BABEȘ-BOLYAI UNIVERSITY

FACULTY OF ENVIRONMENTAL SCIENCE AND ENGINEERING
DOCTORAL SCHOOL OF ENVIRONMENTAL SCIENCE

# DOCTORAL THESIS SUMMARY

## Investigating Agricultural Contributions to Environmental Degradation Using Agri-Environmental Indicators and the Role of Sustainable Alternatives in Transylvania, Romania

**SCIENTIFIC COORDINATOR:**
Prof. Univ. Dr. Eng. Alexandru OZUNU

**PhD CANDIDATE:**
Ionuţ-Alexandru SPÂNU

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# CHAPTER I General Introduction

## 1.1 The Aim and Objectives of the PhD Thesis

The aim of this thesis is to conduct a comprehensive investigation into agricultural sustainability in the Transylvania region of Romania by employing Agri-Environmental Indicators (AEIs). This research undertakes a detailed examination of the 28 AEIs established by the European Union (EU) to assess their relevance and applicability within the context of sustainable agricultural practices. Furthermore, the study evaluates the perceptions and insights of key stakeholders regarding the effectiveness and practical utility of these indicators. A particular emphasis is placed on the critical issue of water contamination, specifically concerning pollution caused by pesticides and nitrates. To address this concern, two AEIs – "Water Quality: Pesticide Pollution" and "Water Quality: Nitrate Pollution" – serve as focal points for analysis, enabling an in-depth exploration of their implications for sustainable agricultural practices in the region. By adopting this approach, the thesis contributes to enhancing agricultural sustainability in Transylvania while aligning with broader European environmental objectives.

To achieve this aim, the study pursues the following four objectives:

1. The first objective is to compare the 28 AEIs of the European Union with those established by the Organization for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization (FAO). Additionally, this objective involves analyzing how these indicators are reflected in existing scholarly literature on agri-environmental indicators. Consequently, a systematic literature review was conducted to assess the role of AEIs in measuring agricultural sustainability.

2. The second objective is to examine stakeholder evaluation of the EU's 28 AEIs in relation to multiple sustainability criteria. At the national level, the development of indicators, including AEIs, often occurs through stakeholder dialogue. This interactive process incorporates stakeholders' perspectives, values, and regional specificities, thereby bridging the gap between practitioners and researchers working towards agricultural sustainability. An evaluation matrix was utilized as an effective tool for capturing stakeholder opinions on the 28 agri-environmental indicators, facilitating their assessment based on predefined criteria.

3. The third objective focuses on assessing nitrate concentrations in the drinking water of Aiton village. This analysis employs Agri-Environmental Indicator 27.1, "Water Quality: Nitrate Pollution," to determine nitrate levels, identify potential sources of

contamination, and assess the role of agricultural activities in nitrate pollution. This investigation provides a deeper understanding of the environmental and public health implications of nitrate contamination, offering practical recommendations for improving water safety and sustainable agricultural practices in Aiton village.

4. The fourth objective is to assess the potential contamination of drinking water in Aiton village due to pesticide use. This analysis utilizes the AEI "Water Quality: Pesticide Pollution" to quantify pesticide concentrations, trace potential sources of contamination, and evaluate the impact of agricultural practices on water quality. By addressing this issue, the study identifies environmental and health risks associated with pesticide pollution and offers insights into improving agricultural management and water conservation efforts in the region.

## 1.2 Novelty and Relevance of the Study

The utilization of agri-environmental indicators (AEIs) to evaluate water resources in Aiton village, Romania, presents a novel approach to understanding the complex connection between agricultural practices and water sustainability. This research is particularly relevant in the context of increasing pressures on water resources due to agricultural product demand, climate change, and socio-economic factors. This is the first research performed in Romania using AEI's to evaluate the state of the art of water resources. All other Romanian studies used Water Quality Index (Frîncu, 2021; Georgescu et al., 2023; Iticescu et al., 2019; Mihali & Dippong, 2023; Sur et al., 2022; Zait et al., 2022). In addition, there is a particular study which proposed a viable low cost method in water quality monitoring in the rural areas using internet-of-things (Bogdan et al., 2023). this research highlights the critical role of agri-environmental indicators (AEIs) in understanding and addressing the intricate relationship between agricultural practices and water resource sustainability. By pioneering the use of AEIs in Romania, this thesis underscores the necessity of innovative methods for assessing and managing water resources in rural areas. The findings emphasize the importance of integrating qualitative and quantitative approaches to foster sustainable agricultural practices. Moreover, the thesis offers valuable insights for policymakers and stakeholders, advocating for targeted strategies to ensure water conservation and agricultural resilience. This work enriches the discourse on sustainable development and sets a precedent for future research in agricultural sustainability within Romania and beyond.

## 1.3 Definition of the Problem

In five distinct scenarios representing a range of plausible socio-economic futures, global food demand is projected to rise by 35% to 56% between 2010 and 2050 (van Dijk et al., 2021). Moreover, the population at risk of hunger is anticipated to vary between a decline of 91% and an increase of 8% during the same period (van Dijk et al., 2021). These scenarios put a lot of pressure on the worldwide food systems and agricultural production. The increasing emphasis on economic goals at the expense of environmental and social considerations has generated widespread dissatisfaction with traditional agricultural practices. This shift in priorities has prompted a growing recognition of the negative impacts of conventional methods, leading to a stronger push for the adoption of more sustainable farming practices that seek to balance economic, environmental, and social objectives (Spânu et al., 2022). Moreover, almost 47% of the Romanian citizens are living in rural areas, and 40% of the labor force is employed in agriculture, its contribution to GDP is only 13.4% (INS, 2021).

## 1.4 Situation at International Level

Agricultural practices have numerous implications for the environment, particularly as they relate to sustainability on an international scale. The intersection of agriculture and environmental issues is a growing area of concern, especially in light of climate change, resource depletion, and ecosystem degradation (Siebrecht, 2020). A nuanced understanding of these issues requires examining the environmental impacts of agricultural practices, the role of sustainability, and the international dimensions that shape these interactions.

The prominence of industrial agricultural methods has led to alarming rates of soil degradation, deforestation, and biodiversity loss globally. Conventional farming, which relies heavily on chemical fertilizers and monocultures, is known to cause soil erosion and nutrient depletion, ultimately reducing land productivity and exacerbating food insecurity (Ankamah et al., 2021; Streimikis & Baležentis, 2020). This shift toward intensive farming practices is seen as a significant contributor to the current environmental crisis, as these methods often neglect ecological balance and soil health (Khan et al, 2021). Moreover, the misuse of fertilizers and pesticides can lead to water pollution and the decline of local ecosystems, thereby threatening water quality and public health (Balogh & Jámbor, 2020).

In conclusion, the issues surrounding agriculture and the environment on an international scale are inherently complex and multifaceted. The imperative for global agricultural sustainability underscores the need for systemic change in production practices, technological innovation, and collaborative international policies. Acknowledging agriculture's dual role as both a contributor to and potential solution for environmental challenges fosters a resilient and sustainable approach within the agricultural sector.

## 1.5 Situation at National Level in Romania

The agricultural sector in Romania, while pivotal for the country's economy and food security, poses significant challenges to its environmental integrity, particularly concerning water resources. Intensive agricultural practices prevalent in Romania have been linked to various forms of water contamination, over-extraction, and alteration of natural water cycles, raising concerns over the sustainability of these methods (Popescu et al., 2021). The application of fertilizers and pesticides, while necessary for increasing crop yields, frequently results in runoff that leads to waterway pollution and eutrophication. Such pollution not only degrades aquatic ecosystems but also threatens the health and livelihoods of communities dependent on these water resources (Ciucure et al., 2020). In the pursuit of productivity, the agricultural practices in Romania often disregard the delicate balance required to maintain water quality. Excessive use of nitrates and phosphates from fertilizers has been attributed to harmful algae blooms in water bodies, contributing to oxygen depletion and loss of aquatic life (Pop et al., 2023). The ramifications extend further, complicating the already challenging landscape of water resource management in Romania, where many regions depend heavily on these bodies of water for irrigation and consumption (M. Popescu et al., 2021).

## 1.6 Agri-Environmental Indicators as Solutions

The value of AEIs lies in informing the stakeholders about the ecological effects of agricultural practices, which leads to the shift from the traditional to the more sustainable way. The pollution counted from field activities can be shown too, when using the Agri-Environmental Indicators (AEI) (Kumar et al., 2023). Furthermore, the incorporation of AEIs into policy schemes such as the EU's Green Deal, directly demonstrates their pertinence in developing agricultural policies that advocate for sustainability (Salvan et al., 2022). One main benefit of AEIs is that their holistic evaluation of the agricultural sector draws attention to the sectors that need particular upgrading and the levels of accountability in accordance with environmental standards (Streimikis & Baležentis, 2020).

To sum up, agri-environmental indicators are essential ways of looking at the sustainability of agriculture. Thus, they are ideal for evaluating farm-related environmental impacts and enabling the agricultural sector to find ways to meet sustainability goals. These tools are instrumental--

not only to judge but to drive policy, support adequate practices, and to check that in rural areas, the economic and environmental goals are in conformity with each other (Mukherjee, 2022; Sau et al., 2023).

## 1.7 Research Gaps

Upon reviewing the literature, significant research gaps have been identified in adoption of sustainable agricultural practices and rural water quality studies.

**1. Adoption of Sustainable Agriculture Practices**

- **Socioeconomic barriers**: More research is needed on the economic and social constraints that hinder farmers from adopting sustainable practices, particularly in smallholder and subsistence farming contexts (Barbosa Junior et al., 2022).
- **Policy effectiveness**: Limited studies evaluate the long-term effectiveness of government incentives, subsidies, and regulatory frameworks in promoting sustainable agriculture (Clune, 2021).
- **Behavioral and psychological factors**: The role of farmer perception, risk aversion, and cultural attitudes in adopting sustainable methods remains underexplored (Muhamadi & Boz, 2022).
- **Adoption in different agroecosystems**: Studies often focus on temperate regions; more work is needed in arid, semi-arid, and tropical areas where climate change impacts may be different (Gutsche & Strassemeyer, 2007).
- **Impact of digital and smart farming**: The role of precision agriculture, AI, and IoT in improving sustainability outcomes and adoption rates needs further study (Kashina et al., 2022)

**2. Water Pollution from Pesticides, Nitrates, and Nitrites**

- **Long-term groundwater contamination**: More studies are required on the persistence of pesticides and nitrates in groundwater and their long-term ecological and health impacts (Foster & Custodio, 2019).

- **Synergistic effects of pollutants**: Limited research examines the combined effects of pesticides and nitrates/nitrites on aquatic ecosystems and human health ( Evans et al., 2019).

- **Low-cost remediation techniques**: More studies are needed on affordable and scalable bioremediation and phytoremediation strategies for developing countries (Lal et al., 2016).

## 1.8 Research Questions

This study's research questions examine the role of sustainable agriculture and agri-environmental indicators as essential tools for advancing agricultural sustainability.

**Research Question1.** "How do the 28 agri-environmental indicators (AEIs) of the European Union compare with those established by the OECD and FAO in assessing agricultural sustainability?"
Response: Objective 1
**Research Question2.** "How do stakeholders evaluate the EU's 28 AEIs based on multiple sustainability criteria?"
Response: Objective 2
**Research Question3.** " What are the sources and impacts of nitrate contamination in the drinking water of Aiton village?"
Response: Objective 3
**Research Question4.** "What is the extent of pesticide contamination in the drinking water of Aiton village?"
Response: Objective 4

## 1.9 Structure of the PhD Thesis

comprehensive parts, each addressing different dimensions of AEI evaluation.

**PART I: Subjective Evaluation of Agri-environmental Indicators**

Chapter II: A Comparative Review of the EU, OECD, and FAO Indicators in Agricultural Sustainability Literature
This chapter aims to provide a thorough comparative analysis of agricultural sustainability indicators (AEIs) employed by the European Union (EU), the Organisation for Economic Co-

operation and Development (OECD), and the Food and Agriculture Organization (FAO). The chapter is divided into four main sections:

- **2.1 Frameworks for Agricultural Sustainability: EU, OECD, and FAO Approaches**: This section explores the various frameworks and models for assessing agricultural sustainability that have been developed by the EU, OECD, and FAO. It highlights the differences in their approaches, underlying principles, and how these frameworks are applied to evaluate agricultural sustainability across diverse regions.
- **2.2 Review Methodology**: Here, the methodology employed in reviewing the AEIs is outlined. The section describes the criteria for selecting relevant literature, the review process, and the comparative analysis approach used to assess the indicators proposed by the EU, OECD, and FAO.
- **2.3 Strengths and Weaknesses of AEIs in Practice**: This section evaluates the effectiveness and practical limitations of the AEIs in real-world scenarios. It examines the applicability of these indicators in agricultural practices, their ability to measure sustainability, and identifies the strengths and weaknesses in their current implementation.
- **2.4 Toward a Harmonized Global Framework for Agricultural Sustainability Indicators**: The final section discusses the need for and potential pathways toward creating a harmonized global framework for agricultural sustainability indicators. It explores how various international organizations might collaborate to ensure the indicators are universally applicable and effective in addressing global sustainability challenges.

Chapter III: Stakeholders' Perceptions on the EU 28 AEIs: Evaluating Sustainability Criteria This chapter focuses on understanding the perceptions of key stakeholders regarding the sustainability criteria used within the EU 28 AEIs. The chapter is organized into the following subsections:

- **3.1 Introducing the Relevant Stakeholders in Agricultural Sustainability**: This section provides an introduction to the key stakeholders involved in agricultural sustainability, such as farmers, policymakers, environmental groups, and agricultural organizations. It outlines their roles and interests in sustainability assessments and their influence on agricultural policy.
- **3.2 Methodology Employed for Evaluating Stakeholder Perceptions**: Here, the research methodology used to collect and analyze stakeholder perceptions is discussed. The section describes the survey, interview, or participatory methods employed to gather data on stakeholder views regarding the sustainability criteria of the EU 28 AEIs.

- **3.3 Key Insights from Stakeholders on Sustainability Criteria**: This section presents the key findings from stakeholder feedback. It outlines the perceptions and concerns of different stakeholders regarding the current AEIs and the sustainability criteria they include, providing valuable insights into the strengths and limitations of the existing frameworks.
- **3.4 Policy Recommendations Based on Stakeholder Input**: Based on the insights gathered from stakeholders, this section offers policy recommendations for improving agricultural sustainability. It suggests adjustments to the AEIs to better align with stakeholder needs and enhance the overall effectiveness of sustainability assessment in the agricultural sector.

## PART II: Objective Evaluation of the Water Resources in Rural Community of Aiton Village using AEIs

Chapter IV: Assessment of Nitrate and Pesticide Contamination in Aiton Village: Integrating AEI 27.1 and 27.2 with General Water Quality Parameters
This chapter focuses on the objective evaluation of water resources in Aiton Village, using AEIs to assess nitrate and pesticide contamination levels and their environmental impacts. The chapter is divided into six subsections:

- **4.1 Study Area Characterization**: This section provides a detailed description of Aiton Village, including its geographical location, agricultural practices, and the specific water resources under study. The section sets the context for understanding the environmental challenges facing the community.
- **4.2 Methodology: Research Design; Samples Collection and Analysis**: This section outlines the research design employed for the water quality assessment, including details on the sampling techniques used to collect water samples from various sources, the parameters analyzed, and the scientific methods applied to interpret the data.
- **4.3 Overview and Significance of General Water Quality Parameters**: This section discusses the water quality parameters used in the assessment, such as pH, turbidity, temperature, and dissolved oxygen. It highlights their significance in determining the overall health of the water resources and their role in understanding the potential impacts of contamination.
- **4.4 Nitrate and Nitrites Pollution: Sources, Dynamics, and Environmental Impacts**: Here, the section delves into the sources and dynamics of nitrate and nitrite

contamination in the village's water systems, focusing on their origins in agricultural activities (fertilizer use, livestock waste) and the environmental implications, such as eutrophication and ecosystem disruption.

- **4.5 Pesticide Contamination: Occurrence, Pathways, and Environmental Implications**: This section examines the presence of pesticide contamination in the water resources of Aiton Village. It explores the pathways through which pesticides enter the water system, such as runoff and leaching, and their environmental consequences, including effects on biodiversity and human health.
- **4.6 Findings and Implications for Environmental Policy in Aiton Village**: The final section presents the key findings of the study and discusses their implications for environmental policy in Aiton Village. It offers recommendations for mitigating contamination and improving water quality management, drawing on the results of the AEI-based assessment.

Chapter V: Thesis General Conclusions and Recommendations
The concluding chapter synthesizes the main findings of the thesis and offers insights into future research and policy directions. It is organized into the following subsections:

- **5.1 Thesis Practical Contributions**: This section summarizes the practical contributions of the thesis to the field of agricultural sustainability and water quality management. It outlines how the findings can be applied in real-world policy and practice to improve agricultural practices and water resource management.
- **5.2 Future Development of the Subject**: This section discusses potential avenues for future research in the field, highlighting emerging issues and the need for further study on agricultural sustainability indicators, water contamination, and stakeholder engagement.
- **5.3 Research Limitations**: Here, the limitations of the research are acknowledged, including any constraints in the data collection process, methodological challenges, or gaps in the analysis that may have impacted the results.
- **5.4 Publications and Other Scientific Activities**: This section lists any publications resulting from the thesis research and outlines other scientific activities, such as conference presentations or collaborative projects, that contribute to the academic discourse on agricultural sustainability and environmental management.

# PART I: Subjective Evaluation of Agri-environmental Indicators

Part I of this thesis is dedicated to exploring the subjective dimensions of AEIs, focusing on evaluating stakeholder perceptions and the role these perceptions play in shaping the adoption and effectiveness of such indicators. A comprehensive literature review on AEIs forms the foundation of this section, providing a critical overview of existing research and frameworks used to assess environmental sustainability in agriculture. This review highlights the evolution of AEIs, their application across different agricultural contexts, and the challenges inherent in developing indicators that resonate with diverse stakeholders.

In addition to this review, the subjective evaluation of AEIs is explored by analyzing stakeholder perceptions. This part of the thesis examines how farmers, policymakers, environmental organizations, and other key actors interpret and prioritize different agri-environmental indicators, and how these perspectives influence the design and implementation of sustainability frameworks.

## CHAPTER II: A Comparative Review of the EU, OECD, and FAO Indicators in Agricultural Sustainability Literature

The pursuit of agricultural sustainability is a pressing global priority, necessitated by the need to address food security, environmental preservation, and economic stability in tandem. Policymakers, researchers, and practitioners alike have sought to measure and evaluate sustainability through a variety of frameworks and indicators. Among the most influential institutions contributing to this discourse are the European Union (EU), the Organisation for Economic Co-operation and Development (OECD), and the Food and Agriculture Organization of the United Nations (FAO). Each organization has developed its own sets of indicators, reflecting diverse methodological approaches, policy priorities, and stakeholder objectives. This chapter provides a comparative review of these institutional frameworks and their respective sustainability indicators. The analysis aims to elucidate the commonalities and divergences in their approaches, offering insights into how these indicators shape agricultural sustainability policies and practices.

## 2.1 Frameworks for Agricultural Sustainability: EU, OECD, and FAO Approaches

Indicators play a crucial role in developing frameworks for agricultural sustainability by providing measurable and quantifiable data that can inform decision-making processes. The use of indicators allows for a systematic assessment of agricultural systems, enabling stakeholders to evaluate sustainability across various dimensions, including environmental, economic, and social factors. For instance, Talukder et al. highlight that the selection of indicators through a sustainability categories framework captures a broader range of aspects within agricultural systems, thereby facilitating a systems-of-systems approach to sustainability assessment (Talukder et al., 2018). This approach is essential as it allows for the integration of diverse sustainability issues, which is often lacking in many existing frameworks.

The AEIs are particularly important in assessing the effectiveness of the Common Agricultural Policy (CAP), which serves as the EU's primary framework for regulating and supporting agriculture. By providing measurable insights into the environmental impact of agricultural practices, AEIs enables policymakers to refine CAP measures to enhance sustainability. These indicators support objectives such as environmental conservation, biodiversity maintenance, and sustainable land management. Through continuous monitoring, AEIs ensure that policy adjustments are evidence-based, fostering a transition towards more environmentally friendly farming systems. The 28 AEIs encompass various dimensions of agricultural sustainability, including soil health, water quality, biodiversity, and greenhouse gas emissions. Scown and Nicholas argue that a robust performance framework is necessary to align these indicators with the Sustainable Development Goals (SDGs) (Scown & Nicholas, 2020). This alignment is crucial as it helps policymakers understand the impact of agricultural practices on environmental sustainability and facilitates the integration of environmental considerations into agricultural policy-making. The AEIs provide a structured approach to assess how well agricultural practices are performing in relation to these goals, thereby enabling targeted interventions where necessary. Moreover, the AEIs are instrumental in the implementation of agri-environment schemes (AES), which are voluntary programs designed to incentivize farmers to adopt environmentally friendly practices. Snoo et al. highlight that these schemes play a critical role in promoting biodiversity and environmental protection in agricultural landscapes (Snoo et al., 2013). By linking financial incentives to the achievement of specific environmental outcomes, the AEIs help ensure that farmers are motivated to engage in practices that benefit both the environment and their agricultural productivity. As they are the main focus of this thesis, the European set of AEIs is listed and defined in Table 1.

**Table 1** EUROSTAT set of Agri-Environmental Indicators (Spânu et al., 2022)

| No | Indicator | Definition |
|---|---|---|
| 1 | Agri-environmental commitments | This indicator refers to the share (%) of area under agri-environmental commitments in Priority 4 on total utilised agricultural area (UAA). |
| 2 | Agricultural areas under Natura 2000 | The indicators includes the share (%) of UAA under Natura 2000. |
| 3 | Farmers' training level and use of environmental farm advisory services | This indicator refers to the share (%) of farm managers with agricultural training (basic training, full training or farm managers with practical experience only). |
| 4 | Area under organic farming | This indicator represents the share (%) of organic farming from total UAA. |
| 5 | Mineral fertiliser consumption | Mineral fertiliser consumption is indicated by the evolution of the consumption of the nutrients nitrogen (N) and phosphorus (P) in mineral fertilisers by agriculture over time. |
| 6 | Consumption of pesticides | The consumption of pesticides refers the use of pesticides per area of cropland. These data are, however, not available today. |
| 7 | Irrigation | The indicator assesses the trend of the irrigable and irrigated areas and their share of the total UAA (The irrigable area is the area which is equipped for irrigation). |
| 8 | Energy use | The indicator relates to the direct use of energy (solid fuels, petroleum products, gas, electricity, renewables, heat) in the agricultural sector – per hectare (ha) of utilised agricultural area (UAA). It assesses the trend of energy consumption, per ha and per fuel type. |
| 9 | Land use change | The indicator assesses the changes in agricultural land use. |
| 10.1 | Cropping patterns | Cropping patterns are defined as trends in the share of the UAA occupied by the main agricultural land cover types (arable land, permanent grassland and land under permanent crops). |
| 10.2 | Livestock patterns | Livestock patterns are defined as trends in the share of major livestock types (cattle, sheep, goats, pigs and poultry) and density of livestock units (LSU) on agricultural land. |
| 11.1 | Soil cover | Share of the year when the arable area is covered by plants or plant residues. |
| 11.2 | Tillage practices | Tillage practices refer to the soil treatment of arable land carried out between the harvest and following sowing/cultivation operation. Three tillage methods can be distinguished: conventional tillage, conservation tillage and zero tillage. |
| 11.3 | Manure storage | The indicator assesses the number of holdings with manure storage facilities. |
| 12 | Farming intensity | The indicator assesses the degree of intensification/extensification of EU agriculture. |
| 13 | Specialisation | Farm specialisation describes the dominant activity in farm income: an agricultural holding is said to be specialised when a particular activity provides at least two thirds of the production or the business size of an agricultural holding. |
| 14 | Risk of land abandonment | Farmland abandonment is a cessation of agricultural activities on a given surface of land which leads to undesirable changes in biodiversity and ecosystem services. |

| | | |
|---|---|---|
| 15 | Gross nitrogen balance | The indicator assesses potential surplus of nitrogen on agricultural land (kg N per ha per year). |
| 16 | Risk of pollution by phosphorus | The indicator assesses potential surplus of phosphorus on agricultural land (kg P per ha per year). |
| 17 | Pesticide risk | The risk of a pesticide is defined as the probability and severity of an adverse health or environmental effect occurring as a function of a hazard and the likelihood and the extent of exposure to a pesticide where exposure is the concentration or amount of a pesticide that reaches a target organism. |
| 18 | Ammonia emissions | This indicator shows the annual atmospheric emissions of ammonia in the EU-28 for 1990-2015. |
| 19 | Greenhouse gas emissions | This indicator tracks trends in greenhouse gas (GHG) emissions by agriculture, estimated and repororted under UN Convention on Climate Change, the Kyoto Protocol and the Decision 525/2013/EC. |
| 20 | Water abstraction | This indicator assesses the amount of water abstraction for agriculture expressed in million $m^3$. |
| 21 | Soil erosion | The indicator soil erosion estimates the agricultural areas and natural grassland affected by a certain rate of soil erosion by water. |
| 22 | Genetic diversity | Genetic diversity is the total number of genetic characteristics in the genome of a species. |
| 23 | High Nature Value farmland | The concept of high nature value farmland refers to the causality between certain types of farming activity and corresponding environmental outcomes, including high levels of biodiversity and the presence of environmentally valuable habitats and species. |
| 24 | Production of renewable energy | This indicator assesses the share (%) of production of renewable energy from agriculture and forestry. |
| 25 | Population trends of farmland birds | The indicator shows the trends of farmland birds population. |
| 26 | Soil quality | The indicator provides an account of the ability of soil to provide agri-environmental services through its capacities to perform its functions and respond to external influences. |
| 27.1 | Water Quality - Nitrate pollution | Nitrate pollution is indicated by current values and trends in nitrate concentrations in groundwater and rivers expressed in mg NO3/l for groundwater and mg N/l for rivers. |
| 27.2 | Water Quality - Pesticide pollution | Pesticides in water are indicated by current values, exceedances and trends in the concentrations (μg/l) of selected pesticides in rivers and groundwater. |
| 28 | Landscape - state and diversity | The landscape state and diversity indicator describes the main characteristics of the agrarian landscape, in terms of structure of the landscape, cultural influence on the potential natural vegetation due to human activities, and societal awareness of the rural landscape. |

## 2.2 Literature Review Methodology

In order to fully address the first objective of the present thesis, a literature review on AEI has been performed and dedicated to measuring sustainability in agriculture. As highlighted by Elliott, maintaining a systematic and up-to-date review is challenging; however, failing to do so compromises the review's accuracy and usefulness (Elliott et al., 2017). Thus, the authors of this study conducted a systematic search of relevant literature across major databases, including PROQUEST Central, Scopus (Elsevier), SpringerLink Journals (Springer), ScienceDirect Freedom Collection (Elsevier), Wiley Journals, Web of Science–Core Collection, Emerald Management EJournals, and Reaxys, all accessed via the Enformation platform. Additionally, after identifying a paper, its citations were further explored using Google Scholar. Following Wohlin's approach, a snowball search was conducted to ensure all relevant papers were included, applying the criteria of "backward snowballing," "forward snowballing," and "inclusion/exclusion" (Wohlin, 2014), which is displayed in Figure 1. The database search was conducted as follows: it targeted paper titles and abstracts containing either a single keyword or a combination of "sustainability indicators," "farm indicators," and "agri-environmental indicators." The reference period covered 1992–2021, and only papers written in English were included.

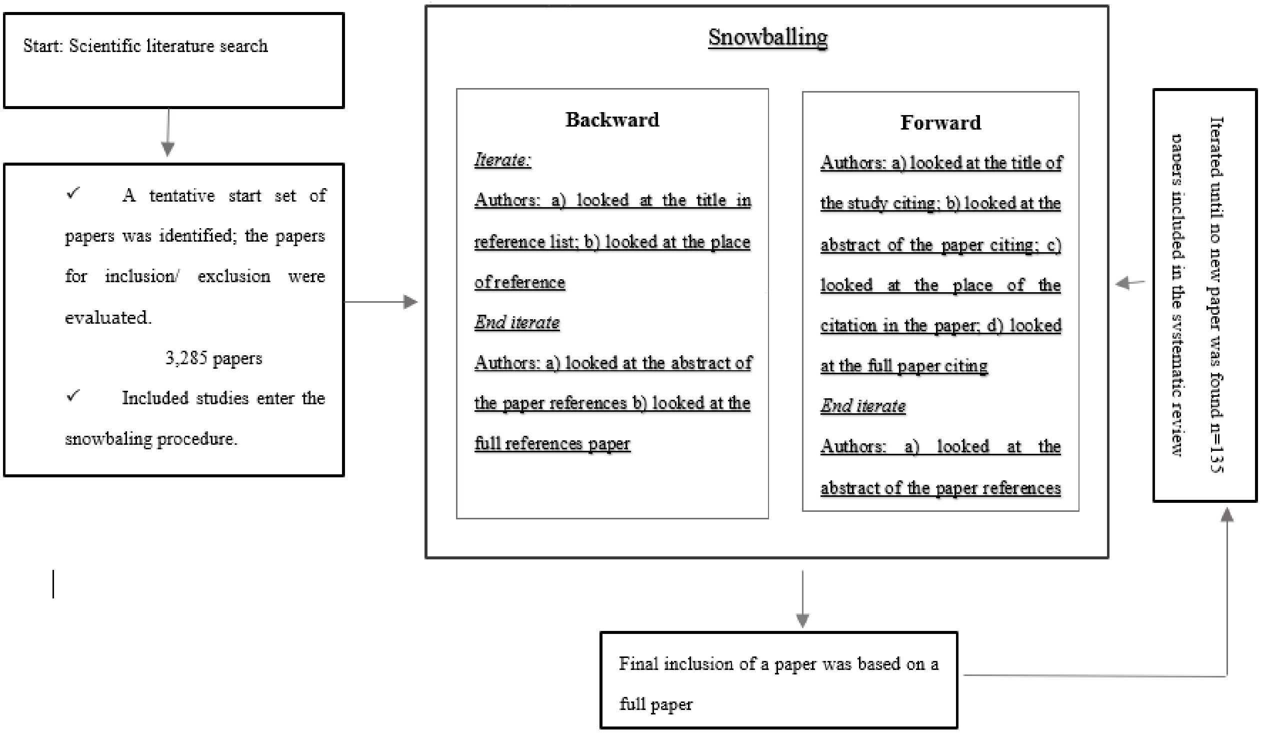


**Figure 1** Snowballing procedure. Source: [adapted after " (Wohlin, 2014)]

Source: (Spânu et al., 2022)

The initial search yielded 3,285 papers, with 2,029 duplicates identified, leaving 1,256 papers for further screening and eligibility assessment. The inclusion/exclusion criteria encompassed the following:

A. Original research papers featuring empirical data collected through questionnaires, interviews, or focus groups;
B. Studies that assessed the quality (strengths and weaknesses) of agri-environmental indicators;
C. Reports developed for international organizations such as FAO or EUROSTAT were deemed relevant; (iv) papers including at least three agri-environmental indicators; and (v) studies incorporating indicators to evaluate farm sustainability.

Additionally, studies were excluded if the agri-environmental indicators focused on a narrowly defined geographical area (e.g., a small regional territory). After applying these criteria, 97 papers were included in the review. Another 38 scientific papers meeting the inclusion criteria were identified through snowball sampling. As a result, the final number of documents retained for the systematic review was 135 (Figure 2). The majority of the selected studies (68.14%) focused on Europe, followed by North America (16.3%), Asia (6.67%), the Middle East (5.19%), Africa (2.22%), and South America (1.48%).

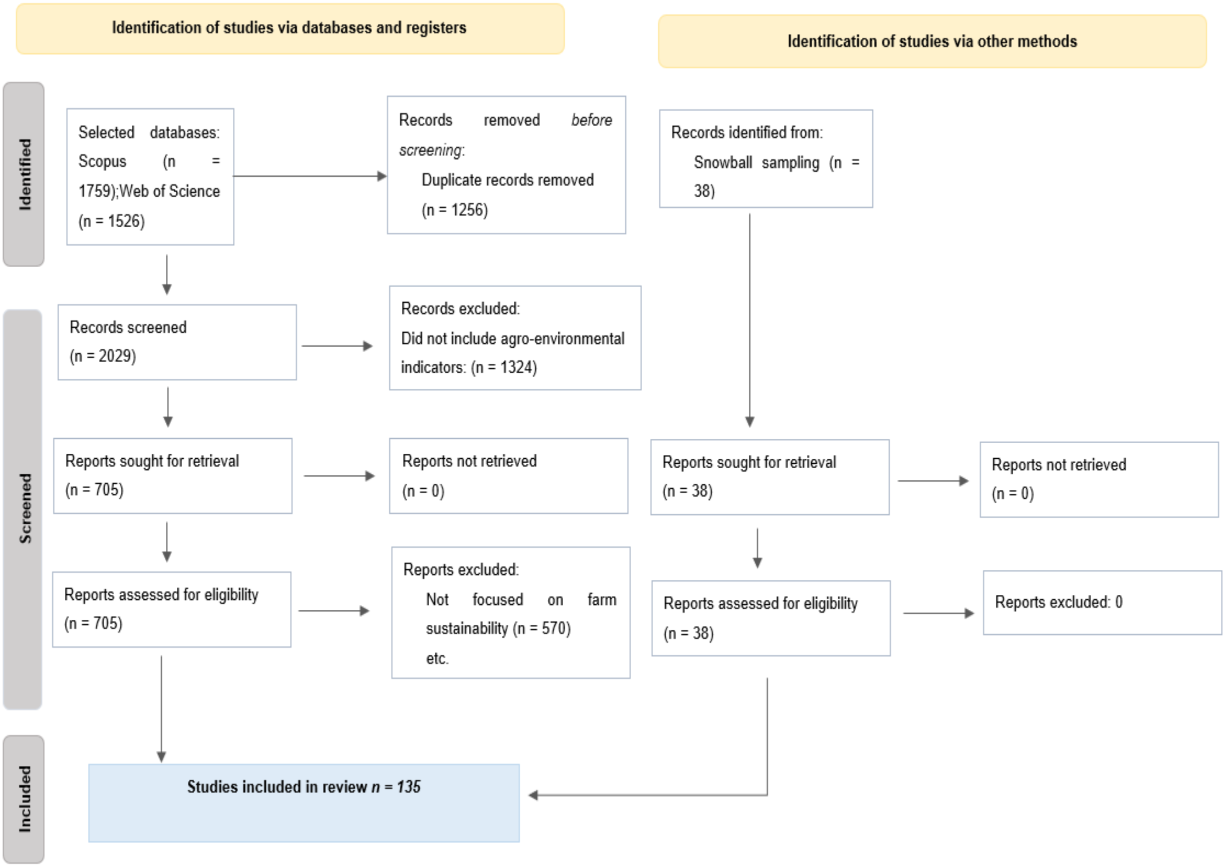


**Figure 2** Flow diagram of the literature search process. Source: (Spânu et al., 2022)

This systematic review clarifies AEIs and their representation in key strategic documents and sustainability literature. Accordingly, Table 3 illustrates the correspondence between the EUROSTAT indicator set and those of the OECD and FAO, alongside relevant scientific literature where they are explained, discussed, or analyzed.

**Table 2** Mirroring EUROSTAT set of AEI's to OECD, FAO and other studies Source: (Spânu et al., 2022)

| No. | Eurostat Indicators | OECD Indicators | FAO Indicators | Studies |
|---|---|---|---|---|
| 1. | Agri-environmental commitments | Not defined | Not defined | 1. (Eiden et al., 2001)<br>2.(Iojă et al., 2016)<br>3.(Piorr, 2003)<br>4.(Buechs, 2003)<br>5. (Früh-Müller et al., 2019) |
| 2. | Agricultural areas under Natura 2000 | Not defined | Proportion of habitat types | 1.(Eiden et al., 2001)<br>2.(Brunbjerg et al., 2016)<br>3.(Bachev et al., 2017)<br>4.(Pe'er et al., 2019)<br>5. (Klaučo et al., 2014) |
| 3. | Agricultural training of farm managers | Farmer education | Not defined | 1.(Theodoros et al., 2010) |

| | | | | |
|---|---|---|---|---|
| | | | | 2.(Ripoll-Bosch et al., 2012)<br>3.(Terres et al., 2015)<br>4.(David and Asamoah 2014)<br>5.(Pan et al., 2017) |
| 4. | Area under organic farming | Organic farming | Not defined | 1.(Brunbjerg et al., 2016)<br>2.(Vitunskiene & Dabkiene, 2016)<br>3.(Theodoros et al., 2010)<br>4.(Allievi et al., 2011)<br>5.(Maes et al., 2016)<br>6.(Terres et al., 2015) |
| 5. | Mineral fertiliser consumption | Nutrient use | Total fertiliser consumption | 1.(BRENTRUP & PALLIERE, 2010)<br>2. (Hak et al., 2012)<br>3. (Saladini, 2018)<br>4. (Kubacka, M., et al, 2016)<br>5.(Haas et al., 2001)<br>6. (Gaviglio et al., 2017)<br>7.(Sajadian et al., 2017)<br>8.(Castoldi et al., 2009) |
| 6. | Consumption of pesticides | Pesticide use | Pesticide use | 1.(Moxey, A., et al, 1998)<br>2. (Bockstaller, C., et al, 1997)<br>3.(Hornsby, 1992)<br>4. (Kovach & et. al, 1992)<br>5.(Hak et al., 2012)<br>6. (Meul et al., 2008) |
| 7. | Irrigation | Irrigation and water management | Irrigations | 1. (Bos, 1997)<br>2. (Moreno-Pérez & Roldán-Cañas, 2013)<br>3.(Fernández et al., 2020)<br>4.(Pereira et al., 2012)<br>5. (Kharrou et al., 2013)<br>6. (Gómez-Limón & Sanchez-Fernandez, 2010) |
| 8. | Energy Use | Energy use and biofuel production | Energy use per agricultural output | 1. (Pervanchon & et al, 2002)<br>2. (Carrasquer & et al, 2016)<br>3. (Dalgaard et al., 2001)<br>4.(Mohammadi et al., 2008)<br>5. (Lin et al., 2017)<br>6. (Martins et al., 2019)<br>7. (Iddrisu & Bhattacharyya, 2015)<br>8. (Häni et al., 2003)<br>9. (Pretty et al., 2008) |

| | | | | |
|---|---|---|---|---|
| | | | | 10. (Langeveld, 2007) |
| 9. | Land use change | Change in agricultural land | Change in agricultural land use | 1. (Jaeger, 2000)<br>2. (Guinée et al., 2002)<br>3.(Salata & Gardi, 2015)<br>4. (Dumanski & Pieri, 2000)<br>5. (Guo et al., 2013)<br>6.(Benini et al., 2010) |
| 10.1 | Cropping patterns | Not defined | Cropping patterns | 1. (Sajadian et al., 2017)<br>2. (Bélanger et al., 2012)<br>3.(Paracchini et al., 2015)<br>4. (Aavik & Liira, 2009)<br>5.(Shahidullah et al., 2006) |
| 10.2 | Livestock patterns | Not defined | Not defined | 1. (Valcour et al., 2002)<br>2.(Chilonda & Otte, 2006)<br>3. (Gaspar et al., 2009)<br>4. (Reed et al., 2008)<br>5.(Aavik & Liira, 2009) |
| 11.1 | Soil cover | Soil cover | Soil health | 1. (Gómez-Limón & Sanchez-Fernandez, 2010)<br>2. (Reig-Martinez et al., 2011)<br>3.(Migliorini et al., 2018)<br>4.(Huffman et al., 2015)<br>5.(Dumanski & Pieri, 2000) |
| 11.2 | Tillage practices | Not defiend | Tillage practices | 1. (Thivierge et al., 2014)<br>2. (Sajadian et al., 2017)<br>3. (Bélanger et al., 2012)<br>4.(Zuber et al., 2017)<br>5. (Telles et al., 2020) |
| 11.3 | Manure storage | Not defined | Not defined | 1. (Merrill & Halverson, 2002)<br>2.(Paavola & Rintala, 2008)<br>3.(Page et al., 2015) |
| 12. | Intensification/Extensification | Not defined | Not defined | 1. (Brunbjerg et al., 2016)<br>2. (Gobin et al., 2004)<br>3. (Aavik & Liira, 2009)<br>4.(Dumanski & Pieri, 2000)<br>5. (Jan et al., 2019) |

| | | | | |
|---|---|---|---|---|
| 13. | Specialisation | Not defined | Not defined | 1. (Gómez-Limón & Sanchez-Fernandez, 2010)<br>2. (Roschewitz et al., 2005)<br>3. (Picazo-Tadeo et al., 2011)<br>4. (Bojnec et al., 2014)<br>5. (Mollenhorst et al., 2006) |
| 14. | Risk of land abandonment | Not defined | Not defined | 1. (Gómez-Limón & Sanchez-Fernandez, 2010)<br>2.(Reig-Martinez et al., 2011)<br>3. (Terres et al., 2015)<br>4. (Vinogradovs et al., 2018)<br>5. (Perpiña Castillo et al., 2020) |
| 15. | Gross nitrogen balance | Nitrogen balance | Not defined | 1. (Meul et al., 2009)<br>2. (Picazo-Tadeo et al., 2011)<br>3. (Pretty et al., 2008)<br>4. (Thivierge et al., 2014)<br>5. (Langeveld, 2007) |
| 16. | Risk of pollution by phosphorus | Not defined | Not defined | 1. (Ouyang et al., 2012)<br>2. (Li et al., 2021a)<br>3. (Buchanan et al., 2013)<br>4. (Milledge et al., 2012)<br>5. (Brazier et al., 2005) |
| 17. | Pesticide risk | Pesticide risk | Not defined | 1. (van der Werf & Zimmer, 1998)<br>2. (Reus & Leendertse, 2000)<br>3. (Stenrød & et al, 2008)<br>4. (Kudsk et al., 2018)<br>5. (Vergucht & et al, 2007) |
| 18 | Ammonia emissions | Not defined | Not defined | 1. (Qiu et al., 2007)<br>2. (L. Evans et al., 2018)<br>3. (de Boer & Cornelissen, 2002)<br>4. (Groenestein et al., 2019)<br>5. (Carew, 2010) |
| 19 | Greenhouse gas emissions | Gross agricultural greenhouse gas emissions | Emission shares | 1. (Latruffe et al., 2016)<br>2. (Thomas et al., 2000)<br>3. (Sözen, et al., 2009)<br>4. (Zhao et al., 2012)<br>5. (van Grinsven et al., 2019)<br>6. (Roesch et al., 2021)<br>7. (Hak et al., 2012) |

| | | | | |
|---|---|---|---|---|
| | | | | 8. (Saladini, 2018)<br>9. (Yli-Viikari & et al, 2007)<br>10.(Langeveld, 2007) |
| 20 | Water abstraction | Not defined | Proportion of renewable freshwater resources abstracted | 1. (Maes et al., 2016)<br>2. (Vanham et al., 2018a)<br>3. (Henriksen et al., 2008)<br>4. (George et al., 2017)<br>5. (Vanham & Bidoglio, 2013) |
| 21. | Soil erosion | Risk of soil erosion by water/ Risk of soil erosion by wind | Erosion control practices | 1. (Zhen & Routray, 2003)<br>2. (Pretty et al., 2008)<br>3. (Maes et al., 2016)<br>4. (Gobin et al., 2004)<br>5. (Panagos et al., 2020) |
| 22. | Genetic diversity | Genertic diversity | Not defined | 1. (Zhen & Routray, 2003)<br>2. (Meul et al., 2008)<br>3. (Bonneuil et al., 2012)<br>4. (Huang et al., 2007)<br>5. (Le Clerc et al., 2006) |
| 23 | High Nature Value farmland | Not defined | Not defined | 1. (Brunbjerg et al., 2016)<br>2. (Morelli et al., 2014)<br>3. (Maes et al., 2016)<br>4. (Strohbach et al., 2015)<br>5. (Paracchini et al., 2015) |
| 24. | Production of renewable energy | Not defined | Not defined | 1. (Liu, 2014)<br>2. (A. Evans et al., 2009)<br>3. (Demirtas, 2013)<br>4. (Dogan et al., 2021)<br>5. (Kuleli Pak et al., 2015) |
| 25. | Population trends of farmland birds | Not defined | Not defined | 1. (Gregory et al., 2004)<br>2. (Freeman et al., 2001)<br>3. (Gregory et al., 2019)<br>4. (Jerrentrup et al., 2017)<br>5. (Gregory et al., 2005) |
| 26. | Soil quality | Not defined | Soil health | 1. (Pretty et al., 2008)<br>2. (Meul et al., 2008)<br>3. (Bélanger et al., 2012)<br>4. (Maes et al., 2016)<br>5. (Velasquez et al., 2007) |
| 27.1 | Water Quality- Nitrate pollution | Water quality risk indicator | Not defined | 1. (Langeveld, 2007)<br>2. (Bell & Morse, 2004) |

| | | | | |
|---|---|---|---|---|
| | | | | 3. (Lacroix et al., 2006)<br>4. (Chica-Olmo et al., 2014)<br>5. (Al Kuisi et al., 2009a) |
| 27.2 | Water Quality - Pesticide pollution | Water quality risk indicator | Not defined | 1. (Pretty et al., 2008)<br>2. (Tixier et al., 2007)<br>3. (Tang et al., 2021)<br>4. (Kookana et al., 2005)<br>5.(Houdart et al., 2009) |
| 28 | Landscape - state and diversity | Environmental features and land use patterns | Not defined | 1. (Fry et al., 2009)<br>2.(Gkoltsiou et al., 2013)<br>3. (Kienast et al., 2015)<br>4. (Weinstoerffer & Girardin, 2000)<br>5. (Dauber et al., 2003) |

## 2.3 Strengths and Weaknesses of the AEIs in Practice

One obvious strength of AEIs is their ability to provide quantifiable data on agricultural environmental impacts. Studies by (Abbou et al., 2023) underscore the importance of a methodical evaluation of environmental sustainability through indicators that assess agrochemical usage and biodiversity conservation. These indicators facilitate comparisons across different agricultural systems, allowing stakeholders to identify best practices. Moreover, AEIs enhances decision-making processes by offering stakeholders a clearer understanding of the environmental consequences of their actions. Safonte (Safonte et al., 2021) highlights that AEIs can foster communal efforts toward sustainability by engaging local stakeholders in monitoring and assessment activities. This participatory approach democratizes data collection and strengthens community commitment to achieving sustainability goals. AEIs are also crucial in aligning agricultural practices with the Sustainable Development Goals (SDGs). As indicated by Chaudhary et al. (Chaudhary et al., 2018), a comprehensive assessment of food systems using AEIs can significantly contribute to achieving several of the SDGs.

Despite these strengths, AEIs also have some weaknesses that must be addressed. One prominent issue is their often-limited scope, which may lead to overlooking critical environmental factors. While AEIs focus on specific aspects like pesticide usage or soil health, they might fail to integrate holistic assessments that encapsulate broader ecological interactions within agroecosystems. Olofinnade et al. (Olofinnade et al., 2025) assert that focusing on singular environmental metrics can lead to incomplete assessments, thereby hindering effective environmental management. Moreover, the selection and interpretation of AEIs can be subjective, leading to inconsistencies in data presentation. Reseach done by other authors point out the risks associated with relying on a narrow set of indicators, which can skew evaluation outcomes and produce misleading conclusions (Deus et al., 2019). This subjectivity complicates efforts to establish universally accepted AEIs, complicating efforts to benchmark performance across different regions and agricultural systems.

## 2.4 Toward a Harmonized Global Framework for Agricultural Sustainability Indicators

In conclusion, pursuing a harmonized global framework for agricultural sustainability indicators represents a pivotal step toward achieving sustainable development in the agricultural sector. As we have explored throughout this chapter, the complexity of agricultural sustainability demands a robust, multidimensional approach that encompasses environmental and economic considerations and social and cultural factors. Currently, the absence of a unified system of indicators often results in inconsistencies, misinterpretations, and fragmented efforts across regions and nations. A globally harmonized framework is essential to overcome these challenges, enabling standardized measurements that are universally applicable yet adaptable to local contexts.

The chapter has highlighted the importance of developing scientifically sound, contextually relevant indicators, and capable of integrating the various dimensions of sustainability. These indicators must be capable of tracking progress toward goals such as reducing environmental degradation, ensuring food security, promoting equitable livelihoods, and fostering resilience in agricultural systems. Moreover, they should be built on principles of inclusivity and transparency, ensuring that all stakeholders –ranging from farmers to policymakers and consumers –can access and engage with the data.

A harmonized global framework for agricultural sustainability indicators is not a distant ideal but an achievable goal that requires concerted effort, innovation, and collaboration across all sectors. Through such a framework, we will be able to measure progress, identify gaps, and guide policies that will shape a sustainable agricultural future for the world.

# CHAPTER III Stakeholders' Perceptions on the EU 28 AEIs: Evaluating Sustainability Criteria

The discussion begins with an overview of the role of AEIs in EU sustainability policy, followed by an examination of the key stakeholder groups and their interests. The chapter then presents findings on stakeholders' evaluations of AEI criteria, such as reliability, usability, and policy impact. Finally, challenges and opportunities for improving stakeholder engagement in the development and implementation of AEIs are addressed. Through this analysis, the chapter provides insights into how sustainability assessments can be refined to better align with the needs and expectations of those directly involved in environmental decision-making.

## 3.1 Introducing the Relevant Stakeholders in Agricultural Sustainability

Table 4 highlights the three primary stakeholders in agricultural sustainability, farmers, policymakers, and environmental researchers, emphasizing their characteristics and roles. A closer analysis of these groups reveals both interdependencies and potential conflicts in their approaches to sustainability.

**Table 3** Relevant stakeholders in Agriculture Source: author's elaboration

| Stakeholder | Characteristics | Role in Agricultural Sustainability |
|---|---|---|
| **Farmers** | - Primary land stewards and food producers.<br>- Range from smallholders to large-scale commercial farmers.<br>- Influenced by economic factors, climate conditions, and policy incentives. | - Implement sustainable farming techniques (e.g., crop rotation, organic farming, precision agriculture).<br>- Balance productivity with environmental conservation.<br>- Provide practical insights into sustainability challenges. |
| **Policymakers** | - Government officials and regulatory bodies at national and EU levels.<br>- Develop and enforce agricultural policies and sustainability regulations.<br>- Balance economic growth, food security, and environmental conservation. | - Design and implement policies promoting sustainable agriculture (e.g., CAP, EU Green Deal).<br>- Provide financial incentives and regulatory frameworks.<br>- Ensure compliance with environmental standards and long-term sustainability goals. |
| **Environmental Researchers** | - Scientists, agronomists, and ecologists specializing in sustainability.<br>- Work in universities, research institutions, and NGOs.<br>- Use scientific methodologies to assess and improve sustainability practices. | - Develop and refine Agri-Environmental Indicators (AEIs).<br>- Conduct research on climate change adaptation, soil health, water conservation, and biodiversity.<br>- Provide data-driven recommendations for farmers and policymakers. |

## 3.2. Methodology Employed for Evaluating Stakeholder Perceptions

To address the second objective of the present thesis, namely, to reveal the stakeholders' assessment of the 28 EU AEI's, the evaluation matrix was considered one of the best ways to weigh stakeholders' opinions about the 28 agri-environmental indicators, rating them based on a set of defined criteria. Moreover, the criteria used to evaluate the indicators are essential for ensuring the reliability of sustainability assessments (Niemeijer & de Groot, 2008).

The 28 AEIs were assessed through a focus group consisting of 15 participants, evenly distributed among three stakeholder groups: farmers (from Cluj County, Romania), policymakers (from the local administration in Cluj County, Romania), and agri-environmental researchers (from the Faculty of Environmental Science and Engineering and the Faculty of Agriculture at two universities in Cluj-Napoca, Romania), with five representatives from each category. The participants were selected based on convenience sampling, and their involvement was voluntary. The indicators are included in Table 1.

In the initial stage, participants were asked to vote on the number of criteria to be used for evaluating the AEIs, selecting a value between 1 and 10. The average number chosen based on their votes was four. Additionally, they had to determine whether the criteria should have equal or varied weights, with the majority opting for equal weights.

During the next stage, participants were provided with a list of 12 core (general) criteria derived from the review by Pires et al. (Pires et al., 2020), along with explanations of their meanings. Each participant was then asked to select four evaluation criteria. The criteria that received the highest number of votes were "Availability," "Relevance," "Target-oriented," and "Operational simplicity."

These criteria were defined as follows: "Availability" refers to the ease of obtaining the necessary data for the indicator at a reasonable cost (Milman & Short, 2008; Pires et al., 2020). "Relevance" indicates how closely an indicator aligns with the issue being investigated (Pires et al., 2020). "Target-oriented" means that an indicator includes a threshold and/or target for comparison (OCDE, 2003). Lastly, "Operational simplicity" denotes the ease of managing and analyzing the indicator (Niemeijer & de Groot, 2008).

Each indicator was assessed using an 11-point scale (0 = lowest performance, 10 = highest performance) based on the four selected criteria. This scale was chosen for its greater ability to differentiate between performance levels compared to scales with fewer points. The 11-point scale was preferred because it offers greater discriminatory power than scales with fewer points. Additionally, it enhances data analysis and improves the reliability of the results (DeJonge et al., 2016; Scherpenzeel, 2008). The participants were asked the following: "Please assess the availability of the following AEIs on a scale from 0 to 10". This request was repeated for each criterion. While many criteria are mentioned in the sustainable agriculture literature (Bartzas & Komnitsas, 2020; de Olde et al., 2017; Marchand et al., 2014; Niemeijer & de Groot, 2008), the author of the present study chose to rely on the work of Pires et al. (Pires et al., 2020), as it provides a comprehensive synthesis of the scientific literature and organizes the criteria within the field of sustainability.

## 3.3 Results from Stakeholders Evaluation on Sustainability Criteria

The results revealed a clear trend, with "Irrigation" and "Soil quality" receiving the highest overall evaluations across the four criteria, indicating that these indicators were deemed particularly important for sustainable agricultural practices. These two indicators were generally considered crucial for improving farming efficiency, resource management, and environmental health, making them highly valued by the stakeholders, especially farmers and researchers.

However, while "Irrigation" and "Soil quality" received high scores overall, they were evaluated much more favorably by farmers and researchers than by policymakers, who assigned them comparatively low scores, as shown in Table 5. This discrepancy suggests that policymakers might have a different perspective on these indicators. For example, policymakers may view irrigation practices in the context of resource management and water conservation, which could be influenced by broader policy goals, regional water scarcity issues, or concerns about the sustainability of water use at a large scale. Similarly, soil quality is a critical issue for farmers, but policymakers might prioritize it differently, depending on broader environmental policies, the economic feasibility of soil conservation measures, or the availability of funding and resources for such initiatives.

The fact that "Agri-environmental commitments" and "Risk of land abandonment" received the lowest rankings across all stakeholder groups highlights the relative lack of consensus on these indicators. While they may be important from an environmental perspective, particularly in addressing long-term agricultural sustainability and land management, these indicators might not resonate as strongly with the more immediate concerns of farmers or policymakers. Farmers may perceive agri-environmental commitments as difficult to implement or costly, while policymakers might view the risk of land abandonment as a less urgent issue compared to other policy priorities, such as productivity or climate change mitigation.

The results from Figure 3 and Table 5 underscore the variations in priorities among stakeholders when it comes to evaluating sustainability indicators. These differences in evaluation can pose challenges when attempting to develop a universal framework for sustainability that all parties can agree upon.

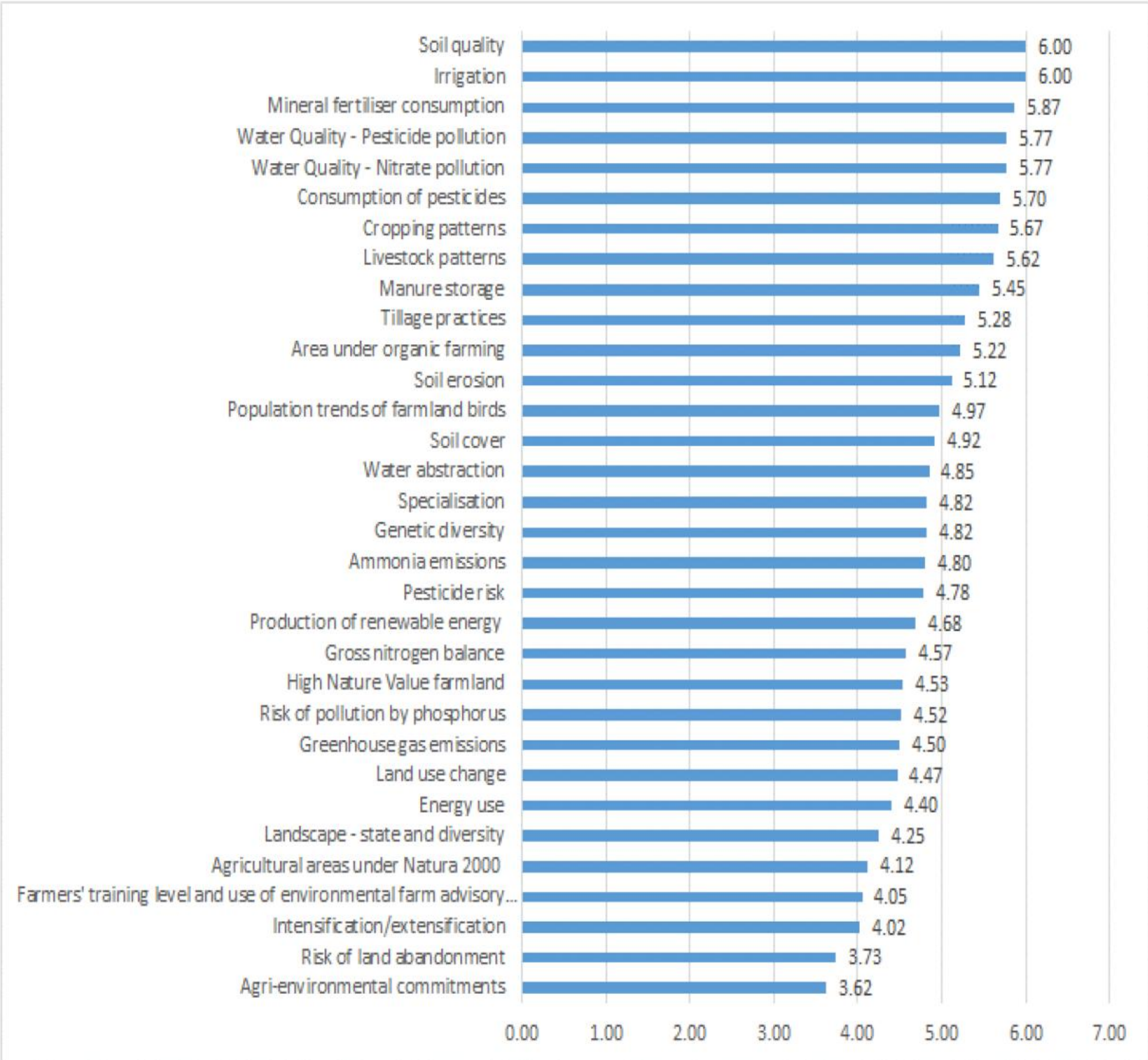


**Figure 3** Indicator ranking from highest to lowest evaluation considering the average evaluation (all stakeholders and all criteria). Source: (Spânu et al., 2022)

**Table 4** The assessment of each indicator by criterion and the overall average evaluation Source: (Spânu et al., 2022)

| **Agri-Environm. Indicators** | **Criteria** | | | | |
|---|---|---|---|---|---|
| | Availability* | Relevance* | Target-oriented* | Operational simplicity* | Overall evaluation** |
| Agri-environmental commitments | 2.1 | 8.7 | 5.9 | 4.4 | **3.6** |
| Agricultural areas under Natura 2000 | 4.3 | 8.0 | 6.6 | 4.3 | **4.1** |
| Farmers' training level and use of environmental farm advisory services | 2.8 | 8.5 | 6.5 | 6.7 | **4.1** |
| Area under organic farming | 4.8 | 9.3 | 6.4 | 9.2 | **5.2** |
| Mineral fertiliser consumption | 5.0 | 9.2 | 8.5 | 8.9 | **5.9** |
| Consumption of pesticides | 4.9 | 9.3 | 8.1 | 8.6 | **5.7** |

| | | | | | |
|---|---|---|---|---|---|
| Irrigation | 5.0 | 9.3 | 9.7 | 8.5 | **6.0** |
| Energy use | 3.6 | 8.1 | 5.4 | 6.9 | **4.4** |
| Land use change | 4.7 | 8.1 | 6.0 | 5.1 | **4.5** |
| Cropping patterns | 6.2 | 8.9 | 5.8 | 9.6 | **5.7** |
| Livestock patterns | 6.2 | 8.6 | 5.8 | 9.7 | **5.6** |
| Soil cover | 3.4 | 9.3 | 7.0 | 7.3 | **4.9** |
| Tillage practices | 4.1 | 9.3 | 6.9 | 8.7 | **5.3** |
| Manure storage | 4.0 | 8.7 | 7.5 | 9.4 | **5.5** |
| Intensification/extensification | 3.7 | 7.4 | 5.5 | 5.9 | **4.0** |
| Specialisation | 5.1 | 7.0 | 5.9 | 8.9 | **4.8** |
| Risk of land abandonment | 3.7 | 6.2 | 5.8 | 4.7 | **3.7** |
| Gross nitrogen balance | 5.2 | 8.1 | 6.9 | 5.8 | **4.6** |
| Risk of pollution by phosphorus | 4.7 | 7.8 | 6.8 | 4.3 | **4.5** |
| Pesticide risk | 5.2 | 8.3 | 5.7 | 6.8 | **4.8** |
| Ammonia emissions | 5.3 | 8.3 | 7.5 | 5.4 | **4.8** |
| Greenhouse gas emissions | 4.4 | 7.9 | 7.7 | 5.4 | **4.5** |
| Water abstraction | 4.6 | 9.1 | 7.2 | 6.2 | **4.9** |
| Soil erosion | 5.0 | 9.3 | 7.5 | 6.5 | **5.1** |
| Genetic diversity | 5.7 | 8.5 | 7.1 | 5.4 | **4.8** |
| High Nature Value farmland | 5.6 | 8.5 | 6.7 | 5.2 | **4.5** |
| Production of renewable energy | 5.3 | 7.2 | 6.9 | 7.2 | **4.7** |
| Population trends of farmland birds | 5.5 | 8.3 | 7.0 | 6.3 | **5.0** |
| Soil quality | 6.7 | 10.0 | 7.4 | 8.5 | **6.0** |
| Water Quality - Nitrate pollution | 6.1 | 10.0 | 8.0 | 7.5 | **5.8** |
| Water Quality - Pesticide pollution | 6.1 | 10.0 | 8.0 | 7.5 | **5.8** |
| Landscape - state and diversity | 4.8 | 7.7 | 5.8 | 5.5 | **4.3** |

* These scores were calculated by summing the evaluations for each indicator given by all participants considering one criterion and dividing the sum by the number of participants (15). ** This score was calculated by summing the evaluations for each indicator given by all participants for all criteria and dividing the sum by 60 (the number of participants × the number of criteria).

The evaluation of each indicator, carried out by the three stakeholder groups—farmers, policymakers, and agri-environmental researchers—using the established criteria, is presented in Table 6.

**Table 6** The assessment of each indicator, by stakeholder group, considering all criteria Source: (Spânu et al., 2022)

| **Agri-Environmental Indicators** | **Stakeholders** | | |
|---|---|---|---|
| | **Farmers** | **Policymakers** | **Agri-environmental Researchers** |
| Agri-environmental commitments | 2.9 | 1.55 | 6.4 |
| Agricultural areas under Natura 2000 | 2.75 | 2.65 | 6.95 |
| Farmers' training level and use of environmental farm advisory services | 2.9 | 1.95 | 7.3 |
| Area under organic farming | 5.05 | 2.55 | 8.05 |
| Mineral fertiliser consumption | 6.6 | 2.35 | 8.65 |
| Consumption of pesticides | 6.6 | 2.25 | 8.25 |
| Irrigation | 7.15 | 2.45 | 8.4 |
| Energy use | 4.7 | 1.8 | 6.7 |
| Land use change | 4.1 | 2.45 | 6.85 |
| Cropping patterns | 5.85 | 2.55 | 8.6 |
| Livestock patterns | 5.65 | 2.55 | 8.65 |
| Soil cover | 5.55 | 1.8 | 7.4 |
| Tillage practices | 6.05 | 2 | 7.8 |
| Manure storage | 6.35 | 2.05 | 7.95 |
| Intensification/extensification | 3.65 | 1.7 | 6.7 |
| Specialisation | 4.4 | 2.4 | 7.65 |
| Risk of land abandonment | 3.15 | 1.9 | 6.15 |
| Gross nitrogen balance | 2.8 | 2.35 | 8.55 |
| Risk of pollution by phosphorus | 3.35 | 2.1 | 8.1 |
| Pesticide risk | 3.65 | 2.3 | 8.4 |
| Ammonia emissions | 3.25 | 2.45 | 8.7 |
| Greenhouse gas emissions | 3.35 | 1.8 | 8.35 |
| Water abstraction | 3.85 | 2.1 | 8.6 |
| Soil erosion | 4.3 | 2.35 | 8.7 |
| Genetic diversity | 3 | 2.5 | 8.95 |
| High Nature Value farmland | 2.15 | 2.65 | 8.8 |
| Production of renewable energy | 3.2 | 2.3 | 8.55 |
| Population trends of farmland birds | 3.6 | 2.35 | 8.95 |
| Soil quality | 5.8 | 2.7 | 9.5 |
| Water Quality - Nitrate pollution | 5 | 2.7 | 9.6 |
| Water Quality - Pesticide pollution | 5 | 2.7 | 9.6 |
| Landscape - state and diversity | 2.5 | 2.3 | 7.95 |

*These scores were calculated by summing up the evaluations for each indicator given by the members of one group considering all criteria and dividing the sum by 20 (the number of participants in a group x the number of criteria).

Farmers, meanwhile, showed a tendency to assign higher scores to indicators directly related to agricultural operations and farm infrastructure, which are of immediate concern to their day-to-day activities. For example, indicators like "Irrigation" (rated 7.15) and "Manure storage" (rated 6.35) reflect farming practices that directly impact farm productivity and operational efficiency. These indicators are crucial to farmers' decision-making processes as they deal with tangible, on-the-ground practices that affect crop yields, resource management, and cost control. Similarly, "Mineral fertilizer consumption" and "Consumption of pesticides" (both rated at 6.6) are also highly relevant to farmers, as these practices directly influence their operational costs, crop health, and environmental footprint.

## 3.4 Policy Recommendations Based on Stakeholder Input

The successful implementation of agri-environmental indicators (AEIs) to promote sustainable agricultural practices depends largely on the involvement of multiple stakeholders—farmers, policymakers, and agri-environmental researchers. Each of these groups brings different perspectives and priorities to the table, which must be carefully considered when developing policies that aim to improve sustainability in agriculture. This document presents several policy recommendations based on the input from these three key stakeholders, with a particular focus on bridging the gaps in their perceptions and ensuring the effective application of sustainability indicators. The recommendations are as follows:

<u>Strengthening Stakeholder Collaboration and Dialogue</u>

<u>Tailoring Policies to Stakeholder Needs</u>

<u>Addressing Policy Gaps and Improving Feasibility</u>

<u>Encouraging Financial Support and Incentives</u>

<u>Fostering Public Awareness and Education</u>

<u>Monitoring, Evaluation, and Adaptation</u>

# PART II: Objective Evaluation of the Water Resources in Rural Community of Aiton Village using AEIs

This part begins with an examination of general water parameters, including physical and chemical indicators that reflect the health of local water bodies. These parameters are essential for understanding the overall state of water resources in Aiton Village and identifying potential risks to human health and the environment. The analysis then shifts to the specific challenges posed by agricultural runoff, including pesticide residues and elevated nitrate concentrations, which are known to degrade water quality and threaten biodiversity. By using AEIs to evaluate these pollutants, this part of the thesis aims to provide a detailed, data-driven analysis of water resources in the community.

The objective evaluation of water resources in Aiton Village is grounded in a systematic approach that utilizes traditional water quality parameters (e.g, turbidity, salinity, pH) and the latest agri-environmental indicator frameworks.

## CHAPTER IV Assessment of Nitrate and Pesticide Contamination in Aiton Village: Integrating AEI 27.1 and 27.2 with General Water Quality Parameters

The objectives of this chapter are to:

1. Assess nitrate concentrations in the drinking water of Aiton village. This analysis employs Agri-Environmental Indicator 27.1, "Water Quality: Nitrate Pollution," to determine nitrate levels, identify potential sources of contamination, and evaluate the role of agricultural activities in nitrate pollution. This investigation provides a deeper understanding of the environmental and public health implications of nitrate contamination, offering practical recommendations for improving water safety and sustainable agricultural practices in Aiton village.

2. To assess the potential contamination of drinking water in Aiton village due to pesticide use. This analysis utilizes the AEI "Water Quality: Pesticide Pollution" to quantify pesticide concentrations, trace potential sources of contamination, and evaluate the impact of agricultural practices on water quality. By addressing this issue, the study identifies environmental, and health risks associated with pesticide pollution and offers insights into improving agricultural management and water conservation efforts in the region.

## 4.1 Study Area Characterization

As illustrated in Figure 4, Aiton is geographically defined by the coordinates 23º39'34" - 23º47'49" E longitude and 46º38'26" - 46º42'48" N latitude. The total area of the village is 52.8 km², which places it below the average surface area of both Cluj County and Romania as a whole. At the county level, Aiton ranks 69th out of 80 communes, with the county's average commune size being 82 km². On a national scale, where the average commune size is 74.9 km², Aiton ranks 3,182nd out of 4,010 communes (*AITON MUNICIPALITY DEVELOPMENT STRATEGY 2014-2050*, 2014).

Despite its relatively small size, Aiton plays an important role in the region's agricultural landscape, contributing to local food production and maintaining traditional farming practices. Its geographical location within the Apuseni Mountains influences its environmental and agricultural potential, making it a relevant case study for assessing the impact of nitrate and pesticide contamination in rural water sources.

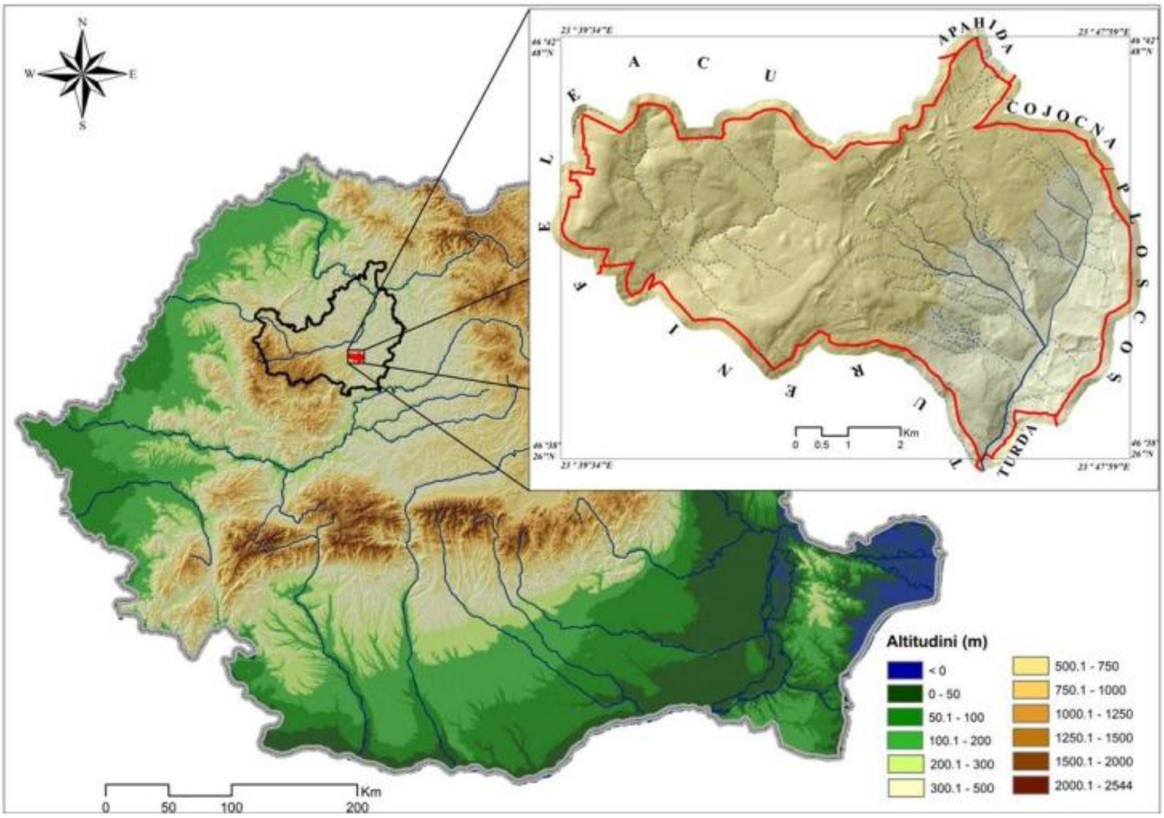


**Figure 4** The location at national and county level of the commune of Aiton. Source: Aiton Municipality Development Strategy 2014-2050 (2014).

As illustrated in Figure 5, the hydrographic network of Aiton Commune is relatively sparse. The commune comprises two villages, Aiton and Rediu, which share similar hydrological characteristics.

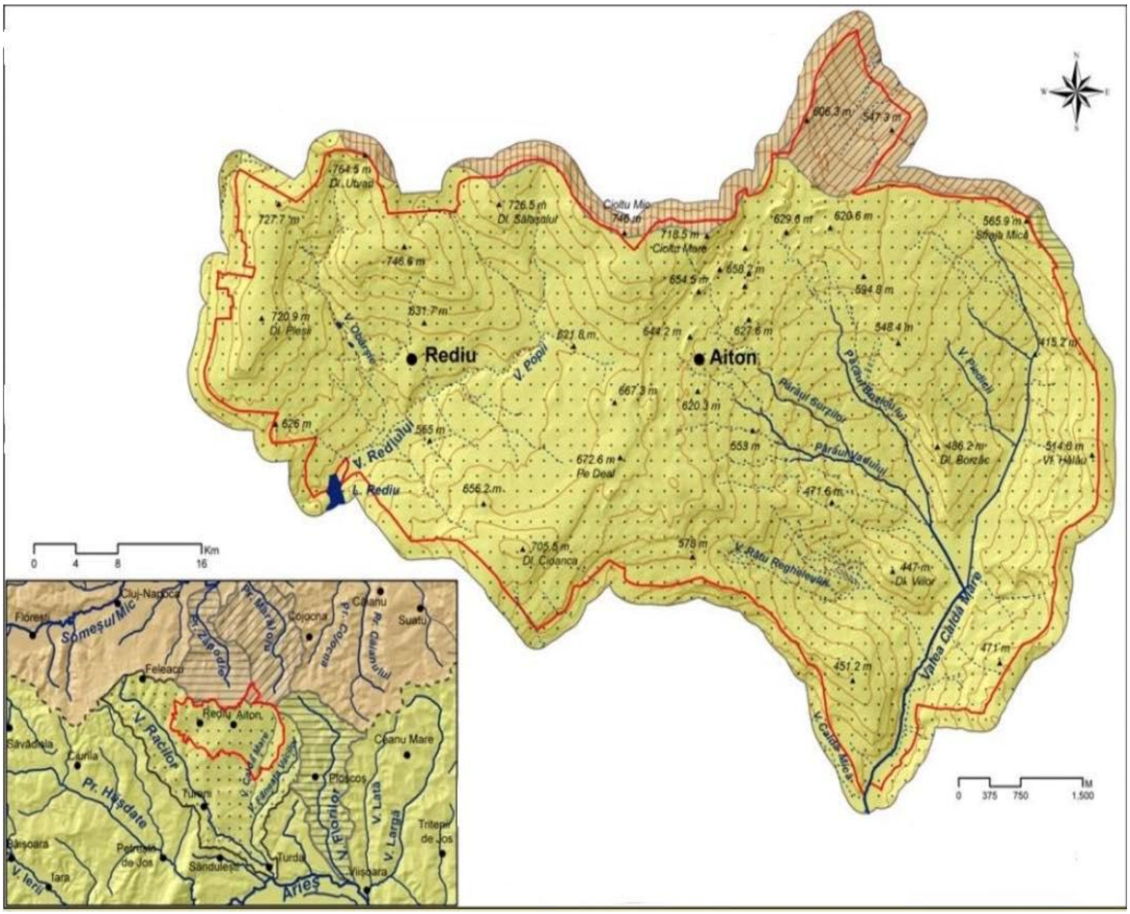


**Figure 5** Hydrographic network of Aiton commune. Source: Aiton Municipality Development Strategy 2014-2050 (2014)

## 4.2 Methodology: Research design; samples collection and analysis

To assess and evaluate the quality of water resources in Aiton Village, a total of 40 water samples were collected. These included 37 samples from local wells, representing a subset of the 115 total wells in the village, and 3 samples from nearby streams. The sampling process followed the standardized methodology outlined in ISO 5667-5:2006 (ISO/TC 147/SC 6, n.d.), ensuring a rigorous and systematic approach to water quality assessment.

Before initiating the water sampling campaign in Aiton Village, a systematic approach was employed to designate precise sampling locations. To achieve a well-distributed and scientifically rigorous selection of sampling sites, Google Earth was utilized to predefine sampling points, ensuring comprehensive spatial coverage of the village's water sources. The designated sampling locations are illustrated in Figure 6.

**Figure 6** Sampling area. Source: (Spânu et al., 2024)

## 4.3 Overview and Significance of General Water Quality Parameters

Water is an essential resource for life, impacting public health, environmental sustainability, and socio-economic development. Given its critical importance, assessing water quality through various parameters is pivotal. This thesis aims to explore the primary water quality parameters comprising pH, Oxidation-Reduction Potential (ORP), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity, Iron Concentration, Chlorine, Nitrites ($NO_2^-$), Nitrates ($NO_3^-$), and Sulphates ($SO_4^{2-}$). Each of these parameters serves as an indicator of water quality and influences the potability of water supplies; understanding their interactions and impacts is crucial for effective water management. Table 7 highlights each parameter with its potential agricultural sources, and their connection to water contamination in rural or agricultural areas.

**Table 5** General water quality parameters description and possible sources of contamination Source: author's elaboration

| Water Quality Parameter | Description | Possible Agricultural Sources of Contamination |
|---|---|---|
| **pH** | Measures the acidity or alkalinity of water. | Fertilizer runoff, agricultural chemicals, and manure can affect pH levels. |
| **Oxidation-Reduction Potential (ORP)** | Indicates the water's ability to oxidize or reduce substances. | Fertilizer runoff, particularly nitrogen fertilizers, and organic matter decomposition. |
| **Electrical Conductivity (EC)** | Measures the water's ability to conduct electricity, indicating ion concentration. | High mineral content from fertilizers and saline irrigation water. |
| **Total Dissolved Solids (TDS)** | Total concentration of dissolved substances in water. | Fertilizers, pesticides, and organic waste from agricultural runoff. |
| **Salinity** | Measures the salt concentration in water. | Irrigation with saline water, fertilizer application, and runoff from salt-affected soils. |
| **Iron Concentration** | Measures the amount of iron in water, which can cause staining and affect taste. | Use of iron-rich fertilizers, runoff from iron-rich soils, and livestock waste. |
| **Chlorine** | The concentration of chlorine, often used in water disinfection. | Chlorine used in irrigation systems or water treatment may leach into water sources. |

| Water Quality Parameter | Description | Possible Agricultural Sources of Contamination |
|---|---|---|
| **Nitrites ($NO_2^-$)** | Nitrites, which can be toxic at high levels, are intermediate products of nitrogenous fertilizers. | Overuse of nitrogen-based fertilizers, manure runoff, and contaminated irrigation water. |
| **Nitrates ($NO_3^-$)** | Nitrates are a common by-product of fertilizer decomposition. | Excessive application of nitrogen-based fertilizers, manure runoff, and irrigation with contaminated water. |
| **Sulphates ($SO_4^{2-}$)** | Presence of sulfate compounds can cause water hardness. | Use of sulfate-based fertilizers (e.g., ammonium sulfate), runoff from agricultural fields, and irrigation water. |

Figure 7 displays the laboratory results of pH for collected samples from Aiton village.

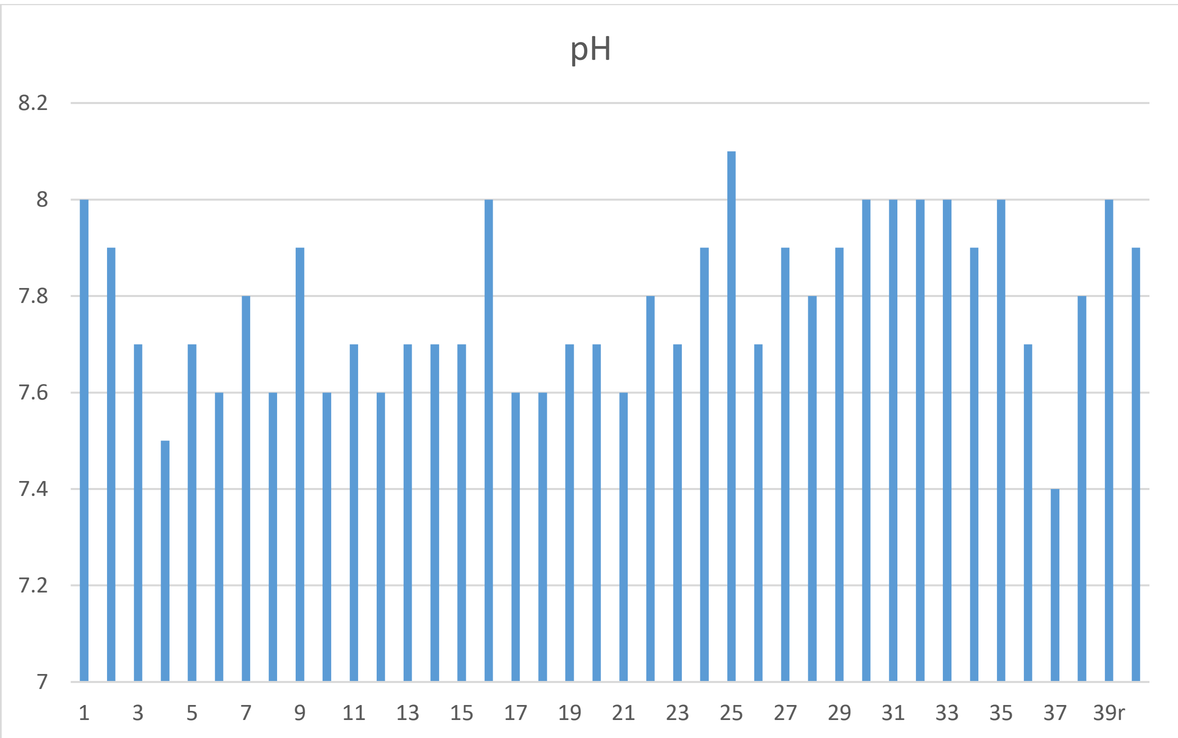


**Figure 7** pH values from Aiton village. Source: author's elaboration

The observed pH values generally fall between 7.2 and 8.1, indicating that the water is slightly alkaline. Some samples reach or exceed a pH of 8.0, while the lowest recorded value is just above 7.2. None of the samples fall below a neutral pH of 7.0, confirming that the water is not acidic. Moderate variation in pH values is present across the samples, with some exhibiting slightly higher alkalinity.

Figure 8 displays the laboratory results of ORP for collected samples from Aiton village.

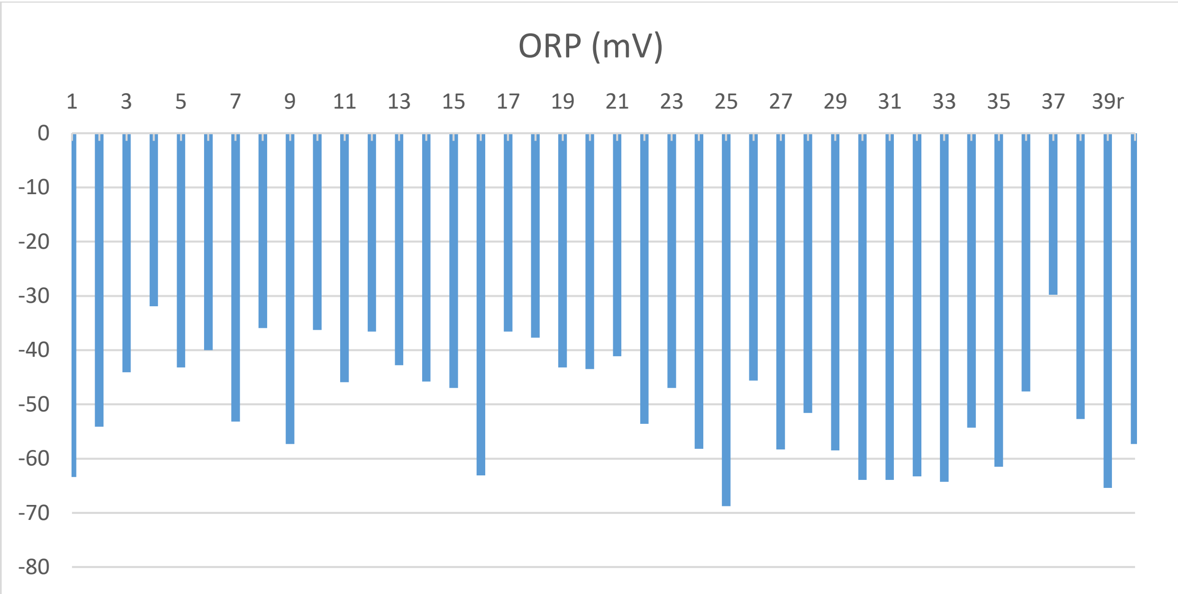


**Figure 8** ORP values form Aiton village. Source: author's elaboration

The graph displays Oxidation-Reduction Potential (ORP) values in millivolts (mV) for 40 water samples. The x-axis represents the sample numbers from 1 to 40, while the y-axis shows ORP values ranging approximately from 0 mV to -70 mV.

Figure 9 displays the laboratory results of EC for collected samples from Aiton village.

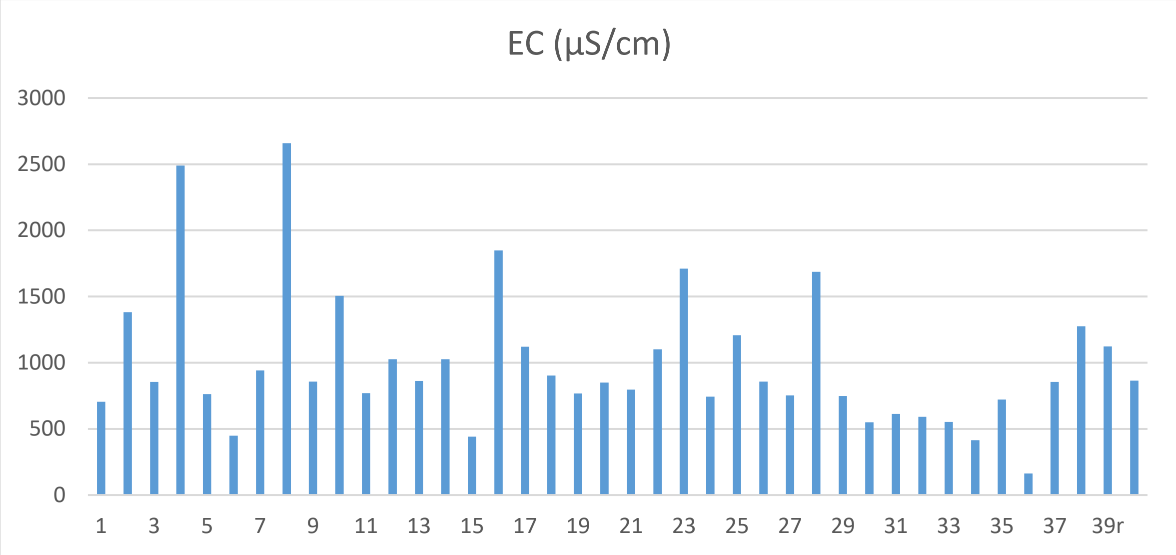


**Figure 9** EC values from Aiton village. Source: author's elaboration

The graph presents Electrical Conductivity (EC) values in µS/cm for 39 water samples. The x-axis represents the sample numbers from 1 to 39, while the y-axis displays EC values ranging from 0 to approximately 3000 µS/cm.

Figure 10 provides the laboratory results of TDS for the collected samples from Aiton village.

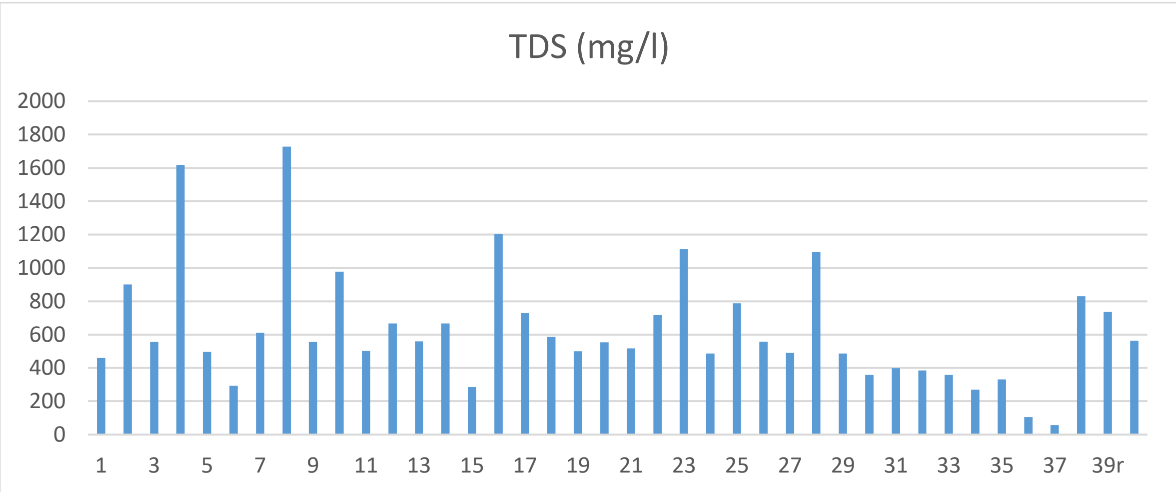


**Figure 10** TDS values from Aiton village. Source: author's elaboration

The bar chart illustrates the Total Dissolved Solids (TDS) concentration in mg/l for various sample points, likely numbered from 1 to 39.

Figure 11 displays the laboratory results of salinity for collected samples from Aiton village.

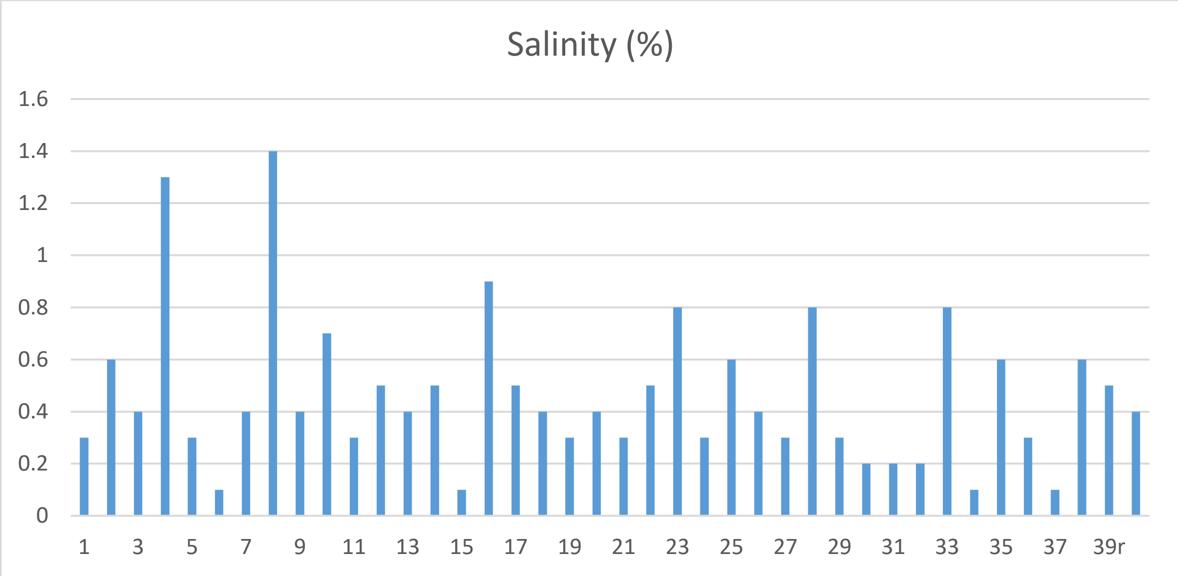


**Figure 11** Salinity values from Aiton village. Source: author's elaboration

The salinity levels vary across different sample points, with some reaching significantly high values above 1.2%, while others remain relatively low, below 0.2%.

Figure 12 displays the laboratory results of fluoride for collected samples from Aiton village.

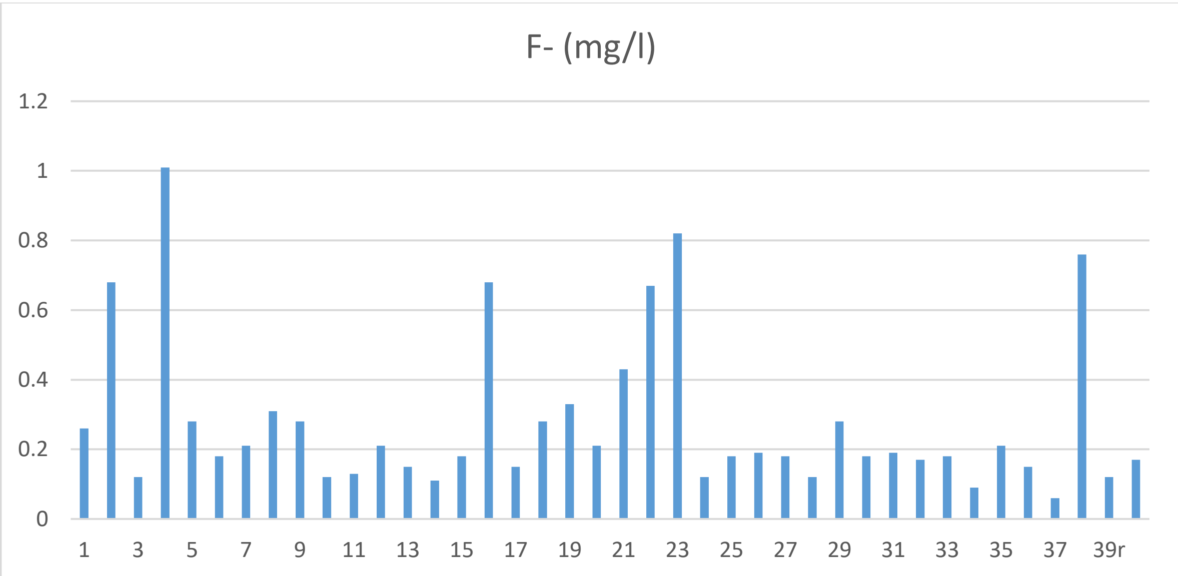


**Figure 12** Floride values from Aiton village. Source: author's elaboration

Fluoride levels vary across different sample points, with some samples exhibiting significantly high concentrations exceeding 1.0 mg/l, while others remain relatively low, below 0.2 mg/l.

Figure 13 displays the laboratory results of chlorine for collected samples from Aiton village.

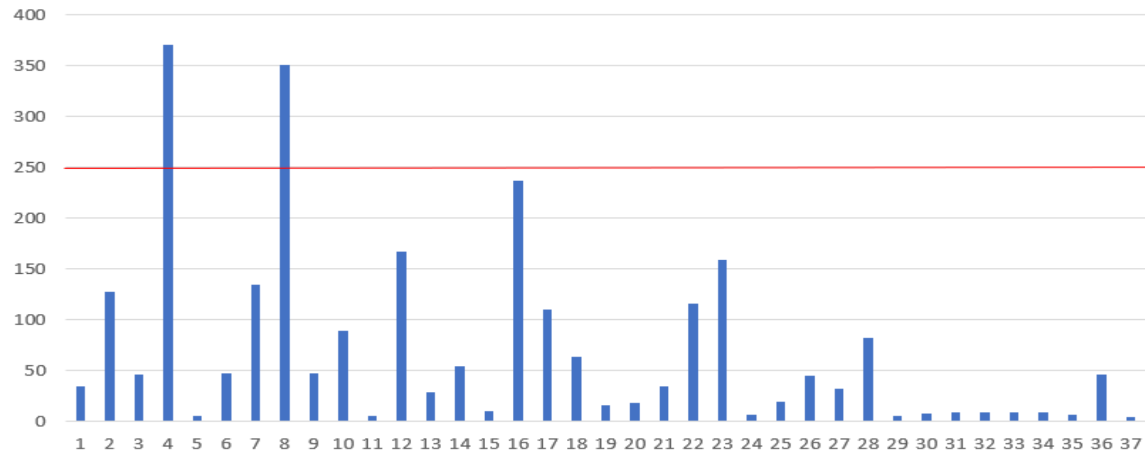


**Figure 13** Chlorine concentration (mg L-1) in collected water samples (wells). Note: the red line represents the maximum allowable limit stated by law. Source: (Spânu et al., 2024)

Chloride concentrations vary significantly across different sample points, with some samples exhibiting high peaks above 350 mg/l, while many others remain below 50 mg/l. Notable peaks occur at sample numbers 4, 8, 16, and 23, with the highest recorded chloride concentration reaching approximately 370 mg/l. Additional moderate peaks appear in samples 7, 17, 22, 28, and 39. In contrast, many sample points, particularly in the latter part of the dataset (samples 30–40), show very low chloride concentrations, often near zero.

## 4.4 Nitrate and Nitrites Pollution Results: Sources, Dynamics, and Environnemental Impacts

Figure 14 displays nitrite concentrations in the samples collected from Aiton village.

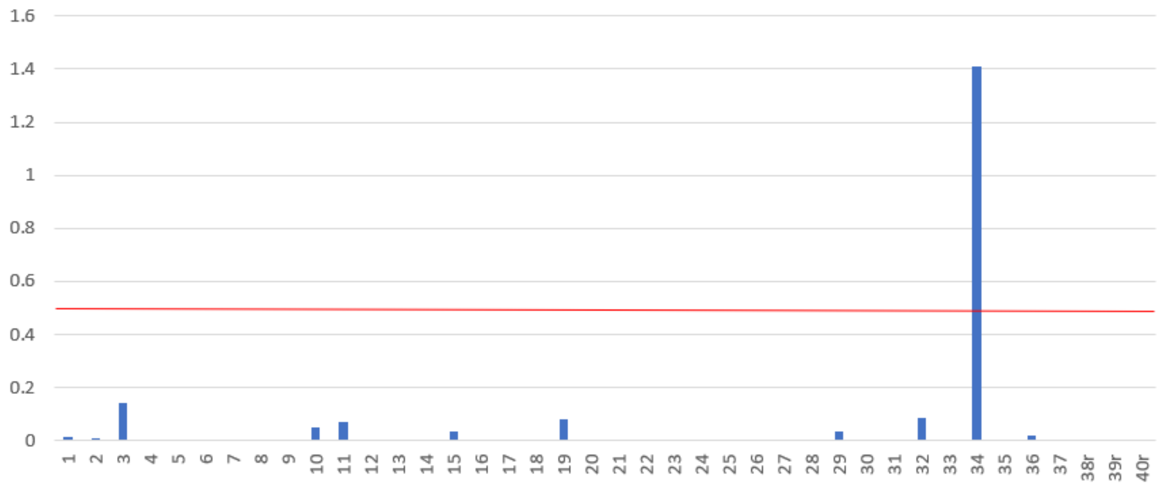


**Figure 14** Nitrites concentration (mg L-1) in collected water samples (wells + streams). Note: the red line represents the maximum allowable limit stated by law. Source: (Spânu et al., 2024)

Nitrite ($NO_2^-$) concentrations in most sample points are very low or negligible, with the majority of values remaining below 0.2 mg/l. However, a sharp spike (~1.4 mg/l) at sample 34 stands out as a clear outlier, indicating localized contamination rather than a widespread issue. Minor fluctuations are observed in samples 3, 11, 19, and 33, but these remain relatively low.

Several factors could contribute to this variability. Naturally, nitrite is uncommon in water due to its instability; it typically oxidizes to nitrate ($NO_3^-$) or reduces to ammonia ($NH_3$). However, human activities can introduce nitrite contamination. The sudden spike at sample 34 may be attributed to sewage contamination, agricultural runoff (from fertilizers or animal waste), industrial discharge, or decaying organic matter.

Figure 15 displays nitrate concentrations in the samples collected from Aiton village.

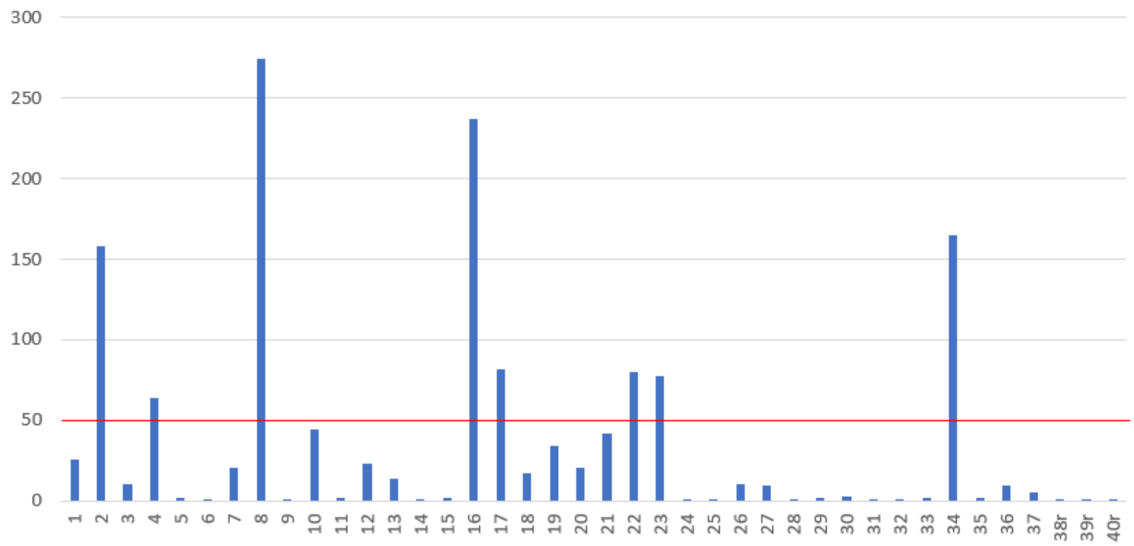


**Figure 15** Nitrates concentration (mg L-1) in collected water samples (wells + streams). Note: the red line represents the maximum allowable limit stated by law. Source: (Spânu et al., 2024)

The nitrate ($NO_3^-$) levels vary significantly across samples, with some samples showing very low concentrations while others reach extremely high levels. Notable peaks occur in samples 2, 8, 16, and 34, with concentrations reaching up to approximately 270 mg/l. Other moderate peaks are observed in samples 9, 22, and 33, where levels exceed 100 mg/l. Conversely, several samples have nitrate concentrations close to zero or very minimal.

High nitrate levels often originate from agricultural runoff, as fertilizers contribute significantly to nitrate pollution. Leakage from septic systems, animal waste, and untreated sewage can also introduce nitrates into water sources. Additionally, certain industries may discharge nitrate-containing waste, leading to contamination.

Figure 16 displays sulphates concentrations in the samples collected from Aiton village.

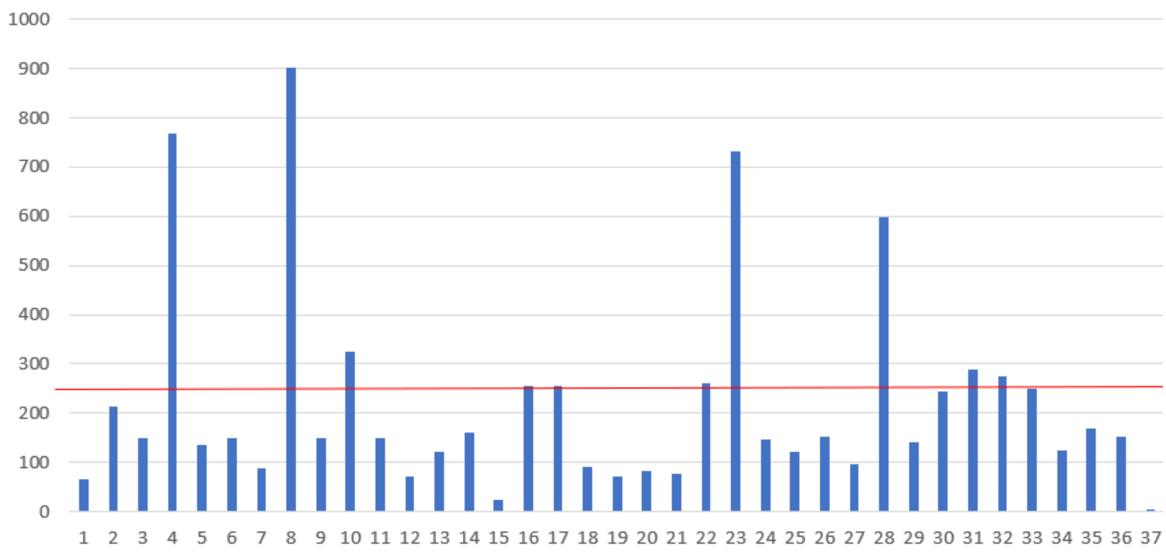

**Figure 16** Sulphates concentration (mg L-1) in the collected water samples (wells). Note: the red line represents the maximum allowable limit stated by law. Source: (Spânu et al., 2024)

Sulfate levels fluctuate widely across different samples, with some showing very low concentrations while others exhibit extremely high levels exceeding 900 mg/l. Notable high sulfate concentrations are observed in samples 3, 8, 23, and 28, with sample 8 reaching approximately 900 mg/l. Moderate peaks are found in samples 10, 22, 30, 31, and 39, while many samples show sulfate levels between 100 and 300 mg/l, indicating consistently moderate concentrations.

High sulfate levels can originate from several sources. Industrial discharge, particularly from mining, tanneries, and chemical industries, is a significant contributor. Agricultural runoff, including fertilizers and pesticides, can also result in sulfate contamination. In some areas, naturally occurring sulfate levels are high due to geological formations.

The analysis of stream water samples from various sites indicated consistently high levels of sulphate, a finding visually represented in Figure 17. Sulphate concentrations exceeded baseline thresholds in all samples, suggesting potential contamination from natural or anthropogenic sources such as industrial discharges, agricultural runoff, or geological weathering of sulphate-containing minerals.

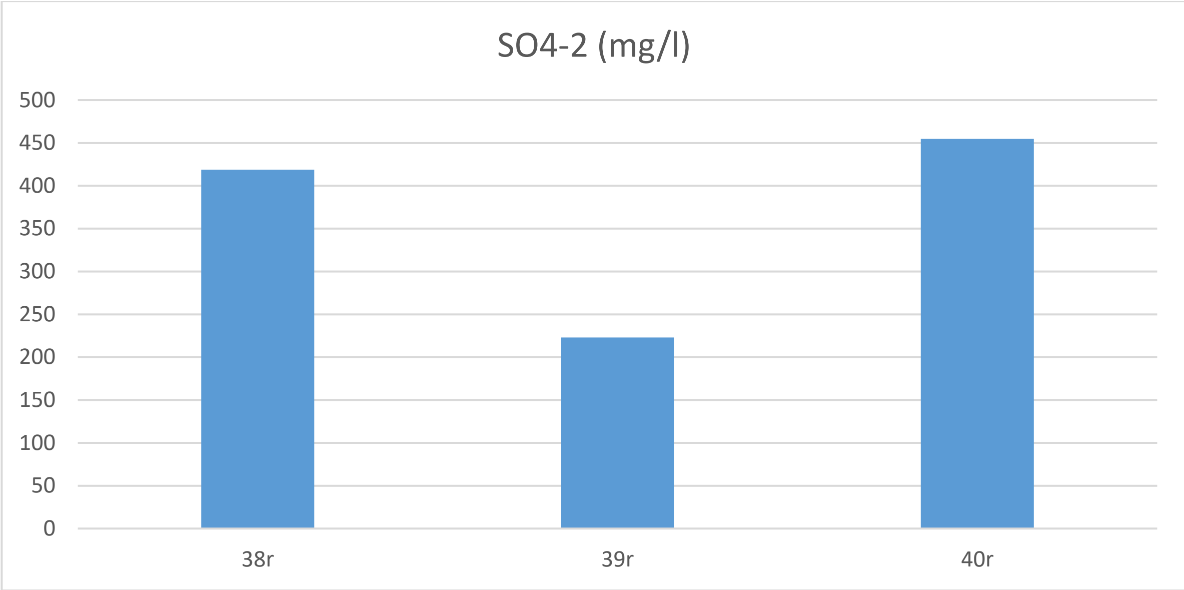


**Figure 17** Sulphates concentration (mg L-1) in the collected water samples (streams). Source: (Spânu et al., 2024)

## 4.5 Pesticide Contamination Results : Occurrence, Pathways, and Environmental Implications

Given the significant agricultural activities in Aiton village, particularly those near residential areas, the study expanded its scope to examine nitrate pollution and 33 additional pesticide compounds detected in water samples from wells and rivers. These compounds and their Chemical Abstract Service (CAS) registry numbers, scientific names, and molecular formulas are detailed in Table 8.

**Table 6** PEST Chemical compounds analyzed. Source: (Spânu et al., 2024)

| ***Chemical compound*** | ***Scientific name*** | ***Molecular formula*** | ***CAS No.*** |
|---|---|---|---|
| Alfa - HCH | Alpha-Hexachlorocyclohexane | $C_6H_6Cl_6$ | 86194-41-4 |
| Beta - HCH | Beta-Hexachlorocyclohexane | $ClCH(CHCl)_4CHCl$ | 319-84-6 |
| Gama - HCH | Gamma-Hexachlorocyclohexane | $C_6H_6Cl_6$ | 104215-85-2 |
| Delta - HCH | Delta-Hexachlorocyclohexane | $C_6H_6Cl_6$ | 319-86-8 |
| Epsilon-HCH | Epsilon-Hexachlorocyclohexane | $C_6H_6Cl_6$ | 6108-10-7 |
| Pentaclornitrobenzene | Pentachloronitrobenzene | $C_6Cl_5NO_2$ | 82-68-8 |
| Aldrin | Aldrin | $C_{12}H_8Cl_6$ | 309-00-2 |
| Dieldrin | Dieldrin | $C_{12}H_8Cl_6O$ | 60-57-1 |
| Heptachlor | Heptachlor | $C_{10}H_5Cl_7$ | 76-44-8 |
| Heptachlor epoxide beta | Heptachlor epoxide | $C_{10}H_5Cl_7O$ | 1024-57-3 |
| Heptachlor epoxide alfa | Heptachlor epoxide | $C_{10}H_5Cl_7O$ | 1024-57-9 |

| | | | |
|---|---|---|---|
| beta-Endosulfan | Beta-Endosulfan | $C_9H_6Cl_6O_3S$ | 959-98-8 |
| alpha-Endosulfan | Alpha-Endosulfan | $C_9H_6Cl_6O_3S$ | 959-98-8 |
| 2,4'-DDE | Dichlorodiphenyldichloroethylene | $C_{14}H_8Cl_4$ | 3424-82-6 |
| 4,4'-DDE | 4,4'-Dichlorodiphenyldichloroethylene | $C_{14}H_8Cl_4$ | 72-55-9 |
| 2,4'-DDD | Dichlorodiphenyldichloroethane | $C_{14}H_{10}Cl_4$ | 72-54-8 |
| 4,4'-DDD | Dichlorodiphenyldichloroethane | $C_{14}H_{10}Cl_4$ | 72-54-8 |
| 2,4'-DDT | Isomer of dichlorodiphenyltrichloroethane | $C_{14}H_9Cl_5$ | 789-02-6 |
| 4,4'-DDT | Dichlorodiphenyltrichloroethane | $C_{14}H_9Cl_5$ | 104215-84-1 |
| PCB 28 | 2,4,4'-Trichlorobiphenyl | $C_{12}H_7Cl_3$ | 7012-37-5 |
| PCB 52 | 2,2',5,5'-Tetrachlorobiphenyl | $C_{12}H_6Cl_4$ | 35693-99-3 |
| PCB 101 | 2,2',4,5,5'-Pentachlorobiphenyl | $C_{12}H_5Cl_5$ | 37680-73-2 |
| PCB 138 | 2,2',3,4,4',5'-Hexachlorobiphenyl | $C_{12}H_4Cl_6$ | 35065-28-2 |
| PCB 153 | 2,2',4,4',5,5'-Hexachlorobiphenyl | $C_{12}H_4Cl$ | 35065-27-1 |
| PCB 180 | 2,2',3,4,4',5,5'-Heptachlorobiphenyl | $C_{12}H_3Cl_7$ | 35065-29-3 |
| PCB194 | 2,2',3,3',4,4',5,5'-Octachlorobiphenyl | $C_{12}H_2Cl_8$ | 35694-08-7 |
| 1,2,3-tricorbenzene | Vic-Trichlorobenzene | $C_6H_3Cl_3$ | 87-61-6 |
| 1,2,4-tridorbenzene | 1,2,4-Benzenetriol | $C_6H_6O_3$ | 33-73-3 |
| 1,3,5-tridorbenzene | 1,3,5-Tris(bromomethyl)benzene | $C_9H_9Br_3$ | 18226-42-1 |
| 1,2,3,5 - tetraclorbenzene | 1,2,3,5-Tetrahydroxybenzene | $C_6H_6O_4$ | 634-94-6 |
| 1,2,3,4 - tetraclorbenzene | 1,2,3,4-Benzenetetrol | $C_6H_6O_4$ | 642-96-6 |
| 1,2,4,5 - tetraclorbenzene | 1,2,4,5-Tetraisopropylbenzene | $C_{18}H_{30}$ | 635-11-0 |
| Pentadorbenzene | 3-phenylpentadiene | $C_{11}H_{12}$ | 37580-41-9 |

Note: CAS = Chemical Abstract Service.

Figure 37 displays the sum of pesticides from well water samples collected in Aiton village.

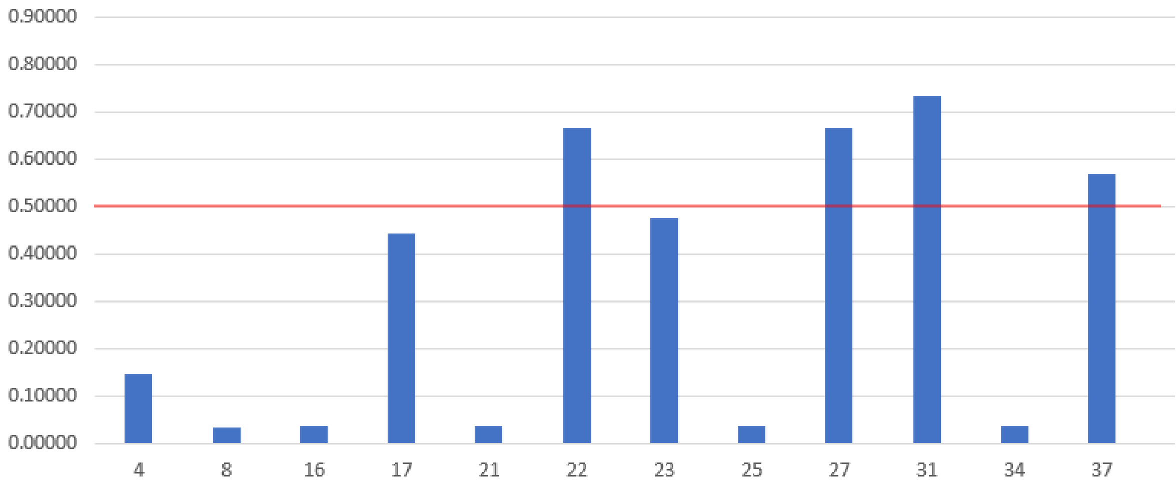

**Figure 18** Total of pesticides (µg L-1) found in the wells water. Note: the red line represents the maximum allowable limit stated by law. Source: (Spânu et al., 2024)

Laboratory analysis revealed that the total concentration of pesticides exceeded the maximum allowable limit in 4 out of 37 wells or samples, representing approximately 10.8% of the tested samples. This finding indicates that while a small proportion of the samples surpass regulatory thresholds, the majority—33 out of 37 samples (89.2%)—remain within the permissible limits. This suggests that, on the whole, most wells or samples comply with established pesticide regulations, reflecting a generally positive trend in water quality.

In Figure 38 it can be observed that in one of the rivers, the sum of pesticides exceeded the maximum allowable limit.

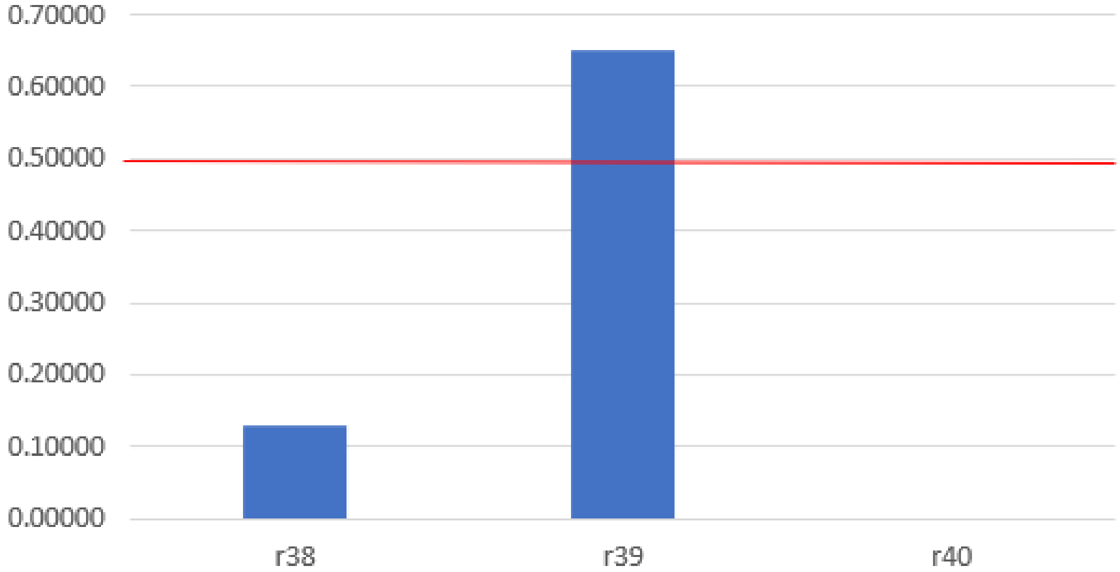

**Figure 19** Total of pesticides (µg L-1) found in the rivers. Note: the red line represents the maximum allowable limit stated by law. Source: (Spânu et al., 2024)

Figure 39 displays the total pollutant load per sampling point which indicates that point 31 is the most polluted, followed by point 27 and 22.

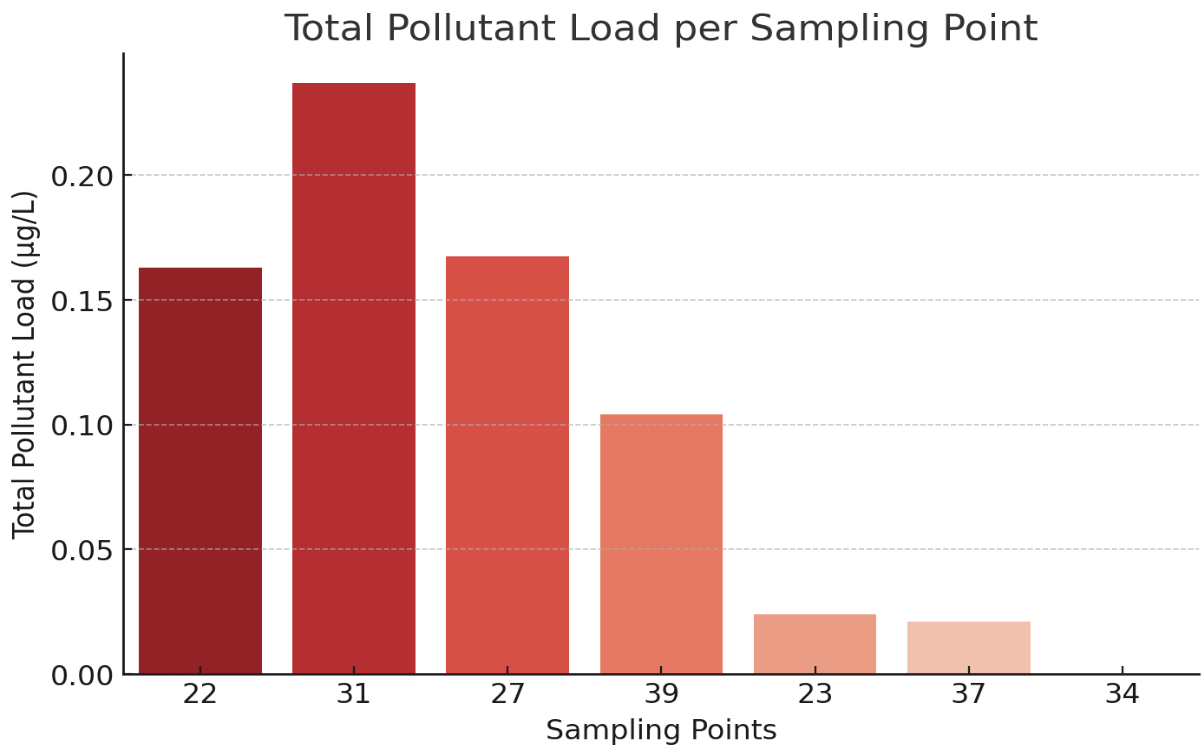

**Figure 20** Total Pollutant Load per Sampling Point. Source: author's elaboration

## 4.6 Findings and Implications for Environmental Policy in Aiton Village

Conclusion

The detection of these pollutants in specific zones underscores the need for urgent environmental intervention in Aiton Village. Legacy contamination from past agricultural and industrial activities remains a major concern, with high persistence and long-term risks associated with DDT metabolites, PCBs, and pentachlorobenzene. By implementing targeted remediation, policy enforcement, and continuous monitoring, authorities can reduce environmental risks and safeguard human and ecological health in the region.
The environmental and health implications of pollution in Aiton Village demand immediate intervention. The contamination of aquatic ecosystems threatens biodiversity, fishery resources, and food security, while the persistence of toxic pollutants in drinking water raises serious public health concerns. Without proactive policy measures, stricter pollution controls, and improved monitoring programs, human and ecological health remain at significant risk.

# CHAPTER V Thesis General Conclusions and Recommendations

## 5.1 Thesis Practical Contributions and Recommendations

The key conclusions drawn from this study are:

1. Agricultural and Industrial Activities as Major Pollution Sources

- The presence of DDT metabolites, nitrates, and heavy metals suggests that historical and ongoing agricultural practices contribute significantly to water pollution.
- The detection of PCBs and pentachlorobenzene at several sites indicates industrial contamination, likely due to inadequate waste management and improper disposal of hazardous materials.

2. Impact of Persistent Pollutants on Ecosystems and Public Health

- FAO guidelines emphasize the risks of bioaccumulation, which is evident in this study. The presence of DDT and PCBs in aquatic environments suggests severe ecological consequences, including:
    - Biodiversity loss due to toxic exposure.
    - Disruption of aquatic food chains, affecting local fisheries.

- Long-term persistence of pollutants in soil and sediments, further degrading water quality.

## 5.2 Future Development of the Subject

**1. Long-Term Environmental Monitoring and Data Analytics**

**2. Policy Integration with Global Environmental Agreements**

**3. Development of Alternative, Eco-Friendly Agricultural Inputs**

**4. Expansion of Pollution Mitigation Strategies**

**5. Community-Led Environmental Conservation Models**

## 5.3 Research Limitations

1) One key limitation lies in the use of AEIs in Romania to evaluate water resources. While this innovative approach offers significant advantages, it also presents challenges due to the limited availability of localized data and established benchmarks for comparison. The lack of a standardized methodology for applying AEIs in the Romanian context necessitated adaptations that might impact the generalizability of the results.

2) The research design looked primarily at the environmental aspect of farming sustainability, therefore excluding the social and economic dimensions of sustainability and relegating them outside the context of this thesis. Furthermore, there's a real possibility that some relevant studies were ignored in the search due to the manual search method employed. The analysis involved participants from a particular area of Romania, and therefore, the results refer only to that region, limiting the generability of the findings. Although the evaluation matrix can be an excellent device for gauging stakeholder perceptions, the results cannot be generalizable since the weighting and scoring process may lead to more subjective judgments. Finally, this study does not propose a generalized solution, nor do the criteria selected always depend on various factors, whose importance, if one so dares, could change depending on the geographical position and environmental, social, economic, or political influences.

3) Data limitations posed a significant challenge, particularly concerning long-term and high-resolution data on water resources and agricultural practices in the study area. This constraint restricted the scope of temporal analysis and have influenced the findings'

comprehensiveness. Additionally, reliance on secondary data sources for certain indicators introduced potential inaccuracies and inconsistencies.

4) The study focuses exclusively on Aiton village, which, while representative of specific rural and agricultural contexts in Romania, limits the broader applicability of the findings. Regional variability in agricultural practices, socio-economic conditions, and climate impacts may reduce the direct transferability of the results to other areas.

5) The use of qualitative and quantitative methods was constrained by technological limitations, particularly in employing advanced monitoring tools or real-time data collection techniques. While the study utilized existing data effectively, the integration of emerging technologies, such as Internet of Things (IoT) devices for water monitoring, could enhance future research.

6) Although the study provides valuable insights for policymakers and stakeholders, its practical implementation and impact are contingent on broader institutional and regulatory frameworks. The limited engagement with policymakers during the research phase may hinder the immediate application of the findings to policy development.

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