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# Mapping Spatio-Temporal Soil Erosion Patterns in the Candelaro River Basin, Italy, Using the G2 Model with Sentinel2 Imagery

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**Abstract:** This study aims at mapping soil erosion caused by water in the Candelaro river basin, Apulia region, Italy, using the G2 erosion model. The G2 model can provide erosion maps and statistical figures at month-time intervals, by applying non data-demanding alternatives for the estimation of all the erosion factors. In the current research, G2 is taking a step further with the introduction of Sentinel2 satellite images for mapping vegetation retention factor on a fine scale; Sentinel2 is a ready-to-use, image product of high quality, freely available by the European Space Agency. Although only three recent cloud-free Sentinel2 images covering Candelaro were found in the archive, new solutions were elaborated to overcome time-gaps. The study in Candelaro resulted in a mean annual erosion rate of 0.87 t ha<sup>-1</sup> y<sup>-1</sup>, while the autumn months were indicated to be the most erosive ones, with average erosion rates reaching a maximum of 0.12 t ha<sup>-1</sup> in September. The mixed agricultural-natural patterns revealed to be the riskiest surfaces for most months of the year, while arable land was the most extensive erosive land cover category. The erosion maps will allow competent authorities to support relevant mitigation measures. Furthermore, the study in Candelaro can play the role of a pilot study for the whole Apulia region, where erosion studies are rather limited.

Keywords: erosion; G2 model; sentinel2

# 1. Introduction

# 1.1. Objectives

In this study, the spatial erosion patterns in the Candelaro river basin, Apulia region (or Puglia region), in the south of Italy, were mapped on month-time intervals. Candelaro was selected due to its morphology, land cover, and crop diversity, as well as for being one of the few sloping areas in Apulia.

The G2 erosion model was employed as an appropriate tool for high-resolution erosion assessments, while Sentinel2 satellite imagery was used to detect vegetation patterns in detail throughout the year. Specific objectives of this study were:

- To indicate the specific contribution of different land covers to soil erosion in Candelaro, especially regarding the seasonal changes of rain intensity and vegetation cover;
- To introduce Sentinel2 imagery in the vegetation factor algorithm of the G2 methodology, thus revising the model; this could be novelty of the current work;

• To assess the potential of the herewith-revised G2 model, through its application in Candelaro, in terms of a pilot study, towards expanding its application at a later time in the whole Apulia Region (where erosion studies are rather limited).

#### 1.2. Erosion in Italy

The Mediterranean region is particularly prone to erosion [1,2], because it is subject to long dry periods followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils. Erosion rates are expected to rise during the twenty-first century due to climate change. This will be reflected by a more dynamic hydrologic cycle that in turn will be associated with frequent torrential rainfall patterns; thus, increasing water erosion intensity [3]. In addition to that, the impacts by the erosion process in the Mediterranean regions are the worst compared with other regions in Europe [4–7]. This is particularly relevant when dealing with typical heavy rainfall events that often characterize the Mediterranean region and Italy in particular [8].

Severe soil erosion affects 17% of the land area of Italy; based on OECD data (2008) [9], about 30% of the Italian territory is affected by soil erosion, with rates greater than 10 t ha<sup>-1</sup> y<sup>-1</sup>. The semi-arid zones of the south of Italy and the islands of Sicily and Sardinia are particularly prone to erosion due to a combination of climatic factors and rugged terrains, often bare of vegetation because of historical overgrazing and frequent forest fires [10,11]. Landslides on the other side are estimated to affect almost half of the Italian cities [12].

The topic of land degradation due to soil loss by water erosion has been extensively studied in Italy. Several soil erosion studies [13–17] and numerous publications [11,18–22] focus on different soil erosion processes. As in many other countries, erosion estimates have also been subject of continuous debates and adjustments. For instance, the estimates made by Van der Knijff et al. (1999) [14], were challenged by Grimm et al. (2003) [23] that estimated lower erosion risk rates for the Alps and the Apennines, and on the contrary, higher ones for the central part of Sicily than those provided by [14].

According to Costantini and Lorenzetti (2013) [24], critical areas at risk of soil erosion are located in central and southern Italy, on slopes where agricultural lands are intensively cultivated. The natural erosion process is typical for several areas of Calabria and Basilicata with the presence of the so-called calanchi (Figure 1). In contrast, woodlands with the highest risk of erosion and landslides are more widespread in northern Italy, on the steep slopes of the Alps, and the Apennines. Italy's annual average erosion rates are equal or more than 11 t ha<sup>-1</sup> y<sup>-1</sup> and the annual economic damage from landslides, floods, and soil erosion is estimated at 900 million euros [24].



**Figure 1.** Evidence of natural erosion in sedimentary claystone/siltstone/sandstone formations in Calabria, Italy (Photo credit: P. Zdruli).

#### 1.3. The G2 Model

G2 is an empirical model for soil erosion on month-time intervals, with two distinct modules: one for soil loss and one for sediment yield [25,26]. The module for soil loss (denoted by G2*los*) uses the main empirical formulas of the Universal Soil Loss Equation (USLE) [27,28], which according to Ferro (2010) [29], is a robust empirical model with a logical structure regarding the variables used to simulate the physical erosion process.

With G2*los*, five input erosion factors are combined in a multiplicative equation, to estimate a quantitative soil loss output from sheet and interill erosion processes [26]:

$$E_m = \frac{R_m}{V_m} \cdot S \cdot \frac{T}{L} \tag{1}$$

where  $E_m$ : soil loss for month m (t ha<sup>-1</sup>);  $R_m$ : rainfall erosivity of month m (MJ mm ha<sup>-1</sup> h<sup>-1</sup>);  $V_m$ : vegetation retention for month m (dimensionless; inversely analogous to C-factor of USLE); S: soil erodibility (t ha h MJ<sup>-1</sup> ha<sup>-1</sup> mm<sup>-1</sup>); *T*: terrain influence (dimensionless; analogous to *LS*-factor of USLE); *L*: landscape effect (dimensionless; inversely analogous to P-factor of USLE). Compared to other USLE-family models, an added value of G2 can be considered the possibility for non-demanding data alternatives for all erosion factors. (Details on the erosion factors are provided in the Methodology section).

Developed in 2010, within the framework of GMES Initiative (now, Copernicus Land Monitoring Service, CLMS) and specifically by the 'geoland2' project team [30], the G2 model was developed with a steady view to serve as an effective decision-making tool based on harmonized datasets and procedures. Since then, it has been revised through a series of published case studies conducted in Greece, Bulgaria, Albania, Cyprus [31], and more recently, in Poland [32]. Today, the G2 model is listed among other well-known models in the 'Water Erosion Theme' of the European Soil Data Centre (ESDAC) of the Joint Research Centre (JRC) [33].

Up until now, the G2*los* module relied on the use of the fraction cover (or FCover) layers for the estimation of the vegetation retention factor, together with information on land cover derived from CORINE Land Cover (CLC) datasets. Provided by CLMS, FCover layers are available at either 333 m or 1 km, processed from MERIS or SPOT/VGT images, respectively, on 10-day intervals. FCover belongs to a set of layers of biophysical properties (known as 'BIOPAR' products), provided regularly by CLMS [34].

Lately, Sentinel2 imagery provided free by the European Space Agency (ESA), through the Copernicus Open Access Hub, as a high-resolution dataset on 5-day intervals, offers the possibility to replace the pre-existing low spatial resolution FCover layers by a higher resolution vegetation layer. Sentinel2 images are captured by the MultiSpectral Instrument (MSI) and carry 13 spectral bands ranging from the visible and near-infrared to the short-wave infrared, ready-to-use in an atmospherically corrected reflectance mode. The spatial resolution varies from 10 to 60 m, depending on the spectral band, with a 290 kilometers field of view [35,36].

#### 2. Study Area and Dataset

#### 2.1. Study Area

The Candelaro river basin is in Foggia regional unit, in the northern part of the Apulia Region, Italy (Figure 2). It comprises a geo-morphological environment typical of the 'Tavoliere delle Puglie', which is the largest alluvial plain in southern Italy and the second largest in Italy [37]. The Candelaro river basin discharges into the Manfredonia Gulf. The drainage catchment area is 2331 km<sup>2</sup>, and the main river course has a length of 67 km. Major streams from north to south, are Macchione Canal and of the Triolo, Casanova, Salsola, Vulgano, and Celone streams. The mean elevation is 300 m above sea level, ranging from 0 to 1142 m. A big part of the upland area of the catchment belongs to the Gargano



National Park, founded in 1991. The soils exhibit a texture varying from sandy-clay-loam to clay-loam or clay. Erosion signs can be observed mainly in the hilly cultivated slopes (Figure 3).

**Figure 2.** The Candelaro river basin; location map (left hand side) and anaglyph with the main stream course (right hand side).



(a)

(b)

**Figure 3.** Typical landscape of Candelaro watershed with agricultural crops in the bottom valleys (**a**) and natural lands on the surrounding slopes (**b**) (Photo credit: P. Zdruli).

From 1990 to 2016, the average annual precipitation in the catchment was 570 mm. The orographic aspects affect rainfall amounts, as well as the patterns of rainfall events. The rainfall is mostly concentrated in autumn and winter seasons, it is unevenly distributed and often occurs with high intensity in short duration. The stream flow regime changes rapidly and follows the precipitation regime closely. The discharge per unit area ranges between 2.6 and 5.6 L s<sup>-1</sup> km<sup>-2</sup>.

The range of average daily temperature is 12–15 °C. The average annual potential evapotranspiration is about 1060 mm [38].

The main economic activity in the plain area is intensive agriculture, the main farm products being durum wheat, tomatoes, sugar beet, olives, and vineyards. In the mountainous part of the basin, natural and manmade forest lands and pasture are frequent, occasionally associated with fruit trees, vineyards, and olive groves [39].

#### 2.2. Dataset Description

According to the parameters of the G2 erosion factor equations, the following required data became available to this research (Table 1):

- Monthly rainfall figures and number of rainy days per month for the period 2000–2013 from 13 weather stations throughout the study area (Source: Hydrographic and Mareographic Office of Bari for the Basins with the mouth of the Adriatic and Ionian coasts from Candelaro to the Lato of Puglia region) (Figure 4). These data were used to compute the monthly rainfall erosivity figures.
- b. Pre-existing soil profiles from 70 locations [40], including texture class, organic matter content, structure class (according to the American Soil Taxonomy), and permeability class (Source: ACLA2 project, Agro-ecological characterization of Apulia region) (Figure 5). The soil profile data were used to the compute soil erodibility values.
- c. A set of almost cloud-free Sentinel2 satellite images acquired in 25 October, 2018; 24 March, 2019; and 7 July, 2019 (Figure 4) [41] (source: Scientific Hub, Copernicus). Because the Candelaro area is not covered by a single Sentinel2 scene, a couple of images were downloaded and mosaicked into single images per date; and then were masked to the outline of the study area (Figure 5). These satellite images were used to compute vegetation index layers, which in turn were input to the vegetation retention factor equation. They were also processed with a Sobel 3 × 3 filter (an edge-detection filter) in order to be used for computing the landscape effect factor.
- d. A digital elevation model (DEM) of 90 m spatial resolution (constructed from digitized contour maps) (Source: Hydrographic and Mareographic Office of Bari for the Basins with the mouth of the Adriatic and Ionian coasts from Candelaro to the Lato of Puglia region) (Figure 5). From this DEM, the flow accumulation (surface runoff) and the slope layers were computed, as input to the topographic influence layer.
- e. Land cover data derived from the CORINE Land Cover (CLC) geodatabase for 2018 (Figure 6) [42]. The CLC layer was used in order to compute the LU parameter, a corrective input variable to the vegetation retention equation.

Erosion Factor	Input Data	Scale/Time Step	Acquisition/Production Time
R, Rainfall erosivity	13 weather stations	1 station per 179 km <sup>2</sup> / Monthly step	2000–2013
V, Vegetation retention	Sentinel2 imagery (6 scenes)	10-m pixel size / 3 dates	25 October, 2018; 24 March, 2019; 7 July, 2019
	CORINE Land Cover	1:100,000	2018
S, Soil erodibility	70 soil profiles	1 soil profile per 33.3 km <sup>2</sup>	2005 (year of survey)
T, Terrain influence	Digital elevation model	90-m cell size	N/A
L, Landscape effect	Sentinel2 imagery (2 scenes)	10-m pixel size / 1 date	7 July, 2019

**Table 1.** Geospatial properties of the input datasets for the Candelaro erosion study.



**Figure 4.** Weather stations in the Candelaro river basin over the 10-m pixel size Sentinel2 image of 25 October, 2018 (here in the visible mode, RGB); sparse small clouds at the north east.



**Figure 5.** The soil profiles over the 90-m resolution digital elevation model (DEM) of the Candelaro river basin.



Figure 6. The 1st level CORINE Land Cover categories exhibited in the Candelaro river basin.

## 3. Methodology

#### 3.1. Overview

Every erosion factor was assessed separately and then introduced to the main G2*los* formula (Equation (1)). Data exploration indicated which alternative would be possible to follow in the Candelaro study; thus, leading to several adaptations or simplifications regarding most of the erosion factors. Matching data with erosion model requirements must be considered as part of the model calibration process [43,44].

## 3.2. R-Factor

For the estimation of the rainfall erosivity (R-factor) per month, the G2 model has adopted the Brown and Foster (1987) [45] formula:

$$R_m = \frac{1}{n} \sum_{i=1}^n \left\{ \sum_{j=1}^k (EI_{30})_j \right\}_i$$
(2)

where  $R_m$ : rainfall erosivity for month m (MJ mm ha<sup>-1</sup> h<sup>-1</sup>); i: the years recorded; *j*: the erosive events during month m; and  $EI_{30}$ : the rainfall erosivity index of event *j*. The event erosivity ( $EI_{30}$ ) is defined as:

$$EI_{30} = \left(\sum_{r=1}^{t} e_r v_r\right) \cdot I_{30}$$
(3)

where  $e_r$ : rainfall energy per surface unit and per rainfall volume of a predefined time interval (e.g., 10 min) (MJ ha<sup>-1</sup> mm<sup>-1</sup>);  $v_r$ : the rainfall volume during the predefined time interval (mm); r: predefined time intervals during the rainfall event; and  $I_{30}$ : the maximum rainfall intensity of the event during a period of 30 minutes (mm h<sup>-1</sup>). The unit of rainfall energy ( $e_r$ ) is computed for each predefined time interval as follows:

$$e_r = 0.29 (1 - 0.72 e^{-0.05i_r}) \tag{4}$$

where  $i_r$ : rainfall intensity during the predefined time interval r (mm h<sup>-1</sup>).

Due to unavailability of rain intensity data on half-hourly basis, however, the true rain intensity parameter ( $i_r$ ) was replaced by a 'simulated rain intensity' term, according to which rain intensity was set equivalent to the ratio of monthly rain volume over the number of rainy days during the same month. This approach was introduced and verified by Panagos et al., 2012 [3], as an alternative to possible lack of the originally required data; and after calibration to the current dataset, it was expressed as follows:

$$i_m = 1.4 \frac{v_m}{d_m} \tag{5}$$

where  $i_m$ : simulated rain intensity, equivalent to  $i_r$  for month m (mm/h);  $v_m$ : rain volume for month m; and  $d_m$ : number of rainy days for month m. Another assumption was that the rain events last one hour, on average, and only one significant rainfall event occurs during a rainy day. From the rain figures, it was also estimated that 70% of the rain volumes on average, occurred during the first hour of the rain events. Thus, adapting for the half-an-hour duration of the I<sub>30</sub> parameter to the hourly duration of  $i_m$ , the constant (0.7 × 2 = 1.4) of Equation (5) was resulted.

The computations of the simulated rain intensity values were made in excel spreadsheets for each of the 13 available stations separately. The year 2000 was selected as a reference year for the available records, with a view to emphasize possible effects of the climate change in the erosion patterns; and also, to match with vegetation and land cover data, which needed to be as recent as possible. Then, the estimated R-values per station were joined to the locations of the corresponding weather stations in a Geographic Information System (GIS).

Finally, the point R-values at the stations were interpolated with ordinary kriging to produce an R surface per month; specifically, a spherical model with 6 neighboring points was applied. All the  $R_m$  layers were produced with a 235-m cell size, resulted from the interpolation process parameters and the density of the weather stations, which was one station per 179 km<sup>2</sup> on average. The annual R-factor layer was produced by summing up the monthly R layers (Figure 7).



**Figure 7.** The computed annual R-factor layer and the locations of the available weather stations for the Candelaro river basin.

#### 3.3. V-Factor

For the estimation of vegetation retention (V-factor) per month, the G2 model has introduced an algorithm, based on vegetation indices and quantification of land cover from experimental data available by USLE and the Erosion Potential Model (EPM or Gavrilovic model). The equation for the computation of V-factor in G2, is as follows [26]:

$$V_{mi} = (1 - imp)^{-1} e^{LU \cdot FC_m} \tag{6}$$

where  $V_{mj}$ : V-factor for month m and land cover j, in range  $[1,+\infty)$  (dimensionless); *imp*: imperviousness degree corresponding to a range of 0–100% of soil sealing, in range [0,1) (dimensionless);  $LU_j$ : empirical parameter for land cover j, in range [1,10], with lower values corresponding to intensive management or unprotected land covers and higher values corresponding to better management conditions [26]; and  $FC_m$ : fractional vegetation cover for month m, in range [0,1] (dimensionless). The exponential shape of Equation (6) is imposed by the relation formed when C-factor values are plotted against plant cover experimental data of USLE [27].

Due to the fact that Sentinel2 images have the potential to detect vegetation on a high resolution compared to the low resolution of the original FCover layers (i.e., 10 m vs. 333 m or 1 km), use of the impervious degree parameter (*imp*) became unnecessary in the current study, and thus Equation (6) was simplified into the following one:

$$V_m = e^{LU \cdot FC_m} \tag{7}$$

The fraction cover layers (FC) for each month were created from the normalized difference vegetation index (NDVI) layers using a formula adapted from Baret et al. (2013) [46]:

$$FC = 1.62 NDVI^{2.1}$$
 (8)

NDVI is a simple and well-known biomass and vegetation vigor index, defined as the normalized difference of the red and near-infrared (NIR) wavelengths of the imaged features, thus ranging in [-1,+1]. Equation (8) was extracted from data derived from SPOT/VGT sensor with a 10-day temporal sampling and about 1-km pixel at equator and is valid for NDVI values up to 0.8 (CYCLOPES products; global coverage, Version 3.1) [46].

Band-4 and Band-7 of the Sentinel2 images were used as input for the red (665 nm) and NIR (783 nm) wavelengths, respectively, in the computation of the NDVI layers for each of the available dates. Then, the NDVI layers for the rest of the months, denoted by  $NDVI_m$ , were computed as a weighted average of the closest available computed NDVI:

$$NDVI_m = a NDVI_1 + b NDVI_2 \tag{9}$$

where  $NDVI_1$ : the closest previous month and  $NDVI_2$ : the closest following month of month m. As an example, NDVI of month April was computed as the weighted average of March and July NDVI layers, with weights: a = 0.75 and b = 0.25. By replacing  $NDVI_m$  in Equation (8) from Equation (9), it results in:

$$FC_m = 1.62 \left( a \, NDVI_1 + b \, NDVI_2 \right)^{2.1} \tag{10}$$

Finally, by replacing  $FC_m$  in Equation (7) from Equation (10), the V layer for every month is estimated as:

$$V_m = e^{1.62 \ LU \ (a \ NDVI_1 + b \ NDVI_2)^{2.1}} \tag{11}$$

The land use empirical parameter values (LU) were assigned to all the different third level CORINE Land Cover (CLC) categories found in the Candelaro basin according to the empirical values elaborated by Karydas and Panagos (2018) [26]. A LU value of 1 was assigned to mineral extraction sites (131) and to all the water surfaces; although the latter are by default non-erosive surfaces, G2 does not skip these

surfaces in mapping, due to the rough spatial detail of CLC, which might neglect small internal surfaces belonging to other categories. A LU value of 3.5 was assigned to vineyards (221). A LU value of 4.5 was assigned to tree and berry plantations (222 and 223, respectively); a LU value of 5.5 was assigned to arable land and associations of annual crops with permanent cultures (211 and 241, respectively); a LU value of 6.5 was assigned to mixtures of agricultural and natural land (243); a LU value of 5.5 was assigned to arable land and associations of annual crops with permanent cultures (211 and 241, respectively); a LU value of 6.5 was assigned to arable land and associations of annual crops with permanent cultures (211 and 241, respectively); a LU value of 7 was assigned to complex cultivation patterns, transitional woodlands, sparsely vegetated areas, and burnt areas (242, 324, 333, and 334, respectively); a LU value of 8 was assigned to natural grasslands (321); a LU value of 9 was assigned to sclerophyllous vegetation (323); a LU value of 9.5 was assigned to pastures (231); a LU value of 10 was assigned to urban, industrial and commercial units, transportation networks and installations, and all types of forests (111, 112, 121, 122, 124, 311, 312, and 313, respectively) (Table 2). All the V<sub>m</sub> layers were produced with a cell size of 10 m, following the resolution of Sentinel2 imagery. A mean V-factor layer was computed from the monthly ones (Figure 8).

CLC Code	LU Value	CLC Code	LU Value
111	10	243	6.5
112	10	311	10
121	10	312	10
122	10	313	10
124	10	321	8
131	1	323	9
211	5.5	324	7
221	3.5	333	7
222	4.5	334	7
223	4.5	411	1
231	9.5	421	1
241	5.5	511	1
242	7	512	1

Table 2. The LU parameter values assigned to the different Candelaro CORINE Land Cover (CLC) categories.



Figure 8. The mean V-factor layer computed from the monthly V layers for the Candelaro river basin.

#### 3.4. S-Factor

For the computation of soil erodibility (S-factor, denoted by K in USLE), the G2 model has adopted the equation introduced by Renard et al. (1997) [28], which is derived from the USLE dataset (and is resolved by the USLE nomographs) [27]:

$$S = 0.001317 \left[ 2.1 \cdot 10^{-4} M^{1.14} (12 - OM) + 3.25 (s - 2) + 2.5 (p - 3) \right]$$
(12)

where, *S*: soil erodibility (t ha h ha<sup>-1</sup> MJ<sup>-1</sup> mm<sup>-1</sup>); M: the textural factor defined as percentage of silt plus very fine sand fraction content (0.002–0.1mm) multiplied by the factor 100-clay fraction; *OM* is the organic matter content (%); *s* is the soil structure class (s = 1: very fine granular, s = 2: fine granular, s = 3, medium or coarse granular, s = 4: blocky, platy, or massive); and p is the permeability class (p = 1: very rapid, ..., p = 6: very slow).

Because the available soil texture and organic matter data from the current study area were only categorical and, thus, Equation (12) could not be resolved as it was, an alternative solution for S values estimation was followed. According to this alternative, which has been applied to several G2 applications [26], the textural factor (*M*) and the organic matter content (*OM*) terms of Equation (12) are replaced by another power-law term developed by Panagos et al. (2012) [3]:

$$S_c = S_0 e^{-0.1013 OM}$$
(13)

where  $S_c$ : soil erodibility value corrected for the organic matter content's effect,  $S_o$ : original soil erodibility value taken from an empirical table elaborated by Van der Knijff et al. (1999) [14], based exclusively on the soils' textural classes (Table 3); *OM*: organic matter content classes (1–4), with high class values corresponding to higher values of organic matter content.

Class	Description	Clay (%)	Silt (%)	Sand (%)	So
0	No information	-	-	-	
9	No texture (Histosols,)	-	-	-	
1	Coarse (clay $< 18\%$ and sand $> 65\%$ )	9	8	83	0.0115
2	Medium (18% < clay < 35% and sand > 15% or clay < 18% and 15% < sand < 65%)	27	15	58	0.0311
3	Medium fine (clay<35% and sand<15%)	18	74	8	0.0438
4 5	Fine (35% < clay < 60%) Very fine (clay > 60%)	48 80	48 20	4 0	0.0339 0.0170

Table 3. Soil erodibility values estimated according to textural classes (from Van der Knijff et al. (1999)) [14].

As a result of the above replacement, Equation (12) was transformed into the following equation (variables explained earlier):

$$S = S_{o}e^{-0.1013 OM} + 0.001317 [3.25 (s-2) + 2.5 (p-3)]$$
(14)

Equation (14) can also be used in other similar cases when only categorical input soil data are available in a test site. Finally, the computed *S* values at the sampled points were interpolated using the inverse distance weighting (IDW) methodology, to produce an *S* surface, which corresponds to the S-factor layer. IDW is an appropriate technique for large scale soil sampling, such as the one applied in Candelaro [47]. The S-factor layer was derived with a 200-m cell size, resulting from the specific interpolation process parameters and the density of the soil profiles, which was one station per 33.3 km<sup>2</sup> on average (Figure 9).



Figure 9. The computed S layer and the available soil profiles for the Candelaro river basin.

# 3.5. T-Factor

For a quantitative estimation of terrain influence (*T*, denoted by LS in USLE), G2 uses the Moore and Burch (1986) formula [48]:

$$T = \left(\frac{A_s}{22.13}\right)^{0.4} * \left(\frac{\sin\beta}{0.0896}\right)^{1.3}$$
(15)

Where  $A_s$ : flow accumulation (as a simulator of surface runoff) (m);  $\beta$ : slope angle (rad). The denominators and the exponents are suggested by Moore and Wilson (1992), as derived from the USLE experimental data [49]. This method is considered to estimate *T* values equivalent to those taken from the original USLE formulas [50].

The available DEM was used as input dataset for computing flow accumulation and slope layers (Figure 6). The spatial resolution of the DEM, i.e., 90 m, can be considered as satisfactory, because the area has a smooth terrain in general, with an average slope of 3 degrees and only 3% of the area higher than 15 degrees. The T-factor layer was produced with the same resolution (90 m), as the original resolution of the input DEM (Figure 10).



Figure 10. The computed T-factor layer for the Candelaro river basin.

# 3.6. L-Factor

Landscape effect (L-factor) expresses the possibility of linear landscape features to function as obstacles to water movement and thus interrupt surface runoff. As such, L-factor can be considered as inversely analogous to the support practice factor (P) of USLE formula. In addition, it can be seen as a corrective parameter to terrain influence (T-factor), specifically for slope length [51].

The L-factor in G2 is computed through a  $3 \times 3$  non-directional edge-detection filter, specifically a Sobel filter applied on the near-infrared (NIR) band of a high-resolution satellite image; NIR is usually the most spectrally variant among image bands. The result of image filtering is a new continuous type image layer (Sobel image).

Landscape features, which might intercept slope and are capable to be captured by a  $3 \times 3$  Sobel filter, include roads, paths, soil strips, fences, hedges, terraces, etc. Because of the corrective role of the L-factor in the main G2 equation, L-values are usually only slightly over 1, and by default less than 2. The standard G2 formula for L-factor estimation is as follows [26]:

$$L = 1 + \sqrt{\frac{S_f}{S_{fmax}}} \tag{16}$$

where, *L*: landscape effect in range [1,2] (dimensionless);  $S_f$ : Sobel 3 × 3 filter value in range [0,  $S_{fmax}$ ] (dimensionless). For the computation of the Sobel filter image, the Sentinel2 image of March was used, as it was the clearest and the richest in landscape alternations. Then, Equation (15) was applied with the derived Sobel image, resulting in the L-factor layer (Figure 11).



Figure 11. The computed L-factor layer for the Candelaro river basin.

# 4. Results

The soil erosion patterns were mapped in Candelaro by implementing the G2 model into a GIS environment. The erosion layers were produced at 10-m cell size, following the resolution of the Sentinel2 images, which was the finest among the input datasets. All the other input layers with lower resolution, such as the LU layer of 100-m (as derived from CORINE Land Cover), or the T-factor layer of 90-m (as derived from the DEM), as well as the interpolated outputs from points (i.e., the R-factor and S-factor layers) were resampled to 10-m resolution layers in order to match spatially with the V-factor layers and the T-factor layer, which originated from the 10-m resolution Sentinel2 images.

After the computation of the monthly erosion maps, the erosion rates were classified into seven groups, according to the Pan-European Soil Erosion Risk Assessment (PESERA) model literature [4]; these groups are (from lower to higher): 0–0.5, 0.5–1, 1–2, 2–5, 5–10, 10–20, and > 20 t ha<sup>-1</sup>. Grouping values allows easier inspection of the erosion maps and better understanding or erosion spatial patterns; moreover, when a fine resolution of 10 meters is available as in the current study. The annual erosion layer was produced by summing up the monthly erosion layers (Figure 12).

The mean annual soil loss rate derived with the G2 model for the area of Candelaro was found to be 0.87 t ha<sup>-1</sup>. The maximum annual value was 210 t ha<sup>-1</sup> and the minimum 0. The mean erosion values per month were found to range from 0.03 t ha<sup>-1</sup> for May up to 0.12 t ha<sup>-1</sup> for September. The very eastern and western parts of the basin show clearly to be more threatened by erosion than the central parts. This could be attributed to the topographic nature of the basin (see Figure 9). In fact, the central part of the basin is flat, in contrast to the sides, which are hilly or mountainous areas.

In addition, the application of the G2 model in Candelaro made it possible to identify soil erosion changes between months; thus, allowing seasonal comparisons. All months from September, October, November, December, and June showed to be the most erosive months over the year. The maximum erosion values per month were found to range from 6.69 t ha<sup>-1</sup> for July up to 27.3 t ha<sup>-1</sup> for November (Table 4).



Figure 12. The annual erosion map for the Candelaro river basin.

**Table 4.** Statistics of monthly erosion (t ha<sup>-1</sup>) derived with the G2 model for the Candelaro river basin.

Month	Jan	Feb	Mar	Apr	May	Jun
Mean	0.05	0.03	0.05	0.06	0.03	0.09
Std	0.21	0.18	0.26	0.24	0.10	0.30
Max	12.7	16.8	12.3	17.6	7.3	21.2
Month	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.06	0.05	0.12	0.11	0.11	0.10
Std	0.17	0.15	0.40	0.39	0.42	0.41
Max	6.7	7.1	24.8	22.4	27.3	26.8

The contribution of each month to the overall spatial distribution of erosion figures in the Candelaro river basin was found generally equivalent in terms of magnitude, with only slight differentiations. However, it seems to differ in spatial distribution; for example, in June, September, November, and December, the mountainous areas show to have higher erosion values than the plains (Figure 13). In general, the seasonal alterations showed to be affected mainly by rainfall erosivity figures rather than vegetation or land use changes (Figure 14).





April

0

10

February

15°40'E







June





41°40'N

41°20'N

20 km



Figure 13. Monthly erosion maps for the Candelaro river basin (refer to the legend of Figure 12).



**Figure 14.** Mean monthly figures of rainfall erosivity and vegetation retention (left axis; logarithmic), vs. erosion (right axis; linear) for the Candelaro river basin.

# 5. Discussion

The current study was the first erosion study in the area; thus, providing a reference for future assessments. Soil erosion does not appear to be a major problem in the study area and quite limited to some spots mostly in the sloping areas. However, erosion is still a problem, even if it concerns limited areas (Figure 15).



Figure 15. Erosion signs in a sloping cropland near Volturino, Province of Foggia (Photo credit: P. Zdruli).

The riskiest land covers for erosion in the Candelaro river basin were found to be the lands principally occupied by agriculture (CLC code 243), the olive groves (CLC code 223) and the burnt areas (CLC code 334). The burnt areas were the riskiest land cover on an annual basis, with a value of 3.90 t ha<sup>-1</sup>, and the monthly values varying from 0.42 t ha<sup>-1</sup> in December to 0.57 t ha<sup>-1</sup> in September. However, the specific surfaces were very limited (0.88 Km<sup>2</sup>) in the Candelaro river basin during the study period and moreover, they change rapidly over time. The agricultural-natural mixtures (CLC code 243) show noticeable erosion risk figures (2.88 t ha<sup>-1</sup>), but they also keep a small share in the land of Candelaro (28.3 Km<sup>2</sup>); this category revealed to contain the riskiest surfaces for most months of the year. Finally, the olive groves show also noticeable values throughout the year, with an annual erosion

rate of 2.04 t  $ha^{-1}$ ; at the same time, they occupy a significant part of Candelaro than the previous two (100.5 Km<sup>2</sup>).

On an annual basis, land covers in the Candelaro river basin, which demonstrate erosion risk higher than the annual average (i.e., larger than 0.87 t ha<sup>-1</sup>) and at the same time cover a significant surface (more than 5 Km<sup>2</sup>) include non-irrigated arable land (CLC code 211), olive groves (CLC code 223), natural grasslands (CLC code 321), sparsely vegetated areas (CLC code 333), small forested surfaces, as well as other types of cropland. It is noticeable that one third of the olive groves, natural grasslands, sclerophyllous vegetation surfaces, sparsely vegetated surfaces, and mixtures of cropland with natural patches, half of the agricultural-natural mixtures, and almost one fifth of the arable land are more erosive than the average on an annual basis (Table 5).

CORINE Land Cover Category	Erosive Extent (Km <sup>2</sup> )	Erosive % of the Class
211 (Non-irrigated arable land)	282.5	18.1
221 (Vineyards)	8.9	8.6
223 (Olive groves)	37.2	36.7
241 (Annual with permanent crops)	9.2	26.7
242 (Complex cultivation patterns)	11.4	8.1
243 (Agricultural-natural mixtures)	13.0	46.8
311 (Broad-leaved forests)	8.8	13.0
321 (Natural grasslands)	22.1	34.1
323 (Sclerophyllous vegetation)	13.5	29.1
333 (Sparsely vegetated areas)	21.5	34.7
Total/Average	427.9	19.4

**Table 5.** Extents for erosion rates higher than the annual erosion mean (0.87 t  $ha^{-1}$ ) per CORINE Land Cover category in the Candelaro river basin.

The generally low erosion figures in the Candelaro basin derived with the current study seem to differ from the moderate to high values  $(5-10 \text{ t ha}^{-1})$  reported for the entire regional unit of Foggia by the Joint Research Centre (reference year: 2010) [2]. However, this difference could be justified by the fact that the two assessments have been conducted at completely different spatial and temporal scales (i.e., the entire regional unit vs. only the Candelaro river basin; and annual vs. monthly assessments). In addition to that, JRC's assessment was focused only on agricultural lands, in contrast to the current, which is generic for all existing land covers.

For the first time, the G2 model was applied using a new satellite image type, namely Sentinel2, concluding with an invention of a new alternative for estimating the V-factor. When there are not cloud-free images for all months, weighted averaging of vegetation cover layers derived from the available cloud-free Sentinel2 images can be computed for the missing months.

# 6. Conclusions

In this research, the Candelaro river basin in Apulia region (Italy) was mapped for soil erosion on a month-time interval, using the G2 model, in a Geographic Information System (GIS), and Remote Sensing modelling framework. The study achieved to reveal the specific contribution of every land cover to soil loss, especially regarding the seasonal changes of rain intensity and vegetation cover.

The mean annual soil loss rate was found to be 0.87 t ha<sup>-1</sup>. The seasonal balance of erosion risk was mainly for autumn months, but also for December and June. Burnt areas, mixed agricultural-natural surfaces, and olive groves grown in the hills proved to be the riskiest land covers in the area. Arable land was the most extensive land cover with erosion figures higher than the mean annual rate.

Soil erosion is not a widespread problem in the study area. However, considering that in specific locations, months, and land covers, erosion exceeds alarm rates (i.e., 10 t ha<sup>-1</sup>), the entire area should be put under careful monitoring, and emphasis should be given to sustainable land management measures.

With the rising number of available cloud-free Sentinel2 image scenes, the new alternative for V-factor computation introduced in this study appears to be suitable for future erosion assessments with G2, or other empirical models.

One more time, the (now, revised) G2 model proved to work as a rapid, robust, and—at the same time—flexible mapping tool. Moreover, it shows to be an appropriate solution for expanding erosion assessments in the whole Apulia region.

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