# Soil Quality Assessment under Emerging Regulatory Requirements

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## Abstract

New and emerging policies that aim to set standards for protection and sustainable use of soil are likely to require identification of geographical risk/ priority areas. Soil degradation can be seen as the change or disturbance in soil quality and it is therefore crucial that soil and soil quality are well understood to protect soils and to meet legislative requirements. To increase this understanding a review of the soil quality definition evaluated its development, with a formal scientific approach to assessment beginning in the 1970's, followed by a period of discussion and refinement. A number of reservations about soil quality assessment expressed in the literature are summarised. Taking concerns into account, a definition of soil quality incorporating soil's ability to meet multifunctional requirements, to provide ecosystem services, and the potential for soils to affect other environmental media is described. Assessment using this definition requires a large number of soil function dependent indicators that can be expensive, laborious, prone to error, and problematic in comparison. Findings demonstrate the need for a method that is not function dependent, but uses a number of cross functional indicators instead. This method to systematically prioritise areas where detailed investigation is required, using a ranking based against a desired level of action, could be relatively quick, easy and cost effective. As such this has potential to fill in gaps and compliment existing monitoring programs and assist in development and implementation of current and future soil protection legislation.

Keywords: Soil; Soil Degradation; Soil Quality; Soil Function; Environmental Monitoring; Indicators; EU Environmental Policies for Soil Protection;.

## Introduction

Soil is relatively complex compared to other environmental media. The complexity is confounded by its spatial heterogeneity both over the Earth's land surface but also with depth. Soil is a continuum covering the earth's surface, not a discrete set of entities, and most soil is below ground and not readily visible (Buol et al. 2003). The complexity of the natural systems is manifested in the subject of soil science, which involves the study of complicated interrelated and interdependent processes (Shainberg 2000). Soil science is interdisciplinary and includes soil physics, soil chemistry, soil pedology, and soil biology.

Soil degradation is the long term decline in soil's current or future productivity and its environment moderating capacity (Lal 1994; Lal 1997; Lal 2001; Oldeman 1988). The main soil degradation processes include soil erosion by water and wind, development of extreme soil reaction (acidification, salinisation/alkalization), physical degradation (structural destruction, compaction, extreme moisture regime), biological degradation, unfavourable changes in the nutrient regime, decrease of buffering capacity, and contamination from natural or anthropogenic sources (Blum 1997; Várallya 1989). Major threats for soil in Europe, highlighted in the EU soil thematic strategy, are erosion, decline in organic matter, local and diffuse contamination, sealing, compaction, decline in biodiversity, salinisation, floods and landslides (European Commission (EC) 2006b). Soil degradation normally signifies a change or disturbance of soil quality, implying decline in quality and capacity of soil through natural or anthropogenic perturbations (Johnson et al. 1997; Lal 2009).

There is a move toward protection of soils to the same extent as water and air and to promote sustainable use of soil (Blum 2003; Quevauviller and Olazabal 2003). This increased importance of soil in environmental disciplines has occurred for a number of reasons. The drivers for this rise has been a proliferation of contaminated land legislation, soil geography and soil-geographical zoning, agricultural soil management zone identification, and environmental impact assessments and strategic environmental assessment taking into account soil quality, their characterisation and management (Fleming et al. 2000; Glasson et al. 2005; Nathanail and

Bardos 2004; Urusevskaya 2007; Wood 2003). Soil is the basis of economic and cultural activities; however the economic value of soil has not adequately been recognised (Görlach et al. 2004). Due to the fundamental link between soil and the economy there are many economic activities that depend both directly and indirectly on soil quality including agriculture, industry and tourism. These economic activities could benefit from development of soil quality assessment methods, action prioritisation systems, and more generally from sustainable soil use and conservation.

Countries including the USA, Japan, Canada, Australia, Brazil and a number of developing countries have established soil protection policies (European Commission (EC) 2006a). Legislation aiming to protect soils in Europe includes the soil thematic strategy (European Commission (EC) 2006b), and the proposed soil framework directive (European Commission, 2006b). In addition in the UK reform to the cross compliance good agricultural and environmental condition (GAEC) standards is taking place to strengthen soils protection (Department for Environment Food and Rural Affairs (DEFRA) 2009),and a code of practice for the sustainable use of soils on construction sites has been developed (Department for Environment Food and Rural Affairs (DEFRA) 2008).

A number of EU member states have legislation that alludes to soil protection; however the majority of this is focused on soil contamination. A number of states do have policies addressing broader soil protection issues including Netherlands, Germany and Belgium. These states are some of the most advanced states for soil protection in EU, and found in a survey in 2003 to be the only states with a specific legally binding definition of soil (Van-Camp et al. 2003). The Netherlands have a number of policies to address long term protection, management and sustainable use of soils including the 1987 soil protection act (amended 2008) (VROM (The Netherlands Ministry of Housing, Physical Planning and the Environment) 1986), the 2003 Soil Policy Letter (van Geel 2003) and the 2009 soil remediation circular (VROM (The Netherlands Ministry of Housing, Physical Planning and the Environment) 2009). German policy for the protection of soils include the 1998 Federal Soil protection act (Federal Ministry for the Environment Nature Conservation and Nuclear Safety 1998), and the 1999 Federal Soil

Protection and Contaminated Sites Ordinance (Federal Ministry for the Environment Nature Conservation and Nuclear Safety 1999). There are a number of government agencies that have been established for soil protection, the Federal Institute for Geosciences and Natural Resources formally established in 1975 and the Federal Environment Agency Soil Protection Commission (KBU) in 2004. The Public Waste Agency of Flanders (OVAM) of the Flanders region of Belgium developed a soil remediation and protection decree in 2007, replacing a previous version of 1995 (Public Waste Agency of Flanders (OVAM) 2007). The Flemish government approved the 'Order of the Flemish Government establishing the Flemish regulation on soil remediation and soil protection' that accompanied the decree in December 2007 (Flemish Government 2007), replacing the previous version of 1995.

The soil framework directive proposes integration of soils into all policy making, prevention of degradation and pollution of soils, implementation of risk/priority areas and action programmes for erosion, compaction, loss of organic matter, salinisation, acidification and landslides, limitation and containment of soil sealing, and identification and remediation of contaminated sites (de Souza 2009). The proposed directive will require identification of risk areas on the basis of common elements, encouraging use of existing monitoring schemes with a move toward development of a harmonised monitoring approach (European Commission (EC) 2006c). There is general support for a Framework directive on soil protection, with the majority of states holding the view that the proposed directive will fill a gap in Union environmental legislation and provide a more holistic approach to soil protection (Council of the European Union 2010). Development of the soil framework has, however, been slow for a number of reasons including problems agreeing on an approach for identifying geographical “risk areas" or "priority areas" (ENDS Europe 2007). A knowledge based approach to soil monitoring aimed at delivering soil protection and sustainable use is introduced and required by the soil thematic strategy (Blum et al. 2004a; Blum et al. 2004b; Quevauviller and Olazabal 2003).

Despite the relatively recent introduction of policies for its protection, soil is an environmental medium that is often neglected, because there is not widespread understanding of the importance it has for ecosystems and the economy (Dimas and Gnacadja 2008). Despite the increase in environmental awareness, the same cannot be shown of the general society's attitude toward soil {160 Ferreira, M. da G. de V. X. 2006}}. The public's knowledge of, and interest in other environmental media such as air and water are higher than of soils. For the case of air, the level of knowledge is mainly because of the impact on public perception of the history of air pollution and dramatic local events (Brimblecombe 2001). Similarly, water is perceived as very important and has played its part in both historical and current conflicts (Gleick 2008). The link between human health and both air and water quality has been a driver for developing public perception and the need for environmental regulations.

Even when conflicts have been associated with the availability of arable land and farm production, soil has never properly understood or perceived as important. On the contrary, soil has often been pushed to the background in public commitment to environmental conservation. This is in part due to the unaddressed problem of clearly defining soil, and the more complicated issue of defining or assessing its quality. The links to the environment and human health are not evident for soil to the same extent as water and air. Soil is often taken for granted and often mistakenly confused with dirt. There is a need for defining and communicating a richer, more broadly nuanced, and positive societal value of soil and its quality.

In an effort to protect soils through encouraging development of soil protection policy and legislation there is a need to clearly define soil and in order to assess the state of degradation to understand the term soil quality. This paper aimed to increase understanding of soil and soil quality through review of the definition of soil and developments in the definition of soil quality and its assessment. The paper summarises concerns that have emerged following a phase of development since the initial definition of soil quality in the 1970's. The historical review was undertaken to understand the difficulties in defining soil quality as well as problems and concerns with assessment of soil quality. The review incorporates major concerns and unease in the field of soil quality and developments in the field of environmental protection to refine the definition of soil quality. This work has suggested development of a complimentary method to inform and prioritise further detailed assessment of soil's quality.

This review is particularly relevant due to the simultaneous development of a number of country specific legislative instruments for soil protection and particularly with the emergence of European legislative drivers. The work has relevance to the situation surrounding the proposed framework directive on soil protection. As such the concepts presented in this work have potential EU- wide application, with relevance at member state level but more importantly for harmonisation across states.

## Soil and Soil Quality

There is some variability in the definition of soil; a selection of definitions is presented in Table 1. An early legislative definition by the Netherlands Ministry of Housing, Physical Planning and the Environment (VROM) is a simple statement about the physical nature of the soil; a definition very similar to that of the Public Waste Agency of Flanders. The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety definition is more detailed than that of the Netherlands and Flanders, and includes not only the physical components of soil but reference to soil's function. The Soil Science Society of America provides the definition that is accepted by the US Department of Agriculture and this definition of soil demonstrates the complex and multifaceted nature of soils (Soil Science Glossary Terms Committee 2008) The definition as used by the Environment Agency of England and Wales (EA) introduces the idea that soil is often seen as a resource, and therefore can be exploited (Environment Agency 2004). The definition in the proposed soil framework directive (in the proposal of the Czech presidency) text is restricted to the chemical, physical and biological aspects of the soil, not mentioning function or economic production.

**Table 1 Definitions of soil in legislation and literature.**

A lot of research has been undertaken to understand soil and describe its characteristics in more general terms. For example, the chemical function of soil has been assessed on national, regional and local levels by use of geochemical mapping (Barraclough 2007; Johnson et al. 2005). The technique was developed in the 1950's to give information on the spatial distribution of chemical elements and compounds at the earth's surface (Johnson and Ander 2008). In general, there has been a great deal of work to investigate simplified functions and processes of soil science; these however are regularly limited to the specific sub discipline such as soil physics, soil biology or soil chemistry. There is a need to review the advances and development in the term soil quality, to define how the term relates to the uses of land and to anthropogenic activities.

The potential effects upon other media from the soil system have the ability to influence compliance with regulatory standards such as the European Union Water Framework Directive which sets controls on the diffuse pollution from soil (European Commission (EC) 2006b). A method for prioritisation of impacts to groundwater from soils on a city wide scale is being developed by the British Geological Survey that takes into account factors including soil properties and soil metal concentration from urban soil survey data (Ó'Dochartaigh et al. 2009).

Despite the great deal of research into specific aspects of soil's quality, most of this work defines and assesses soil quality based on different simplified functions and processes of soil itself. An example of this is the agricultural land classification developed implemented in the UK to assess quality of agricultural land taking into account climate, site and soil characteristics and the interactions between them (Ministry of Agriculture, Fisheries and Food 1988). Another example is the great increase in research into, and investigation of, contaminated land since the 1970's. This was mainly a reaction to a number of high profile contamination incidents that attracted media attention, such as Love Canal and Times Beach in the USA, Lekkerkerk in the Netherlands, Minimata in Japan, and incidents in the UK such as the landfill gas explosion at Loscoe, redevelopment of a munitions factory in Enfield, the detection of hexachlorobutadiene in houses in Cheshire, and The Corby Litigation Group v Corby District Council case concerning reclamation of a former steel works in Corby (Nathanail and Bardos 2004; Williams and Aitkenhead 1991). The increase in contaminated land research is also due to an increase in development of Brownfield sites, inclusion of contaminated land as a consideration in the planning process, and a willingness of companies to identify environmental liabilities (Alker et al. 2000; Department for Environment Food and Rural Affairs (DEFRA) 2002; Harrison and Hester 2001).

Contaminated land has the potential to pose serious environmental risks, including surface and groundwater contamination, and risks to human health and safety (Balasubramaniam et al. 2007). Although likely to be covered in future holistic soil protection regimes contaminated land is just one aspect of soil quality. It has traditionally had a separate legislative area with its own related legislation and policy, independent from that of soil science and soil quality. Environmental standards used to assess contaminated land should not be confused with assessment of soil quality. The contaminated land legislative area includes not only legislation specific to contaminated land but also general environmental, waste and resources, health protection, and planning and building control. Exhaustive lists of contaminated land legislation are available from state governments; however examples of the main acts relating to contaminated land in a number of European states are detailed in Table 2.

**Table 2 Examples of main contaminated land legislation in EU member states**

There are some states with legislation specific to contaminated soil, and a number of states that have overarching soil protection legislation; however these still focus to a large extent on soil contamination. The legislative framework in EU member states has similarities in investigation of presumed contamination; mostly following a similar stepwise approach with preliminary investigation followed by detailed investigation and remediation (Provoost et al. 2006). Soil cleanup standards are seen as a trigger for detailed investigation and remediation, however these values vary in derivation and application across member states. For the case of soil quality indicators, apart from contaminant concentration, trigger values for action have mostly not been adequately researched and there is a lack of implementation so far within member states (UK Soil Indicators Consortium 2006).

To support development of national contaminated land management programmes, a likely requirement of the EU SFD (European Commission (EC) 2006c) a driver-pressure-state-impact-response (D-P-S-I-R) framework has been suggested to provide an information framework to support interventions on contaminated land management at a national level and the source-pathway- receptor model to provide guidance at a site level (Rodrigues et al. 2009). This method would meet the requirement in the proposed SFD of identification of contaminated sites but would not go so far as to meet the requirement to identify geographical risk or priority areas. However, this identification will not be carried out by environmental policy itself and is likely to require the development and use of additional tools.

Presence of contaminants from diffuse sources potentially present below traditional risk screening levels should not be overlooked. Although through risk assessment the presence of these contaminants is not necessarily considered a threat to human health, their presence can impact upon other aspects of soil quality such as soil biodiversity (van Straalen and van Gestel 2008). Diffuse pollution of soils also has the potential to exacerbate the impact of other soil quality aspects such as erosion, leaching and run off and ultimately upon a number of soil functions (Quevauviller 2007).

Soil quality needs to include such contamination aspects, within a holistic assessment approach that includes other aspects of soil quality. As previously stated, soil degradation can be defined as a decline in soil quality, and major soil degradation processes are erosion, decline in organic matter, local and diffuse contamination, sealing, compaction, decline in biodiversity, salinisation, floods and landslides. Ultimately extreme degradation leads to desertification, an advanced stage of land degradation where the soil has lost part of its capability to support human communities and ecosystems (European Environment Agency (EEA) 1999). These soil degradation processes can, therefore, be seen as key threats to decline in soil quality and seen as a key focus of the definition, identification and assessment of soil quality.

## Historical Review of Assessment of Soil Quality

Proposals to assess soil quality emerged initially in the USA. An early proponent of the concept was Alexander (Alexander 1971) who first suggested developing soil quality criteria. The development of the definition of soil quality over time is detailed in Table 3.

**Table 3 Development of the definition of soil quality**

The report “*A framework for land evaluation*” by the Food and Agriculture Organization (FAO) of the United Nations defined land quality as “*a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use*” (Food and Agriculture Organisation (FAO) 1976). The FAO report introduced the idea that land quality is complex and should be assessed in relation to the specific function that the land serves Carter *et al.* (Carter et al. 1997) outlined the differences between land and soil quality whereby soil quality is more restrictive than land quality but frequently incorporates the same emphasis on use.

Warkentin and Fletcher (Warkentin and Fletcher 1977) developed soil quality as initially suggested by Alexander (Alexander 1971) by integrating the relationship of soil quality with the land function. The authors stated that assessment of soil quality was needed to facilitate better land use planning because of the increasing number of functions that soil resources must either provide or accommodate. Warkentin and Fletcher (Warkentin and Fletcher 1977) recognised the value of soils in the biosphere and stated that soils have not only current use value but also should have an intrinsic value. The relationship between soil quality and environmental quality is evident in the Anderson and Gregorich (Anderson and Gregorich 1984) definition.

Larson and Pierce (Larson and Pierce 1991) along with their definition of soil quality suggest a minimum data set of soil parameters which could be used to express the 'health' of a soil. The Larson and Pierce (Larson and Pierce 1991) definition introduces soil health, a term that can be used interchangeably with the term soil quality. The term soil quality, however, is one used more regularly by soil scientists and soil health used by other parties. The phrases, although used interchangeably, do however have different emphasis. Karlen *et al.* (Karlen et al. 1997b) state that soil quality can be viewed as an inherent characteristic of the soil, or as the condition or “health” of the soil. However, the difference in emphasis between soil health and soil condition was highlighted in Mausbach and Tugel (Mausbach and Tugel 1995) with soil health differing from soil condition whereby soil health “*is the ability of the soil to perform according to its potential*. *Soil condition changes over time due to human use and management or to unusual natural events*”.

Seybold et al. (Seybold et al. 1998) suggested that soil quality evokes various responses depending on scientific and social background. To the land manager and farmer, soil quality is often viewed as that of soil health (Romig 1995). Soil health is a term preferred by some as it portrays soil as a living, dynamic system whose function is mediated by a diversity of living organisms that require management and conservation (Doran and Zeiss 2000). Doran and Zeiss (Doran and Zeiss 2000) state that the term soil quality is associated with a soil's fitness for use and the term soil health is associated with the capacity of a soil to function as a vital living system, to sustain biological productivity, promote environmental quality and maintain plant and animal health.

Pierce and Lal (Pierce and Lal 1992) differentiated between the intrinsic properties of a soil as determined by the soils development and degradation processes, and the soils productivity describing the efficiency in use and management of resource inputs.

The classification of soil quality as "fitness for use" aligns soil quality assessment with soil function (Pierce and Larson 1993). Assessment of soil quality requires the intended soil use to be determined in order to establish the soils capacity to function (Schoenholtz et al. 2000). Recent and proposed soil protection policy requires action on threats to soil with regard to the soil function (Blum et al. 2004a; de Souza 2009). Carter *et al.* (Carter et al. 1997) suggested a framework for evaluating soil quality that includes describing each soil function on which quality is to be used, selecting soil characteristics of properties that influence the capacity of the soil to provide each function, choosing indicators of characteristics that can be measured, and using methods that provide accurate measurement of those indicators.

The Doran and Parkin (Doran and Parkin 1994) definition includes not only soils ability to function, but includes key soil functions in the definition. A widely used definition of soil quality is that of Karlen et al. (Karlen et al. 2001), the product of a Soil Science Society of America (SSSA) Ad Hoc Committee on Soil Quality (S-581). The result of the committee on soil quality is clearly based upon the Doran and Parkin (Doran and Parkin 1994) definition. The Karlen *et al.* (Karlen et al. 1997a) definition is used widely by the United States Department of Agriculture including in their recent technical note (USDA- NRCS 2008). The definitions from both Doran and Parkin (Doran and Parkin 1994) and Karlen *et al.* (Karlen et al. 1997b) include dynamic soil quality, a term that refers to the condition of soil that is changeable in a short period of time by human impact including agricultural management practices (Idowu et al. 2008; Seybold et al. 1998).

Patzel *et al.* (Patzel et al. 2000) attempted to make a distinction between soil fertility and soil quality for the German language literature. The distinction of soil quality from soil fertility was recommended to prevent ideal attributes in soils being included in the definition of soil fertility and to reduce confusion associated with the two terms as has been seen in the USA.

In the USA the establishment, in 1993, of a Soil Quality Institute (SQI) provided the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) with an emphasis on soil quality. The SQI has a mission to develop and disseminate tools for soil quality assessment (Ditzler and Tugel 2002).

In summary soil quality has developed from the suggestion by Alexander (Alexander 1971) that soil quality criteria should be developed, later in the 1970's it was suggested that soil quality should be evaluated in relation to land function (Warkentin and Fletcher 1977). The interaction with holistic environmental quality, water and air quality was discussed in the mid 1980's (Anderson and Gregorich 1984). There was much discussion of the subject in the 1990's including suggestion of minimum data sets for assessment, discussion about the differences between soil health and soil quality, and a differentiation between the intrinsic properties of a soil and soils productivity as a result of management practices (Doran and Zeiss 2000; Karlen et al. 1997b; Larson and Pierce 1991; Mausbach and Tugel 1995; Pierce and Lal 1992; Romig 1995; Seybold et al. 1998). Doran and Parkin (Doran and Parkin 1994) and Pierce and Larson (Pierce and Larson 1993) developed the definition further by including key soil functions, the fitness for use and the dynamic state of soils in the definition of soil quality, which clearly inspired later definitions (Karlen et al. 1997b; USDA- NRCS 2008), and soil protection policy (Blum et al. 2004a; de Souza 2009).

**Concern over the definition of soil quality**

Despite formation of a soil quality institute in the USA and a large amount of discussion predominantly attempting to define soil quality, consensus amongst the scientific community on a precise definition of soil quality has not been reached (Ditzler and Tugel 2002). This is likely to be due to the innate difficulty in the definition of soil and the complex nature (i.e., scientific, personal, and social) of environmental concerns (Carter 2002).

Following the large amount of work to define soil quality, there has more recently been some dispute about the relevance and impact of soil quality. MacEwan and Carter (MacEwan and Carter 1996) and Carter (Carter 2002) stated that although soil quality describes an objective state or condition of the soil, it also is subjective, evaluated partly on the basis of personal and social determinations. Doran and Parkin (Doran and Parkin 1996) described that in the 5 years preceding the publication there had been concern about deficiencies in the basic understanding of soil quality and a lack of a mechanistically based soil quality methodology, particularly of the soil biota.

Sojka and Upchurch (Sojka and Upchurch 1999) expressed concern over the move in soil science from value neutral tradition of edaphology, and specific problem solving to paradigm based on variable and often subjective societal perceptions of environmental holism. Sojka and Upchurch (Sojka and Upchurch 1999) suggested that although soil quality does acknowledge the variable soil functions it fails to integrate simultaneous, diverse and often conflicting soil functions and emphasises the importance of understanding rather than rating of the soil resource. Conflicts occurring for example between agricultural production or use as a platform for construction and functioning as an environmental buffer and store of water.

Concerns expressed by Karlen *et al.* (Karlen et al. 2001) emphasise the lack of inclusion of soil functions and meaningful indicators for those functions. Karlen *et al.* (Karlen et al. 2001) discussed the difficulty in interpreting indicators for various soil functions that can be used to track soil quality over time. Letey *et al.* (Letey et al. 2003) expressed that soil quality has a dysfunctional definition, that there are problems in the approach to quantification of soil quality.

Letey *et al.* (Letey et al. 2003) agreed with Sojka and Upchurch (Sojka and Upchurch 1999)who stated there is a failure of soil quality to integrate simultaneous soil functions which often require contradictory soil properties and management, for example high levels of mineralisable nitrogen/ low levels of nitrate nitrogen and levels of available nitrogen to crops (Karlen et al. 1997b).

Sojka *et al.* (Sojka et al. 2003) expresses many of the concerns in earlier literature including those about the elusiveness and value-laden nature of the soil quality definition. The work reiterates concerns expressed by earlier studies into the often multiple functions of soils that occur simultaneously and that development of soil quality assessment has diverted research and management away from developing improved management to solve problems.

There have been issues defining the boundaries of assessment when evaluating soil quality. Rather than focusing on ability to carry out specific functions increasingly issues such as the environmental cost of agricultural production and the potential for reclamation of degraded soils is considered when discussing soil quality (Singer and Ewing 2000).

**Soil Functions**

As described by critics of soil quality, soil can have multiple functions. Sojka and Upchurch (Sojka and Upchurch 1999) describe how soil performs several functions simultaneously not several functions separately.  Letey *et al.* (Letey et al. 2003) described how soil may perform well for one function and badly for another function that is occurring simultaneously. Letey *et al.* (Letey et al. 2003) describes how Karlen (Karlen et al. 1997a) acknowledged problems with assessing soils multiple functions when reviewing Doran and Werner (Doran and Werner 1990) where the soil management was affecting the rating and performance of two functions.

There is considerable overlap in the functions of soil as expressed in the literature, though expressed in different wording the soil functions expressed by different sources cover the same areas:

- Maintains biological activity and productivity (Doran and Parkin 1994; Karlen et al. 1997b), serves as a medium for plant/food/fibre growth (European Commission (EC) 2006b; Larson and Pierce 1991; Loveland and Thompson 2002), supports plant productivity/yield (Karlen et al. 1997b), supports human/animal health (Doran and Parkin 1994; Karlen et al. 1997b);
- Acts as a biodiversity and gene pool (European Commission (EC) 2006b; Lal 1997; Lal 1998; Montanarella 2008)
- partitions and regulates water/solute flow through the environment (Karlen et al. 1997a; Larson and Pierce 1991);
- serves as an environmental buffer or filter (European Commission (EC) 2006b; Larson and Pierce 1991; Loveland and Thompson 2002), maintains environmental quality (Doran and Parkin 1994; Karlen et al. 1997a)(Karlen et al. 1997a){{181 Karlen, D.L. 1997}}(Karlen et al. 1997a);
- cycles nutrients, water, energy and other elements through the biosphere (Karlen et al. 1997a);
- supports socioeconomic structure, cultural and aesthetic values, (Lal 1998) and a platform for human activities and landscape (European Commission (EC) 2006b; Sombroek and Sims 1995)(Sombroek and Sims 1995){{231 Sombroek, W.G. 1995}}(Sombroek and Sims 1995);
- an archive of heritage (European Commission (EC) 2006b; Lal 1998; Sombroek and Sims 1995).

Lal (Lal 2007) reviewed the scientific literature and classified soil function research into the themes of food security, bio fuels production, waste disposal, carbon, farming, and water resources.

The soil functions that have been suggested in the literature generally fit in with the definition of ecosystem services, the benefits that human beings gain from natural ecosystems as defined by Daily (Daily 2000). Ecosystem services can be categorised as the production of goods, regeneration processes, stabilizing processes, life fulfilling processes, and preservation of options (Daily 2000).

Soil quality has connections to other environmental mediums, and the biological systems that are supported by the soil. The interconnections can be described as direct or indirect, as detailed in Figure 1.

**Figure 1 Connections between soil health and the environmental and biological systems supported by soil. Direct (1a-1d) and Indirect (2a-4a) quality and health connections of soil to air, water, plants, animals, and people (after, Harris et al., 1996).**

The ecological risk assessment process (also referred to as environmental risk assessment) evaluates the potential significance of impacts in regard to likely effects upon ecological receptors as the result of exposure to a stressor (Hope 2006; Suter 2007). Ecological risk assessment includes evaluation of ecological aspects for each soil use to formulate soil screening values based upon soil use (European Chemicals Bureau 2002; Quercia et al. 2002).

Toxicity of contaminated soils has become a major focus in ecological risk assessment, and can be used to set generic or site-specific soil quality guidelines and for guiding on-site contamination mapping and remediation (Burns et al. 1996; Suter 2000). Toxicity data informing ecological risk assessment can be comprised of single-chemical or single material data; ambient media toxicity, site-specific insitu or laboratory toxicity tests of contaminated media; or biological survey, site specific sampling or observations of organisms, populations or communities in contaminated areas(Suter 2000). Increasingly use of single bioassays have been found not to provide a full enough picture of the quality of the environment, therefore battery tests of a number of bioassays of different animal and plant species from different trophic levels have been used to reduce uncertainty(Bierkens et al. 1998; Juvonen et al. 2000). Although bioassays have been used extensively in assessing the effects of contaminants in soil, use in assessment of other aspects of soil quality have been limited (Schloter et al. 2003; Seybold et al. 1998). It has been suggested that bio assays should not be used as the only measure of soil quality. The response of a bioasay is a function of many confounding non-soil factors in addition to soil quality. Soil sustainability and the effects of management should be determined by measuring soil properties and processes directly (Burger 1996; Seybold et al. 1998).

## Soil Quality Indicators

Soils have chemical, biological and physical properties that interact in a complex way to give soil its capacity to function (Seybold et al. 1998). Owing to the wide scope of functions encompassed in the definition of soil quality, it is not possible to directly assess soil quality (Burger and Kelting 1999; Ditzler and Tugel 2002; Doran and Parkin 1994). Existing methods have first identified the functions of interest and selected indicators to observe and measure, inferring the ability of the soil to perform that function (Ditzler and Tugel 2002). The use of indicators of soil quality has been discussed widely in the literature and minimum data sets suggested in a number of studies (Arshad and Cohen 1992; Bouma 1989; Doran and Parkin 1994; Larson and Pierce 1991).

Common to the minimum data sets of soil quality indicators suggested in the literature is that they include a combination of physical, chemical and biological soil properties. This suggests that for a soil to function effectively all three factors must be addressed, as illustrated in Figure 2 (Ditzler and Tugel 2002; Stenberg 1998). These classes of properties match the physical, chemical and biological soil degradative processes, mechanisms that set in motion the degradative trends (Lal 1997). Typically soil assessment has looked at chemical properties, measured using chemical indicators, or has looked at properties and indicators specific only to the function of interest.  Holistic soil quality attempts to integrate the three types of soil properties (Karlen et al. 2003). There is rarely an exact match between function and indicator, with a function often supported by a number of soil properties and a soil property or process being relevant to several soil attributes or functions simultaneously (Schoenholtz et al. 2000). Correspondingly categories of soil properties (chemical, biological, physical) do not exactly align with the soil functions. The complex interactions between soil properties, indicators, and soil functions require that for assessment of soil quality integration of soil properties into the soil property categories is necessary.

**Figure 2 Relationship between soil quality factors, soil quality and environmental quality (after Andrews et al., 2002).**

Burger and Kelting (Burger and Kelting 1999) suggested that good indicators should have the following features:

- possess an available baseline against which to compare change;
- provide a sensitive and timely measure of a soil's ability to function;
- be applicable over large areas but specific enough to be sensitive;
- be capable of providing a continuous assessment;
- be inexpensive, easy to use, collect, and calculate;
- discriminate between natural changes and those induced by management;
- be highly correlated to long-term response; and
- be responsive to corrective measures.

The increase in the value of basic data by using it to estimate more expensive and laborious to obtain data were named by Bouma (Bouma 1989) as pedotransfer functions (PTFs) and defined as translating data we have into what we need. Computer programs such as Soilpar (Acutis and Donatelli 2003) and Rosetta (Schaap et al. 2001) were developed to estimate the soil hydraulic properties from surrogate soil data such as soil texture, bulk density, organic carbon, soil pH, and cation exchange capacity. Pedotransfer functions were the basis for the development of soil interference systems (SINFERS) that take measurements known with a level of certainty and infer data that is not known with minimal inaccuracy using logically linked predictive functions (pedotransfer functions) (McBratney et al. 2002).

## Risk Based Approach to Soil Quality

Regulatory bodies are increasingly using risk based approaches to environmental decision making (Pollard et al. 2002).  Such risk based decision making does, to some extent, include soil quality, however this is predominantly in the assessment and management of soil contamination, just one part of soil quality. Although use of risk based methods have not been extensively used to assess other aspects of soil quality, the methods and decision making processes have potential for wider application in soil quality assessment.

In such current soil contamination risk based assessment the effect of contaminants on humans and ecosystems is investigated, rather than using the total contaminant concentration in the soil (Madejón et al. 2006). The source- pathway- receptor pollutant linkage is used in environmental risk assessment and used extensively in the assessment of risks from contaminated land (Nathanail and Bardos 2004). In assessment of risk from contaminated land a potential for risk exists if there is a source of contaminants, a receptor sensitive to the contaminant at the level of exposure present, and a pathway linking the two. A potential risk is said to exist, only if all three (source, pathway and receptor) elements are present (Hardisty and Özdemiroǧlu 2005).

Definition of a soil's quality in terms of the source- pathway- receptor linkage allows potential for assessment in terms of the risk posed to or from soil to other environmental mediums, and allows the inclusion of soils often multiple functions. Although a function of soil is to act as an environmental filter (European Commission (EC) 2006b; Larson and Pierce 1991; Loveland and Thompson 2002) soil has the ability to act as a source, a pathway and a receptor to contaminants. All three aspects being affected by indicators of properties regularly used to determine soil quality, the linkage, processes and properties are detailed in table 4.

**Table 4 Interaction between risk linkage, soil process, and soil properties**

A contaminant is a substance that is not naturally present in the environment or is present in concentrations with the potential to adversely alter an environment (Saunier and Meganck 2009). Soil can act as a primary source of contamination, that is a direct flux, or a secondary source by the release of contaminants that have previously affected the soil. The potential of soil to act as a source is highly variable due to the heterogeneous nature of the soil both with regard to controlling soil properties but also the chemicals present and their concentration. The nature of soils being dynamic means that there is a flux of chemicals across soil depths (i.e. movement from topsoil to sub soil and the opposite) and spatially. There are constant changes in the soil state due to natural leaching processes and interactions/ fluxes between soil water, soil gas and the organic and mineral components of soil.

Soils functioning as a source can occur when water travels through the soil matrix, combined with carbon dioxide to form a weak carbonic acid, acting as a pathway. As the weak carbonic acid moves through soil, small amounts of naturally occurring minerals and man-made chemicals held within the soil matrix are dissolved and held in solution, a process known as leaching (Neung-Hwan and Richter 2004). Potential receptors can include ground and surface waters, drinking water, humans, animals, services, industrial processes, and household appliances. Calcium and magnesium leached from the soil is a cause of "hard water" making soaps and detergents less effective and effecting water-using appliances (Boyd 2000). In small doses fluoride, iron, and copper can be beneficial to human health but in larger doses can be harmful (Bogden and Klevay 2000). Elements such as lead, arsenic, and mercury are of concern to human health (Alloway 1994). Although carbonic acid is the main leaching agent in natural systems leaching is dependent on the type, quantity and characteristics of the leaching agent; there are many natural and anthropogenic lixiviation agents including sulphuric acid, and humic or fulvic acids (Johnson et al. 1979). Alternative leaching agents have been researched extensively in the remediation of contaminated soils (Dirilgen et al. 2010; Johnson et al. 1979). Common soil properties that determine the rate and quantity that material is leached from soils include the cation exchange capacity (C.E.C.), crop/ plant cover, soil texture, soil permeability, soil organic matter, soil pH. Leaching is also dependent on climatic factors such as temperature and precipitation. Due to the number of controlling factors and the large variability in these properties soils have a resultant highly variable susceptibility to leaching,

In addition, soil can act as a source of contaminants through pathways such as the ingestion of plant or animal products that have assimilated contaminants from the soil, with humans or animal health as receptors (Collins et al. 2006; Earl and Kearney 2000; Michaud et al. 1991; Sjöström et al. 2008). Soil properties which affect the bioavailability of contaminants include soil pH, soil texture, soil C.E.C., soil organic matter, porosity, bulk density, water content, hydraulic conductivity, and soil temperature (Chiou et al. 2001; Hung and Mackay 1997; Massas et al. 2002; Ryan et al. 1988; Topp et al. 1986; Trapp and Matthies 1995; Travis and Arms 1988). Plants can modify the rhizophere by production of organic acids and therefore may exclude or accumulate contaminants selectively (Glick 2004).

There is also potential for the ingestion of contaminated soil directly by humans (especially children) and animals (Beyer and Connor, E. E. Gerould, S. 1994; Calabrese et al. 1997). In this case the soil would be a source and a pathway to the receptor. In this case a physiologically based extraction test (PBET) can relate bioavailability to soil properties such as pH, C.E.C., Fe- and Mn-oxide content, particle size distribution, and total organic and inorganic C, water content, bulk density, porosity (Stewart et al. 2003a; Stewart et al. 2003b; Thompson et al. 1992). The atmosphere can act as a pathway of contaminants from a soil source where there is a vapour transfer of contaminants to a receptor of humans, animals or buildings (Cowherd et al. 1985; Jury et al. 1990; Little et al. 1992).  Soil vapour transfer is influenced by climatic and meteorological factors as well as soil properties of total porosity unsaturated zone, water filled porosity unsaturated zone, organic carbon fraction, soil dry bulk density, soil permeability, moisture content, soil texture as well as soil temperature (Evans et al. 2001; Fischer et al. 1996). Besides vapour transfer of contaminants other soil to atmosphere transfers exist such as radon. Radon-222 is a natural radioactive gas that is produced from the decay of radium ($^{226}$Ra), itself produced from the decay of uranium, found naturally in small, but hererogenous, quantities in all soils and rock (Appleton 2007).  Exposure to radon indoors is the largest contributor to radiation exposure  and has been linked to lung cancer (Darby et al. 1998; Miles and Appleton 2005). Soil gas has been identified as the main source of indoor radon (Nazaroff and Sextro 1989). Radon potential is the result of a combination of the properties of the soil, and the underlying geology such as the radium concentration and its distribution in the soil, the soil porosity, permeability, moisture content and also meteorological variables (Winkler et al. 2001).

Soil, as mentioned above, has the potential to act as a pathway. An example of this is the creation of soil particulate matter by the process of wind erosion (Cave et al. 2009; Macleod et al. 2006). The particulate matter can carry contaminants to receptors such as humans or other organisms. Soil properties affecting wind erosion include soil erodible fraction, soil crust, soil roughness, soil texture, and bulk density, plant factors that can affect wind erosion include growing crops and flat and standing residues in addition to climatic factors (Fryrear et al. 1998; Fryrear et al. 2000). Another example is the soil migration, plant uptake and volatilisation of radio-selenium material through from contaminated groundwater, dependent on the soil redox status (Ashworth and Shaw 2006).

Soils can also be a receptor, especially when they are perceived as a product, or a media that needs to be protected from pollution. Sources of soil contamination are diverse and can be defined as point source or non point source (Rawlins et al. 2005). Point sources are those where the source of pollution is clearly identifiable and can be traced back to the specific source such as leakages from underground storage tanks (Naidu et al. 2006a). Point source pollution is typically associated with acute pollution incidents and the assessment of this falls under the remit of traditional contaminated land investigation. With an increase in environmental legislation and environmental awareness since the 1970s and 1980s point source pollution has come under increasingly strict control. There has consequently been an increasing emphasis on non point source pollution. The historic definition of soil quality has related to non-point or diffuse pollution and its effects on the ability of soil to function. The effects of anthropogenic contamination can be assessed through monitoring of soil quality indicators over time. Non point source pollution of soils is where there is no obvious single point source of discharge and the contamination is widespread in nature (Naidu et al. 2006b). This type of contamination, when compared to point source contamination, can typically be described as chronic pollution and can be associated with a decline in soil quality. Non point contamination sources that have the potential to effect upon soils ability to function can include aerial transport and deposition of contaminants from a number of anthropogenic activities such as transport and heavy industry (Facchinelli et al. 2001) fertiliser and pesticide application (Mostaghimi et al. 2001; Torbert et al. 2002), and use of soil amendments (Voulvoulis and Lester 2006). The susceptibility of soils to act as a receptor to contaminants depends not only on the presence of point or diffuse sources of pollution and the concentration of contaminants but on a number of soil properties and other factors. Susceptibility of soils to act as a receptor can be defined as the potential of soils to be effected by contaminants, this either by limiting build up of contaminants, by buffering contaminants, or degrading them (Glazovskaya 1990; Karlen et al. 2001).

## Discussion

The range of definitions of soil quality has developed since its initial inception by Alexander (Alexander 1971), notably by the inclusion of consideration of the soil function. Since the initial activity however, development has slowed and there have been a number of challenges to the definition of soil quality. Recent concerns are due to the failure of soil quality assessment to integrate simultaneous soil functions which often require contradictory soil properties and management (Letey et al. 2003; Sojka and Upchurch 1999; Sojka et al. 2003).

Soil quality should not be defined solely by the ability of soils to perform a single function (Sojka and Upchurch 1999). It should include the potential to perform the multiple functions that are desired of it, by humans, ecosystems and to be able to successfully provide ecosystem services. It should also encompass that the soil can act as a source or pathway to other environmental media or soil functions.

Such a multiple functional soil quality definition takes into account the growing need for assessment of soil quality to incorporate the multiple and possibly conflicting functions of soils (Letey et al. 2003). Therefore soil quality assessment should be improved to meet changes in attitudes to soil and the environment being more than just a resource.

Soil quality assessment, taking into account the multiple functions that soil provides, normally utilises a selection of indicators specific to the soil functions of interest (Ditzler and Tugel 2002). To that extent, dynamic indicator systems, whether selected using expert opinion or other methods such as principal component analysis, can create a good data set for assessment of soil quality. However even then, such methods cannot effectively compare soil quality between different soils of different functions. In addition, they often require indicators which are expensive and difficult or laborious to collect data for. Although there may be conflicting functions that soil is required to carry out, there is a notion that this does not happen in many circumstances and that simultaneity of soils functions can take place. While soils function may determine ideal values for soil properties, there is overlap between the soil properties necessary for the assessment of the ability to carry out a specific function and these properties can be included in a minimum dataset.

Following a risk based approach such methods could be used initially to rank sites according to a specified soil function, but could not allow for the identification and prioritisation of areas for further investigation required for cross functional improvements. To improve such a screening step, cross functional indicators could be developed to enable ranking and prioritisation across different soil functions to inform further detailed investigation and risk assessment. The use of soil indicators in soil protection and soil quality assessment in legal frameworks is currently limited across Europe. The European environment agency has mapped soil quality of some southern European states, using indices based on soil parent material, soil depth, soil texture and the slope of the land surface. The indicator system appears to focus on desertification, where the soil has lost part of its capability to support human communities and ecosystems (European Environment Agency 2009). The UK Environment Agency undertook research into soil quality indicators, and suggested using total above-ground biomass production, total below-ground soil organic carbon, topsoil pH, buffering capacity, keystone species, soil microbial diversity, soil surface condition, extent and depth of ploughing, area of land taken for mineral workings (Loveland and Thompson 2002; Merrington et al. 2006). In a review of this work in 2006, the minimum data set was revised to soil organic carbon, total nitrogen, Olsen P, available and total copper (Cu), nickel (Ni) and zinc (Zn), bulk density, and pH. This minimum dataset has a bias toward soils chemical factors.

The cross functional indicators should collect information on soils chemical, physical and biological properties and the associated factors that determine soils quality. Specific indicators used would depend on the method of data collection, sampling strategy, available resources, desired decision making output, and scale of application. Assessment must take place if a desired level of data quality will be met for indicators selected to allow adequate evaluation of the soil quality. However independent of factors controlling the amount of information collected there is a minimum dataset that will be required for assessment of soil quality. The minimum dataset is likely to include pH, soil texture, organic carbon, infiltration rate, root presence, plant cover, soil odour, soil organism presence and diversity, soil colour, evidence of anthropogenic disruption (i.e. presence of construction material, coal/ soot) and penetrability. In addition important information about landuse and habitat will provide useful information. This information will likely provide more useful information when investigated spatially and not necessarily at a site specific level. The scale at which these indicators would be applied depends on the spatial variation of soil properties, and research into this should be undertaken in the design stage of the system. Such method should be built upon significant experience of the use of screening tools in environmental and other applications.

Detailed environmental assessment is often informed by the use of screening tools. Screening tools are generally designed to gather a large amount of information quickly and at a low cost. Screening tools are used extensively in many areas including healthcare, product development, international development, and environmental quality (Calantone et al. 1999; Department for International Development (DFID) 2003; Elmore et al. 2005). Screening tools used in the environment include flood risk (Department of Communities and Local Government (DCLG) 2006), site prioritisation and regulation (Environment Agency 2009), contaminated land (Environmental Protection Agency 1996; Pollard et al. 2004), air quality (Department of the Environment (DoE) 1997) , water quality (Alvarez-Guerra et al. 2009), environmental fate (Duarte-Davidson and Jones 1996; Wilson et al. 1996)and chemical risk (Pan et al. 2009). Similarly, the development of a ranking and prioritisation method for soil quality assessment has the potential to help toward implementing current and future soil regulation, for example the soil thematic strategy (European Commission (EC) 2006b) and the likely requirements of the SFD (European Commission (EC) 2006c; Van-Camp et al. 2004). The development of cross functional soil indicators could facilitate direct comparison of soils and as such allow prioritisation of soils flagged for further attention. Such indicators should be standard for every soil assessed, allowing expert knowledge of the methodologies by personnel carrying out multiple assessments with a resulting decreased level of error. The output of such assessment should still provide all the information incorporated and not just be a single index figure of soil quality. It should aim to provide evidence collated into a number of indices; that could be used by specialists to inform further decision making.

The selection of cross functional soil indicators, development of their indices and methods for interpreting them are all very challenging tasks.  The use of Pedotransfer functions as predictive functions of certain soil properties when determining soil quality indicators could support efficient assessment of soil quality (Bouma 1989; Jana et al. 2007). For example, soil name, topsoil textural class, land use, and mean temperature are often used to facilitate the estimation of the topsoil organic carbon (Daroussin and King 1999). A compiled cross functional soil indicator dataset could also be complemented by data from other sources to make estimates of other soil properties. Use of soil inference systems can be used to make estimates of expensive, difficult to obtain or unavailable indicators from the less expensive and easier to obtain broad soil indicators (McBratney et al. 2002).

In addition, previous soil quality assessment methodologies have not assessed soil organisms in the same detail as soil physical and chemical properties. The presence and types of soil organisms can facilitate cross functional screening indicators and their use has great potential in soil quality assessment and remediation (Héry et al. 2008; Singer et al. 2001). Such as approach is in accordance with other environmental quality assessments that incorporate ecological risk in their frameworks (Ashton et al. 2008).

The system of prioritisation of soils using measurement of cross functional indicators suggested in this paper does not aim to replace current methodologies that are required for risk assessment. It is not an alternative to the Triad approach that requires the simultaneous and integrated deployment of chemical, toxicological and ecological lines of evidence for risk assessment (Chapman 1986; Rutgers et al. 2001). On the contrary, the results of this screening step aim to support the weight of evidence approach (Burton et al. 2002; Chapman et al. 2002; Interdepartmental Group on Health Risks from Chemicals 2002) by identifying areas of concern, focusing risk assessment investigations to reach a conclusion about an environmental system or stressor.

Such a screening option has also the potential to facilitate long term soil quality monitoring programmes. Although soil surveys have been carried out, these generally are not repeated in time and therefore qualify as inventories rather than monitoring programs (Department for Food and Rural Affairs (DEFRA). 2003). Monitoring programs currently generally rely on repeat visits to a number of preselected sites e.g. Countryside Survey (Carey et al. 2008) and the

Environmental Change Network (Environmental Change Network 2009). Existing monitoring and inventory programs, especially those carried out before 1990, have largely omitted urban soils due to the emphasis of the programs use on mineral extraction, wanting to exclude anthropogenic pollution (Johnson and Ander 2008). There are also issues with difficulty of accessing sites, and the heterogeneity of the urban environment. A prioritisation method that repeats surveys over time has the potential to be used to monitor soils and to provide data for areas where lacking from other programs, however will not replace existing monitoring programs. Such methods have the potential to fill in gaps in existing monitoring regimes and inform the need for further function specific assessment, potentially providing useful information to meet current and future regulations relating to soil and their protection. Methodologies to assess the impacts of land management practices and pollution on soil need to be developed, with this leading to practices preventing and managing degradation of soils. Broad cross functional indicators might be more appropriate for such use.

Soils do not have a static state and properties can vary significantly both spatially over small distances, and over time. Due to the dynamic state of the system a single measurement in space or time can be problematic in evaluation. There is a need to assess the dynamics of soil quality associated with varying soil properties and intrinsic cycles and trends associated with the spatial and temporal variability of soil properties and soil quality, which can be evaluated using methods such as control charts (Larson and Peirce 1994). There is a need to relate clearly how the dynamic state of soils influences its ability to function, and ultimately the soil quality. Use of suggested cross functional soil quality indicators could allow repeat measurements can be affordably collected. Collection of repeat indicator measurements can allow determination of how spatial and temporal variability of soil properties can influence soil quality. It is with this knowledge that it can be adequately determined if soil quality is changing due to natural variation or is in fact subject to decline.

Screening methodologies could be developed with the potential to act as the basis for collection of soil characteristics by non specialists, allowing for even more cost effective, relatively quick, easy screening of soil characteristics. Use of a larger group of personnel makes regular repeated measurements of soils more feasible than solely using experts; however it would require considerable organisation and commitment from participants to provide more than just one off data. This could however be accomplished using keen specialist groups.

In general, based on the review undertaken in this work, further research is required to develop an effective methodology/ framework for soil quality assessment under emerging regulatory requirements. As discussed, research is needed to better establish the spatial and temporal variation in soil properties this allowing the scale of application of soil quality assessment methods to be determined. There is a clear need to establish the relationship between soil organisms, soil properties and soil quality; this has the potential benefit of identifying organisms/ species that can be used as holistic bioindicators of soil quality or of more specific threats for example soil contamination. There is an ongoing need to establish linkages between soil indicators, effectively allowing further development of pedotransfer functions allowing the most resource efficient establishment of soil properties. Development of a method for assessment of the collected information needs to build upon the significant application of environmental risk assessment and screening decision making; research will need to draw upon expert knowledge of the soil system and interactions between the biological, chemical and physical factors. Methodology development will need considerable calibration with existing datasets and field testing in a range of situations from severely degraded sites to those considered pristine.

As well as soil regulation, screening and prioritisation of sites could have the ability to fit well with the modern needs of environmental protection and policy, complimenting the recent move to a holistic approach to environmental appraisal.

## Conclusion

There are a number of new and emerging regulations which aim to protect soils and prevent soil degradation. Soil degradation is often seen as closely related to, and effecting, soil quality. In order to protect soils from a decline in soil quality and ultimately from soil degradation it was necessary to improve the understanding of the terms soil and soil quality and to review how soil quality is assessed.

This paper has reflected that assessment of soil quality that has integrated soils function has not achieved consensus in the scientific community. Assessment of soil quality with respect to its function can rely on expensive and time consuming methods. The use of different indicators chosen dependent on the soil function is potentially challenging with regard to comparison of quality between soils with different functions. A method to evaluate and prioritise further investigation and risk assessment could be developed that uses cross functional indicators. Use of cross functional indicators could prove a more effective method to assess soils ability to meet the multiple and often conflicting requirements of it. The use of indicators in this way should significantly contribute to the knowledge based approach to soil monitoring and inform soil protection and sustainable use.

A standardised methodology for the assessment and comparison of many soils with different and multiple soil functions requires the development of set of a broad soil indicators. Indicators that are selected for inclusion in a site identification and prioritisation method should be cross-functional, that is applicable to many soil functions. Soil quality indicators currently in use in existing soil quality assessment tools and monitoring programmes should be assessed for their ability to act as cross-functional indicators and inclusion in Pedotransfer functions.

The use of screening methods using broad soil indicators that do not rely upon specific soil functions has the ability to fit well with the modern needs of monitoring within soil regulation, as well as general environmental protection and policy. It has the potential to provide information to assist in compliance with legislation requiring monitoring or identification of geographical risk/priority areas such as the proposed EU Soil Framework Directive and the EU Soil Thematic Strategy. Such methods could highlight areas requiring further attention and threat dependent assessment for example detailed identification of areas requiring special protection from erosion, organic matter decline, compaction, salinisation, landslides, and acidification, using indicators specific to the threat in question. There have been problems reaching agreement on the content of the proposed Soil Framework Directive partly because of the different methods used in European member states and the requirement to identify risk/priority areas requiring special protection from erosion, organic matter decline, compaction, salinisation, landslides and acidification. A systematic approach to identification of areas of concern could help with this requirement and allow progress to be made on development of the directive.

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**Table 1** **Definitions of soil in legislation and literature**

| Soil Definition | Jurisdiction | Reference |
|---|---|---|
| The upper layer of the earth's crust, as far as this layer fulfils the soil functions, and including its liquid components (soil solution) and gaseous components (soil air), except groundwater and beds of bodies of water | Germany | Federal Ministry for the Environment Nature Conservation and Nuclear Safety 1998 |
| The solid part of the earth including liquid and gaseous compounds and organisms therein | Netherlands | VROM (The Netherlands Ministry of Housing, Physical Planning and the Environment) 1986 |
| Soil is the zone where plants take root, the foundation for terrestrial life and the basis for a large amount of economic production and varies in depth from a few centimetres to several meters | UK | Environment Agency 2004 |
| Solid part of the earth, including the groundwater and the other components and organisms that are present in it | Belgium – Flanders | Public Waste Agency of Flanders (OVAM) 2007 |
| Soil is generally defined as the top layer of the earth's crust, formed by mineral particles, organic matter, water, air and living organisms | EU | European Commission (EC) 2006b |
| The top layer of the Earth's crust situated between the bedrock and the surface. The soil is composed of mineral particles, organic matter, water, air and living organisms | EU | Council of the European Union 2009 |
| (i)The unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.<br>(ii)The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics | N/A | Soil Science Glossary Terms Committee 2008 |
| (i)A dynamic natural body composed of mineral and organic solids, gases, liquids, and living organisms<br>(ii)The collection of natural bodies occupying parts of the Earth's surface that is capable of supporting plant growth and that has properties resulting from the integrated effects of climate and living organisms acting upon parent material, as conditioned by topography, over periods of time | N/A | Brady and Weil 2008 |

**Table 2 Examples of main contaminated land legislation in EU member states**

| State | Act | Reference |
|---|---|---|
| Belgium – Franders | Soil Remediation Decree, 2006 | Public Waste Agency of Flanders (OVAM) 2007 |
| Belgium-Brussels | Ordonnance du 5 mars 2009 relative à la gestion et à l'assainissement des sols pollués | Brussels Ministre de l'Environnement 2009 |
| Belgium-Walloon | Décret du 5 décembre 2008 relatif à la gestion des sols | Gouvernements de communaute et de region-Region Wallonne 2009 |
| Germany | Federal Soil Protection Law, 1998 | Federal Ministry for the Environment Nature Conservation and Nuclear Safety 1998 |
| Italy | Ministerial Decree 471 on the remediation of polluted sites, 1999 | Governo Italiano 1999 |
| Netherlands | Soil Protection Act, 1987 (Amended 2008) | VROM (The Netherlands Ministry of Housing, Physical Planning and the Environment) 1986 |
| Spain | Royal Decree on contaminated soils, 2005 | Spanish Central Government 2005 |
| Sweden | Environmental Code, 1999 | Swedish Ministry of the Environment 1999 |
| UK- England | Contaminated Land (England) Regulations 2006 | UK Government 2006 |
| UK- N. Ireland | The Waste and Contaminated Land (1997 Order) (Commencement No. 6) Order (Northern Ireland) 2002 | Northern Ireland Executive 2002 |
| UK- Scotland | The Contaminated Land (Scotland) Regulations 2005 | The Scottish Government 2005 |
| UK- Wales | Contaminated Land (Wales) Regulations 2006 | National Assembly for Wales 2006 |

**Table 3 Development of the definition of soil quality**

| Soil Quality Definition | Year | Reference |
|---|---|---|
| The sustained capability of a soil to accept, store and recycle water, nutrients and energy | 1984 | Anderson and Gregorich 1984 |
| The state of existence of soil relative to a standard, or in terms of a degree of excellence | 1991 | Larson and Pierce 1991 |
| The capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental | 1994 | Doran and Parkin 1994 |

| | | |
|---|---|---|
| quality, and promote plant and animal health | | |
| Ability of soil to perform or function according to its potential, and changes over time due to human use and management or to unusual events. | 1995 | Mausbach and Tugel 1995 |
| The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation | 1997 | Karlen et al. 1997a |
| Encompassing an indefinite (open) set of tangible or dispositional attributes of the soil. These attributes may be substituted for or supplemented by other attributes without needing to change the term. Therefore it is a vessel to contain what is assigned to it. The attributes assigned to the term will differ among soil and the various demands, because the term is influences by value judgements | 2000 | Patzel et al. 2000 |

**Table 4 Interaction between risk linkage, soil process, and soil properties**

| Linkage | Process | Soil Properties |
|---|---|---|
| Source | Leaching | Cation exchange capacity, crop/ plant cover, soil texture, soil permeability, soil organic matter, soil pH |
| | Ingestion of plant of animal products | pH, soil texture, cation exchange capacity, soil organic matter, porosity, bulk density, water content, hydraulic conductivity, soil temperature |
| | Direct ingestion | pH, cation exchange capacity, Fe- and Mn oxide content, particle size distribution, total organic and inorganic carbon, water content, bulk density, porosity |
| | Vapour transfer | Total porosity of the unsaturated zone, water filled porosity unsaturated zone, organic carbon fraction, soil dry bulk density, soil permeability, moisture content, soil texture, soil temperature |
| | Radon Exposure | Radium concentration and its distribution in the soil, soil porosity, permeability, moisture content |
| Pathway | Wind erosion | Soil erodible fraction, soil crust, soil roughness, soil texture, bulk density, crop/ plant cover |
| | Migration, plant uptake and volatilisation of radio selenium | Soil redox status |
| Receptor | Point or diffuse source pollution (natural and anthropogenic) | Buffering capacity, soil microbes, ph and redox conditions, occurrence of carbonates, Fe- and Al- hydroxides, inorganic substances capable of chemisorptions, content and composition of orgnanic substances, clay content and mineralogy, hydrolytic acidity, cation exchange capacity, amount of exhangable bases and exchangeable Al, soil texture |

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