



The G2 erosion model: An algorithm for month-time step assessments

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ABSTRACT

A detailed description of the G2 erosion model is presented, in order to support potential users. G2 is a complete, quantitative algorithm for mapping soil loss and sediment yield rates on month-time intervals. G2 has been designed to run in a GIS environment, taking input from geodatabases available by European or other international institutions. G2 adopts fundamental equations from the Revised Universal Soil Loss Equation (RUSLE) and the Erosion Potential Method (EPM), especially for rainfall erosivity, soil erodibility, and sediment delivery ratio. However, it has developed its own equations and matrices for the vegetation cover and management factor and the effect of landscape alterations on erosion. Provision of month-time step assessments is expected to improve understanding of erosion processes, especially in relation to land uses and climate change. In parallel, G2 has full potential to decision-making support with standardised maps on a regular basis. Geospatial layers of rainfall erosivity, soil erodibility, and terrain influence, recently developed by the Joint Research Centre (JRC) on a European or global scale, will further facilitate applications of G2.

1. Introduction

Erosion modelling is used in order to achieve a better understanding of erosion processes, provided that experimental conditions from which directly measured outcomes could be derived, are either impossible or impractical to create (Tolk, 2015). The importance and achievements of erosion modelling (either for soil loss, sediment yield, or both) have been argued by a plethora of research works; see the review of Merritt et al. (2003).

The wide spreading of geographic information systems (GIS) and use of remote sensing data has accelerated erosion model development significantly, as it allows for data input from multiple sources, easy model structure modifications, and unconditioned model rescaling (Giordano et al., 1991; de Vente and Poesen, 2005). According to Karydas et al. (2014), more than 80 erosion models have been developed for different purposes in half a century. Despite the wealth of erosion models and applications, though, selection of an appropriate model for operational mapping remains a difficult undertaking.

With a view to support regular monitoring by decision-makers involved in environmental and agricultural policies, the geoland2 project has developed the G2 erosion model, in the framework of the Copernicus Land Monitoring Service (<http://land.copernicus.eu/>) (former GMES). The development of a new erosion model was justified by the requirements for operational, standardised mapping solutions, raised by the new environmental policies in Europe, such as the Soil

Thematic Strategy (Montanarella, 2015) and the Common Agricultural Policy (Panagos et al., 2016), in the view of rapid land use changes and the climate change effects. Fundamental in a new modelling approach would be a seasonal time-step (rather than averaged annual assessments), which could be accomplished by using regularly updated space-born data. On the other hand, a new model had to take advantage of previous experience, taking account of the urgent character of the monitoring tasks ahead and the potential high cost of creating new experimental data.

As a result, G2 was based on RUSLE and EPM heritage (for soil loss and sediment yield assessments, respectively), trying at the same time to overcome reported drawbacks of both models; for example, the questionable applicability in different areas from those where these models were developed or on a different temporal scale than annual, limitations to sheet and interrill processes, etc. (see Kale and Vadsola, 2012). Considering that G2 adopts fundamental empirical equations from RUSLE and EPM, it can be classified as an empirical model, too.

G2 has been made available to interested parties, through the European Soil Data Centre (ESDAC) of the Joint Research Centre (JRC), with provision of guidance, datasets and technical support (<http://esdac.jrc.ec.europa.eu/themes/g2-model>). Up until now, the G2 model has been implemented in five different study areas in SE Europe and in Cyprus. In two of these cases (Crete and Cyprus), pre-existing field data were available either for calibration or rough verifications.

The objective of this paper was to present a complete and detailed

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description of the G2 erosion model and discuss the experience gained from algorithm development and revisions, and the case-studies conducted since model introduction in 2010. Also, to offer guidance and suggestions to potential users on an appropriate data collection, processing, and analysis. Finally, to examine model's perspectives in Europe and the world after recent improvements in data availability.

2. Model overview

G2 is an empirical model for soil erosion rates on month-time intervals and has evolved with time into a quantitative tool with two distinct modules: one for soil loss and one for sediment yield.

The module for soil loss (denoted as G2los) inherits its main principles and many of its formulas from the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and the Revised-USLE (RUSLE) (Renard et al., 1997). Ferro and Porto (2010) argues that USLE is a robust empirical model with a logical structure regarding the variables used to simulate the physical erosion process. The input datasets of the G2 applications can be derived from geodatabases freely and regularly available by European or other international institutions.

The module for sediment yield (denoted as G2sed) adopts the sediment delivery ratio (SDR) formula from the Erosion Potential Method (EPM) (Gavrilovic, 1988; Marques da Silva et al., 2014). The main input dataset is a high resolution digital elevation model (DEM), from which the required topographic and hydrographic properties can be derived. The G2sed module uses the outcome of the G2los module and the calculated EPM figures, to produce sediment yield maps (Karydas and Panagos, 2016) (Fig. 1).

G2 model is designed to run in a GIS environment, as it adopts modifications made by Moore and Burch (1986) for spatially distributed soil loss assessments. G2 produces soil loss maps as raster layers at a 100-m resolution and sediment yield maps as vector layers at a 100-ha minimum mapping unit (MMU), on a month-time step.

The spatial scale of application in G2 is affected mainly by the terrain dataset, which has been proved to cause tremendous effect on erosion outputs; see for example, Tantasirin et al. (2016), Barrios and Frances (2012), and Rojas et al. (2008). As therefore, the cell size of the erosion maps is determined by the resolution of the terrain dataset, taking also account of its positional accuracy. For example, a DEM of 25–30 m resolution (e.g. an ASTER-GDEM or a EU-DEM), will allow to map erosion features at a 100-m cell size. Bringing the dataset closely to model specifications, or (inversely) adapting a model to the particularities of the available dataset can be understood as 'hidden calibration' of a model, a process inevitable in empirical modelling (Longley et al., 2004).

Temporal scale of G2 is set by default to month-time intervals, instead of yearly assessments originally provided by USLE or EPM; a month is the finest time-step, for which rainfall data could be made available for long periods and wide areas.

3. G2los module

G2los consists of a set of algorithms (adopted, revised, or developed) for producing month-time step maps and statistics of soil loss caused by sheet and interrill erosion processes. Inherited by RUSLE, five input erosion parameters are combined by G2 in a multiplicative equation, to estimate a quantitative erosion output:

$$E_m = \frac{R_m}{V_m} \cdot S \cdot \frac{T}{L} \quad (1)$$

Where E_m : soil loss for month m (t ha^{-1}); R_m : rainfall erosivity of month m ($\text{MJ mm ha}^{-1} \text{h}^{-1}$); V_m : vegetation retention for month m (dimensionless); S : soil erodibility ($\text{t ha h MJ}^{-1} \text{ha}^{-1} \text{mm}^{-1}$); T : terrain influence (dimensionless); L : landscape effect (dimensionless).

Compared to the RUSLE main equation, in Eq. (1):

- R is identical to R of RUSLE;
- V plays a role analogous to that of C in RUSLE (though in an inverse manner, i.e. $V \sim 1/C$);
- S is identical to K of RUSLE;
- T is identical to LS of RUSLE; and
- L plays a role analogous to that of P in RUSLE (though in an inverse manner, $L \sim 1/P$); also, L plays a corrective role to T .

Factors in the numerator of Eq. (1) (i.e., R , S , and T) express natural erosion forces related to the specific site, whereas factors in the denominator (i.e., V and L) express natural or human-induced (related to land management), anti-erosion forces; the product $V \times L$ (always ≥ 1) could be seen as a sustainability quantum.

The R and V factors are those with a dynamic character over an annual cycle; R expresses the cumulative erosive effect of all rainfall events in a specific month; whereas, V expresses the protective role of vegetation coverage and proper land use management applied during the same month. The rest factors (T , S , and L) can be considered as static, although Borselli et al. (2012) have reported that soil erodibility shows some seasonal fluctuations. Only R and S are dimensional by default, whereas the rest are dimensionless. Value ranges for R , S (K), and T (LS) are determined by RUSLE equations and nomographs (adapted to the Metric System); while V is always greater than 1 and L ranges between 1 and 2 (Table 1).

4. Erosion factors

4.1. Rainfall erosivity (R)

According to Wischmeier and Smith (1978), rainfall erosivity (R) is defined as the numerical measure of the erosive potential of rainfalls within a specific period of time. In physical terms, R indicates how particle detachment and transport capacity are combined in the erosive

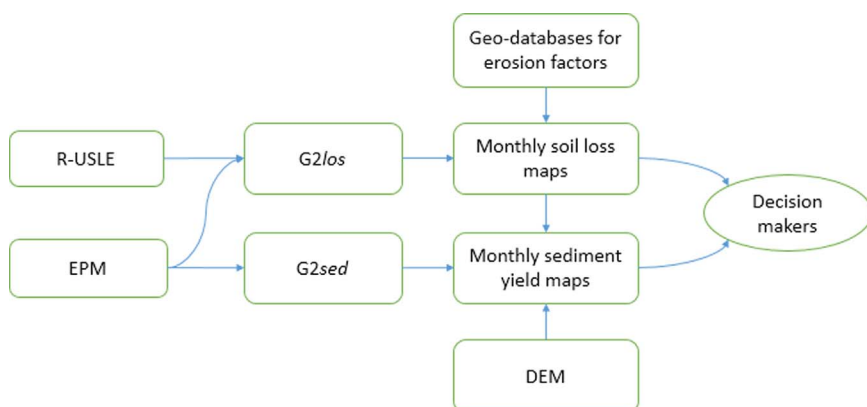


Fig. 1. A flowchart of the contribution of R-USLE and EPM models to the modules of G2 and their relation to input and output data.

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