Ecological Assessment of Anthropogenic Impacts on the Soil Cover in the Absheron Peninsula

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Abstract

Soil ecosystems serve as crucial carriers of ecological functions, ensuring the sustainability of biocenoses, nutrient cycling, and agricultural productivity. However, intensive anthropogenic impacts—including industrialization, urbanization, and agricultural expansion—lead to the transformation of the morphogenetic characteristics of the soil cover, structural degradation, and disruption of chemical balance. Therefore, the conducted studies comprehensively assessed the ecological and geochemical status of soils on the Absheron Peninsula under the influence of anthropogenic pressure. In these studies, soil samples collected from the districts of Garadag, Surakhani, and Sabunchu were analyzed for pH, electrical conductivity, nitrogen-phosphorus-potassium balance, particle size distribution, as well as by X-ray spectral and X-ray diffractometric methods. The results indicate that the soils are predominantly characterized by weakly to strongly alkaline conditions, with certain areas exhibiting nutrient deficiencies and elevated ion concentrations. Samples obtained from oil fields in the Sabunchu district showed evidence of organic contamination, high carbonate content, and enrichment with heavy metals, indicative of ecotoxicological effects. Additionally, using GIS technologies and satellite imagery, the degradation status of the land cover, the degree of disruption in soil-vegetation integrity (expressed in percentages), and existing materials were assessed, allowing for the classification of soils into four ecological status groups: satisfactory (5%), conflicted (48%), critical (5%), and catastrophic (42%). This categorization confirms that the soil resources of the peninsula are under severe ecological risk.

Keywords: ecosystem, anthropogenic impacts, degradation, chemical balance, ecological, electrical conductivity, ion concentration, ecological risk

1. Introduction

Soil ecosystems, as an integral component of the environment, play a vital role in vegetation development, the cycling of water and nutrients, and human life activities (İmanova S. H., 2014, Geography of the Republic of Azerbaijan, Vol. 1).

Soils are not limited to serving as resources for agriculture and industry; they are also essential components for the conservation of biodiversity and the sustainable development of the environment. However, anthropogenic activities have increasingly impacted soils in recent years, negatively affecting their structural, functional, and chemical properties (Alizadeh E. K., Rustamov Q. I., Karimova E. J., 2015; Hasanov X. E., 1998).

A number of researchers have conducted various scientific studies to assess the degradation, pollution levels, and ecological-geochemical characteristics of the soil cover on the peninsula (Alizadeh, E. K., Rustamov, Q. I., Karimova, E. J., 2015; Ismayilov, A. I., Yashar, Ə. Y., Feyziyev, F. M., 2021; Mammadov, Q. Sh., Həkimova, N. F., 2003; Mirzayev, A. B., Shikhaliyev, F. B., 2012; Suleymanov, T. I., Yashar, Ə., 2016; Budagov, B. A., Mamedov, R. M., Ismatova, Kh. R., Mikayilov, A. A., 2002; Bayramova, L. A., 2024; Guliyev, A., Islamzade, R., Suleymanova, P., Babayeva, T., Aliyeva, A., Hajiyeva, Kh., 2024; Hajiyeva, G. N., Ibrahimova, L. P., 2024).

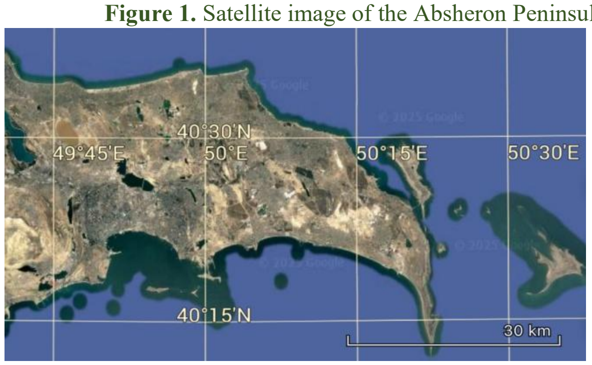
However, the analysis of existing studies indicates that over the past decade, intensive anthropogenic pressures on the soil cover of the area have exacerbated ecological problems. Therefore,

there is a need for a comprehensive assessment of the physical-chemical properties, biological productivity, natural resilience, balance against anthropogenic pollution, and overall ecological status of the soils of the Absheron Peninsula under contemporary conditions, as well as for identifying future development trends. In this context, the ecological assessment of anthropogenic impacts on the soil cover of the Absheron Peninsula remains highly relevant.

2. Materials and Methods.

The Absheron Peninsula, selected as the study area, is located in the southeastern part of the Republic of Azerbaijan and covers an area of 2,110 km². To the north, the peninsula is bounded by the city of Sumgait and the surrounding territory of the Absheron District (Fig. 1).

Figure 1. Satellite image of the Absheron Peninsula



The eastern boundary of the Absheron Peninsula is limited by the Caspian Sea. This part of the peninsula includes sea-related ports, oil platforms, and industrial facilities. The eastern boundary encompasses the peninsula's most remote coastal points. The southern boundary is also bordered by the Caspian Sea, covering the southern coastal areas of Baku, including Bibiheybet, Bayil, and Shikov. The southern shores of the Absheron Peninsula are also known for oil platforms and industrial zones. To the west, the peninsula is bordered by the low-mountainous areas of Gobustan, with a length of approximately 60 km and a maximum width of 30–35 km (Mammadov, Ə. Y., Suleymanov, (2011); Shirinov, N. Sh., Valiyev, X. A., Aliyev, (1998); Geography of the Republic of Azerbaijan, Vol. 1, 2014).

The peninsula includes the cities of Baku, Sumgait, and Khirdalan, where approximately 40% of the country's population resides (Environmental Status in Azerbaijan, 2025., Regions of Azerbaijan, 2024).

A comprehensive approach was applied to study the impact of anthropogenic factors on the soil cover of the Absheron Peninsula, utilizing the following methods:

Route Observation. Visual observations were conducted at pre-designated sites within the study area to assess the impact of anthropogenic factors on the soil-vegetation cover. Structural changes occurring on the soil surface were recorded. In addition, the effects of industrial enterprises, settlements, and agricultural fields on the soil cover were evaluated through direct observation.

Laboratory Analysis. Physical and chemical analyses were conducted on soil samples collected from the selected study sites. Parameters such as pH, humus content, pollutant concentrations, and other key characteristics were determined. These analyses provided a substantial database for assessing the impact of anthropogenic factors on soil quality.

Geographic Information Systems (GIS) Analysis. To achieve the main objectives of the study, observations were conducted across various areas of the peninsula using modern Geographic Information Systems (GIS) and satellite imagery. Visual changes in the soil cover and anthropogenic impacts were mapped. Analyses of satellite images were performed to determine changes in soil cover and levels of degradation. GIS technologies were used to assess the spatial distribution dynamics of anthropogenic effects and to identify the factors and directions of landscape transformation.

Statistical Analysis. Systematic statistical analyses were conducted on the collected data to determine the relationships between various anthropogenic impacts and soil properties. The results of soil analyses were comparatively evaluated using statistical methods to assess the degree of anthropogenic influence.

Comparative Analysis. Based on observations and analyses conducted in areas with different ecological conditions and levels of anthropization, comparisons were made. Soil sites located near and far from industrial facilities were compared to determine the extent of anthropogenic effects on the soil cover.

3. Analysis and Discussion

Based on the applied methods, a scientific analysis of the impact of anthropogenic factors on the soil cover in the studied area was conducted, and several essential recommendations were proposed for the conservation and restoration of soil resources in the region.

For the study, areas of the Absheron Peninsula with varying degrees of anthropization were selected. Industrial zones, residential areas, and regions with livestock farms were the main criteria for selection. Soil samples were collected from these areas and analyzed under laboratory conditions. The sampling sites covered the industrial zones of Garadag, Surakhani, and Sabunchu (Fig. 2).

Figure 2. Observation pilots

The physical-geographical conditions of the sampling sites were initially analyzed in a laboratory setting. At each sampling plot, the soil surface was cleared of vegetation, and a profile was excavated to collect soil samples from specified depths. Samples were taken using the envelope method from depths of up to 30 cm, where the root system of the vegetation and the majority of organic matter are concentrated. The envelope method involved dividing the plot into five points—four corners and one center. From each point, soil samples were collected at depths of 0–10 cm, 10–20 cm, and 20–30 cm, then mixed separately by depth to produce a composite sample for each site (Fig. 3).

Figure 3. Soil sampling procedure

Figure 4. Packaging of soil samples

After collection, the soil samples were sent to the Soil Science and Agrochemistry Institute of ANAS (Azerbaijan National Academy of Sciences) for laboratory analyses.

In the laboratory, both physical and chemical analyses were conducted on the soil samples. The physical analysis determined the particle-size distribution of the soil, providing information about its physical properties, while the chemical analyses allowed evaluation of the main agrochemical parameters of the soil solution.

To examine the chemical characteristics and structural composition of the soil, X-ray spectral and X-ray diffractometric methods were applied.

- pH value: The electrometric method was used to assess the acidity-alkalinity balance of the soil. This parameter directly affects soil biological activity and the uptake of nutrients by plants.
- Total nitrogen (N): Determined using the Kjeldahl method, this parameter was used to evaluate the nitrogen reserves and productivity potential of the soil.
- Available phosphorus (P): The content of available phosphorus was determined using the Olsen method. This analysis assessed the soil's phosphorus supply level and fertilization requirements.
- Available potassium (K): Measured using the ammonium acetate extraction method, this parameter evaluated the soil's potassium richness. Potassium is a macronutrient crucial for the soil-plant system, and its content is a key indicator of soil fertility.
- Electrical conductivity: Measured to determine soil salinity and ion concentration, this analysis helps identify processes of salinization and sodification in the soil.
- Soil texture: The particle-size distribution (sand, silt, clay) was determined using the hydrometer method. This analysis provided information on soil structure, water retention capacity, aeration, and resistance to erosion.

Thus, within the study methodology, soil samples were collected from selected sites and analyzed for their physical and chemical properties using modern laboratory techniques. The applied methods allowed assessment of changes in the soil cover and the identification of anthropogenic impacts. The obtained results provide a basis for developing effective measures to prevent soil degradation in the next phase of the study.

The data obtained from mechanical and chemical analyses of soil samples collected from observation plots, along with GIS analysis of satellite imagery, clearly demonstrate the varied impacts of anthropogenic factors on soil properties in the Absheron Peninsula.

Sample 1. Collected from the Garadag district (40°27'35" N, 49°39'38" E), the soil had a pH of 7.8, indicating a mildly alkaline condition. Mildly alkaline soils, with pH values between 7 and 8.5, significantly influence plant growth and soil productivity. In these soils, the mineral and chemical composition plays a crucial role in plant development and agricultural suitability.

Mildly alkaline soils are generally considered fertile due to high organic matter and mineral content, which enhances productivity. However, under highly alkaline conditions, the mobility of certain micronutrients, particularly iron and phosphorus, may decrease, negatively affecting nutrient uptake by plants. Water retention and circulation are also important; these soils usually have good drainage, preventing prolonged water retention and providing favorable conditions for crops. Additionally, high carbonate content strengthens soil structure and can influence root system development. Therefore, although mildly alkaline soils possess positive productivity potential, appropriate agrotechnical management can further enhance their fertility.

Sample 2. Collected from the Surakhani district (40°28'39" N, 49°56'23" E), the soil also exhibited a pH of 7.8, indicating mildly alkaline conditions. Its characteristics are similar to Sample 1; however, the proportions of nitrogen, phosphorus, and potassium differ from the first sample.

Sample 3. Collected from an oil-extracting area in the Sabunchu district (40°26'48" N, 49°55'41" E), the soil had a pH of 8.8, indicating strongly alkaline conditions. Strongly alkaline soils have a pH above 8.5, creating a more challenging environment for plant growth. High alkalinity in these soils can limit the uptake of certain minerals by plants, reducing soil fertility.

The mineral composition of strongly alkaline soils, particularly calcium and magnesium, is high, which can alter soil structure, leading to compaction and disruption of water circulation. Water retention is shorter in these soils, aiding drought resistance; however, excessive water can damage soil structure and plant root systems. High alkalinity also reduces the mobility of certain micronutrients, especially phosphorus and iron, limiting their absorption by plants. Consequently, plant nutrition is weakened, and growth is slowed.

Table 1. Results of chemical analyses of the study sites

Sample №	Sample name	pH	Degree of soil nutrient supply (based on gradation)			EC (ds/m) – Electrical Conductivity
			Nitrogen 40-120 Mg/kg	Phosphorus 15-60 Mg/kg	Potassium 300-600 Mg/kg	
			Sample nutrient supply indicator			
			Nitrogen N/NH_4 Mg/kg	Phosphorus P_2O_5 Mg/kg	Potassium K_2O Mg/kg	
1	Garadag (40°27′35″ N, 49°39′38″ E)	7.8	7,76	22,22	177,13	2,87
2	Surakhani (40°28′39″ N, 49°56′23″ E)	7.8	5,17	18,89	134,96	2,12
3	Sabunchu Oil Area (40°26′48″ N, 49°55′41″ E)	8.8	6,9	23,33	169,90	1,97

As shown in the table, the soil samples were found to have very low availability of nitrogen in the ammonium form, moderate availability of available phosphorus, and very low availability of exchangeable potassium—all of which are essential nutrients for plant uptake.

The presence of key nutrients such as nitrogen, phosphorus, and potassium in the soil is crucial for healthy plant growth and high productivity. The availability of these three primary elements directly affects nutrient uptake by plants and their overall development.

Nitrogen is one of the most important nutrients for plants. It plays a fundamental role in the production of proteins and other organic compounds. Adequate nitrogen in the soil promotes vegetative growth, stimulates leaf and stem development, and participates in photosynthesis, providing energy for plants. However, excessive nitrogen can weaken root development and disrupt the balanced uptake of nutrients.

Phosphorus is a microelement essential for energy metabolism, root development, and flowering. Its presence in the soil supports healthy root system growth and contributes to photosynthesis and other biochemical processes. Phosphorus deficiency can lead to weak plant development and reduced productivity.

Potassium regulates water circulation in plants, strengthens cell walls, and enhances resistance to diseases. Adequate potassium in the soil improves nutrient uptake, facilitates water-related processes, and increases stress tolerance, contributing to overall plant health. Potassium deficiency can result in poor plant growth and lower yields.

The electrical conductivity (EC) indicated in the table reflects the soil's ability to conduct electric current and is primarily related to the concentration of ions in the soil. High electrical conductivity signifies a high content of salts and minerals, which can hinder plant growth. Low electrical conductivity indicates low levels of minerals and ions, which may reduce soil fertility. In summary, soil electrical conductivity is a key indicator of soil salinity and productivity.

In the analyzed soil samples, low salinity was observed. Notably, Sample 3, contaminated with oil, showed lower salinity compared to the other samples.

Soil texture represents the proportion of mineral particles (sand, gravel, clay, etc.) in the soil. This composition significantly affects soil structure and properties. For example, sandy soils have good drainage but low water retention, whereas clay soils retain water well but have poor aeration. Soil texture is crucial for water retention, air circulation, and root development.

The analyzed soil samples were found to be loamy-clay in texture. Loamy-clay soils occupy an intermediate position between sandy and clay soils in terms of structure. They allow good water and air permeability while retaining adequate moisture. The mechanical composition of light loamy soils facilitates cultivation and is favorable for agriculture. However, to maintain fertility, these soils should be enriched with organic matter and managed with proper irrigation practices.

Table 2. Results of mechanical analyses of soils in the study area (percentage of each fraction relative to total soil mass)

Sample No	Section No	1-0,25	0,25-0,05	0,05-0,01	0,01-0,005	0,005-0,001	<0,001
1	Garadag (40°27′35″N, 49°39′38″ E)	1,70	14,70	12,00	9,60	24,00	38,00
2	Surakhani (40°28′48″N, 49°56′23″ E)	4,66	71,74	12,00	2,80	4,00	4,80
3	Sabunchu Oil Area (40°26′48″ N, 49°55′41″ E)	11,10	64,90	11,20	1,60	6,00	5,20

As shown in the table, the soil at the observation site in Garadag is primarily loamy-clay in texture. The high proportion of clay and silt particles indicates strong water retention and a dense soil structure. This soil type can lead to slow water infiltration and increased susceptibility to erosion.

The soils at the observation site in Surakhani mainly consist of coarse silt particles. Such soils retain a moderate amount of water but are prone to wind erosion.

At the Sabunchu Oil observation site, coarse silt particles predominate, but the relatively higher sand content indicates a lighter soil structure. This soil type allows better water permeability but increases water loss and sensitivity to drought.

Furthermore, results from X-ray spectral analysis of the soil sample from the Sabunchu Oil site revealed significant changes in the chemical composition. The analysis indicates that several soil properties reflect anthropogenic impacts, particularly contamination from oil and petroleum products.

Table 3. Results of X-ray spectral analysis (chemical composition) of the oil-contaminated soil sample

Name of chemical substance	Percentage (%)
Na_2O	1,60
MgO	1,55
Al_2O_3	9,26
SiO_2	50,31
P_2O_5	0,16
SO_3	0,45
K_2O	2,33
CaO	14,02
TiO_2	0,74
MnO	0,13
Fe_2O_3	6,02
BaO	0,09
SrO	0,07
ZrO_2	0,07
ZnO	0,05
Cr_2O_3	0,02
NiO	0,01
CuO	0,01
Rb_2O	0,0095
CT	0,59
LOİ (Loss on Ignition at 950 °C)	12,51

As shown in the table, the oil-contaminated soil sample is predominantly composed of silicon dioxide (SiO_2) – 50.3%. Additionally, aluminum oxide (Al_2O_3) – 9.26%, iron oxide (Fe_2O_3) – 6.02%, magnesium oxide (MgO) – 1.55%, potassium oxide (K_2O) – 2.33%, and sodium oxide (Na_2O) – 1.60% were observed. The high content of calcium oxide (CaO) – 14.02% indicates the presence of carbonate deposits or technogenic impacts in the soil.

The presence of phosphorus pentoxide (P_2O_5) – 0.16% and sulfur trioxide (SO_3) – 0.45% can be considered as factors increasing soil acidity, likely resulting from industrial and petroleum activities. Furthermore, the loss on ignition (LOI) at 950 °C was 12.51%, indicating a high amount of carbonates, oil residues, hydrocarbons, and other volatile substances in the soil.

The analysis also revealed that the total organic matter content is 9.23%, highlighting a high level of organic contamination, directly associated with organic compounds introduced into the soil through oil extraction activities

4. Conclusion.

The results of our study on the soils of the Absheron Peninsula indicate that anthropogenic impacts in the investigated area have affected both the physical and chemical properties of the soil, weakened its natural structure, reduced fertility, and increased its sensitivity to exogenic processes. The influence of anthropogenic factors has caused significant changes in the physical and chemical characteristics of the soil cover. In areas contaminated with industrial and petroleum waste, soil structure degradation, depletion of the fertile layer, and increased salinity were observed.

The analysis of the mechanical composition of soil samples showed that in some areas the proportion of clay and silt fractions had increased, leading to disturbances in water and air regimes, higher soil compaction, and increased susceptibility to erosion. Chemical analyses demonstrated variability in the content of essential nutrients, with some areas showing deficiencies in nitrogen, phosphorus, and potassium, while others exhibited increased salinity. Additionally, X-ray spectral and X-ray diffraction analyses revealed that soils were heavily exposed to petroleum-derived contamination, with high contents of carbonates, clays, and metal-bearing oxides (Fig. 5

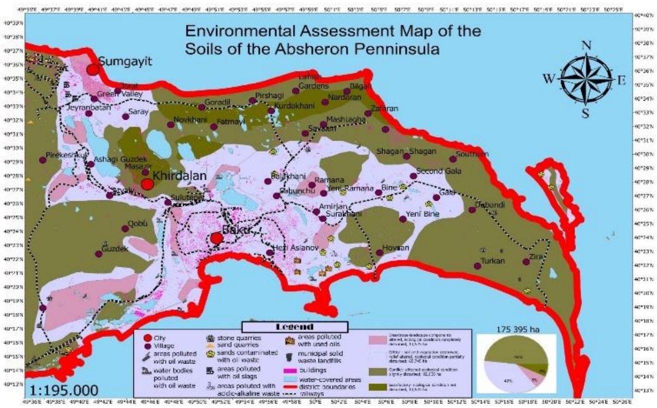


Figure.5. Ecological assessment of soils in the Absheron Peninsula

In the final stage of the study, based on a systematic analysis of the existing materials and satellite imagery, the soils of the peninsula were classified into four categories according to their ecological status: satisfactory (5%), conflicted (48%), critical (5%), and catastrophic (42%).

The results indicate that 95% of the peninsula's area has lost its natural balance, experiencing varying degrees of ecological transformation. Comparative analyses show that in all analyzed soil samples, the permissible limits of heavy metals (MPC indicators) have been exceeded. In particular, Fe, Cu, Ni, Zn, and Cr present a very high risk of contamination, which is primarily of technogenic origin.

The main sources of contamination include oil and industrial waste, sludge, acidic and alkaline substances, as well as waste from stone and sand quarries and municipal waste.

Comparison of the soil's mineralogical composition with normal reference le-vels indicates a high content of calcite, anorthite, and hematite, reflecting strong anthropogenic influence. Although clay minerals (montmorillonite, illite, and kaolinite) are present at sufficient levels, the low proportion of montmorillonite suggests limited swelling capacity and restricted water retention. The low SiO_3 content indicates a soil with a heavy fraction and structurally weak charac-teristics (Fig.6).

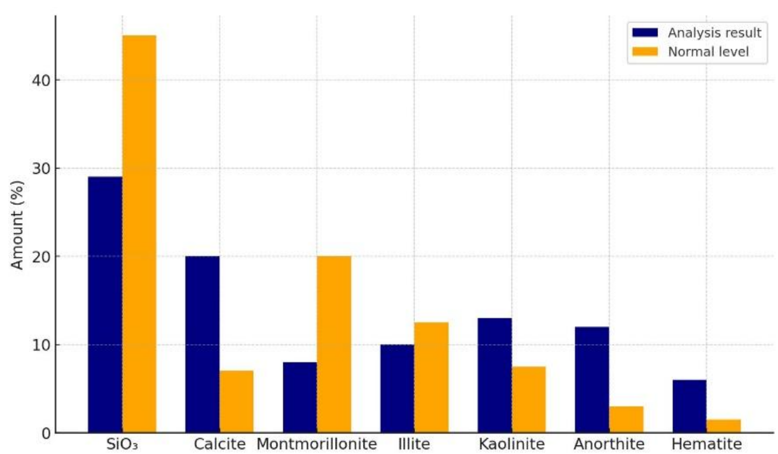


Figure 6. Comparison of soil mineral composition

The obtained results indicate that restoring the ecological balance of the soil cover in the Absheron Peninsula requires the implementation of proper soil management strategies. Implementing comprehensive measures aimed at preserving fertility, preventing erosion, and rehabilitating contaminated soils is crucial for environmental sustainability.

Currently, there is no single standardized reclamation model for restoring oil-contaminated soils worldwide. This is mainly due to the diverse physical-geographical conditions of oil- and gas-producing areas.

The choice of the method to be applied depends on several factors, including the intensity of contamination, oil composition, duration of contamination, soil physicochemical properties, landscape, and climatic conditions (Agayev, Sh. B., Afkerov, Q. X. (2007); Aslanov, H. Q., Safarli, S. A. (2008); Hasanov, X. A. (1998); Ibadova, S., Aliyeva, N., Abdullaeva, K., Bagirova, N. (2025).

The financial costs required for carrying out soil reclamation and phytoremediation measures on the Absheron Peninsula have been estimated based on an approximate economic evaluation. The total area of the peninsula is 211,000 hectares. Based on general analyses of the area, it was determined that 82,000 hectares are slightly degraded, 65,745 hectares are partially degraded, and 13,925 hectares are completely degraded. The economic evaluation of reclamation and phytoremediation measures to restore the soil cover of the area is presented in Table 4.

Table 4. Approximate Economic Evaluation of the Absheron Peninsula Soils

(Calculations are based on projects implemented by SOCAR)

Type of Measure	Area (ha)	Average cost (AZN)	Total cost (AZN)
Phytoremediation (weakly degraded areas)	82,000	600	49200000
Reclamation(partially degraded areas)	65745	1200	78894000
Reclamation+Phytoremediation (fully degraded areas)	13925	1600	22280000
Total	-	-	150374000

Thus, based on our economic assessment, it has been determined that the total investment required for the restoration of the soil cover and the maintenance of ecological balance is approximately 260–270 million AZN.

The results indicate that the implementation of reclamation and phytoremediation measures is essential for restoring the ecological stability of the soil cover in the Absheron Peninsula. According to the economic analysis, the total investment needed for this process is estimated at 260–270 million AZN.

The analyses and results presented in this article provide a basis for identifying practical measures to protect soil resources and ensure the sustainability of the natural environment.

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