits (Neogene). Miocene deposits are created as „Poznan series", which are clays, silts, and sands with some lignite in them. Younger deposits include boulder clays, glacial sands and gravel, sands and muds accumulated by still waters, aeolic sands and Holocene deposits in the beds of valleys - clays, sands, gravel, mud which contain organic residue, and peat (Figure 1) (Buksinski, 1974; Winnicka, 1988). The major part of Wroclaw is located on the valley of Odra, which is filled with alluvial deposits. The south of the city is created mostly out of fluvioglacial and glacial deposits and in the west part of it neogenic deposits are noticed on surface. These parts of the city are situated on uphill, outside of the valley. The youngest sediments can be found in Downtown and these are anthropogenic embankments with thickness even over 10 meters.

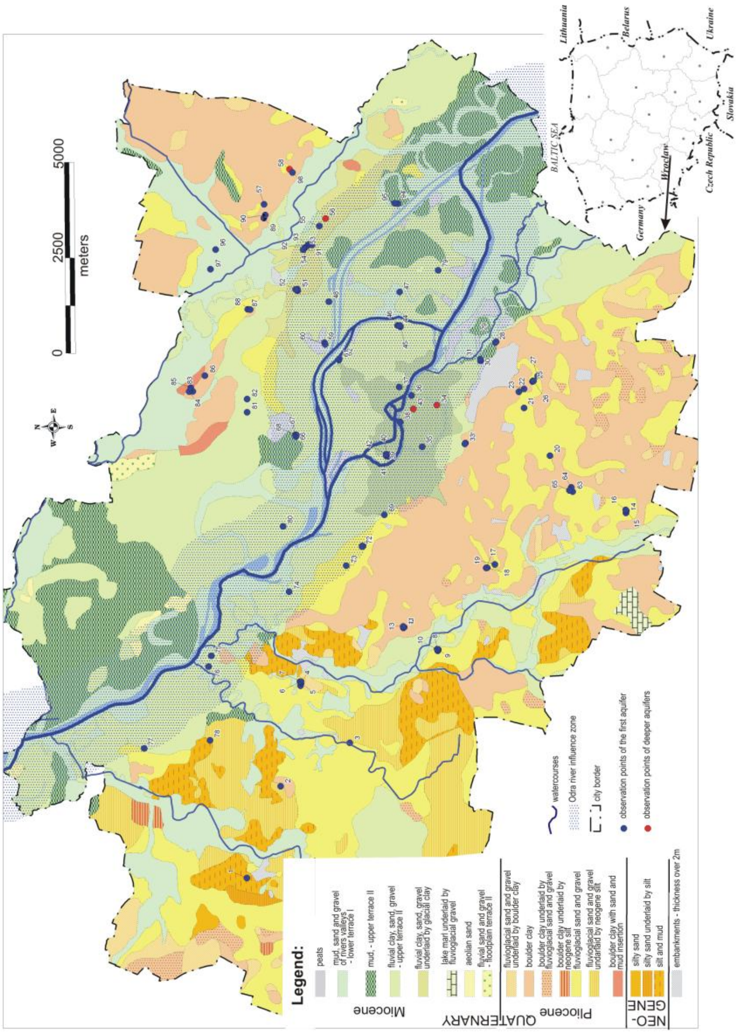

Figure 1. Geological map of Wroclaw and location of observation points.

Hydrogeology

There are three main multiaquifer formations in the city of Wroclaw. (Nowicki, 2007; Paczynski, Sadurski, 2007) (Figure 2): quaternary aquifer is mostly found in fluvioglacial and fluvial sandy-gravel deposits. These can be found in the majority of the area of the city, except for the south-west part. Thickness of this formation varies from 5 to 30 m. Groundwater table is unconfined and lies on average depth of 5 m b.g.l; neogene aquifer, which is bound up with sandy-gravel interbeddings and pockets within clayey deposits. Upper and lower levels are distinguished in this aquifer; triassic aquifer which include fissure waters in "shell limestone" (middle Triassic) and in "variegated sandstone" (early Triassic). "Shell limestone" can be found only in the east part of Wroclaw.

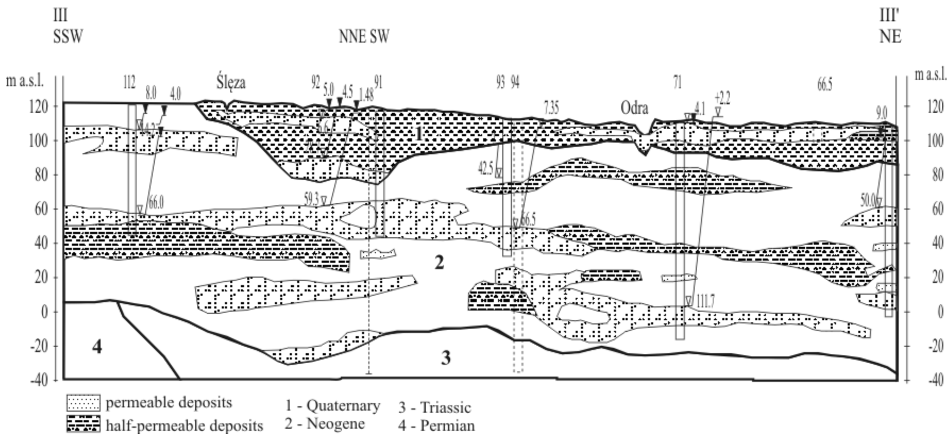

Figure 2. Hydrogeological cross-section trough the City of Wroclaw (after Mroczkowska & Michniewicz, 1976, changed).

The study was performed in the first out of total three aquifers. It occurs in three units within Wroclaw, which were recognized by Kowalski (1977): the area of river deposits in the Odra ice-marginal valley and valleys of Olawa, Sleza, Lugowina, Bystrzyca and Widawa; the area of pleistocene deposits and fluuvio-glacial coverage, which divide into two regions-North and South Upland; the areas of shallow deposition of Miocene and Pliocene sediments.

METHODS

During the two hydrological years (2004–2005) observations of the first water table were performed. The research was done weekly (every Monday). Such a frequency of measurements guaranteed capture short-term changes in the position of the groundwater table (Taylor, Alley, 2001). In the beginning of described observations there were 100 observation points and at the end the number lowered to 85.

According to Tomaszewski (1990) the observation can be classified as medium-term and pointing types of fluctuations could be possible. The point of reference in the study was generalized pattern of shallow groundwater table fluctuation common for weather conditions in Middle Europe and Poland, presented by Konoplancew and Siemionow (1979). This pattern is characterized by two minimal and two maximal states of groundwater table in a year.

In order to classify groundwater table fluctuation the results of only the points researched for over one hydrological year were taken into consideration, so data from 85 boreholes were thoroughly analyzed. The shape of hydrograms, periodicity of fluctuation and occurrence time of extreme states were analyzed and based on final results, the main groups of wells were distinguished. Also factors of correlations between ground water levels and level of Odra river (measured in weirs and water gates) and amount of precipitations were analyzed. The classification was made based on the first groundwater table rises and falls and also on the value of correlation factors.

RESULTS

Based on hydrograms analysis four main types of groundwater table fluctuations of the first aquifer were found in the city of Wroclaw:

- type I: 4-extremal (Figure 3), comparable to the natural cycle described by Konoplancew and Siemionow (1979). Two minimal levels and two maximal ones during a period of one year distinguish this type. The first minimal levels (H1) appeared in spring time (April and May) and then in the months of June and July the table was rising to reach its first peak in the middle of the month July (H2). Right around October and November appeared the second minimal level (H3) and in December and January we could observe the second maximum (H4), which was slightly lower than the spring one. This kind of periodicity of groundwater table fluctuation was being noticed in 10 observational points in the south highlands, particularly in the Gaj District.

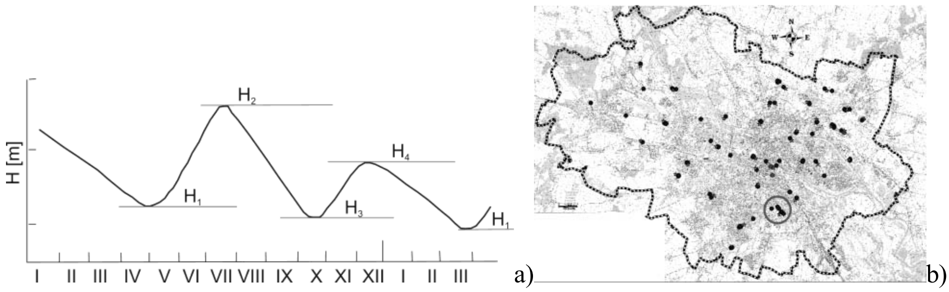

Figure 3. Type I of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points.

- type II: 2-extremal (Figure 4), was characterized by one distinct minimum and one maximum. The rise of the table was noticed until April (H1), and than it was gradually lowering until it reached a minimum in October and November (H2). This type qualifies as the most common type of groundwater table fluctuation in the city of Wroclaw (39 hydrological boreholes). The boreholes, which represented Type 2, were localized within south and north highlands and also on the border of river valleys. This cycle of groundwater table fluctuation is typical around river areas and is characterized with mild changing process. It points to major influence of Odra (far over the valley limits) in water dynamics in the first aquifer in the city of Wroclaw.

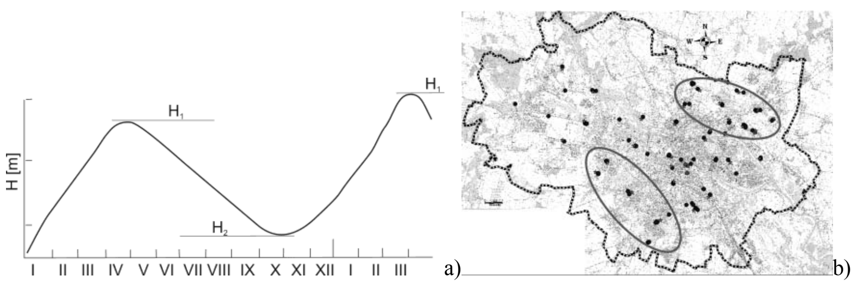

Figure 4. Type II of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points.

- type III: 2-extremal (Figure 5), influenced by the rhythm of the Odra fluctuations. This kind of groundwater table fluctuation was described by a high frequency depended on the level of Odra. Boreholes were situated hundreds of meters from riverbed and its hydrograms strictly imitate these of Odra. Also seasonal and annual amplitudes of fluctuations are very similar to the values observed in the river. Changes of the water table in Odra almost immediately influence changes in groundwater level – it was clearly visible in the few observed daily points. Despite the high frequency of water table fluctuations the two extremes (spring – H1 and fall – H2) were still noticeable on the hydrograms. This type was marked out in 25 hydrogeological boreholes in the basin of the Odra and the area directly influenced by it. Within the city limits Odra is divided into many branches, its bed is regulated and waters are damming up by weirs, which belong to Wroclaw Water Node (Wroclawski Wezel Wodny). Damming up of Odra waters and balancing of its table at designed levels causes the rhythm of fluctuation being unnatural.

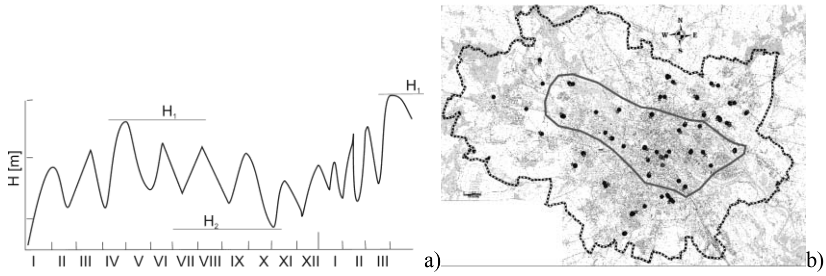

Figure 5. Type III of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points; c) example of hydrogram.

- type IV: irregular and being a result of incidental anthropogenic events (Figure 6). Hydrographs that present the Type IV of groundwater table fluctuation show numerous disturbances of the fluctuation rhythm–sudden, high drops (H_x) and rises of the groundwater level. Further analysis of the local conditions pointed to human influence. Short lived and intense drainage of the surrounding areas, pumping of the water for domestic and farming purposes and also frequent failures of water supply system were the most common causes of sudden groundwater table variations. These features were distinctly observed in 11 observational points placed in different parts of the city.

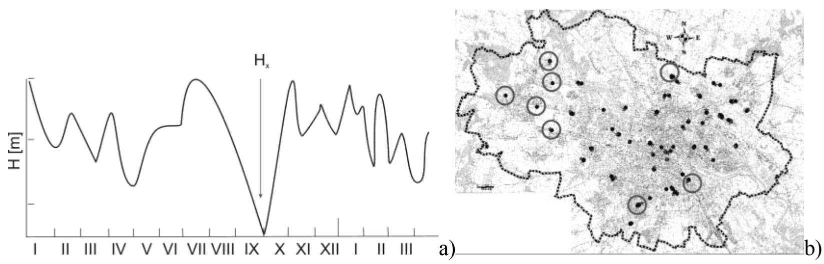

Figure 6. Type IV of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points.

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