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Soil Pollution Education: A Broad View of Knowledge on Soil Pollution and Educational Activities for Undergraduate Students

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Abstract

Soil pollution is a major challenge for ensuring a healthy environment and for human health. One of the critical points in soil pollution policy is the education and public awareness of the problem caused by soil pollution. Education influences decision-making on soil and water care. It is crucial to spread knowledge to undergraduate and graduate students about the determinantal effects of soil pollution on ecosystems and humans, considering today's students are tomorrow's guardians of soil and human health. A course on soil pollution aims to provide students with a foundation of the knowledge and skills required to work in this field. Knowledge of soil and contaminant properties, soil-pollutant interaction processes, transport of pollutants by soil and water, human health and ecological risk assessment, and measures for preventing soil pollution are fundamental for the sustainable management of soil and food safety. Students should be aware of the need to avoid the three types of soil pollution (chemical, radioactive, and biological) in industrial, agricultural, forest, and urban soils. This article provides a broad view of the knowledge taught in subjects related to soil pollution and introduces learning activities for undergraduate students.

Keywords
Soil education; soil sciences; soil pollution; awareness; university

1. Introduction

Soil is a complex medium and a non-renewable resource that sustains agricultural production, supplies raw materials, filters water, regulates biochemical and geochemical processes, degrades pollutants, stores carbon, etc. [1-3]. Soil is under pressure due to industrial/commercial activities, urbanization, agricultural practices, etc. [4, 5]. According to the European Union's 2006 Soil Thematic Strategy [6], some of the main threats to soil are declining organic matter and soil biodiversity, erosion, salinization, soil sealing, soil compaction, and local and diffuse soil contamination.

Soil pollution is a worldwide phenomenon that is faced by both developed and developing countries [7-9]. Soil pollutants negatively affect the soil's physical, chemical, and biological properties, can reduce its productivity, and even affect human health [10-15]. Zhang [16] reports that the problem of soil contamination is extremely complex because of the heterogeneity and anisotropy of soils, the process of adsorption of contaminants on clay minerals and organic matter, and the diversity of contaminants. Zhang [16] developed a scenario for the feasible remediation of soil and groundwater contamination that considers sustainable development. In this scenario, the author included elemental technology (investigation and assessment technologies, remediation and countermeasure technologies, risk assessment and management technologies), the integration of environmental, social, and economic aspects into the decision-making process of selecting countermeasures, and the involvement of industry-academia-government-stakeholders-local residents.

The primary objective of a soil contamination policy is to prevent soil pollution, provide criteria, standards, and technical specifications, offer financial aid for the remediation and rehabilitation of orphan sites, and encourage sustainable remediation practices. Soil quality should be preserved and monitored, all polluted soils should be remediated, and the use of remediated polluted soil should be optimized. To avoid soil pollution, it is necessary to have a legislative system, and also monitoring and early warning systems, increase basic and applied research, and develop sustainable and environmentally friendly techniques in both industrial processes and the agricultural field [17, 18].

Healthy soils are crucial for food safety and security, and it is necessary to accommodate productivity and food safety. The social demand for the control and remediation of polluted soils is extremely urgent [17]. The awareness of the significance of soil pollution is increasing worldwide, which has led to further research being conducted on the assessment and remediation of soil pollution [19]. Nevertheless, there is a need to increase the awareness of the scientific community, decision-makers, and the general public nationally and internationally. As pointed out by several participants in the Global Symposium on Soil Pollution [19], the awareness of civil and public health administrators should improve, considering soil pollution greatly impacts human health.

The second pillar of the Global Soil Partnership includes education and awareness, considering the general lack of societal awareness of the significance of soil on the lives of people and the planet. Deficient education can, in some cases, be the specific underlying cause of unsustainable land management practices and can lead to a lack of awareness of having to take preventive measures to avoid soil pollution.

Various studies have demonstrated the concern of university students about environmental protection [20-24]. Student awareness signifies developing responsible behavior toward, in this case, soil pollution, based on knowledge and attitudes. The more students can learn about the role of healthy and clean soils on human health and in sustaining the environment, the more they understand its significance and the more likely they are to take care of it.

Learning activities related to soil pollution could increase students' concern about the wide range of issues involved and allow them to apply more analytical and creative thinking tools and problem-solving skills.

The primary objective of this paper is to provide a broad view of knowledge taught in soil pollution-related subjects and to share classroom activities that can increase the knowledge and awareness of students on the issues of soil pollution. [1]

2. Soil Contamination and Soil Pollution

According to the Food and Agriculture Organization of the United Nations (FAO), soil contamination occurs "when the concentration of a chemical or substance is higher than would occur naturally but is not necessarily causing harm". In contrast, soil pollution refers to "the presence of a chemical or substance out of place and/or present at higher than the normal concentration that has adverse effects on any non-targeted organism" [19]. These two terms were defined by Knox et al. [25] and Batjes [26]. Chapman [27] mentions that "Contamination is simply the presence of a substance where it should not be or at concentrations above background. Pollution is contamination that results in or can result in adverse biological effects to resident communities". However, these terms are often used interchangeably without definitional clarity. Cachada et al. [28] define contaminants as chemicals that are not harmful and pollutants as chemicals that cause actual environmental harm.

Some national policies do not have specific definitions of "contaminated soil", "contaminated site", "potentially contaminated site" or "polluted soil". The definitions vary by country (Table 1). The European Soil Data Centre (ESDAC) defined "contaminated site" and "potentially contaminated site" according to the European Environment Agency (EEA) [29]. Mizutani et al. [30] reported that developing uniform global definitions of "contaminated soil" would be beneficial to making progress in addressing the issue.

[1] This article is based on a conference paper that the authors presented at the Global Symposium on Soil Pollution entitled "Soil contamination policy: increasing students' awareness". This Symposium was held at the FAO headquarters in Rome, Italy, on 2-4 May 2018.

Table 1 Examples of definitions of "contaminated soil", "contaminated site", "contaminated land", "potentially contaminated site", "uncontaminated site" and "polluted site" obtained from various national policies.

Country	Definition
Sweden	**A contaminated site**: "site where land and water areas, buildings and structures are so polluted that they may cause damage or detriment to human health or the environment".
Netherlands	**Contaminated site**: "site where the soil is contaminated or in danger of becoming contaminated in relation to territories that, on account of said contamination, the cause of the consequences thereof is connected with each other in a technical, organizational of planning sense". **Seriously contaminated site**: "site where the soil is, or there is a danger that it will be contaminated, so that the functional properties which soil has for man, flora and fauna have been, or are in danger of being, seriously reduced. (Soil Protection Act, Section 1)".
Italy	**Potentially contaminated site**: "a site where the concentrations of one chemical or more in environmental media (soil, subsoil, and groundwater) exceed "Contamination Threshold Concentrations" (CTCs, i.e., screening values for residential and industrial commercial land uses) and needs a detailed site investigation followed by a site-specific risk assessment, to evaluate the contamination level and the "Risk Threshold Concentrations" (RTCs, i.e., site-specific target values)". **Contaminated site**: "a site where "Risk Threshold Concentrations", derived by a site-specific risk assessment carried out on the basis of a detailed site investigation, are exceeded". **Uncontaminated site**: "a site where contamination in environmental media (soil, subsoil, and groundwater) is below CTCs, or if CTCs are exceeded, it is below the RTCs derived by a site-specific risk assessment".
Germany	**Contaminated sites** "within the meaning of this Soil Protection Act are 1. closed-down waste management installations, and other real properties, in/on which waste has been treated, stored, or landfilled (former waste disposal sites), and 2. real properties that house closed-down installations, and other real properties, on which environmentally harmful substances have been handled, … (former industrial sites) that cause harmful soil changes or other hazards for individuals or the general public. Harmful soil changes are harmful impacts on soil functions that are able to bring about hazards, considerable disadvantages or be considerable nuisances for individuals or the general public".

France	**Contaminated land**: "site presenting a real or potential long-lasting risk for human health or the environment as a result of the pollution of a given milieu resulting from former or current human activity". **Polluted site**: "site with media quality no compatible with its current or future use".
Spain	**Contaminated soil**: "soil with properties that have been negatively modified by the presence of hazardous chemical components deriving from an anthropic source, and at such a concentration level that it represents an unacceptable risk for human health or the environment, and have been declared as such in a resolution specifically adopted for this purpose. Therefore, contaminated soils are those exhibiting chemical concentrations in soil which yield a higher risk level than an acceptable risk (hazard quotient >1 for substances with systemic effects and $>10^{-5}$ for carcinogenic ones)".

Source: General questionnaires on Contaminated Land Management in the EU Member States (https://www.commonforum.eu/Questionnaires/LF/LF_QUEST.asp).

3. Broad View of Knowledge on Soil Pollution

Soil pollution is a current topic in soil science [31]. Soil pollution interacts with other areas of science, such as chemistry, geology, biology, physics, and hydrology. The knowledge of soil pollution comprises several concepts and techniques to analyze and treat polluted soils, methodologies, and processes (e.g., volatilization, photodegradation, biodegradation, dissolution, leaching, oxidation, hydrolysis, adsorption, precipitation, etc.) [32, 33]. Several activities can pollute soils, such as industrial activities, agricultural activities, waste disposal, mining, and nuclear activities. [34-37].

Figure 1 presents the information on soil chemical and radiological contamination that students should be aware of to become highly competent professionals.

Soil chemical and radiological contamination

<table>
<tr><th>Knowledge of soil constituents and properties</th><th>Criteria for determining if a site is contaminated</th><th>Site remediation planning and management</th></tr>
<tr><td>Sources and causes of soil pollution</td><td rowspan="3">Site characterisation
- Site inspection - Soil properties
- Lithology - Hydrogeology
- Topographical map, geological map, hydrological map
- Environmental scenario (risk in the nearby area: water sources, agricultural areas, etc.)</td><td rowspan="3">Remediation technologies
Chemical/Physical/Biological treatment
Containment
Confinement
Transfer to landfill</td></tr>
<tr><td>Potential receptors of contamination</td></tr>
<tr><td>Soil pollutants exposure pathways</td></tr>
<tr><td rowspan="5">Potential pollutants
- Chemical compounds: organic, inorganic
- Degradation products
- Chemical species, bioavailability
- Synergies, antagonisms
- Physico-chemical properties (solubility, volatility, solid-phase matrix affinity, etc.)
- Soil screening values- soil uses</td><td rowspan="5">Risk assessment
- Acceptable and unacceptable risk concept
- Criteria for identifying sites that require a risk assessment
- Source-pathway-receptor model
- Future soil use
- Human health risk assessment
- Ecosystems risk assessment
- Quantitative models for assessing risks in polluted soils</td><td>Best Available Techniques (BAT)</td></tr>
<tr><td>Selection criteria of remediation technologies</td></tr>
<tr><td>Treatment technologies
- contaminated gases
- contaminated liquids</td></tr>
<tr><td>Pilot project</td></tr>
<tr><td>Postclean-up monitoring planning</td></tr>
<tr><td>Effects of soil pollution on human health and ecosystems</td><td rowspan="3">Soil contamination sampling and monitoring
- Soil and groundwater sampling strategies
- Field investigation techniques
- Sampling methodology
- Analytical techniques for contaminants
- Data quality
- Statistical techniques</td><td>Work safety measures</td></tr>
<tr><td>Soil contamination transport and model parameters</td><td>Environmental liability</td></tr>
<tr><td>Soil-pollutants interactions</td><td>Volunteer remediation procedure</td></tr>
<tr><td colspan="2">Soil pollution preventive measures in the industry
- Design - Defence
- Facilities management and organisational</td><td>Laws, regulations, regulatory policies
International/National/Local</td></tr>
</table>

Figure 1 Information on soil chemical and radiological contamination.

If soil pollution due to the use of sewage sludge, organic fertilizers, and treated wastewater in agricultural soils is studied, other topics should be considered as well, such as biological contaminants, specific sampling, and analysis methods for soil treated wastewater, and sewage sludge, knowledge of use restrictions of sewage sludge, organic fertilizers and treated wastewater, knowledge of limit values of pathogens, and organic and inorganic chemical contaminants, in soil and treated wastewater and sewage sludge (Figure 2).

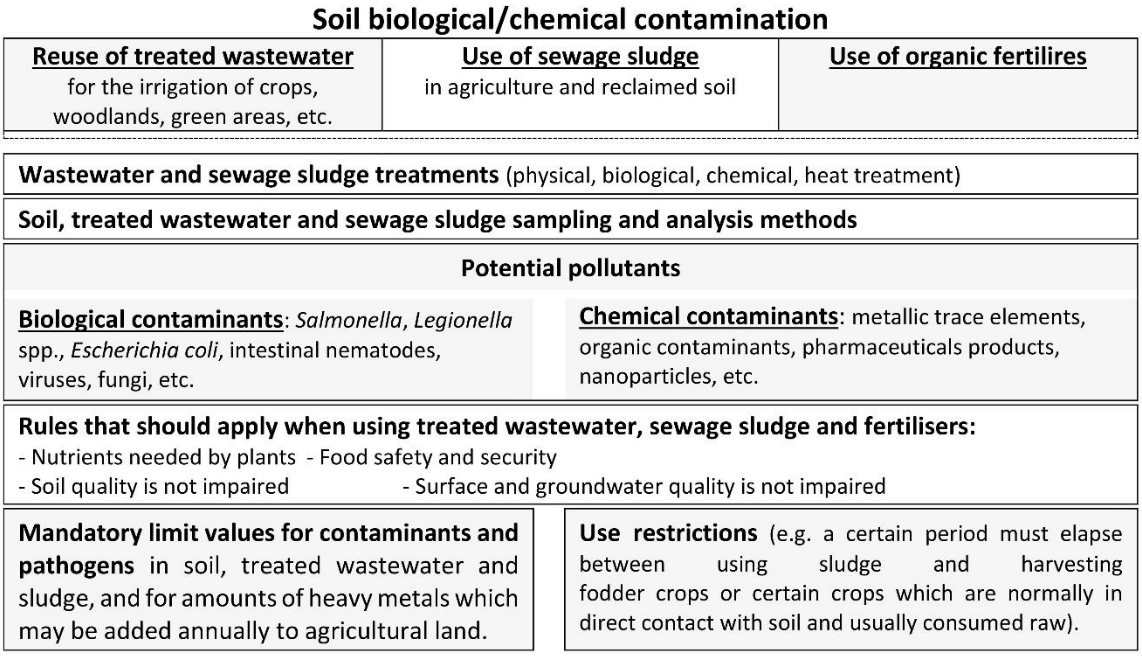

Figure 2 Specific knowledge of soil biological and chemical contamination due to the use of treated wastewater and sewage sludge in agricultural soils.

Soil pollution must be incorporated into human health or food safety and security subjects at the university. Angelos et al. [38] recently proposed the One Health approach in the food safety curricular framework following a transdisciplinary approach to solving food safety and security problems, which will be essential for sustainably meeting the current and future demands for food supplies. The approach comprises soil contamination as the subject matter. The authors discuss the soil contamination issues of movement of contaminants through the soil, effects of soil contamination on ecosystem health, effects of soil contamination on food safety (animal and plant), soil contamination types (microbial, heavy metal, chemical, radiation, toxic), the impact of modern agriculture on soil contamination and quality, land exhaustion effects on food production, an overview of strategies that mitigate and prevent soil contamination, including phytoremediation, and regulatory oversight to prevent soil contamination.

A proposal for a Body of Knowledge (BOK) for soil pollution may be developed in the future. A BOK may be defined as: (1) "Structured knowledge that is used by members of a discipline to guide their practice or work", (2) "The prescribed aggregation of knowledge in a particular area an individual is expected to have mastered to be considered or certified as a practitioner" [39], (3) "The core teachings and skills required to work in a particular field of human endeavor or industry" [40]. According to Lizano and Stage [41], a BOK represents all the elements of knowledge connected to a discipline or professional field. University lectures may benefit from the clarity that a defined BOK can provide.

4. Increasing Students' Awareness of Soil Pollution through Various Activities

This article presents some didactic activities to increase the motivation of students regarding the learning process and to raise their awareness of soil pollution. These activities are derived from educational experiences acquired while teaching soil pollution in the Degree of Environmental Science at the Universitat Politècnica de València (Spain). The classroom activities include real-world cases, audiovisual aids, participation in online forums, and the use of computer simulation models to predict nitrate leaching.

4.1 Real-world Cases: Linking Pollutants with Health and Environmental Problems

Real-world cases can play an important role in knowledge transfer and learning motivation. Students are introduced to soil pollution using several real-world cases, which teach students about the close connection between soil pollution and the risks to humans and ecosystems. Considering that several students today are concerned about their health and the environmental consequences of their actions, the first step to getting them involved is to discuss soil contamination-risk pairing (Figure 3) by illustrating this coupling with real-world cases (Table 2).

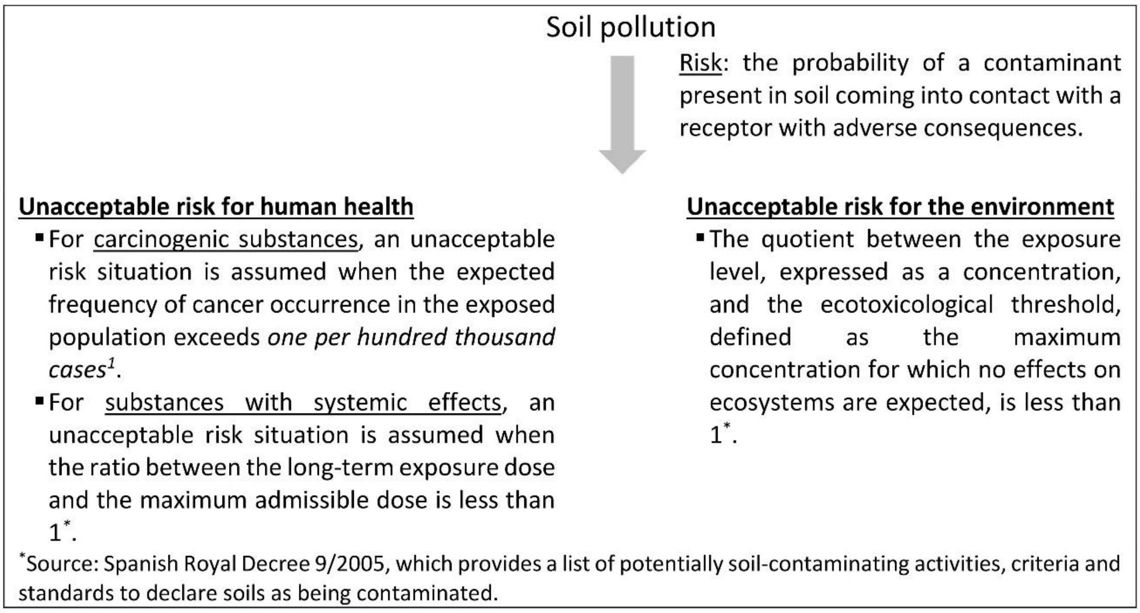

Figure 3 Definition of unacceptable risk for human health and the environment.

Table 2 Real-world cases used in lectures as part of the awareness and learning process on soil pollution.

Location	Contamination type	Year	Location	Cited by
Love Canal	Chemical	The 1970s	USA	Phillips et al. [42]
Lekkerkerk	Chemical	1970s	Netherlands	Brinkmann [43]
Aznalcollar	Chemical	1998	Spain	Madejón et al. [44]
Sabiñánigo	Chemical	From the late 1970s onwards	Spain	Gómez-Lavín et al. [45] Santos et al. [46]
London Olympic Park	Chemical	Since the 19th century	United Kingdom	Hellings et al. [47]; Mead et al. [48] Hou et al. [49]

Fukushima	Radioactive	2011	Japan	Yasunari et al. [50] Yamasaki and Utsunomiya [51]
Chernobyl	Radioactive	1986	Ukraine	Steinhauser et al. [52]; Yoschenko et al. [53]

Real-world cases like “Love Canal” (USA) [42, 54] and “Lekkerkerk” (Netherlands) [43] have been interesting for students, firstly because the relation between waste-soil contamination-health/environmental problems is clearly provided, and secondly because after these cases, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in the USA and the Soil Clean-Up Act 1983 in the Netherlands were enacted.

Two real-world cases utilized in Spain may be interesting to initiate Spanish students on the topic of soil pollution. One is the Aznalcóllar mine accident, one of the largest major mine accidents in the world and a large-scale ecological catastrophe [44]. The other is the case of the Sardas and Bailin landfills, located in Sabiñánigo (Spain), where lindane (an organochlorine pesticide) waste was dumped by a company that contaminated the soil in both the landfills [45, 46].

Another interesting real-world case may be the remediation of contaminated soils of the Olympic Park of the London 2012 Olympic and Paralympic Games. This involved maximum reuse (about 80%) of the soil cleaned from the Olympic Park, which avoided transporting large volumes of waste to landfills, applying four on-site remediation techniques. The pollution model (source-pathway-receptor) and project good practices have been published [47, 48].

Two major nuclear power plant accidents occurred in Fukushima and Chernobyl. Research information about the characterization of these radioactively contaminated sites, the methods used for reducing the volume of contaminated soil, and the removal of radioactive contaminants from the soil [50-53] may be studied in class with the students.

Other real-world cases that may be used in the classroom are found in the document “European achievements in soil remediation and brownfield redevelopment” [55]. These examples represent relevant soil remediation and brownfield redevelopment achievements (e.g., 2012 London Olympic Park). The examples presented in the document demonstrate progress in research and innovative technologies, novel approaches for soil remediation management, the beneficial integration of stakeholders into decision making, and fruitful progress in raising public awareness and citizen science [55].

The students work on real-world cases as project work through training in the classroom. Students form teams with three or four members. Project-based learning is introduced at the beginning of the course, which they presented orally at the end of the course. Their presentations comprise the following: location, surface and depth of contamination, involved company, event, origin, causes of contamination, contaminants (concentration, toxicity, physicochemical properties, soil screening value), receptors, conceptual site model, consequences of contamination for health and the environment, clean-up strategies, social consequences of contamination, regulation (official soil contamination declaration), etc. The students were guided in real inquiry, in planning their tasks, and also in finding acceptable sources of information. Participation with the accompaniment of representatives of soil pollution companies will be implemented in future work throughout the project period, with them attending the oral presentation as guest lecturers.

After studying these real-world cases, students understand that the first soil pollution principle is prevention as the best way to take care of the soil, groundwater, human health, and the environment. Soil pollution principles may be explained by appealing to the student's sense of responsibility to the environment and future generations. The Prevention Principle means that action should be taken to protect the environment at an early stage. This principle aims to prevent damages from occurring in the first place [56]. Taking preventive measures for soil contamination is a direct way toward the conservation of natural resources, reducing exposure to chemical products, and preserving the environment [57].

The Precautionary Principle implies that "If there is a strong suspicion that a certain activity may have environmental harmful consequences, it is better to act legally before it is too late, rather than wait until scientific evidence is available" [56]. The Proximity Principle considers that waste should be managed as near as possible to its place of generation, mainly because transporting waste has a significant environmental impact (EC Framework Directive on Waste). Therefore, remediation actions should prioritize *in situ* treatment techniques that avoid the generation, transfer, and elimination of waste. The Polluter Pays Principle implies that "Polluters bear the costs of their pollution, including the cost of measures taken to prevent, control and remedy pollution and the costs it imposes on society" [58].

Decisions on the clean-up, management, or setting aside of polluted soil are based on several considerations, including ecological and human health risks. It is, therefore, crucial that students learn how to conduct a risk assessment, including how to carry out a preliminary investigation, design a sampling protocol, and carry out a detailed risk assessment, as well as have the relevant knowledge about using computer-based models for transporting contaminants in soil and groundwater.

4.2 Audiovisual Aids: Stimulating Critical Thinking on Soil Pollution

Audiovisual aids may be used to support the teaching and learning process [59]. Well-informed documentaries on soil remediation techniques prepared by industrial companies are available online. A documentary was used to support the Sabiñánigo case study (Table 2; [60]), a site contaminated with lindane (γ-hexachlorocyclohexane) [45]. Students are asked to deliver a report that outlines and discusses waste management, the toxicity and chemical properties of lindane, the relationship between contaminated soil and contaminated water, the environmental and health consequences of irresponsible industrial practices, landfill requirements for collecting toxic waste, soil remediation techniques and the application of the Polluter Pays Principle. This activity functions on the transversal competence of "critical thinking".

The documentary entitled "Going for Green: Britain's 2012 dream" min 7:25–12:20 [61] is shown in the classroom to support the London Olympic Park case study. Students are then asked to mention which contaminants may be found in an abandoned industrial site by considering the site's historic industrial activity [48] and to preselect the soil remediation technologies that can be applied at the site based on sustainability considerations [49]. In addition, they are asked about the advantages of carrying out the *ex-situ* on-site soil washing technique for soil remediation and discuss the reason for separating gravel and sand from the other soil materials. The students are further asked to relate this to the colloidal properties of clay particles and to ascertain the disposal of a filter cake which is a resultant of fine silts and clays after soil washing. They are then asked about the techniques that can be applicable for finer-grained soils contaminated principally by hydrocarbons. Students are taught that this decontamination is achieved through *ex-situ* bioremediation using a bioremediation bed (biopile) [48].

Another documentary to be used with students is one prepared by the Kepler company [62]. It deals with a pilot-scale project for the bioremediation of two contaminated soils with different granulometries and a total petroleum hydrocarbons (TPH) concentration in biopiles. After the students watch the video, they work in small groups and discuss the differences between biostimulation and bioaugmentation techniques, how to obtain specialized bacterial cultures, pile system requirements, the importance of soil granulometry, and the TPH concentration to fulfilling bioremediation goals. In addition, they are encouraged to take an in-depth look at problems caused by iron in one of the soils and later discuss which of the two bioremediation techniques are more effective and which technique (biostimulation or bioaugmentation) is the most effective. Finally, they discuss the advantages of bioremediation techniques. Before viewing this audiovisual in the classroom, students learn about TPH using a questioning technique. They are asked what TPH is and if TPH has a defined mixture. When students become aware that TPH has no defined mixture due to different origins of crude oil, refining process, and environmental degradation, they understand that the toxicity of the mixture and its migration potential depends on the TPH composition. They are then asked if the TPH measurement in soil samples can be used as a first indication of the presence or absence of soil contamination. Students would have been taught beforehand that, according to Spanish regulation [63], if the TPH value of the soil exceeds 50 mg/kg, it is mandatory to perform a quantitative risk assessment. The students are later asked if the global TPH value provides enough information to be able to characterize a risk at a site. They are then introduced to the "fraction-based" approach developed by the Total Petroleum Hydrocarbons Criteria Working Group (TPHsCWG) to assess human health risks by evaluating individual compounds of potential concern (e.g., benzene, toluene, ethylbenzene, and xylene (BTEX), carcinogenic polycyclic aromatic hydrocarbons (cPAHs)) and the inclusion of biodegradation metabolites by an assessment of human health risks.

4.3 Exploring Legal Frameworks: Can We Improve Our Soil Pollution Laws and Regulations? Think about It!

Exploring advanced soil pollution regulations may be a challenge for students. The objective of this activity is for students to learn to undertake a high-level assessment of legal frameworks for soil contamination to both: i) use the frameworks and tools offered by legal and policy arrangements to avoid soil contamination and remediate polluted soil; ii) advocate improvements in legal, policy and institutional arrangements to avoid soil pollution.

Varied aspects of soil contamination and soil pollution are addressed in several legal documents. For instance, in the European Union, it is not straightforward to find the relevant legal documents that affect soil contamination considering they are scattered across different policies and regulations. In class, students learn to undertake a legal scan for soil contamination [64], including the collection of key legal documents, identifying and managing relevant information, organizing information, reflecting and analyzing information, and presenting it to their classmates.

Currently, the Spanish regulation on the protection of the environment, and particularly of soil, considers only heavy metals to be potential harmful compounds when sewage sludge is used in agriculture. It is interesting for students to work on more advanced regulations [65] like Decree

453/2013, which aims to regulate the use of sewage sludge in agricultural and forest soils in the Basque Country (Spain) and consider metals, organic compounds, and microorganisms. Another advanced regulation is Law 4/2015 for the prevention and remediation of soil contamination in the Basque Country, which includes a ban on producing a resolution declaring a site in which there is an old uncontrolled waste deposit or a landfill containing hazardous waste suitable for housing use.

Various topics (e.g., regulation of organic contaminants in the sewage sludge to be used in agricultural soils, prohibition in different countries of using sewage sludge by considering soil characteristics such as pH and cation exchange capacity, prioritizing contaminant encapsulation techniques against their transfer to landfill, building houses on a previously uncontrolled waste deposit) are offered to groups of students to avoid them feeling overwhelmed by the amount of legal information. They will then present their findings orally to the whole class.

Activities in the future may include drafting a bill. This may either be for a law that does not exist or an amendment to existing law. A "bill template" may be provided to the students. Students will develop the rationale for their legislation and establish the title, the enactment cause, and the legislative body, including the main effect of legislation, limitations or restrictions, and penalties that accompany the new law. Each proposed bill will then be debated in class.

4.4 Computer Simulation Model: Soil Pollution-Water Pollution

The connection between soil contamination and groundwater contamination may be shown to the students using simulation models. Excessive use of fertilizers constitutes an environmental risk that can affect human health and pollute water. Applications of nitrogen-based fertilizers and livestock manure to soils may lead to groundwater pollution through nitrate percolation. In the Bachelor's Degree in Environmental Science at the Universitat Politècnica de València, the LEACHM (Leaching Estimation and Chemistry Model) [66] is used to evaluate the effect of nitrogen fertilization on nitrate leaching with citrus production. Students should have previous knowledge of the behavior of different nitrogen chemical forms, including mobility in soils, adsorption to the soil cationic exchange complex, leaching, and root absorption. In an intensive irrigated agriculture scenario, with high inputs of fertilizers and pesticides and with groundwater used for human consumption, the students analyze the incidence of the provided nitrogen fertilizer dose, the chemical form used, and the fractionation of the application on nitrate leaching with the LEACHM model. The model describes nitrogen transport and transformation in unsaturated soils. Students determine the application rates required for optimum crop growth and minimal nitrate leaching during this exercise. The results they obtain are: i) using ammoniacal N forms in spring and nitric-ammoniacal forms in summer reduce the risk of leaching; ii) the fractionation of the N dose during the growing season in three applications, compared to one application or two reduces N losses due to N leaching; iii) after dry winters, a 50% reduction in N provided in the first application of spring saves fertilizer and reduces nitrate leaching; iv) the need to consider soil organic matter mineralization in the calculation of N fertilizer to contribute to minimizing losses by leaching.

The use of LEACHM allows students to understand the influence of soil texture, organic matter content, and pH in the adsorption and leaching of the different herbicides used to grow citrus crops. Likewise, the amount of leached pesticides and the residual amounts remaining in the soil profile depends on the half-life of the herbicide and its adsorption coefficient, with degradation being the primary route of most of the active materials used in the reduction of this crop.

The exercise concludes with a proposal of specific measures to reduce N leaching and, therefore, the possible nitrate contamination of groundwater. Students should consider that the amount of applied N fertilizers should be per the legislation on the protection of waters against diffuse pollution produced by nitrates from agricultural sources, soil conditions, soil type, slope, climate conditions, rainfall and irrigation, land use, and agricultural practices.

4.5 Online Forum: Highly Competent Professionals in Soil Pollution for the Labor Market

An important goal of the lectures is to prepare students for the labor market. Students will need to know the services that companies dedicated to contaminated land research and remediation of the land contaminated offer. Companies have the experience, equipment, and technical knowledge to diagnose and clean up soil contamination. Several company websites include confirmed case studies of soil remediation that can also help students in improving their knowledge of soil pollution. An enrichment activity for students could be an online forum in which they discuss the information collected from companies. This information may include: i) the aspects of the consultancy process in a preliminary risk assessment; ii) examples of conceptual site models; iii) intrusive site investigation; iv) soil sampling; v) remediation options; vi) cost and sustainability analysis for each possible remediation technique; vii) design, planning and implementation of remediation; viii) technologies for the remediation of contaminated soils; ix) long-term monitoring plans; x) treatment licenses that enable companies to offer treatment technologies; xi) contaminants included in hazardous waste management licenses; xii) software for risk assessment, etc.

With this activity, students may begin to meet industry needs and be aware of the developments in the industry. Field et al. [67, 68] argue that the main focal point of soil science education is to develop active and independent thinking of soil science graduates who will meet industry needs and that of research.

Universities should be aware of the need to promote collaboration among industries, research, and education to train individuals to become highly competent soil pollution professionals.

5. Conclusions

This study contributes to the core body of knowledge on soil contamination. Teaching soil pollution is a challenge. There are several didactic tools to encourage in-depth study of soil pollution. This matter (I refer to soil pollution) is relevant for food safety, food security, soil health, human health, and ecosystems. This paper attempts to highlight the importance of teaching and active learning to ameliorate soil contamination and soil pollution by raising the awareness of students. Students are asking for activities such as real-world cases, case studies, audiovisual aids, and field trips. They should meet industry needs and those of research. A better connection between students, lecturers, and companies is therefore necessary.

Author Contributions

Cristina Lull: conceptualization, writing, reviewing and editing. Antonio Lidón: reviewing and editing. María Desamparados Soriano: reviewing and editing.

Competing Interests

The authors have declared that no competing interests exist.

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