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# EVALUATION METHOD OF GROUNDWATER QUALITATIVE AND QUANTITATIVE FLUCTUATIONS IN THE SMALL RIVER CATHMENTS OF URBANIZED TERRITORIES

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**Abstract.** Preservation of groundwater resources and improvement of its quality are the main environmental problems of urbanized territories. The increasing levels of pollution reduce the number of surface water basins suitable for aesthetic and recreational purposes. Moreover, processes taking place in the small river basins deteriorate the groundwater quality. Meanwhile the groundwater and interstitial water of small river basins represent the main resources of drinking and technological water.

Atmospheric water infiltration depends on the lithological composition of deposits. It is determined by analysis of geological and geomorphological maps and material from the boreholes in the studied areas. The data from boreholes also is informative about the groundwater table and chemical composition of infiltrated water. Water samples for quality assessment are taken from the topsoil (for determining the background), from the subsoil layer and from the aeration zone at 1 m intervals down till the depression zone. Also water sample is taken from the upper horizon of groundwater. A system of lysimeters and piezometers is necessary for observation of water quality fluctuations and vertical groundwater table fluctuations in the course of time. Also the system of lysimetric boreholes allows recording and mapping of spatial fluctuations of the mentioned parameters. The article introduces methods of drilling lysimetric boreholes of original construction and development and use of long-term water quality observation system.

**Keywords:** river catchment, infiltration, lizimetric borehole, groundwater fluctation.

## 1. Introduction

The economic activity is responsible for substantial changes of water balance in river basins. These processes are especially obvious in the small river basins where fluctuations of precipitation, transformation of anthropogenic relief and changes of land use structure radically affect the groundwater resources. The rainfall water infiltrating the groundwater discharge is responsible for water volume in large and small rivers, amounts of groundwater and interstitial water and their safe yields. Infiltration water, which never is distinguished for good quality, supplements the groundwater aquifers. Groundwater exploitation is especially intensive in urbanized suburban territories and is responsible for reduction of water supplies in small river basins. The reducing supplies of groundwater are especially obvious in the Lithuanian cities and peripheral parts of cities where intensive expansion of urban areas takes place. The ever increasing groundwater exploitation reduces the number of surface bodies of water suitable for aesthetic and recreational purposes. Moreover environmental degeneration processes deteriorating the groundwater quality are taking place in the small river basins. These negative trends became especially obvious at the end of the 20th–the beginning of the 21st centuries (Baubinas, Taminskas 1998; Kadūnas 2007).

Analysis of water samples provides information about the momentary state of hydrogeological and chemical conditions at the studied point. A properly performed analysis provides data about the source and degree of pollution and allows forecasting the possible outcomes (Christine et al. 2010; Klizas 2007). It should be reminded that hydrogeological and hydrochemical conditions in the underground hydrosphere are subject to spatial and temporal fluctuations and that groundwater represents a dynamic system. For this reason, frequency of sampling and arrangement of monitoring points over the studied territory should be well considered and based on possibly accurate and all-round assessment of geological and hydrogeological conditions. This also is important attempting to distinguish between the actual hydrochemical fluctuations and imaginary ones occurring as a result of sampling, storage and analysis errors. Every field measurement or water sample taken for laboratory examination also must characterize a concrete point of monitoring network. Often, emphasis is placed on the importance of mere quality control and preservation. Nothing can be better than good quality samples and field measurements in situ (Groundwater… 1999). The main goal of monitoring is to determine the actual values of the processes taking place in the hydrogeosphere under natural conditions. Establishment of monitoring points to smaller or greater extent deform these natural conditions: the natural texture of deposits and water impermeable layers between aquifers are disturbed, the groundwater horizon is directly connected with the atmosphere, etc. Besides, certain conditions develop in the contact point between the deposits and wall of observation point. These circumstances are responsible for the deviations between the factual conditions in the hydrogeological layers and their values measured in the observation point. The deviation value depends on many factors: technology of observation point installation, constructional design, geological and hydrogeological conditions, scale and type of pollution of the underground, etc.

Practically any tool allowing measuring the indicative parameters of groundwater state is suitable for groundwater monitoring (Klimas et al. 2003; Kevin 2000). The most popular tools are: soil lysimeter, hydrophysical test pit and lysimetric borehole. The process of establishing an observing point always takes two stages. The first stage includes a survey of geological section at a chosen point and the second is represented by installation of the point itself. In the first stage, a precise geological section is made: core samples are taken by drilling or geophysical investigation (diagraphy) is carried out in the borehole for reliable identification of the geological section.

The aim of the present investigation is to work out methodical principles for evaluation of groundwater qualitative and quantitative fluctuations based on the methods of empirical observation and cartographic analysis.

## 2. Methods

Quantitative groundwater assessment was based on evaluation of a few environmental components in the small river basins (precipitation, evaporation, discharge, surface relief, deposits and land use structure). This kind of assessment employs empirical formula defining the quantitative values of the mentioned components). Regional and local features of the small river basins are an important factor. Unfortunately, their determining often is a problem.

The amount of precipitation in basins was evaluated in a few aspects: quantity, duration, intensity and frequency. The evaluations were based on the interpolated and extrapolated data from the closest meteorological stations. It is rather problematic to evaluate the amount of effective precipitation predetermining the factual water supplies of river basins. For this purpose one must be aware of the extent of retention an interception. Besides, evaluation of evaporation in the small river basins requires individual field investigations.

Infiltration properties of surface deposits are an important factor predetermining the groundwater supplies. Large-scale (1:10 000) lithological and soil maps are helpful for evaluation of deposits (Baubinienė at al. 2002).

The precipitation infiltration conditions are predetermined by horizontal and vertical distribution of surface forms in river basins. Surface inclination is one of the main indices affecting the infiltration of rainfall water. Even a small slope angle accelerates the direct downslope runoff of rainfall water and reduces its infiltration (Baubinienė et al. 2002).

Land use structure is one of the anthropogenic factors that predetermine the infiltration conditions in a basin and affect retention and interception of precipitation. The land use structure is evaluated using topographic maps at a scale 1:10 000 and digital databases (Cartographic Data Base... 2009; Colourful Raster Data Bases... 2009; Data Base of the Cropland... 2010).

Lysimetric boreholes were chosen for empirical groundwater level and quality investigations. This was predetermined by a few reasons:

1. Lysimetric boreholes entail least deformations of the natural state of deposits and groundwater.

2. Conditions for unified observation are created independent on the bedding depth of groundwater.

3. Simple technical means and small physical efforts allow reaching the greatest depth.

A manual helical drilling device designed by A. Litvinaitis was used for making boreholes. The drill kit includes drills 80 mm or 160 mm in diameter and drill extenders. With the aid of this device it is possible to drill a borehole 7 m in depth. Using special extenders in sand and loam soils the borehole even may be deeper. For rotation of drills, a 4 AG petrol engine was used. A tripod lift winch (with lift force of 320 kg) was used for lifting the drills.

The studied river basins were mapped for even network of boreholes. The boreholes were spaced 10 m perpendicularly to the bank. The first borehole was located in the river bank and followed by two intermediate boreholes and the last borehole outside the water barrier zone (Fig 1).

For determining the water quality, the samples were taken from the topsoil (for determining the background), from the subsoil layer and from the aeration zone at 1 m intervals down till the depression zone. The following hydrochemical parameters were analysed: biogenic materials (ammonium, nitrates, nitrites and phosphates), ph and the content of oxygen.

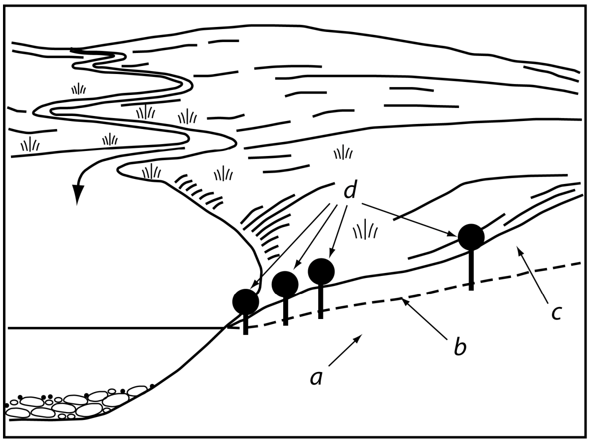


**Fig 1.** Scheme of boreholes places (a – groundwater zone, b – groundwater table, c – aeration zona, d – places of lisimetric boreholes)

The water for rapid performance of environmental tests using portable photometer Hanna HI83206 was expressed out by a special soil press from deposits lifted up by drill vanes. The soil press constructed by A. Litvinaitis is designed for extraction of moisture from soil. Later on, the water quality was evaluated by chemical analysis methods. The gravitational and capillary water from the deposits was extracted by a hydraulic press weighing 30 t (the pressure in the cylinder reached 58.5 MPa).

Water samples for laboratory analysis also were collected from lysimetric boreholes. The mouths of the boreholes were mounted in such a way as to prevent access of incidental pollutants into the boreholes (Fig 2). The mouths of the boreholes were covered with special mantles resistant to mechanical impacts. The borehole number and contact data of owners were written on the mantels. Gravitational forces pushed the water flow in the direction of smaller pressure. The water was collected in filtrate reservoirs spaced in the boreholes every one metre till the groundwater table. The impermeable layers under the reservoirs limited the possibility of water percolation into deeper layers. Each reservoir had 20 mm thick filters with gravel filling mounted above. The size of the filling grains depended on the granulometric composition of deposits and determined interlayer coefficient (Groundwater… 1999) at a ratio 7/15.

$$E = \frac{D_{80\,filler}}{D_{80\,sedment}} \qquad (1)$$

The parts of the boreholes above the mouth and the filter were filled by deposits lifted during the drilling process. The reservoirs were connected with the earth surface by PVC tubes 4 mm in diameter. They performed two functions: filtrate sampling and reducing pressure in reservoirs.

A sandy area undisturbed by human economic activity on the Žeimena River bank 1 km above the Jusinė River (Vilnius District) was chosen for field experiments. The filtrate for laboratory examination was taken in autumn. Before sampling, the reservoirs of lysimetric boreholes were emptied and samples of new filtrate were taken. The experiment was carried out in the summer–autumn period of 2010.

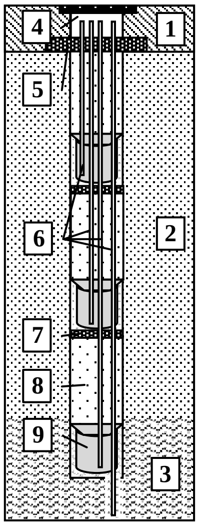


**Fig 2**. Principle scheme of lizimetric borehole (1 – soil layer, 2 – zone of aeration, 3 – groundwater layer, 4 – pipes and piezometer chamber with cover, 5 – insulating cover, 6 – pipes and piezometre, 7 – insolatin layer, 8 – destroed sediments laye, 9 – reservoir with cather and cover)

## 3. Results and discussion.

In 1998–2010, the infiltration conditions and dynamics related with climate oscillations were investigated in the basins of 11 small Neris River tributaries (Fig 3). The influence of the annual amount of precipitation and one long intensive rainfall on formation of water supplies was evaluated. During the investigation, the climate data from the Vilnius meteorological station, lithological, soil and topographic maps and digital databases were used.

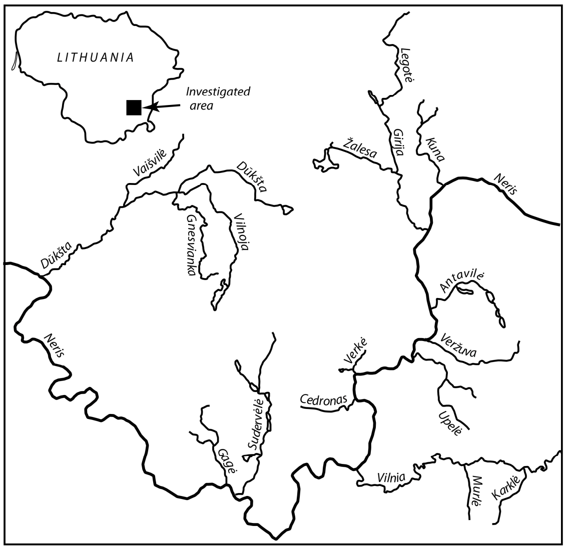


**Fig 3.** Investigated small rivers

The investigation showed that in the small river basins from 0.5 to 3 million $m^3$ of water annually merge into the groundwater discharge (Table 1). The amounts of water are closely linked with basin size, type of deposits, morphological indices of the surface and land use structure (Table 2).

The most favourable natural conditions for direct surface runoff are characteristic of all observed small river valleys and sub-valleys with rugged relief (lower reaches of Žalesa, Kuna and Verknė). The most intensive surface evaporation takes place in agrarian territories (middle reaches of Žalesa and Kuna Rivers). The weakest evaporation takes place in the forested Antavilė and Veržuva basins.

Lysimetric boreholes were installed in a sandy area undisturbed by human economic activity on the Žeimena River bank 1 km upstream the Jusinė River (Vilnius District). The boreholes were spaced perpendicularly to the bank (Table 3). The analysed hydrochemical parameters included: ph, oxygen and biogenic materials (ammonium, nitrates, nitrites and phosphates).

**Table 1.** Phreatic water amount in small tributaries catchments of the Neris River

| River | Catchment area, km² | Annual amount, m³ | Ultimate rainfall amount, m³ |
|---|---|---|---|
| Gnesvianka | 8.87 | 2 570 000 | 97 800 |
| Cedronas | 7.26 | 902 000 | 34 000 |
| Karklė | 9.20 | 3 000 000 | 14 000 |
| Legotė | 10.6 | 3 540 000 | 11 000 |
| Gagė | 6.16 | 1 780 000 | 68 000 |
| Vaišvilė | 10.75 | 3 000 000 | 100 000 |
| Vilnoja | 8.14 | 2 350 000 | 75 000 |
| Kuna | 14.03 | 7 830 000 | 109 500 |
| Murlė | 8.40 | 580 000 | 83 000 |
| Girija | 11.12 | 1 960 000 | 59 000 |
| Upelė (Kairėnė) | 9.22 | 1 880 000 | 71 000 |
| Salotė | 8.50 | 191 000 | 31 000 |
| Antavilė | 6.88 | 3 990 000 | 20 000 |
| Veržuva | 18.30 | 10 614 000 | 58 000 |
| Verkė | 10.7 | 9 800 000 | 39 000 |

**Table 2.** Lithological and land using structure in small tributaries catchments of the Neris River (%)

| River | Sediments | | | | | Land using | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | sand | sandy loam | loam | peat | clay | forests | grassland | arable | urbanize territories | water |
| Gnesvianka | 10 | 24 | 31 | 12 | 23 | 14 | 46 | 36 | 3 | 1 |
| Cedronas | 45 | - | 65 | - | - | 25 | 12 | - | 62 | 1 |
| Karklė | 32 | - | 68 | - | - | 16 | 70 | 9 | 5 | - |
| Legotė | 8 | 10 | 52 | 12 | 18 | 21 | 30 | 45 | 5 | - |
| Gagė | 81 | 11 | - | 8 | - | 25 | 30 | 37 | 8 | 1 |
| Vaišvilė | 11 | 16 | 69 | 4 | - | 7 | 82 | 6 | 2 | 1 |
| Vilnoja | 39 | 6 | 51 | 4 | - | 25 | 70 | 4 | 1 | 1 |
| Kuna | 5 | - | 55 | - | 40 | 55 | 30 | 15 | 5 | - |
| Murlė | 3 | 26 | 58 | 11 | 2 | 13 | 49 | 14 | 24 | - |
| Girija | 3 | 63 | 19 | 10 | 5 | 27 | 41 | 31 | 1 | - |
| Upelė (Kairėnė) | 80 | - | - | 20 | - | 44 | 16 | 24 | 24 | 1 |
| Salotė | 84 | 12 | - | 4 | - | 32 | 38 | 11 | 18 | 1 |
| Antavilė | 82 | 6 | - | 12 | - | 48 | 14 | 12 | 22 | 4 |
| Veržuva | 79 | 9 | - | 12 | - | 52 | 16 | 7 | 24 | 1 |
| Verkė | 46 | 13 | 23 | 18 | - | 44 | 12 | 2 | 38 | 4 |

The ph of infiltrate and groundwater in all layers remained stable throughout the investigation period. The concentrations of dissolved oxygen ranged depending on the depth: from 9.9 mg/l in the upper layers to 8.3 mg/l in the upper groundwater layer. The concentrations of oxy gen increased after rainfalls. The concentrations of ammonium compounds in the infiltrated evenly changed with depth: from 1.8 mg/l in the soil water and in the subsoil to 0.5 mg/l in the groundwater. A 10 % increase in the concentration of ammonium compounds was observed in all lysimetric boreholes at a depth of 3–4 m.

**Table 3.** Parameters of lizimetric bore holes

| Distance from bank, m | Ground-water table deep, m | Changes of groundwater table deep in observation period, m | Amount of reservoirs |
|---|---|---|---|
| 2 | 0.5 | 0.15 | 1 |
| 10 | 2.5 | 0.15 | 2 |
| 20 | 4.5 | 0.20 | 4 |
| 40 | 5.0 | 0.18 | 5 |
| 200 | 6.5 | 0.15 | 6 |

The concentrations of nitrogen compounds in the infiltrate showed no extreme values over the whole section of aeration zone. Their temporal and depth variations ranged between 0.4 and 6.2 mg/l. The higher concentrations (up to 7 mg/l) only were observed closer to the surface at a depth less than 1 m outside the boundaries of the barrier zone.

The concentrations of nitrates were higher in the groundwater. The higher values of nitrogen compounds in the infiltrate and in the groundwater can be accounted for not only by agricultural activities but also by high concentrations of nitrogen compounds in the rainfall water. The concentration of nitrates in some rainwater samples amounted to 8 mg/l and the concentration of ammonium compounds 6 mg/l.

The observation results showed that even without direct anthropogenic loads, the impact of polluted environment on the infiltrated water and groundwater is appreciable. Yet determining the migration patterns of pollutants requires a longer observation time span and a greater number of observation points in different natural environments.

## 4. Conclusions

The most intensive infiltration of rainfall water takes place in the Antavilė, Veržuva, Kairėnė and Gagė cathchments with dominant glaciofluvial coarse-grained deposit.

The changes of direct surface runoff and infiltration conditions were mainly predetermined by the changes of land use structure in the investigated river basins and especially by the expansion of the urbanized areas in the last 30 years. The most marked changes have occurred in the basins of Verkė and Cedronas rivers. Artificial surfaces in the Verkė basin (streets, footpaths, buildings, approaches, and yards of individual houses) occupy up to 38 %, in the Cedronas basin 62 % of the basin area.

The changes of water budget were entailed by artificial transformation of basin configuration (Antavilė and Veržuva rivers) and hydrotechnical constructions in the Upelė catchment.

Lysimetric boreholes as observation points are most suitable for the described type of investigations as they least contribute to deformations of the natural state of deposits and groundwater, offer identical observation conditions independent of the depth and are easily manually installed.

Analysis of hydrochemical indices of rainfall water, infiltrated water and groundwater showed that anthropogenic chemization and atmospheric pollution produce a substantial impact on infiltrate and groundwater. Meanwhile determining the migration patterns of pollutants requires a longer observation time span and a greater number of observation points in different natural environments.

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