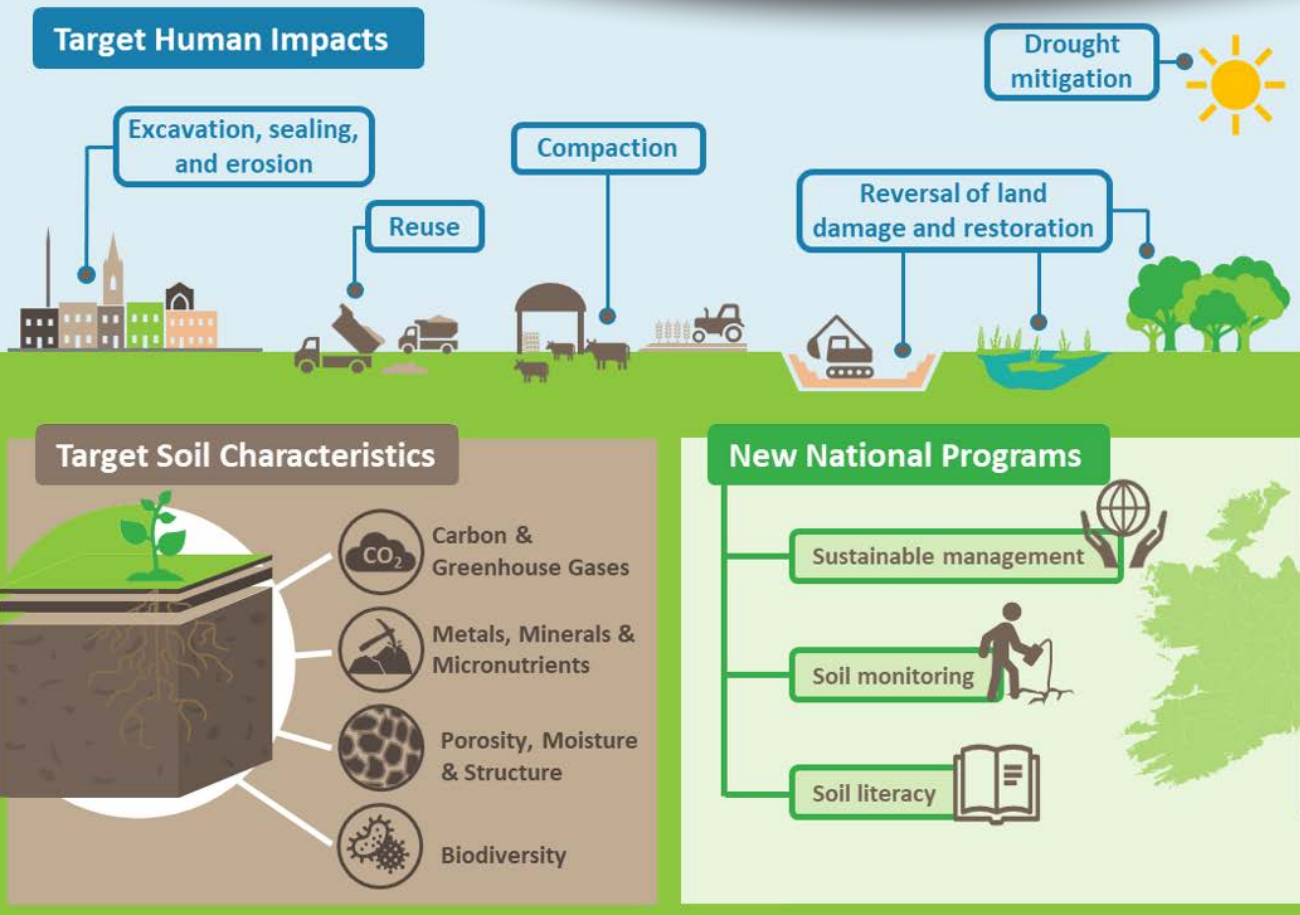
epa Research

Evidence Synthesis Report: 1

A Signpost for Soil Policy in Ireland



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Geological Survey
Suirbhéireacht Gheolaíochta
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ENVIRONMENTAL PROTECTION AGENCY

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- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2021–2030

A Signpost for Soil Policy in Ireland MUCKISOILS (Mapping Understanding and Current Knowledge of Irish Soils)

(2021-NE-1029)

EPA Research Evidence Synthesis Report

Supplementary supporting outputs such as the Soils research bibliography and Infographics referenced in this report are available on request from EPA Research (research@epa.ie)

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DISCLAIMER

This report is based on research carried out/data from November 2021 to March 2022. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Soil provides critical environmental services linked to topical themes such as climate change, carbon sequestration, productivity, pollution and remediation. Soils, however, are increasingly subject to pressures arising from changes in biomes, climate, agriculture, industrialisation and urbanisation. Given that soils are a non-renewable resource, legislative frameworks are required to ensure that they are protected. These frameworks, in turn, must be supported by a comprehensive understanding of the factors that affect soil health and quality. The recent publication of the EU Roadmap New Soil Strategy and the commitment in Ireland's Programme for Government 2020 to urgently put new national soil policy in place emphasise the immediate need to support the development of policy for soil research and protection in Ireland through the synthesis of our current knowledge of Irish soils and of how soils are affected by human activities and climate change.

This study aimed to generate an accessible evidence base to support the development of new policy on soil and to enable Ireland to meet its commitments to both national and EU soil strategies. The study reviewed Irish soil research from 2013 to the present. The literature search encompassed government reports and academic papers on soil quality, health, damage, management, remediation, biodiversity and climate change, and on soils in urban, agricultural and other settings.

The results reveal major knowledge gaps. Current research on Irish soils is biased towards those counties with permanent soil research facilities and soils in agricultural settings. Soils in other counties and settings, notably urban and mining settings, are underrepresented. As a result, current research is biased towards the collection of data on soil pH and nitrogen content. Other physical and chemical soil parameters are understudied; in particular, there is a lack of data on other major elements, metals, cation exchange capacity, structure, porosity and biodiversity. It is of **extreme concern** that no more than one-third of studies cover priority topics identified by the EU Soil Strategy for 2030 and national bodies; that is, there is a major misalignment of current research and strategic EU and national priorities. Future policy must address this issue urgently to ensure that Ireland meets its commitments under the Programme for Government 2020 and the EU Soil Strategy for 2030.

To address these issues, this study recommends that future government policy should prioritise three key areas (Figures ES.1–ES.3):

1. supporting soil research, in particular research on human impacts on soil in non-agricultural settings and soil characteristics that are understudied;
2. developing new national programmes for soil monitoring, literacy and sustainable management;
3. ensuring data quality by developing national guidance on protocols and more integrated collaboration between soil experts from different disciplines.

Future policy should also provide for schemes to access facilities and laboratory infrastructure.

Policy target	Theme	Why?
Human impacts on soil	Excavation	Better alignment with EU policy Enhanced sustainable management Fill knowledge gaps
	Sealing	
	Erosion	
	Reuse	
	Compaction	
	Reversal of land damage	
	Restoration	
	Drought mitigation	
Soil characteristics	Carbon & greenhouse gases	
	Metal, minerals & micronutrients	
	Porosity, moisture & structure	
	Biodiversity	
National programmes	Soil literacy	Broaden geographic coverage
	Soil monitoring	Less soil damage
	Sustainable management	Align with EU policy
Data quality	Quality control measures	High-quality data
	Sampling protocols	Enhance comparative power
	Multidisciplinary coordination	Big data

Figure ES.1. Summary of priority targets for future soil policy in Ireland.

Figure ES.2. Word cloud summarising the targets for future soil policy in Ireland. Font size is related to the size of the knowledge gap on a topic, e.g. there is a large knowledge gap for human impacts on soil.

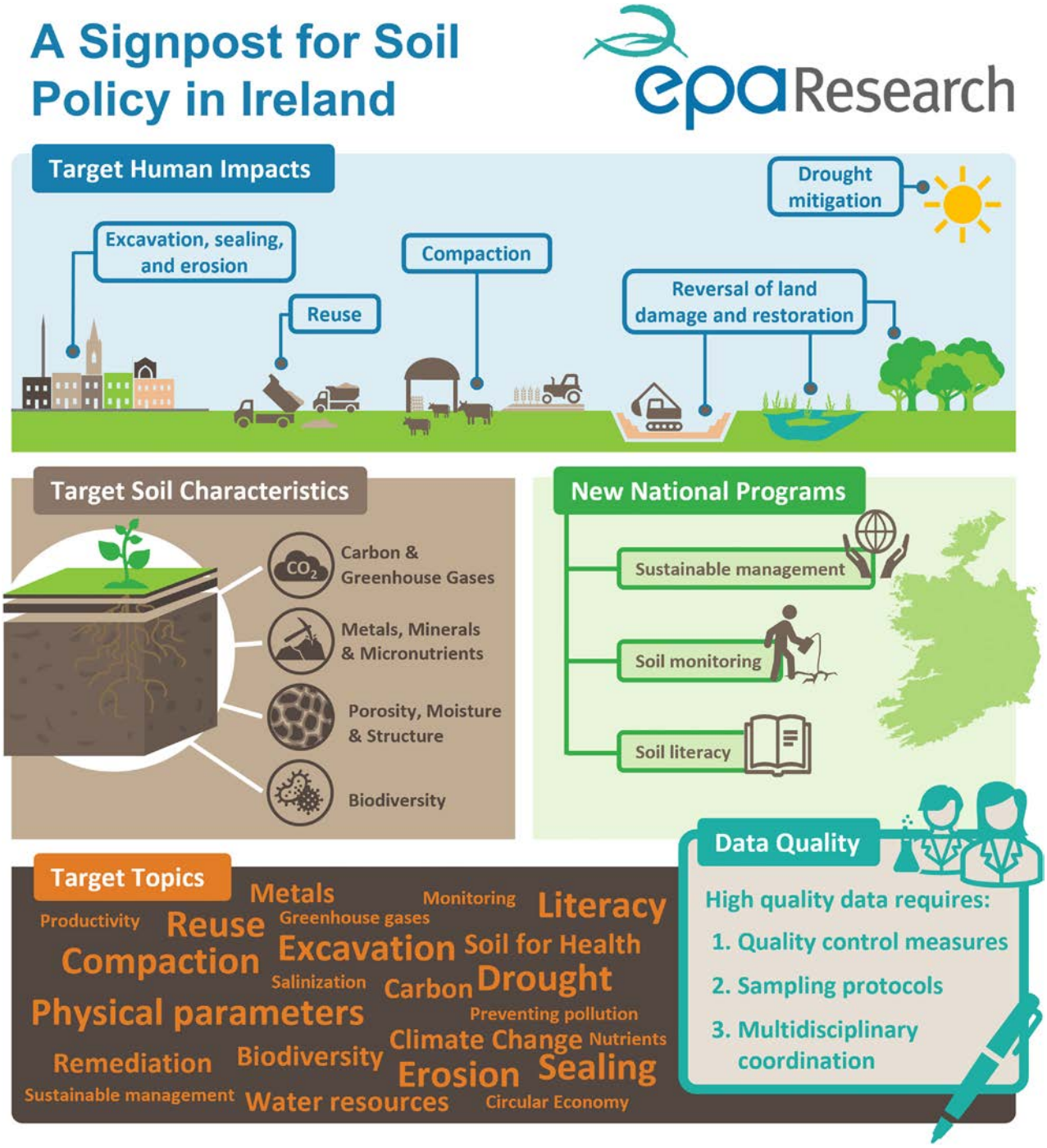

Figure ES.3. Infographic summarising the key recommendations of this report. Future soil policy should target specific human impacts on soil, plus soil characteristics and research themes that are understudied. Future policy should also provide for new national programmes to improve soil literacy and should emphasise the importance of high-quality data.

1 Introduction

1.1 Background

1.1.1 Soil functions

Soil provides critical ecosystem and environmental services (Carilli, 2014; Agrilinks, 2019; Renforth and Campbell, 2021) that maintain key components of global climate and biodiversity (Hector *et al*., 1999; Kleijn and Sutherland, 2003; Gessner *et al*., 2010; Isbell *et al*., 2011; Doula and Sarris, 2016). Soil directly impacts biomass production, habitat diversity, biodiversity and the storage of many elements (e.g. carbon, nitrogen) and substances (e.g. water, organic matter; EC, 2017). From a socioeconomic perspective, soil underpins the security of the global food chain for people and animals, the production of fibre, environments that promote health and well-being (Bevik *et al*., 2020), and a potential nature-based solution to help mitigate the impacts of flooding and climate change. Soils are central to the discussion of topical issues such as carbon sequestration, nutrient availability, pollution, remediation and equitable economic development. Soil quality (the characteristics and dynamics of soil physical properties, chemistry and biology; Wander *et al*., 2019) and soil health (the functional ability of soil to provide ecosystem services and management outcomes; Wander *et al*., 2019) should therefore be key elements of any policy framework relating to soils and soil management.

1.1.2 Soil pressures

Soil quality and health face major threats (UKSO, 2022). These include shifting biomes, changes in temperature and precipitation patterns, erosion, fertiliser application, overintensification of agriculture and contamination by metals and volatile organic compounds. As the formation of soil requires extremely long timescales (at least 30 years per 10 mm of soil; USDA, 2017), it is effectively a non-renewable resource and should be protected (EC, 2017). Current pressures on soil include inappropriate and negative land management (especially in agriculture and forestry), industrial activities, tourism and urban development. Degraded soils can exhibit high erosion rates, loss of organic matter, compaction, salinisation, landslides, contamination and/or sealing (i.e. urbanisation; EC, 2017; EPA, 2021a). Soil contamination can result from waste-related activities, historical activities and accidental spillages and leaks of chemicals (EPA, 2021a). These factors have immediate impacts on water quality, human health, climate change, biodiversity protection and food safety. Indirect impacts of soil degradation/contamination are the depreciation of land and property, increased insurance costs, the need to limit exposure by soil segregation, treatment and/or disposal, water treatment and food safety controls, and increased pressure on remaining soils (EC, 2017).

1.1.3 Soil policy

The United Nations (UN) Sustainable Development Goals (SDGs) (UN, 2020) refer repeatedly to soil composition and impacts, especially SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production) and SDG 15 (Life on Land). Specific aims are to reduce illness and death due to soil pollution (SDG 3), to reduce the release of chemicals and wastes to soil (SDG 12) and to restore and rehabilitate soil to avoid loss of fertile land (SDG 15). The UN highlighted soil degradation at the UN Conference on Sustainable Development (Rio+20) and has called for a land degradation-neutral world (UN, 2012).

Despite this awareness of the importance of soil at the global level, the *policy on soil health is much more fragmented at European and national levels*. There is *no single comprehensive set of rules or piece of legislation* relating to soils in the EU; currently, existing EU policies on agriculture, water, waste, chemicals, etc., indirectly contribute to soil protection (EC, 2021a). The recent publication of the *EU Soil Strategy for 2030: Reaping the Benefits of Health Soils for People, Food, Nature and Climate* (EC, 2021b), however, provides important signposts for improving EU soil policy, including the identification of priority themes for research and policy and a proposal for the introduction of a dedicated EU law on soil health by 2023 (Wilson, 2021). The strategy aims to achieve land degradation neutrality by monitoring soil quality, protecting soil

fertility, reducing erosion, increasing soil organic matter (SOM) content, identifying contaminated sites, restoring degraded land and defining good ecological status (EC, 2021b; ICOS, 2021). This strategy is supported by the European Commission Soil Health and Food Mission (EC, 2020) and, in coming years, will be supported by the forest monitoring legislation and the law on nature restoration that are proposed under the EU Biodiversity Strategy for 2030 (EC, 2021c) (part of the European Green Deal; EC, 2021d). These policies and incipient legislation collectively indicate an emerging awareness of the critical nature of soil as a provider of diverse environmental, ecosystem and socioeconomic services. Soils also feature heavily in the revised Common Agricultural Policy 2023–2027 (EC, 2022), especially the role of soils in carbon sequestration and reducing greenhouse gas emissions. Policies that promote soil protection and enhance soil health are highlighted below.

At the national level, soil has historically featured as an ad hoc element of disparate policy strands (Irish Statute Book, 2022). The development of the National Soils Strategy is a welcome commitment in the Programme for Government 2020 (Government of Ireland, 2020a) to responsibly balance the competing demands on, and functions and impacts of, soil and soil use. This strategy will provide a mechanism for responding to the EU Soil Strategy (EC, 2021b). Soils also fall under the remit of the Climate Action Plan 2021 (Government of Ireland, 2020b), with particular focus on the transformation of Irish soils from a net carbon source to a carbon sink through rehabilitation of boglands, afforestation, management of mineral soils, use of cover crops and rewetting of organic soils. Pilot programmes already under way include the Green Restoration Ireland project and the Danu Farming Group project, which aim to generate guidelines for programmes to transition to carbon farming and biological farming, respectively, using data on soil physical and chemical properties (Government of Ireland, 2020b). The 2020 Ag Climatise Roadmap (Government of Ireland, 2020c) points to the management of soil pH as a mechanism for reducing fertiliser loads, and the establishment of the National Agricultural Soil Carbon Observatory enables the quantification of soil carbon sequestration. The Environmental Protection Agency (EPA) *State of the Environment Report 2020* (EPA, 2020) and the *Climate Change and Land Use in Ireland* report (Haughey, 2018) also highlight the need for Irish soils to become net carbon sinks through transformative changes to land management practices, rehabilitation of peatlands and increased forest cover, but this requires investment and may have a negative impact on biodiversity (Haughey, 2018). The Programme for Government 2020 will enhance knowledge-sharing across government departments for land science and support decision-making on sustainable land use.

It is necessary and timely to support policy development through the synthesis of current knowledge of Irish soils in the broadest context, including soil quality, health, risks and threats, and of how Irish soils relate to topics of current intensive research, such as soil microbial communities (Doula and Sarris, 2016), biodiversity (Hector *et al*., 1999; Kleijn and Sutherland, 2003; Gessner *et al*., 2010; Isbell *et al*., 2011; Doula and Sarris, 2016) and climate change (Pascual *et al*., 2017).

2 Overview of the Research

2.1 Objectives

The overall objective of the research was to generate an accessible evidence base to support the development of relevant new policy on soil and to support Ireland to meet its commitments to national and EU soil strategies. The research included several specific aims. First, the research aimed to conduct a comprehensive overview of Irish soil research focusing on literature from 2013 to the present. The scope of the literature search encompassed key thematic areas relating to soil quality, health, damage, management, remediation, biodiversity and climate change, and to soils in urban, agricultural and other rural settings. Second, the research aimed to analyse the data from the literature review to identify key threats and risks to Irish soils, critical knowledge gaps, recommendations for soil assessment and management, and national priority areas for future research. This report thus provides a new roadmap for identifying key thematic areas for future research on Irish soils to support the development and implementation of soil policy and provide an effective government response to EU soil policy.

2.2 Methods

2.2.1 Inclusion criteria

The research used a bespoke literature search strategy. Data were included from peer-reviewed journal articles and government reports from the EPA, EPA-funded projects, Geological Survey Ireland (GSI), Teagasc, the Department of the Environment, Climate and Communications (DECC), other government bodies (including technical reviews and best practice documents) and the European Commission. Articles were identified using the title, abstract and keyword functions in the Web of Science, Scopus and PubMed databases in a search performed on 7 December 2021. The search terms related to the broad subject matter and relevant related topics.

The following search string was used: TITLE-ABS-KEY (soil) AND TITLE-ABS-KEY (Ireland OR “Republic of Ireland” OR Carlow OR Cork OR Donegal OR Dublin OR Galway OR Kerry OR Kildare OR Kilkenny OR Laois OR Leitrim OR Limerick OR Longford OR Louth OR Mayo OR Meath OR Monaghan OR Offaly OR Roscommon OR Sligo OR Tipperary OR Waterford OR Westmeath OR Wexford OR Wicklow) AND TITLE-ABS-KEY (“degradation” OR “organic carbon” OR “carbon stock*” OR “carbon loss” OR “carbon reservoir” OR “carbon sequestration” OR “carbon-rich” OR “carbon rich” OR “compaction” OR “sealing” OR “reuse” OR “remediation” OR “bioremediation” OR “restoration” OR “protection” OR “recovery” OR “erosion” OR “structure” OR “literacy” OR “biodiversity” OR “biodiversity loss” OR “biomass” OR “ecosystem” OR “salinisation” OR “salinization” OR “pollution” OR “contamination” OR “contaminant” OR “climate neutrality” OR “climate-neutral” OR “climate neutral” OR “nutrient loss” OR “climate change” OR “circular economy” OR “land take” OR “recycling” OR “land damage” OR “quality” OR “nutrient” OR “nutrient recovery” OR “sustainable soil management” OR “ssm” OR “sustainable” OR “soil management” OR “fertility” OR “resilience” OR “drought” OR “fertiliser” OR “pesticide” OR “health” OR “organic matter” OR “urban soil” OR “land use” OR “exploitation” OR “climate” OR “regulation” OR “carbon” OR “productivity” OR “wetland” OR “densification” OR “monitoring” OR “land cover” OR “human health”) AND PUBYEAR > 2012.

This search yielded 1919 records. Following removal of duplicate entries, 1189 records remained (1081 journal articles, 108 government reports) prior to the application of exclusion criteria.

2.2.2 Exclusion criteria

Initial screening was based on the content of the title and abstract. The exclusion criteria are shown in Figure 2.1. In the first instance, records were excluded based on the title and abstract (739 records excluded). If the scope of the study was not sufficiently clear from the title and abstract to allow a decision to be made, the full text was then assessed (186 records excluded). A total of 264 records remained in the dataset following application of the exclusion criteria.

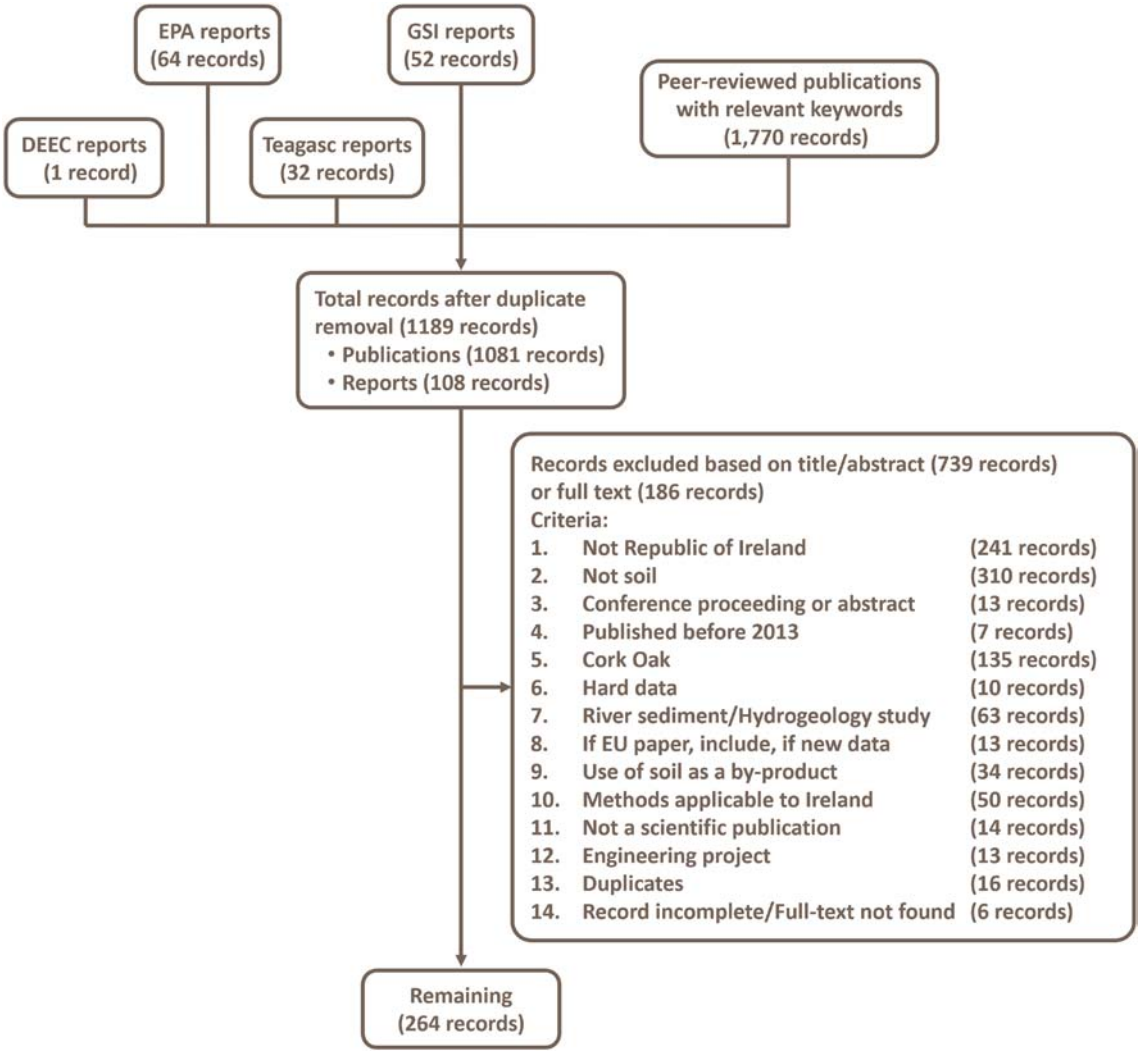

Figure 2.1. Schematic overview of the screening process applied to the literature examined for this study. Of the 1919 studies identified during the literature search, 264 remained at the end of the screening process following the removal of duplicates and records with a focus beyond the scope of the current study, e.g. those not based on Irish soils or those comprising a dataset ("hard data").

2.2.3 Data analysis

The research identified a comprehensive set of target data to mine from each publication in the dataset relating to data quality, county, setting, soil type, analyses conducted, EU Soil Strategy themes, author gender and key recommendations. These are listed in Table 2.1. Note that the analysis recorded the number (and percentage) of records corresponding to different categories under each parameter. As a single record can be associated with multiple categories (e.g. for study location or soil type), the percentage data for all records for a certain parameter may sum to greater than 100% (as a single record may, for example, refer to soils in Counties Cork, Dublin and Leitrim).

Table 2.1. Data mining strategy: type of target data assessed for each record in the dataset

Target data	Details
Basic parameters	Author; year; title; DOI; URL; journal/publication title
County	Each county
Setting	Urban; agricultural; forest; bog/peat; heath; mining; dune; upland/mountain
Soil type	Type as per record; classification scheme
Data quality	Number of sites and samples used; field duplicates; analytical replicates; use of standards; blind insertion of duplicates, replicates and standards; sampling protocol for comparability, representativeness, cross-contamination and accuracy; post-processing of analytical data to respond to quality control issues
Soil characteristics measured	pH; <2 mm fraction; soil temperature; BD; SOC; depth of SOC; SOM; LOI; TP; moisture content; GHG emissions; concentrations of carbon, nitrogen, phosphorus and potassium; soil minerals/micronutrients; CEC; XRF; ICPMS/ICPAES/ICPOES; use or inclusion of pre-existing data; use of simulations, models or mapping of soil data
National themes of concern	Reducing erosion; carbon loss; compaction; soil structure; soil literacy; biodiversity loss; salinisation; excavated soil; soil quality/health
Preventing soil and land degradation and restoring healthy soils[a]	Sustainable soil management; preventing desertification; preventing soil pollution; restoring degraded soils and remediating contaminated sites
Soil as a key solution for big challenges[a]	Climate change mitigation and adaptation; soil and the circular economy; soil biodiversity for human, animal and plant health; soil for healthy water resources
Soil research[a,b]	Digital agenda; data mining; monitoring; research and innovation
Enabling the transition to healthy soils[a]	Funding; literacy and societal engagement
Specific additional themes	GHG emissions; soil moisture; climate mitigation; nutrient loss prevention; SOC; soil productivity; climate change resilience; reversing land damage; drought mitigation; soil sealing; soil reuse
Author gender	First author; last author; corresponding author

[a]Key themes identified in the EU Soil Strategy.

[b]The EU Soil Strategy theme "We need to know more about soils".

BD, bulk density; CEC, cation exchange capacity; DOI, digital object identifier; GHG, greenhouse gas; ICPAES, inductively coupled plasma atomic emission spectroscopy; ICPMS, inductively coupled plasma mass spectrometry; ICPOES, inductively coupled plasma optical emission spectrometry; LOI, loss on ignition; SOC, soil organic carbon; SOM, soil organic matter; TP, total phosphorus; XRF, X-ray fluorescence.

3 Examination of the Findings

3.1 Basic Data: Geography, Setting, Soil Type

Most studies in the dataset (87%) provide basic data on the location of the study (Figure 3.1). There is marked variation in the intensity of study of soils in different counties. Counties Cork and Wexford show the most records, with 49 (18.5% of total records) and 42 (15.8% of records), respectively; Counties Tipperary (36 records, 13.6%) and Galway (33 records, 12.5%) are also commonly studied. Counties Kerry, Roscommon and Longford show the fewest records, with only 13 (4.9%), 12 (4.5%) and 9 (3.4%) records, respectively. Only 1.5% of the records a national dataset.

Most studies in the dataset (93%) provide basic data on the nature of the local setting (Figure 3.2). The vast majority of records are from agricultural settings (172 records, 65%). Bogs (71 records, 25%) and forests (52 records, 20%) are also important. Urban soils account for only 43 records (16%). Mining settings account for only four records (1%) and sand dunes and upland/mountain settings account for a single record each.

Most studies (59%) provide basic data on soil type (Figure 3.3), but there is no consistent use of a single soil classification scheme. Most studies (81%) used one of four classification systems: Irish Soil Information System (ISIS; 20 records), World Reference Base (WRB; 19 records), US Department of

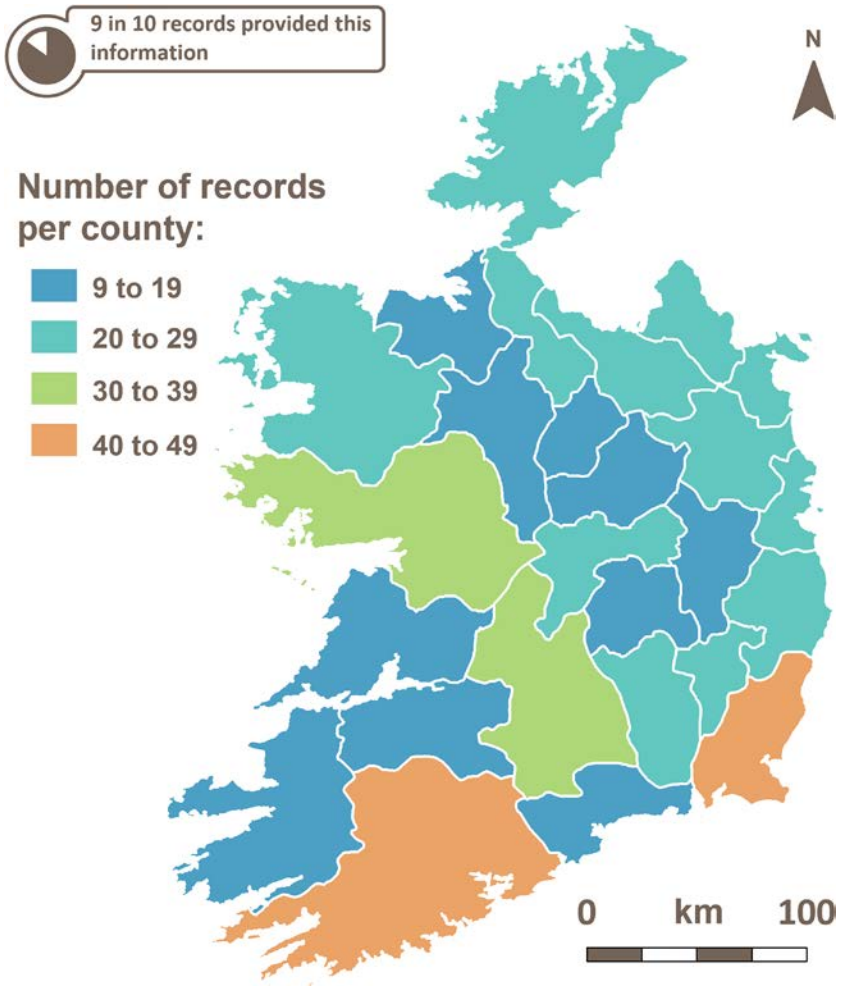

Figure 3.1. Location of studies on Irish soils expressed as the number of records (studies) per county.

Figure 3.2. Local setting of studies on Irish soils expressed as the number of records (studies) per setting.

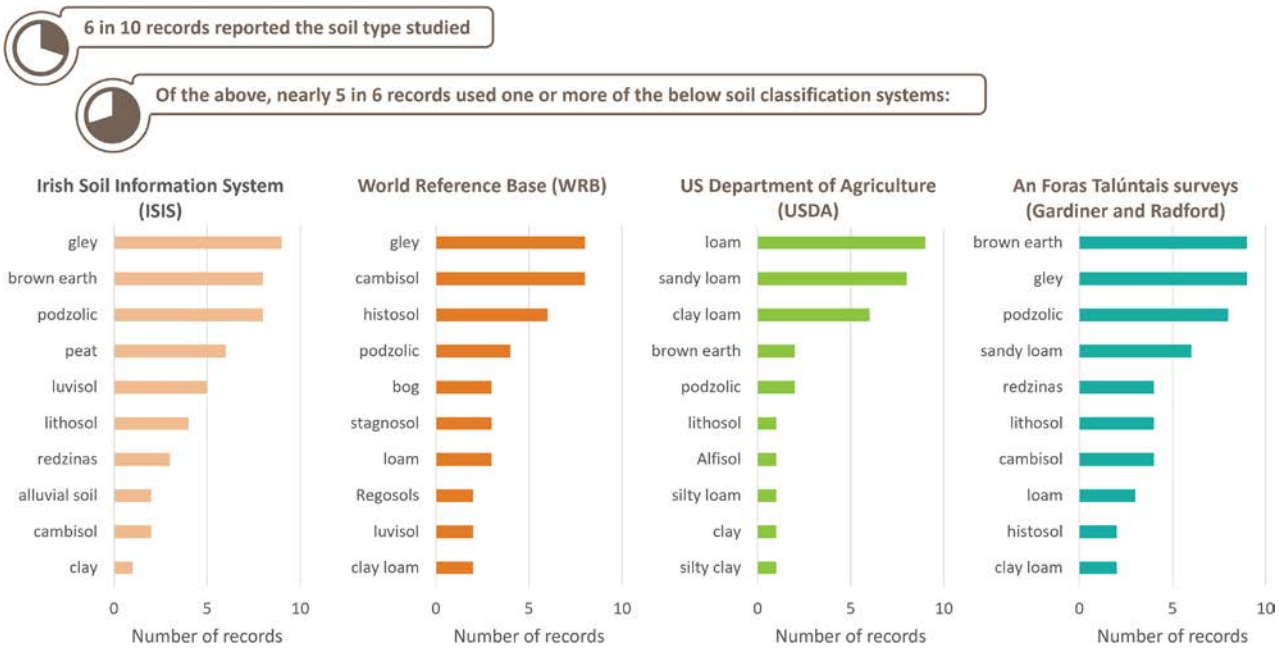

Figure 3.3. Soil type and soil classification scheme used by studies on Irish soils.

Agriculture (USDA; 16 records) and An Foras Talúntais surveys (Gardiner and Radford; 14 records). The soil categories in different systems are not, however, directly comparable; many categories are unique to one system. Furthermore, different classification systems are used in different contexts; different terminology is used by, for example, engineers, farmers and gardeners to describe the same soil.

3.2 Data Quality

Data quality was assessed using a number of parameters. The most basic of these are the number

of soil samples analysed and the number of sites studied (Figure 3.4); these are important because studies with larger datasets, and which compare multiple sites, are usually more robust than studies with small datasets from a single site. Most studies in the dataset (220, 86% of records) state the number of soil samples analysed. Of these, 50% of studies (109 records) used a small dataset of ≤30 samples; 11% of studies (29 records) used a medium-sized dataset of 31–100 samples and almost one-third of studies (82 records, 31%) used a large dataset of >100 samples. Most studies (71%, 182 records) used data from more than one site.

The research also considered a range of additional indicators for data quality (Figure 3.5). However, very few studies in the dataset (20% of records) incorporated any of the components that ensure data robustness and reproducibility. Field duplicates for soil samples (to ensure data repeatability) are used in only 29 studies (11% of records). Specific sampling protocols (to ensure data comparability, representativeness and accuracy, or to mitigate cross-contamination) were used in only 24 studies (9% of records). Only 21 studies (8% of records) used standards (to calibrate quantitative data) and only 18 studies (7% of records) used analytical replicates (to ensure data repeatability). Data were post-processed (e.g. using statistics, to address quality issues) in only 16 studies (6%), and only seven studies (3%) used blind insertion of duplicates, replicates and standards (i.e. sample type hidden at time of analysis to avoid researcher bias). Fewer than half of studies used pre-existing data (42%; for comparative purposes) and only one-third of studies (36%) used computer simulations, models or mapping techniques.

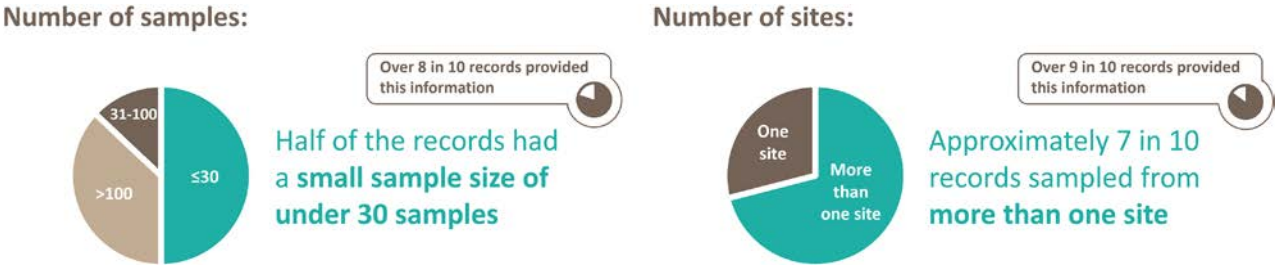

Figure 3.4. Basic data quality indicators. Number of soil samples analysed (left) and number of sites studied (right).

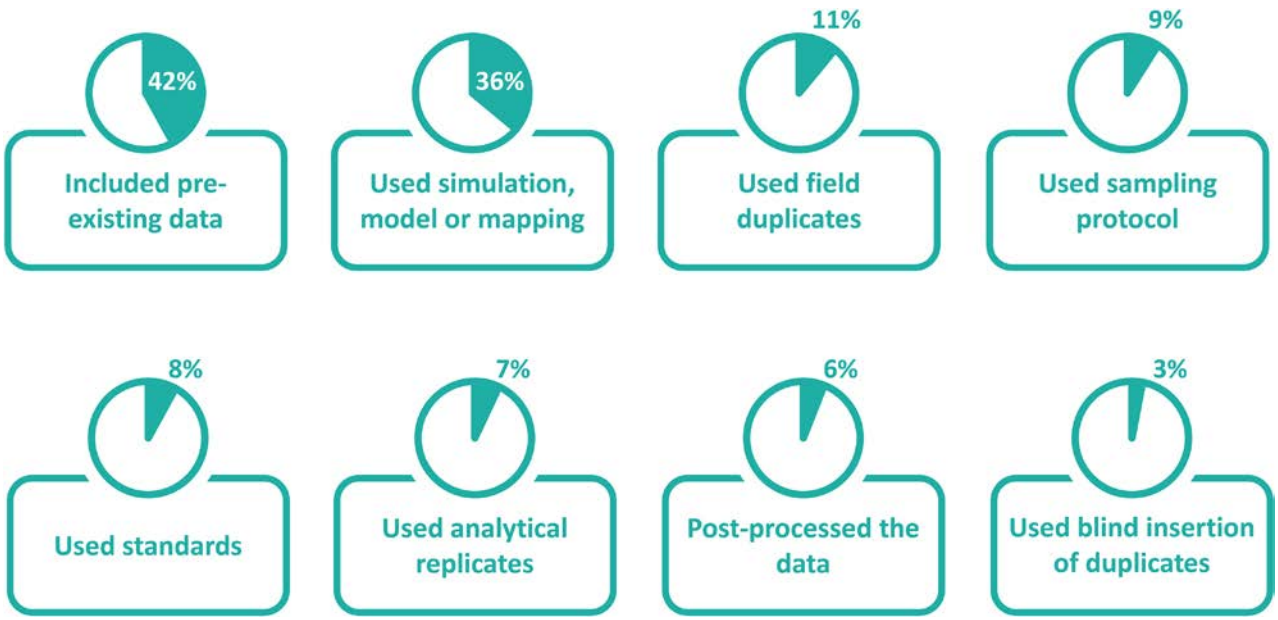

Figure 3.5. Percentage of studies incorporating specific indicators of data quality.

3.3 Soil Parameters Analysed

Most studies in the dataset (240, 91% of records) report the type of soil parameters analysed (Figure 3.6). The most common are pH (81 records, 31%), nitrogen concentrations (69 records, 26%), bulk density (50 records, 19%), the proportion of the <2 mm size fraction (46 records, 17%), carbon concentrations (46 records, 17%) and SOM content (45 records, 17%). Less commonly reported parameters are greenhouse gas content (40 records, 15%), phosphorous concentrations (38 records, 14%), soil moisture content (35 records, 13%), soil organic carbon (SOC) content (33 records, 13%), soil mineral composition (31 records, 12%), metal content determined by ICPMS (inductively coupled plasma mass spectrometry)/ICPAES (inductively coupled plasma atomic emission spectroscopy)/ ICPOES (inductively coupled plasma optical emission spectrometry) (23 records, 9%), soil temperature (22 records, 8%), cation exchange capacity (13 records, 5%) and soil potassium content (19 records, 7%). The least common parameters studied are total porosity (10 records, 4%) and metal content using X-ray fluorescence (XRF) (7 records, 3%).

Collectively, these data reflect biases in research on soils in particular settings. Preferential analysis of pH and nitrogen content probably reflects biases towards research on agricultural soils; the rarity of data on soil metal concentrations reflects a lack of research on soils in urban and mining settings and on remediation and pollution; and the rarity of data on soil carbon, organic matter and greenhouse gases reflects a lack of research on the impacts of soils on climate and climate change resilience. These data are concerning because they indicate that a lack of data on key soil parameters is linked to a lack of research on key themes identified as priority areas under the EU Soil Strategy.

3.4 EU Soil Strategy Themes

Most studies (260, 99%) incorporate one or more of the four overarching EU Soil Strategy themes (Figure 3.7). Of the studies, 77% relate directly to the theme “preventing soil and land degradation and restoring healthy soils” and 73% of studies relate to “soil as a key solution for our big challenges”. Only 22% of studies, however, relate to other aspects of soil research (e.g. “we need to know more about soils”) and <2% of studies relate directly to the theme “enabling the transition to healthy soils”.

The research also considered the sub-themes of the EU Soil Strategy (Figure 3.7). The most common themes in the dataset are sustainable soil

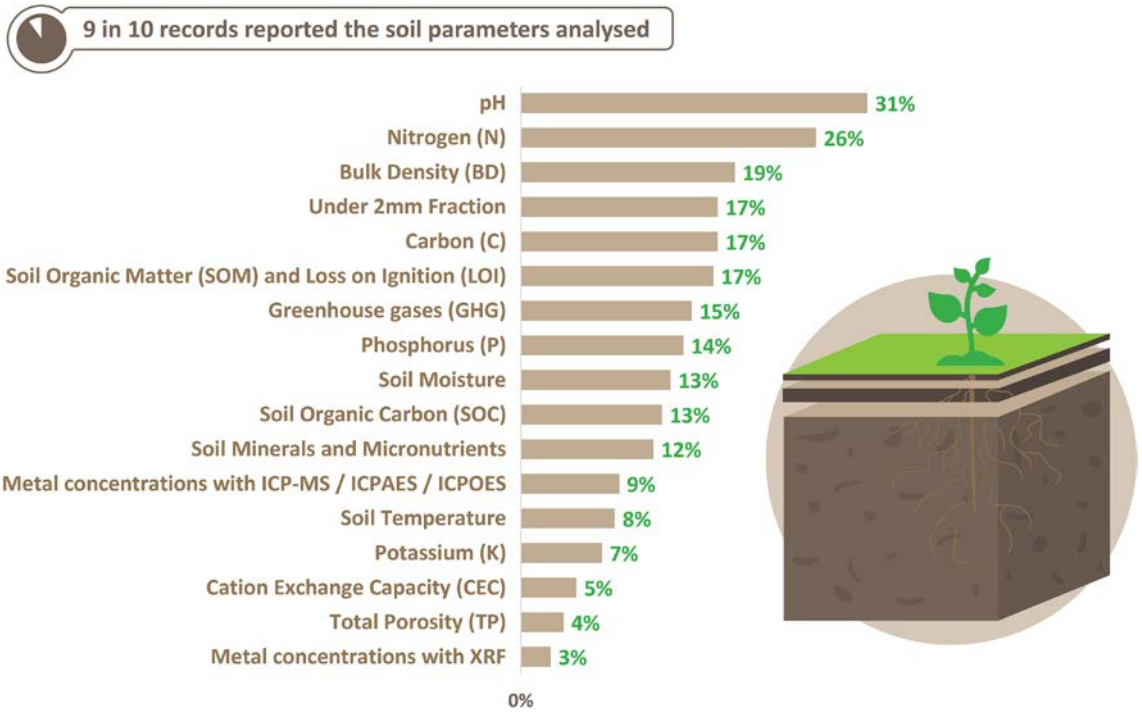

Figure 3.6. Types of soil parameters analysed.

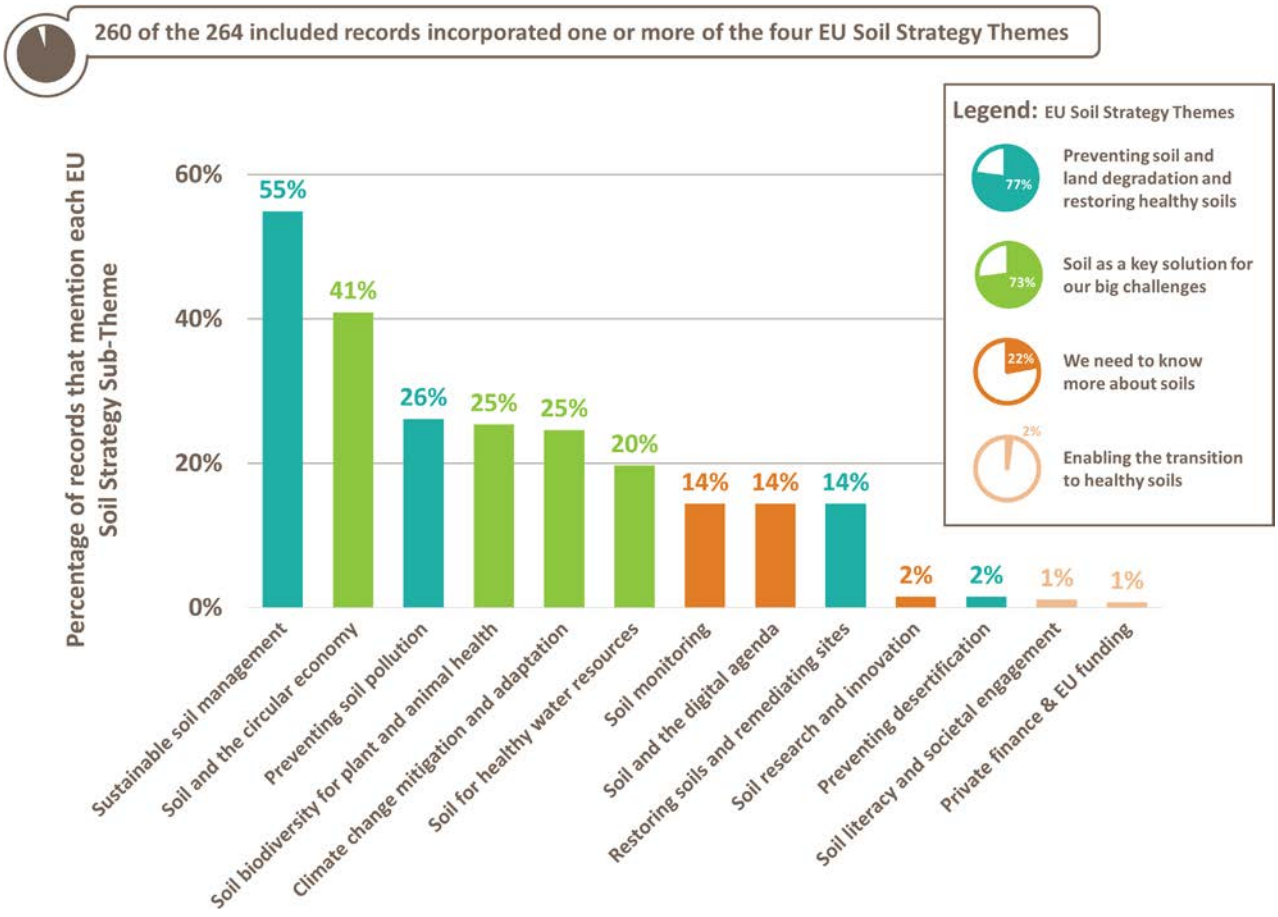

Figure 3.7. Proportion of studies in the dataset that relate to the four overarching themes and sub-themes of the EU Soil Strategy.

management (55% of studies) and soil and the circular economy (41% of studies). All other sub-themes in the EU Soil Strategy do, however, feature in a minority of studies. The sub-themes preventing soil pollution; soil biodiversity for human, plant and animal health; climate change mitigation and adaptation; and soil for healthy water resources are a focus of only 20–26% of studies. The sub-themes restoring degraded soils and remediating contaminated sites, soil and the digital agenda and soil monitoring each are a focus of only 14% of studies. The sub-themes preventing desertification, soil research and innovation, soil literacy and digital engagement, and private finance and EU funding each feature in only 1–2% of studies.

Finally, the research considered specific themes highlighted in the EU Soil Strategy (Figure 3.8). Among these, the most common themes in the dataset are nutrient loss prevention (37% of studies), SOC (33% of studies), climate mitigation (26% of studies) and soil productivity (22% of studies). Less common are soil and climate change resilience (14% of studies) and reversing land damage and restoring soil (13% of studies). Very few studies focus on the themes drought mitigation (3% of studies), soil sealing (2% of studies) and soil reuse (1% of studies).

3.5 National Themes of Concern

The research considered a number of themes of national concern relating to research on Irish soils that were identified in the national research call document (Table 2.1; EPA, 2021b). Unfortunately, very few studies in the dataset focus on these themes (Figures 3.9 and 3.10). Only 12% of studies focus on the loss of soil biodiversity; 11% focus on soil quality or health; 9% on soil carbon loss; 6% on soil structure; 4% on soil compaction; 2% on reducing erosion and 1% on soil literacy; excavated soil and soil salinisation are each represented by < 1% of studies.

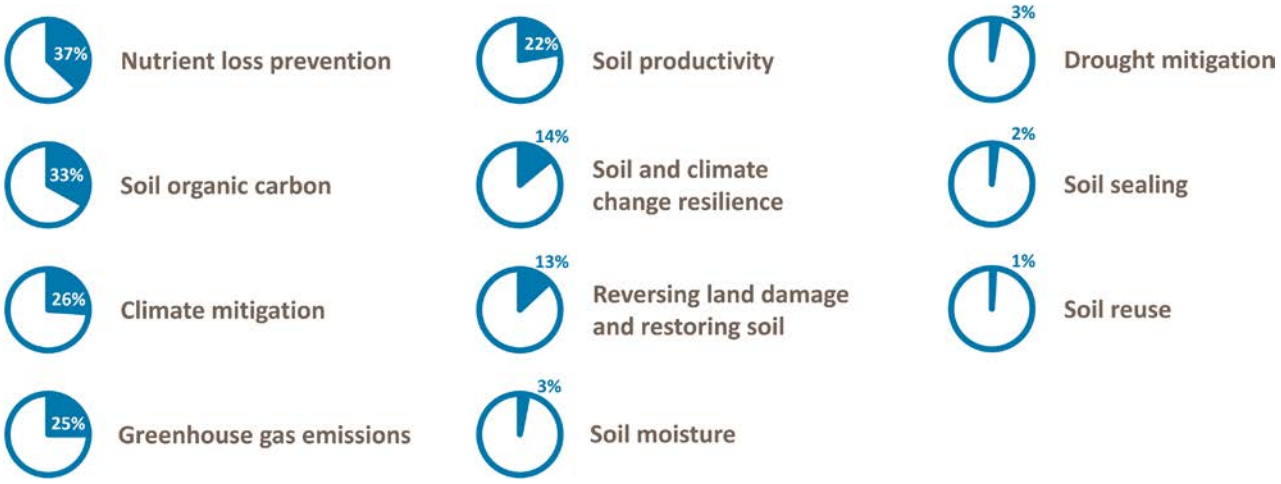

Figure 3.8. Percentage of studies in the dataset that relate to specific themes of concern identified in the EU Soil Strategy.

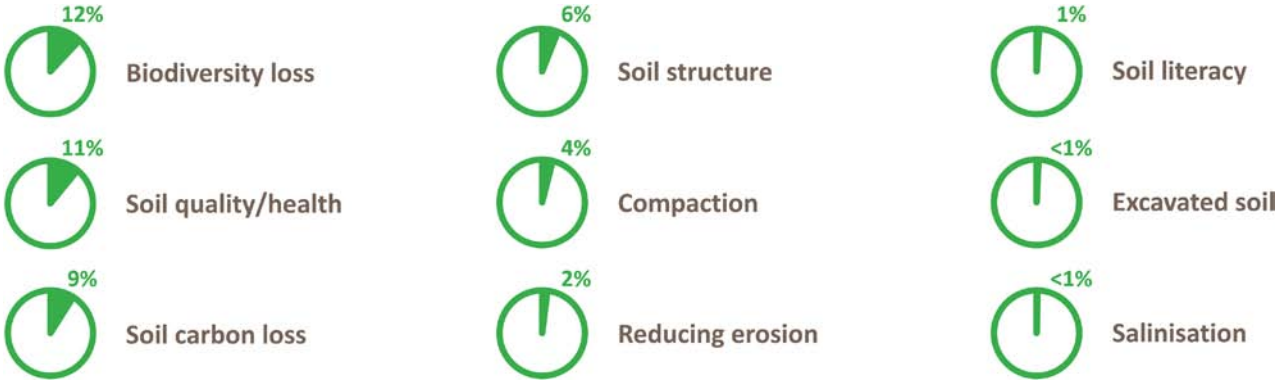

Figure 3.9. Percentage of studies in the dataset focusing on national themes of concern.

3.6 Author Gender

The research considered the gender of authors in the dataset: 75% were male, slightly more than the global mean proportion of male researchers in science, technology, engineering and mathematics (STEM) (globally estimated at 70%) (Figure 3.11). This indicates a similar level of gender bias in soil science research as in the sciences overall.

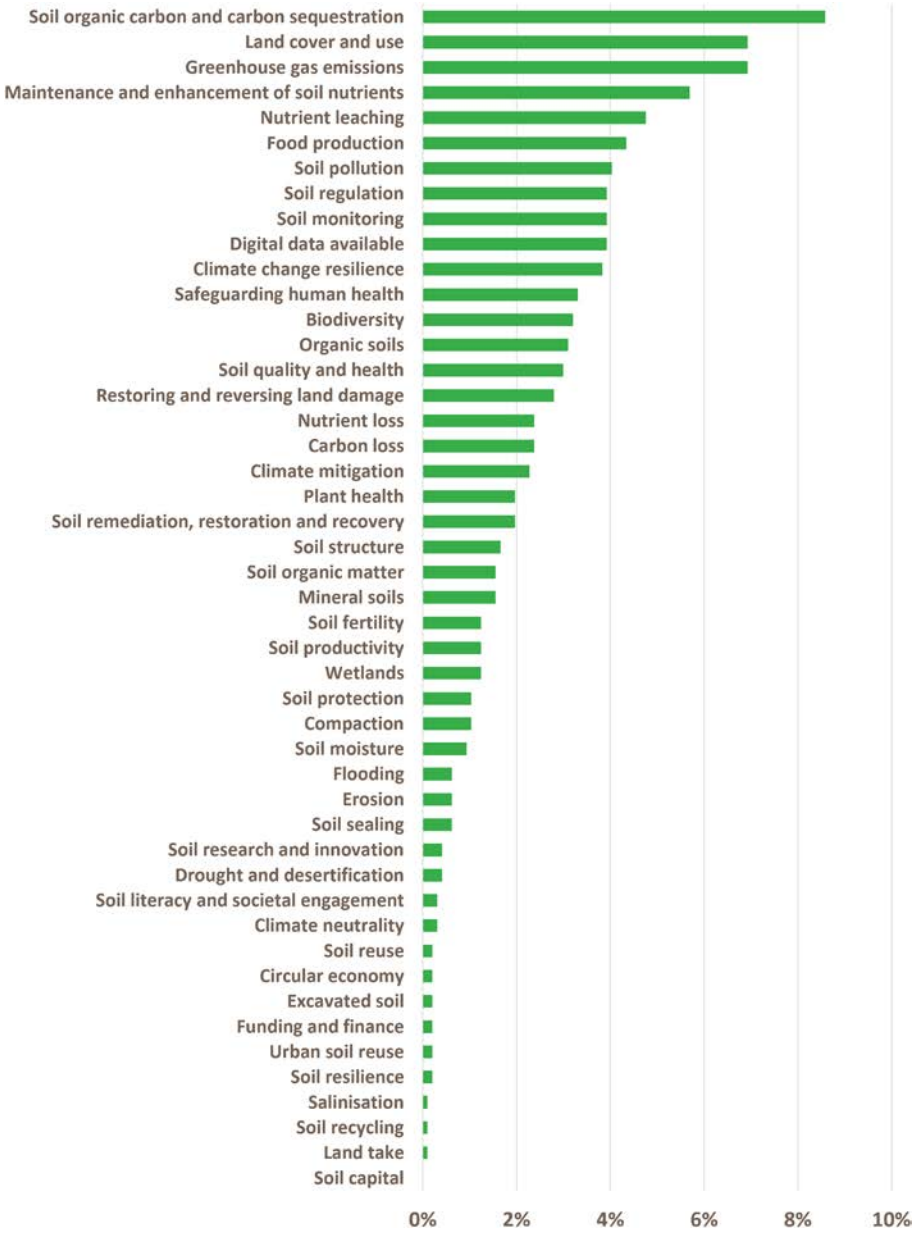

Figure 3.10. Ranked list of specific research themes (of national concern and identified in the EU Soil Strategy) featured in research on Irish soils. Percentage values indicate the percentage of studies in the dataset that focus on a particular theme.

Figure 3.11. Author gender for key categories of author for the studies in the dataset.

4 Conclusions and Policy Recommendations

4.1 Conclusions

This research has identified important features of research into Irish soils. These are divided here into features that relate to broad study context and methods and features that relate specifically to research themes of concern, as identified in the national research call document and the EU Soil Strategy. The research also revealed that not all studies provided basic data such as the number of samples used, the study location(s), the type(s) of analyses performed and whether or not protocols were in place to ensure data repeatability and reproducibility.

4.1.1 Research context and methods

This research has identified six key features of research on Irish soils (Figure 4.1).

Uneven geographical coverage

Although no county dominates the dataset, the first major feature of the dataset is that current research is clearly highly biased in terms of the geographical context; certain counties have five times the number of studies as others. There is no latitudinal or longitudinal pattern in this variation. The high abundance of studies in County Wexford and County Cork almost certainly reflects the presence of major research facilities, but the specific reasons for the small number of studies in much of the Midland and West regions are not clear.

Agricultural focus

The second major feature of the dataset relates to a bias in land use setting. The overwhelming majority of records are from agricultural settings. Less than one-sixth of studies are from urban areas despite this

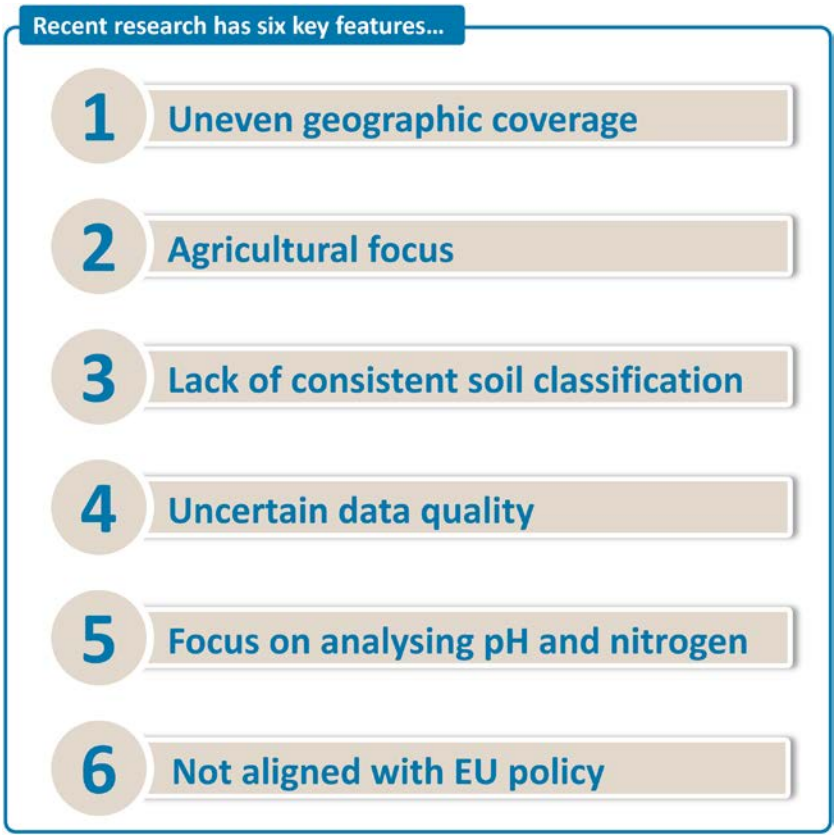

Figure 4.1. Key features of recent research on Irish soils.

being a field of increasing interest, not least because the Irish population is increasingly urban. Very few studies focus on mining settings despite the potential for contamination of soil and groundwater and the associated risks to human health and the environment.

Lack of consistent soil classification

The third fundamental feature of Irish soil research is that there is no consistent use of a single soil classification scheme. Instead, four schemes are used with a similar level of frequency. This renders it difficult to compare data on soil type in the dataset.

Uncertain data quality

The fourth major feature of the dataset relates to data quality. Most studies meet basic criteria relating to the size of the dataset (> 30 samples analysed) and include an element of comparison between two or more sites. The vast majority of studies, however, do not incorporate additional methodological components to ensure that data are robust and reproducible, e.g. by using field duplicates or analytical replicates.

Focus on analysing pH and nitrogen

The fifth major feature of the dataset relates to the nature of the data collected. Soils have many important physical and chemical soil parameters, but research is biased towards the collection of data on pH and nitrogen content. Other parameters that feature commonly in the dataset are bulk density, the proportion of the < 2 mm size fraction, soil moisture content, carbon content (including SOC and SOM) and greenhouse gas emissions. Relatively few studies analyse soil metal content, cation exchange capacity, phosphorus and potassium contents and temperature. These biases reflect biases in research on the local setting; that is, studies in agricultural settings are overrepresented and studies in urban, industrial and mining settings are underrepresented.

Thematic misalignment with EU policy

The sixth major feature of the dataset relates to the scope of the research undertaken to date; current research on Irish soils is, in the main, not aligned with EU policy. This is detailed in section 4.1.2.

4.1.2 Research themes

At a broad scale, most studies in the dataset focused on one of the overarching themes of the EU Soil Strategy, especially “preventing soil and land degradation and restoring healthy soils” and “soil as a key solution for our big challenges”. These data, however, belie marked variation in the extent to which the more specific EU Soil Strategy sub-themes are a focus of Irish soil research. Most studies relating to the overarching theme “preventing soil and land degradation and restoring healthy soils” focused on the specific sub-theme “sustainable soil management”, and most studies relating to the overarching theme “soil as a key solution for our big challenges” focused on the sub-theme “soil and the circular economy”. All other sub-themes feature in up to 25% of Irish soil research. Although a small number of sub-themes are of limited relevance to Ireland, e.g. preventing desertification, there is no obvious reason why the remaining themes are not a research focus. Again, this low return rate is a concern across the range of research themes represented, but especially for sub-themes such as soil monitoring, restoring degraded soils and remediating contaminated sites, which are represented by < 20% of studies in the dataset.

Consideration of the data for specific additional themes of concern is also insightful. These themes vary widely in the extent to which they feature in Irish soil research and demonstrate a certain amount of research momentum for the specific themes prevention of nutrient loss and SOC, which are each represented by approximately one-third of studies. The return rate is particularly concerning for the specific themes soil and climate change resilience, reversing land damage and restoring soil, drought mitigation, soil sealing and soil reuse, each of which are represented by up to 14% of studies.

This research reveals that the topics of key concern identified in the national research call document are rarely the focus of research on Irish soils, with each of these key topics represented by up to 12% of studies. This return rate is a real concern across the range of topics identified but especially for topics such as soil compaction, reducing erosion, soil literacy, excavated soil and soil salinisation, which each feature in up to 4% of studies.

4.1.3 Gender

Globally 7 in 10 scientists are men. The data presented here on the gender balance of the authors of the reports included in this research reveal a similar gender bias.

4.2 Policy Recommendations

This research concludes with general recommendations regarding the development of future soil policy in Ireland. Future policy should prioritise three key areas (Table ES.1, Figures ES.2 and 4.2):

1. supporting soil research, in particular research on human impacts on soil in non-agricultural settings and soil characteristics that are understudied;
2. developing new national programmes for soil monitoring, literacy and sustainable management;
3. ensuring data quality by developing national guidance for protocols and more integrated collaboration between soil experts from different disciplines.

Future policy should also provide for schemes to access facilities and laboratory infrastructure.

4.2.1 Support soil research: human impacts

Priority targets include soil excavation, sealing, erosion, reuse, compaction, restoration, reversal of land damage and drought mitigation. By targeting these activities, future national policy will align better with EU policy. As many of these activities apply in urban and industrial areas, targeting human impacts will also resolve the existing bias towards agricultural soils. Enhanced knowledge of human impacts on soil and the soil environment will inform the development of policies for sustainable soil management and climate resilience.

4.2.2 Support soil research: soil characteristics

Priority targets include (1) carbon and greenhouse gases; (2) metals, minerals and micronutrients; (3) porosity, moisture and structure; and (4) biodiversity. Targeting these soil parameters will

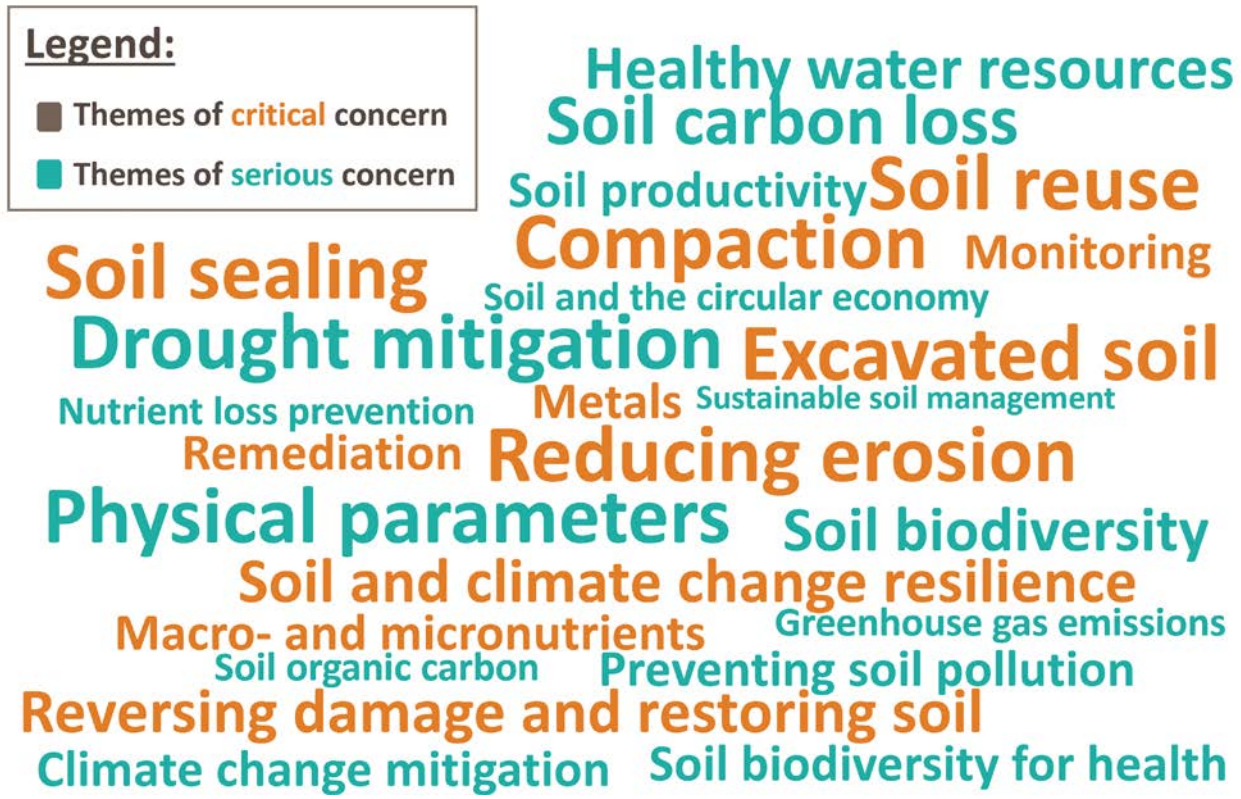

Figure 4.2. Word cloud highlighting major thematic areas that should be prioritised in future policy. Font size is related to the size of the knowledge gap on a topic, e.g. there is a large knowledge gap for soil sealing.

provide essential data to support focused work on priority EU themes. This will require future policy to provide for schemes to access facilities and laboratory infrastructure and to encourage multifaceted, multidisciplinary approaches to studying soil.

Collectively, the thematic areas listed above can be assigned to two levels of urgency. Themes of **critical concern** are currently represented by few or no data and should be prioritised in future policy. These are (in no particular order) soil compaction, reducing soil erosion, excavated soil, soil sealing, soil reuse, soil monitoring, remediating contaminated sites, reversing land damage, restoring degraded soil, soil and climate change resilience, metals and macro- and micronutrients.

Themes of **serious concern** are characterised by a small but growing body of data but are still represented by a minority of recent studies and require substantial research development. These themes of serious concern should therefore also be prioritised and include soil biodiversity loss; soil carbon loss; soil greenhouse gases; soil structure; sustainable soil management; soil and the circular economy; preventing soil pollution; soil biodiversity for plant, animal and human health; climate change mitigation; soil for healthy water resources; nutrient loss prevention; SOC and soil productivity; physical parameters (structure, porosity, etc.); and drought mitigation.

Some themes that are strongly underrepresented in Irish soil research are unlikely to be of major historical relevance, e.g. soil salinisation and drought mitigation. While this trend is likely to continue for salinisation, persistent warm dry conditions and droughts in recent years indicate that drought mitigation should be included in future priority lists for research and policy development.

4.2.3 National programmes

Future policy should develop national programmes to enhance soil literacy among the general population and specific demographic cohorts, e.g. miners, engineers and farmers. Policy should also aim to develop a new soil monitoring programme with national geographical coverage to better characterise soils of different types from disparate settings and regions, thus reducing the existing geographical bias in soil research. Collectively, these actions will help align national and EU policies and will decrease the risk of unintentional land damage and degradation, especially as a result of human activities.

4.2.4 Data quality

Future research policy should highlight the importance of high-quality data going forward. Policy should facilitate guidance on certain aspects of research on Irish soils, especially the co-ordination of expertise that uses different soil classification systems and scientific approaches, so that the outcomes can be used by workers and individuals in many different contexts. Documentation associated with future funding calls should clarify expectations regarding the collection and publication of fundamental study parameters (e.g. sample size, study location, data collected) and protocols that demonstrate data repeatability and reproducibility (e.g. use of field replicates, analytical duplicates, blind insertion of samples, data processing controls and checks). These policies will promote the collection of high-quality data with enhanced comparative power and the generation of “big data”, i.e. new large datasets on Irish soils that can be mined by future studies to better understand trends, patterns and processes affecting Irish soils.

Finally, the research highlights a similar extent of gender bias in the research community working on Irish soils as in the STEM research community globally. Efforts should be made to promote the uptake of careers in STEM and, more specifically, environmental research among women and to investigate the factors influencing the career progression choices of women working in STEM and specifically environmental research in Ireland.

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Abbreviations

EPA	Environmental Protection Agency
ICPAES	Inductively coupled plasma atomic emission spectroscopy
ICPMS	Inductively coupled plasma mass spectrometry
ICPOES	Inductively coupled plasma optical emission spectrometry
SDG	Sustainable Development Goal
SOC	Soil organic carbon
SOM	Soil organic matter
STEM	Science, technology, engineering and mathematics
UN	United Nations
XRF	X-ray fluorescence

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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