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Evaluation of water erosion at a mountain catchment in Poland using the G2 model

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ABSTRACT

The Western Carpathians region in southern Poland is characterized by high erosion risk due to steep slopes, flysch formation and intense precipitation with frequent storm events. The G2 model, based on the principles of the Universal Soil Loss Equation (USLE), was used to investigate soil erosion assessment, except that the yearly rainfall erosivity factor was substituted for by the monthly one. The plant cover factor was determined based on the CORINE land cover 2012 database and field observations of vegetation stages. Slope intercept was estimated by applying a Sobel filter. Terrain properties were calculated from a 5 m DEM of the area. Modeling investigations were carried out in the agricultural basin of the mountain catchment (1.47 km^2) in the years 2011–2014. Rainfall data were collected from weather stations, and soil properties were measured in 43 locations. The G2 model estimated total annual soil loss as between 3.37 Mg ha^{-1} (2012) and 31.05 Mg ha^{-1} (2014). The erosive events that contributed most to yearly erosion occurred in May (2014: 80.40% of yearly total) and June (2013: 57.08%). Redundancy analysis based on land-use types provided factors affecting soil erosion by water. In conclusion, the G2 model was useful in erosion estimation in a steep-sloped agricultural basin with a variable hydrological regime.

1. Introduction

Water erosion of soil is a complex process during which fertile topsoil is detached, carried away and deposited in another location (Ballabio et al., 2017). It causes leaching of nutrients, terrain surface deformations and deterioration of water quality in catchments as well as silting of water structures and water supply and drainage systems (Żmuda et al., 2005). Even slight erosion negatively affects farming conditions and yield, impedes agrotechnical treatments, and may exclude the entire affected area from agriculture (Halecki et al., 2016). The intensity of erosion events is shaped by physiographic and hydrological factors prevailing in a specific catchment area (Verstraete and Poesen, 2001; Zabaleda et al., 2007), and by land use and plant cover (Podwojewski et al., 2008; Mao and Cherkauer, 2009). It also highly depends on geological factors, soil type, and climate (Nadal-Romero et al., 2008).

The accuracy of soil loss evaluation with models depends largely on how the model parameters describe important characteristics of the catchment. Many researchers focus on the assessment of the parameters provided by the Geographic Information System (GIS) and remote sensing data. These techniques are useful for quick evaluation of the spatial distribution of erosion within large areas, and can cover remote areas where no measurements are actually conducted (Dabral et al., 2008; Bahadur, 2009). The parameters estimated with these techniques do not differ much from those obtained from field measurements (Lee and Choi, 2010). Additionally, new geostatistical methods allow for development of maps with predicted data values that previously have had to be developed from highly time-consuming and expensive point observations (Burrough, 2001). Telemetry combined with GIS techniques and geostatistical methods enable the implementation of holistic and integrated visions of sustainable development.

The most important climatic factor is precipitation, and its frequency, duration, and intensity are critical for erosion in a catchment. Water erosion processes play an important role in terrain shaping causing transformations that under natural conditions result in formation of new forms of relief. In Poland, these processes are particularly visible in mountain and foothill areas. The literature provides many generations of erosion models describing water runoff and erosion events that differ in their limiting factor(s).

The most popular and widely used is the Universal Soil Loss

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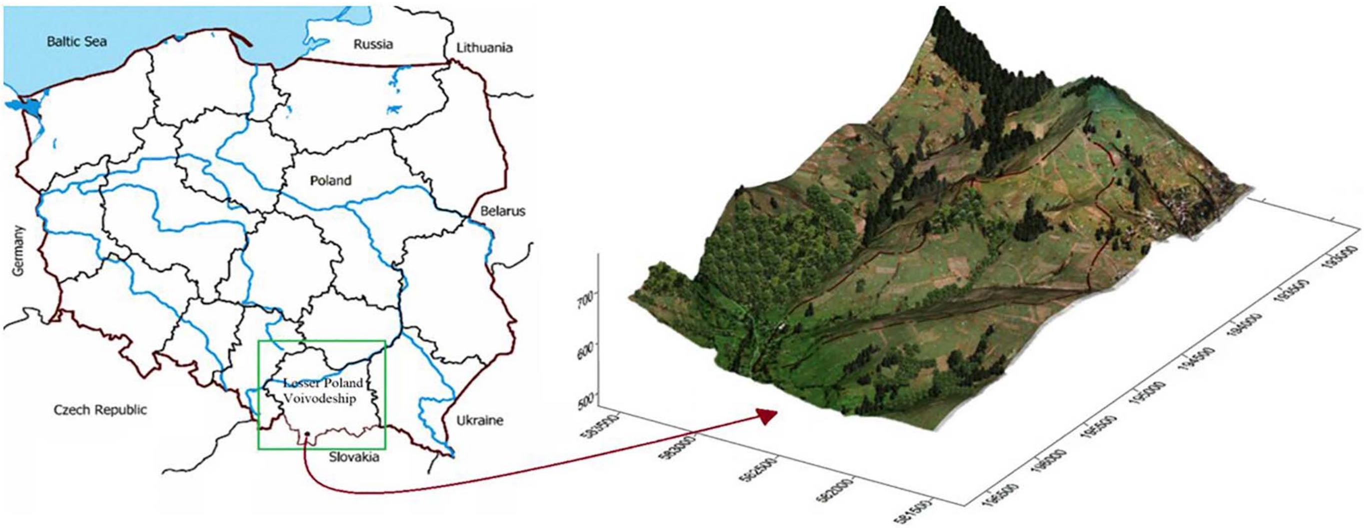

Fig. 1. Location of the investigated catchment of the Mątny stream.

Equation model (USLE) developed in a series of papers by Wischmeier and Smith (1978); Flanagan et al. (2003); Laflen and Moldenhauer (2003); Perović et al. (2013); and Kruk et al. (2016). The model formula, expressed as a logical product that combines all main natural and anthropogenic factors shaping the type and extent of soil erosion is as follows:

$$A = RKLSCP \tag{1}$$

where: A — mean annual weight of eroded soil per unit area ($Mg\,ha^{-1}\,y^{-1}$), R — mean annual erosivity of rainfall and runoff ($MJ\,mm\,ha^{-1}\,h^{-1}\,y^{-1}$), K — soil erodibility ($Mg\,ha\,h\,MJ^{-1}\,ha^{-1}\,mm^{-1}$), L — slope length coefficient (dimensionless), S — slope steepness coefficient (dimensionless), C — coefficient determining the type of crops and land use (dimensionless), and P — soil and water conservation (dimensionless).

The USLE model is used to estimate total annual soil loss within a multi-year period. It has been constantly modified and amended as research progress is made and the availability and quality of software are improved. The following modifications are worth mentioning: MUSLE (Smith et al., 1984; Zhang et al., 2009; Cârdei, 2010, Kruk, 2017), RUSLE (Park et al., 2011; Mhangara et al., 2012; Kumar and Kushwaha, 2013), USLE-M (Kinnell and Risse, 1998; Kinnell, 2016), and USLE-MM (Bagarello et al., 2015). In 2012, G2, a new erosion model based on the USLE structure was developed at the Aristotle University of Thessaloniki and Joint Research Centre of the European Commission under the GEOLAND2 project. The model formula was elaborated by Panagos et al. (2012, 2014b, 2015a), Karydas et al. (2014, 2015), Karydas and Panagos (2016) and Zdruli et al. (2016). It is used to estimate the erosion extent on a monthly basis. Several published studies of G2 implementation, e.g. in the cross-borders basin of the Strymonas/Struma river (Greece and Bulgaria), in the basins of the Ishmi-Erzeni river and Korce region (Albania), in the Mediterranean islands of Crete (Greece) and Cyprus, have yielded realistic results (Panagos et al. 2014a; Panagos et al. 2015a,c, Karydas and Panagos, 2016, 2018, Zdruli et al. 2016).

The choice of erosion modeling method usually depends on availability of proper data and the purpose of the simulation. An important advantage of the presented models is their simplicity and low requirements concerning the input data as compared with other erosion models such as SWAT — Soil and Water Assessment Tool (Ustun, 2008).

The G2 model can assess soil loss in cropland and forest-dominated land uses. We hypothesized that systematically enhancing soil conservation practices might substantially reduce soil loss in consecutive years. We decided to use the G2 model because it was the newest generation among all the available water erosion models of the USLE family. There has been a lack of investigation on its use in Polish conditions. Therefore, the objectives of this study were (1) to apply the G2 model to quantitative assessment of water erosion in an agricultural mountain catchment and (2) to evaluate the effect of soil and water conservation (SWC) on total soil eroded mass in a highly erosion-prone landscape.

2. Materials and methods

2.1. Study area description

The study was conducted in the Outer Western Carpathians, in the southern region of Małopolska Province (Fig. 1). The terrain comprises low and medium height mountains with peak heights ranging from 617.6 m a.s.l. to 732.0 m a.s.l. The lowest point is situated 490.0 m a.s.l. The mean height of the catchment is 582.66 m a.s.l. The slope distribution is as follows: < 5%, 4.08%; 5–10%, 18.37%; 10–18%, 45.58%; 18–27%, 21.09%; and > 27%, 10.88%. The weighted mean slope for the entire catchment is 16.28%. Study area was characterized by a deep or relatively deep soil profile. The length of the main watercourse is 2.37 km and its average slope 5.7%. The river network density is 2.96 $km\,km^{-2}$. The Mątny stream (1.47 km^2) flows into the Mszanka river in the Skiby hamlet at E 20°9′2.35″, N 49°37′30.52″. The catchment land use structure is dominated by grassland (73.5%); an arable land cover of 14.3%, including spring oat (*Avena sativa*) — 7.3%, potatoes (*Solanum tuberosum*) — 4.3%, common wheat (*Triticum aestivum*) — 2.7%; forests account for 9.5%; and urban areas 2.7%. The catchment area is cut by a network of dirt roads. Most of them are deeply furrowed and tend to transform into water-carrying streams during and after rain events.

2.2. Climatic conditions and soil of the study area

The mountain and sub-mountain climate is characterized by large contrasts within the local climate, which is rather cold, with a considerable amount of rainfall. Floods, occasionally disastrous, occur twice a year (spring and summer). The rivers are fed by rain, ground water and snow (Kondracki, 2000). The long-term annual average total precipitation is 846.63 mm (2011–2014). Total precipitation in the individual years in the study was 786.8 mm (2011), 813.8 mm (2012), 837.8 mm (2013), and 948.1 mm (2014). In the annual cycle, the highest total precipitation is typical of the summer and the lowest in the winter. The highest monthly total precipitation in the test period was