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NATURAL AND ARTIFICIAL RECHARGE ASSESSMENT IN URBAN ENVIRONMENT

Summary. The methodology of assessment of rainfall-runoff conditions in urban areas is presented. The assessment is based on combination of hydrological methods, numerical simulations and data processing and visualization using geoinformation technologies. Natural water balance components are simulated using model of groundwater flow through unsaturated zone (UNSAT Suite system), verified by saturated flow model (MODFLOW).

OSZACOWANIE NATURALNYCH I ANTROPOGENICZNYCH SKŁADOWYCH ZASILANIA W ŚRODOWISKU MIEJSKIM

Streszczenie. Metodyka oszacowania odpływu wód opadowych na terenach zurbanizowanych. Obliczenia opierają się na kombinacji klasycznych metod hydrologicznych, współczesnych metod symulacji numerycznej oraz wizualizacji z zastosowaniem technologii geoinformatycznych. Składowe naturalne bilansu wodnego wydzielonych stref symulowane są w modelu przepływu wód podziemnych przez strefę aeracji (UNSAT Suite), weryfikowane w modelu przepływu przez strefę saturacji (MODFLOW).

1. Problem definition

Urbanization has a great impact on the original rainfall – runoff characteristics of the land surface. The urban and industrial construction and extensive adaptations in these areas (built-up sites, roads and other paved surfaces) result in the changes of rainfall-runoff characteristics and decreased natural recharge to groundwater. Increased surface runoff and subsequent quick reaction of surface water streams (enhanced by contribution of water collected by storm water

network) can cause local flood problems in case of heavy precipitation events. On the other hand, artificial recharge due to leakages from water supply lines and from sewage systems can become a significant component of a groundwater balance in the urbanized areas.

2. Research project and its goals

The research project described by this article was focused on the development of methodology of the water balance quantification in the areas influenced by urbanization and industrial activities resulting in landcover changes.

The methodology was tested in the city of Ostrava, in its part located in the valley terrace of the Odra River. The average yearly precipitation reaches 690 mm there; average yearly temperature is slightly above 7°C. The size of the study area was approximately 24 km^2. One of the reasons for the pilot study area selection was availability of unusually deep information on its geology and hydrogeology. Under these circumstances, it was possible to compare the present water budget derived by the developed methodology with the original one, existing there before urbanization, which was derived by a model simulation.

The project work was focused on the following tasks:

- Quantification of retention capacity of the unsaturated zone,
- Specification of the infiltration ratio in dependence on rainfall intensity and its duration and in dependence on landcover type (coefficient of infiltration regression),
- Specification of the hydrologic balance in the industrialized and urbanized areas, including contribution from water supply network,
- Influence of urbanization on recharge – runoff ratio.

3. Methodological approach

The following approach was used to achieve the project goals:

1) Regime observations of groundwater head changes on approximately 30 monitoring wells were performed. Three new purpose-built observation points, on which a continuous record of hydrologic and basic meteorological parameters was carried out, supplemented the net of existing wells with long-term observation records.
2) The pilot are was divided into classified infiltration zones with exploitation of GIS tools, on the base of these criteria:

- Landcover type e.g. pure soil, grass, forest, built-up sites, paved areas etc. (with exploitation of aerial photos and cadastral plans),
- Geomorphologic analysis (processing of the digital terrain model),
- Analysis of lithology of the unsaturated zone and the first aquifer including specification of their hydropedologic characteristics. Their spatial distribution was derived with exploitation of existing extensive geological and hydrogeological database from the study area (more than 2000 boreholes).

The combinations of parameters (type of landcover, soil properties, terrain slope etc.) were classified in map using GIS and quasihomogeneous polygons were generated.

3) Quantification of water balance components for all types of specified infiltration zones was done by simulation of flow in the unsaturated zone (program package UNSAT Suite). Furthermore input of leakage from water supply network was calculated and added as a component of recharge. As there was not possible to quantify input from sewage network, the areas where sewage network acts as a source and as a sink were delimited.
4) Resultant value of recharge (natural and artificial) was verified by previously calibrated model of flow in the saturated zone. The area under study represents the case when the rate of recharge is controlled by the amount of water that the aquifer system can transmit to the discharge area [2]. This transmission is controlled by the permeability of the geologic framework. The permeability of aquifers was a calibrated parameter in the previous stage of modeling studies. Groundwater flow model was calibrated on more than 200 calibration targets with mean absolute error in heads of 20 cm.
5) Development of the complete hydrological water budget of the study area and specification of recharge - runoff ratio variations in dependence on landcover changes.

4. Achieved Results

A development of a replicable methodology for the assessment of rainfall-runoff characteristics in the industrial and urbanized areas is a gain of the project on general level. The methodology is based on the combination of classical methods of hydrology with modern methods of mathematical simulations and with exploitation of GIS tools for data processing and visualization.

Unfortunately, regime observations had not fulfilled expectations and could not be fully exploited because of extreme precipitation deficit during the whole time available for the project.

As for the study area itself, the project results represent the first quantification of the hydrologic balance equation. Surface runoff reaches 10,4%, groundwater recharge is 18%, evapotranspiration reaches 70,4% and storage changes represent 1,2% of the total budget. Average natural recharge for the whole area under study is 140 mm per year. Water balance components appertaining to different infiltration zones were simulated by HELP model (Hydrologic Evaluation of Landfill Performance). The figure 1 presents the water balance calculation for the typical soil profile with vegetation cover and terrain slope below 12%.

Groundwater recharge to the first aquifer is increased by 10% (15 mm per year) due to artificial recharge from the water supply network. This quantification was based on the measurements supplied by the network operator in the area with relatively low density of water supply network. Recalculation for typical urban environment proved that artificial recharge could be at least six times higher than above-given value.

The distribution of both components of recharge (natural and artificial) was set up in the area (fig. 2) and verified by saturated flow model.

The type of landcover is the primary factor controlling the ratio between a surface runoff and groundwater recharge in industrial and urbanized areas. GIS tools were used for simulation of impact of various land cover changes in the area. An attention was paid especially to specification of dependence on ratio of built-up (sealed) and natural areas with different vegetation cover.

An industry prevails in the study area. The density of buildings is lower there in comparison with typically urbanized districts of the town. According to simulation results, the runoff is 5% higher in comparison with natural conditions, under which there would be no buildings and paved surfaces at all. It represents 547 660 m^3 of water in a yearly balance. It must be kept in mind that large portion of this increased runoff is concentrated to short periods of heavy precipitation events and than may cause real practical problems.

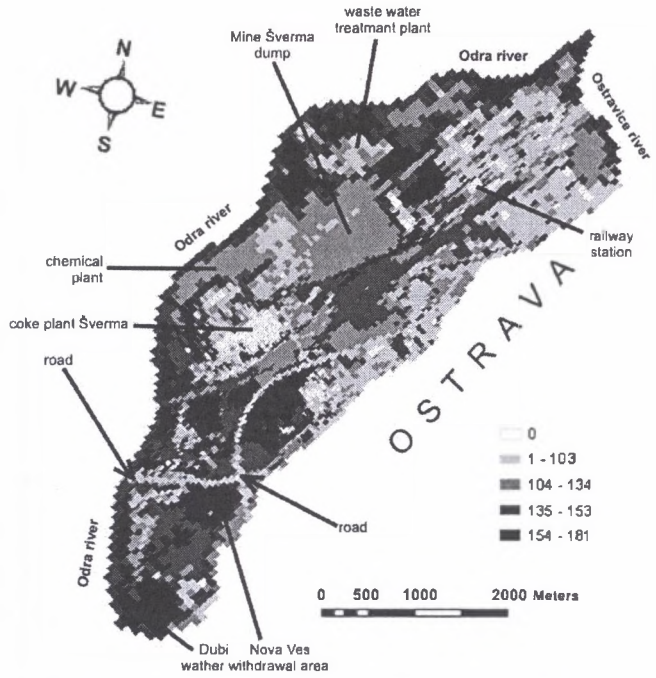

Fig. 1. Distribution of groundwater recharge (mm/year) in the area of interest
Rys.1. Zróżnicowanie zasilania wód podziemnych (mm/rok) w badanym obszarze

The figure 3 presents results of simulation - dependence of surface runoff on the density of urbanization (expressed as a relative density of built-up cover – areas with buildings and paved surfaces).

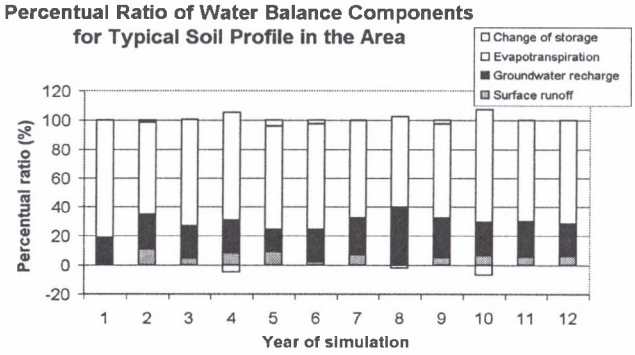

Fig. 2. Percentual ratio of water balance components for typical soil profile in the area
Rys.2. Procentowy udział składowych bilansu hydrologicznego dla typowego profilu na badanym obszarze

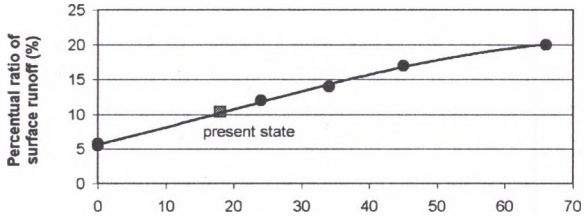

Fig. 3. Dependence of surface runoff on density of urbanization
Rys.3. Zależność odpływu powierzchniowego od gęstości zabudowy

5. Conclusions

The proposed methodology based on the combination of numerical modeling and GIS analysis is applicable for the assessment of water balance in the urban and industrial areas on various levels of detail and consequently degrees of uncertainty. It can even provide rough assessment of water balance based on remote sensing data and limited geological and hydrogeological information under given climatic conditions.

The further conclusions are to be accepted as site-specific. Among the calculated components of water budget, groundwater recharge is supposed to be the most reliable one due to its verification by saturated flow model. In the tested area groundwater recharge is predominantly dependent on the landcover type. The influence of terrain slope is lower due to sufficient infiltration capacity of soil. The sensitivity of water budget components calculations on the precise description of geological profile of unsaturated zone was relatively low (due to the scale of model area). It means that with good knowledge of hydropedological characteristics of typical soil profile in the area, the estimate of thickness variations of individual layers could be in orders of meters (maximum thickness of unsaturated zone of 15 m in our case).

The comparison of our results with similar study conducted by Coldewey et al. [1], focused on the effect of urbanization on groundwater recharge, showed relatively good agreement especially in the evaluation of present state. The results differ in assessment of ratio of evaporation and surface runoff on the sealed soil (built-up sites, paved areas etc.). Our future research should be concentrated on the precision of evaporation component in the urban environment, which was potentially overestimated on the sealed area.

Acknowledgement

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