## ANNEX I. TOOL METHODOLOGY

The objective of this tool is to improve the accuracy of European level soil vulnerability maps at a European level (using a pixel size of 25 m) based on remote sensing. This improvement is very important in order to effectively monitor and quantify erosion risks, which is essential to take into account when making planning decisions, establishing protective and prevention measures, etc. In particular, the potential of LiDAR data for the development of high resolution Digital Terrain Models (DTM) opens up new possibilities for the analysis of erosive factors that depend on the topography of the terrain.

Amongst the most frequently used models for soil erosion risk assessment is the Revised Universal Soil Loss Equation (RUSLE). In the case described here, we develop a tool to calculate the LS factor (Slope Length and Steepness factor), which shows the effect of topography on soil erosion. This is achieved by merging the S-Factor –which measures the effect of slope steepness– and the L-Factor –which defines the impact of slope length.

### 1. DATA

Two data sources were used to design this tool:

- LiDAR data: free LiDAR data from CNIG (Centro Nacional de Información Geográfica, Spanish National Centre for Geographic Information, Spanish Ministry of Public Works and Transport), specifically data from flights in 2012 taken from the Plan Nacional de Ortofotografía Aérea (PNOA, Spanish National Plan for Aerial Orthophotography), with an average density of 0.5 points/$m^2$.
- Maps from the European Soil Data Center (ESDAC) of the European Commission from which were taken the other factors relating to the RUSLE equation: rainfall erosivity factor (R), soil erodibility factor (K), cover-management factor (C) and support practice factor (P).

### 2. METHODOLOGY

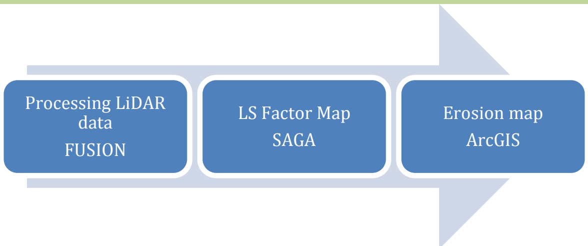



*Fig. 1. Workflow to develop a soil erosion vulnerability map*

1. For the processing of the LiDAR data the *Fusion* software of the American Forest Service was used, following these steps:

   - Review of the quality of the LiDAR data through the command *Catalog* of *Fusion*.
   - Selection of pixel size. For this, the minimum return density of LiDAR data was taken into account, in order to have at least one return per pixel. Considering

the density of LiDAR points, the minimum size should be 2 m. However, to ensure higher density in order to obtain an appropriate digital terrain model (DTM), and taking into account the pixel size of the ESDAC cartography, a pixel size of 5 m was chosen. This step is important especially for the S-factor, since slope decreases as cell size increases (Molnar & Julien, 1998).

- Generation of the DTM in raster format using the GridSurfaceCreate command (using the points classified as ground). This raster in DTM format was transformed with the dtm2ascii tool in ascii format to enable subsequent work to be done in Geographical Information Softwares (GIS).

2. To estimate the LS factor, SAGA software was used as it includes numerous applications such as those focused on DTMs, hydrology and terrain analysis.
    - DTM (ascii format) was imported into SAGA and saved as a grid. Then, using the Fill Sinks tool (Planchon & Darboux method, 2001), the depressions were filled. Often the sinks represent errors due to the resolution of the data, or the rounding of elevations to the nearest whole value, which is why it is necessary to fill these depressions or sinks, thus guaranteeing the correct representation of basins and streams.
    - A slope map was created with the *Slope, Aspect, Curvature* tool of SAGA, using 9 parameters and a 2nd degree polynomial of Zevenbergen & Thorne (1987).
    - To generate collection area or flow accumulation, the Flow Accumulation tool was used, using the DEMON method, available in SAGA, using the MDT as a base without depressions.
    - In SAGA there are three different algorithms for calculating the LS factor. In this project the original equation of Desmet & Govers (1996) was used, implemented in SAGA, which incorporates a multiple flow algorithm and helps to estimate the flow accumulation estimation (Panagos et al., 2015).
    - Delimitation of the basin in a shape-type file. To do this we started with the DTM with the filled depressions created previously. The delimitation of the basin was made with the SAGA Upslope Area Interactive tool, for which it is necessary to obtain the channel network in advance using the Channel Network tool.
3. ArcGIS: the estimation of soil losses using the RUSLE equation was made in ArcGIS software. As starting data, ESDAC maps of R, K, C and P factors, the LS factor map developed in the last step and basin shape were used. The workflow for this is the following:
    - Reprojection to the same coordinate system using the *Project* tool.
    - Resampling of maps from ESDAC to a 5 m pixel size using the *Resample* tool and a variety of techniques depending on the type of data (continuous or discrete). In this case the Nearest technique was chosen for the factors C and P (discrete values) and the bilinear technique for R and K (continuous).
    - Using *Extract by mask* of ArcGIS, with the rasters of factors and basin shape, the rasters of the different factors were obtained at basin level.
    - Revised Universal Soil Losses Equation (RUSLE): using *Raster Calculator* ArcGIS, to multiply R, K, LS, C and P and to obtain a raster of 5m pixel with the estimated soil losses per year.

## 3. CASE STUDY: LS FACTOR ESTIMATION IN RIO NEGRO BASIN

A pilot basin –the Río Negro basin (municipality of Valdés, Asturias) (Fig. 2)- was chosen for the methodological development because it is very representative of the area, with steep slopes and varying vegetation cover, mostly forest land. In addition, this area suffers frequent forest fires, which increases its vulnerability to erosion processes.

The lithology of the region comprises: sandstones (24%), limestone (1.6%), quartzites (59%) and slate (15%). Rainfall is abundant throughout the year: the average annual total rainfall ranges from 973 mm to 1,718 mm. Temperatures are typical of a temperate climate, with average annual temperatures ranging between 10.8 °C and 13.3 °C.
LiDAR data was downloaded from CNIG (121 LAZ archives with 2x2 km$^2$) and European level maps of R, K, C, and P-factors (ESDAC) (Fig. 3).

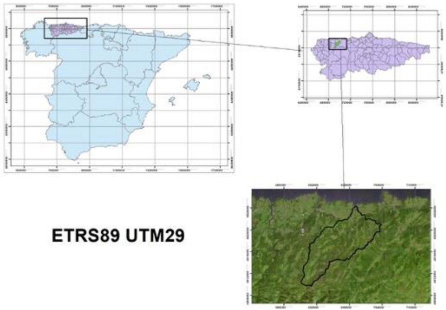
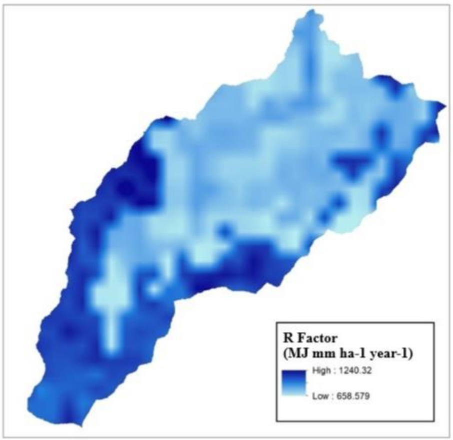
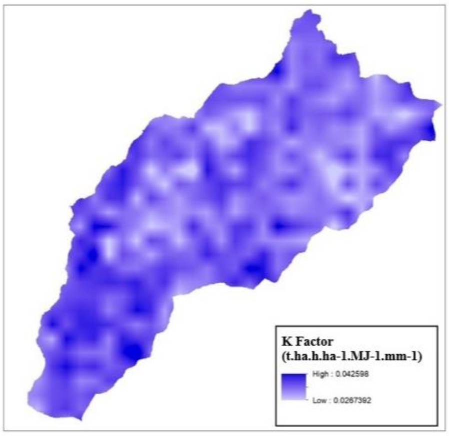



*Fig. 2. Location of the study area.*



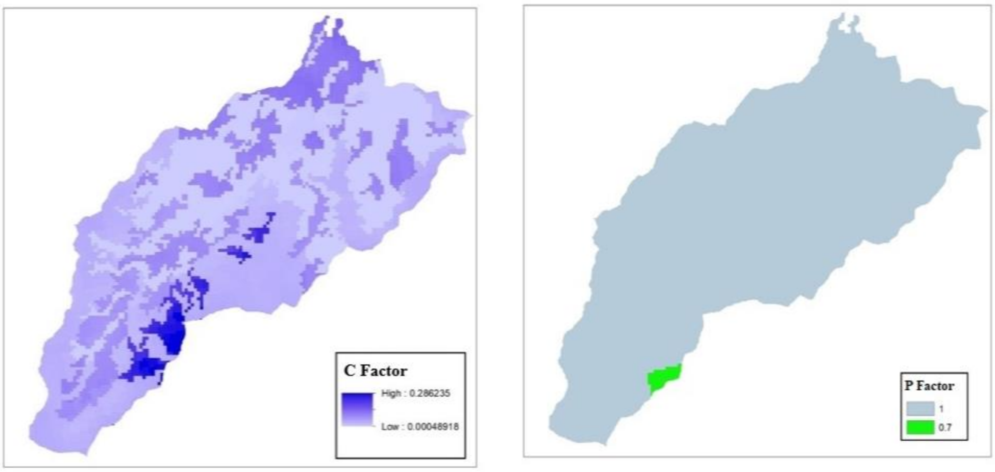



*Fig. 3. R, K, C, and P-factors maps from European Soil Data Center (ESDC) for the study area.*

As a step prior to calculating the LS factor, a slope map was created (Fig. 4) after which LS was calculated using Desmet & Gobers (1996) algorithm (which was also used in the LS factor map from ESDAC). The area of the river basin which corresponds to each level of the LS factor is shown in Table 1.

*Table 1. Summary of LS values and their corresponding areas.*

| LS Factor | Area (ha) | Area (%) |
|---|---|---|
| 0 – 3 | 1,181.40 | 13.34% |
| 3 – 5 | 1,147.33 | 12.95% |
| 5 – 7 | 1,640.40 | 18.52% |
| 7 – 9 | 1,960.87 | 22.14% |
| 9 – 11 | 1,588.30 | 17.93% |
| 11 – 13 | 777.11 | 8.77% |
| 13 – 15 | 288.56 | 3.26% |
| 15 – 17 | 119.64 | 1.35% |
| 17 – 19 | 57.03 | 0.64% |
| >19 | 96.57 | 1.10% |

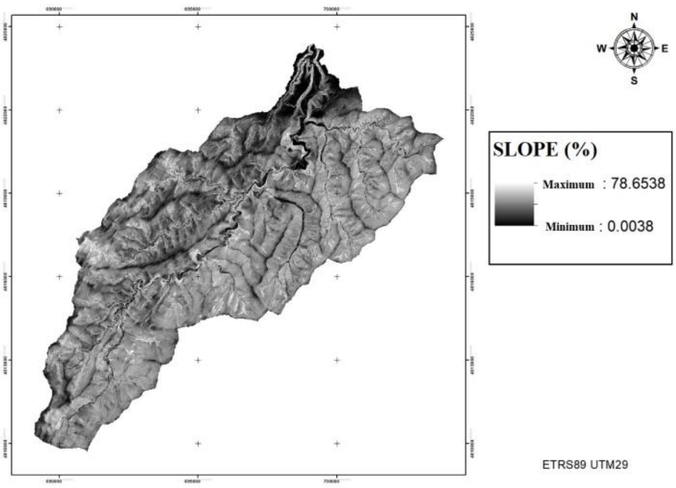


*Fig. 4. Slope map.*

The pilot basin covers 8,857.18 hectares, and has an average slope of 24.87% and maximum slope of 78.65%. The values obtained for LS factor were between 8.82 and 183.56, the average being 7.49. Table 2 shows a comparison of descriptive statistics of the SL factor between the results of the Plurifor tool and those in the ESDAC map.

*Table 2. Summary of statistical data relating to LS in the two maps.*

| Maps | Min. | Max | av | Std. Dev. | CV |
|---|---|---|---|---|---|
| ESDAC map | 0.04 | 65.71 | 6.20 | 3.23 | 0.52 |
| PLURIFOR map | 8.82 | 183.56 | 7.49 | 4.15 | 0.55 |

It can be seen from the comparison that both the mean and the standard deviation vary by almost one unit between maps, while there are large differences in the maximum and minimum values. This is due to the fact that the PLURIFOR map has better resolution (pixel size of 5 meters, compared to 25 meters in the ESDAC map), meaning that steeper areas are represented with greater accuracy because at lower resolutions the values are smoothed. Another factor contributing to this difference is that in calculating the data for the ESDAC map the estimation of this factor is limited to areas with a slope of less than 50%, while in this project no such limit was imposed and so areas with very steep slopes have much higher values of LS.

The higher the DTM resolution, the better the characteristics of the landscape will be observed, the more accurately the topographic factor of soil erosion will be represented and therefore estimates of soil losses due to erosion will be closer to the real values. This all underlies the utility and value of this new tool in planning actions to minimize the risk of soil erosion.

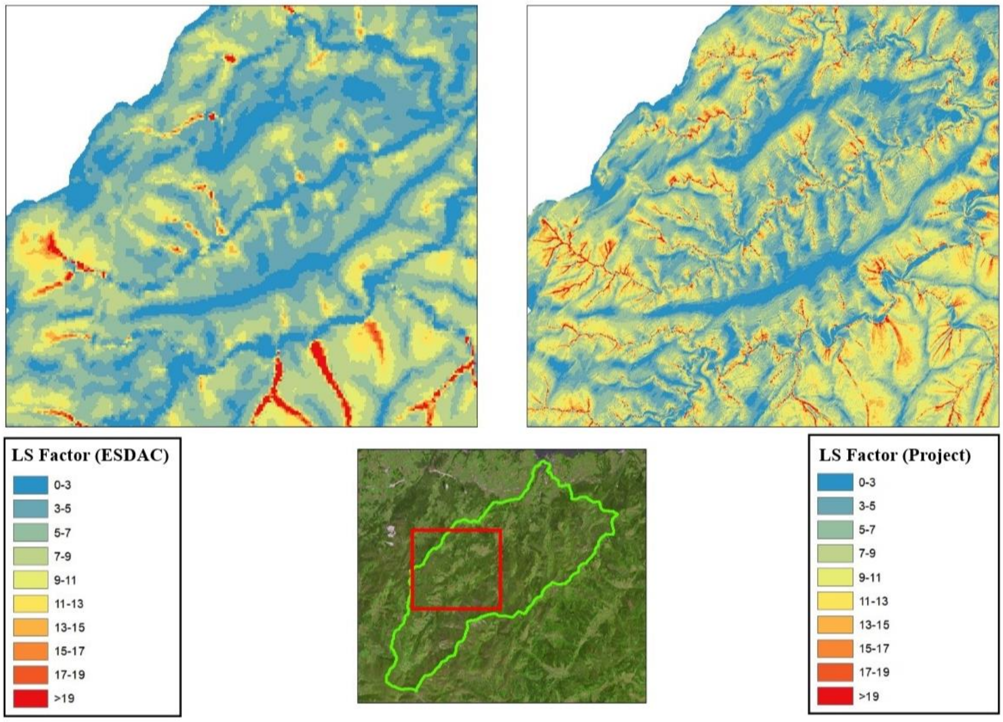



*Fig. 5. Comparison of LS factor in ESDAC map (left) and the map produced in this Project (right)*

The main limitation of the methodology used to calculate the LS factor with this tool is the existence of various elements in the landscape (roads, tracks, fences, stone walls, etc.) which can interrupt water flow and thus reduce slope length, but which are not identified in the DTM (Panagos et al., 2015).

**SOIL EROSION LOSSES MAP (RUSLE)**

Figure 6 shows soil losses in $t.ha^{-1}.year^{-1}$ in the Rio Negro basin with a pixel size of 5 m.

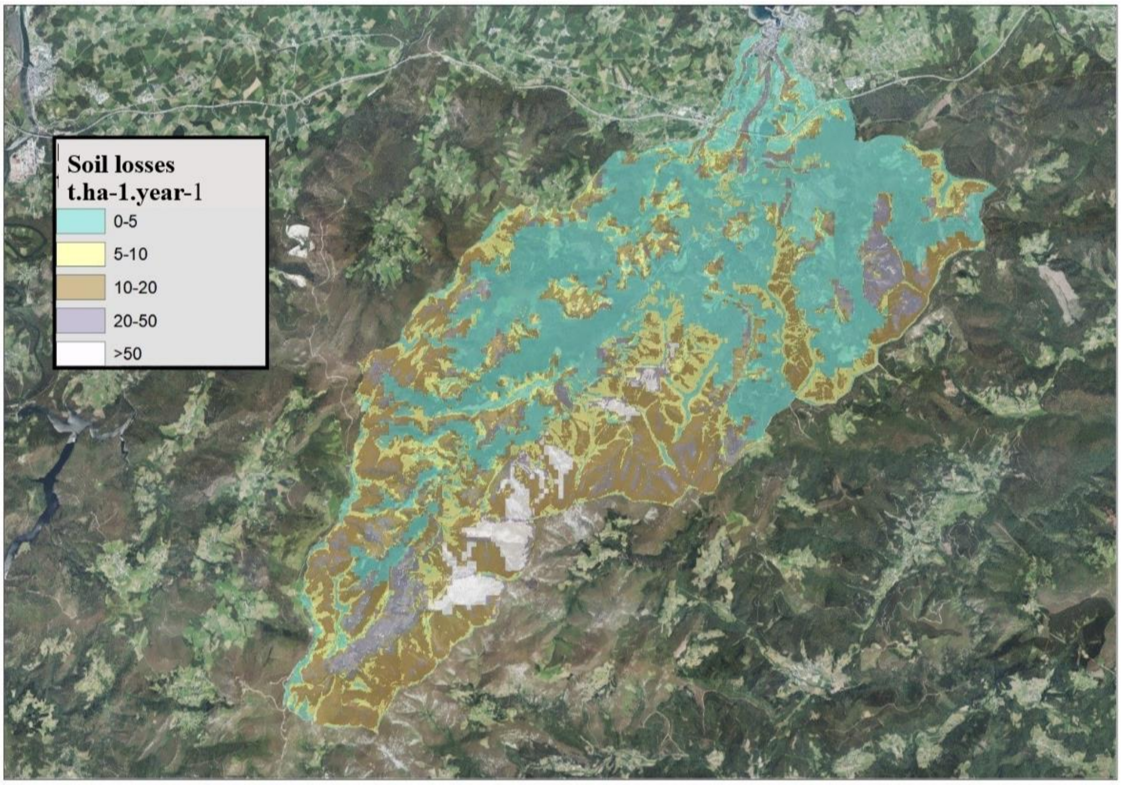



*Fig. 6. Soil losses map ($t.ha^{-1}.year^{-1}$) in Rio Negro basin in Valdés (Asturias).*

The LS map has a pixel size of 5 m, but the other RUSLE factors have a pixel of between 100 m and 1 km, so it is necessary in the future to increase the spatial resolution of the other factors at basin level. Table 3 shows a summary of soil erosion values and the surface area affected.

*Table 3. Summary of erosion values and size of area affected.*

| Erosion ($t.ha^{-1}.year^{-1}$) | Area (ha) | Area (%) |
|---|---|---|
| 0 – 5 | 3,813.61 | 43.18 |
| 5 – 10 | 1,367.22 | 15.48 |
| 10 – 20 | 2,376.53 | 26.91 |
| 20 – 50 | 948.28 | 10.74 |
| >50 | 326.34 | 3.69 |

Average soil loss for this area is 11.55 $t.ha^{-1}.year^{-1}$. Values higher than 50 $t.ha^{-1}.year^{-1}$, represent less than 4% of the total area.

In relation to the percentage of land area affected by the different levels of soil loss and according to the FAO-UNEP-UNESCO classification (1980), 58.66% of the area suffers from low erosion (**0-10 $t.ha^{-1}.year^{-1}$**), 37.65% has moderate erosion (**10-50 $t.ha^{-1}.year^{-1}$**), while high or very high erosion **(>50 $t.ha^{-1}.year^{-1}$)** only affects 3.69% of the area. However, according to Verheijen et al. (2009) average soil formation in Europe is 1.4 $t.ha^{-1}.year^{-1}$, meaning that in the Rio Negro basin more than 50% of the area is affected by levels of erosion that do not allow for the recovery of the soil.

The high values of erosion obtained here are due in large part to the orography of Asturias, the repeated occurrence of forest fires and the traditional systems of agriculture employed in the area that leave the ground uncovered by vegetation for a large part of the year since vegetation cover is one of the most important impediments to erosion by water.

## 4. CONCLUSION

This tool allows the accuracy of calculating soil loss values to be improved thanks to the use of a DTM with higher resolution than that used by the European Soil Data Center (ESDAC) in European maps, thereby greatly assisting in decision-making and the planning of prevention measures. However, this tool is not suitable on its own for make definitive decisions, and the use of local measurements and data is recommended. It is also very important to note that this map and its values should be renewed every so often, since both the R factor (rain erosivity) and the C factor (vegetation cover) of the RUSLE equation vary seasonally, meaning that it is vitally important to update the information at least annually.

It is also important to create a higher resolution map for factor C, which together with LS, is the factor that most affects soil erosion. The calculation of factor C could be developed with LiDAR data, which allows the estimation of vegetation coverage and strata.

The fact that the methodology developed here is based on maps at the European level (ESDAC), allows its application to other European countries, especially those regions involved in the European project INTERREG PLURIFLOR.