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How the EU Soil Observatory contributes to a stronger soil erosion community

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ABSTRACT

New policy developments have emerged in relation to soil conservation after 2020. The Common Agricultural Policy (CAP) 2023–2027, the proposal for a Soil Monitoring Law and the mission 'A Soil Deal for Europe' have shaped a new policy framework at EU level, which requires updated assessments on soil erosion and land degradation. The EU Soil Observatory (EUSO) successfully organised a scientific workshop on '*Soil erosion for the EU*' in June 2022. The event has seen the participation of more than 330 people from 63 countries, addressing important topics such as (i) management practices, (ii) large scale modelling, (iii) the importance of sediments in nutrient cycle, (vi) the role of landslides and (v) laying the foundations for early career scientists. As a follow up, among the 120 abstracts submitted in the workshop, we received fifteen manuscripts, out of which nine were selected for publication in the present special issue. In this editorial, we summarize the major challenges that the soil erosion research community faces in relation to supporting the increasing role of soils in the EU Green Deal.

1. Background

Soil erosion is a significant threat to food security as it may reduce crop productivity and lead to the loss of agricultural land (García-Ruiz et al., 2017). Soil erosion is a global problem, with about 80 % of current agricultural land degradation being affected by it (Hossain et al., 2020). The economic impact of soil erosion can be substantial, with an estimated annual costs of eight billion US dollars to global GDP (Sartori et al., 2019). To address this issue, it is important to better understand the relationships between on-site and off-site consequences of soil erosion and to implement effective soil conservation measures.

The main objective of this editorial is to present the developments in the soil erosion community as discussed in the EU Soil Observatory workshop on soil erosion in June 2022.

2. Policy developments and challenges for soil erosion within the EU Green Deal

In recent work (Panagos and Katsoyiannis, 2019), it was described how the main focus of the policy drivers for soil conservation in the European Union before 2020 were the Common Agricultural Policy (CAP), the Sustainable Development Goals (SDGs) and the Soil Thematic Strategy (2006). In 2020, the European Commission puts healthy soils at the core of the European Green Deal to achieve climate neutrality, zero

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pollution, sustainable food provision and a resilient environment (Montanarella and Panagos, 2021). However, none of the objectives of the EU Green Deal is related to soil conservation unlike carbon sequestration, soil contamination and soil biodiversity.

Within the European Common Agricultural Policy (CAP), the main instruments addressing soil management explicitly are the 'Good Agricultural and Environmental Condition' (GAEC) standards and the agri-environment and climate measures (AECMs) (Bartkowski et al., 2021). Ecoschemes is one of the new elements of the CAP 2023-27 supporting farmers in adopting practices that minimise the negative impact of agriculture on the environment and climate (including soil protection), and help them evolve towards more sustainable farming models (Cuadros-Casanova et al., 2023). The 2023–2027 CAP includes some provisions for soil conservation, especially by three GAECs on soil erosion risk management and soil cover, and certain targeted voluntary measures. Banning of burning arable stubble (GAEC 3), tillage management (GAEC 5) and minimum soil cover (GAEC 6) contribute to soil conservation (Fig. 1).

Based on scientific evidence, 60–70 % soils in the EU are currently in an unhealthy state (Veerman et al., 2020). All Member States of the EU face land degradation with Mediterranean countries suffering the most (Ferreira et al., 2022). The European Commission has proposed the Soil Monitoring Law in July 2023 with four objectives: a) provide a clean common definition of soil health b) put in place a solid and coherent monitoring framework c) make sustainable soil management the norm and d) identify and investigate potential contaminated sites (European Commission, 2023). The proposal recognizes that 24 % of all EU lands (32 % of agricultural lands) suffers from unsustainable water erosion (>2 t ha^{-1} yr^{-1}) mainly in cropland with projections referring to possible increase of 13–25 % by 2050 (Panagos et al., 2021). However, the proposal also underlines that other soil erosion processes should be also quantified and considered in EU soil protection policies. According to a recent modelling assessment (Borrelli et al., 2023), water erosion is the main contributor to soil erosion processes in the EU, but tillage erosion, wind erosion and soil loss by crop harvesting still play a relevant role, especially in some European regions. Soil erosion is one of the eleven soil descriptors (indicators) to monitor in the proposal for the Soil Monitoring Law (European Commission, 2023). It is also among the four descriptors with criteria for healthy soil condition established at Union level (current proposal for a threshold at 2 t ha^{-1} yr^{-1}).

In September 2021, the European Commission adopted five Research and Innovation Missions (within HORIZON Europe) to bring concrete solutions in response to major societal challenges delivering tangible results by 2030. 'A Soil Deal for Europe' is one of the five EU missions and aims to lead the transition to healthy soils by 2030. Establishing a network of one hundred living labs in rural and urban areas will advance the development of a harmonized soil monitoring framework and increase the awareness of the importance of soil (Löbmann et al., 2022; Panagos et al., 2022b). The Mission 'A Soil Deal for Europe', with a total budget of 1 billion Euros, will play a crucial role in developing and sharing the knowledge on soil health. The Soil Mission has set eight objectives and the 'soil erosion prevention' is among them. In addition, the Soil Mission has proposed eight soil health indicators to monitor progress for soil health, including specifically soil erosion (Fig. 1).

As a common ground for all policy developments, there is an urgent need for updated and more frequent assessments of soil erosion at European scale, updated indicators to better monitor soil erosion, enhanced knowledge of all erosion processes (water, wind, gully, tillage, piping, landslides, crop harvesting, etc.) and the effectiveness of best management practices to mitigate erosion based on different pedo-climatic conditions and cropping systems in Europe.

3. Establishment of the EUSO and the working group on soil erosion

In the policy context of the EU Green Deal, the European Commission

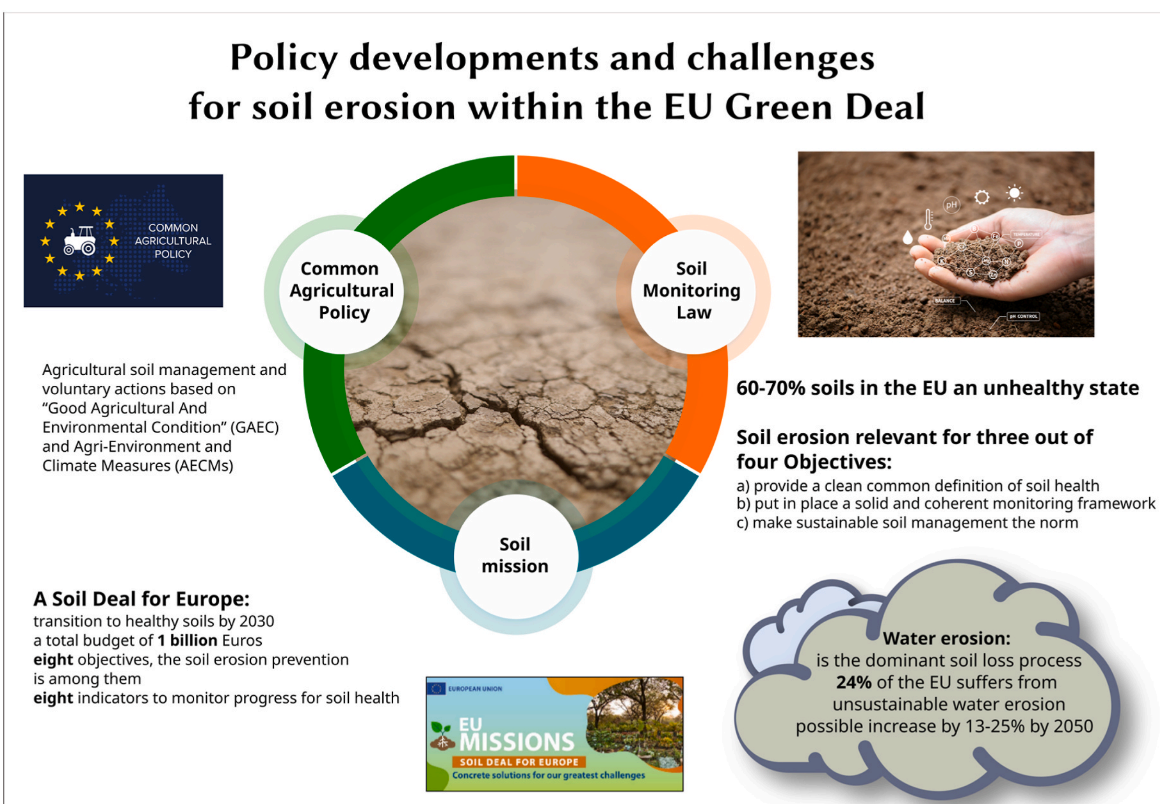

Fig. 1. Main policy drivers for soil erosion developments in the EU.

has established the EU Soil Observatory (EUSO) to support the implementation of the above-mentioned emerging soil related policies. The EUSO was established in 2021 and one of its key elements are the six Working Groups aiming to discuss technical advances on a particular topic, i.e., soil erosion, data sharing and integration, soil pollution, soil monitoring, soil biodiversity and carbon monitoring, reporting and verification. Co-chaired by EUSO staff and external partners, the Working Groups are composed of experts from academia, businesses or policy experts with recognised experience in the topic. The EUSO Working Groups (WG) develop their individual work agenda with a view to provide relevant advances to current scientific and policy questions.

The technical working group on Soil Erosion includes more than 50 members. The objectives of the Soil Erosion WG are to develop an object oriented (bottom-up) approach for estimating soil erosion and erosion-related soil health indicators at farm scale. In addition, the WG develops integration of soil erosion with complementary issues such as soil contamination, nutrient losses and food security. Finally, the WG proposes ways to improve large-scale assessments on soil erosion and recommends sustainable soil conservation practices.

Among the major achievements of the Soil Erosion WG are:

- The EUropean SEDiments collaboration (EUSEDcollab) database which contains a compilation of data contributions from monitored catchments across multiple European institutions (Matthews et al., 2023).
- The quantification of off-site costs of removing sediments contributing to the impact assessment of the Soil Monitoring Law (Panagos et al., 2024). It was estimated that removing more than 1 billion of m^3 of sediments due to erosion may costs about 5–8 billion euro per year.
- The database of multiple concurrent soil erosion processes (Borrelli et al., 2023). This first-ever assessment at European scale combines the threat of water, wind, tillage and crop harvesting to reveal their cumulative impact on arable land. It is a basis for developing a comprehensive monitoring system for soil health.
- The Global Applications of Soil Erosion Modelling Tracker (GASEMT; Borrelli et al., 2021). The GASEMT database provides comprehensive insights into the state-of-the-art of soil-erosion models and model applications worldwide.

4. Workshop on soil erosion for the EU

In June 2022, the EUSO WG on soil erosion organised an online workshop ‘Soil erosion for the EU’. More information about the workshop and the relevant presentations can be found here: https://esdac.jrc.ec.europa.eu/euso/euso-wg-soil-erosion-europe. There was a call for presentations which received more than 120 abstracts, out of which 69 selected for oral presentations.

During the workshop, 333 scientists and stakeholders from 63 countries debated about future soil erosion challenges. Two thirds of the participants were from EU countries, being the remaining share of participants of high importance for extending the scientific debate beyond the EU borders. The vast majority of the participants was from research and scientific community (69 %), with a good appreciation of students (12 %) and private sector and national administrations (9 %).

The workshop was organised in eight thematic areas: i) Soil erosion and climate change, ii) large scale modelling, iii) farm and field scale modelling, iv) erosion mitigation and management practices, v) sediments, vi) landslides vii) food security and nutrient losses and viii) early career research in soil erosion (Fig. 2). In the following paragraphs we summarize the main outputs of each thematic area.

Soil erosion models are increasingly being used to assess the impact of climate change on soil erosion. This is largely driven by the increased availability of climate change projections based on the Representative Concentration Pathways (RCPs) (Eekhout and de Vente, 2022; Panagos et al., 2022a). These assessments show that climate change will cause a significant increase (33–66 %) in soil erosion at a global scale. However, soil conservation measures, such as reforestation, reduced/conservation/no tillage and structural measures can significantly reduce the impact on soil erosion. Still, there remain some challenges with respect to the methodologies applied in these assessments. Eekhout and de Vente (2022) recommend the use of a climate model ensemble of at least five climate models, trend preserving bias-correction methods and a soil erosion model forced by precipitation and runoff. Moreover, only 15 % of the studies apply land use change scenarios, which urges to incorporate land use and socio-economic changes in climate change assessments, for instance based on the Shared Socio-economic Pathways (SSPs) (Fig. 3).

In the large scaling modelling session, the results of multiple modelling experiences were presented. Besides RUSLE-type models that

Fig. 2. The Soil erosion workshop in a nutshell.

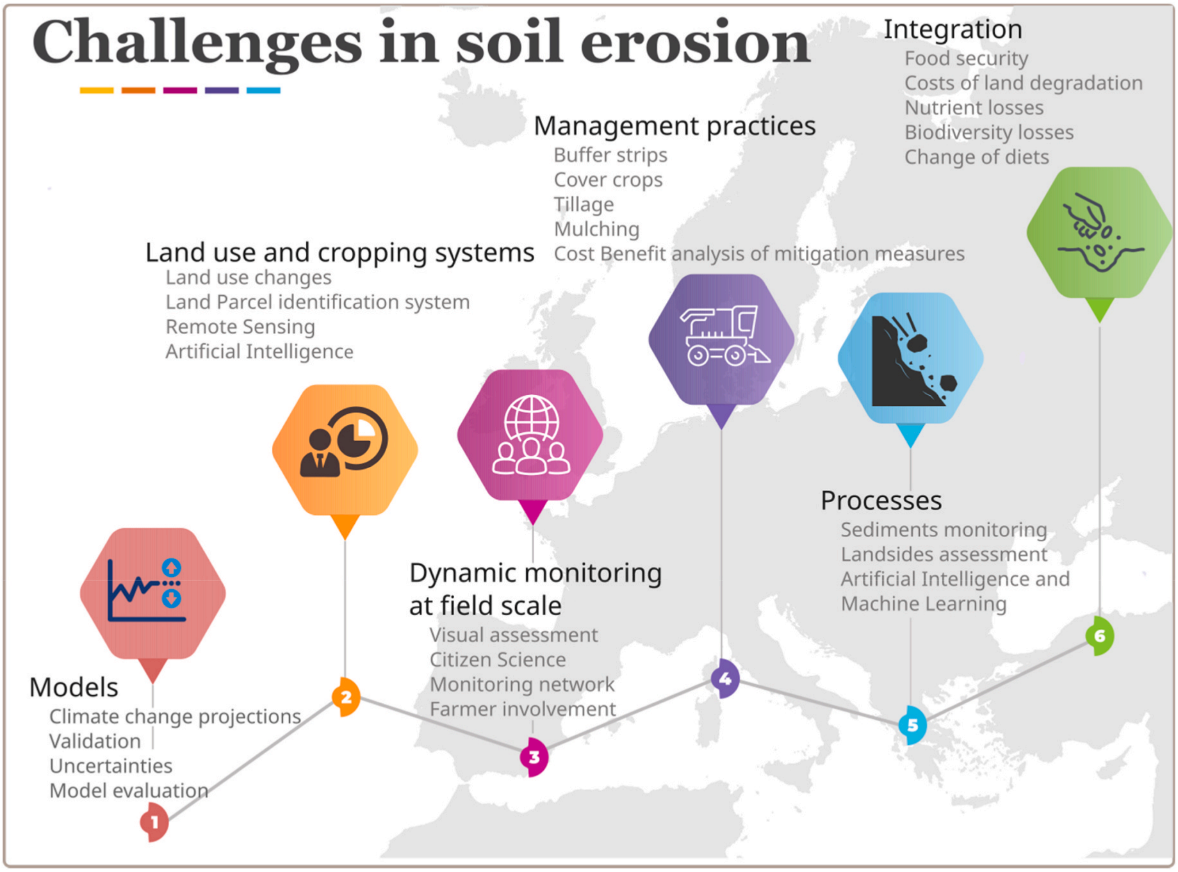

Fig. 3. Main challenges in soil erosion (after the EUSO workshop).

remain largely applied in Europe, an interesting tendency towards large-scale applications of other models (PESERA, G2, MMF and EPM, among others) was noted, which represent a positive element of innovation compared to previous EUSO workshops. Related to the observed diversification in soil erosion modelling, another interesting outcome of the session came from the discussion on how the modelling community may make a step towards inter-comparison of large-scale and global multi-models. This can be a research direction that would enable gaining new insights concerning advantages and disadvantages of the individual models. Finally, it was stressed, once again, the need to better evaluate the performances of soil erosion models through greater use of uncertainty and calibration techniques (Van Oost et al., 2005; Borrelli et al., 2021) (Fig. 3).

In farm scale modelling, the emerging challenges include: i) the high variability of the features affecting soil erosion, both temporal and spatial, due to the adopted soil management practices (including introduction of new tools for soil management), with a proper estimation/calibration of associated parameters; ii) the different 'site-specific' processes that affect runoff and erosion risk, such as gullies and wildfires; iii) the integration of different approaches, from proximal and remote-sensing, in-field assessment (visual checking and measurements), citizen science (farmers and stakeholders) involvement in conjunction with modelling in order to have a site-specific erosion risk evaluation (Fig. 3). In addition, data such as the farmers declarations in the Land Parcel Identification System (LPIS) could be important sources for dynamic erosion assessments.

The main challenges for mitigating soil erosion are to develop long-term soil erosion measurements in collaboration with farmers who apply management practices to reduce erosion. High quality data can contribute to the dissemination of the findings within the farmers' community. Another challenge for scientists is to estimate the cost of the management practices application (cover crops, catch crops, reduced tillage, mulches, micro-dams, strips, etc.) and transfer this knowledge to the policy level. It is important to promote a new model of agricultural production with less chemicals, more biodiversity, lower soil losses and healthier soils.

Sediments are an important element of the erosion-sedimentation cycle and can be an indicator of increased soil erosion or landslides activity in the catchment. Sediments are often associated with negative consequences as high-concentrations can be harmful for aquatic biota or they can transport pollutants. However, sediment connectivity along the river network should be ensured. Therefore, compiling and maintaining a database of sediments is of huge importance since the data from such databases can be used to calibrate soil erosion models, estimate off-site costs or evaluate the potential changes in rivers from the climate change perspective. Future work should also focus on limiting the uncertainties related to sediment quantification with the combination of field work and lab experiments. Finally, the community should also try to monitor the extreme catastrophic (compound) events that are becoming more frequent and that can generate the majority of sediment transport (Bezak et al., 2023).

As a session was dedicated to landslides, the future challenges for landslides community are: (i) further validation and improvement of European Landslide Susceptibility Map (ELSUS) (Wilde et al., 2018) using more accurate regional susceptibility maps (Tavoularis et al., 2021), (ii) utilisation of more quantitative, inventory-based statistical susceptibility modelling techniques (Reichenbach et al., 2018), (iii) preparation of landslide hazard scenario estimates using spatially distributed climatic and seismic data, (iv) compilation of an open-access European landslide inventory applicable for continental, national, regional and site specific level landslide studies, and (v) implementing Artificial Intelligence and Machine Learning methodologies using (free) open-access Web-GIS platforms with a variety of geo and soil data.

In spite of a session dedicated to food security and nutrient losses, there was, surprisingly, very limited interest of the community on this topic. This lack of interest is astonishing and may have different causes such as the lack of causal link between food security and nutrient losses. Notwithstanding, this implies that the soil erosion community should also address this kind of question combining science and technology with more societal issues, such as fully integrating food sovereignty issues on a European and global scale. We must remain proactive to solicit researchers and advance scientific questions in order to have transfer between knowledge and the implementation of public actions in this area of food safety - nutrient losses, as quickly as possible.

Early career researchers have an important role to play in laying the foundations for future soil conservation. One of the challenges that has arguably always confronted soil erosion scientists is building effective bridges of communication between research and policy communities (Evans et al., 2022). Given the proportion of the land surface which is already degraded, ensuring that evidence-based work is acknowledged and realized in effective policy making is of great urgency. Similarly, translating findings from research into accessible messages for farmers and land managers is also vital. For the next generation of soil scientists, these are some of the grand tasks we face.

5. Manuscripts in this special issue

The manuscripts in this special issue deal with different aspects of soil erosion modelling and provide an outlook on the ongoing research, potentially contributing to new advancements in better soil protection. The papers included in this special issue are a follow-up to the online workshop organised by the EUSO working group on soil erosion in the Joint Research Centre (Ispra, Italy) in June 2022. In this special issue there were fifteen submissions with nine published manuscripts.

Jadhao et al. (2023) evidences the importance of rainfall simulations as one of the best methodologies used to assess sediment losses under laboratorial conditions. This work addressed the simulation of rainfall characteristics by a pressurized nozzle-type laboratory simulator, assessing specifically the reproducibility and variables affecting sediment yield under laboratorial conditions. Rainfall intensity and slope resulted as main contributing variables to sediment transport, positively affecting soil erodibility. While raindrop parameters, kinetic energy and runoff rate substantially affect the sediment detachment, and overland flow affected sediment yield.

Sittig and Sur (2023) provide an overview of the literature on the use of micro-dams in agricultural fields, to increase the general understanding of different strategies in mitigating water runoff, soil erosion by water, and the transport of plant protection products from agricultural fields. Moreover, this study concluded that the application of micro-dams provides considerable reduction in surface transport, and can therefore be used as input in environmental exposure assessments through improved modelling of runoff, erosion, and pesticides transport.

Matranga et al. (2023) assess the reliability of a novel soil surface roughness measurement technique, based on proximal sensing acquisition, by comparing C-factor estimated (using ORUSCAL) from field data with literature model inputs, and its performance when a soil erosion model was applied (MMF). The results of this work evidenced a good agreement with C-factor obtained using the value indicated in the RUSLE database and the estimation of the C-factor with the data measured in the field. When predicting soil erosion, the MMF achieved better performance in predicting soil erosion from Conventional tillage when compared to areas treated with Grass cover.

De Geeter et al. (2023) have developed the first gully head susceptibility map of Africa at 30m resolution using a data driven approach with >30,000 gully heads in 1,216 locations. Variables included in their empirical model are topography, climate, vegetation, soil characteristics and tectonic context which are consistent with evidence about gully formation and evolution. The model shows that gully occurrences mainly depend on slope steepness, soil texture and vegetation cover and to a lesser extent on rainfall intensity and tectonic activity (De Geeter et al., 2023).

Barberena et al. (2023) explored the possibility of obtaining long and accurate time series of suspended sediment concentration in the Network of Experimental Agricultural Watersheds (NEAWGN). In their work, simple linear regressions between sediment concentration and turbidity were proposed learning models incorporating a larger number of predictive variables. It was not possible to obtain a satisfactory model for estimating the concentration of suspended sediment; however, the findings suggest that better results could be obtained by including in the analysis variables such as soil texture and exported sediment texture, rainfall erosivity, the state of vegetation cover and riparian vegetation (Barberena et al., 2023).

Gaspar et al. (2023) combined cosmic-ray neutron sensor and fallout 137^{Cs} to explore the connection of soil water content with soil redistribution in an agroforestry hillslope. The results of this study provide strong field evidence that soil type significantly affect soil moisture spatial variability, highlighting the key impact on soil erosion and sedimentation rates. Finally, applying the cosmic-ray neutron sensor and fallout 137^{Cs} method, it was concluded that soil depth, hydraulic conductivity, erosion rates and SOC significantly affect variability of soil moisture (Gaspar et al., 2023).

Ramler et al. (2023) explored the effect of vegetated filter strips (VFS) in phosphorus retention and runoff decrease and reduced sediments. The width of a VFS is an important factor contributing to retention efficacy. Equally important are, however, other VFS traits such as vegetation type and structure, as well as external factors such as field topography or the severity of erosive event. VFS can be highly valuable measures against water pollution and sediment losses (Ramler et al., 2023).

Đokić et al. (2023) applied remote sensing and nuclear techniques for high-resolution mapping and quantification of gully erosion in a highly erodible area close to Nis in Serbia. The study highlights the effectiveness of using a 360-degree camera for photogrammetric modelling in creating detailed models of gullies. It expands the capabilities of remote sensing to assist in identifying appropriate sampling locations. The slope is a more important erosion factor within gullies than the slope length (Đokić et al., 2023).

Torra et al. (2023) assessed badlands susceptibility and its governing factors using a random forest approach. Badlands are considered hotspots of sediment production, contributing to large fractions of the sediment budget of catchments and river basins. The most sensitive variables related to badlands occurrence are lithology and Normalized Difference Vegetation Index (NDVI) (Torra et al., 2023).

6. Reflections and outlook

The workshop presented an excellent opportunity to regroup the soil erosion community, discuss in a variety of topics, as listed in the eight subject areas, and connect to policy makers who also expressed their needs in relation to the Soil Monitoring Law, the Common Agricultural Policy and the Soil Mission.

What emerged during the discussions was the evident need for an EU monitoring network on erosion/sediments, which can contribute to better modelling at large scales, and streamlining best management practices towards policy implementation. Then, it is important to develop modelling applications at field scale towards more precise land management recommendations. A step forward would be to upscale such modelling applications at large scale thoroughly quantifying uncertainties and running scenario analysis. The integration of soil erosion with other processes (nutrient losses, contamination, biodiversity decline, climate change and economic impacts) is a way forward to make the community more interdisciplinary and have an impact on land degradation assessments.

As positive outputs of the workshop, we celebrate the large participation of early career soil scientists who actively present and discussed their findings. This is in line with the objectives of the first Young Forum of the EUSO in 2021. In addition, the workshop was followed by a large number of researchers and stakeholders from West and Southern Europe plus many overseas (USA, China, Iran, Turkey, Brazil, among others). On the other side, the participation from Eastern European countries was limited. Finally, the workshop attracted great participation of scientists and researchers while stakeholders from other sectors (e.g. farmers, regional policy makers, practitioners) were limited.

A similar workshop is foreseen for 2024/2025 depending on the resources and organisers availability. In addition, soil erosion research is expected to be part of the future Soil Mission HORIZON calls the co-creation of the 100 Living Labs. Finally, the working group continues its participatory approach by launching a call for collaborative network targeting soil erosion by water plot data from European field experiments (EU_ERPlot). This is among the priorities of the WG which proposes actions for open data infrastructures hosting plot data, sediments measures and modelling results.

CRediT authorship contribution statement

Panos Panagos: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Diana Vieira:** Data curation, Formal analysis, Methodology, Resources, Writing – original draft. **Joris P.C. Eekhout:** Conceptualization, Methodology, Writing – original draft. **Marcella Biddoccu:** Conceptualization, Methodology, Writing – original draft. **Artemi Cerdà:** Conceptualization, Methodology, Writing – original draft. **Daniel L. Evans:** Conceptualization, Methodology, Writing – original draft. **Nikolaos Tavoularis:** Conceptualization, Methodology, Writing – original draft. **Nejc Bezak:** Conceptualization, Resources, Writing – original draft. **Philippe Negrel:** Writing – original draft. **Athanasios Katsoyiannis:** Conceptualization, Project administration. **Pasquale Borrelli:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Panos Panagos reports financial support was provided by European Commission, Joint Research Centre, Ispra. Panos Panagos reports a relationship with European Commission Joint Research Centre Ispra that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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