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Bucharest city urban groundwater monitoring system

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Abstract

Bucharest City is the capital of Romania and also the biggest city. Situated in an alluvial plane, the geological settings are represented by a series of overlaying Quaternary strata of aquifers and aquitards. Some of these aquifers are used for water supply (the deeper aquifers) and the shallow and medium ones are characterized by an intense interaction with the urban infrastructure.
The paper presents the drivers and also the architecture of the urban groundwater monitoring systems developed in the last years in order to observe the urban impact upon the first two aquifers layers. The anatomy of the system is correlated with the urban infrastructure. Also the paper presents the future monitoring system that will be develop within a European JPI project.

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1. Introduction

Bucharest City covers around 240 km^2 (6 districts). Hydrological features are playing an important role in the water balance of the city. Two rivers are crossing the city, both of them being modified. The north river (Colentina) is landscaped in a series of lakes communicating directly with the shallow aquifer. The south river (Dambovita - crossing the centre of the city) is channelized and the communication with the aquifer is interrupted. This river is connected to an important artificial lake (Lacul Morii), located in the west part of the city, constructed in the '70 for flood management and urban landscape improvement. Also, a significant number of artificial and natural lakes comprising around 11 km^2 are spread on the city surface. The geological settings are represented by Quaternary sediments (clay, loam, marl, loess, sands and gravel) either fluvial, lacustrine or eolian. From the Lower Pleistocene (200 -150 bgs) to the latest Holocene deposits, three important aquifer formations are representative for the Bucharest area: (1) the deeper aquifer - used for water supply, (2) the medium depth aquifer - used also for water supply in some cases and in a direct (natural and anthropogenic) hydraulic connection with the (3) shallow aquifer (in direct connection with the underground infrastructure).

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2. Urban Groundwater Monitoring System

The Urban Groundwater Monitoring System (UGMS) of Bucharest City tries to capture the most important urban hydrogeological characteristics. The development of the UGMS took into account several requirements (Table 1) and constrains (Table 2).

Table 1 - Requirements of the UGMS

z	TYPE	SOLUTION
Coverage area	**Geometry - Location**	The distribution of the UGMS points cover around 110 km^2 (Figure 1), almost a half of the administrative area of Bucharest City.
Target aquifers		The UGMS is a monitoring system developed for the urban aquifer system. The UGMS focuses only on the first two aquifer layers (Colentina - shallow aquifer and Mostistea - medium depth aquifer). The number of monitoring points in the shallow aquifer is larger (116 points) than in the medium depth aquifer (only 30 points), due to the fact that the shallow aquifer shows a strong interaction with the urban infrastructure.
Special urban infrastructure features		The specificity of an urban groundwater monitoring system is to capture the impact of urban infrastructure effect upon groundwater. Many of the monitoring points are located in the vicinity of the Dambovita lined-up channel and of the LaculMorii lake. Other special urban infrastructure elements (subway line, deep foundations, others) have also monitoring points in their surrounding areas.
Parameters and tests	**Data**	Each project involves a limited budget. In order to optimize it, a certain balance between the drilling procedure, well equipment, laboratory and in-situ tests must be taken into account. The development of the UGMS was made in 2 different phases, using two different drilling procedures. In the first phase the wells were done using hydraulic rotary drilling (around 34 monitoring points) and in the second one by using auger drilling with protective casing. The parameters and the data collected during and after the development of the monitoring wells are described in Table 2.
Monitoring parameters		Hydraulic head data, results of water sampling and laboratory analysis represent the needed information. In order to reduce the costs and to maximize the data benefit, several monitoring boreholes were equipped with double tubing targeting both two aquifers. The sealing between the two aquifers was made of a mixture of clay, bentonite and cement.

Table 2 - Constrains of the UGMS

CONSTRAINS	TYPE	SOLUTION
Security and well integrity	**Geometry - Location**	Security of the monitoring points is a key aspect in an urban environment. There are several area social triggers that need careful attention: (1) scrap iron black market - in this case the metallic components (well head protection) must be eliminated or somehow made invisible - for UGMS most of the metallic components (well cover) are found at ground level in public places, (2) vandalism - there is no real solution regarding the public places (ex. UGMS lost around 6 monitoring points due to vandalism - wells were filled with stones and other materials, the well casing broken and the cover stolen). The general solution, to avoid these risks, was to set up (as much as possible) the monitoring points in private locations belonging to the municipal water company.
Budget	**Data**	The budget limitation is a constrain for each project. With the available budget the UGMS had to respond to two needs: (1) characterization of the aquifer media - around 10 hydrogeological cluster points, located in key points of the city and (2) hydraulic head monitoring points (double tube wells) .

During the development of the UGMS (the drilling and testing phases) certain advantages and disadvantages were observed taking into account the drilling method (Table 3).

Table 3. Drilling procedures - advantages and disadvantages

No.	Parameters - Data - Test	Hydraulic rotary drilling	Auger drilling
1	Lithology description	+	+++
2	Granulometry	+	+++
3	Electric resistivity (16, 64 Ωm)	+++	-
4	Natural Gamma (Api)	+++	+
5	Temperature	+++	+
6	Hydraulic pumping test	++	+++
7	Slug test	+	++
8	Level measurements	+++	+++
9	Chemical sampling	++	+++
	Legend - Not applicable | + Satisfactory | ++ Good | +++ Excellent		

The urban groundwater monitoring system in Bucharest is composed (end of 2014) by a total number of 145 monitoring points/stations. The distribution of the monitoring points (Figure 2) is concentrated in the center of the city, along the channelized Dambovita River. This can be explained by the high density of urban underground infrastructure elements found in the area:

a. the channel of the Dambovita river,
b. the main sewer collector of Bucharest City located under the channel,
c. 2 major wastewater conduits located in parallel to the Dambovita river,
d. the subway line,
e. Dambovita channel left bank drain
f. a new drainage system that will be implemented (currently under construction) on the channel right bank.

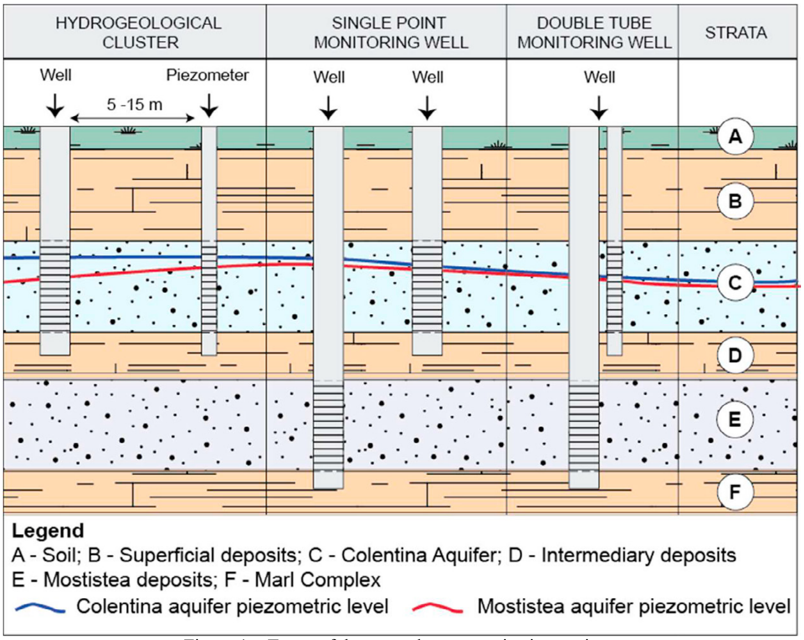

Figure 1 – Types of the groundwater monitoring stations

The monitoring stations/points are divided in three types (Figure 1):

1) Single point monitoring well - this type is a simple hydraulic head monitoring well with an outer diameter (OD) between 90 - 114 mm. For almost all of this kind of monitoring points, geophysical logging and hydraulic testing (pumping tests for 114 mm OD and slug tests for 90 mm OD) have been performed. In some cases, samples from the aquifer strata (sand and gravel) were collected to determine the granulometry.
2) Double tube monitoring well - this type of monitoring station is designed to measure the hydraulic head for both Colentina and Mostistea aquifer strata. In the borehole there are installed two tubes: 90 mm and 32 mm. For both of the tubes slug tests as well granulometric analyses were performed.
3) Hydrogeological cluster - this type of monitoring station is composed by a well (140 mm OD) and a piezometer (90 mm OD) targeting the same aquifer unit (the distance is between 5 to 15 m). This type of monitoring station was designed to give a proper description on the hydrogeologic parameters by performing pumping tests.

Considering the typical urban environment, the monitoring system responds to two more challenges (1) data acquisition during the development phase and (3) support for the operational decisions.

The UGMS is an important part of the Bucharest Groundwater Model. The hydrogeological model was developed during several years (between 2010 - 2015) within the Groundwater Engineering Research Center. The first realization of the model (2013) was based only on 46 monitoring points [1] and it took into account the urban infrastructure elements and their interaction with the groundwater: sewer and water supply network [2], subway tunnels and stations barrier and drainage phenomena [3], impervious surfaces, etc. The next model (2015) used the entire set of monitoring points (145) .

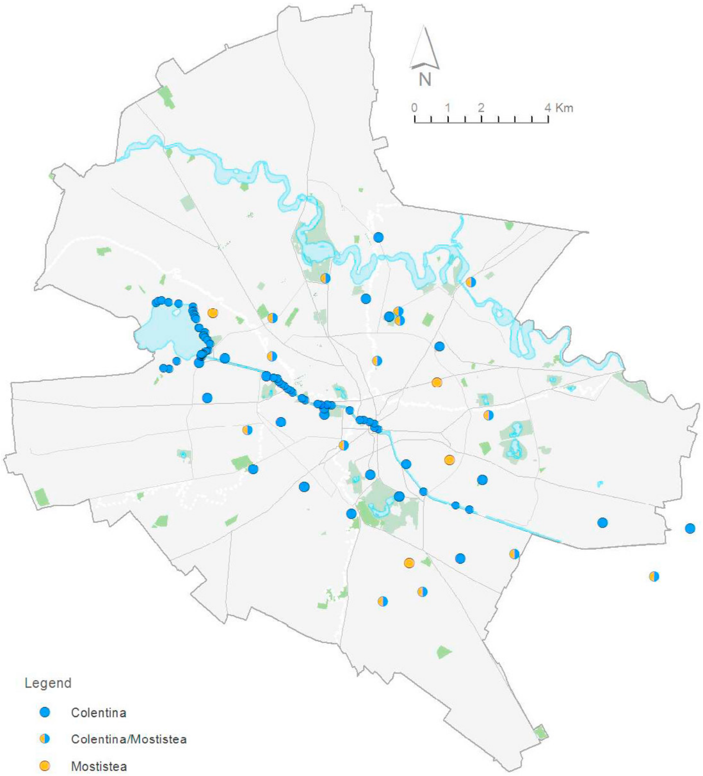

Figure 2. Bucharest City Urban Groundwater Monitoring System

3. Future challenge

Within the INXCES project (JPI-Water Projects) a new monitoring system will be developed. The system will combine the different types of urban engineering scientific measurements: (a) geotechnical, (b) hydrogeological, (c) meteorological and (d) topographic. The monitoring system will be composed of two major components: surface devices and equipment and underground equipment.

The surface components are: (A) Corner reflector provides high intensity InSAR data assuring the presence of remotely sensed deformation time series at the location where a large rang of other relevant parameter are being recorded using in-situ measurement techniques. (B)Meteorological station composed of a rain gauge, an evaporation tank, and humidity-temperature--atmospheric pressure sensors. (C) Levelling benchmarks: each monitoring station will be equipped with 3 referencing points to be used for filed levelling.

The subsurface components are: (A) Inclinometric tube will provide vertical profiles with horizontal displacements (along two perpendicular directions – longitudinal and transversal) with a temporal resolution lower than that provided by TDR. (B) Groundwater level and pressure compartments will be equipped with probes (Divers) that will provides groundwater level variations in multiple aquifers (from the same borehole using the multilevel piezometer technology) and pressure in the vadose zone. (C) Subsurface temperature profiling compartment will be equipped with sensors. Compensation of environment temperature will be made using the surface control and data acquisition unit. Changes in this parameter shall provide information related to the infiltration process. (D) Water sampling compartments equipped tubes that can be used for low flow approach water sampling. Qualitative analysis of groundwater will provide insights on possible impact/risks related to extreme hydro-climatic events on groundwater quality as it can help be used quantify the infiltration urban into aquifers.

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