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The rainfall kinetic energy–intensity relationship for rainfall erosivity estimation in the mediterranean part of Slovenia

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SUMMARY

Rainfall kinetic energy–intensity relationships for rainfall erosivity estimation were established on the basis of raindrop size distribution measurements performed in the Brkini hilly area in southwest Slovenia, a transitional area between the Mediterranean and continental climate conditions. A set of measurement instruments, an optical disdrometer coupled with a rain gauge, was installed on two locations: Koseze and Kozjane. The data set contained raindrop size distribution and rainfall intensity measurements of the rainfall events that occurred during a one-year period in the 2008/2009 season. The rainfall intensities obtained with the rain gauges were used for event rainfall depth control measured by the disdrometers and testing the established kinetic energy–intensity (*KE–I*) relationships. Two exponential *KE–I* relationships were established for each measuring site, for 1-min and 5-min rainfall intensity data, respectively. Their performances were tested and compared with the performances of other *KE–I* relationships proposed by authors throughout the world, which could be recognised as relatively suitable for kinetic energy estimation in the Mediterranean area. The comparison included 11 *KE–I* relationships expressed with linear, linear-log or exponential formulations. The analyses exposed the rainfall intensity overestimation by the disdrometers and the limited use of the tipping bucket rain gauge for kinetic energy estimation under such climate conditions. According to our results, the established *KE–I* relationship for 5-min intensity data in Koseze is recommended to be used while estimating rainfall kinetic energy in the Mediterranean part of Slovenia. As input data, rainfall intensities measured with precise weighing rain gauges, as those installed in the Slovenian meteorological network, should be used. However, when using rainfall intensity data obtained with a tipping bucket rain gauge of lower accuracy or insufficient intensity range, the exponential relationship of Coutinho and Tomás (1995) is expected to deliver better kinetic energy estimations.

1. Introduction

Soil erosion is a mechanical land degradation process caused by natural and anthropogenic erosive forces. It may critically affect the most important ecological soil functions: food production for humans and animals; capacity to filter, buffer and transform materials that circulate in the biosphere; and biological habitat for the living organisms (Blum et al., 2006). Despite the generally fair knowledge about the soil erosion processes, the global diversity of topography, land use, soil and climate characteristics demand locally targeted investigations on soil erosion factors, rates, consequences, control and soil conservation measures and strategies (Boardman and Poesen, 2006) supporting environmental management. Our study took place in the part of Slovenia that belongs to the Mediterranean area, where soil erosion is the most serious land degradation hazard (Kosmas et al., 2002). The Mediterranean environment is characterised by seasonally contrasted climate, with low annual rainfall depths and irregular but frequent rain events with extreme intensities, scarce vegetation cover and poor soil characteristics (López-Vicente et al., 2008). The vulnerability of the Mediterranean region to soil erosion hazard is mostly influenced by the frequent coincidence of dry summer periods with violent rainstorms, causing one of the highest average annual soil losses in Europe (Hill, 1993).

Gravity, wind and rainfall are the driving forces affecting the energy balance of the soil erosion processes (Sukhanovski et al., 2001). The erosivity of rainfall and its consecutive overland runoff is recognised as a crucial factor for erosion processes (Mannaerts and Gabriels, 2000). The rainfall–runoff erosivity (R), in terms of the widely used methodology for soil loss estimation USLE/RUSLE (Wischmeier and Smith, 1978; Renard et al., 1997), is defined as a product of the rainfall kinetic energy (KE) and the maximum 30-min rainfall intensity (I_{30}). Direct measurements of rainfall kinetic energy are very rare (Mikoš et al., 2006) as they require sophisticated and costly instruments (Fornis et al., 2005) and it is

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often derived from widely available rainfall intensity (I) data by implementing empirical kinetic energy–rainfall intensity (KE–I) relationships. The relationships of these kind found in the literature are mainly established from rainfall kinetic energy derived from raindrop size distribution (DSD) measurements performed at a certain location with specific climate conditions and valid for a limited intensity range. The use of any KE–I relationship in a climatically different environment than the one it was formulated for should be justified prior its implementation.

The rainfall kinetic energy can be expressed as a rate, kinetic energy per unit area per time KE_A, or as a quantity, kinetic energy per unit volume (per unit area per rain depth) KE_B (Rosewell, 1986). These two expressions of the kinetic energy are related to each other through the rainfall intensity I in the following formulation: $KE_A = c \cdot I \cdot KE_B$, where c is a constant that solves possible unit differences. The KE–I relationship established as a linear-log equation by Wischmeier and Smith (1958) inspired the later work of many other researchers developing such relationships of equal (Zanchi and Torri, 1980, Brandt, 1990), linear (Sempere-Torres et al., 1992; Usón and Ramos, 2001), polynomial (Carter et al., 1974), exponential (Rosewell, 1986; Brown and Foster, 1987; Coutinho and Tomás, 1995; Cerro et al., 1998, Jayawardena and Rezaur, 2000; van Dijk et al., 2002) or power law (Uijlenhoet and Stricker, 1999; Steiner and Smith, 2000; Brodie and Rosewell, 2007) mathematical expression. The individual raindrop characteristics needed for rainfall kinetic energy calculation are mass and fall velocity. The raindrop mass is derived from the raindrop diameter D obtained in DSD measurements, while the fall velocity can be measured or estimated from the empirical laws (Salles et al., 2002) that link the terminal fall velocity (v_t) and the raindrop diameter (D), such as those proposed by Atlas et al. (1973), Beard (1976), Atlas and Ulbrich (1977) or Uplinger (1981).

The DSD measurements can be based on different physical principles. The primary measurements based on the impact technique, like flour pellet, introduced by Bentley in 1904, and the filter-paper method of Wiener of 1895, measured the raindrop diameter D only (Sempere-Torres et al., 1992). In 1967, Joss and Waldvogel introduced an impact disdrometer, an electronic instrument for the DSD measurements based on the electromechanical principle, capable of determining the raindrop diameter from the vertical force applied on a transducer (Löffler-Mang and Joss, 2000). The second group of instruments is based on imaging techniques like pluviospectrometer (Frank et al., 1994) or 2D video disdrometer (Schönhuber et al., 1994). Beside the raindrop diameter, the latter instrument also determines the raindrop fall velocity. The third group consists of instruments that utilise the optical scattering phenomenon, like vertically looking micro rain radar (Peters et al., 2002), laser-based optical disdrometer (Löffler-Mang and Joss, 2000) or X band radar (Prodi et al., 2000). Only the latter instrument is not capable of detecting the raindrop fall velocity.

The present work aimed at establishing a KE–I relationship, valid for the Mediterranean part of Slovenia and possibly elsewhere in the Mediterranean area under similar climate conditions. It had to be suitable for rainfall kinetic energy estimation from the available rainfall intensity data obtained in the Slovenian meteorological network (5-min rainfall depth values) or by other instruments commonly used for research purposes. The KE–I relationship was established on the basis of the DSD measurements performed in the Brkini hilly area in the southwestern part of Slovenia, close to the Adriatic sea.

2. Site description and measuring equipment

The rainfall intensity and the raindrop size distribution measurements took place on two monitoring sites in the Brkini hilly area, southwest Slovenia (Fig. 1): in Kozjane, at the altitude of 595 m a.s.l., and in Koseze (405 m a.s.l.), close to the town of Ilirska Bistrica. The Brkini hils, with a maximum altitude of 810 m, situated approximately 30 km east of the Gulf of Trieste and 20 km southwest of the Dinaric-Alpine barrier, are recognised as the transitional area between the Mediterranean and the continental climates. Autumn is the wettest season of the year followed by the spring, with mainly frontal rainfall, while the majority of the summer rain events have convective nature, with short duration and high intensity. Periodical snow cover during the winter is common only in the highest parts of the Brkini hills. The mean annual precipitation for the Brkini hilly area amounts to 1440 mm (Rusjan et al., 2006), while the mean annual temperature is 9.6 °C (Rusjan et al., 2008).

The raindrop size distribution on the Kozjane monitoring site was measured by the LPM300 optical disdrometer manufactured by Thies Clima (Fig. 1), while on the Koseze monitoring site, which is maintained by the Environmental Agency of the Republic of Slovenia (ARSO) in the frame of the national meteorological network, the OTT Parsivel optical disdrometer was installed. These disdrometers have a slightly different construction but their measurements are based on the same physical principle. A precipitation particle falling through laser light sheet of specific thickness and detection area reduces the transmitted signal amplitude for a certain period of time. The instrument detects the diameter and the velocity of the falling precipitation particle from the reduced amplitude and the duration of the weakened signal, respectively (Löffler-Mang and Joss, 2000). The particles that have passed through the laser sheet within an interval of 1 min are classified into size and velocity classes after the volume equivalent diameter of the particles is determined. After the correction for coincident particles in the light sheet is applied, the disdrometer determines the 1-min rainfall intensity by integrating the volumes of all single particles. A short summary of both instruments' specifications is shown in Table 1. In their technical specifications the manufacturers had skipped the information about the accuracy of the disdrometer raindrop fall velocity measurements. Nevertheless, Löffler-Mang and Joss (2000) mention that the raindrop velocity measurements performed by the Parsivel sensor have an accuracy of 25% and 5% for the drops of 0.3 and 5 mm diameter, respectively.

On the Kozjane monitoring site the rainfall intensity was measured with Onset RG2-M, a tipping bucket rain gauge equipped with a data logger. The Koseze monitoring site was equipped by ARSO with the weighing rain gauge OTT Pluvio prior to the start of our measurement campaign. A short specification summary of the rain gauges is shown in Table 2. The RG2-M rain gauge was calibrated before mounting by using a constant flow rate of 20 mm/h, while the Pluvio was calibrated in the manufacturers' laboratory.

The optical disdrometers used in our study had been included in the WMO field intercomparison of rainfall intensity gauges (Vuerich et al., 2009), which showed overestimation and small dispersion of the measured rainfall intensity by both optical disdrometers. The comparable behaviour was assigned to the same measuring principle of the optical disdrometers, despite the different calibration procedure of the manufacturers: the LPM300 is subjected to precise light sheet measurement and volume calibration on an automated calibration bench where uniform droplets with a diameter of about 3 mm are used (Lanzinger et al., 2006), while Parsivel is calibrated on the bench which simulates high-precision reference particle sizes (0.5, 1.0, 2.0 and 4.0 mm) and velocity (intensity ranges up to 1800 mm/h) using a rotating disc (Nemeth and Löffler-Mang, 2006). The weighing rain gauge OTT Pluvio had also been a subject in the WMO rain gauge field intercomparison (Vuerich et al., 2009), where Pluvio showed excellent accuracy in the laboratory as well as in the field, with an average relative error within ±0.5% and with almost all 5-min measurement points within the 5% tolerance region of the reference.