

THE STUDY OF LAND USE CHANGES AND THEIR IMPACT ON RUNOFF IN THE PUNKVA CATCHMENT

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Abstract

Use of the landscape has a high influence on the water retention capacity of the soil. Water retention is important in terms of surface runoff formation. Identification of areas with increased surface runoff leads to proposals of flood protection of a catchment. The work focuses on the evaluation of factors influencing water retention in the landscape, depending on land use, based on the assessment of runoff conditions at a site in 4 periods strategically influenced by political and economic decisions leading to fundamental changes in the landscape in terms of water retention. Years evaluated were 1954, 1971, 1996, and 2009, and the site is the Punkva catchment. The area of the entire model territory, which extends into 16 cadastral areas, is 50.18 km². The site is located in the central part of Moravia, Czech Republic.

The analysis used the existing evidence of the Czech Hydrometeorological Institute, information database on soils and aerial photos of the area. Simulation of the runoff was created in the HydroCAD model. It has been proved that the land use changes have affected the runoff. Suitable use of the landscape can reduce surface runoff from the catchment.

Keywords: runoff, flood protection, land use, catchment, water retention

Introduction

Water, soil and forest – each of these takes a significant part in the creation of the landscape. They are effective in cooperation and their mutual relations are reflected mainly in the water cycle. These components of landscape do not work in their natural form – they have been modified and controlled by human activities, mainly water and forest management as well as agriculture. Based on knowledge of mutual relations and nature's principles, we can coordinate their effects by agreed regimes; collisions can be prevented and conditions supporting favourable factors can be created. The conditions of their cooperation vary in different areas: one of the components can prevail and develop at the expense of the others in some areas while in others its significance can be diminished.

Human activity considerably changes the water regime in the landscape. The effect of a functional land use on the runoff is essential and dramatic and extensive changes of land use can have a significant impact during extreme events. Deforestation, intensive agriculture, landscape urbanization and industrialization are the changes with the greatest influence on runoff processes in the landscape.

This study of changes in land use and their effect on runoff conditions has been processed for the Punkva catchment area. The area of the catchment is 50.18 km² and it extends into 16 cadastral areas.

Materials and methods

The runoff curve number (CN) method can be used to assess the effects of various ways of catchment use, erosion prevention measures, and other changes on the surface runoff and to propose and evaluate technical erosion prevention measures. The basic input of the CN method is the rainfall. The volume of rainfall is transformed into the volume of runoff using runoff curve

numbers. The input data for the establishment of CN values included soil quality units (in Czech BPEJ). Soil quality units (SQU) represent an agronomic evaluation of sites used by agriculture based on the climate, the soil and the terrain configuration. The data for the establishment of CN values in forests came from the analysis of forest stands in the study area. Other data for the establishment of CN values were the land use in periods 1954, 1971, 1996 and 2009. The analysis of the study area with the aim to find the changes in land cover in these periods was based on aerial photography and orthophotomaps. The aerial photos were georeferenced into the coordinate system of the Unified Trigonometric Cadastral Network.

The investigation of runoff processes in the catchment also included the initial data in the form of precipitation sums and flow rates. The hydrological hydraulic model HydroCAD, in which the runoff from the catchment was modelled, used the data on rainfall when establishing the design rainfall and when deriving the intensities of calculated rainfall. The input quantity for the HydroCAD model simulation of all the researched periods was the value of two-year 24-hour precipitation sum, which is 36.5 mm for the weather station in Sloup (run by the Czech Hydrometeorological Institute). The parameters of constant intensity of calculated rain of 600 min., which enter the HydroCAD model in the form of unit hydrogram, were established using the method of reduction of daily maximum precipitation sums.

The case study also uses the vector digital terrain model 5 (DTM) created in ArcGIS, version 10, with the Spatial Analyst extension. The monitored area was divided into 16 sub-catchments, where the DTM became a basis for individual morphological features of the area, such as the hydraulic length of the catchment, the inclinations and areas of the catchment or inclinations of currents. These features were then used as input parameters for the HydroCAD model.

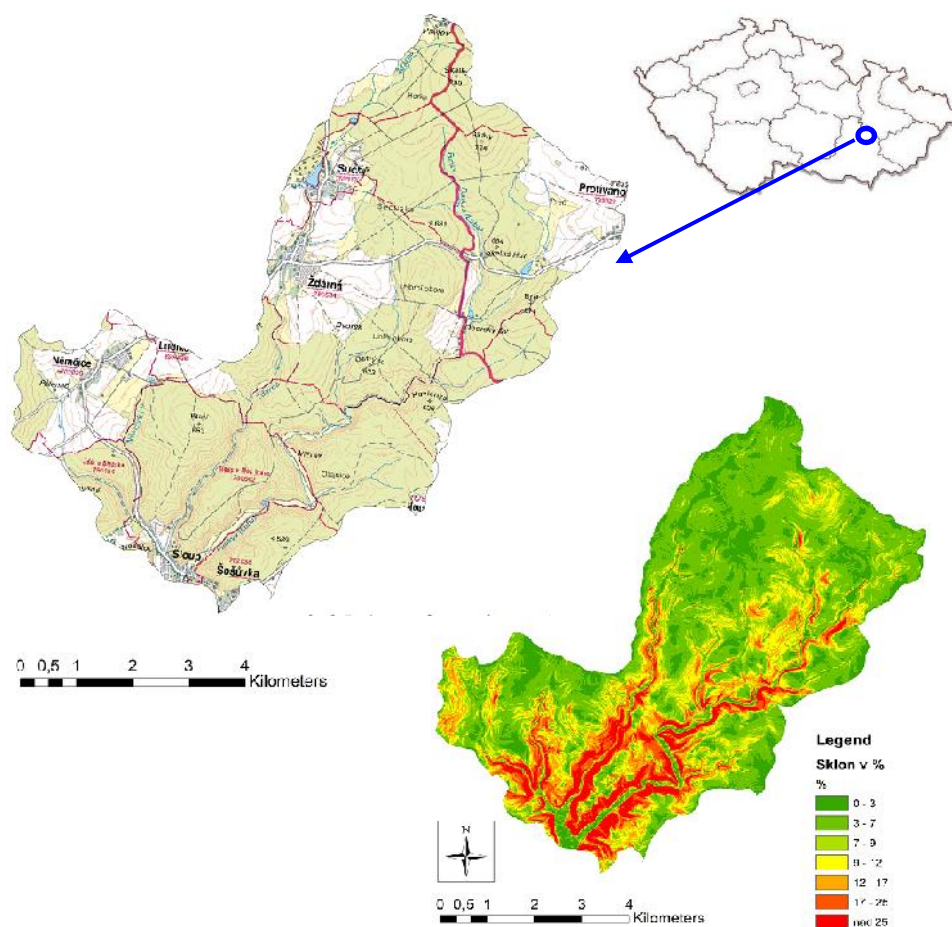


Fig.1 Study area

Results and discussion

The georeferenced aerial photos were used as data for detailed maps of the land cover in the four explored periods. The aerial photos show the development of the landscape structure and the development of the changes in land cover. They provide an idea of the shapes, sizes and layout of lands and structural elements in the landscape as well as their changes in time.

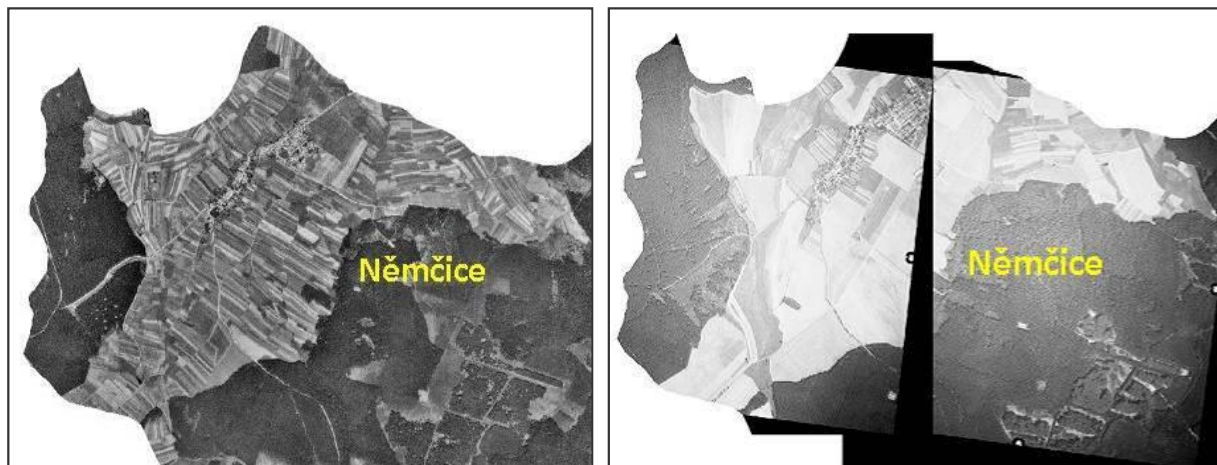


Fig.2 Examples of georeferenced aerial photos from 1954 and 1971 © CENIA, česká informační agentura životního prostředí, © VGHMÚ Dobruška

Assessment of land cover changes

Eight categories of cover were distinguished for a detailed assessment of land use: forests, permanent grassland, arable land, scattered greenery, built-up area, water surface, gardens, and orchards. The category of permanent grassland includes meadows and pastures.

Tab. 1 Assessment of land cover changes

Land category	Land area							
	1954		1971		1996		2009	
	[km ²]	[%]	[km ²]	[%]	[km ²]	[%]	[km ²]	[%]
Forests	33.87	67.51	34.34	68.57	34.37	68.52	34.64	69.05
Permanent grassland	2.77	5.53	2.66	5.30	2.93	5.85	4.87	9.72
Arable land	12.09	24.09	11.40	22.73	10.38	20.70	8.17	16.29
Scattered greenery	0.53	1.06	0.59	1.17	0.96	1.92	0.69	1.38
Built-up area	0.63	1.26	0.81	1.61	1.18	2.35	1.41	2.81
Water surface	0.08	0.16	0.10	0.20	0.116	0.23	0.119	0.24
Gardens	0.099	0.20	0.12	0.25	0.21	0.42	0.23	0.46
Orchards	0.096	0.19	0.076	0.15	0.002	0.01	0.031	0.06
total	50.18	100	50.18	100	50.18	100	50.18	100

The table shows a general trend of a steady increase in the area of forests during the explored periods 1954, 1971, 1996, and 2009. Forest stands with their 34.64 km² have a dominant position in the study area. The area of forests increased by 1.54% of the total area during the observed 55 years. The area of permanent grasslands expanded up to 9.72 % in the last years. As a consequence, the area of arable lands was reduced. It decreased from 12.09 km² in 1954 to 8.17 km² in 2009, which is an 8 % decrease. A trend similar to forest stands can be seen in the built-up areas. Their area increased from 1.26% to 2.81% between 1954 and 2009.

The proportions of crop plants in the study area in the explored periods are given in Table 2 .

Tab.2 Proportions of crop plants

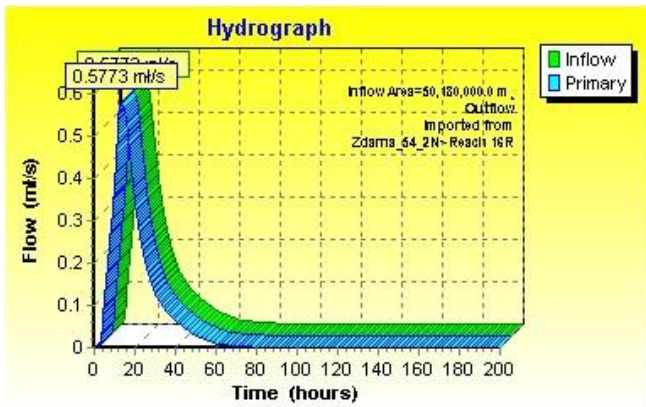
Crop plants	Area within the study area [%]			
	1954	1971	1996	2009
cereals	7.92	5.66	6.89	6.62
fodder crops	8.95	6.92	8.46	7.20
potatoes	7.22	9.23	1.46	0.05
maize	0.00	0.92	3.89	2.42
arable land in total	24.09	22.73	20.70	16.29

The table of crop plants shows that

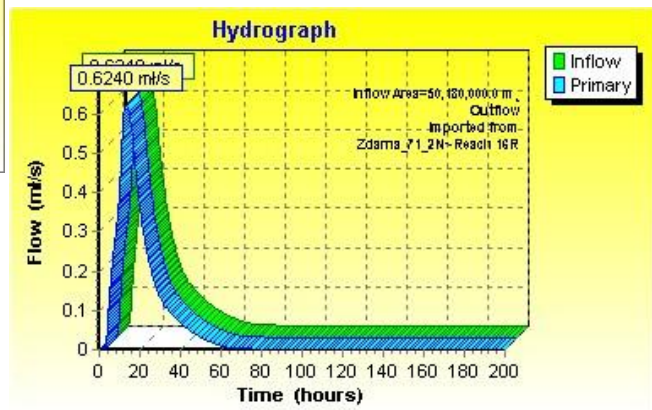
in the observed periods there is mainly a considerable change in the proportion wide-space crop plants. There has been a visible reduction in growing potatoes since the 1950s and a rise in maize since the 1970s. This has a significant impact on the runoff conditions in the study area.

HydroCAD model outputs for periods 1954, 1971, 1996, and 2009

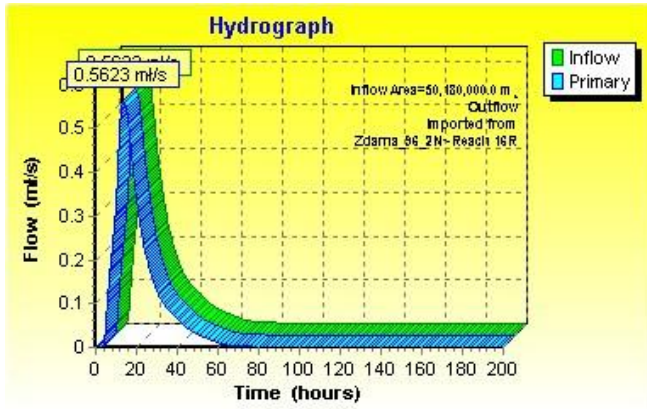
The input quantities of the model, which were variables for editing of individual periods, were the mean values of runoff curve numbers in particular sub-catchments. These values changed with the development of the changes in land cover in the given periods.



Graph 1 The result of simulation of 24-hour precipitation sum with 2- Years repetition time for 1954

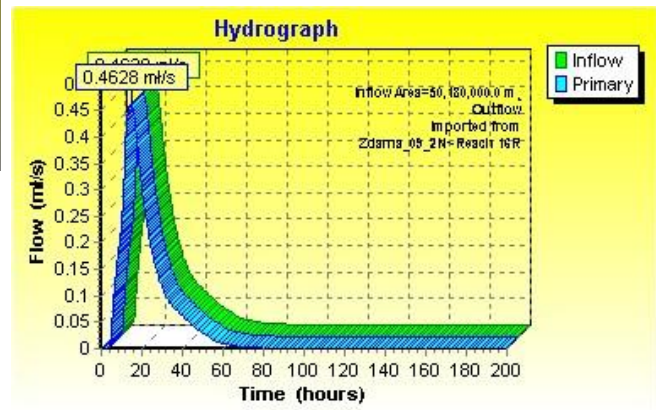


Graph 2 The result of simulation of 24-hour precipitation sum with 2-Years repetition time for 1974



Graf 4 The result of simulation of 24-hour precipitation sum with 2-Years repetition time for 2009

Graf 3 The result of simulation of 24-hour precipitation sum with 2-Years repetition time for 1996



The graphs show that the results reflect the analysed condition of the land cover in the particular years indicating the trend of a decreasing arable land area and an increasing forest area. This fact has been manifested in the simulated hydrograms. The years of the most significant changes in land use are 1954 and 1971. The results of model hydrograms from these years show an increase in culmination by 25.41%. By contrast, culmination decreased by 25.8% between 1971 and 2009. Although these values need to be considered of only an informative character due to the simplifications of input data and modelling technique, we can deduce the influence of land cover on the runoff in the catchment.

Conclusion

The main aim of the study was to evaluate the factors affecting water retention in the landscape in dependence on land use based on the assessment of runoff conditions in the area in 4 periods strategically affected by political and management decisions leading to essential changes in the landscape as regards water retention. Considering the gained results of analyses and calculations, we can state that the data simulated for the particular periods show that a choice of plant cover can influence the runoff to a significant extent.

The changes in land use as regards land cover, size and category of lands in 1954, 1971, 1996, and 2009 significantly affected the runoff in the catchment area. The area of forest stands increased by 1.54% from 1954 to 2009. The area of permanent grassland shows an increase by 4.55% between 1971 and 2009. Also the built-up area expanded between 1954 and 2009: from 1.26% to 2.81%. There were also changes in the range of crop plants. Most considerably, there was a change in the proportion of wide-scale crops – potatoes (fodder beet, sugar beet) dominated between 1954 and 1971 and were replaced by maize starting from the 1990s.

In order to improve the runoff conditions in the study area, based on the terrain configuration and land use, it would be suitable to propose organizational, agrotechnical or biotechnical measures. As regards the organizational and agrotechnical measures, it is suitable to improve the soil structure by raising the content of humus. It is possible to use vegetation with good root systems and make the soils with a high content of clay particles lighter, which leads to the granularity of the soil profile with the optimum amount of pores. It is also possible to choose the optimum species composition

for the soil cover with a sufficient percentage of cover. By this we will achieve a higher roughness of the surface and thus also slowing down of the non-concentrated surface runoff, we will prevent destruction of the surface soil structure by the dynamics of falling rains, provide shade to the soil and thus maintain the optimum moisture for immediate water infiltration.

It is necessary to exclude wide-space crop plants (root crops, maize, etc.) from lands endangered by erosion with an inclination over 10%, or use a belt layout of the crop plants as this has a higher erosion prevention effect.

Further, it is recommendable to delineate critical areas that could be endangered by higher erosion and intensive surface runoff. The areas with an inclination over 7° should be predominantly used for permanent grassland.

As regards the biotechnical measures, measures close to nature, these are mainly erosion preventive baulks, water infiltration bands, grass sowing in valley lines, and, possibly, a polder.

The implementation of the integrated flood protection in the model area should start with area modifications of the catchment that diminish erosion effects of rainfalls and their runoff. Only then, water management and hydro technical measures can be taken using water works or other water constructions.

Acknowledgements

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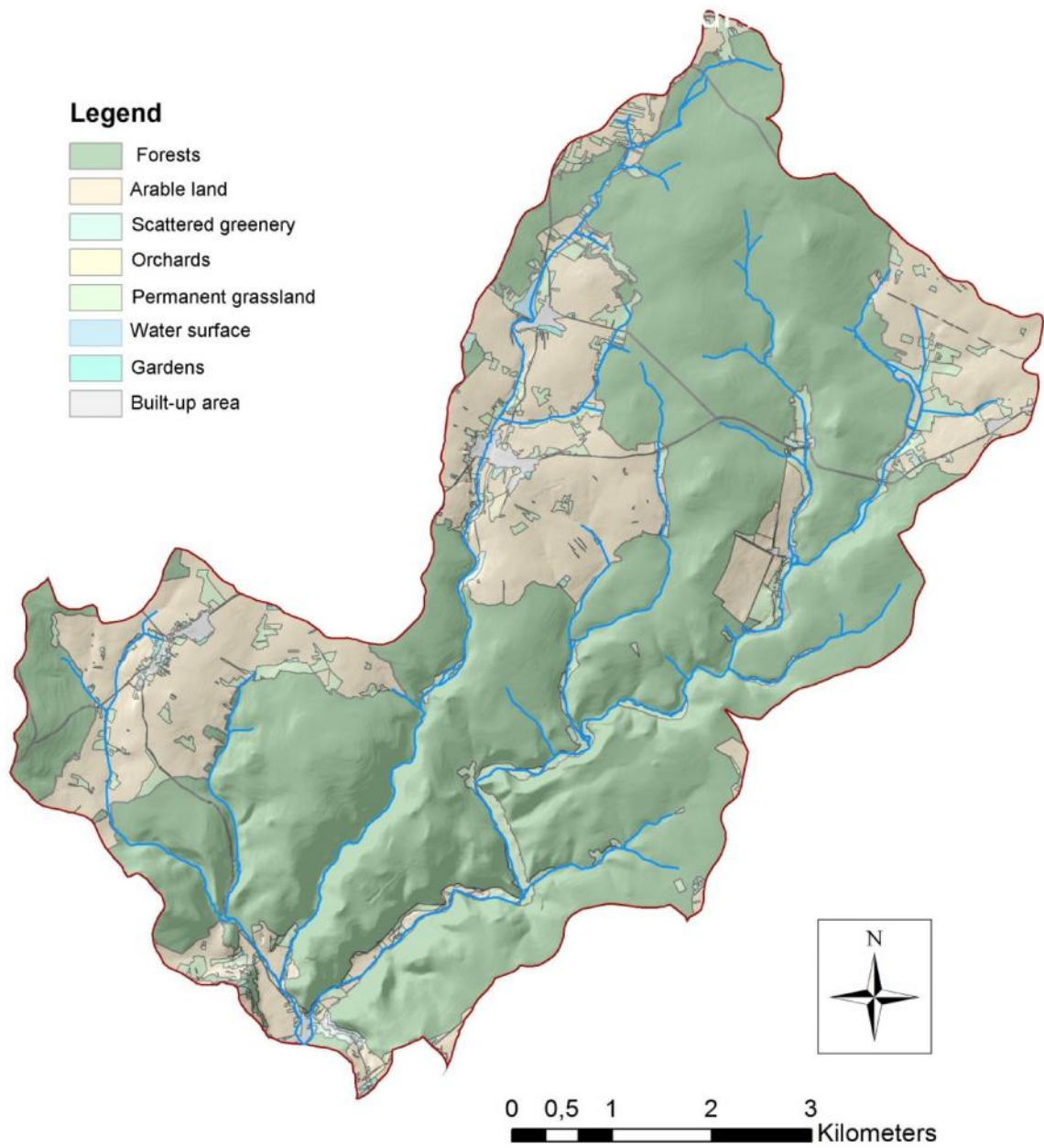


Fig.3 Land use 1954

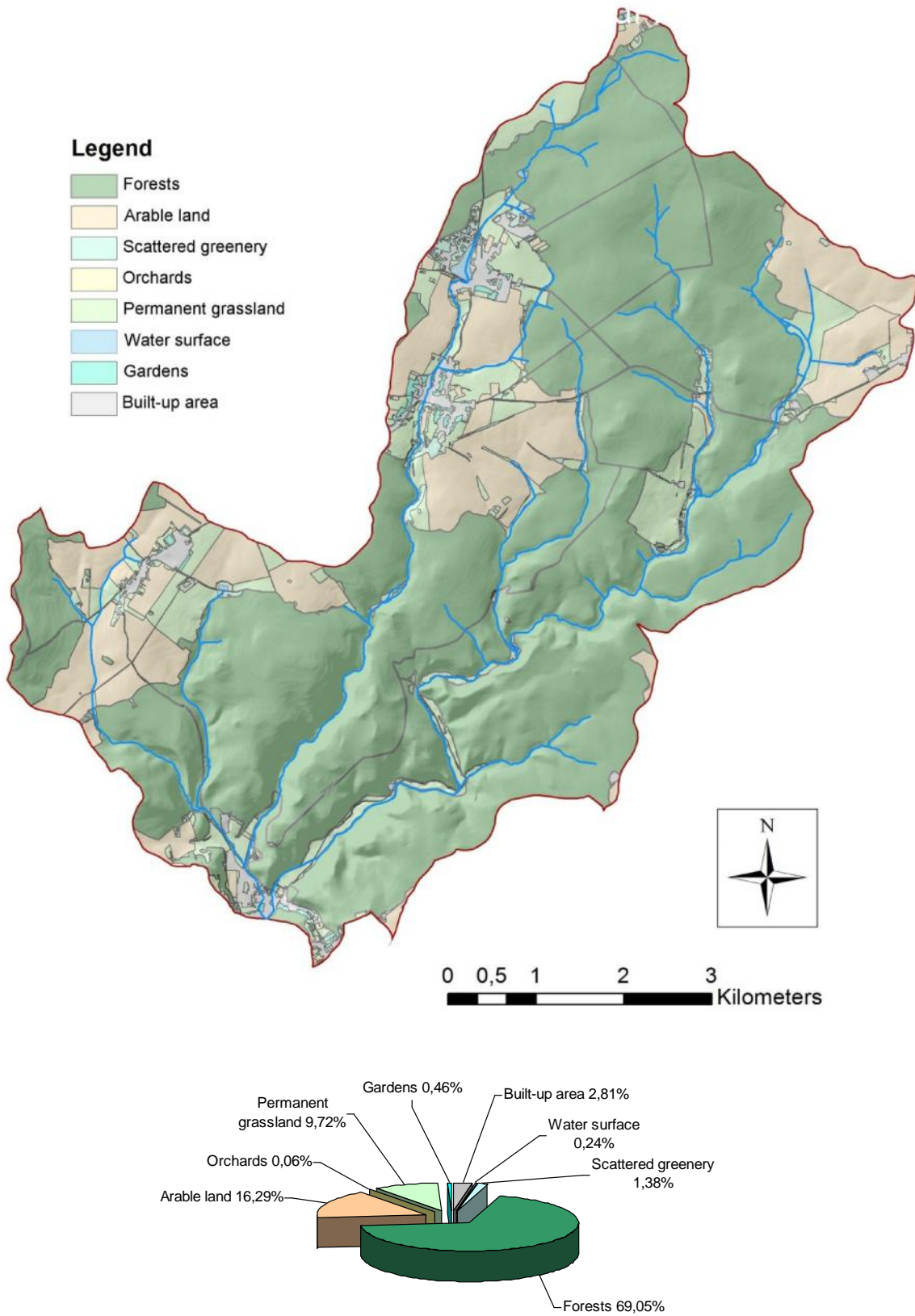


Fig.4 Land use 2009