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Comparison of infiltration water budget in small rivers catchment of Western and North Lithuania

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Abstract

The atmospheric water infiltrating the underground predetermines the water budget of small rivers catchment, groundwater and stratum water supplies and groundwater safe yield. Climate components (precipitation, evaporation, vegetation structure) fluctuation cycles affect the natural fluctuations of groundwater horizon, its amount and partially quality. Surface sediments composition, decided the velocities and amounts of infiltrated groundwater. Groundwater exploitation, usually responsible for reduction of groundwater supplies and is another important factor of groundwater dynamics in a horizon. Finally groundwater amount decided of the surface water regime sources. The goal of the present research is to evaluate the groundwater supplies in West and East Žemaičiai Plateau and Žiemgala Lowland. For evaluation used data of climate factors, sediments distribution, land using. Influence of different factor calculating was based on Lithuania Geographical Information Infrastructure date and ArcGIS 10.1 programme using. Research results show that there are direct link between precipitation amount, surface sediments and relief dissection (relief morphometric parameters), which decided surface runoff.

Keywords: river catchment; precipitation; infiltration; retention; interception; relief dissection.

1. Introduction

The atmospheric water entering the underground predetermines the water budget of large and small rivers, groundwater and laminated water supplies and groundwater safe yield. Climate fluctuation cycles affect the natural fluctuations of groundwater horizon. Groundwater exploitation, usually responsible for reduction of groundwater supplies, is another important factor of groundwater dynamics in a horizon [1–4]. Preservation of groundwater supplies and improvement of its quality are the main environmental problems in setlements and in country areas. Due to increasing rates of pollution, surface bodies of water are unable to satisfy the recreational and aesthetic demands of the population. Moreover, processes deteriorating the groundwater quality are taking place in small rivers catchments. Their groundwater and interstitial water represent the potable and technological water supplies.

Erosion activity of rainfall waters is another important aspect in the context of deteriorating groundwater quality. Blocks of flats and individual houses often are built in the wrong places: slopes of hills and valleys. Steep and long slopes are responsible for concentration of surface water flows during rainfalls and development of linear erosion forms [5–7].

The goal of the present study is to systematize the methods for preliminary evaluation of water supplies based on analysis of atmospheric water amounts, surface deposits and distribution patterns of land use types and landscape elements.

The evaluation of water catchments and water infiltration has been performed in Western and Northern Lithuania. The minor rivers catchments have been analysed. They are located in Western and Eastern Žemaičiai plateau as well as in Mūša – Nemunėlis and Žiemgala lowlands (Fig. 1). The goal of the article is evaluate water supplies amount, which are determine by precipitation, surface dissection, sediments and land using.

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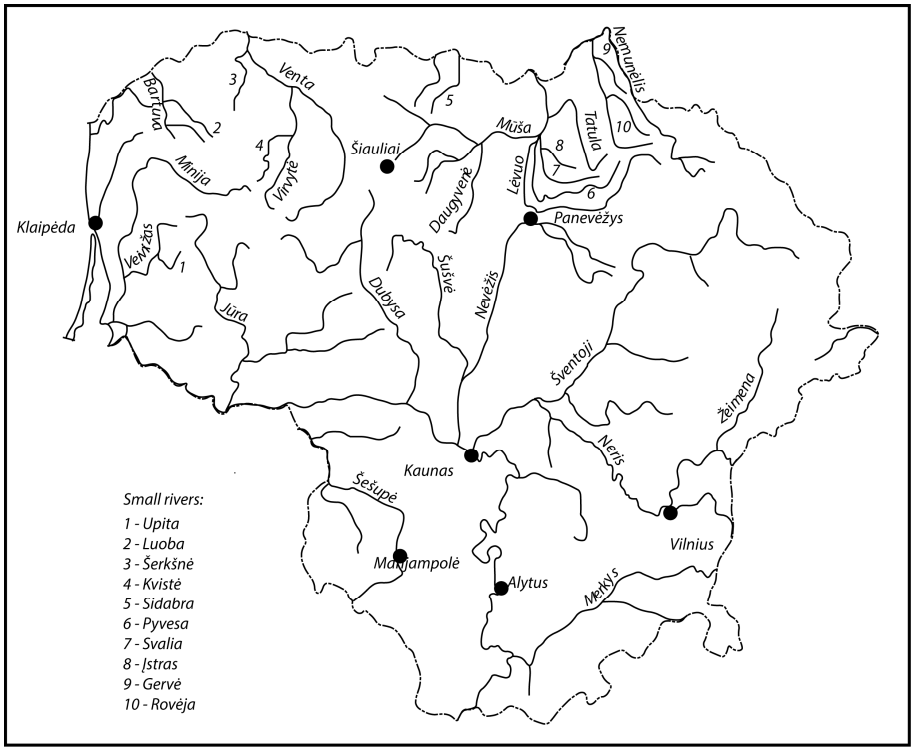

Fig. 1. Investigated rivers catchment

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.

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 [8].

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 down-slope runoff of rainfall water and reduces its infiltration.

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 [9–11].

3. Evaluation of precipitation and water inflow

Precipitation in river basins is evaluated in a few aspects: amount, duration, intensity and frequency. Lack of local observation data is the major problem in this context. Interpolation-extrapolation of the data from a few closest meteorological stations is one of the possible solutions.

The intensity of rainfalls is one of the major indices [12], [13]. Yet the data on the intensity of rainfalls are provided only by meteorological stations. The interpolation-extrapolation method for evaluation of rainfall intensity is not ultimately reliable whereas establishment of additional observation posts (rain gauges) is time-consumptive and expensive. Besides, when the observation time is short (one year), the network of rain gauges in a catchment must be rather dense [14].

Effective precipitation represents one more important index for evaluation of water balance in river catchments. Effective precipitation is the amount of precipitation that is actually added and stored in the surface deposits. Less than 5 mm of rainfall is not considered effective as this amount of precipitation actually would not soak into the ground. It would likely evaporate or be transpired by vegetation. Moreover, only 75% of slightly more than 5 mm of rainfall are considered effective.

Retention is one of decisive factors of slow distribution of rainfall water on the ground. Vegetation is a sort of barrier for precipitation to reach the ground directly. The amount of precipitation retained by plants depend the type of vegetation: the multi-storey vegetation (forests) act as a “leaky umbrella”. It retains rainfall water for some time and then lets it concentrate. The higher plants especially strongly modify the intensity and distribution of precipitation depending on: their leaf type (coniferous or deciduous), leaf parameters and their distribution [15]. Besides, in the middle latitudes, large amounts of precipitation are preserved as snow in cold season.

The constituent of interception is important in the precipitation balance. The term interception is applied to precipitation temporarily retained by trees, shrubs or grasses before reaching the ground. In coniferous forests, interception accounts for 25–35% of the annual precipitation, in deciduous forests and shrubberies for 15–25% and in meadows and cornfields for 11–19%.

Evaporation rates from the small river catchments require individual field investigations. Using the data from meteorological stations, the long-term evaporation values can be taken as a constant and eliminated from calculations. Evaluation of groundwater quantity in the river catchments is based on evaluation of three components: precipitation, evaporation and discharge.

The values of these three outflow components are obtained by proceeding long term observations in water measurement and meteorology stations. However, the network of water measurement and meteorology stations is rare. This determine the situation that water balance and outflow surface – subterranean outflow are evaluated by invoking the indirect measurements.

For evaluation of water resources in river catchments, it is expedient to use blocks of empirical formulae defining the quantitative values of precipitation, evaporation, infiltration and surface runoff. It is important that the calculations were based on the coefficients reflecting the local or regional conditions [16], [17].

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. The West Lithuanian distinguished most precipitation amount and it's determined water infiltration and groundwater amount. North Lithuania river catchments are in precipitation shadow and water infiltration is substantially lesser (Table 1).

Table 1. Infiltration water amount in North and West Lithuania rivers.

River	Region	Catchment area, km²	Annual amount, m³	Ultimate rainfall amount, m³
Tatula	North Lithuania	453.4	31229937	27174101
Pyvesa	North Lithuania	501.6	30550208	22487332
Daugyvenė	North Lithuania	488.0	36140475	32940000
Sidabra	North Lithuania	144.0	10629551	9688235
Gervė	North Lithuania	43.8	3255898	2967567
Įstras	North Lithuania	119.0	8716231	7944353
Svalia	North Lithuania	72.0	2461231	4846055
Rovėja	North Lithuania	216.0	14865450	12690305
Šerkšnė	West Lithuania	285.2	6666300	5844600
Luoba	West Lithuania	353.9	17563300	5989800
Kvistė	West Lithuania	102.0	15616098	8738510
Upita	West Lithuania	50.0	18261723	3314307

4. Geological and geomorphological features of investigated rivers catchments

Surface sediments cover is one of the most important factors influencing rivers catchments infiltration specifications. The Western and Eastern Žemaičiai plateau surface has been covered by continuous moraine sediment lugs determined by the deglaciation processes happening 15 000–11 000 years ago. During the active melting of ice in thermo-glacial glacier edge environment ("dead ice" zone) the rough gravel and pebble sediments have been gathering. Subsequently they have been covered by alongside-glacier catchments sand and clay sediments. This type of deglaciation has been happening in Western Žemaičiai height slope and Western part of plateau (Fig. 2). Melting period waters have flowed along with melting glacier edge to the South where in Western Žemaičiai plateau southern part have formed thicker sand layers. This fact determined the layer of varicoloured sediments in Western Žemaičiai plateau surface. This layer distinguishes with a variety of infiltration features.

In the Eastern Žemaičiai plateau deglaciation processes have been happening almost identically. Glacier melting waters have flowed towards south along with eastern plateau edge; by this process, it has formed several minor fluvioglacial deltas that contemporary appear to exist along with Dubysa valley. Sediment layers in this area characterise with good infiltration features as well.

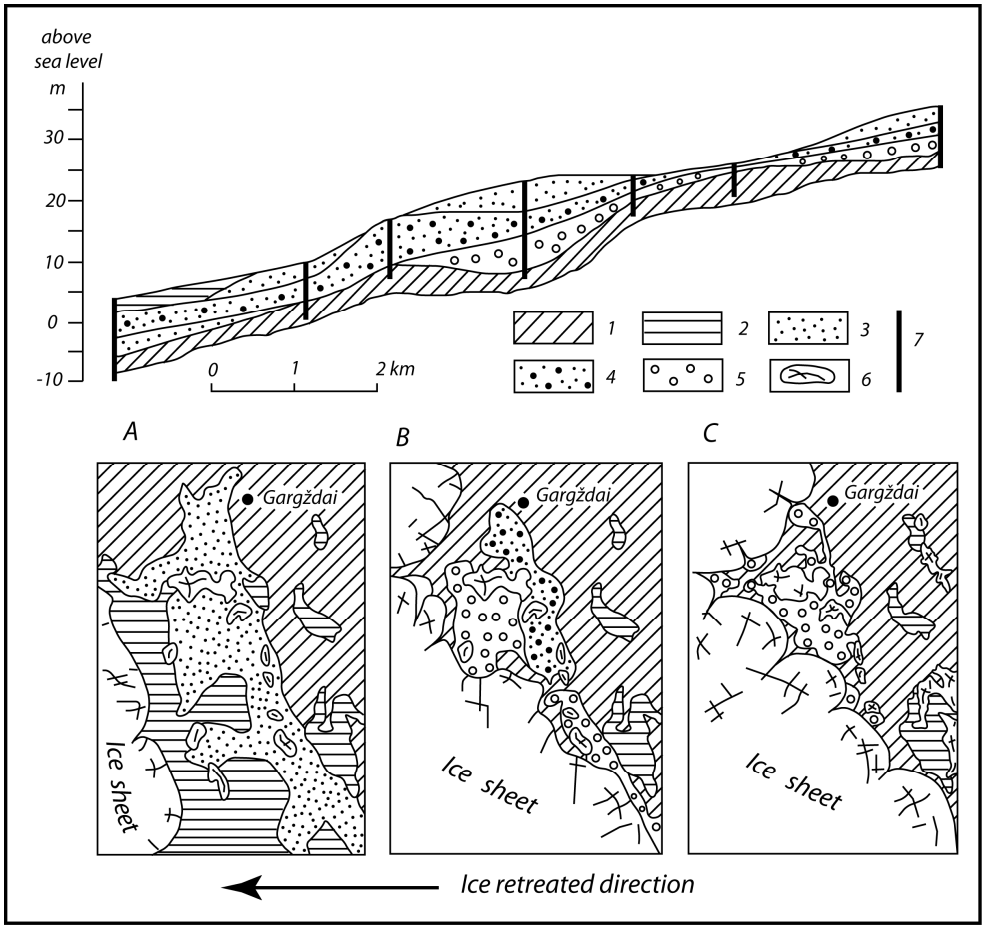

Fig. 2. Deglaciation processes in West Žemaičiai Plateau: 1 – morainic loam; 2 – glaciolacustrine clay; 3 – sand; 4 – sand and gravel; 5 – pebble; 6 – melting ice; 7 – boreholes

Deglaciation process was quite similar in Northern Lithuania as well. Fundamental difference was the fact that the glacier melting waters have ponded at the edge of the glacier. Sufficiently thick layer of clay has formed in the deep glaciolacustrine catchments (Fig. 3). This type of glaciolacustrine clay cover determines the poor infiltration of the precipitation and marginal subterranean outflow.

Several surface water infiltration areas determined by surface dissolution and surface sediments could be distinguished in Western and Northern Lithuania:

1. Divide area of Žemaičiai Upland distinguishing for complicated disordered surface and wide range of sediments diversity.

2. The area of Western and Eastern Žemaičiai Plateaus as well as Venta Plain; it characterizes as smoother (wavy) surface and dominating till sediments.

3. Žiemgala Lowland area where plain and few sloping clayey plains dominate.

Evaporation rates from the small river catchments require individual field investigations. Using the data from meteorological stations, the long-term evaporation values can be taken as a constant and eliminated from calculations.

5. Relief dissection and land use structure

Relief dissection is evaluated using large-scale (1:10 000) topographic maps or digital data bases. Surface inclination is one of the main indices of relief dissection affecting infiltration rates. Even a small slope angle conditions a rapid flow of precipitation water down the slope. Especially large losses of precipitation water occur in the areas with an artificial surface (concrete, asphalt). The rainfall water may accumulate at the bottoms of slopes what are the cases during intensive rainfalls and spring thaws. There is a high probability that the larger part of the down-slope rainfall water flows will be carried away by a direct surface runoff and only some of it will soak the surface deposits and enter the groundwater discharge. This runoff models is characteristic of the small river catchments with glaciolacustrine and basal till deposits of Middle and Coastal Lithuanian Lowlands. Meanwhile, in the Žemaičiai Upland and East Žemaičiai Plateau distinguished for coarser deposits, infiltration of rainfall water is more intensive. In these territories, the rainfall water is carried away by direct surface runoff only in very rare cases (intensive summer rainfalls).

Land use structure is evaluated using topographic maps at a scale 1:10 000 and digital data bases at a scale 1:50 000. Based on them, natural and anthropogenic types of land use are distinguished: ploughed fields, meadows and pastures, forests, homestead plots of lands, compact plots of land of individual houses and collective gardens, quarters of the blocks

of flats, industrial buildings, roads and other artificial water-impermeable surfaces. These types of land use are distinguished by different infiltration conditions (Table 1).

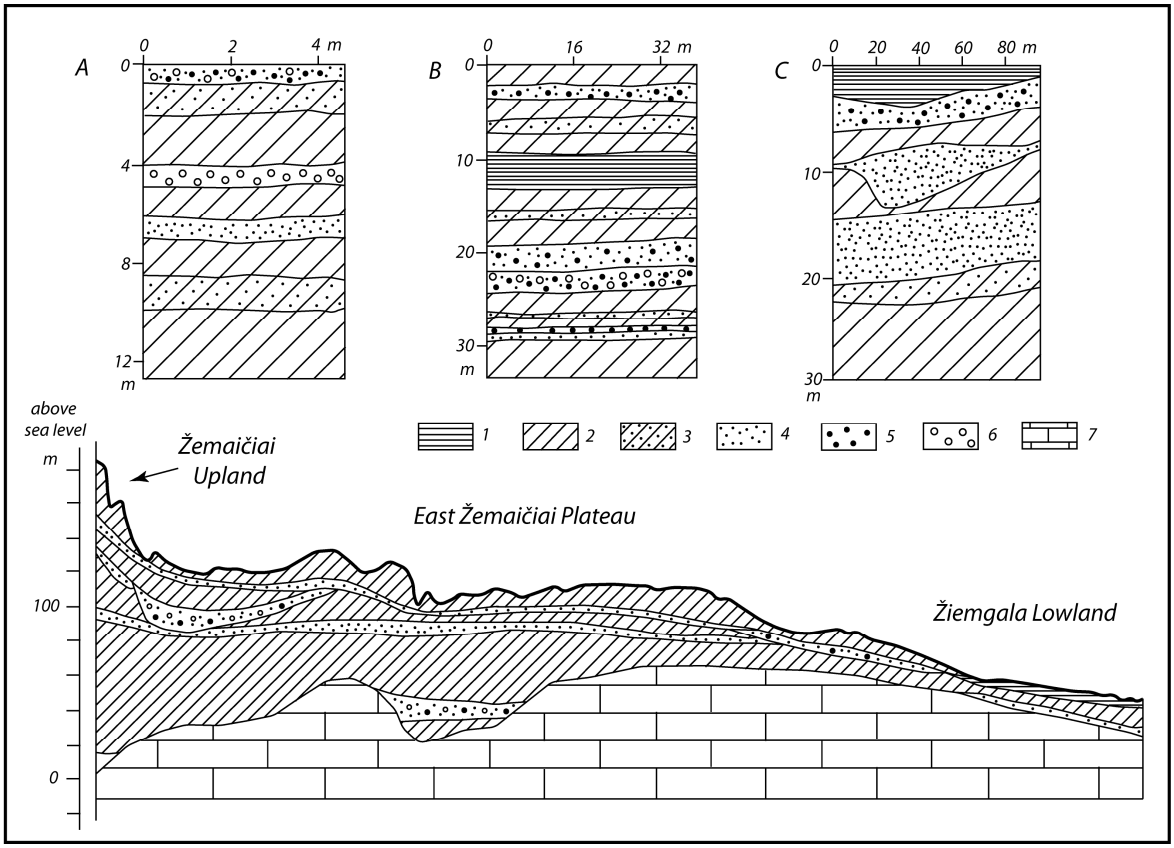

Fig. 3. Deglaciation process in East Žemaičiai Plateau and Žiemgala Lowland and outcrop sediments: 1 – glaciolacustrine clay; 2 – morainic loam; 3 – sandy loam; 4 – sand; 5 – gravel; 6 – pebble; 7 – limestone

Comparison of water infiltration condition in small rivers catchment of West and North Lithuania show that major diversity of sediments in West Lithuania create better condition for groundwater accumulation. In sandy areas the modules of infiltration arise to 5–7 l/s km² and in glaciolacustrine clay and morainic loam areas – only 2–4 l/s km². In North Lithuania groundwater infiltration conditions are worse. In ground moraine plains and edge moraine chains modules of water infiltration increase to 3–4 l/s km² and in glaciolacustrine plains – only 2–3 l/s km². In boggy areas modules of water infiltration are sub-zero – in more cases (–1) or (–2) l/s km².

Table 1. Surface sediments and land using structure in North and West Lithuania river catchments (%).

River	Sediments					Land using				
	sand	sandy loam	loam	peat	clay	forests	grassland	arable	urbanize territories	water
Tatula	6	31	61	1	1	17	1	81	2	0
Pyvesa	7	71	8	13	1	34	6	54	4	2
Daugyvenė	3	3	89	2	3	24	2	67	6	1
Sidabra	2	5	91	2	0	12	4	78	6	0
Gervė	2	2	16	9	71	51	8	40	1	0
Įstras	46	8	23	14	9	27	14	54	5	0
Svalia	20	15	20	5	40	25	11	60	3	0
Rovėja	19	27	33	16	5	31	13	50	6	0
Šerkšnė	2	61	31	6	0	27	6	66	1	2
Luoba	4	31	49	3	13	35	2	52	11	0
Kvistė	8	4	84	2	2	12	3	81	3	1
Upita	7	31	60	2	0	21	4	73	2	0

6. Conclusions

The catchments of West Lithuania rivers distinguish miscellaneous surface sediments. In this region predominate sandy loam and loam surface sediments. In some catchments sand (Kvistė, Upita) and clay (Luoba) widely outspread. In North Lithuania widely common loam, but in some catchment large area was covered by sand (Įstras, Svalia, Rovėja), sandy loam, clay and peat. Sediments varieties create different condition of water infiltration.

Land using structure in West and North Lithuania region are different too. In both regions predominate arable lands, but in North Lithuania widely prevalent grassland and forest (Gervė catchment). Essentially influence on precipitation infiltration in different river catchments are land using. In arable areas infiltration are in two time intensively than in forests and one and a half than in grassland.

In West Lithuania annual infiltration of precipitation is more intensive then in North Lithuania. Complex factors determine this phenomenon: abundant precipitation, better infiltration, dissection of surface. Average annual water supply module in North Lithuania is about 6 l/s km² and in West Lithuania it increased to more than 7 l/s km².

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