soil systems

Review

Criteria for Assessing the Environmental Quality of Soils in a Mediterranean Region for Different Land Use

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Abstract: Since the 1980s, there has been a notable increase in environmental sensitivity, which has decisively contributed to an improved perception of the role of soil in ecosystems. European (and especially Mediterranean) soils have a long tradition of use, which places them among the three Earth soils that have been affected the most by anthropic pressure. The definition of soil quality identifies and recognizes the soil's main functions regarding productivity, environmental quality, and human health. Interpreting the criteria for assessing soil quality requires continuous information on its state. Therefore, certain measurable characteristics and properties of the soil are useful, as they can be affected by processes that impact its quality, and analyzing its variation can reflect or show that impact. The parameters used to measure a soil's state are called indicators. Indicators are useful because they provide summarized and simplified information on the state of a process, but with a meaning that goes beyond an association with an individual parameter. There is an urgent need for consensus among soil scientists and institutions on the concept of soil quality and the applicable environmental quality indicators, as well as establishing interpretative guides for the selected indicators. Soil quality can be analyzed and assessed using several scales with different analysis objectives, information requirements, soil data, implications, and consequences for appropriate soil management. Spanish soil scientists developed a methodological proposal to assess the environmental quality of soil, its environmental impact, and plan and organize land use in the scope of a Mediterranean region. This manuscript is a contribution to the knowledge of the state-of-the-art research in the field of assessing the environmental quality of soils, providing the vision of numerous authors and a methodological proposal for an assessment on a regional scale that may be of interest in other regions or fields of study.

Keywords: soil quality; multifunctionality of soil; ecosystems services; indicators; scales; Mediterranean soils

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1. Introduction

In Spain, soil maps and their reports are presented in scientific terms of classification, without providing other information. The behavior of the same type of soil distributed in a region varies depending on the environmental conditions and socio-economic characteristics of the area [1]. The possibility of establishing a different relationship between soil types and their vulnerability is complex to apply in significantly heterogeneous territories such as the Valencian region. The inappropriate use of land can cause irreversible soil degradation, especially in Mediterranean environmental conditions in a context of climate change, which determines a low regeneration capacity of soils altered by anthropic activities. The main soil problems in the Valencian region are desertification, soil erosion, salinization, and soil pollution [1].

Soil is the top layer of the Earth's surface, which acts as the bearer and foundation for most of the activities that take place in the biosphere. From the beginning of Western culture, the Greeks identified this element, together with fire, air, and water, as one of the four key pillars of our natural system, a consideration that has withstood the passage of time [2]. In China, Needham [3] wrote,

> *"It was Chinese farmers and economists too who laid the foundations of pedology or the science of soils, for many different kinds of soils are described in the Yugong chapter Shujing, which can hardly be later than the early the 5th century B.C., and also in the Guanzi, which may be dated in the 4th B.C".*

The beginning of soil sciences was potentially born in China. However, it is also true that the scientific study of soil only began in the 19th century. More specifically, in the 20th century, the Russian and European schools of soil sciences established the basic pillars that led to the development of a specific science that studied soil, considering it a dynamic natural system [4]. Dokuchaev created the first scientific classification of soils according to their agricultural capacity. Dokuchaev also said that the distribution of soils was based on environmental conditions and introduced the concept of zonality. Early soil classification systems (Russian Classification, 1938) focused on soil formation factors and their environment for zonal (determined by vegetation and climate development), zonal, and intrazonal (determined by their parent material and formation time) soil classification. They differentiated between azonal and intrazonal soils based on the development of the soil profile. Glinka established the ISSS (International Society of Soil Science) foundation in 1924 and defined soil as a surface geological entity, crust, or altered crust that exhibits aspects of zonality corresponding to large climatic areas. The consideration of soil as an independent entity worth studying has slowly gained more ground, generally focusing on its potential agricultural use, rather than as a natural and complex entity.

In recent years, there has been a notable increase in environmental sensitivity, which has decisively contributed to an improved perception of the role of soil in ecosystems. European (and especially Mediterranean) soils have a long tradition of use, which places them among the three Earth soils that have been affected the most by anthropic pressure [5–7]. The political, economic, and cultural changes on a European level have left their mark on soil landscapes. The not-always-sustainable use of soil as a resource has caused (and continues to cause) dysfunctions and disruptions in its behavior, both for ecological and agricultural purposes, which has severe environmental consequences [2,6].

With a rate of creation in the order of two to three centimeters every 1000 years (depending on the type of soil and the area), soil can be considered a potentially renewable resource. However, inappropriate practices (overexploitation, salinization, deforestation, abusive use of fertilizers, pesticides, as well as heavy machinery that has compacted the soil. etc.) have caused significant and, in most cases, irreversible soil loss worldwide.

This manuscript is a contribution to the knowledge of the state-of-the-art research in the field of assessing the environmental quality of soils, providing the vision of numerous authors and a methodological proposal for an assessment on a regional scale that may be of interest in other regions or fields of study. In this context, Spanish soil scientists Racatalá and Sánchez developed a methodological proposal for assessing the environmental quality of soil, its environmental impact, and planning and organizing land use in the scope of the Valencian Mediterranean Region (Spain). Therefore, it is an assessment of soil quality on a regional scale, where the quality is considered an intrinsic characteristic of the soil. In other words, quality is defined in line with the first of the two viewpoints detailed by Karlen [8] in their methodological framework. This manuscript aims to facilitate the use of soil mapping, interpretation, and evaluation of the quality of Mediterranean soils as well as urgent decision-making to avoid their irreversible deterioration.

2. Conceptual Framework

As stated by Doran and Parkin [9], the common element in all the definitions of soil is the reference to its ability to work effectively, both in the present and in the future. Likewise, these authors specify that focusing exclusively on the established definitions of soil quality, or on the meaning of the term, can miss the real point, which is to identify the main issues that appear and affect the functions of soil. These same authors suggested a definition for soil quality based on the main issues linked to soil functions, as defined at the conference on the Assessment and Monitoring of Soil Quality, which took place at the Rodale Institute [10].

According to these authors, soil quality is '*the capacity of a soil to function within ecosystem limits to sustain biological productivity, maintain environmental quality, and promote plant and animal health*' [9]. This definition of soil quality identifies and recognizes the main functions of soil regarding (i) productivity, or the soil's ability to allow and facilitate the biological and plant productivity of terrestrial ecosystems; (ii) environmental quality, or the soil's ability to mitigate and buffer the effects of environmental contaminants, pathogens, and other external effects; and (iii) human health, or the interrelation between the soil and the health of plants, animals, and human beings.

According to Karlen [8], the different approaches to the concept of soil quality reveal the existence of different perceptions of what this concept means. Thus, some scientists [11] suggested that soil quality is simply related to the number of crops produced. Ohers [12] have highlighted the importance of soil quality in regard to the quality of foods and nutrition. In fact, the quality of soil resources has historically been perceived as closely connected to soil productivity [13]. Soil quality and soil productivity have often been considered nearly synonyms [14]. However, in the late 20th century, in the 1990s, there was growing recognition of the fact that the functions performed by soil, both in natural and agricultural ecosystems, go beyond the growth and development of plants. This was established in several international symposiums and conferences focused on discussing the concept of soil quality, such as the Soil Quality Standards Symposium, organized by the Soil Science Society of America in October 1990, and the Workshop on Assessing and Monitoring Soil Quality [13]. At these forums, the attendees stressed the importance that all soil functions have on preserving the environment. This led to an increased awareness of several aspects (other than productivity) linked to the dynamic nature of soil, which must be considered if the concept of soil quality is to also cover soil management (which, for example, sustains forest ecosystems), soils used to store substances from urban and/or industrial activities, mining, leisure activities, and the preservation of ecosystems, etc. In 1993, the National Academy of Sciences published the book entitled Soil and Water Quality: An Agenda for Agriculture [13], which established that 'soil quality is the ability/capacity of the soil to promote plant growth, protect watersheds by regulating infiltration, and prevent air and water pollution through its buffering power over potential contaminants such as agrochemicals, organic residues, and industrial pollutants'.

Ultimately, there is a perception of the concept of soil quality that has transcended the traditional viewpoint of associating the term with soils that allow for better agricultural productivity and profitability (i.e., the most productive soils). This perception includes other functions of soil, such as protecting and preserving environmental quality. Beyond the productive function of soil, other functions (buffering contamination, regulating the water cycle, etc.) are gaining importance in the conceptualization of soil quality. This has been clearly expressed by some authors [8,15], who emphasized the need to develop a consensus in order to appropriately assess soil quality from an environmentalist viewpoint. For example, Sims et al. [15] increased the need for scientists to discuss soil in terms of soil quality and develop new methods for quantifying the environmental risks that threaten soils, both in agricultural and non-agricultural environments. Figure 1 shows a simplified overview of the evolution of the term 'soil quality'.

The change in the conceptualization of soil quality from a productivist to an environmentalist viewpoint and the emergence of several definitions for the term showed the concern, not only of the scientific community, but of other groups of interest (conservationists, politicians, etc.). This was proven by the appearance of scientific dissemination articles (some of which were even sensationalist) to encourage public debate on this topic [11,16,17], whose origin was based on the different visions shaped around the workability and usefulness of soil resources in recent decades. This vision expanded the productivist perception of soil of the mid-20th century to include a dimension that reflected the increasing concern and sensitivity towards issues connected to soil degradation and their inevitable consequences on the deterioration of the environment. The Soil Sciences Society of America [18] defines soil quality as 'the capacity of a specific type of soil to function, within the limits of natural or managed ecosystems, in sustaining plant and animal productivity, in maintaining or improving water and air quality, and in supporting human health and habitat'. A few important developments in the field have been conducted in 21st century. Such as McBratney [19] on digital soil mapping, Dominati et al. [20] on the environmental services provided by soils, and Cowie et al. [21] and Henry et al. [22] on land degradation processes [23]. Theses references will provide further reading about some of the latest developments in the field.

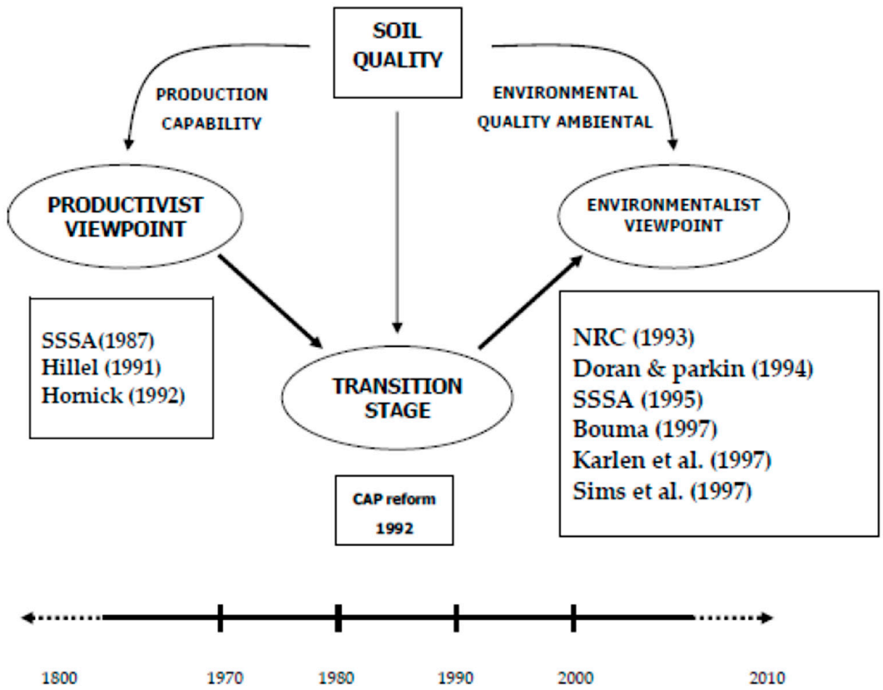

Figure 1. Simplified overview of the evolution of the term 'soil quality' [7–9,11–15,18].

3. Quality and Multifunctionality of Soil

According to Blum [24], soil has six basic ecosystems services, namely the production of biomass; the filtration, buffering, and transformation of substances; biological habitats and gene pools; a platform for man-made structures; a source of raw materials; and cultural heritage. In short, these functions refer to the following.

The production of biomass. Soil is the substrate for a wide range of plants, animals, and microorganisms that live inside it, helping to create a medium that is essential for the primary production of ecosystems. Of all its functions, this has been most used and exploited by humankind to ensure its survival through the production of food, either with crops or indirectly (e.g., for grazing). This function is key in terms of agricultural, livestock, and forest activities, as well as to provide biodiversity and landscape differentiation.

Filtering, storing, buffering, and transformation of substances. These can be seen as part of a more general function of regulation [25]. This function refers to the process of moving, transporting, and transforming flows of substances and energy. It can be considered a group of internal mechanisms of the soil that aid in the creation, evolution, and differentiation or the soil's profile, and also as a function to regulate the exchange of components in the atmosphere, vegetation cover, hydrosphere, and surrounding ecosystems (other soils or lithologic materials). The various processes include filtering substances from rain, retaining and releasing (polluting and non-polluting) chemical and biological substances, the infiltration and draining of rainwater or floodwater, storing nutrients, regulating the exchange of energy, and the role of soil as a source and drain of gases.

Biological habitat and gene pool. Soil provides a habitat for numerous organisms and microorganisms. The connection between soil variation and the diversity and distribution of higher plants has been studied in depth. However, the significant contribution of soil to microorganism biodiversity and gene pools has not been studied enough, despite the essential role they play, or could play, in transforming toxic and dangerous pollutants into inert substances. In this sense, some institutions (e.g., the German Advisory Council on Global Change [26]) have emphasized the urgent need to assign more efforts and support to researching edaphic ecology, fauna, and flora to study the role of edaphic organisms in elemental cycles and in the transformation of matter and energy in the context of the ecosystem. The gene pool of soil is a potential significant reserve of biotechnological processes for the pharmaceutical industry and agri-food production. Other important aspects to improve the functions of soil as a habitat are the possibilities when applying the information to develop methods for restoring soil (bioremediation).

Platform for man-made structures. This function refers to the production of goods and services. The soil becomes a base for the development of infrastructures (roads, housing, industries, etc.) and the dumping of urban industrial waste. The soil in town surroundings obtains a major economic value when it is used as urban land for industrial activities, residential areas, or touristic infrastructures. These changes in the use of the soil are generally conducted without considering its quality and productivity. As a result, many hectares of high-productivity soils located around urban areas (e.g., fluvisols in alluvial formations) are being irreversibly erased by urban and industrial expansion.

Source of raw materials. Soil can provide several materials for numerous activities. The extraction of peat, gravel, sand, clay, rocks, and minerals, etc. is a significant and growing economic function of soil. The environmental impacts caused by these extractions are not yet well regulated, leaving permanent and visible marks on the landscape.

Cultural heritage. Soil holds archaeological and paleontological sites, registering the moment when the location was abandoned after adding new materials, which can lead to the development of new soil. This way, the soil becomes a reflection of history, registering the landscape's evolutive processes, climatic processes, catastrophic events, anthropogenic impacts, etc., that can provide important data for the scientific knowledge of several historical aspects linked to the environment or its use by human communities.

Twenty years later, a framework for classifying and quantifying the natural capital and ecosystem services of soils was established by Dominati et al. [20].

4. Assessing Soil Quality

4.1. Indicators of Soil Quality

Interpreting the criteria for assessing soil quality requires continuous information on its state. Therefore, certain measurable characteristics and properties of soil are useful, as they can be affected by processes that impact its quality, and analyzing its variation can reflect or show that impact [27]. The parameters used to measure the soil state are called indicators [28]. Indicators are useful because they provide summarized and simplified information on the state of a process, but with a meaning that goes beyond an association with an individual parameter [29–31]. For example, the ease with which soil allows water to pass through its profile can be measured using an individual parameter (permeability). However, when we use permeability as an indicator of a process, such as the water erosion of soil, its meaning goes beyond simply expressing greater or lesser ease for the water to infiltrate the soil. To assess the potential for soil erosion caused by water, it is necessary to identify the rainfall erosivity, the particle size, the organic matter content, the landform, including the slope percentage and slope length, and the land management history and practices. It seems unlikely that soil permeability alone would be a sound measure of the potential for soil erosion caused by water, but it is an interesting indicator. If the permeability decreases, the erodibility of the soil increases, as does the loss of soil caused by water erosion, which entails a decrease in the soil's ability to perform its functions (i.e., a loss of soil quality). It is important to use soil quality indicators [32] since analyzing them can reveal the following.

- The conservation efforts made to preserve and improve the quality of the soil.

- An assessment of the suitability of the practices and techniques to handle and manage the soil.
- How soil quality is connected to the quality of other natural resources.
- The information needed to analyze and establish trends regarding changes in soil quality.
- What decisions soil managers should propose and adopt.

The NRCS classifies the indicators into four groups: visual, physical, chemical, and biological. The novelty, compared to other proposals, lies in the inclusion of visual indicators (e.g., soil color, presence of grooves, plant response). These make it possible to obtain information using visual and photographic interpretation and can be easily read by farmers and soil managers in order to detect changes and trends in soil quality.

Griffith et al. [33] noted that the USDA Forest Service uses soil quality standards that include edaphic cover, soil porosity, and organic matter content to protect the long-term productivity of the National Forest System.

Alexander and McLaughlin [34] suggested that changes in the soil structure are particularly important for assessing changes in the quality of forest and meadow soils and suggested using bulk density and penetration resistance as indicators for monitoring changes in the soil structure.

Arshad and Coen [35] proposed physical and chemical indicators for soil quality, such as the effective depth of the soil, available water capacity, bulk density, penetration resistance, hydraulic conductivity, aggregate stability, organic matter content, nutrient availability, pH, electrical conductivity, and exchangeable sodium.

Doran and Parkin [9] proposed the following set of physical, chemical, and biological characteristics of the soil as basic indicators of soil quality, namely the soil texture, rooting depth, bulk density and infiltration, water retention capacity, available water, soil temperature, total organic carbon and nitrogen, pH, electrical conductivity, mineral nitrogen, phosphorus content, potassium content, microbial biomass, potentially mineralizable nitrogen, soil respiration, ratio of total biomass to total organic carbon, and ratio of respiration to biomass.

The advantage of this last proposal is that it included indicators connected to the soil's biological activity, which, as mentioned by some authors [36,37], were not as developed as those related to the soil's physical and chemical properties.

Researchers of the CEBAS (CSIC, Murcia, Spain) indicated that biological or chemical parameters (indicators of microbial activity in the soil) would be the most sensitive to the changes that take place in the soil. This is important to keep in mind when dealing with soils in a semi-arid climate that are subjected to degradation processes, such as those in the southeast Iberian Peninsula [38]. The importance of the physical and chemical parameters must not be downplayed, as the interrelation between them is effective for understanding the quality of the soil. Furthermore, detecting them is usually easier, common, well known, and routine. The researchers highlighted that, before a sharp alteration in the quality, the biological and biochemical parameters would be able to offer a faster and more efficient response. As a result, the studies aimed at identifying the microbial activity in the soil were highly relevant when dealing with the environmental quality criteria of soils [39]. The enzyme activity in the soil was responsible for forming stable organic molecules that helped stabilize the soil's ecosystem and partake in the cycles of elements that are as important to it as nitrogen (urease and protease-BAA), phosphorus (phosphatase), and carbon (β-glucosidase). On the other hand, it is hard to identify the general state of the soil nutrients or determine its microbiological activity rate by knowing its enzyme activity alone. However, simultaneous measurements of several enzymes can be useful as indicators of bioactivity and can be used to express the soil's biochemical fertility [40–42].

Table 1 shows the environmental quality indicators that were most used by numerous authors. It is merely a proposal of the basic indicators of soil quality and can be adapted or modified for each case study depending on the type of soil being analyzed.

Table 1. Parameters proposed to be included as the basic indicators of soil quality.

Type of Attribute	Parameter
Physical	Soil texture Bulk density and infiltration Aggregate stability Water holding capacity Humidity and temperature
Chemical	pH Electrical conductivity Total organic carbon Labile carbon fractions Total and removable N, P and K content
Biological and Biochemical	Microbial biomass carbon Soil respiration Microbial biomass C/total organic C (TOC) qCO2: Respiration/microbial biomass C ratio Enzyme activities

4.2. Organisation and Use of the Indicators

After selecting the indicators and choosing the most suitable units of measurement, the implementation of a set of indicators by decision makers, soil planners, and managers is easier if the indicators are organized in a chart or framework. One of the environmental assessment frameworks that is useful for organizing soil quality indicators is the so-called pressure-state-response framework [43–45], as expressed by several authors [46–50]. In fact, this framework has been implemented by the World Bank and most OECD countries. The benefit of the pressure-state-response framework is that it considers the relationships and connections between the pressures exerted on the soil by human activities, the changes in soil quality, and the responses of society to these changes. Therefore, this framework provides a feedback mechanism that allows for a dynamic approach to the monitoring and assessment of soil quality. This framework classifies the indicators as pressure, state, and response indicators. The indicators of environmental pressures (e.g., the biomass extraction rate) are connected to the level of intensity and the performance of soil management and use (e.g., agriculture with crop waste disposal). The indicators of environmental conditions refer to the soil state at any given time. The indicators of societal response (e.g., the recommendations to retain crop waste) refer to the actions or decisions taken by soil managers or encouraged by policies or programs designed to improve soil quality [51–54]. In a case study, the procedure whereby a set of indicators organized in a pressure-state-response framework enables the assessment and monitoring of soil quality is as follows [55,56].

(a) Measuring the indicators makes it possible to identify the state of the soil regarding the associated properties, which were previously selected as relevant for the case study. Measuring these indicators over time makes it possible to detect changes in these properties due to, for example, degradation processes (e.g., salinization). As an example, regularly measuring the electrical conductivity of soil from irrigated land in an arid or semi-arid area with low quality water due to dissolved salts will make it possible to detect the soil salinization process and its escalation due to the continuous provision of water.

(b) If the rate of water extraction for irrigation (indicator of pressure) and the degree to which the use of that irrigation water is controlled by policies and programs is known, the trend of the escalation of the soil salinization process (and, as a result, the loss of quality) can be analyzed and assessed.

(c) Periodically measuring the electrical conductivity (an environmental condition indicator) enables the monitoring of the previously identified trend. When soil managers are interested in assessing the environmental quality of soils, the soil water quality must be considered, as this will also affect the environmental quality of soils as a whole.

The natural environment itself does provide some pressures on the maintenance of soil quality. Factors such as the rainfall erosivity, rainfall intensity, leaching potential of nutrients and acidification potential, wind erosion, sources of salt and salinization, and other natural features of the landscape can impose pressures on soil quality. It would be useful to identify the specific pressures imposed by different land uses than can affect soil quality, such as the grazing intensity, cropping intensity, irrigation, and contamination, etc. The processes associated with land degradation processes are obvious. Similarly, some of the specific responses might be identified, such as conservation agriculture, environmental legislature, education, pollution control, and improved irrigation management, etc. Additionally, these responses can help to identify which soil properties are being measured to assess the soil quality or soil condition, pH, electrical conductivity, soil depth, soil texture, soil organic carbon, and values compared to original condition.

4.3. Scales for Assessing Soil Quality

Soil quality can be analyzed and assessed using several scales with different analysis objectives, information requirements, soil data, implications, and consequences for an appropriate management of soil functions [57,58]. Karlen et al. [8] recognized that soil quality can be assessed from two different viewpoints or methodological approaches, namely (i) as an inherent characteristic or attribute of the soil, or (ii) as the condition of the soil to function fully and adequately in a specific use.

These authors specified that, under the first viewpoint, the inherent quality of the soil is governed by soil-forming and soil-related processes. As a result of these processes, each soil has the natural capability for conducting its functions. The second viewpoint assumes that, if a soil works with all its potential for a specific use, it is said to have excellent quality. However, if the soil works below its potential, it is said to have low quality, or its quality is decreasing due to the management activities being performed in that system. In this case, assessing the quality requires measuring the soil conditions with indicators, which are associated with the fundamental properties to analyze the relevant functions in the situation being studied. Comparing these measurements to the desired values is the basis for assessing soil quality. This approach can also be used to analyze temporary changes associated with management practices, and, where necessary, to propose the implementation of more suitable practices to recover, preserve, or even improve soil quality.

Following the framework proposed by Karlen et al. [8] for assessing soil quality on different scales, these authors noted that an assessment using a point scale, which is the most detailed assessment included in the framework, is usually conducted at a sub disciplinary level where the soil's functions are defined in specific terms following specific characteristics, properties, and physical, chemical, and biological processes. The work is conducted practically at the soil profile level, taking occasional, specific, and local measurements. For example, in the case of a small area of soil that would be used to store waste, assessing the function for protecting the environmental quality would be performed by sporadically measuring the chemical properties such as the CEC, pH, organic matter content, content and mineralogic composition of the clay, hydraulic conductivity, and depth of the soil. Due to the limited size of the project (e.g., a small landfill), if the spatial variability of the soil is practically irrelevant or homogeneous, assessing the function planned could be achieved by measuring the proposed properties at a point that defines the soil profile [59].

On the other hand, soil quality assessments on a plot scale are usually conducted using a disciplinary approach, analyzing one or more functions of the soil (e.g., environmental quality productivity and protection). According to Karlen et al. [8], this assessment requires a transition from a way of working that was primarily based on experimenting (field experiments) to a more interdisciplinary methodological framework based on approaches that monitor and control certain characteristics and properties of the soil that are less specific and detailed than at other scales. It is at this scale that decision makers and soil managers interact, collaborating with soil scientists and researchers. The quality indicators used at this scale often refer to characteristics and properties that can easily be observed or measured, such as those proposed by the US National Research Council for assessing the quality of soil used for grazing [13]. The visual indicators proposed by the National Resources Conservation Service (USDA) [32] include the soil's color, the presence and thickness of grooves, the symptoms of deficiencies in plants, etc. However, the concept of a field or farm referred to by Karlen et al. [8] does not correspond to the sizes of fields in Spain or, in general, in Europe. In the U.S., agricultural holdings can comprise large tracts of land—even entire watersheds.

On provincial, regional, national, and international levels, it is also interesting to assess the quality of the soil, especially since those levels are generally where primary policy decisions that affect soil resources are made. Thus, it must represent a significant challenge for soil scientists and researchers to develop methodologic approaches to establish an initial analysis of soil functions on these general decision-making levels. At these scales, it is common for soil quality assessments to be included in comprehensive frameworks that assess territorial units. From a sustainability viewpoint, they are part of methodological approaches for planning the uses of certain territories. In these frameworks, the soil quality assessment is performed by analyzing and interpreting the indicators associated with the chemical, physical, and biological characteristics and properties of the soil, even though they use broad information given the general scope of these studies. The less detailed the scale for the assessment, the broader the information. Monitoring soil quality can occur at different scales such as paddock, farm, district, regional, and national.

5. Methodology Proposed for Assessing the Environmental Quality of Mediterranean Soils

In connection to the previous level of assessment, Spanish soil scientists Racatalá and Sánchez [60,61] developed a methodological proposal for assessing the environmental quality of soil, its environmental impact, and planning and organizing land use in the scope of the Valencian Mediterranean Region (Spain). Therefore, it was an assessment of the soil quality on a regional scale, where the quality was considered an intrinsic characteristic of the soil. In other words, the quality was defined in line with the first of the two viewpoints detailed by Karlen et al. [8] in their methodological framework. This proposal included the environmentalist viewpoint of assessing soil quality, recognizing the role of soil as an element of the ecosystem, and attempting to provide a methodological framework to quantitatively assess the environmental impacts on the soil in accordance with the requirements of the Valencian Law and Regulation on Assessing the Environmental Impact [62]. Each year, additional pressure has caused high environmental impacts in the Valencian region such as soil erosion, desertification, and soil pollution. Figure 2 shows the characteristics and properties of the soil and its parameters, features, and criteria for assessing the soil's environmental quality. The reference systems classified the soils into one of five classes, established for their qualities of erodibility, ecologic value, and natural fertility. The reference system for erodibility was established based on the results obtained in the studies [63,64] on the variability of the K factor in the Universal Soil Loss Equation (USLE) in the Valencian Mediterranean region. The reference system for the ecologic value was defined in line with the soil's tendency to balance the region's environmental conditions. Recatalá and Sánchez [60,61] and Recatalá [65] studied all the trends in the Valencian region.

The various evolutionary stages of these trends, identified using certain diagnostic properties (salic properties, FAO [66]) or diagnostic horizons (e.g., mollic horizon, FAO [66]), were used to establish the various classes of the reference system for the ecological value. The reference system for natural fertility was established based on the types of surface substrate and modifiers established in the Soil Fertility Capability Classification (SFCC) [67]. Erodibility was considered where erosion was recognized as the main soil problem in the Mediterranean region [68]. The ecological value considered the soil function of maintaining the ecological balance of terrestrial ecosystems using the interrelations established between the soil and other components of the ecosystem, mainly vegetation. Natural fertility recognized the soil function connected to providing substrates and nutrients to plants. In addition to these three attributes, the rarity of the soil was also considered when assessing the environmental quality. The rarity reflected the fact that the soil of a specific ecosystem could be special in the context of the Mediterranean region due to its scarcity.

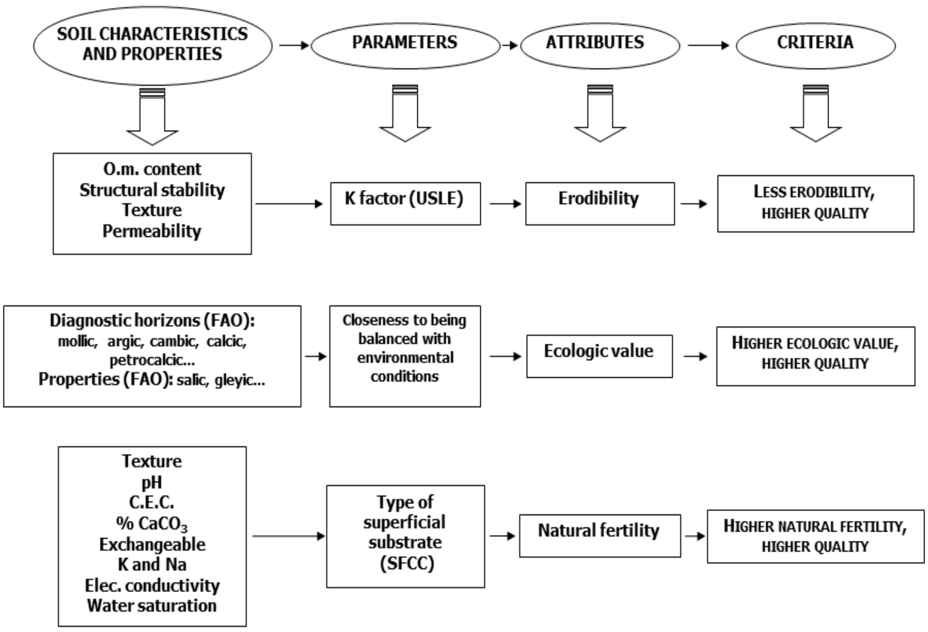

Figure 2. Characteristics of the soils. Parameters, attributes, and criteria for assessing the quality of soils in the Mediterranean region (modified from [60,61]).

More specifically, when assessing the environmental quality of soil following this proposal, it was considered that the soils with the most resistance to erosion (less erodibility), highest ecological value (higher closeness to being balanced with the natural environmental conditions), and higher natural fertility (most favorable physical and chemical conditions for plant growth and development) had a greater environmental quality. However, rare soils (less than 5% of the total surface in the region) were classified and assessed as soils with a very high environmental quality.

Nevertheless, the criteria of lower erodibility, higher ecological value, and higher natural fertility must be quantified for various land uses. Otherwise, it would not be necessary to assess the environmental quality of the soils in any particular region since the environmental quality of a soil for agricultural use is not the same as land for industrial use.

Figure 3 shows the established procedure for classifying and assessing the environmental quality of soil. For soils that had no rarity, the assessment of environmental quality was performed over several phases, including the following.

(1) Assigning figures (conventionally taking even numbers from two to 10) to the different classes of the reference systems, according to their meaning regarding the environmental quality of the soil (e.g., the class with a very high ecological value was assigned a 10).

(2) Assigning weights or values of importance to the different attributes considered to define the environmental quality of the soil using the Delphi method [69] and a trial-and-error analysis with the test and diagnostic units selected for the region.

(3) Aggregating the figures obtained from the soil following the classes of the reference system used to classify it and weighting them by the importance of each attribute. An additive algorithm was used for this aggregation.

Table 2 shows a practical example of the classification of Mediterranean soils into *very high* and *very low* classes using the three attributes defined by Recatalá and Sánchez: erodibility, ecological value, and natural fertility [61].

Table 2. Example of the classification of Mediterranean soils into very high and very low classes using the attributes erodibility, ecological value, and natural fertility.

Quality	Erodibility	Ecological Value	Natural Fertility
VERY HIGH	K < 0.15 t/ha	Soils with a mollic A horizon with a shortage of salic and fluvial properties. Soils developed on sandstones with an argillic B horizon. Soils with gleyic properties at 50 cm from the surface in natural conditions with a shortage of fluvial properties.	Soils with a loam texture up to 50 cm of depth, unmodified.
VERY LOW	K > 0.45 t/ha	Soils whose depth is limited by rocks and cemented horizons 30 cm from the surface, with no mollic A horizon. Soils to which human activities have caused major modifications from their natural conditions.	Soils with a lithic contact less than 20 cm from the surface. Saturated soils up to 60 cm from the surface for most of the year. Soils with an electrical conductivity of >0.4 S/m. Soils with an amount of exchangeable sodium. 15% higher than their cationic exchange capacity.

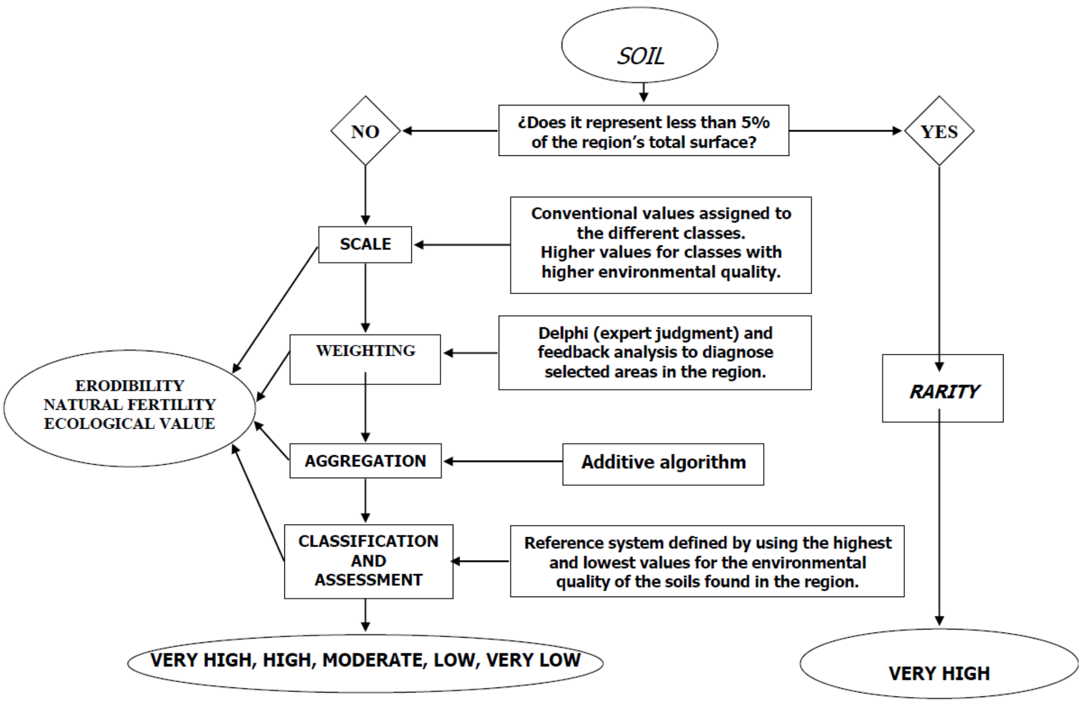

Figure 3. Procedure for assessing and classifying the environmental quality of soils in the region.

This methodology is still valid for 21st century. Undoubtedly, Recatalá and Sánchez were ahead of their time by adopting an environmentalist vision (long before there were discussions of ecosystem services) and proposing a methodology for assessing the environmental quality of soils that collects previous knowledge and uses classic parameters. This article examined the proposals in which the indicators were most effective, noting that there were clear overlaps with research on ecosystem services, land degradation neutrality, and so-called 'nature-based solutions'. Today, scientists and soil managers can use modern indicators, such as biological, microbiological, biochemical, or those based on molecular biology.

The methodology proposed for the Valencian region can be reviewed and updated due to new scientific and technical knowledge using new analytical and technological protocols, such as the latest remote sensing techniques and geographic information systems.

Lastly, the environmental quality of the soil fell into one of the five classes (from very high to very low). The highest and lowest values that a soil in the region could obtain were taken as a reference to establish these classes, following the methodology proposed. To conduct this assessment, values (one to five) were traditionally assigned to the different classes of environmental quality. For example, for soil in natural conditions (e.g., eutric gleysol; FAO [66]), whose environmental quality would be expected to fall between high (value four) and low (value two) when implementing irrigation, the environmental impact of its change in use could be expressed with the following calculation: 2 (projected value due to the impact of its use) − 4 (initial value) = −2 units of environmental quality.

However, if irrigation were to change to urban use, the corresponding environmental impact would be –4 units of environmental quality since the soil would go from high to zero environmental quality. In the first case, the implementation of irrigation in gleysol entails, in most cases, transforming the original soil into a cumulic anthrosol [66], which is a soil developed by humans through drainage and adding allochthonous materials and which would be classified as having low environmental quality. In the second case, the implementation of an urban use would entail a decrease of four units of environmental quality since it would involve the loss of soil due to sealing [70]. Furthermore, these impacts could be classified as critical, severe, moderate, low, or very low, depending on whether the affected soil had a very high, high, moderate, low, or very low environmental quality. The environmental impacts of a single use could be different for different types of soil (e.g., the implementation of irrigation in a calcareous cambisol represents a moderate impact of −1 unit of environmental quality and implementing urban use leads to −2 units). In this sense, assessing the impacts on the soil in the context of territorial planning provides a basis for managers to assess the situation and make decisions on implementing the appropriate use so that the impact entails less of an environmental cost [71,72]. However, the soil must also have an acceptable capability of fulfilling that use (Figure 4).

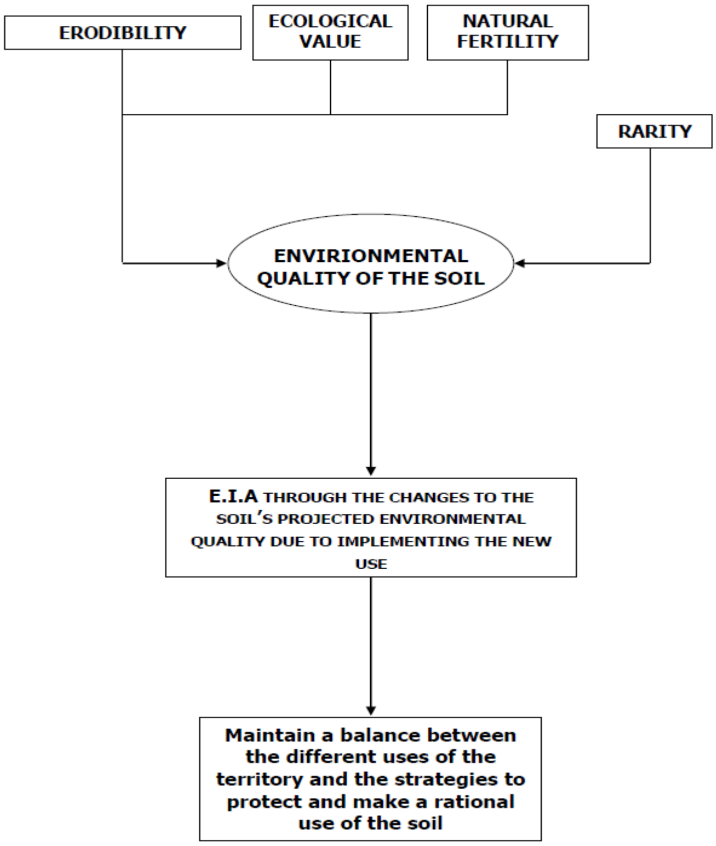

Figure 4. Information on the soil environmental quality for environmental impact studies in the context of planning uses for the soil.

6. Conclusions

The concept of soil quality must be understood from a double perspective, namely the production capacity and environmental quality of the soil. A soil quality assessment can be addressed from two different methodological approaches: (i) as an inherent characteristic or attribute of the soil governed by soil processes of soil formation, or (ii) as the soil's condition to function properly for a specific use. Policies still exist today in many countries to increase land exploitation and production (e.g., the intensification of agriculture). These policies encourage farmers to achieve higher levels of production through technical and financial support, but with significant environmental consequences. A method for assessing the environmental quality of soil, its environmental impact, and planning and organizing land use in the scope of the Valencian Mediterranean Region (Spain) was proposed. A battery of environmental quality indicators of Mediterranean soils was selected. To simplify the study, three attributes were selected to evaluate soil quality (erodibility, ecological value, and natural fertility) based on environment quality indicators. Following this method, soil scientifics can assign weights or values of importance to the different attributes considered to define the environmental quality of the soil and conduct a trial-and-error analysis using test and diagnostic units selected for the region. An additive algorithm was used for the value aggregation. This methodology proposed for the Valencian region is an excellent starting point and should be reviewed and updated using the new scientific and technical knowledge, such as new analytical and technological systems (latest remote sensing techniques and geographic information systems). Finally, it should be noted that there is an urgent need for consensus among soil scientists and institutions on the concept of soil quality and the applicable environmental quality indicators, as well as establishing interpretative guides for the selected indicators.

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