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Site-specific behaviour analysis of the LANCA model for assessing the impact of change of use on soil quality: comparison between Spanish and French soils

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LIST OF ACRONYMS

ABSTRACT

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BP: Biotic Production

BPLP: Biotic Production Loss Potential

CEC: Cation Exchange Capacity

CF: Characterization Factor

CICES: Common International Classification of Ecosystem Services

EC: European Commission

EDA: European Diary Association

EEA: European Environmental Agency

EF: Environmental Footprint

ER: Erosion Resistance

EP: Erosion Potential

EPLCA: European Life Cycle Assessment Platform

ES: Ecosystem Services

ESDAC: European Soil Database Classification

FAO: Food and Agriculture Organization

GEZ: Global Ecological Zones

GWR: Groundwater Regeneration

GWRRP: Groundwater Regeneration Reduction Potential

HWSD: Harmonized World Soil Database

ILCD: International reference Life Cycle Data System

ISPRA: Istituto Superiore per la Protezione e Ricerca Ambientale

ISO: International Organization for Standardization

IRP: Infiltration Reduction Potential

JRC: Joint Research Centre

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

LCT: Life Cycle Thinking

MEA: Millenium Ecosystem Assessment

MF: Mechanical Filtration

NPP: Net Primary Production

OEF: Organization Environmental Footprint

OEFCRs: Organization Environmental Footprint Category Rules

PEF: Product Environmental Footprint

PEFCRs: Product Environmental Footprint Category Rules

PF: Physicochemical Filtration

PFRP: Physicochemical Filtration Reduction Potential

RUSLE: Revised Universal Soil Loss Equation

SDF: Subtropical Dry Forest

SETAC: Society for Environmental Toxicology and Chemistry

SOC/SOM: Soil Organic Carbon/ Soil Organic Matter

TMS: Temperate Mountain System

TOF: Temperate Oceanic Forest

UE: Unione Europea

UNCCD: United Nations Convention to Combat Desertification

UNEP: United Nations Environment Programme

USLE: Universal Soil Loss Equation

ABSTRACT

Life Cycle Assessment method need factors, called, Characterization Factors (CF), to transform consumptions and emissions into environmental impacts. LANCA model is recommended by European Commission to calculate CFs for the environmental impact category "Land Use" of 5 soil quality indicators: erosion potential, filtration reduction potential, physical-chemical filtration reduction potential, groundwater regeneration reduction potential and biotic production reduction potential. Default CFs, according to the model, are provided on national base and land use type. LANCA model permits the CFs calculation also by site-specific parameters. The aim of this thesis was to evaluate which of three grouping methods (national base, FAO GEZ (Global Ecological Zones) classification, clay percentage) gives more significant CFs groups. This means maximising difference among groups and minimizing difference within a group.

To do this, 48 sampling sites were randomly selected so that the sites belonged to two countries, Spain and France, and fall in 3 FAO GEZ (subtropical dry forest, temperate mountain system, temperate oceanic forest). Then, CFs were calculated, ANOVA analysis was carried out and the variance within each group and between the different groups, for various grouping methods (country, FAO GEZ and clay percentage), was studied.

From the study it emerged that the FAO GEZ grouping is the one that gives more significant groups for four out of five soil quality indicators. Concluding, although nationality is the LANCA default method to define generic CFs for “Land Use”, this thesis results show that FAO GEZ could offer a more suitable classification method. The larger significance of the FAO GEZ grouping is probably due to the fact that it already classifies climate, vegetation and it also linked with soil characteristics while nationality can bring together zones very different in term of climate, vegetation and soil.

1. INTRODUCTION

1.1 Importance of soil: ecological function and ecosystem services

In order to better understand this thesis, it is necessary to briefly explain the meaning of landscape, territory, land and soil. The “landscape” in ecology is defined as a spatially heterogeneous geographical area characterised by diverse and interacting patches or ecosystems, ranging from relatively natural terrestrial and aquatic systems such as forests, grasslands and lakes to human-dominated environments. It is therefore considered as "a complex system of ecosystems", in which the events of nature are integrated with the actions of human culture[1]. The term "territory" usually refers to the land surface not covered by seas, lakes or rivers; it includes the entire land mass, including continents and islands. In more everyday use, terms such as "land" are used; this can be formed by rocks, stones, soil, vegetation, animals, water holes, buildings, but can be covered by various types of vegetation (e.g., natural or man-made pastures, arable land and marshes) and artificial surfaces (e.g., roads and buildings). The "soil", on the other hand, is the most superficial portion of the earth's surface, resulting from the alteration of a rocky substratum, called parent rock, by chemical, physical and biological action exerted by all surface agents and organisms present in it. More clearly, it defines the upper layer of the earth's crust, formed by mineral components, humus, water, air and living organisms. The properties of the soil, such as its texture, color and carbon content, may vary from one area to another but also between the different layers (horizons) of the same site. Soil plays a key role in natural cycles, particularly in the water and nutrient cycles (carbon, nitrogen and phosphorus)[2].

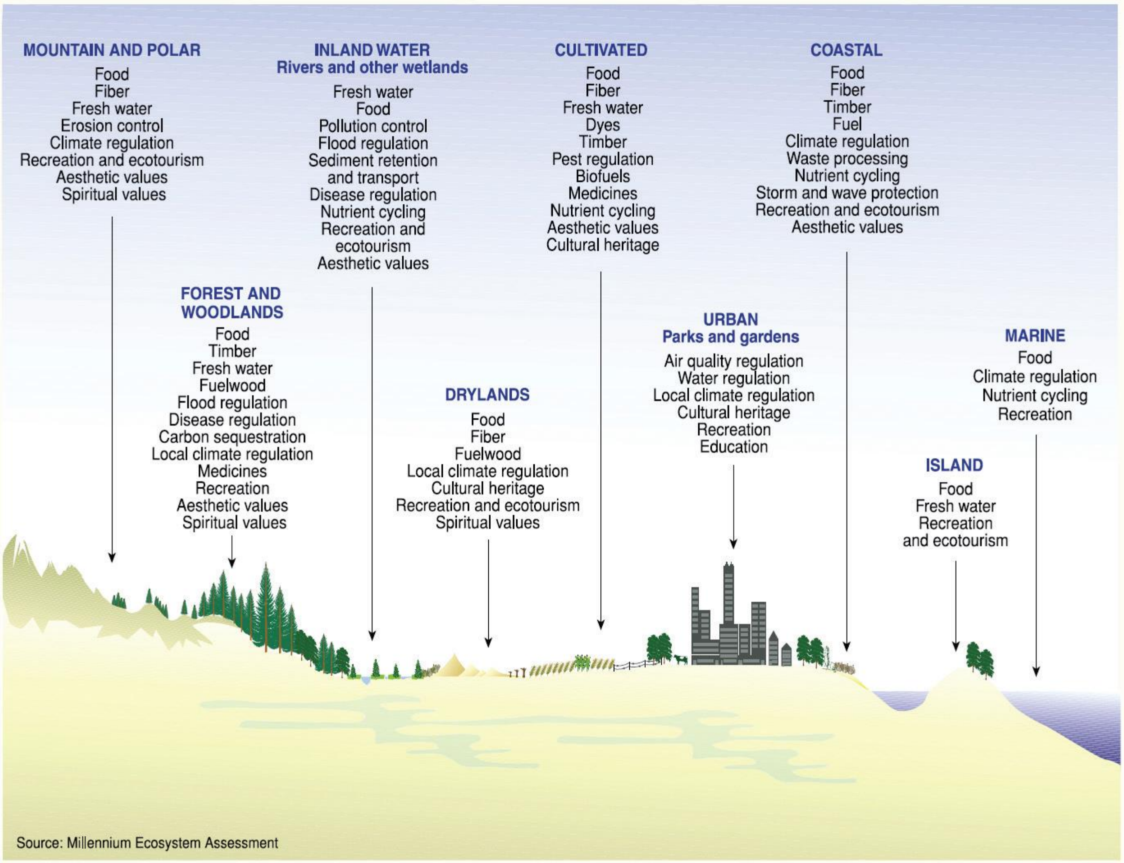
Important institutions such as, for example, the European Union, have formulated definitions of soil. One of the most adopted is: "*Soil is an essentially non-renewable resource and a very dynamic system, which performs many functions and provides essential services for human activities and the survival of ecosystems*"[3]. The socio-economic changes of recent centuries have strongly influenced the relationship between man and the environment. If on the one hand we observe an improvement in living conditions, on the other hand we must consider that progress has led to a deterioration in environmental quality. Above all, the demographic increase, the strong urbanization and the not always correct anthropic activities have contributed to the degradation of the soil, making this resource increasingly vulnerable. As soil formation processes are extremely slow, this resource can be considered as non-renewable, so it is necessary to monitor and protect the functionality and health of this system to ensure its many functions. Although we have a lot of information on the soil matrix today, the importance and fragility of this resource is still very low among non-experts, even though interest in environmental issues is growing significantly.

Soil provides a number of key environmental, economic, social and cultural functions that are indispensable for life. The Millennium Ecosystem Assessment, addresses ecosystem services by defining them as "the multiple benefits provided by ecosystems to mankind" and provides a state and trend of the condition of the world's ecosystem systems and services, as well as the scientific basis for their conservation and sustainable use. While, the "environmental function" refers generically to an impact related to the presence of environmental resources, the "ecosystem service" has a close relationship with the welfare conditions of the community[4].

Therefore, even if there are many different definitions and classifications of ecosystem services (SE), it is appropriate to refer to what has been proposed by the MEA in agreement with CICES (Common International Classification of Ecosystem Services)[5], a more consolidated reference at international level, Ecosystem Services can be divided into three categories:

- APPROVAL. This class covers all nutritional, non-nutritional and energy elements from living systems and, abiotic products (including water). A distinction is made between supply services based on biomass (biotic) as raw materials and food, and the results of the aqueous (water storage) and non-aqueous (biomaterials) abiotic ecosystem.
- REGULATION AND SUPPORT. All ways in which living organisms can mediate or moderate the environment, which affects human health, safety or comfort, together with abiotic equivalents. These services include:
  - Regulation of CO_2/O_2 by autotrophic organisms through photosynthesis and chemosynthesis
  - Water regulation and purification: the soil performs an important protective function, through a filter/barrier action, buffering power and biochemical and microbiological decomposition, it allows to mitigate the effects of pollutants, "blocking" their passage into groundwater or the food chain through chemical-physical adsorption processes.
  - Climate regulation: the soil can help reduce atmospheric CO_2 concentrations by storing organic carbon within the soil.
  - Soil formation: the development of the soil and the associated ecosystem is a function of the weather, the underlying rocky materials, altitude, topography, climate, precipitation, temperature, exposure, humidity, vegetation development, in other words, its formation depends on pedogenetic factors.
  - Nutrient cycle to support plant growth (primary production) including food and fibre production

- CULTURAL. All non-material results of ecosystems (biotic and abiotic), which influence people's physical and mental states.



Source: Millennium Ecosystem Assessment

Figure 1 Identification of the main ecosystem services of the Earth's biomes, according to the Millenium Ecosystem Assessment [4].

All these services are provided by the soil, as long as it is healthy and functional. Therefore, as some important services may not yet have been identified, it is advisable to take a precautionary approach to safeguard our natural capital[2].

1.2 Soil Degradation

In Europe, policies to reduce soil degradation processes only started in 1998 with the first European Soil Forum, which led to the "Thematic Strategy for Soil Protection in 2006"[6]. This document recognizes that soil degradation is caused by human activities, such as inadequate agricultural or forestry practices, industrial activities, tourism, urban and industrial expansion. Such activities lead to loss of fertility, carbon, biodiversity, water retention capacity, alteration of nutrient cycles; they therefore have an extremely negative impact on the soil, preventing it from performing functions and services for the ecosystem.

In this context, it is important to provide a definition of "soil quality", as proposed by the Soil Science Society of America Ad Hoc Committee on Soil Quality, as "*the ability of a specific soil type to function, within natural or managed ecosystem boundaries, to support plant and animal productivity, maintain or improve water and air quality and support human health and housing*"[7].

This resource, however, is often considered with little awareness and attention when assessing the effects of the loss of its functions.

Ensuring the maintenance of high-quality standards for the state of the soil is therefore a fundamental requirement for global sustainability[8]. A report on the state of soil resources in the world[9], shows that most soils are in fair, poor or very poor condition. Some of the most worrying conditions are characterized by advanced degrees of erosion, leading to crop losses, and increased soil acidity, with a lack of nutrients, which limits food production[10] [11].

In order to have a clear view of the issue of "soil degradation", a clear distinction must be made between soil consumption, soil cover and land use.

Soil consumption is a phenomenon associated with the loss of soil resources due to the occupation of land originally agricultural, natural or semi-natural. The phenomenon refers, therefore, to an increase in artificial land cover, mainly due to the expansion of cities, or the conversion of land within an urban area. The concept is, therefore, defined as a variation from a non-artificial land cover (unconsumed land) to an artificial land cover (consumed land)[12].

Land cover is a related but distinct concept from land use. Land cover means, in fact, the biophysical cover of the earth's surface. It is defined by Directive 2007/2/EC as "*the physical and biological cover of the earth's surface including artificial surfaces, agricultural areas, forests, semi-natural areas, wetlands, water bodies*"[13].

Land use, on the other hand, is a reflection of the interactions between man and land cover, and is therefore a description of how soil is used in human activities. Directive 2007/2/EC defines it as a "*classification of land according to its functional dimension or socio-economic use present and planned for the future (e.g., residential, industrial, agricultural, commercial*)"[13].

Soil degradation can therefore be defined as a complex phenomenon, which usually involves the partial or total loss of soil, biomass, biodiversity, with consequent loss or reduction of biological and economic productivity of the soil resource, for the present and for the future.

The Soil Protection Directive recognizes the environmental function of soils, their strong interrelation with other environmental matrices and the need, due to their extreme spatial variability, to incorporate a strong local component in protection policies[6]. It also identifies the main threats that risk irreparably compromising soil functions:

Table 1 Main risks from soil overexploitation [14].

THREATS	**MEANS**	**MAN-INDUCED CAUSES**	**CONSEQUENCES**
NUTRIENT IMBALANCE	Nutrient deficiency or excess	Nutrient inputs through the addition of chemical and organic fertilizers or other sources	Nutrient deficiency leads to food insecurity. Excess nutrients are a major contributor to deteriorating water quality and greenhouse gas emissions.
SOIL EROSION	Removal of soil from the soil surface by water, wind and tillage	Non-conservative tillage practices, loss of SOC, deforestation of vegetation	Reduction in potential yield; loss of soil nutrients; adverse operating conditions
LOCAL AND/OR DIFFUSE SOIL CONTAMINATION	Addition of chemicals or materials	Mining activities, agrochemical products, waste disposal, accidental losses	Significant adverse effects on any organism or soil functions
SOIL SEALING	Permanent covering of an area of land and its soil with waterproof artificial material	Urbanisation, building construction	It affects fertile farmland, endangers biodiversity, increases the likelihood of flooding and water scarcity and contributes to climate change.
LOSS OF ORGANIC MATTER	Loss of organic compounds (non-marginal components)	Intensive cultivation systems, removal of plant residues	Decreased resistance to human-induced climate change by not regulating the water supply to plants,

			increased erosion due to runoff and reduced sites for nutrient retention and release
SOIL COMPACTION	Densification and reduction of pore volume between particles	Non-conservative tillage practices	It damages the functions of both the upper soil and the subsoil and hinders root penetration and water and gaseous exchange.
LOSS OF BIODIVERSITY	Decrease in variability and number of species living in the pedosphere	Soil sealing, soil erosion, SOM impoverishment, salinisation, contamination, compaction	Impact of temporary ecosystem functions, including decomposition rates, nutrient retention, soil structural development and nutrient cycle.
SOIL WORMING	Exceeding water content in soil pores, saturation	Vegetation cleaning, soil compaction and soil erosion	Leads to lack of oxygen and other harmful gases; salinisation, surface runoff of water
SOIL SALINISATION	Process of increasing salt content	Inappropriate irrigation practices, such as the use of mineralized groundwater; the phenomenon of water clogging	It reduces the productivity of crops; it allows the increase of groundwater; it leads to an additional need for water.
SOIL ACIDIFICATION	Increased hydrogen cations by reducing the pH of the soil	Use of ammonium fertilizers	Loss of basic cations such as calcium, magnesium, potassium and sodium; reduction in plant growth and microbial activity.

The trend towards soil degradation is expected to continue, with an expected increase in livestock production, deforestation rates, poor water and nutrient management and large-scale pesticide applications[9]. So, the way forward is clear: we urgently need to change the way we use and manage land and the resources it provides. This will require considering the landscape as a whole, with all its activities and elements[2].

1.3 How climate change impacts on soil quality

The way we use soil and land is also closely linked to climate change; in addition, changes in land use can accelerate or slow down these changes.

Soil contains significant amounts of carbon and nitrogen, which can be released into the atmosphere depending on its use. Soil, according to FAO[15], is the second largest natural carbon sink after ocean and soil, due to its ability to capture CO_2 from the atmosphere. The carbon pool in the soil includes organic carbon (SOC) and inorganic carbon, whose concentration depends on climatic and soil conditions. Approximately 75 billion tons of organic carbon (SOC) are stored in the EU soil. To understand the scale of this phenomenon, according to the most recent EEA (European Environmental Agency) estimates, total CO_2 emissions in the EU in 2017 were about 4.5 billion tons; therefore, the amount of organic carbon present in European soils may be slightly increasing, but estimates of the speed of this change are very uncertain[2].

Climate change, at the ecosystem level, may affect soil humidity and temperature, water availability and plant cover with a consequent decrease of SOC in the soil. This could lead to a loss of soil quality and ecosystem functions as SOC increases resilience against human-induced climate change by regulating water supply to plants, reducing erosion and providing sites for nutrient release. These changes can lead to a decrease in soil stability by increasing soil susceptibility, causing negative impacts on biomass productivity, biodiversity and the environment[16].

The contribution to soil degradation resulting from climate change is not only an ecological issue, but involves many human activities, including agriculture. It should be noted that agriculture contributes about 24% to greenhouse gas emissions, generally associated with intensive farming systems[17]. Land use practices therefore also change air quality by altering emissions and changing atmospheric conditions that affect reaction rates, transport and deposition. In addition, the effects of land use also affect air quality, leading to dust, biomass combustion, and other sources of air pollution.

1.4 The different land uses

Land use has, generally, been considered a local environmental issue, but it is becoming a force of global importance. Cultivated land, pastures, plantations and urban areas globally have expanded in recent decades, accompanied by a sharp increase in energy, water and fertilizer consumption and a significant loss of biodiversity. These changes in land use have allowed humans to take an increasing share of the planet's resources, but they also potentially undermine the ability of ecosystems to sustain food production, maintain water and forest resources, regulate climate and air quality and improve infectious diseases. We face the challenge of managing trade offsets between immediate human needs and maintaining the biosphere's capacity to provide long-term goods and services[18].

a)

Land Cover types	Label	
Artificial Surfaces	01	🟥
Cropland	02	🟨
Grassland	03	🟧
Tree Covered Areas	04	🟩
Shrubs Covered Areas	05	🟫
Herbaceous vegetation, aquatic or regularly flooded	06	🟩
Mangroves	07	🟪
Sparse vegetation	08	🟨
Baresoil	09	⬜
Snow and glaciers	10	⬜
Water bodies	11	🟦

b)

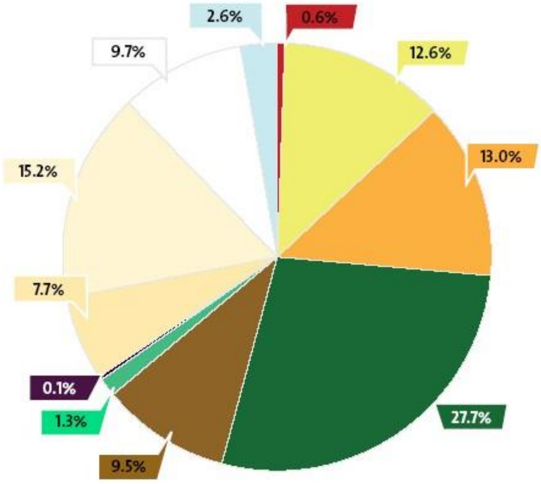


Figure 2 Legend (a) and distribution (b) of Global Land Cover types [19].

Sealing is probably the most widespread and most dangerous use of soil as it permanently compromises soil functionality, mainly its primary function in the nutrient cycle and carbon storage. The phenomenon of soil sealing involves the permanent covering of soil by artificial materials and represents the most widespread and obvious form of artificial cover. This phenomenon occurs mainly with urbanization; cities and concrete infrastructure continue to expand. Today almost three-quarters of Europeans live in urban areas and Europe's urban population is expected to continue to grow, increasing by a further 30 million people by

2050[2]. This growth often results in urban sprawl, with built-up land spilling over to fertile and farmland in some cases, resulting in permanent loss of arable land. For example, Spain is a typical case of very intense artificial expansion, particularly the extension of economic infrastructure. Therefore, it shows a higher occupancy rate of artificial land in Europe. So does France, whose land cover has doubled compared to the past. Globally, about 2-3 % of the land area is currently urbanized; it is expected to increase to 4-5 % by 2050. Urbanization is expected to result in the loss of 1.6-3.3 million hectares of top quality agricultural land per year between 2000 and 2030[20].

Population growth is not the only cause of soil consumption and degradation. Higher wage levels also play an important role, as this often results in larger housing, as well as more homes, commercial and industrial facilities designed to meet consumer demand. A simple way to limit the expansion of urban areas is to redevelop existing urban spaces, a technique already applied in some European countries such as France and Spain. In fact, there is a considerable amount of recycling of developed urban land, mostly represented by the transformation of former construction sites into residential and/or industrial and commercial areas. However, today land reuse and densification account for only a small part, about 13% of new developments[2].

Agriculture is by far the largest human use of land, covering about 38% of the earth's surface. Currently, it is the dominant, and usually the largest, driver of land use change[21]. The remaining natural land suitable for agriculture is limited, with increasing expansion onto more marginal land that is more difficult to treat. Thus, additional land for agriculture has to expand into less productive areas. Agricultural activities have different significance depending on management practices and techniques; although modern agriculture has been successful in increasing food production, it has also caused extensive environmental damage. For example, increased productivity is often the result of the use of synthetic fertilizers and plant protection products that can cause damage to water quality. In addition, some irrigated land has become heavily salinated, causing the loss of hectares of arable land and loss of production worldwide. Up to 40% of global production even cultivated land can be subject to soil erosion, reduced fertility and overgrazing. Habitat loss also affects agricultural production by degrading pollinator services. Thus, the use of modern agricultural practices may consist of short-term increases in food production but long-term losses[18].

Future projections suggest that meeting global food demand means more primary production and thus greater soil stability. Therefore, increasing competition and trade in land goods and services and the different interests of stakeholders should be managed through land use planning and integrated land management that ensures efficient land allocation that promotes sustainable land use options and helps balance competing uses[20].

1.5 Need for Sustainable Primary Production

The soil is the basis of food production. It has been shown that sustainable soil management contributes to increasing agrifood production, promoting the nutritional quality of food and enabling soil to gradually mitigate and adapt to climate change.

The FAO, according to the World Soil Report, strongly supports the adoption of sustainable soil management strategies to increase soil fertility and thus productivity, minimizing environmental impacts, addressing all causes of soil degradation and promoting agricultural land management that includes not only more conservative and organic farming but also grassland management, to the detriment of the common "green revolution" (known as the industrialization of agricultural productivity), which causes a huge environmental impact from the heavy use of pesticides[9]. For this to happen, it is mainly necessary to avoid or plan carefully only if soil use changes, such as soil conversions, are indispensable and to ensure a good percentage of stable grasslands because they contribute to the maintenance of carbon content. In addition, continuous vegetation cover, such as crop rotation and agroforestation techniques, should be ensured in order to guarantee and increase SOC stocks and the biodiversity pool, as its loss can cause a reduction in soil quality[15], thus promoting sustainable agriculture that involves the addition of high amounts of biomass to the soil, which causes minimal soil disturbance, conserves soil and water, improves soil structure, increases the activity and diversity of soil fauna species and strengthens the mechanisms of the elements cycle[16]. Increasing SOC can increase food production by 17.6 megatons ($1.76\ 10^7$ kg) per year and help maintain productivity in drought conditions[17].

Second, the soil nutrient balance and cycle must be promoted. The presence of permanent grassland for grazing means less use of synthetic fertilizers due to the contribution of organic matter and therefore natural nutrients from ruminant manure[22]. It is essential, however, to choose an appropriate management system and a suitable approach based on the characteristics of the soil accompanied by a given agricultural practice: increasing irrigation efficiency, application of organic and inorganic soil conditioners balanced and calibrated to the context (composting) and/or innovative products (e.g., slow and controlled release fertilizers). Fertilizer application should be appropriate to limit losses and promote nutrient uptake and ensure a long-term nutrition curve by limiting its spread; this reduces the impact on the environment and human health[15].

However, much attention needs to be paid to the excess of some nutrients and the potential ecological impacts arising from them. Synthetic fertilizers contain mostly nitrogen, phosphorus and potassium and, to a lesser extent, other elements such as calcium, magnesium, sulphur, copper and iron. On the one hand, they ensure more crops are harvested on a given soil, allowing more food to be produced, while on the other, not all the nitrogen used is absorbed by the plants. Excessive use can contaminate soils, rivers and aquifers, as well as penetrating the atmosphere in the form of nitrous oxide, which is one of the main greenhouse gases[2].

In terms of primary production, agriculture and livestock farming, FAO lists several management practices, distinguishing "conservation farming" from "conservation ploughing"; the first expression is explained as follows: "Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation and to enhanced and sustained agricultural production. It can also be defined as an "effective and efficient way of using resources in agriculture"[9]; this includes minimal soil disturbance, permanent land cover and diversified crop associations and rotations. While "conservation tillage" refers to a set of practices that leave crop residues on the surface that increase water infiltration and reduce erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion.

Among the sustainable meadow management practices defined as permanent, in particular dedicated to pastoralism, an even more targeted approach is adopted, since an individual management plan is applied which must be contextualized in relation to the area considered. Furthermore, the measures are adjusted year by year[23].

The different approaches, therefore, are aimed at promoting sustainable soil management, aimed at increasing productivity. Sustainable soil use and management are linked to many aspects of sustainable development since what was defined in the 1987 Bruntland Report represents a common objective, namely "*to enable present generations to meet their needs without compromising the ability of future generations to meet their own needs*"[24]. However, the current rate of soil degradation threatens the ability of future generations to meet their most essential needs. Therefore, achieving sustainable management of soil resources will generate great benefits for all communities and nations and contribute to the maintenance of healthy soils and, consequently, to efforts to eradicate hunger, ensure food security and build stable ecosystems[9].

1.6 Indicators to evaluate the soil quality and soil functions: review of literature proposals

A definitive and universally accepted definition of soil quality does not exist. Even today it is very complex to give an exhaustive definition of soil quality, indeed it emerges that depending on the intended use of the soil the concept of quality may be different[25]. Consequently, it is equally difficult to define quality indicators that fully reflect the functionality of a soil.

M. J. Singer and S. A. Ewing argue that soil has static and dynamic properties that vary spatially and for this reason the concept of soil quality is constantly evolving[26].

This concept started to develop in the late 1970s thanks to Warkentin and Fletcher[27] who, besides stressing that the different types of land use influenced the decision-making aspects related to management, considered that there could not be a single measure that could establish its quality. "Soil quality" was defined by Larson and Pierce[28] as the ability of a soil to function and interact positively with the surrounding ecosystem; this concept began to be seen as a dynamic and sensitive possibility to verify soil conditions in response to management or stress due to natural and/or anthropogenic causes. Since the concern and attention for environmental health has grown, the quality of soil in terms of ecosystem functions and different uses for different soil types has started to be considered[29]. Therefore, the concept of soil quality stems from the desire to assess soils, to combine appropriate management and use for each soil and to measure changes in soil properties. However, it is a controversial concept among scientists because it is subjective as well as dependent on management and climate.

To proceed from definition to quantitative measurement, hypothetically it would be necessary to select a minimum set of characteristics representing soil quality, considering that many properties vary, some quickly, others very slowly and therefore insensitive to short-term changes. There are qualitative and quantitative indicators that in general must have the following characteristics[30]:

- to be well correlated with ecosystem processes;
- integrate chemical, physical and biological soil processes and properties;
- to be useful to interpret soil properties and functions that cannot be measured directly;
- to be accessible to different users;
- to be sensitive enough to reflect long-term management and climate change influences, but not so sensitive as to be influenced by short-term changes;
- to be part of soil databases.

Larson and Pierce[28] to overcome these problems advanced the idea that in order to define the health status of a soil a minimum data set of static and dynamic parameters with specific biological, chemical or physical characteristics of the soil to be used should be set and methodologies and procedures should be standardized to identify changes in the set parameters.

Physical factors such as porosity, hydraulic conductivity and grain size are potential indicators of soil quality and easily measurable. Other physical properties, such as structure, texture and profile characteristics, influence management practices in agriculture, but only indirectly plant productivity. Water potential, temperature and mechanical resistance directly affect plant growth and are excellent indicators of the physical quality of a soil for production, but are difficult to measure[21].

Among soil components, desirable and undesirable chemical characteristics can be distinguished; desirable soil characteristics are properties that promote soil productivity and/or other important soil functions. For example, pH can be a positive or negative characteristic depending on its value, while undesirable characteristics are, for example, the presence of contaminants that may affect some soil functions. Generally, the measurement and evaluation of these characteristics requires the implementation of an analytical procedure. However, nutrient availability depends on the physical and chemical processes of the soil and its chemical characteristics, since at low and high pH, for example, some nutrients are not available to plants and some toxic elements become more available[30].

The core of many soil quality definitions is soil biology and therefore, biological indicators play a key role. Although they are not easy to measure, they are very sensitive to different soil conditions and man-made disturbances. The assessment includes dynamic properties such as microbial biomass, microbial respiration, organic matter mineralization and organic matter content. The presence of taxonomic diversity at group level and the species richness of different dominant invertebrate groups can be used in the assessment of soil quality[21].

Since soil quality cannot be represented by a single parameter, it is necessary to carry out a calculation of the different indicators to obtain representative and quantitative indices, which provide an evaluation of soil quality with a numerical value; these can be additive, multiplicative or combined through more complex functions.

1.7 Life Cycle Thinking: a brief summary

The environmental damage resulting from continuing anthropogenic pressures on nature and ecosystems is becoming so common that it is attracting the attention of public opinion, but also of political institutions. In recent decades, new methodologies for assessing potential environmental impacts have been developed: in addition to the traditional "end of pipe" approach (remedying existing environmental problems), more attention is being paid to an analysis of the entire life cycle of a product, understood as a good or service, based on prevention.

One of these new approaches is Life Cycle Thinking (LCT), which considers a range of environmental, social and economic impacts over the entire life cycle of a product, and is supported by an element known as "Life Cycle Assessment" (LCA), a tool standardized internationally by ISO 14040 and ISO 14044[31], to quantify and assess emissions, resources consumed and pressures on health and the environment that can be attributed to a product (goods and services). It takes into account the entire life cycle, from extraction of natural resources to material processing, production, distribution and use; finally, reuse, recycling, energy recovery and waste disposal[32].

The fundamental objective of the LCT is to reduce the overall environmental impact by paying particular attention to avoid the shifting problems from one phase of the cycle to another.

The European Commission established the "European Life Cycle Assessment Platform" (EPLCA) in 2005, with the aim of promoting LCT in European politics and economy. This facilitated the development of an ILCD manual containing life cycle assessment guidelines fully compatible with international standards, ISO 14040 and ISO 14044[31], which aim to ensure the quality and consistency of assessments based on scientific evidence[33].

LCA is a multi-criteria methodology, covering a wide variety of pressures and impacts associated with human health, ecosystem health and natural resources. The range of impact categories considered in LCA studies is expanding. In this methodology the most important burdens, the most relevant life cycle phases and the most relevant processes contributing to environmental impacts are assessed[34]. However, it is still a young and evolving application[35]: its procedures are not globally standardized and there is no general scientific consensus on the different approaches, so the user's ability, experience and skills play a fundamental role in each specific situation; moreover, it may not be the most appropriate tool to be used in all situations since, generally speaking, it does not deal with economic or social issues of a product, but with the life cycle approach and methodologies described and present in the International Standard.

The LCA study[31]consists of four phases:

1. Phase of definition of the objective and scope of application: it describes the motivation of the study with annexed decisional context and the definition of the scope of application with identification of function and functional unit, boundaries and limits of the system and details of the LCA study.
2. Life Cycle Inventory Analysis (LCI) phase: consists of the collection of input/output data related to the study object defined in the objective and necessary to quantify the environmental pressures.
3. Impact Assessment Phase (LCIA): aims to assess potential environmental impacts by correlating the results of the LCI to environmental issues ranging from global warming to human toxicity, using impact indicators calculated by adopting characterization factors. The result of the LCIA phase should be seen as the identification of potential environmental impacts and then the identification of more relevant environmental impact categories and quantify the corresponding impacts.
4. Interpretation phase: this is the final phase of an LCA and mandatory study, where on the basis of the results of either an LCI or LCIA, or both, conclusions, recommendations and limitations of the study are made, referring strictly to the intended applications defined in the study objective.

In order to have a good understanding of the results and thus of the final assessment, great attention needs to be paid to LCIA, the most practical phase.

As illustrated by Pennington[36], LCIA contains a set of mandatory and optional sub-phases:

- Selection of impact categories of interest and indicators for each impact category;
- Classification: it is necessary to understand what pressure affects which impact category and therefore, to assign LCI results to one or more impact categories;
- Characterization: calculate the "impact score" (SI) through the use of characterization factors; for each specific impact category and each specific flow, the SI is given by the sum of the products between each pressure and the corresponding “characterization factor” (CF). These factors represent the output of the "characterization models", measured relative to a reference condition or pressure;
- Normalization (optional): calculation of results respect reference values;
- Grouping and/or weighting (optional);
- Data quality analysis (obligatory).

1.8 Land Use in Life Cycle Assessment: a new Impact Category

According to the DPSIR (Drivers, Pressures, State, Impacts, Responses) framework, an impact category is a class of potential impacts on the environment and human health associated with a good or service, starting from the respective consumption of resources and emissions of contaminants defined as "environmental pressures", i.e., alterations in the natural environmental state.

The impact categories considered in LCA studies fall into three broad areas of environmental protection: environmental conservation, resource depletion and human health. The first impact categories include global warming, ozone depletion, photochemical ozone formation, acidification of aquatic and terrestrial systems, terrestrial and aquatic eutrophication and resource depletion. Several studies have led to the broadening of the spectrum of investigation to include different environmental matrices within the context of an LCA study[36]. Over time, scientific progress has brought to light new pressures and potential impacts, such as land use. Therefore, the damages and consequences related to over-exploitation and poor soil management mentioned above have led us to consider and analyze in depth this new category of impact; moreover, soil is becoming increasingly important also in non-agricultural sectors, such as energy and for this reason it requires more attention and study[37].

The first efforts to address impacts on soil properties and functions in LCA date back to the 1990s, thanks to a study conducted by a scientific working group on land use within the Society for Toxicology and Environmental Chemistry (SETAC), which discussed and compiled the most important basic methodological information on land use[38].

Given the complexity of the soil matrix, the evaluation of soil quality is very demanding. Therefore, there is no universally accepted characterization method for CF calculation as none fully meets a minimum set of quality requirements. In particular, it is increasingly evident that the selection of a specific indicator (or set of indicators) is problematic due to the spatial and temporal variability of soil properties. The current lack of a globally recognised and applied method is also due to the lack of mostly scientific knowledge on soil impact, which prevents us from outlining a clear cause-effect chain, describing in detail the causal relationships between a hypothetical change in land use and soil quality changes[39].

UNEP-SETAC[40], highlighted that the strength of the LCA is to provide a life cycle perspective and therefore requires methods that are able to assess land use impacts in relation to a wide variety of land use types and on a detailed spatial scale, although regionalization of land use assessment has been identified as one of the main shortcomings of the LCA[41].

1.9 Soil Quality: Occupation, Transformation and Regeneration time

An alteration in soil quality compared to a reference situation is usually represented by natural soil cover change or - more commonly - by land use change. This may result in damage or more rarely in benefit. In LCA a positive value of impact score denotes damage, therefore a decrease in quality, while a negative value of impact score is synonymous with benefit, i.e., an improvement in quality. Each characterization model gives the concept of soil quality a different meaning by choosing one or more indicators to give a measure of quality.

The impact category "land use" reflects the damage to ecosystems due to two types of effects and interventions on the land, such as land occupation and soil transformation.

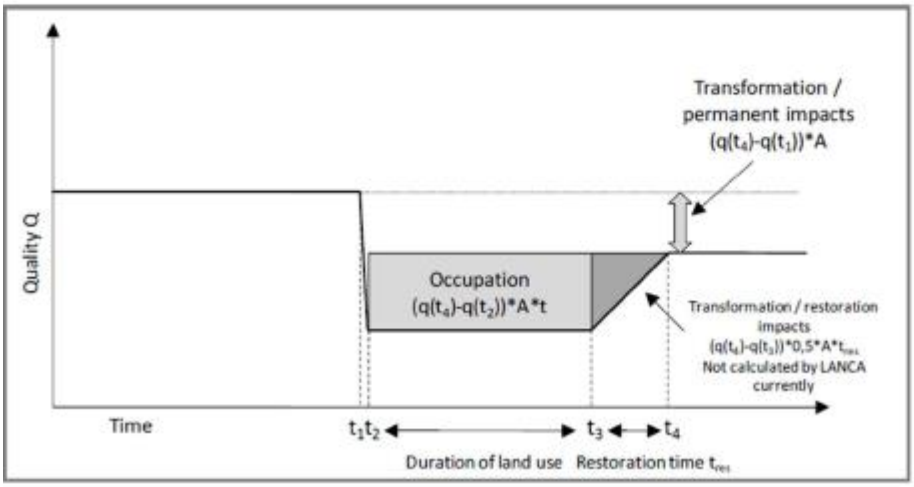


Figure 3 Illustration of transformation and employment [38].

During the transformation of the soil, the properties of a piece of land are modified to make it suitable for an intended use, such as drainage of the soil to establish arable fields (Fig.1 from t1 to t2). It is possible to distinguish between "transformation to" and "transformation from"[42]; the former refers to the transformation from a reference situation to a type of land use, the latter refers to the transformation from a previous type of land use and the respective quality of the ecosystem to the reference situation, due to the restoration capacity of the soil or positive human intervention (t3 to t4). During the land occupation, the land is used in the intended productive way (e.g. a arable field) and the properties of the land are maintained over time, as shown in Figure1 from t2 to t3. These land use interventions have an impact on the quality of the ecosystem for a certain period of time. These impacts derive both from land use, because the quality of the ecosystem is maintained at a different level from what would be naturally present, and from land transformation, because the characteristics of the ecosystem are modified on purpose[40].

Therefore, transformations are time-independent and their quantification depends only on the transformed area; employment impacts, on the contrary, must also consider employment time.

Often transformation is followed by employment, or employment takes place in an area that has been previously transformed[33]. However, if no employment process would follow a soil transformation, ecosystem properties would gradually return to their initial quality, although the original ecosystem quality may not be achieved. This means that the absence of human action continues for a sufficient period of time, causing the abandoned land to develop into site-dependent natural vegetation; this is known as regeneration time.

Therefore, one could say that the regeneration time depends on the intensity of the type of land use during the transformation phase. Saad[40], in the UNEP-SETAC guideline, suggest some values of the regeneration time necessary for an ecosystem to recover its maximum potential, according to each biome: these range from 52 years (for mangroves) to 138 years (for mountain grasslands and shrubs). Although there is limited knowledge about the regeneration time of ecosystems, two schools of thought are generally addressed[38]:

- Assuming a total lack of soil regeneration capacity at the end of the intervention, since the impacts are known as "permanent" and therefore not reversible;
- Considering the impacts as reversible and therefore imagining a linear trajectory of ecosystem regeneration.

However, during an LCA study involving land use impact assessment, it is necessary to collect at least data on geographical location, spatial and temporal extent of use in the life cycle inventory analysis phase[43].

1.10 Characterization models: different approaches

Over the last 15 years, considerable efforts have been made to quantify the impacts on soils from production and related supply chains. The focus is on models linking soil employment and soil transformation to soil impact indicators that can be applied in the context of life cycle assessment. Initially, a range of soil-related models were selected and evaluated according to several criteria, including scientific robustness, stakeholder acceptance, reproducibility and applicability of the models from the perspective of LCA practitioners[39].

Over the years, as part of the selection of soil indicators, evaluation models have been proposed that address impacts on land use through multiple indicators: LANCA[38,40] and SALCA-SQ[44]. These models assess and cover different impact factors, while others are based on the use of a single indicator (usually Organic Soil Substance in Soil), while neglecting other parameters. Furthermore, models have also been developed that follow a more qualitative approach, proposing a holistic approach in soil quality characterisation, based on a very detailed and comprehensive qualitative scoring system for the list of soil aspects considered. However, the current models that could be applicable in the LCA are not able to represent exhaustively the multiple impacts arising from land use and land use change[39].

The model currently recommended in the ILCD manual is by Mila i Canals[41], which provides for the use of a single soil quality indicator including soil organic carbon (SOC). The SOC is used as an indicator of the productive capacity of the soil, which in turn can affect two areas of protection: natural resources and the natural environment; in addition, an increase in the SOC implies a benefit, whereas any decrease is accounted for as damage to the system. Unlike the previous version of the land use framework (Mila i Canals[41]), which characterised impacts only in the UK, Brandão and Mila i Canals[40] have provided CF for a global application of the model based on Ecoinvent land use flows, which have been further adapted to ILCD inventory flows (for employment and transformation).

In addition to these, however, there are other models that indirectly address the problem of soil occupation and soil transformation through the consideration and analysis of additional soil issues and soil functions that contribute to the loss of soil quality such as desertification, compaction and so on. Table 2 reports the current characterization models used.

Table 2 Resuming table about current used characterization models.

Reference (year)	**Soil indicators**	**Spatial resolution of CF**	**Transformation / Employment**	**Main features**
Milà i Canals (2007)	SOM	Global	Both	Current ILCD recommendation
Brandão and Milà i Canals (2013)	SOC	Climate regions	Both	Consider 8 types of agriculture and crop management practices
Saad et al.(**2013)**	Erosion resistance; Mechanical filtration; Physical-chemical filtration;	Global and biogeographical regions	Both	Consider 7 types of land use

	Groundwater recharging			
Oberholzer et al. (2012)	Many soil properties (SOC, rooting depth, etc.); organic pollutants; risk of erosion and compaction	Local	It is not clear	Includes land management practices; CF provided locally only
Nuñez et al. (2010)	Desertification index (DI)	Ecoregions	Employment only	DI is based on aridity (due to weather conditions), erosion, over-exploitation of groundwater and the risk of fire.
Garrigues et al. (2013)	Compaction; Loss of pore volume	Local	It is not clear	CF only from case studies for a set of crops and a selection of countries
Nuñez et al. (2013)	Loss of NPP;	Regions and countries	Employment only	Indicators based on the USLE equation
Alvarenga et al. (2015)	HANPP	Global and Country	It is not clear	Few types of land use at a high hierarchical level and specific crops
Impact World+ Bulle et al., (2013)	Biodiversity and other indicators	Global	Employment only	Includes calculation of impacts on the supply of natural resources
Cato et al. (2015)	Erosion resistance; Mechanical filtration; Physical-chemical filtration; Groundwater recharge; Climate regulation potential; Biotic production	Country	Both	Converts biophysical impact indicators from soil ecological functions into ecosystem services expressed in economic units using economic assessment

1.11 Product Environmental Footprint Category Rules

The environmental footprint of a product intended as a "good" or "service" is a measure based on the assessment of the environmental performance of a product, according to ISO 14040[31], analysed throughout its life cycle, from raw material supply to end of life, calculated in order to reduce the environmental impacts of such good or service. The European Commission has published Recommendation 2013/179/EU defining a single European method for the assessment and communication of the environmental footprint of products called "Product Environmental Footprint-PEF", with the overall objective of contributing to a greater availability of clear, reliable and comparable information on the environmental performance of products for all stakeholders, including those involved in the whole supply chain and building a single market for green products[45].

These are therefore methodologies, based on LCA, aimed at calculating a product's environmental performance, which introduce many improvements over other existing methods, such as:

- a clear definition of the categories expressing the type of potential environmental impact, to which reference should be made in order to carry out a comprehensive life cycle assessment;
- the obligation to assess the quality of the data;
- the introduction of minimum data quality requirements;
- more precise technical instructions to address some critical aspects of LCA studies (such as allocation, recycling).

In order to facilitate data comparability, specific standards have been developed for priority products and sectors such as the PEFCR "Product Environmental Footprint Category Rules", i.e. rules, based on the life cycle, which complement the PEF method by identifying additional requirements for a given product category[46].

In particular, PEFCRs provide specific guidance for the calculation of potential environmental impacts of the life cycle of products with the aim of establishing a coherent set of rules to calculate relevant environmental information for products belonging to the same category and to allow comparisons and comparative statements in all cases where this is relevant and appropriate. Significant comparisons can only be made when products are capable of performing the same function (expressed in the functional unit)[46].

Similar rules to PEFCR exist in standards for other types of life cycle based product claims, such as ISO 14025[31] (type III environmental declarations). However, the purpose of the PEF study is to prevent an applicant who does not have access to company-specific primary data from carrying out a PEF study and reporting its results by applying only default data[47].

Between 2013 and 2016 the European Commission conducted an Environmental Footprint pilot phase defining three main objectives[47]:

- to test the process of developing product- and sector-specific rules;
- to test different approaches to verification;
- to test communication vehicles to communicate environmental life-cycle performance to business partners, consumers and other company stakeholders.

In the period between the end of the Environmental Footprint pilot phase and the eventual adoption of policies to implement the Environmental Product and Footprint Methods (PEF) and the Environmental Footprint Organization (OEF), the transition phase is established. The main objectives of this phase are to provide a framework for [47]:

- monitoring the implementation of existing Environmental Product, Footprint Category Rules (PEFCRs) and Footprint Environmental Organization Rules (OEFSRs);
- the development of new PEFCRs/OEFSRs;
- new methodological developments.

1.12 Soil Use in PEFCR

Land use falls into the 16 impact categories for the calculation of the PEF profile.

Impacts of land use and damage to the quality of ecosystems can be measured with different indicators that express the intrinsic value of biodiversity and natural landscapes or the functional value of ecosystems in terms of goods (i.e. natural resources such as timber or food) and services (i.e. life support functions such as climate regulation or erosion regulation)[41]. In this context, the focus is on the development of site-specific characterisation factors, which provide information related to soil quality and fertility, by analysing all those parameters related to land use through the application of the LANCA model, recommended for the EF as follows a land use classification fully compatible with the ILCD manual[42].

2. AIMS OF THE STUDY

The Life Cycle Assessment method needs factors, called Characterization Factors (CF), to transform consumption and emissions into environmental impacts. The model, LANCA, is recommended by the European Commission in the framework of the Environmental Product Footprint to calculate CFs for the environmental impact category "Land Use" of 5 soil quality indicators: erosion potential, filtration reduction potential, physicochemical filtration reduction potential, groundwater regeneration reduction potential and biotic production reduction potential. Default CFs, according to the model, are provided on a national basis and on the type of land use. The LANCA model also allows the calculation of CFs on the basis of site-specific parameters. The aim of this thesis was to evaluate the behaviour of the LANCA model, i.e. which of the three grouping methods (national basis, FAO GEZ (Global Ecological Zones) classification, percentage of clay) provides more meaningful groups of CFs and thus which of the three groupings is more representative in characterising CFs.

To do this, 48 sampling sites were randomly selected so that the sites belonged to two countries, Spain and France, and fell into 3 FAO GEZs (subtropical dry forest, temperate mountain system, temperate oceanic forest). Then, CFs were calculated, ANOVA analysis was carried out and the variance within each group and between groups was studied for various grouping methods (country, FAO GEZ and clay percentage).

The importance of this work is linked to the fact that soil, as a non-renewable resource subject to strong anthropogenic pressures, is at risk of losing its integrity and stability and compromising functions essential to the balance of the planet. Therefore, this study aims to improve the methodology in order to obtain a more specific and truthful assessment of the potential impacts of land use in order to preserve its characteristics and functions for future generations.

3. MATERIALS AND METHODS

3.1 Brief illustration of the LANCA model

LANCA (Land Use Indicator Value Calculation for Life Cycle Assessment)[42] is the characterization model for the calculation of characterization factors at national and global level to assess the environmental impact on soil ecosystem services due to land use; the model is designed to be integrated into life cycle assessment studies. This version 2.0 is being updated to better meet PEFCR requirements. The soil quality indicators selected by the LANCA developers are erosion resistance (ER), mechanical filtration (MF), physicochemical filtration (PF), groundwater regeneration (GR) and biotic production (BP). The model not only presents CFs based on globally available spatial data, but allows the user to calculate site-specific CFs according to the calculation systems proposed in the LANCA guide by entering specific data. The soil quality parameter data for the calculation of CF are provided at country level by LANCA and are average values on a national scale.

3.2 Data search and choice of sampling sites

The data search was carried out for all input data necessary for the calculation of the five soil quality indicators. Most of the data were obtained through the use of a European ESDAC platform "EUROPEAN SOIL DATABASE CLASSIFICATION"[48], a platform containing soil data at European level. This includes soil data such as soil texture, pH, cation exchange capacity, slope and elevation, and other factors expressing intrinsic characteristics and soil management practices, including Land Cover Factor, Rainfall erositivity Factor, Practices support Factor, Erodibility Factor, which will be discussed in detail later. As for climate data, some of them such as precipitation, temperature and solar radiation have been obtained through a "World weather online" platform[49], while other data such as evapotranspiration and groundwater depth (below ground surface) have been obtained differently: In the case of evapotranspiration, this was determined by applying a physical formula, precisely through the Hargreaves equation, while for groundwater depth, national portals were consulted for access to groundwater data, for France the "ADES" portal[50] and for Spain the portal of the "Ministry of Agriculture and Fisheries"[51]. For land use, instead, the portal "Copernicus"[52] was consulted, in particular the Catalogue "Corine Land Cover, 2018"; in our case study the use of agricultural land was considered, in particular the 2.3.1. corresponding to "pastures" and 2.1.1. corresponding to "non-irrigated soils", because it is more present in the sampling sites considered. Tables (3a-b,4a-b) below detail the input data from Spain and France respectively required for the calculation of the five characterization factors.

Table 3 (a-b) input data from Spain sampling sites necessary for the calculation of characterization factors.

a)

Sampling sites	Texture	Land use	Clay	Silt	Sand	pH	CEC	Cfactor	Kfactor	Lsfactor	Pfactor	Rfactor
Units of measurement			%	%	%		cmol/kg					
A Coruna	sandy loam	231	20	30	50	5.8	12.3	0.1	0.04	11.8	0.8	1262
Albacete	sandy loam	231	30	20	50	8.3	17.8	0.2	0.03	11.8	0.8	559
Barcelona	clay loam	231	35	40	25	7.3	17.8	0.1	0.04	11.8	0.8	1262
Benasque	clay loam	231	30	30	40	6.8	23.4	0.2	0.04	41.5	0.8	1848
Bilbao	silty loam	231	25	50	25	6.4	17.8	0.1	0.03	23.7	0.8	1613
Broto	sandy clay loam	231	25	25	50	6.8	28.8	0.1	0.02	41.5	0.6	1262
Cervera de pisuerga	clay loam	231	40	30	30	6.8	17.8	0.2	0.04	23.7	0.8	559
Eibar	silty loam	231	25	55	20	5.9	12.3	0.1	0.02	23.7	0.8	2316
Foz	silty loam	211	20	50	30	5.4	6.8	0.1	0.03	23.7	0.8	1262
Gijon	clay loam	231	35	40	25	6.8	12.3	0.1	0.02	11.8	0.8	910.9
Isaba	sandy loam	231	15	30	55	6.4	28.8	0.2	0.04	41.5	0.8	910.9
Lugo	sandy loam	231	10	30	60	5.8	12.3	0.1	0.03	11.8	0.7	1262
Malaga	clay	231	40	30	30	7.7	17.8	0.2	0.03	11.8	0.8	559
Orreaga	silty loam	231	20	50	30	6.4	12.3	0.05	0.02	23.7	1	910.9
Oviedo	silty loam	231	15	55	30	6.8	12.3	0.2	0.02	23.7	0.8	559
Potes	silty loam	231	20	50	30	6.4	17.8	0.1	0.02	11.8	0.8	559
Salamanca	sandy loam	231	15	25	60	6.8	12.3	0.2	0.04	0.03	0.8	208.4
Santander	silt loam	231	20	50	30	6.8	17.8	0.2	0.04	11.8	0.7	1262
Santiago de compostela	sandy loam	231	10	30	60	5.8	12.3	0.1	0.03	11.8	0.8	1965
Sevilla	clay	231	50	25	25	8.3	17.8	0.2	0.03	0.03	0.8	910.9
Toledo	clay loam	231	35	25	40	7.7	17.8	0.2	0.04	11.8	0.8	208.4
Valencia	clay loam	211	35	40	25	7.7	17.8	0.2	0.03	0.03	0.8	910.9
Vielha e Mijaran	clay loam	231	30	30	40	6.4	23.4	0.1	0.04	41.5	0.7	1848
Zaragoza	silty clay loam	231	30	50	20	8.3	17.8	0.2	0.05	11.8	0.8	559

b)

Sampling sites	Average P	Average T	Δ_T	UV index	ET_0	Water table depth
Units of measurement	**mm/y**	**°C**	**°C**	**MJ/m2day**	**mm/y**	**m**
A Coruna	1014	14.7	6.1	4.6	310.0	28.5
Albacete	351.6	14.2	12.8	5.8	442.1	49.3
Barcelona	564	18.2	6.1	5.1	343.4	0
Benasque	2551.2	5.6	6.5	2.6	230.4	151.3
Bilbao	1122	14.6	9.7	4.6	389.7	60
Broto	2773.2	6.4	5.6	2.8	221.2	172.2
Cervera de pisuerga	1744.8	13.6	6	4	297.0	102
Eibar	2156.4	14.5	6.6	4.3	320.4	181
Foz	1779.6	13.8	7.6	3.9	336.4	73
Gijon	1572	14.2	6.7	4.3	319.9	39.9
Isaba	3165.6	7.5	7.3	2.8	264.0	128.6
Lugo	1068	12	11.1	3.9	383.4	61.1
Malaga	534	18.6	9.3	6	428.7	46.4
Orreaga	1320	12.6	10.3	4	376.8	80
Oviedo	962.4	13.3	8.3	4.6	346.0	89
Potes	1744.8	13.6	6	4	297.0	41
Salamanca	373.2	12.1	13	5.3	416.3	140.2
Santander	1128	14.5	8	4.6	352.8	111.3
Santiago de compostela	1788	13	9.3	4.7	362.7	35
Sevilla	540	19.2	12.4	5.7	503.1	18
Toledo	342	15.8	12.6	5.4	460.6	120
Valencia	474	18.3	8.9	5.3	415.9	0
Vielha e Mijaran	2551.2	5.6	6.5	2.6	230.4	179.7
Zaragoza	321.6	15.5	11	5.1	426.5	36.8

Table 4 (a-b) input data from the French sampling sites necessary for the calculation of characterization factors.

a)

Sampling sites	Texture	Land use	Clay	Silt	Sand	pH	CEC	Cfactor	Kfactor	Lsfactor	Pfactor	Rfactor
Units of measurement			%	%	%		cmol/kg					
Aix En Provence	sandy clay loam	211	25	50	25	7.6	17.8	0.2	0.03	12.5	0.8	1842
Albertville	clay loam	231	30	40	30	7.1	23.4	0.1	0.03	24.9	0.8	621
Ales	clay loam	211	35	40	25	7.6	12.3	0.2	0.03	12.5	0.8	2078
Amiens	silt loam	211	10	30	60	7.1	12.3	0.2	0.05	12.5	0.8	256.4
Bastia	sandy clay loam	211	25	50	25	7.1	12.3	0.1	0.03	24.9	0.8	2078
Bussang	clay loam	231	35	25	40	5.6	12.3	0.1	0.03	24.9	0.8	621
Caen	silt loam	231	15	25	60	6.6	12.3	0.2	0.05	12.5	0.6	256.4
Chamonix-Mont Blanc	clay loam	231	35	40	25	6.1	17.8	0.2	0.04	49.9	0.8	985.2
Digne les bains	clay loam	211	35	40	25	7.6	28.8	0.1	0.03	49.9	0.8	621
Dijon	clay loam	211	30	25	45	7.1	12.3	0.2	0.04	12.5	0.8	256.4
Le Puy En Velay	sandy clay loam	231	30	50	20	6.1	12.3	0.1	0.03	12.5	0.7	985.2
Les orres	clay loam	231	30	40	30	6.6	17.8	0.2	0.04	49.9	0.8	1842
Limoges	sandy clay loam	231	25	50	25	5.6	12.3	0.2	0.03	12.5	0.8	985.2
Marseilles	clay loam	211	30	35	35	7.6	23.4	0.2	0.03	12.5	0.8	1842
Mende	sandy clay loam	231	30	50	20	6.6	17.8	0.1	0.03	24.9	0.8	985.2
Montpellier	clay	211	40	35	25	8.1	17.8	0.2	0.03	12.5	0.8	2078
Nant	clay loam	231	35	35	30	6.6	23.4	0.1	0.02	24.9	0.8	985.2
Nantes	sandy clay loam	231	30	50	20	6.6	17.8	0.2	0.03	12.5	0.6	256.4
Orange	sandy clay loam	211	25	50	25	7.6	12.3	0.2	0.03	12.5	0.8	2078
Perpignan	clay loam	231	30	35	35	8.1	17.8	0.3	0.04	0.03	0.8	985.2
Pontarlier	silty clay	231	40	20	40	6.6	28.8	0.1	0.03	12.5	0.8	1842
Toulouse	clay loam	211	30	35	35	7.1	17.8	0.2	0.04	12.5	0.8	621
Tours	sandy clay loam	211	25	65	10	7.1	17.8	0.2	0.03	12.5	0.8	256.4
Versailles	sandy loam	231	10	55	35	6.6	17.8	0.1	0.04	12.5	0.8	256.4

b)

Sampling sites	Average P	Average T	Δ_T	UV index	ET_0	Water table depth
Units of measurement	**mm/y**	**°C**	**°C**	**MJ/m2day**	**mm/y**	**m**
Aix En Provence	645.6	13.1	9.3	4.4	348.1	247.7
Albertville	2019.6	8.3	8.3	3.2	202.0	3.8
Ales	1260	14.4	8.5	4.4	346.8	6.8
Amiens	864	11.4	8	3.3	228.8	16.9
Bastia	774	13.8	5.4	4.6	283.6	4.2
Bussang	1615.2	10.6	7.9	3.3	221.1	5.9
Caen	1214.4	11.7	7	3.3	216.2	12.5
Chamonix-Mont Blanc	1797.6	6.7	7.3	2.2	122.3	3.9
Digne les bains	1563.6	10.2	10.4	3.8	288.1	1.6
Dijon	760.8	10.5	8.9	4	283.5	17.9
Le Puy En Velay	1204	9.5	10.2	3.4	248.9	31.5
Les orres	2341.2	5.4	8.1	2.5	138.6	9.1
Limoges	1023.6	11.3	10.4	4.3	338.8	2.3
Marseilles	591.6	14.2	9.2	4.4	358.5	131.2
Mende	1635.6	9	9.1	3.3	224.0	-0.2
Montpellier	628.8	14	10.2	4.4	375.1	8.9
Nant	1472.4	10.8	9.1	3.6	260.7	10.2
Nantes	819.6	11.6	8.2	4	282.7	2.8
Orange	712.8	16.3	8.6	4.6	386.2	2.4
Perpignan	585.6	15.4	8.7	4.7	386.4	7.8
Pontarlier	2370	9.5	8.3	3.3	217.9	5.6
Toulouse	698.4	12.7	9.9	4.4	354.5	4.6
Tours	696	11.7	8.7	4	292.2	31.3
Versailles	654	10.5	7.6	3.7	242.3	6.6

The choice of the sampling sites was mainly made by determining the number of the sample, statistically calculated through the following formula[53]:

Equation 1

$$N = \frac{4\sigma^2 * (Zcrit+Zpwr)^2}{D^2}$$

where:

σ^2 = variance

Zcrit and Zpwr = standard normal deviates at a level of significance and at a 1-β power, respectively, with β being the type II error.

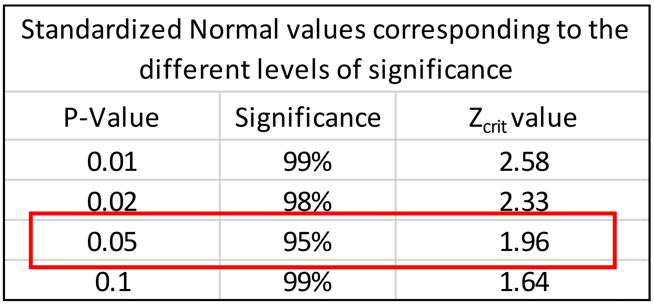
D^2 = is the square of the minimum expected difference

In our case we can say that:

- σ^2 = 5, as, conventionally, the significance level is set at 0.05 (5%), which implies that it is acceptable to have a 5% probability of incorrectly rejecting the null hypothesis.
- Zcrit = 1.96,(according to table 5a) with 95% level of significance (P=0.05); by level of significance we mean a quantitative estimate of the probability that the differences observed are due to chance.
- Zpwr = 1.28, (according to table 5b) with 90% potency; potency means the probability of correctly identifying a difference between two groups under study when this difference exists in the populations from which the samples were extracted (Country - Eco-zone - % clay).
- D^2 = represents the random variability of the phenomenon under study.

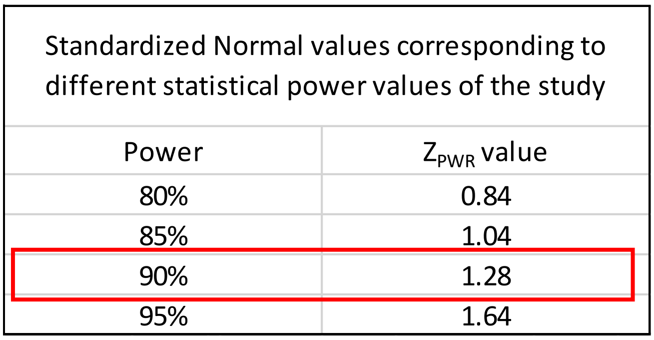
*Table 5 (a) Standardized Normal values corresponding to the levels of significance and (b) Standardized Normal values corresponding to statistical power values [53]**.***

a)



Standardized Normal values corresponding to the different levels of significance		
P-Value	Significance	Z_{crit} value
0.01	99%	2.58
0.02	98%	2.33
0.05	95%	1.96
0.1	99%	1.64

b)



Standardized Normal values corresponding to different statistical power values of the study	
Power	Z_{PWR} value
80%	0.84
85%	1.04
90%	1.28
95%	1.64

Therefore, by applying these data to the formula we obtain the number of samples that we have to collectc for each country (Spain and France):

Equation 2

$$N = \frac{4*5*(1.96+1.28)^2}{3^2} = 23$$

The sites to be sampled was chosen according to a random stratification criterion. Stratification was based on three levels of interest and reference, including country (Spain and France), Eco-zone and the third level of interest selected at the operator's discretion. Eco-zone refers to a global distribution of potential natural vegetation, whose reference situation is given according to the global map of ecological zones provided by FAO[54], classified by biome type, which are the main global plant communities determined by rainfall and climate[55]. In our case, three ecological zones present in both states were considered, including: Subtropical Dry Forest (SDF), Temperate Mountain System (TMS)and Temperate Oceanic Forest (TOF). Finally, there were two main candidates for the third level of interest: slope and elevation (LS factor) and clay: the LS factor has much influence in the indicator of erosion resistance, while clay (a component of soil structure) has lower influence, but it is included in three different CFs calculation. The choice of the latter level was therefore made at the discretion of the operator, who designated clay as the third choice, because she considers that it provides, contrary to the LS factor, a more important data for the calculation of soil quality, as it is present in the calculation of several indicators; moreover, for the use of the considered soil, i.e. stable meadows, it is a fundamental parameter in the production of humus and the biotic component because a good vegetative production is essential for grazing and in turn for the production of different foodstuffs.

On the basis of these criteria, we were able to obtain 23 homogeneous samples per country divided, homogeneously, into the three eco-zones, so that each eco-zone had the same number of samples; for this reason, wanting to have eight samples representative of the eco-zone, we rounded N to 24.

All these data have been graphically represented through the "QGis" software (Figures 4-6).

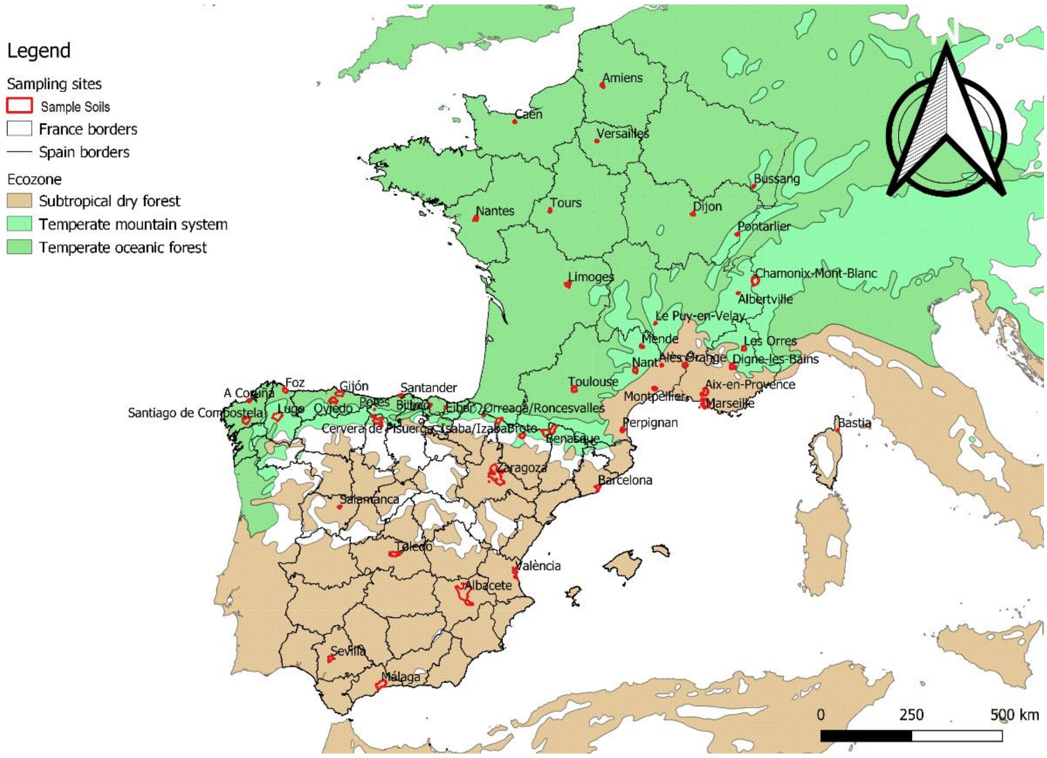


Figure 4 Representation of the three eco-zones considered in the study; the red lines indicate sample soils in Spain and France within the reference eco-zones.

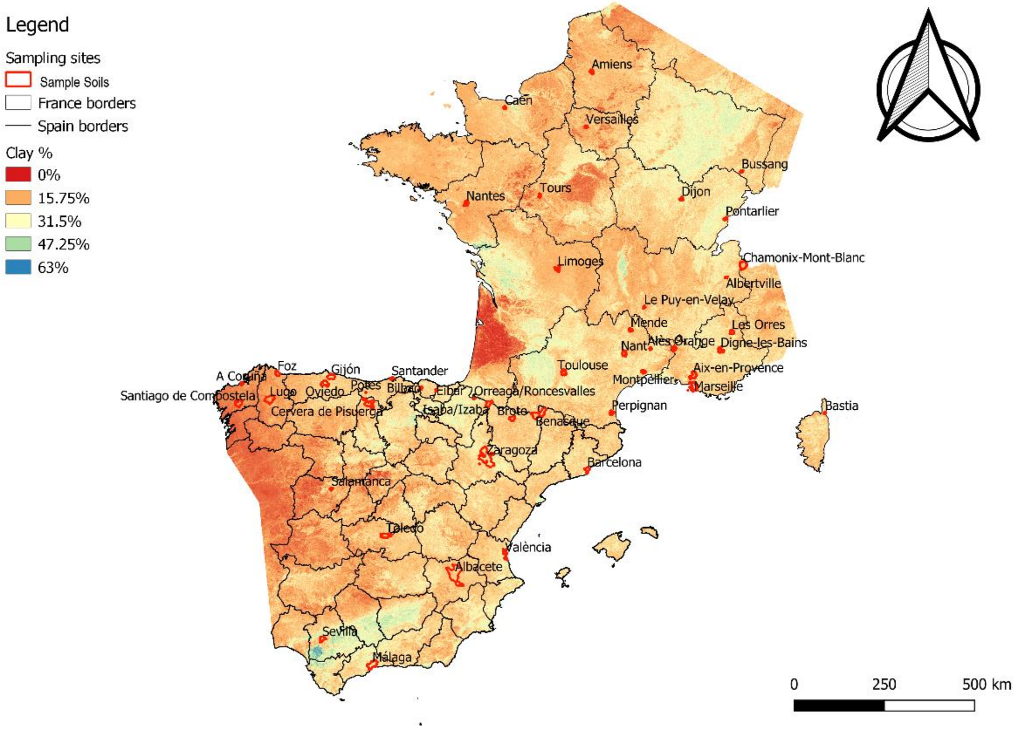


Figure 5 Representation of clay content in Spain and France; the red lines indicate sample soils from Spain and France containing a % of clay.

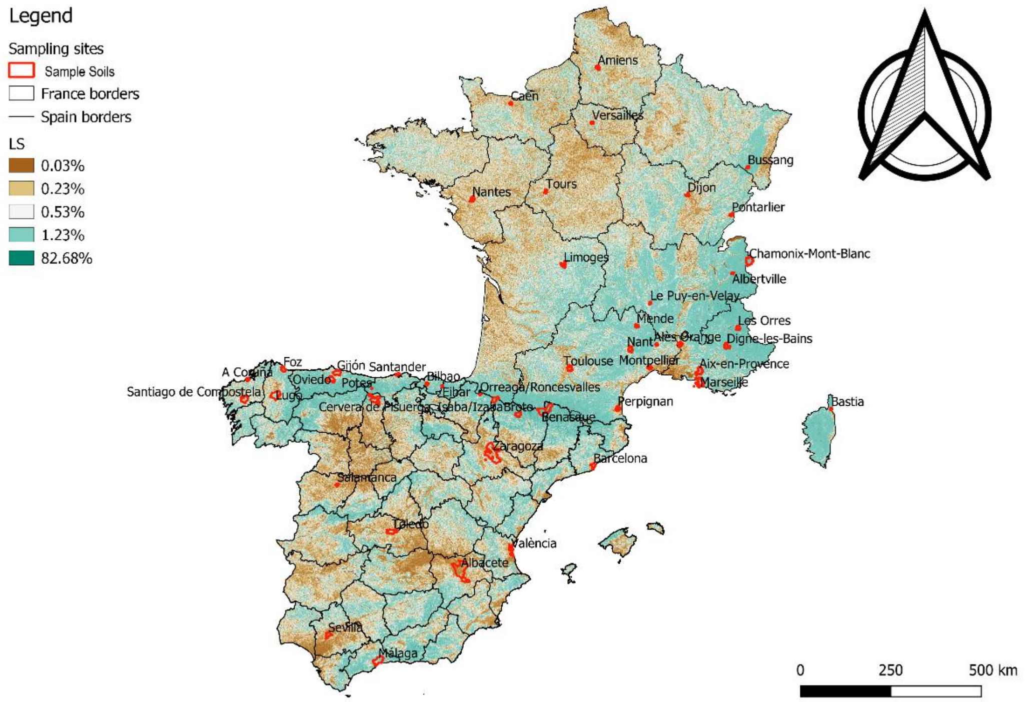


Figure 6 Representation of the LS factor in Spain and France; the red lines indicate the sample soils from Spain and France with a LS value.

3.3 Data analysis

The data collection was carried out on the parameters needed to calculate the five soil quality indicators foreseen by the LANCA model as they better represent soil and ecosystem health, leading to the identification of impacts. The indicators are: erosion resistance (ER), mechanical filtration (FM), chemical-physical filtration (PF), groundwater regeneration (GWR) and biotic production (BP).

The definition of indicators, environmental relevance, measurements and the calculation framework are reported as Bos[42] did. Figure 7 briefly illustrates the calculation structure of the characterization factors and the input data required for this purpose.

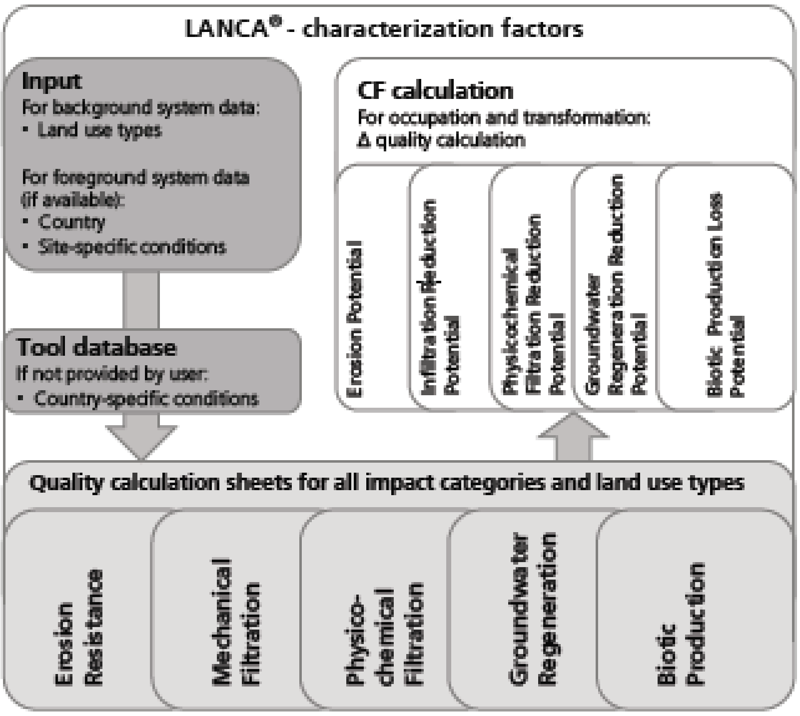


Figure 7 Structure of the calculation of Characterization Factors [42].

3.3.1 Erosion resistance

Soil erosion describes the process of removing and transporting soil particles by water or wind, which occurs if the intrinsic resistance of the soil against mechanical influences is no longer given[56]. Soil loss is a major threat to the environment, including impacts on the water and nutrient cycle, root depth and soil productivity[57]. The ability to resist erosion is therefore an important function of the natural ecosystem and is therefore considered by the LANCA model as an indicator of the impact of land use. The corresponding CF is the "Erosion Potential".

In this study, the RUSLE model[58] was applied as the calculation basis for erosion resistance. Therefore, soil losses were determined with the following equation:

Equation 3

$$A = R * K * LS * C * P$$

Where:

- A = are the annual average rates of soil erosion predicted based on precipitation [$kg_{soil}/(m^2*y)$];
- R = is the erosiveness factor of precipitation;
- K = is the erodibility factor;

- LS = is the slope length factor;
- C = is the ground cover factor;
- P = is the supporting practice factor

Figure 8 shows schematically the calculation structure of the "Erosion resistance" indicator and all input data used in the calculation.

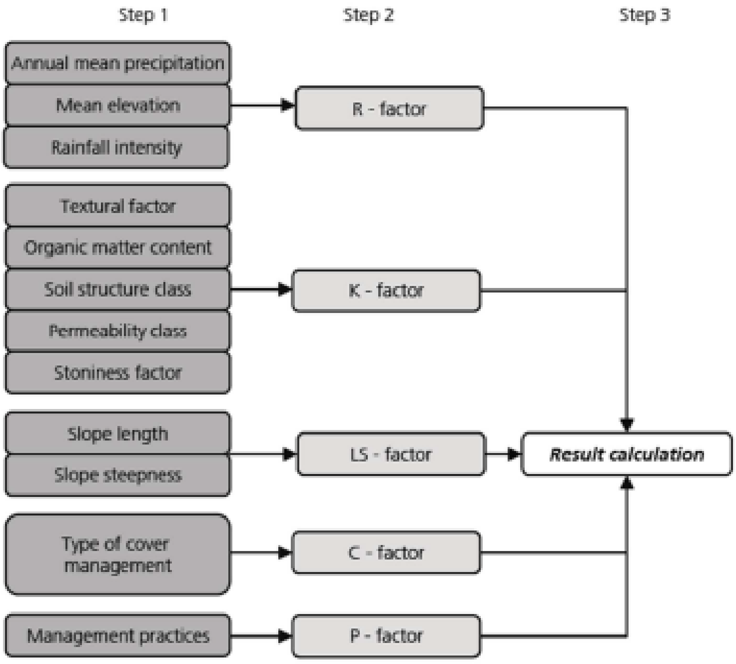


Figure 8 Calculation structure of the indicator Erosion resistance [42].

R Factor

The rainfall erosivity factor describes the amount of kinetic energy of raindrops transferred to the ground surface. The erosion due to raindrops depends on the amount of kinetic energy per area and the intensity of the rainfall. For the LANCA characterisation factors several simple approximation equations are applied for each climate zone according to Koppen and Geiger[59]. In our case study, however, the R-factor data were derived from the European ESDAC platform.

K Factor

It refers to the natural susceptibility of soil to erosion, usually obtained from the equation of Panagos[60]:

Equation 4

$$K = \frac{2.1*10^{-4}*M^{1.14}*(12-OM)+3.25*(S-2)+2.5*(p-3)}{100}*\frac{0.1317*St}{100}$$

Where:

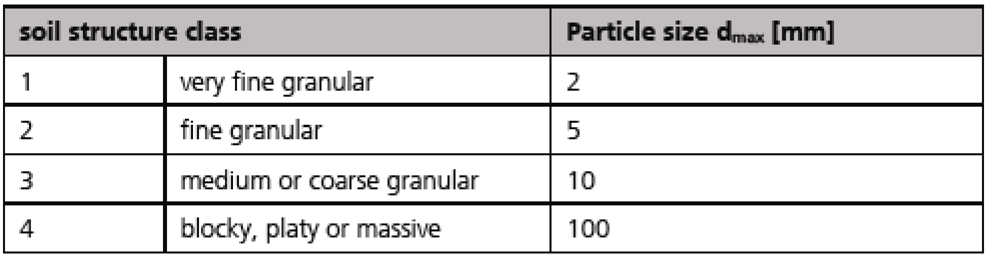
- M = is the structural factor; it represents the quantity of the different classes of soil structure, i.e. the quantity of clay, silt and sand, and is determined by the following equation[60] as follows:

Equation 5

$$M = (silt + fine\ sand) * (100 - clay)$$

- OM = is the content of organic matter; LANCA data from the world harmonised soil database (H.W.S.D.)[61]
- S = is the soil structure class, defined by the Soil European Database Classification (ESDAC)

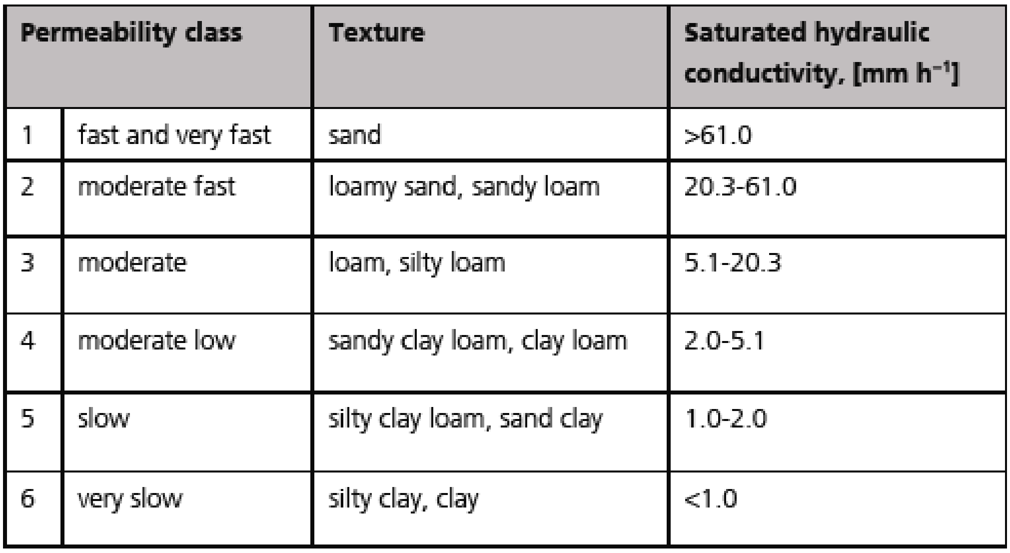
Table 6 Soil structure class definition based on ESDAC [42]



soil structure class		**Particle size d_{max} [mm]**
1	very fine granular	2
2	fine granular	5
3	medium or coarse granular	10
4	blocky, platy or massive	100

- P = is the permeability class; defined according to the European Soil Database Classification[48] (ESDAC) as follows:

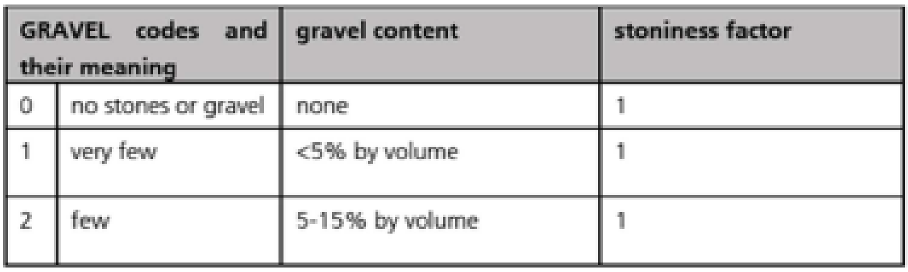
Table 7 Permeability class assignment based on soil texture according to ESDAC [42].



Permeability class		Texture	Saturated hydraulic conductivity, [mm h^{-1}]
1	fast and very fast	sand	>61.0
2	moderate fast	loamy sand, sandy loam	20.3-61.0
3	moderate	loam, silty loam	5.1-20.3
4	moderate low	sandy clay loam, clay loam	2.0-5.1
5	slow	silty clay loam, sand clay	1.0-2.0
6	very slow	silty clay, clay	<1.0

- St = is the stoniness factor; describes the gravel content of the soil; defined according to ESDAC and Panagos[60] as follows:

Table 8 Stoniness factor based on ESDAC and Panagos [42,60].



GRAVEL codes and their meaning		gravel content	stoniness factor
0	no stones or gravel	none	1
1	very few	<5% by volume	1
2	few	5-15% by volume	1

In this study, the data was obtained simply through ESDAC.

LS Factor

It refers to the topography of the terrain and depends on the length and the angle of the slope. For LANCA characterization factors, the LS factor is calculated using a linear regression model[62] with high correlation (R^2 = 0.9892) and a resolution of 25 m for EU countries. The correlation between the mean slope and the mean LS factors is modelled to obtain the following linear equation:

Equation 6

$$LS = 0.31 * slope + 0.0227$$

Where, S = is the slope [%]; average values for each country are obtained through GIS software with digital elevation models with a resolution of 250 m[63], and 1 km for countries where data are not available at higher resolutions.

However, our data have been obtained from the ESDAC platform.

C Factor

It represents the different types of land management and cultivation practices; its value ranges from 0 to 1. The data come from internal expert estimates and various bibliographical resources obtained in our case from the European ESDAC platform.

P Factor

It describes the effects of management practices that aim to combat the loss of soil from erosion, such as contour tillage or terrace systems. It ranges from values 0 to 1. Since the supporting practice factors only have an effect on a small scale, a value of about 1 is assumed, while for water and forest bodies, where a supporting practice cannot be expected, a value of 0 is used.

3.3.2 Mechanical filtration

The term mechanical filtration describes the ability of the soil to be mechanically infiltrated by a suspension and is expressed by the water permeability Kf [cm/d], which passes through the soil in a given unit of time. In general, water permeability depends on soil texture, soil porosity, distance from the groundwater table and type of soil use. The corresponding CF is the "Infiltration reduction potential". The calculation structure is based on a landfill evaluation system in Germany by Mueller (1975), but the calculation of the CF for mechanical filtration capacity has not been changed compared to the previous version of the model[38].

Figure 9 schematically illustrates the calculation structure of the "Mechanical Filtration" indicator and all the input data used in the calculation and the steps to be performed.

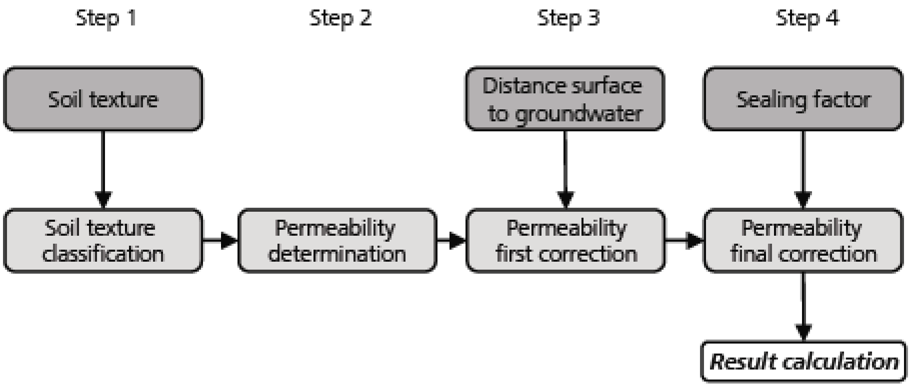


Figure 9 Calculation structure of the indicator Mechanical filtration [42].

In LANCA, the Kf value is obtained by following these steps:

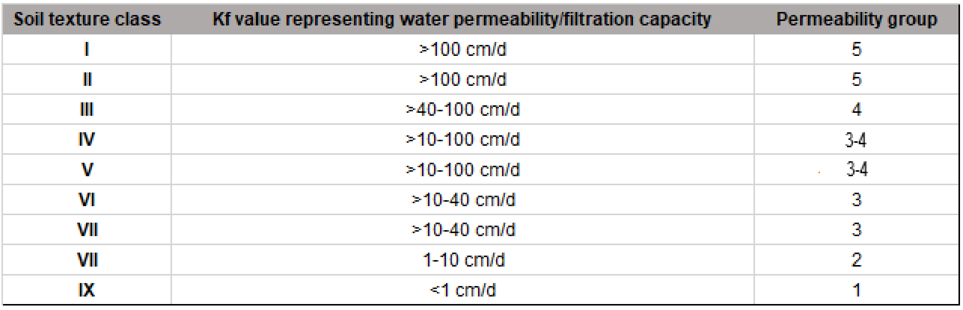
1. Determination of the soil texture: assignment of the texture class, according to Leser[64] classification through the following table; LANCA data obtained from ESDAC.

Table 9 Soil texture class assignment [38].

Soil texture	Soil texture class
No soil cover (rocks, opern water)	0
Silt	4
Weakly loamy silt	7
Medium clay silt	7
Medium silty loam	7
Medium sandy silt	4
Strongly loamy silt	7
Sandy loamy silt	7
Strongly clay silt	7
Silty loam	7
Weakly sandy loam	6
Silty loamy sand	4
Strongly silty sand	4
Silty clay loam	8
Weakly clay loam	8
Medium sandy loam silty sandy loam	6
Medium silty sand	4
Silty clay	8
Fine sand	2
Medium clay loam	8
Medium loamy clay	9
Sandy clay loam	8
Strongly sandy loam	5
Strongly sandy clay	9
Strongly loamy sand	5
Medium loamy sand	3
Weakly silty sand	3
Weakly sandy clay	9
Medium sandy clay	9
Medium clay sand	5
Weakly loamy sand	3
Cobble	1
Gravel	1
Coarse gravel	1
Medium gravel	1
Fine gravel	1
Sand	2
Clay (max)	9
Clay	9
Medium sand	2
Weakly clay sand	3
Coarse sand	2

2. Subsequently, each soil texture class is assigned a Kf interval value and a permeability group according to the following Leser[64] table:

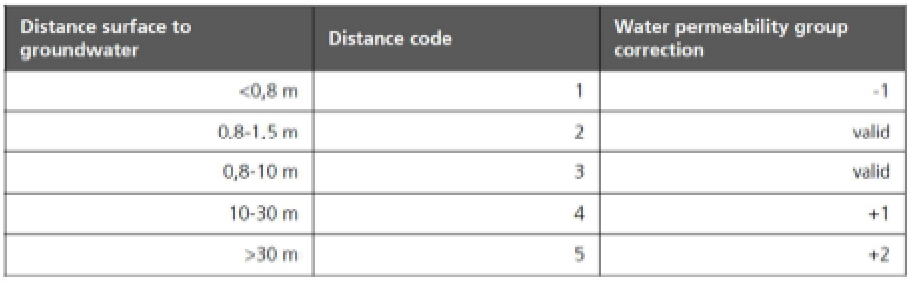
Table 10 Kf values of soil texture classes [38].



Soil texture class	Kf value representing water permeability/filtration capacity	Permeability group
I	>100 cm/d	5
II	>100 cm/d	5
III	>40-100 cm/d	4
IV	>10-100 cm/d	3-4
V	>10-100 cm/d	3-4
VI	>10-40 cm/d	3
VII	>10-40 cm/d	3
VII	1-10 cm/d	2
IX	<1 cm/d	1

3. The following table of Bastian[65] p. 213 and p. 250, assigns the correction of permeability considering the distance between surface and groundwater; it is assumed that the longer the mechanical filtration the longer the filtration capacity. The distance between groundwater and surface data was used by the authors[66].

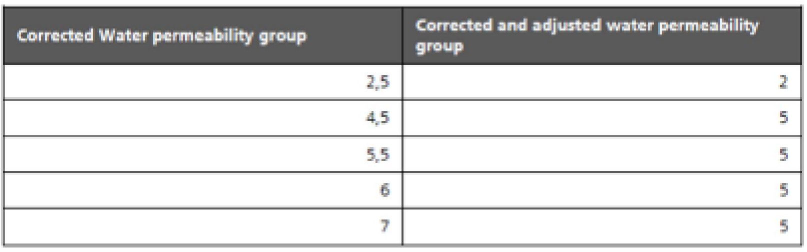
Table 11 Water permeability group correction based on the distance surface – groundwater [38].



Distance surface to groundwater	Distance code	Water permeability group correction
<0,8 m	1	-1
0.8-1.5 m	2	valid
0,8-10 m	3	valid
10-30 m	4	+1
>30 m	5	+2

After making the correction, the permeability group must be readjusted according to the following table from Bastian[65]:

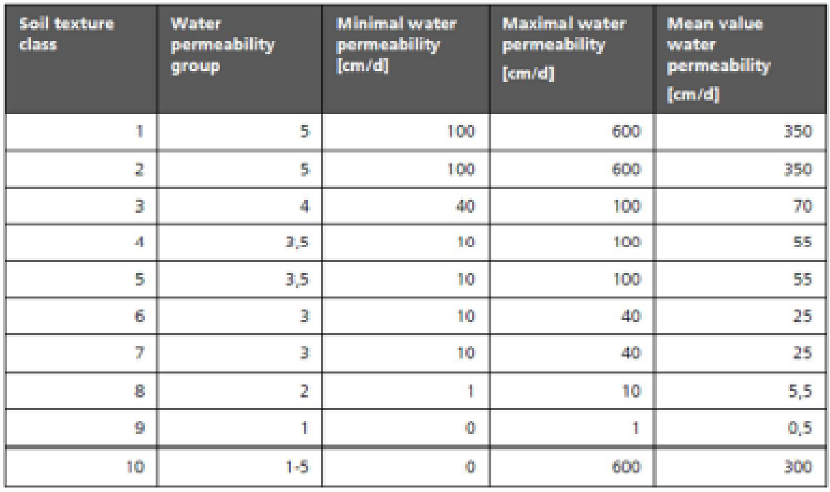
Table 12 Adjustment of corrected water permeability group [38].



Corrected Water permeability group	Corrected and adjusted water permeability group
2,5	2
4,5	5
5,5	5
6	5
7	5

The water permeability groups obtained are thus assigned to the respective average permeability values “Kf mean”:

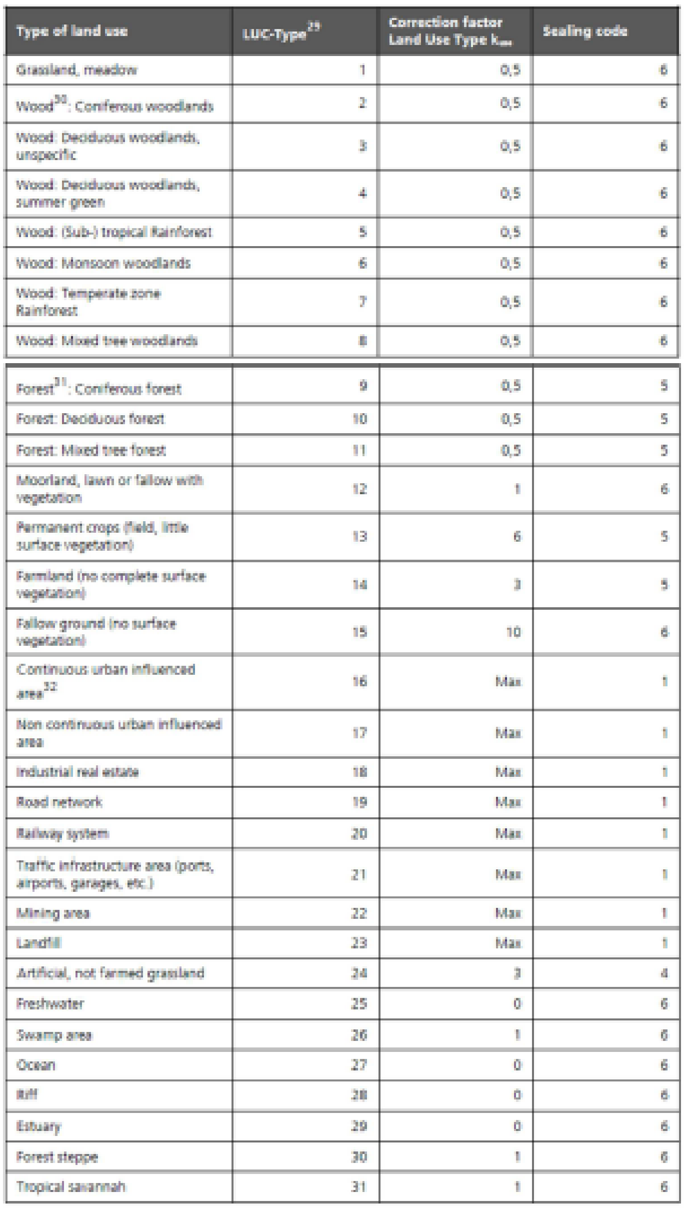
Table 13 Reassigned of corrected mean permeability [38].



Soil texture class	Water permeability group	Minimal water permeability [cm/d]	Maximal water permeability [cm/d]	Mean value water permeability [cm/d]
1	5	100	600	350
2	5	100	600	350
3	4	40	100	70
4	3,5	10	100	55
5	3,5	10	100	55
6	3	10	40	25
7	3	10	40	25
8	2	1	10	5,5
9	1	0	1	0,5
10	1-5	0	600	300

4. Finally, the permeability value is corrected according to the type of soil use: a sealing code is assigned to each type of soil use:

Table 14 Sealing code to each land use type [38].

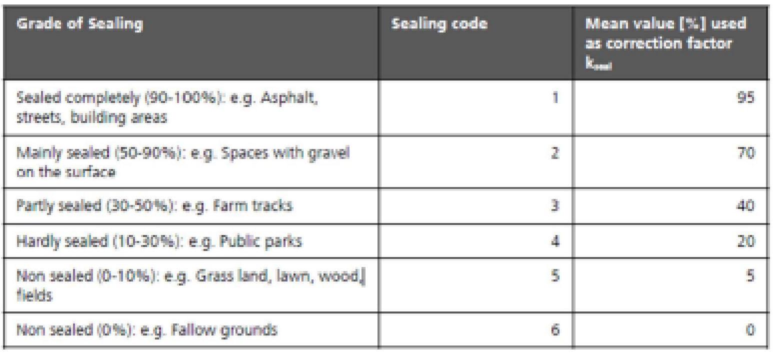


Type of land use	LUC-Type[29]	Correction factor Land Use Type k_{luc}	Sealing code
Grassland, meadow	1	0,5	6
Wood[30]: Coniferous woodlands	2	0,5	6
Wood: Deciduous woodlands, unspecific	3	0,5	6
Wood: Deciduous woodlands, summer green	4	0,5	6
Wood: (Sub-) tropical Rainforest	5	0,5	6
Wood: Monsoon woodlands	6	0,5	6
Wood: Temperate zone Rainforest	7	0,5	6
Wood: Mixed tree woodlands	8	0,5	6
Forest[31]: Coniferous forest	9	0,5	5
Forest: Deciduous forest	10	0,5	5
Forest: Mixed tree forest	11	0,5	5
Moorland, lawn or fallow with vegetation	12	1	6
Permanent crops (field, little surface vegetation)	13	6	5
Farmland (no complete surface vegetation)	14	3	5
Fallow ground (no surface vegetation)	15	10	6
Continuous urban influenced area[32]	16	Max	1
Non continuous urban influenced area	17	Max	1
Industrial real estate	18	Max	1
Road network	19	Max	1
Railway system	20	Max	1
Traffic infrastructure area (ports, airports, garages, etc.)	21	Max	1
Mining area	22	Max	1
Landfill	23	Max	1
Artificial, not farmed grassland	24	3	4
Freshwater	25	0	6
Swamp area	26	1	6
Ocean	27	0	6
Riff	28	0	6
Estuary	29	0	6
Forest steppe	30	1	6
Tropical savannah	31	1	6

In our study the land use considered as "permanent grassland" is included in the LANCA classification of land use in the term "grassland"; for sampling sites that do not have grassland soils we have considered non-irrigated soils that are included in the LANCA classification in the term "moorland".

Each seal code is assigned a correction factor, as shown in the table 15:

Table 15 Kf correction factor K_{seal} according to the sealing code [38].



Grade of Sealing	Sealing code	Mean value [%] used as correction factor k_{seal}
Sealed completely (90-100%): e.g. Asphalt, streets, building areas	1	95
Mainly sealed (50-90%): e.g. Spaces with gravel on the surface	2	70
Partly sealed (30-50%): e.g. Farm tracks	3	40
Hardly sealed (10-30%): e.g. Public parks	4	20
Non sealed (0-10%): e.g. Grass land, lawn, wood, fields	5	5
Non sealed (0%): e.g. Fallow grounds	6	0

The final result is given by:

Equation 7

$$MF = \text{mean value of water permeability} * (1-K_{seal})$$

3.3.3 Physico-chemical filtration

The physical-chemical filtration of a soil is represented by its ability to fix and exchange cations to clay and humus particles, also considering the pH dependence on the intensity of humus absorption. This quantity is called effective cation exchange capacity. The corresponding CF is the "Physical-Chemical Filtration Reduction Potential" [cmol/kg soil] and is calculated based on soil properties and surface sealing, as shown in figure.

Figure 10 schematically illustrates the calculation structure of the "Physical-chemical filtration" indicator and the input data used in the calculation.

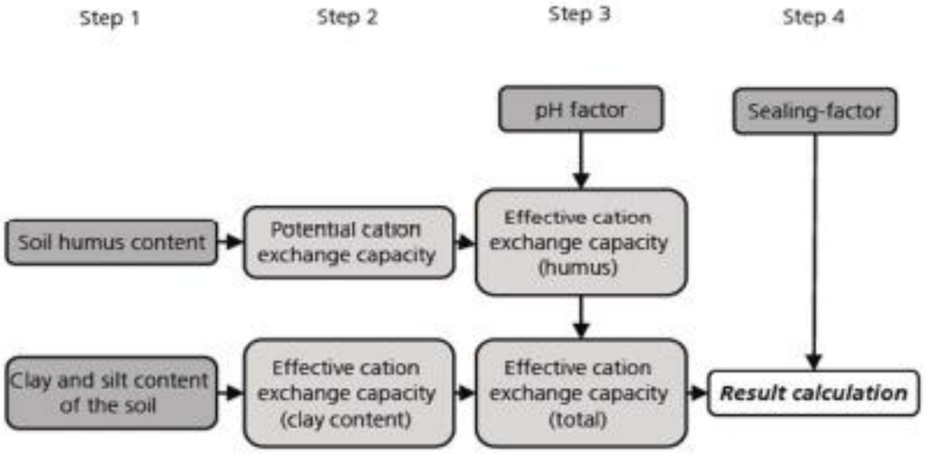
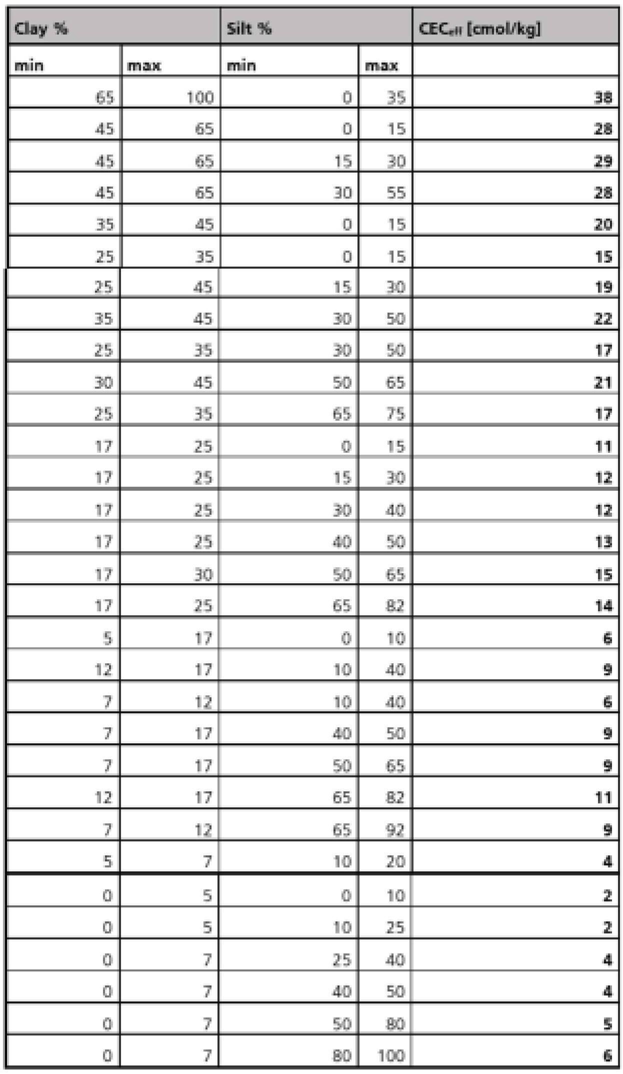


Figure 10 Calculation structure of the indicator Physicochemical filtration [42].

Calculation phases:

1. Determination of the effective cation exchange capacity, CECeff, of the soil (that describes the actual free cation absorbing spaces[38]) dependent on the clay and silt content only, according to the following table based on suggestions from Umweltlatlas Berlin and Bundesanstalt fur Geowissenschaften und Rohstoffe[67]:

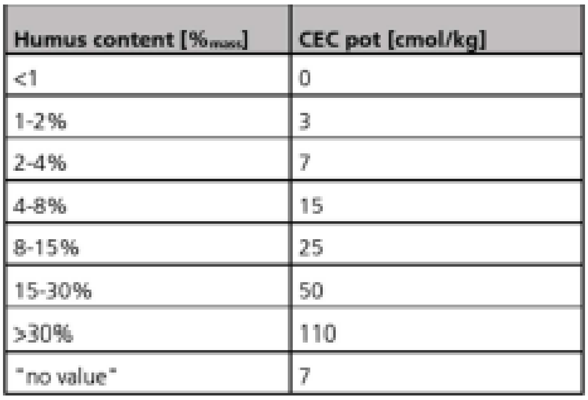
Table 16 CECeff depending on clay and silt [42].



Clay %		**Silt %**		**CEC_{eff} [cmol/kg]**
min	max	min	max	
65	100	0	35	**38**
45	65	0	15	**28**
45	65	15	30	**29**
45	65	30	55	**28**
35	45	0	15	**20**
25	35	0	15	**15**
25	45	15	30	**19**
35	45	30	50	**22**
25	35	30	50	**17**
30	45	50	65	**21**
25	35	65	75	**17**
17	25	0	15	**11**
17	25	15	30	**12**
17	25	30	40	**12**
17	25	40	50	**13**
17	30	50	65	**15**
17	25	65	82	**14**
5	17	0	10	**6**
12	17	10	40	**9**
7	12	10	40	**6**
7	17	40	50	**9**
7	17	50	65	**9**
12	17	65	82	**11**
7	12	65	92	**9**
5	7	10	20	**4**
0	5	0	10	**2**
0	5	10	25	**2**
0	7	25	40	**4**
0	7	40	50	**4**
0	7	50	80	**5**
0	7	80	100	**6**

2. The potential cationic exchange capacity displays the amount of exchange spaces at neutral pH conditions[38] and it is used to quantify the humus content of the soil determined as (Arbeitsgruppe Bodenkunde 2013):

Table 17 Potential CEC due to humus content [42].



Humus content [$\%_{mass}$]	CEC pot [cmol/kg]
<1	0
1-2%	3
2-4%	7
4-8%	15
8-15%	25
15-30%	50
>30%	110
"no value"	7

Humus content data in soils are very difficult to find, both from local sources and smaller scale maps. For this reason, we used the regression equation that Beck[38] used for the potential CEC calculation and we inverted the variables. Our input potential CEC collected data are [mmeq/100g] that is equal to [cmol/kg], so we multiplied it by 10 to make it suitable for the equation;

the original equation is:

Equation 8

$$CEC\ Pot\,\frac{mmol}{kg} = 46 + 3{,}4 * clay + 8.6 * humus\ [\%]$$

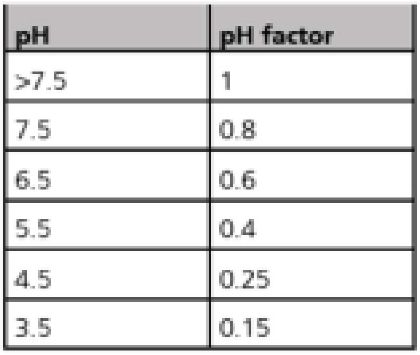
in our case we have adapted it as follows:

Equation 9

$$Humus\ [\%] = \frac{CEC\ Pot. - 46 - 3.4 * clay}{8.6}$$

3. The influence of soil pH on cation exchange potential is taken into account through a pH factor correction given in the Arbeitsgruppe Bodenkunde table (2013):

Table 18 pH factor correction [42].



pH	pH factor
>7.5	1
7.5	0.8
6.5	0.6
5.5	0.4
4.5	0.25
3.5	0.15

The pH factor is then multiplied by the potential cation exchange capacity, resulting in an effective cation exchange capacity of the humus content.

4. The final result is given by:

Equation 10

$$PF = CEChumus + CECclay\&silt$$

where CEChumus is the effective cation exchange capacity related to the humus content in the soil and CECsilt&clay is the effective cation exchange capacity related to the silt and clay content in the soil only.

3.3.4 Groundwater regeneration

Groundwater regeneration represents the capacity of the soil to regenerate groundwater sources, i.e. the ability of rain to infiltrate the soil and become part of the groundwater. This capacity depends mainly on surface vegetation, climate zone and soil structure. The corresponding CF is the "Groundwater regeneration reduction potential" [mm/y]. The estimation of the regeneration potential does not include incoming and outgoing lateral groundwater, so it is not taken into account.

Figure 11 shows schematically the calculation structure of the "Groundwater Regeneration" indicator and the input data used in the calculation.

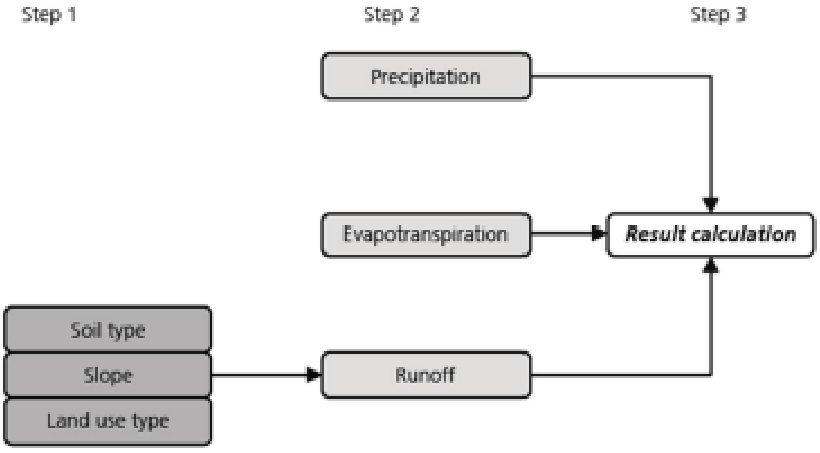


Figure 11 Calculate structure of the indicator Groundwater regeneration [42].

For the estimate, LANCA proposes a simple hydraulic equilibrium equation:

Equation 11

$$GWR = P - E - R$$

Where:

- P = is the total annual precipitation [mm/y]; data obtained from "World weather online".
- E = is evapotranspiration [mm/y]; calculated by applying the Hargreaves equation:

Equation 12

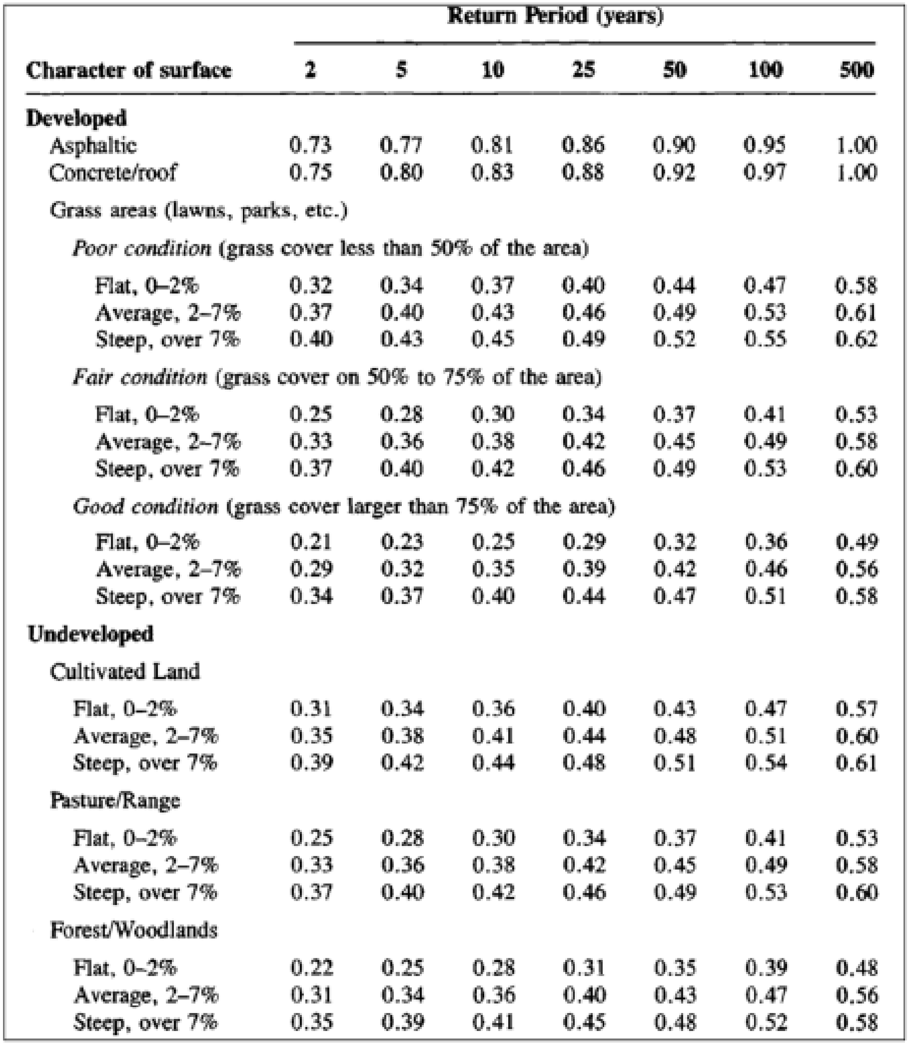
$$E = 0{,}0023 * R_A * \sqrt{TD\ °C} * (T\ °C + 17{,}8)$$

where:

- E = evapotranspiration [mm/y]
- R_A = average solar radiation [MJ/m2day]; obtained from the "World weather online" portal
- TD = difference between maximum and minimum temperature (average) over the period (°C); data obtained from "World weather online"
- T = average air temperature (°C); data from "World weather online".
- R = is the surface runoff [mm/y], it represents the fraction of rainwater that does not infiltrate the soil but flows over the surface of the soil; LANCA data obtained from the "rational method", i.e., the calculation of a runoff coefficient (CoeffR, dimensionless

value) based on land use, slope and type of land use or return time. Other factors influencing CoeffR are rainfall intensity, subsoil porosity, and vegetation. The coefficient should represent the integrated effects of all these factors; suggested values are given in the following table:

Table 19 Runoff coefficient for the rational method [68].



	Return Period (years)						
Character of surface	**2**	**5**	**10**	**25**	**50**	**100**	**500**
Developed							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass areas (lawns, parks, etc.)							
Poor condition (grass cover less than 50% of the area)							
Flat, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair condition (grass cover on 50% to 75% of the area)							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good condition (grass cover larger than 75% of the area)							
Flat, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Undeveloped							
Cultivated Land							
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Pasture/Range							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/Woodlands							
Flat, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

The variable of the return period strongly influences the Rcoeff value; since, for the LANCA application, we should not consider exceptional stormy events but common rainfall, we choose the conventional lower return period. Consequently, Rcoeff should not be considered as an input variable, because it depends on land use and slope (considering the return period as a conventionally selected constant value).

3.3.5 Biotic production

Biomass production or primary production represents the capacity of an ecosystem to continuously create reserve biomass, leading to an increase in the amount of available biomass. It depends on the type of land use, nutrient availability, climate, soil and vegetation. The corresponding CF is the "Biotic production loss potential" [kg/(m2*y)]. The primary production is estimated by LANCA as in the first version[38], i.e. a specific value of biotic production is related to each type of land use considered, according to some publications[69–71] and, in some cases, corrected according to the type of use and the degree of sealing by a sealing factor.

Table 20 NPP for each land use type [38].

Type of land use	NPP [g/(m²*a)]
Grassland, meadow	500
Wood: Coniferous woodlands	800
Wood: Deciduous woodlands, unspecific	average = 1575
Wood: Deciduous woodlands, summer green	1200
Wood: (Sub-) tropical Rainforest	2200
Wood: Monsoon woodlands	1600
Wood: Temperate zone Rainforest	1300
Wood: Mixed tree woodlands	1420
Forest: Coniferous forest	650
Forest: Deciduous forest	650
Forest: Mixed tree forest	650
Moorland, lawn or fallow with vegetation	500
Permanent crops (field, little surface vegetation)	650
Farmland (no complete surface vegetation)	650
Fallow ground (no surface vegetation)	130
Continuous urban influenced area	0
Non continuous urban influenced area	150
Industrial real estate	0
Road network	0
Railway system	40
Traffic infrastructure area (ports, airports, garages, etc.)	80
Mining area	40
Landfill	0
Artificial, not farmed grassland	620
Freshwater	500
Swamp area	2000
Ocean	125
Riff	2500
Estuary	1500
Forest steppe	700
Tropical savannah	700
Temperate savannah	600
Semi-desert	93
Desert, glacier	3
Tundra	140
Alpine area	140

3.4 Statistical analysis

The last step of this case study is the statistical analysis with the application of the "two-way ANOVA" analysis, better known as two-way variance analysis. The analysis is carried out on the five characterization factors calculated for each soil under examination, in order to assess precisely the variance, i.e. how much the values reported for the individual sampled sites deviate from the average of the group to which they belong (with different grouping criterion: country - Eco-zone - % clay) and how much the average of each group deviates from the overall average. In this way it is possible to assess if a certain group is statistically different from the overall population, i.e. if it makes sense to distinguish the group from the population or not. Moreover, it tells how much the group is different from the population – so that it is possible to compare different groupings based on their ability to identify meaningful groups; for example, if the groups formed based on the country variable are different enough between them to be really different, and if the country grouping is better at defining different groups than the Eco-zone or % clay grouping.

The null hypothesis underlying our study is:

- There is no difference between the averages in grouping A (the two countries, Spain and France);
- There is no difference between the averages of grouping B (Eco-zones: SDF, TOF, TMS);
- There is no difference between the averages of grouping C (the clay classes);
- There is no interaction between the three factors: countries, Eco-zones and clay classes.

Therefore, the analysis must assess whether the difference between groups (if any) is statistically significant, considering a 5% confidence interval (Pr<0.05).

Before applying the analysis of variance, it is important that the data meet certain requirements of the test, including the normality of the data, i.e. that the distribution of the data has a normal trend in the groups considered and that the variances of the groups are equal. In our case study, we can assume that the data have a normal distribution, but that the variances are heterogeneous because different groups. To confirm our assumption, we performed the Shapiro-Wilk test, which checks normality for small samples. From the application of this test we obtain a "p-value", which gives us the level of significance of our data. From the values obtained we can see that all the characterization factors, except GWRRP, deviate significantly from normality (p=0) and therefore from the null hypothesis (H0:p=0). In order to overcome the problem of normality, the CFs of EP,IRP and PFRP, are transformed into log-normal, so that they can follow a normal distribution and proceed with subsequent analyses. We then proceed with the calculation of the mean and standard deviation of all the characterization factors in relation to the three groups considered (Country, Eco-zone and % clay) excluding the "BPRP" because it presents values that are the same for all the sites sampled. The table below shows the mean and standard deviation (transformed values) of each characterization factor in relation to the three groups considered (Country, Eco-zone and % clay).

Table 21 Average and standard deviation of each CF (transformed values).

		Transformed values							
		ln(EP)		**ln(IRP)**		**ln(PFRP)**		**ln(GWWRP)**	
		average	dev. Standard	average	dev. Standard	average	dev. Standard	average	dev. Standard
Country									
	ES	Inf (3.22)	NaN (2.30)	2.20	1.16	3.39	0.37	6.27	1.16
	FR	3.79	1.46	1.79	0.74	3.27	0.30	5.55	1.29
Ecozone									
	SDF	Inf (2.65)	NaN (2.86)	1.44	1.18	3.56	0.29	4.26	1.46
	TMS	4.31	1.19	1.89	0.52	3.35	0.28	6.80	0.49
	TOF	3.55	0.75	2.65	0.76	3.07	0.25	5.80	0.68
Clay									
	10	Inf (2.87)	NaN (2.28)	2.84	0.70	2.92	0.31	6.07	0.78
	20	4.02	0.81	2.52	0.79	3.17	0.16	5.80	1.00
	30	3.57	2.04	1.77	0.32	3.47	0.25	5.84	1.51
	40	4.18	0.59	0.51	1.38	3.70	0.09	5.63	2.25
	50	-2.30	NA	-0.69	NA	3.85	NA	NaN	NA

As can be seen in the table of transformed values, some of the averages of the erosion potential characterization factor have values going to infinity as the logarithm of 0 gives -infinity and no results are obtained; for this reason the infinity value has been replaced with 0.1, a value within the calculated margin of error. The margin of error is used to quantify how much the estimates of a search might differ from the "true" value; this is measured by the following formula:

Equation 13

$$MOE = Zcrit * \frac{\sigma^2}{\sqrt{n}}$$

Where:

MOE = margine of error;

Zcrit = 1.96 critical value, according to table 5 of the standard normal distribution

σ^2 = standard deviation;

n = sample number

However, it can be seen from a first reading that each CF has lower standard deviation values in correspondence with the Eco-zone grouping and this could mean that for all calculated factors the Eco-zone grouping is more representative of the Country and % clay grouping. The % clay group also appears slightly more representative than the Country grouping. Overall, however, the data trend does not show a substantial difference around the standard deviation values.

The development of the ANOVA analysis therefore involves[72]:

1. Calculate the average for each group (Countries - Eco-zone - clay factor);
2. Calculate the overall average for all combined groups;
3. Within each group the total deviation of the score of each individual "component" in this case soil, from the average of the group, is calculated; this tells us if the soils of a Country - Eco-zone - % clay, tend to have similar scores or if there is a lot of variability between different soils of the same Country - Eco-zone - % clay; known as "Variance within the group".

Equation 14

$$\sigma^2 In = \frac{\sum i \sum j \, (Yij - \bar{Y}i.)^2}{n-1}$$

Where:

- ∑j and ∑i = are respectively the sum of "j" subjects in "i"-th groups;
- Yij = is the score of the single component (soil);
- Ȳi. = is the average of the group in which it is located;
- n = is the number of observations;
- 1 = is the degree of freedom

4. Next, we calculate how much the average of each group deviates from the overall average; this is known as "Variance between groups".

Equation 15

$$\sigma^2 Bet = \frac{\sum i \sum j \, (\bar{Y}i - \bar{Y}..)^2}{a * (n-1)}$$

Where:

- ∑j and ∑i = are respectively the sum of "j" subjects in "i"-th groups;
- Ȳi = is the average of each group;
- Ȳ.. = is the overall average;
- a = is the number of treatments;
- n = is the number of observations;

- 1 = is the degree of freedom

5. Finally, an F statistic is calculated, which is the ratio between "variance between groups" and "variance within the group".

Equation 16

$$F = \frac{\sigma^2 Bet}{\sigma^2 In}$$

This allows us to assess the significance of our variables and thus understand which group most characterises CFs.

The calculation was carried out using the statistical software R, which provides statistical information through the reading of tables and graphs such as BoxPlot.

The BoxPlot is a graphical representation used to describe the sample distribution with dispersion indices (interquartile range, variance, standard deviation) and position indices (mean, median). This diagram, thanks to its "box of whiskers" structure, allows us to understand what happens to 50% of the observed values (values that fall within the box, identified by the 1st and 3rd quartiles) and to study the tails of the distribution, i.e. the dispersion of the values lower than the 1st quartile and of the values higher than the 3rd quartile (indicated by the whiskers, segments that extend downwards and upwards from the box) and the possible outliers, indicated by isolated points positioned above and/or below the whiskers. The line inside the box indicates the mean value[73].

4. RESULTS AND DISCUSSION

4.1 Results of LANCA calculation

From the calculation of the soil quality indicators we obtained the five soil characterization factors for each sampling site considered within each country (Spain and France); below the results for each characterization factor are shown in Table 22.

Table 22 Characterization factors calculated for each sampling site in Spain and France.

Sampling sites	ID	Ecozone	Clay%	CF1	CF2	CF3	CF4	CF5
A Coruna	ES	T.O.F	20	47.7	25	21.9	328.8	500
Albacete	ES	S.D.F	30	31.7	25	45.8	-220.6	500
Barcelona	ES	S.D.F	35	47.7	5.5	42.2	11.9	500
Benasque	ES	T.M.S	30	490.8	5.5	36	1376.8	500
Bilbao	ES	T.O.F	25	91.7	25	22.7	317.2	500
Broto	ES	T.M.S	25	62.8	5.5	29.3	1525.9	500
Cervera de pisuerga	ES	T.M.S	40	84.8	5.5	39.7	802.2	500
Eibar	ES	T.O.F	25	87.8	25	21.9	1038.1	500
Foz	ES	T.O.F	20	71.8	25	19.7	784.7	500
Gijon	ES	T.O.F	35	17.2	5.5	35.4	670.5	500
Isaba	ES	T.M.S	15	241.9	5.5	34.3	1730.3	500
Lugo	ES	T.M.S	10	31.3	5.5	13.9	289.4	500
Malaga	ES	S.D.F	40	31.7	0.5	45.8	-92.2	500
Orreaga	ES	T.M.S	20	21.6	25	24.4	454.8	500
Oviedo	ES	T.O.F	15	42.4	25	24.4	260.3	500
Potes	ES	T.M.S	20	10.6	25	27.7	802.2	500
Salamanca	ES	S.D.F	15	0.0	25	19.4	-136.4	500
Santander	ES	T.O.F	20	83.4	25	27.7	357.8	500
Santiago de compostela	ES	T.O.F	10	55.6	25	13.9	763.7	500
Sevilla	ES	S.D.F	50	0.1	0.5	46.8	-98.1	500
Toledo	ES	S.D.F	35	15.7	5.5	46.8	-245.1	500
Valencia	ES	S.D.F	35	0.1	5.5	38.8	-60.4	500
Vielha e Mijaran	ES	T.M.S	30	214.7	5.5	36	1376.8	500
Zaragoza	ES	S.D.F	30	52.8	5.5	38.8	-223.8	500
Aix En Provence	FR	S.D.F	25	110.5	5.5	29.8	58.6	500
Albertville	FR	T.M.S	30	37.1	5.5	37.7	1070.3	500
Ales	FR	S.D.F	35	124.7	5.5	31.3	447.0	500
Amiens	FR	T.O.F	10	25.6	25	18.8	315.5	500
Bastia	FR	S.D.F	25	124.2	5.5	21.8	204.0	500
Bussang	FR	T.M.S	35	37.1	5.5	23.9	796.4	500
Caen	FR	T.O.F	15	19.2	25	16.4	548.8	500
Chamonix-Mont Blanc	FR	T.M.S	35	314.6	5.5	25.7	1010.2	500
Digne les bains	FR	S.D.F	35	74.4	5.5	43.8	697.0	500
Dijon	FR	T.O.F	30	20.5	5.5	21.8	195.7	500
Le Puy En Velay	FR	T.M.S	30	25.9	5.5	22.4	509.6	500
Les orres	FR	T.M.S	30	588.3	5.5	22.7	1336.3	500
Limoges	FR	T.O.F	25	59.1	5.5	16.9	306.1	500
Marseilles	FR	S.D.F.	30	110.5	5.5	42.4	14.2	500
Mende	FR	T.M.S	30	58.9	5.5	25.7	806.4	500
Montpellier	FR	S.D.F	40	124.7	0.5	36.8	20.9	500
Nant	FR	T.M.S	35	39.3	5.5	33.0	666.8	500
Nantes	FR	T.O.F	30	11.5	5.5	25.7	233.6	500
Orange	FR	S.D.F	25	124.7	5.5	24.3	62.8	500
Perpignan	FR	S.D.F	30	0.3	5.5	29.8	52.8	500
Pontarlier	FR	T.M.S	40	55.3	5.5	39.3	1275.2	500
Toulouse	FR	T.O.F	30	49.7	5.5	26.2	85.5	500
Tours	FR	T.O.F	25	15.4	5.5	25.2	146.3	500
Versailles	FR	T.O.F	10	10.3	25	14.7	169.6	500

As can be seen in the table above, the characterization factors obtained, such as CF1 = "EP, Erosion Potential", CF2 = "IRP, Infiltration Reduction Potential", CF3 = "FPRP, Physical-Chemical Filtration Reduction Potential", CF4 = "GWRRP, Groundwater Regeneration Reduction Potential" and CF5 = "BPRP, Biotic Production Reduction Potential", classified by State, Eco-zone including subtropical dry forest, temperate oceanic forest, temperate mountain system and % clay respectively. The characterization factor "Biotic Production Reduction Potential", as can be seen, has the same values for all sampling sites as the main parameter considered in the calculation is land use and in our study land use is common to all sites considered.

4.2 Results of statistical analysis

A statistical analysis was carried out on the results obtained from the LANCA calculation, specifically the "two-way analysis of variance", which aims to assess the main effect of each independent variable on the characterising factor.

The following results emerged from the development of the analysis:

- "Erosion Potential":

*Table 23 Results of the statistical analysis applied to the characterization factor "Erosion potential" in relation to the three reference parameters; Signif.of codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

For ln(EP)	*Df*	*Sum sq*	*Mean sq*	*F value*	*Pr(>F)*
Country	1	3.87	3.87	1.33	0.25
Eco-zone	2	21.97	10.98	3.78	0.03*
% Clay	4	32.87	8.20	2.82	0.04*
Residuals	40	116.01	2.90		

In this analysis we see that: the group "Country" is not important, it shows a significance of 0.25 and therefore a 75% probability of incorrectly accepting the null hypothesis in this case of group A, so it does not show a statistically significant difference; while the factors eco-zone and clay have a significance of 0.03 and 0.04 respectively, so they show a statistically significant difference.

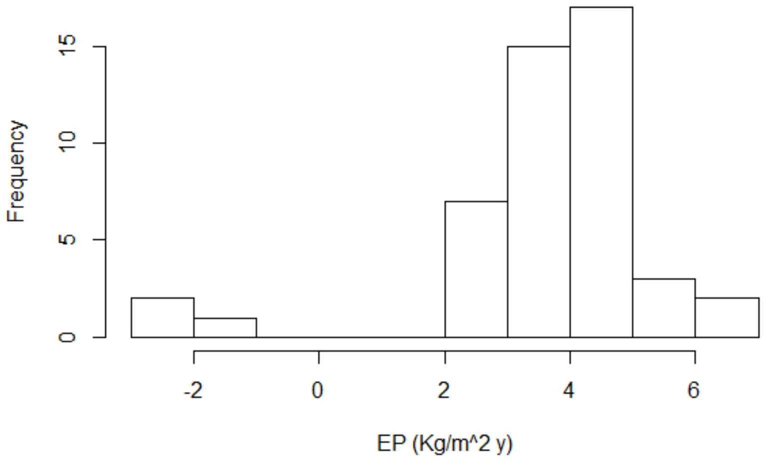


Figure 12 Frequency distribution of the values of the characterization factor "EP" present at the sites sampled

Figure 12 shows the frequency distribution with which erosion potential values occur at the sampling sites. In particular, it can be seen that only few soils have a high erosion potential (about 6 kg/m^2 per year), while a few soils have a negative erosion potential, indicating no soil loss. The average erosion loss for a large proportion of the sampled soils is about 4 kg/m^2 per year.

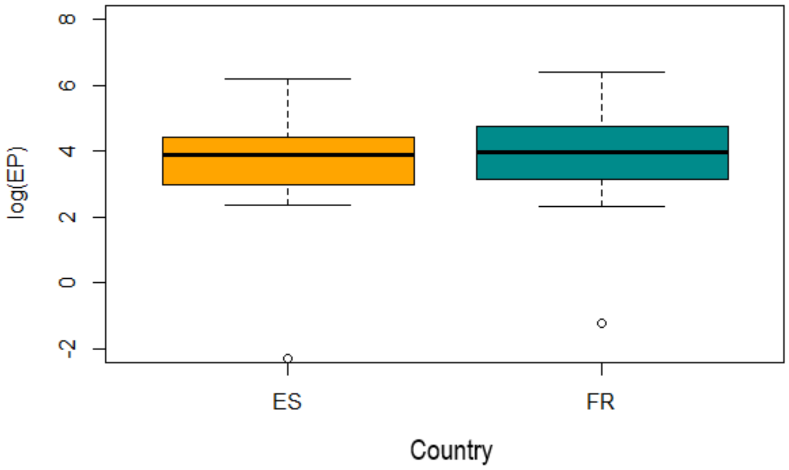


Figure 13 Boxplot of the CF of the "EP" in relation to the individual Country considered.

Figure 13 shows the distribution of the Erosion Potential data per country; these show very similar median values and first and third quartile values. It can be seen that France has slightly higher maximum Erosion Potential values than Spain and this is also visible in the table of input values for the LS factor; however, the difference in values is not statistically significant, in fact the two groups do not appear different in the figure.

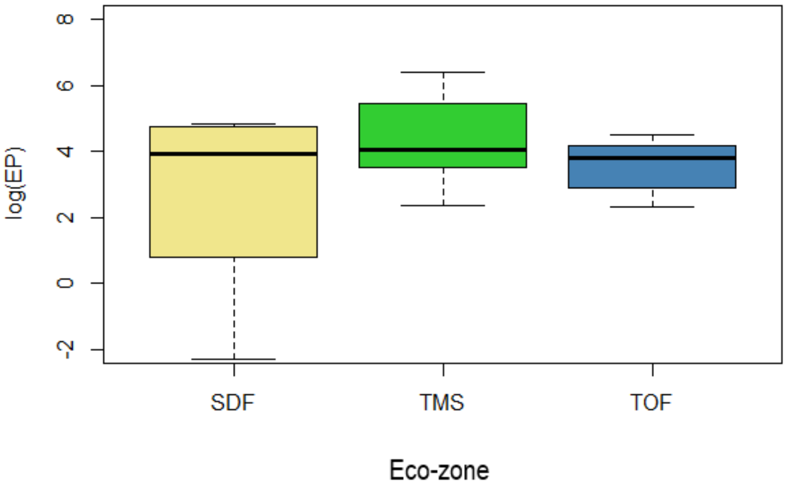


Figure 14 Range of minimum and maximum values of the CF of the "EP" in relation to the three Eco-zones considered in the study.

The three groups of ecozones appear different in Figure 14 of the boxplot: although the median values are similar (the thick black line inside the boxes), the distribution of values in the three groups (i.e. the shape of the boxes and their whiskers) are visibly different between the three groups, so the representation confirms the values obtained from the analysis.

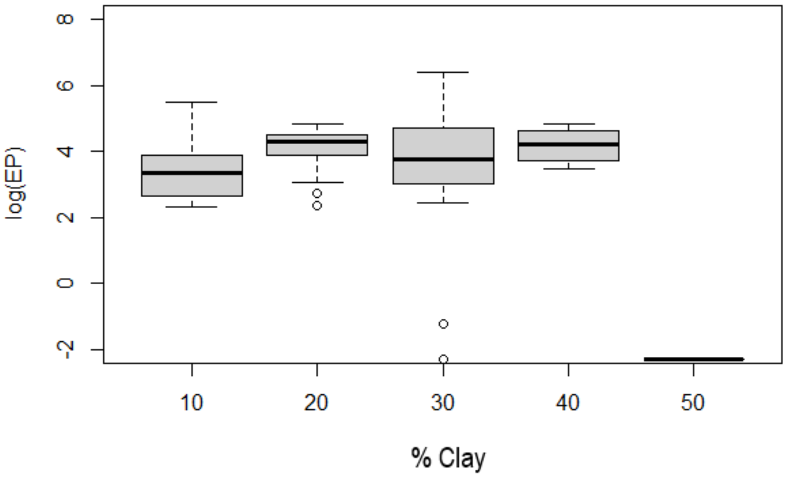


Figure 15 Range and maximum values of the CF of the "EP" in relation to the clay classes considered.

In figure 15, as in the eco-zone grouping analysis, there is only a slight difference between the groups (the boxes), apart for group 50%, which is clearly different. A limitation of the two-way ANOVA is that it can only tell if there is a statistically significant difference between the groups, not between which groups in the dataset. Here, for example, the clear difference between the 50% clay group with respect to the other groups may hide the fact that the other groups are not statistically different among them. In addition, soils with a higher amount of clay, in this case 40%, should show lower erosion values. Correct behaviour can be observed on sites with 50% clay, since erosion is also related to soil texture: the finer the grain size, the less erosion and therefore the lower the erosion potential because the soil tends to be more compact[68].

- “Infiltration reduction potential':

*Table 24 Results of the statistical analysis applied to the characterization factor "Filtration reduction potential" in relation to the three reference parameters; Signif.of codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

For ln(IRP)	*Df*	*Sum sq*	*Mean sq*	*F value*	*Pr(>F)*
Country	1	1.96	1.96	5.17	0.028*
Eco-zone	2	11.90	5.95	15.65	$9.50e^{-06***}$
% Clay	4	16.19	4.04	10.65	$5.69e^{-06***}$
Residuals	40	15.20	0.38		

The results of the analysis show that: the clustering Country in relation to the characterization factor IRP has significance values of 0.03, thus presenting a significant difference, which is relatively low; while the clustering Eco-zone and % clay have a good influence, both present statistically significant differences, i.e. a 99.9% probability of incorrectly accepting the null hypothesis (that the groups are equal). However, the whole dataset, despite the log-normal transformation, does not appear very 'normal' and the diversity of values suggests that the data trend follows an asymmetrical distribution. In theory, a sample like the one in our study, being finite, will never be perfectly distributed according to the Gaussian normal[74]. But we know that a random frequency distribution will behave in the same way as the normal and therefore we consider a normal distribution, albeit less obvious in this case. This will be clearly evident in the specific graphs for the three groups: Country, Eco-zone and % Clay.

GRAPHICS “IRP”

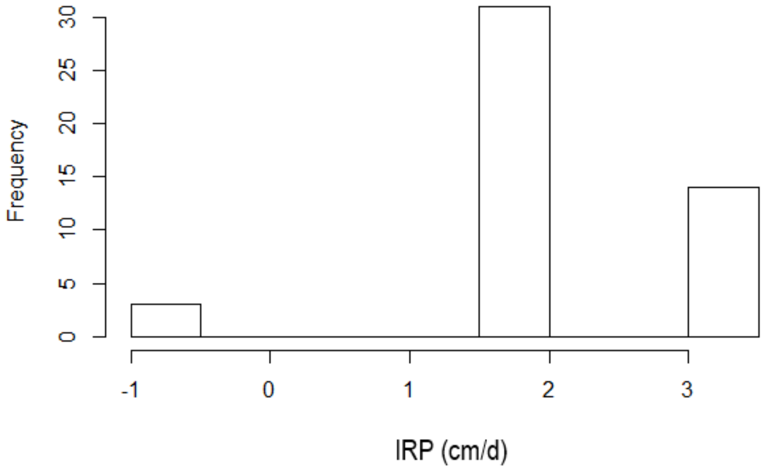


Figure 16 Frequency distribution of the values of the characterization factor "IRP" present at the sites sampled.

Figure 16 shows the frequency distribution with which Filtration Reduction Potential (IRP) characterises the sampling sites; it can be seen that the data trend follows a positive asymmetric distribution, i.e. the dataset of this CF is characterised by higher values. In fact, only very few soils present an IRP of less than 0 cm/d, while the majority of soils present values of around 1.5-2 cm/d and about half of these are characterised by a filtration capacity of more than 3 cm/d. The sampling sites fall into three precise ranges of IRP values.

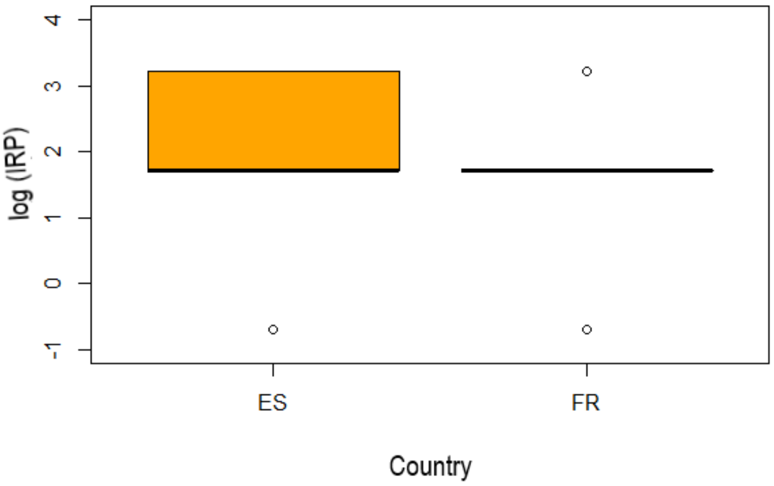


Figure 17 Range of minimum and maximum values of the CF of the "IRP" in relation to the individual Country considered.

Figure 17 shows the Filtering Reduction Potential in the two Countries; in this case one can clearly see a difference between Spain and France, although both Countries show the same average values around 1.8 cm/d. Spain shows values above 3 cm/d while for France outliers can be seen, i.e. values well below the average, around -0.8, also present for Spain and above the average coinciding with the third quartile (of the box) of Spain. The graph reflects both the results obtained from the analysis and the anomaly of the dataset.

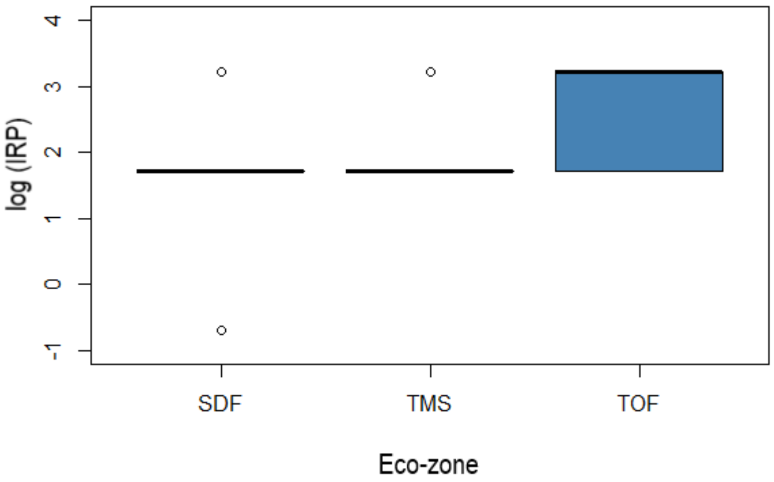


Figure 18 Range of minimum and maximum values of the CF of the "IRP" in relation to the three Ecozones considered in the study.

In figure 18, the clustering of the ecozones visibly shows differences. The SDF and TMS ecozones do not show substantial differences, presenting the same mean values of IRP around 1.8 cm/d; while the TOF ecozone presents mean and maximum values above 3 cm/d and the first quartile and minimum values around 1,8; this confirms the positive asymmetric distribution of the dataset towards higher values where the mean is greater than the median (2 quartile).

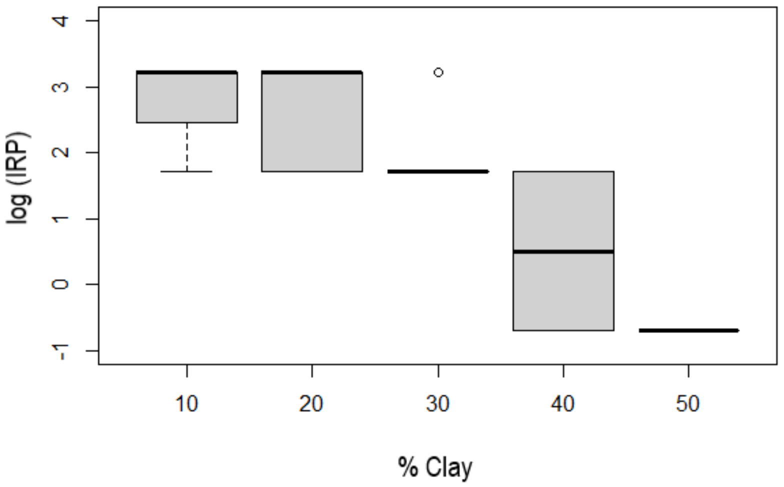


Figure 19 Range of minimum and maximum values of the CF of the "IRP" in relation to the clay classes considered.

In figure 19, significant differences can be seen between the different clay classes, in particular between the BoxPlots of the 10-20 % clay classes and the 40-50 % classes. The five BoxPlots show different structures and mean values (except for the 10-20% class) and, in particular, only the 40% clay has the entire box size characterised by the first quartile, median and third quartile. From this relationship it can be seen that soils with 10-20 % clay have higher IRP values, which should mean that they have a higher filtration capacity; on the contrary, sites with a higher % clay show lower values, even below 0, i.e. a lower filtration potential. Despite the asymmetrical pattern of the dataset, this provides a consistent interpretation of the data. However, the % clustering of clay proves to be a good indicator of differences between the averages.

- “Physical and chemical filtration reduction potential":

*Table 25 Results of the statistical analysis applied to the characterization factor "Physical-chemical filtration reduction potential" in relation to the three reference parameters; Signif.of codes: 0'***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

For ln(PFRP)	*Df*	*Sum sq*	*Mean sq*	*F value*	*Pr(>F)*
Country	1	0.17	0.17	4.80	0.03*
Ecozone	2	1.98	0.99	27.91	$2.58e^{-08***}$
% Clay	4	1.71	0.43	12.04	$1.62e^{-06***}$
Residuals	40	1.42	0.04		

The results from the analysis of variance of the CF PFRP in relation to the three groupings show significant values. In particular, the country grouping has a Pr (significance) of 0.03, but compared to the Pr values of Ecozone and % clay it is less significant. The Ecozone and % Clay clusters appear to have the most differences between the averages. This difference is more present in the Ecozone grouping and this is also visible from the F-value, which is larger the stronger the evidence against the null hypothesis. Both, however, show a significance of 99.9%.

GRAPHICS “PFRP”

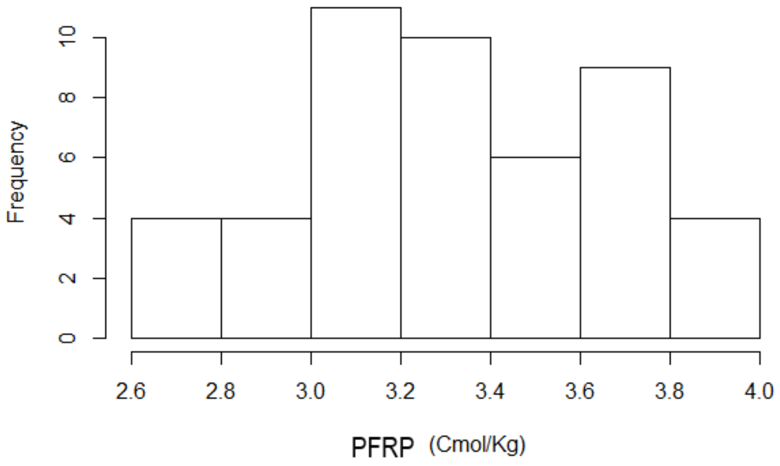


Figure 20 Frequency distribution of the values of the characterization factor "PFRP" present at the sites sampled.

Figure 20 shows the frequency distribution of the dataset for the characterization factor of Physical-Chemical Filter Reduction Potential in the soils sampled; the highest frequency occurs for Potential values of 3-3.2 cmol/kg, 3.2-3.4 cmol/kg and 3.6-3.8 cmol/kg; on average the sites have PFRP values of 3-3.5 cmol/kg.

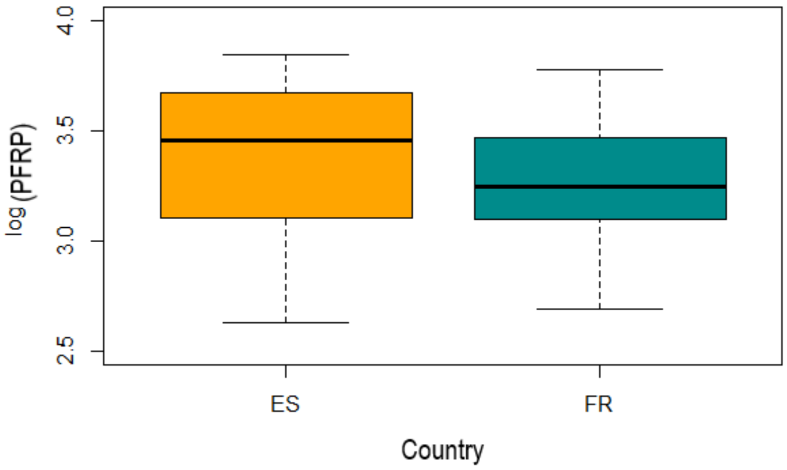


Figure 21 Range of minimum and maximum values of the CF of the "PFRP" in relation to the individual Country considered.

Figure 21 shows the reduction potential of physical-chemical filtration in relation to the two countries. The two countries show small differences, including the median value (for Spain about 3.5 cmol/kg and for France about 3.2 cmol/kg). The distribution of the values of the two groups (box shape) is also visibly different even though they have the same 1st quartile value of 3.1 cmol/kg.

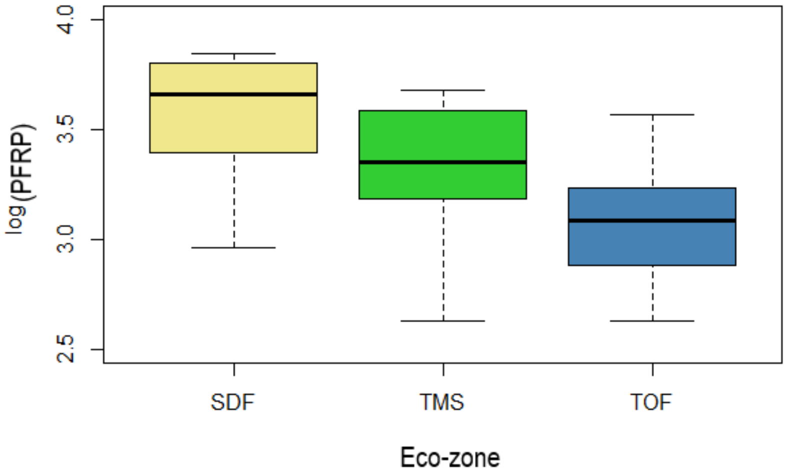


Figure 22 Range of minimum and maximum values of the CF of the "PFRP" in relation to the three Ecozones considered in the study.

In figure 22, it is evident that PFRP behaves differently in the three eco-zones. It can be seen that the three groups show different mean values and distribution of data (box shape and whiskers). In fact, observing the whiskers and therefore the dispersion of the data, it can be seen that the SDF eco-zone (Subtropical Dry Forest) presents higher minimum and maximum values than the other TMS and TOF; therefore, soils in this ecological zone have higher values of PFRP, and more clearly lower PFRP. The TMS ecological zone has the same minimum values as the TOF but higher maximum values; finally, the TOF ecological zone is the group with the lowest PFRP and therefore a higher filtration capacity.

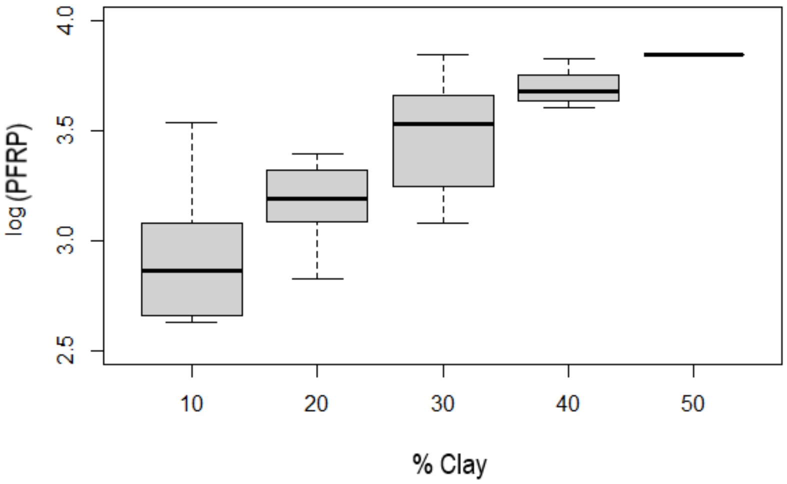


Figure 23 Range of minimum and maximum values of the CF of the "PFRP" in relation to the clay classes considered.

From the figure 23 it emerges that the five clay classes are visibly different: the distribution of the data has a gradual increasing trend, starting from small amounts of clay and low physico-chemical filtration capacity to large amounts of clay and higher filtration capacity. The five BoxPlots show different average values. In addition, it can be seen that the box corresponding to 10% clay presents maximum values with same magnitude as the average value of the box corresponding to 30% clay, which in turn presents maximum values greater than the average value of the box corresponding to 50% clay. From this graph it emerges that soils with a low percentage of clay have a low PFRP and therefore a good physical-chemical filtration capacity. Proceeding in ascending order of % clay, the PFRP takes on greater values and therefore soils with greater quantities have lower physical-chemical filtration capacity.

- "Potential for reducing groundwater regeneration":

*Table 26 Results of the statistical analysis applied to the characterization factor "Potential for reducing groundwater regeneration" in relation to the three reference parameters; Signif.of codes: 0'***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

For ln(GWRRP)	*Df*	*Sum sq*	*Mean sq*	*F value*	*Pr(>F)*
Country	1	5.15	5.15	6.51	0.02*
Ecozone	2	32.32	16.15	20.43	$1.49e^{-06***}$
% Clay	3	0.46	0.15	0.19	0.90
Residuals	34	26.89	0.79		

This analysis shows that: the eco-zone is again the most relevant factor in identifying differences between averages, showing a statistically significant difference of 99.9% in the probability of incorrectly accepting the null hypothesis (that the groups are the same); clay, on the other hand, shows a Pr of 0.9 and therefore does not present a statistically significant difference; on the contrary, the Country, in relation to this characterization factor, presents a statistically significant difference and a 98% probability of incorrectly accepting the null hypothesis.

GRAPHICS “GWRRP”

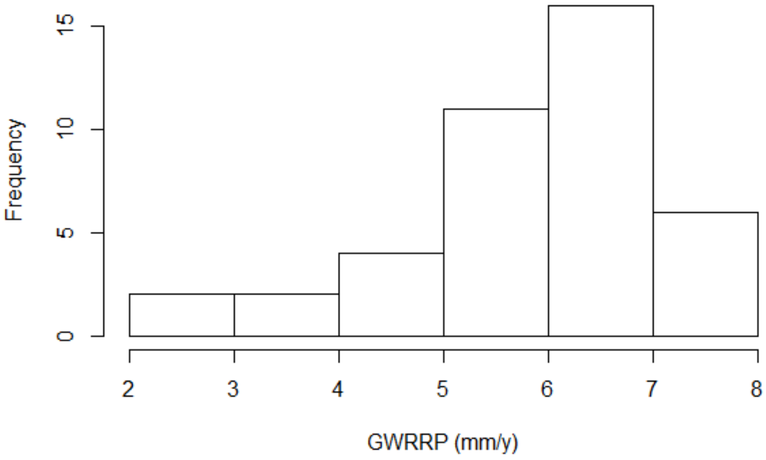


Figure 24 Frequency distribution of the values of the characterization factor "GWRRP" present at the sites sampled.

Figure 24 shows the distribution of the dataset in relation to the Groundwater Regeneration Reduction Potential characterization factor. As mentioned before, the data for this CF were normally distributed, which is why the log-normal was not studied, as we will see in the next graphs.

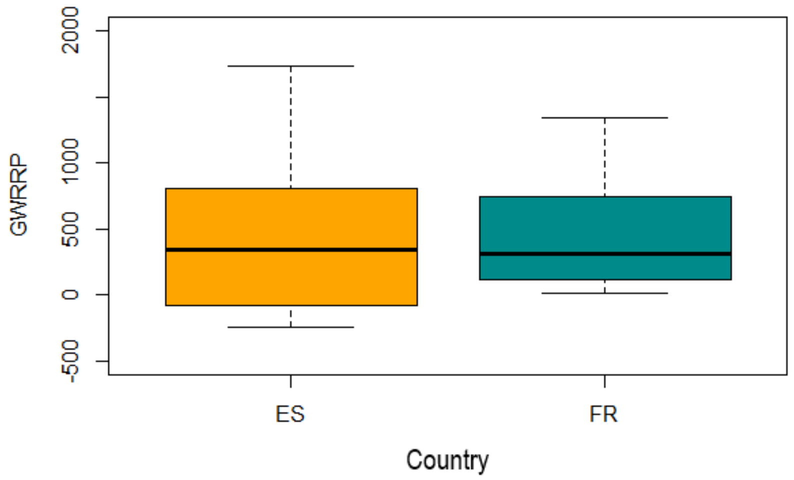


Figure 25 Range of minimum and maximum values of the CF of the "GWRRP" in relation to the individual Country considered.

The figure 25 relates the GWRRP to the two countries; in this case the two groups have different minimum and maximum values, as do the first and third quartiles. Spain has a larger interquartile range than France's box size, but the median value is very similar. Spain also has negative minimum values, in contrast to France which has minimum values just below 0. The maximum values for Spain are always greater than France.

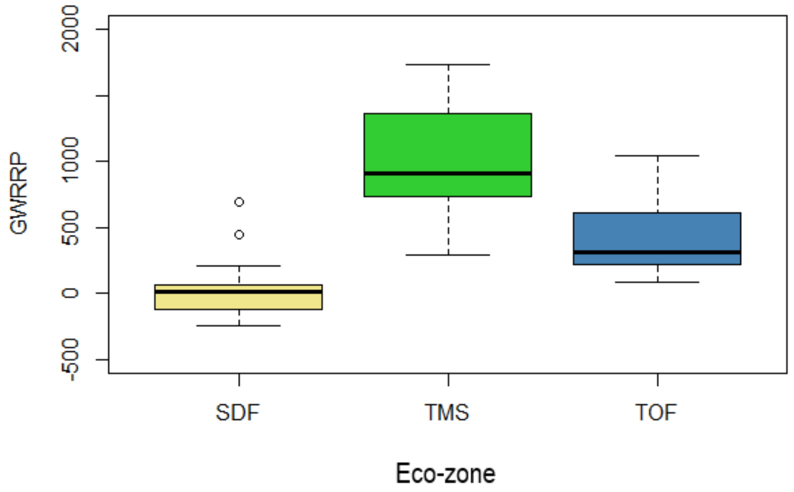


Figure 26 Range of minimum and maximum values of the CF of the "GWRRP" in relation to the three Ecozones considered in the study.

This figure 26 relates the GWRRP to the ecological zone. It can be visibly observed that the three groups have different distributions, each characterised by a different mean value. In the case of the SDF ecological zone, one can mainly see a very small interquartile range; it also shows average values around 0 and GWRRP values lower than all three groups (negative values); one can also see the presence of outliers, positioned higher than the maximum value. The TMS ecozone, on the other hand, shows a greater interquartile range and higher minimum and maximum values than the SDF and TOF ecozones. The TOF ecozone has a mean value that coincides with the minimum value of the TMS ecozone, a minimum value corresponding to the mean value of the SDF group and a maximum value close to the mean value of the TMS group.

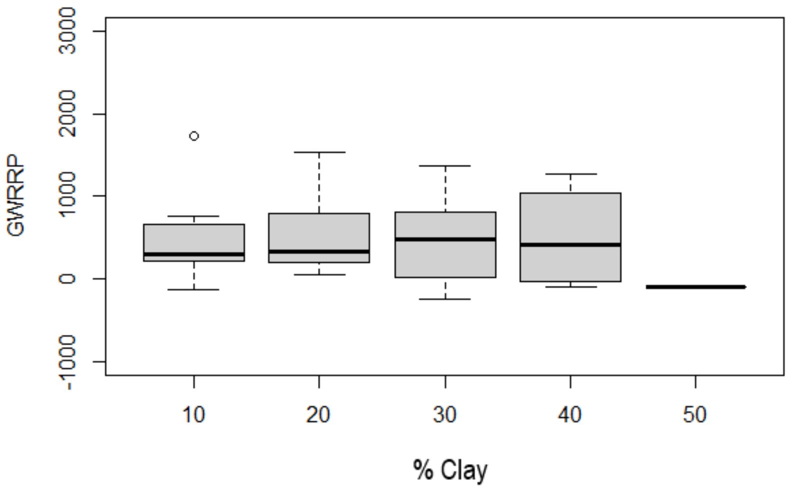


Figure 27 Range of minimum and maximum values of the CF of the "GWRRP" in relation to the clay classes considered.

In the figure 27 there are no big differences between the different clay classes; they show different average values, but the distribution of the data within the box is very similar. What can vary in the structure are the whiskers, i.e. the maximum and minimum values of each clay class and the presence of an outlier near the values higher than the maximum values at the 10% clay quantity. Regardless of the amount, the soils show a potential ranging from 0 mm per year for soils with 50% clay to 250 mm per year for soils with a lower %. The GWRRP is similar in all clay classes and reflects the value of $Pr > 0.05$.

Overall, therefore, we can say that among the three groupings (Country, Eco-zone and % clay) the one that is statistically most relevant is the Eco-zone, which proves to be an excellent indicator of the differences between the averages and therefore the one with the greatest influence in the analysis of all the characterization factors. On the contrary, the clusters Country and % clay, depending on the CF, are less relevant than the eco-zone, both in discriminating the difference between the averages and in the characterization factors. The cluster % clay, compared to the cluster Country (classification usually used by the method in question), shows a slightly higher significance in the CFs of EP, IRP and FPRP, with the exception of GWRRP.Therefore, the factor that most influences soil quality is the Eco-zone, which characterises in particular the soil matrix, as climatic characteristics have a great influence on the physico-chemical properties of the latter and therefore on soil quality, productivity and fertility.

4.3 Discussion of results

From the results of the statistical analysis, we observed that the grouping of the Ecozone, called Global Ecological Zones (GEZ), is the parameter that best represents and characterises the CFs used in the method. Why? A possible answer could be the following. Morphological, geographical and environmental characteristics that influence the input data needed to calculate the LANCA model depend on the Ecozone to which they belong, because they are defined by geographical and environmental criteria. The ecozone is in fact the expression of phenotypic characteristics resulting from soil functioning in relation to factors such as weathering, flora and fauna. These are classified on the basis of climatic and altitude data to delimit the zones and maps created taking into account potential vegetation and vegetation classification[75]. This could be the explanation for why Ecozones represent and cover CFs better and more precisely than the classification at national level. Moreover, the new classification criterion could be applied globally as well as nationally, as we can see from Figure 28, since these are ecological zones subdivided by climate classifications based on the main vegetation types and plant communities present all over the globe and not just plots of land.

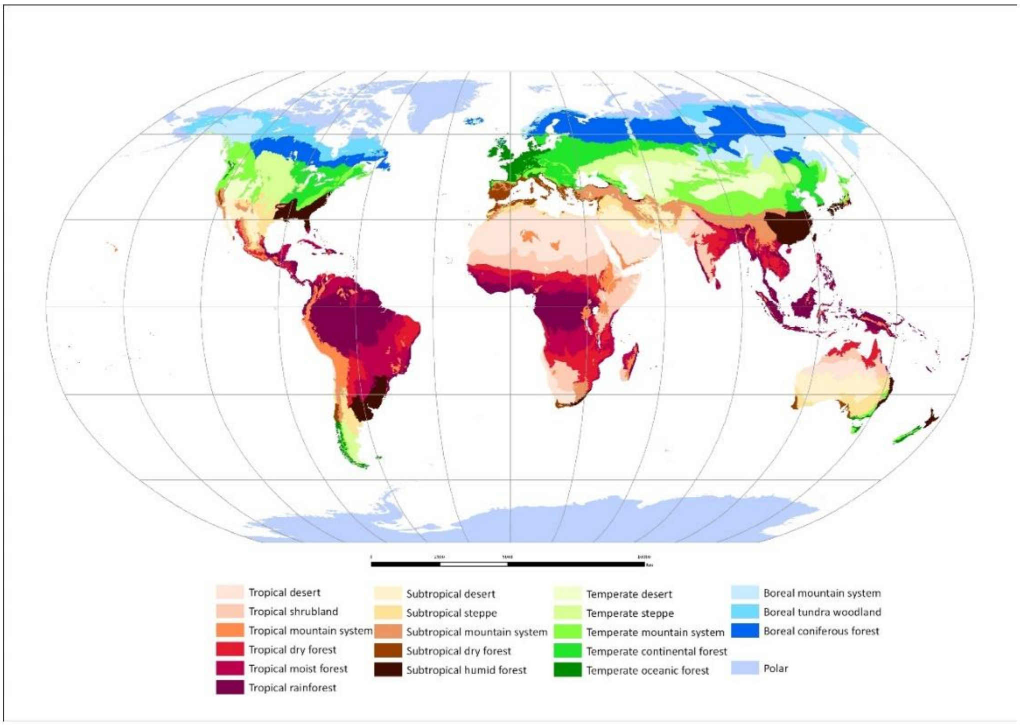


Figure 28 Global ecological zone map[75].

The research study involves the evaluation of the model in several European countries, including Spain, France, Germany and Italy, and the comparison of the results. I was interested in and dealt with the evaluation of Spain and France, while my colleague Francesco Antonucci dealt with the study on the countries of Italy and Germany. His study[76] showed that, for all CFs except the PFRP, the ecozone is more representative than the country classification, which best represents the PFRP CF. First of all, my results confirm Antonucci's general results, by indicating that Ecozones offer the best grouping to calculate CFs. In the work of Antonucci[76] the CFs of PFRP represent an exception in which the country grouping is the best one. This was found in the present study as well, and I have tried to give an explanation to this observation. A possible explanation is that, the parameters used in the calculation of the PFRP factor were substantially different at sites within the same country, which characterised the country and influenced the final calculation. If we look specifically at the individual CFs for the four countries (Spain, France, Italy and Germany), we can see how much they vary between them. From Table 27 below, we can observe a substantial variance between the two pairs of countries: ES-FR and IT-DE.

Table 27 Variance of CF between the four countries compared.

	Variance of CF in the 4 countries							
	EP		**IRP**		**PFRP**		**GWRRP**	
	media	varianza	media	varianza	media	varianza	media	varianza
ES	3.22	5.52	2.20	1.34	3.39	0.14	6.27	1.34
FR	3.79	2.15	1.79	0.54	3.27	0.09	5.55	1.66
IT	-2.04	13.85	-1.08	0.45	3.13	0.05	772.5	520741
DE	-0.82	7.33	-1.73	3.80	3.40	0.02	540	1148669

As can be seen in the table above, the CFs for the 4 countries are overall variable and distributed with respect to the mean value. The values in the table are transformed so that the datasets follow a normal distribution, except for the GWRRP characterization factor of the countries of Italy and Germany because they are already normally distributed. The factor that responds most equally across nations is PFRP, as it has a mean value of about 3.30 cmol/kg and a very low variance, meaning that the data, i.e. the CF in question, across sites within each nation are concentrated around the mean value. This can probably be due to the parameters involved in the calculation of the factor, which are on average similar; for example the pH of the countries of Spain, France and Italy present values of 6.8, 6.9 and 6.5 respectively as well as the % of clay is similar on average. On the contrary, the cation exchange capacity (CEC) is very close between the countries of ES-FR (16.8 cmol/kg and 17.4 cmol/kg), while between the countries of IT and DE there is a more pronounced difference (26.4 cmol/kg and 22.9 cmol/kg respectively), and this confirms and characterizes the classification of CF PFRP on a national basis for these two countries. For the characterization factor Biotic Production Reduction Potential there is no variability in the distribution because the variance is 0.

Furthermore, this thesis study can be expressed as a continuation of the work carried out by Daniele Terranova, who was mainly concerned with applying and evaluating the LANCA model at a regional level, highlighting its strengths and weaknesses[77]. From the Terranova's work it emerged that the CFs calculated at a regional level (Emilia-Romagna) differ by a wide margin from the default CFs tabulated and classified on a national basis, as proposed in the LANCA's methodology. This further supports the result that a classification by ecozone is more representative than a classification by country.

4.4 Limitations of the study

The study has some limitations. During the development of the study, several problems were encountered related to the availability of certain input data. First of all: the humus content data for the sampling points was not available; for this reason, it was essential to consult the

LANCA manual[38], from which the formula (found in the previous chapter) was extrapolated to obtain the humus data in the soil. Another data that was difficult to find was the depth of the water table from the ground level. This data was not actually available for all the sampling site; very often it was necessary to approximate the value the closest measured point near the site where data was missing. Another important limitation has been the difficulty of finding some books on certain procedures for applying the LANCA model, in particular: Schultz 1988, Lieth 1975 and Kalusche, 1993, which are only available in German and not freely accessible. In addition, some data, such as those relating to mechanical filtration have a trend that is not 'normal', probably because the number of sites considered was the minimum necessary to be able to conduct the study given the timeframe of a thesis. Therefore, the results could be more robust if the study were repeated with more observation sites.

CONCLUSIONS

Observing the results obtained, we can confirm that the most influential and relevant parameter in the statistical analysis of the characterization factors is the Ecozone grouping indicated by the FAO, which characterises and represents all the CFs better than the classification on a national basis and classification on % clay. This study therefore confirms the result of the study conducted by my colleague Antonucci. In addition, this information therefore shows us that climatic and environmental factors are of extreme importance for soil quality, since the climate factor, together with other elements such as parent rock, morphology, biotic production and weather, is one of the five factors of pedogenesis and therefore fundamental and decisive in soil formation, development and conservation. As already mentioned, the ecozone is the expression of phenotypic characteristics resulting from the functioning of the soil in relation to factors such as weathering, flora and fauna. Moreover, this factor particularly characterises the soil matrix, influencing its chemical-physical characteristics and thus the quality, productivity and fertility of the soil, a requirement of extreme importance given the land use considered in the study. The importance of considering the ecozone is also remarked by the fact that soil functionality is the basis of ecosystem services, which allow life on earth and from which man benefits. Therefore, it is here proposed to draw up tables containing CFs classified by ecozone for future analysis because they are more representative of CFs classified on a national basis (usually used by the LANCA method).

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