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## RESEARCH ARTICLE

## Conflicts in Land Use and Management

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### ABSTRACT

As land is limited, conflicts between land uses, and, consequently, conflicts between land users about land use inevitably arise. The objective of this paper is to provide a broad, cross-sectional overview of land use conflicts as perceived by different actors and to explore the actors' experiences with these conflicts. We conducted 45 face-to-face interviews with key land use actors in the Republic of North Macedonia. Then we applied a qualitative text analysis or identification of keywords to identify the most relevant conflicts across all land use sectors (agriculture, forestry, nature protection, etc.) and their impacts on local actors' daily experiences. The results show that actors are aware of many diverse land use conflicts, most frequently regarding land uses for environmental/species conservation, forestry, and agriculture. Thus, land use conflicts play an important and mostly negative role in the experiences of land use actors. These findings fill current gaps in the literature on land use conflicts regarding the types of conflicts of which actors are aware and the consequences of these conflicts. The results also underline the relevance of addressing conflicts in land use planning and governance, the need for appropriate conflict management, and the necessity of providing local actors with sufficient resources to deal with land use conflicts.

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## 1. Introduction


Land as one of the most important resources is the subject of interest of various users. The needs and requirements of the users are different: as an ecosystem for agricultural production and other primary activities, space for the construction and development of human settlements, for the use of natural resources and other economic activities. Users have different goals, priorities and interests that are often conflicting. The inappropriate and irrational use of land by different users is a possibility for producing numerous conflicts and is often the cause of various forms of land degradation. Therefore, to ensure sustainable development and rational use of this important

resource, conflict management is imposed as an integral part of land planning, use, management and protection.

The focus of the subject research is conflicts related to land use and land resources. The complexity of the land as an integral structure that unites the soil, relief, hydrological and mineral resources, the living world and climatic characteristics, condition the complexity and diversity of the conflicts that are present in the use of the land.

## 2. Theoretical Background

Conflicts as a social phenomenon are not only related to politics and political issues. The occurrence of conflicts and conflict situations is present in all segments of social

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development, as a result of different attitudes, representations, perceptions and interests. The broadest definition of conflicts comes from Walker and Daniels (1997), who provide a list of terms to define the concept of conflict: struggle, competition, tension, incompatibility, communication, strategic behavior and interaction. Conflicts are most often classified according to intensity. Keltner and Robinson (1993) offers a wide range of degrees of conflict intensity, from mild differences to litigation and physical confrontation.

There are many conflict theories in the literature. The earliest political theorists, from Thucydides and Sun Tsu to Machiavelli and von Clausewitz, concentrated on just one element: force. The use of force is a central element of macro conflict theory. Proponents of this theory agree that power takes many different forms: economic, political, war, and even cultural (Cunningham, 1998, p. 9). A common assumption of macro or classical theories of conflict is that the root of conflict lies in competition between groups.

The opposite of the macro theory is the behaviourist or micro theory which is based on the observation of individuals in their environment.

Another element that defines conflicts is the material aspect. According to O'Connell (1989), "With the advent of agriculture, and later politics, the conflict became part of the human experience". Human Needs Theory is a generic or holistic theory of human behaviour. It is based on the hypothesis of basic human needs that need to be met, to ensure stable societies (Cunningham, 1998, p. 20). People in conflict situations struggle within their institutional environments at all social levels to satisfy their primal and universal needs, such as: security, identity, recognition and development. They constantly strive to control their environment. Since the demands for basic human needs always exceed the supply, conflicts are the result of people's failure to meet their needs. The role of conflict management is to enable the actors to understand that everyone has legitimate needs that must be met to resolve the conflict (Cunningham, 1998, p. 22) which is necessary to ensure the satisfaction of their needs.

Finally, conflict management theories attempt to produce a synthesis between consensus and conflict theories. Turtiainen (1996, p. 21), advocates a potentially positive role for conflicts in social development, because they keep public authorities on their toes, raise awareness of problems, help define them, promote checks and balances in the adoption of decisions, motivate and encourage solutions to problems, raise morale and cohesion, encourage creativity and allow individual interests to be heard.

### 3. Methodology

To detect conflicts in land use, the qualitative method was applied in the research - face-to-face interviews with

representatives of the stakeholders from which primary data were obtained that confirm or deny what was previously ascertained based on the analysis of secondary data. The interview was conducted based on a previously prepared questionnaire. It is formulated as semi-structured with a total of 12 questions, of which 4 direct answers are given, and on 8 questions the respondent gives his opinion. The issues are grouped into 4 groups, namely: issues of a socioeconomic nature, issues related to conflicts during land use planning; questions about ways of managing conflict situations, questions about overcoming conflicts, that is, recommendations for future work. The conceptualization of the questions was influenced by the determination to make a real selection of respondents who, based on their competencies and expertise, will make a significant contribution to the qualitative research. A total of 45 interviews were conducted with representatives of institutions responsible for the management, use, planning and protection of natural resources, that is:

- Ministry of Agriculture, Forestry and Water Management,
- Ministry of Environment and Spatial Planning,
- Ministry of Economy,
- Ministry of Local Self-Government,
- Ministry of Transport and Communications,
- Hans Em Faculty of Forest Science, Landscape Architecture and Ecoengineering,
- Faculty for agriculture,
- Spatial planning agency
- The City of Skopje,
- ELS Sopsishte, Ilinden, Petrovec, Zelenikovo,
- State Forestry and Hunting Inspectorate,
- State Environmental Inspectorate,
- PE National Forests,
- PE Macedonian Pastures,
- PE Parks and greenery,
- PUK Water and sewerage
- PE MSH, Karadzica Branch,
- HS Skopsko Pole,
- PU PNP Jasen,
- NGO Ursus Speleo,
- NGO Peoni.

1-4 representatives of each institution were interviewed, depending on the structure of the institutions (the number of departments and departments relevant to the research). All respondents are professional and competent in their scope of competencies and most of them hold high and managerial positions in their respective institutions. The interviews were conducted in the period March - May 2012, in the working environment of the respondents. After completing the

interviews, the material was averaged and analyzed by coding keywords.

## 4. Results and Discussion

The topics of the interviews conducted with the representatives of the institutions responsible for land use and management, i.e. their answers to the questions, can be grouped into several groups:

### 4.1. Socioeconomic Issues

The first group of questions refers to the structure of the respondents: their position in the institutions, work experience and communication and cooperation with other institutions.

Most of the respondents are state, i.e. public servants, employed in administrative bodies, public enterprises and LGUs, in management positions and with work experience in the current position of 3-5 years, and with a total work experience in the same institution of 5-15 and more years. The institutions with which the respondents most often cooperate are the ministries, PE National Forests, PE Pastures, ELS, the City of Skopje, the State Inspectorate and NGOs. Most of the respondents stated that the cooperation with the institutions is not satisfactory. They are either partially satisfied with the cooperation with all institutions in general or indicate specific satisfaction or dissatisfaction with individual institutions. Thus, according to the answers of the representatives of the Ministry of Environment and Spatial Planning, the cooperation with the Ministry of Transport and Communications is “unsatisfactory, because there is no adequate treatment of the activity of spatial planning, even though it is the basis for the preparation of urban plans”. The representative of the Ministry of Local Self-Government expressed total dissatisfaction with the cooperation with the ministries and municipalities, due to, as he stated, “insufficient communication, information and coordination in conducting compatible policies”.

### 4.2. Issues Related to Conflicts

The second group of questions refers to the conflicts, that is, the problems faced by the respondents in the course of work, the nature of the problems, the reasons for their occurrence and the time frame. The problems are different, but most often they arise between the institutions that have competencies that complement each other, intertwine, or are opposed. Thus, respondents working in institutions responsible for agricultural and forest land cited the transformation of agricultural land and the issuance of concessions as frequent and serious conflicts. Also, when issuing concessions for the exploitation of mineral resources, it happens that the subject of the concession is land for which approval was previously issued by another institution or an agreement was concluded for the lease of land or the use of pasture, or it is located in a protected area. Allowing a concession for one raw material sometimes has detrimental effects on another. Thus, when issuing a concession for the

exploitation of mineral resources on forest land, the forest roads are exploited, that is, the roads are destroyed without compensation.

The problems with uncontrolled conversion of fertile agricultural land into construction land, which often has the character of usurpation, is the most serious and current conflict, according to the statements of representatives of the Faculty of Agriculture. At the same time, the determination of the Spatial Plan of the Republic of Macedonia (which also has the meaning of law) is ignored, which strictly advocates the protection of productive land of categories 1-4.

Some of the respondents whose competencies are in the field of forestry indicated the sectoral approach, especially during the preparation and adoption of forest management plans, as a serious source of conflicts. Precisely because of this approach, as well as due to the absence of legal provisions, there is no planning of other public functions of forests for tourism, recreation and other purposes that do not conflict with the use and protection of forests. According to the statement of the representative of PE NF Karadžica, “the exclusion of the public in the procedure of adoption of the Business Plans also leads to the impossibility of intervention on the one hand and the adoption of bad plans on the other hand”.

In protected areas, the problems seem to be the most serious, or at least the most complicated. There, the responsibilities of the environmental inspection, forests, and LGUs are intertwined, and according to the law there is an entity for managing the protected areas which, according to the Law on Nature and the Proclamation Act, integrally manages the entire territory of the protected area. “The overlapping of powers between the competent institutions and the lack of regulation are the biggest problems in the operation”, according to the words of the representative of the Environmental Administration at the Ministry of Environment. From the responses of the respondents, it can be concluded that the approach is mostly sectoral, and sometimes beyond the own powers provided by the law. Illegal activities are present in the protected areas, starting from the construction of buildings without respecting the measures for integral protection, through the exploitation of forests in a way that is not suitable for a protected area, to the exploitation of mineral resources. The problems are all the more serious because part of these activities are foreseen by appropriate planning documents to which the Ministry of Environment and Spatial Planning is obliged to give its opinions, i.e. consents, for the positive outcome of which part of the administration is often exposed to political pressures from high level. Part of the respondents see the source of such problems in the way of declaring the protected areas, which according to them is often unprofessional and non-transparent, with which the representatives of the Ministry of Forestry and Hunting agreed. If the boundaries of the future protected area are not defined as a result of a comprehensive analysis and

research, it often happens that they include natural resources that do not have protection values and that have economic value, which, by declaring the area as protected, cannot be used, that is, subject to rigorous protection measures, which are often the reason for unprofitability of exploitation.

#### **4.3. Issues Related to Conflict Resolution, that is, Conflict Management**

The third group of questions refers to problem solving, the method of solving and the main actors in conflict management. A very small part of the respondents answered that they manage to deal with the problems, that is, to manage them in cooperation with representatives of other involved institutions, so that the problems do not get a bigger dimension. The majority of the respondents answered that the problems are difficult to solve, that there is usually no dialogue from the other side and it often happens that they rise to the highest level, while not infrequently there are also “pressures to solve”, as stated by the representative of PE Pastures.

#### **4.4. Recommendations for Overcoming the Problems**

The last group of questions asked the respondents to give their suggestions, solutions and recommendations for overcoming the problems. The representatives of the institutions responsible for water management emphasized the institutional reorganization, because they believe that within their competencies, the main cause of the problems is precisely the fragmentation of competencies in many institutions that are not coordinated among themselves and do not cooperate in the direction of an integral solution to the problems. Thus, the representative of the Water Management Administration proposed “integrating all the responsibilities related to water in one institution, including water management and energy; establishing a special inspectorate for water, or a special department within the State Inspectorate”.

The representatives of the institutions responsible for forests and pastures also proposed a more serious approach in the procedures for the exploitation of mineral resources to ensure a more equal treatment of resources by introducing compensation for destroyed resources, degraded areas, use of forest infrastructure and the endangerment of the environment at the expense of exploitation. Due to the seriousness of the conflicts in the field of forestry, some of the interviewees also proposed systemic reforms that imply legal changes, transformation of competent institutions and strengthening of their capacity. Within the support of integral management as a necessary approach, the representative of “JP NS Karadzica” suggested the “unification of all competencies except agriculture (forests, pastures, mineral resources, water and protected areas) in one institution”.

The representative of the Water Management Authority stated that “it is particularly important to respect the expert’s

word, that is, making decisions with respect for the expert’s opinion, which should be a guide in management”.

A characteristic of the answers in this group of questions is that a large part of the recommendations was proposed by the majority of respondents. They are the following:

- the necessity of changes in the legal regulation in the direction of simplifying the competencies and their clear definition to avoid overlaps,
- strengthening (where it exists), i.e. introducing an integral approach in planning and management,
- respect for expert opinion at all levels of planning, management and decision-making,
- strengthening the capacity of competent institutions, greater control and responsibility and a higher level of cooperation,
- participatory approach - equal participation of all actors, especially those outside the state institutions,
- political will and support, which is necessary to realize all unlisted recommendations,
- creation, updating and maintenance of the database, and as the next stage creation of a comprehensive electronic cadastre with which all institutions will be connected in a single database.

To involve local people in ecosystem management, the results of scientific analysis must be communicated more effectively and structurally to politicians, planners and managers, and the public. This is done by promoting and supporting local co-management initiatives, learning lessons and methods from experiences, supporting the development of collaborative management policies and fighting for the inclusion of collaborative management principles and practices.

## **5. Conclusion**

Theoretical analyses and specific research unequivocally indicate that conflicts in land use are a very present element in our practice of planning, implementation of plans and land management.

The huge number of theories and scientists and experts dealing with the problem of conflicts only confirms the seriousness of the issue of conflicts and indicates the necessity of its management at all levels.

The conclusions of the conducted interviews confirm that the conflicts in the Skopje region, as the most developed in the Republic of North Macedonia, not only appear in many forms and on a large scale, but already manifest various forms of land degradation, as one of the most serious consequences.

The lack of fertile land for agricultural cultivation is felt, as a result of the intensification of the process of permanent sealing of the land with various constructions.

Hence, the basic priority of the overall development of the region should be to control the processes of degradation and prevent their occurrence, first of all, the phenomena of land sealing.

A necessary tool for the realization of this priority goal is the management of conflicts in land use.

Success in conflict management can only be guaranteed by the integral involvement of conflict management at all levels (national, regional, local) in the planning, implementation and monitoring of land use planning solutions.

### **Conflict of Interest**

The authors declare that they have no conflict of interest.

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## RESEARCH ARTICLE

# Usability of the Various Land Use Optimization Models for the Spatial Planning Purposes in the Republic of North Macedonia

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## ABSTRACT

The land use optimization process uses different models generally belonging to two groups: mathematical models and heuristics models. A variety of models have been developed for various purposes. Each has its positive and negative sides, advantages and disadvantages. This research aims to define the usability of different land use model optimization for spatial planning in the Republic of North Macedonia. The basic methodological tool in this chapter covers the collection, study, and comparative analysis of relevant literary data and the evaluation of selected research. In the absence of domestic literature, mostly literature from several countries from Europe, the USA, and Asia was analyzed. Then 17 models were selected for detailed analysis. To examine the possibilities of applying the optimization models described in the analyzed research. An evaluation was performed according to the following criteria: a) availability of the data used by the model, that is, the possibility of providing the data used in the model from official sources; b) the number of optimization goals; c) the number of land uses; d) local adaptability, which implies conformity of the goals, purposes, influencing factors, limitations and other specifics of the model with those in our conditions; e) scope of the research. More of the reviewed papers on the analyzed optimization models and methods, marked by the authors, clearly indicate the fact or exceptional difficulty in determining the optimal land use model. The most appropriate model are as following: M15 - Integrating Socio-Economic and Land Use Models to Support Urban and Regional Planning; M14 - Functional analysis and valuation as a tool for assessing land use conflicts in planning for sustainable, multifunctional landscapes, by Rudolf de Groot; M16 - Spatial conflict management in urban planning, by Athina Santorineou, John Hatzopoulos, Katy Siakavara, Climis Davos; and M11 - GIS-Based Multi-Criteria Approaches for Land Use Suitability Assessment and Allocation.



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## 1. Introduction

The theory and practice of land use know in many models. Each of them has its positive and negative sides, advantages and disadvantages. Land use planning is a very complex process consisting of a multitude of activities, activities, actors and policies. Inadequate approaches and patterns of use give rise to numerous conflicts that are often the cause of the emergence

and development of various forms of land degradation. Creating an optimal land use model is a very complex process. That is why the use of land in modern conditions tends to the optimization of the models, which implies a continuous direction of the process toward achieving better, more rational, and sustainable solutions. The aim of this research is to be defined usability of various land use model optimization for the

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purpose of spatial planning in the Republic of North Macedonia.

## 2. Theoretical Review

The optimization of land use implies a spatial allocation to different purposes that will enable a rational and efficient use of land, taking into account the numerous and different restrictions. It is a very complex process that needs to respect not only numerous spatial factors, attributes, and constraints but also numerous and often conflicting objectives (Cao et al., 2011; Chen et al., 2010). Therefore, finding effective decision-making methods to determine the effects and costs of solutions in different spatial scenarios is becoming more important (Loonen & Koomen, 2007).

Numerous optimization methods are used to solve the problem of spatial allocation of land uses, which can be categorized into two groups: mathematical models of programming and heuristic methods.

A mathematical model represents a description of a system or process through the use of "mathematical language" A mathematical model can be defined as a set of mathematical relationships that describe or define the relationship between certain physical quantities of the observed process. A mathematical model is a more or less simplified way that the real relationship between the values that characterize the process and the important characteristics of the process are expressed. Mathematical models can be divided into: a) linear or non-linear; b) deterministic or stochastic (probabilistic); static or dynamic, discrete or continuous. Depending on the area and the available database, an appropriate model is selected (Blinkov et al., 2011). Mathematical programming models (such as the linear models of Campbell and Aerts and mixed models require that all variables, constraints, and objectives have an exact mathematical definition (Crohn & Thomas, 1998). The spatial allocation of land uses is a complex geographical process that includes a large number of constraints, complex spatial relations and decision-making by stakeholders and therefore cannot meet the conditions set by mathematical models. This led to the incorporation of scientific methods into the optimization process and scientists into optimization teams.

A heuristic is a technique for solving either faster than conventional methods, or finding approximate solutions when traditional methods cannot find an exact solution. In heuristic approaches, at the expense of sorting speed are optimality, completeness and accuracy. Heuristics include methods and techniques of problem solving, learning, and discovery that are based on experience. A heuristic model is a method that leads to new discoveries and insights. For certain concepts, hypotheses and theories, it is emphasized that they have a primary heuristic meaning, which means that, regardless of their authenticity, they can serve as a good incentive to find new

facts, as well as to produce new research and theoretical discussions. The goal of heuristics is to quickly come up with a solution that is good enough to solve the problem. This solution is not always the best or may even be only close to the correct solution. But such a solution is valuable, because it does not consume too much time.

A trade-off criterion is used to decide for or against the use of a heuristic for a given problem, and this includes the following: a) - Optimality: When there are multiple solutions to a given problem, if the heuristic guarantees finding the best solution? Do we have the best solution? b) Completeness: If there are multiple solutions to a particular problem, does the heuristic find all solutions? Do we even need all the solutions? Many heuristics find only one solution. c) Precision and accuracy: Can the heuristic provide a confidence interval for a putative solution? Is the solution error too large? d) Execution time: Is this the best heuristic for this type of problem? Some heuristics converge faster than others, while some are only marginally faster than conventional methods.

A heuristic can be a result itself, or it can be used in combination with an optimization algorithm, in order to improve their efficiency (Blinkov, 2011). Heuristic methods provide different possibilities for the formulation of variables, constraints and objectives and provide many alternative solutions for subjects making spatial decisions, according to the optimization objectives (Loonen & Koomen, 2007).

Many researchers use heuristic algorithms, such as genetic algorithms by Stewart et al. (2004) and Cao et al. (2011), which, combined with multi-objective optimization techniques, can generate land use scenarios that support the decision-making process. Such research promotes a completely new approach to solving spatial allocation problems (Cao et al., 2011). Genetic algorithms, first introduced by Holland as it described in more detail by Goldberg and Holland (1988), provide a different, much more effective way of searching for complex spatial solutions in a variety of applications and have been shown to be very effective in finding the optimal solution across a range of applications. The combination of genetic algorithms with GIS technology opens up possibilities for numerous spatial analyzes and searches and the creation of various maps and graphical presentations of spatial solutions that significantly improve the visual characteristics of the models enrich the database and enable compatibility between different models and spatial solutions.

To solve multi-objective problems, the so-called "Pareto method" ("Pareto front based method", Legriel et al. (2010)) and the method of weighted sums. All optimization models are based on one of these methods.

The development of computer technology and GIS offers strong technical support for spatial data analysis in making spatial decisions for land use optimization. The combination of

mathematical models with GIS has become the focus of this research and also promotes the development of scientific research on land use.

The process of optimization of land use by defining an optimal model of allocation of purposes, as one of the methods for achieving sustainable development, should ensure the achievement of numerous goals in the field of economy, society and the environment. Although economic benefit is a key factor, social and environmental aspects are also significant driving forces for sustainable development. In that sense, in recent years many attempts have been made to integrate socioeconomic models with land use models. Integral models are constituted in the form of an integrated decision support system (Integrated Spatial Decision Support System - ISDSS), which enables the evaluation of the impacts of different political options (related to spatial planning, infrastructure development and economic initiatives) using a set of social, economic and environmental indicators and testing these political alternatives in different conditions/. Sustainable development in conditions of high demand for land from different stakeholders with often conflicting goals and interests indicates the necessity of including multi-objective and multi-criteria analysis in optimization models. Conflict resolution is a crucial segment of the optimization process that guarantees acceptability of solutions by stakeholders and guarantees the absence of obstructions in the process of implementing spatial solutions. For security acceptability, it is necessary to include conflict analysis and conflict management in the optimization process (De Groot, 2006).

We have known for nearly two centuries that economic theory can be successfully used in the process of land use allocation. The ideas of Von Thunen, cited in Heady and Hall (1968), and others who dealt with this problem were described with the simplest equations and graphic illustrations, until the computer was discovered. The computer enabled reality testing of these models.

### 3. Methodology

The basic methodological tool in this chapter covers collection, study and comparative analysis of relevant literary data and the evaluation of selected researches. In the absence of domestic literature, mostly literature from several countries from Europe, USA, Asia was analyzed. First, a study of the general theoretical framework related to the optimization process was carried out, followed by special specialist studies and research related to different methods, models and approaches in the optimization process. A comparative analysis of all studied papers was made, in order to perceive the positive and negative aspects of each paper separately. Based on the evaluation of the analyzed research, according to several criteria, an assessment was given for the

possibility/impossibility of applying the presented optimization models in the subject research.

To examine the possibilities of applying the optimization models described in the analyzed research. An evaluation was performed according to the following criteria:

1. Availability of the data used by the model, that is, the possibility of providing the data used in the model from official sources. The evaluation according to this criterion has 4 levels:

- minimal (availability up to 30% of the total amount of data),
- partial (availability of 30% - 60%),
- satisfactory (availability of 60% - 90%),
- complete (90% - 100% availability);

2. Number of optimization goals, with 3 levels:

- small (up to 3 targets),
- medium (3 – 5 goals),
- large (over 5 goals);

3. Number of land uses, with 3 levels:

- small (up to 3 purposes),
- medium (3 – 5 uses),
- large (more than 5 uses);

4. Local adaptability, which implies conformity of the goals, purposes, influencing factors, limitations and other specifics of the model with those in our conditions. The evaluation according to this criterion has 3 levels:

- low (up to 30%),
- medium (30 % - 60%),
- high (over 60%);

5. Scope of the research, which is related to the methodological approach, the program, the goals and tasks, the purposes and the nature and character of the research, as well as the solutions it offers. According to this criterion, the evaluation has 2 levels:

- sectoral, which is contrary to the methodological approach of this research),
- integral, which methodologically corresponds to the research in question.

The overall evaluation in relation to all the described criteria cannot be represented by a quantitative assessment or calculation, due to the nature and character of the optimization process in which the qualitative assessment has a crucial importance. Because of that, some of the models are rated as unsuitable, even though they have relatively high scores according to different criteria. Data availability is insufficient if it is a model with a small number of goals and uses or low local adaptability. Also, some of the sectoral models are evaluated as

partially eligible, although they are contrary to the integral approach which is essential in this research, because it is evaluated that some of the analyses, methods and tools they contain can be successfully applied in models with an integral approach, but only in certain aspects of the research.

## 4. Results and Discussion

### 4.1. Essence of Selected Models

Land use optimization is one of the basic research aspects in planning that is increasingly becoming a key measure for achieving sustainable land use. Within the framework of the research, several studies on the topic of optimization of allocation of land uses have been analyzed. Most of them refer to selected regions, locations and cities in China, then Vietnam, Netherlands, Greece and the USA. From the analyzed research, 17 were selected for more detailed analysis and evaluation. At the national level, there are no suitable papers in this area.

*M1. Spatial multi-objective land use optimization: extensions to the non-dominated sorting genetic algorithm-II* by Cao et al. (2011).

The subject of this study is the search for optimal scenarios for land use, based on the application of a model of multi-objective spatial optimization of land uses with genetic algorithms, known as "NSGA-II-MOLU" model. The model was developed for Tongzhou New Town in China and addresses three conflicting objectives: - minimization of costs for land use conversion, - maximizing accessibility and - maximizing the compatibility of different uses. The long-term goal of the model is to achieve sustainable development, as a balance between economic development, environmental protection and efficient use of natural resources. The model uses genetic algorithms that are particularly effective for searching complex spatial solutions in various applications. This model is useful as a tool to support the planning process for the optimization of land uses in complicated conditions of interaction of spatial objectives and variables.

*M2. Sustainable land use optimization using Boundary-based Fast Genetic Algorithm* by Cao et al. (2012).

The model applied in this study consists of more comprehensive objectives and is more effective and efficient than the one applied in the previously described research and is called the BFGA - MOLU model, which is applied to a case study in Tongzhou Newtown, Beijing, China, Newtown, a central urban area of Tongzhou, which promises to become a major urban area of Beijing in the future. The land uses in this research are simplified into 5 main types: residential land, industrial land, commercial land, green spaces and land with no purpose. The following parameters were used in the optimization process: area, repetition, population, overlap, mutation, generation. The BFGA-MOLU model was obtained from 5000 iterations using the following parameters: 8

objectives, which include: maximization of GDP, minimization of land conversion, maximization of geological stability, maximization of environmental suitability, maximization of affordability, maximization of clause impact for non-concurrency, maximization of compactness and maximization of compatibility; certain restrictions.

*M3. Spatial optimization method for sustainable multiobjective land use allocation* (Ligmann-Zielinska et al., 2008).

The model uses GIS techniques to construct a digital elevation model of the terrain, from which a pattern of slopes and land uses is extracted. Based on that model and additional environmental and other factors, an evaluation of the suitability of the land for certain uses was made. The research area is divided into 4 optimization zones (developmental, main, restricted and prohibited).

*M4. Simulating Multi-Objective Spatial Optimization Allocation of Land Use Based on the Integration of Multi-Agent System and Genetic Algorithm* by Zhang et al. (2010).

The model of multi-objective spatial allocation of uses (MOSO) model, based on the application of the so-called multi-agent is applied to solve a practical multi-objective spatial optimization of land use allocation in Changsha region, China, where land use in urban areas is characterized by inefficient low density and extensive land use patterns. The general goal of the MOSO model is saving natural resources and achieving environmental suitability. To improve the operability of the model, appropriate sub-goals and constraints are set.

*M5. Modeling and Supporting Multi-Actor Spatial Planning Using Multi-Agents Systems* by Ferrand (1996)

This research is very similar to the previous one. Here too, the application of Multi-Agents Systems (MAS) is proposed, in that unlike the previous research, two approaches are presented here: - the first is based on the use of multi-reactive agent systems (Multi-Reactive -Agents Systems) to optimization, which are encountered when trying to ensure the least impact on the environment from the infrastructure;- the second, uses multi-cognitive agent systems (Multi-Cognitive-Agents Systems), to support and simulate changes and dynamism of spatial phenomena and policies, taking into account general political values, specific spatial limitations, and social characteristics and relationships between actors.

*M6. Land-use Spatial Optimization model based on particle swarm optimization* by Shifa et al. (2009).

This research promotes a spatial optimization model based on an evolutionary particle swarm algorithm, which is an advance over previous algorithm-based models and largely overcomes their shortcomings. Particle swarm optimization is a type of evolutionary algorithm, which is capable of analyzing multidimensional discrete spatial decision data in parallel. This

model is suitable for spatial optimization of uses, because it can be used at the micro level, as a point (place, location) of use.

*M7. Global-to-local modeling of land use dynamics in Vietnam Potential effects of high climate impact and high economic growth scenarios* by Rutten et al. (2012).

In this study, the global to local approach is implemented, which is a combination of the macroeconomic model, MAGNET (Modular Applied General Equilibrium Toolbox) and CLUE (Conversion of Land Use Change and its Effects) land use model. The research concerns Vietnam and actually represents the connection of the global economic simulation model with the spatially explicit land use model. Two scenarios are considered that aim to quantify the impact of global and national driving forces and policies on land use in Vietnam by 2030.

*M8. Optimization of Land use suitability for agriculture using Integrated Geospatial model and Genetic Algorithms* by Mansor et al. (2012).

In this study, a geospatial model of land use allocation is developed from a position of biological autonomous environmental adaptability and infrastructural advantages. The model is based on a multi-agent genetic algorithm. Tailored to accommodate a set of constraints in the research space, such as resource conservation and environmental suitability. Then, the model is applied to solve a practical multi-objective optimization of land use allocation in the Menderjan Basin region of Iran.

*M9. Land use allocation optimization models applied to future use in the u.s. doe's major nuclear weapons sites* by Greenberg (1999).

This research was carried out for one of the so-called "Departments of Energy" (DOE), with a national mission to develop, test and produce nuclear weapons. Today, the planning and use of land is changing in these areas as well, so certain uses that were not thought of at all during the cold war (such as recreation) have now become part of the efforts to domesticate these spaces and incorporate them into the plans for land use and management. Included in the survey are 5 potential types of uses and a series of constraints related to land availability.

*M10. Multipurpose allocation of areas with intensive production of wood products and maintenance of fauna and biodiversity* by Mincev (2007).

This is a research concerning regions in Northern Italy, based on conflicting objectives: achieving intensive wood production and maintaining fauna biodiversity. The process of multi-objective allocation (MOLA) is performed with the support of IDRISI Kilimanjaro software.

*M11. A GIS based multicriteria approaches to land use suitability assessment and allocation* by Mendoza (1999).

This document aims to create an integrated GIS model based multicriteria approach for land suitability analysis, to achieve optimal allocation of the most suitable uses for each type of land. The GIS environment enables a spatially explicit evaluation of land suitability and the application of various measures of suitability to specific geographical areas. Such an integrated model combines the spatial capabilities of GIS with the analytical power of multi-criteria analysis allows at the same time analytical planning and optimization of land use decisions at different levels.

*M12. A solution to the Land Allocation problem integrating multicriteria analysis, fuzzy logic, and GIS* by Miranda (2004).

In this research, the application of GIS systems is integrated with two techniques: fuzzy logic and multicriteria analysis. The paper presents a test with real data to solve an allocation problem in a specific geographical area in Guaria, Spain for sugarcane cultivation.

*M13. Model of land use spatial optimization based on a knowledge guide genetic algorithm* by Yaolin et al. (2013).

This model, based on GA as a knowledge guide is proposed to overcome the shortcomings of previous studies. The model is a modification of traditional GA with local land use knowledge consisting of spatial characteristics and land use change rules. The research concerns Gaoqiao Town, an area located in the northern part of Fuyang City, in Zhejiang Province, in China.

*M14. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes*, by De Groot (2006).

This paper, which advocates for ensuring sustainable development in conditions of high demand for land and natural resources from different actors (stakeholders) with often conflicting interests, indicates the necessity of including environmental, economic and socio-cultural values in the process of planning and decision making. It offers a comprehensive framework for the integral assessment of ecological values and services and the socio-economic benefit of natural ecosystems and landscapes. That framework can be implemented at different levels and for different ecosystems and basically consists of three steps:

- functional analysis (reducing ecological complexity to a limited number of ecosystem functions that in turn provide a range of goods and services),
- functional valorization (which includes ecological, socio-cultural and economic valuation methods),
- conflict analysis (involving interested parties with participation methods, in order to facilitate the application of functional analysis and valuation at different levels). A comprehensive cost-benefit analysis for different options

(alternatives) of land use is essential for achieving sustainable use of land and resources and maintaining "natural capital".

*M15. Integrating socio-economic and land-use models to support urban and regional planning*, by Van Delden et al. (2011).

In this research in the field of finding optimal land use models, there are several attempts to integrate socio-economic models with land use models, which mostly apply a one-way relationship between the two models. The model presented in this paper enables a more dynamic integration of the two processes, which enables feedback of land use models on economic models. To facilitate its application in planning and policy building, the integral model is constituted in the form of an integrated decision support system (Integrated Spatial Decision Support System - ISDSS), which enables the evaluation of the impacts of different political options (related to spatial planning, infrastructure development and economic initiatives) using a set of social, economic and environmental indicators and testing these political alternatives in different conditions (mainly demographic and macroeconomic). This model is applied to the Wellington region in New Zealand. One of the main results of this approach is that the feedback incorporated into the system shows that socio-economic development is a significant driving force of land use change, but limited natural resources also have an impact on economic development and limit economic growth which is the most of the economic models predict it. The simulation model starts from the current land use map for the initial year and, applying a set of driving forces and factors, calculates future development. The model uses an application based on a grid of cells in which each cell has a specific land use. Reassignment is not based only on the state in neighboring cells (as in most previous models), but on local characteristics, such as availability of infrastructure, suitability of the location for a specific purpose and spatial planning applied to different locations.

*M16. Spatial conflict management in urban planning*, by Santorineou et al. (2008).

In this research, an effort has been made to develop a methodology for making spatial decisions, to support urban planning. The focus is placed on the management of spatial conflicts - interests, use and valuation that are created by land use change options, so that the final decisions should ensure sustainable development. The research area is the coastal urban belt of the Perama region in Athens, Greece, with an area of 243 ha. The proposed methodology, referred to as Spatial AGORA, integrates elements of participatory conflict management algorithm AGORA (Assessment of Group Options with Reasonable Accord), GIS and CA (Cellular Automata), which use Multicriteria Evaluation Methods, Basic Theory and Game Theory. The GIS is used to collect, analyze and manage all the necessary data for the researched area in total and defined sub-

areas that are used as decision units. Mobile automata have been used for the land use change simulation model. Stakeholders from the decision units are the main participants in the application of the purpose model.

*M17. Pine Nut Allotments (NV) Land Use and Development Procedural Plan, Land Use Suitability Analysis* (Working Paper, Pine Nut Allotments (NV), 2009).

In this paper, an analysis of the suitability of the land is elaborated, based on the following criteria:

- Topography (slope and height);
- Access (distance to the road infrastructure and access to an existing road);
- Services, i.e., communal services (energy and communications, underground water potential, the possibility of sewerage - wastewater treatment);
- Soil (suitability for construction, construction materials, land management, development of recreation and sanitation services);
- Ownership (number of plot owners)

This analysis was done for an area of 176 parcels in Douglas County, Nevada. For each of the criteria, the pilot space is evaluated in several (5-8) categories (well, humble, poor, very poor, unfit, etc.). Then, by integrating the eligibility of the parcels according to the defined criteria, the most suitable ones for certain purposes according to all or most of the criteria are selected.

A characteristic of single-purpose models is the generation of only one solution, which is a disadvantage of the model from several aspects: efficiency, effectiveness, economic justification and lack of support in planning.

Therefore, in the process, multi-objective models are applied, which require the introduction of more variables in the model, which, together with the relations between them, have qualitative characteristics and cannot be included in linear models. The introduction of more variables and the relationships between them increases the complexity of the models and makes them non-linear. The application of GIS tools is necessary for such models.

In fact, the shortcoming of all traditional optimization models is the inability to effectively unify the quantitative and spatial structure.

Regardless of the method used, the complexity of the optimization process grows, not only because of the large number of variables, but also because of the growing number of objectives. It is simply impossible for planners to think, evaluate different possibilities, or solve any problem without a numerical method.

In the last few decades, scientists have been actively involved in designing optimal solutions. For example in the research "Pine Nut Allotments (NV) Land Use and Development, Procedural Plan, Land Use Suitability Analysis" as a result, genetic algorithms were introduced, which are used to search for complex spatial solutions in various applications. Genetic algorithms (GA) are suitable for solving multi-objective optimization problems by applying the "Pareto front based method", step by step.

The advantage of genetic algorithms is in the efficient applicability of many variables and their mutual relations and relations, as a result of which a multitude of configurations with almost the same characteristics is obtained in a relatively short time. This is particularly attractive to politicians, who can evaluate alternative deployment configurations, each with their own specific socio-economic impacts, and still achieve optimal results.

Although genetic algorithms represent a great advance in optimization, they also have several drawbacks that limit their application, especially in our conditions as follow.- the use of complicated maps instead of coding, which makes the program difficult to implement and with little ability for spatial correlation; limited number of targets used in these models, which reflects their sustainability; application of network units, or cells for which the optimization is investigated, which excludes the application of these models at the macro level; the time required to obtain a clear and good solution, which makes it difficult to apply this method in planning support; absence of inclusion of local specifics, factors and influences in the research (the so-called "trapping of the GA in the local specifics of the space").

These shortcomings of the models have been ascertained in most of the analyzed research (models M1-M9 and M13), which makes them unsuitable for application in the research in question. A serious drawback of most of the analyzed papers is the research area, which is mostly an urban area, as well as the small number of goals and purposes that are included in the model. Functional analysis and valorization of the space with ecological, socio-cultural and economic valuation models, as well as the comprehensive cost-benefit analysis for different options (alternatives) of land use, which is essential for achieving sustainable land use are advantages of some of the analyzed models, but inapplicable in our conditions due to the unavailability of the data needed for the analysis.

The greatest progress in this research is the combination of mathematical models with GIS tools and GA. The positive characteristics of the analyzed models, which can be partially applied in our conditions, refer to:

- Application of a digital elevation model of the space in GIS technique and evaluation of suitability of the land for certain purposes;

- Multi-criteria approach in evaluating the suitability of land for certain purposes and creating an integral model of purpose in GIS;

- Generation of an optimal purpose model obtained by valorization with suitability indices.

#### 4.2. Final Evaluation of Analyzed Models

Some of the models are rated as unsuitable, even though they have relatively high scores according to different criteria defined in the methodology. A comparative analysis of the optimization models was performed in order to evaluate their suitability for application in our conditions.

According to the value of each of the particular models and approaches (Table 1), no one is fully applicable to our planning system. The most appropriate are as following:

- M15. Integrating Socio-Economic and Land Use Models to Support Urban and Regional Planning, by Van Delden et al. (2011), an integrated system for spatial decision support - ISDSS), which enables the assessment of the impacts of different political options using a set of social, economic and environmental indicators and testing these political alternatives in different conditions (mainly demographic and macroeconomic). The fact that planning in our country is largely under political influence, that is, spatial planning decisions are also political decisions for making plans and for expectations from those events in a case of conflicts.

- M14. *Functional analysis and valuation as a tool for assessing land use conflicts in planning for sustainable, multifunctional landscapes*, by De Groot (2006) and M16. *Spatial conflict management in urban planning*, by Santorineou et al. (2008) - which must inevitably be part of planning theory, taking into account the different and often conflicting interests in land use of the different stakeholders, who impose a necessary need for the same inclusion of the conflict so that a sustainable and generally accepted solution can be reached for all the parties concerned.

- M11. *GIS-Based Multi-Criteria Approaches for Land Use Suitability Assessment and Allocation* by Mendoza (1999) – and this is a good part of GIS spatial analyzes based on our methodology, in which an unlimited number of factors and aspects of valuation and analysis of a specific area can be included; it also includes multi-criteria analyses, which in our case is related to the characteristics of the natural features and natural assets of the country, due to the demographic situation that is the basis for planning.

Part of the methods and models applied in the models evaluated as certain eligible, have been applied in the process of creating an optimal model of the use on the territory in the Skopje region by experts and stakeholders, conflict management and integration of socio-economic and land use models in the form of an integral DSS decision support system.

**Table 1.** Evaluation of optimization models for application in spatial planning in the RNM.

Model	Data availability	Number of targets in the model	Number of Method Usage	Method	Local adjustability	Scope	Evaluation
M1	minimal	small	medium	GA	low	sectoral (urban)	ineligible
M2	minimal	small	medium	GA	low	sectoral (urban)	ineligible
M3	minimal	small	high	GA+GIS	low	sectoral (urban)	Partially eligible
M4	partial	small	medium	GA+GIS	low	sectoral (urban)	ineligible
M5	minimal	small	medium	GA+GIS	low	sectoral (urban)	ineligible
M6	minimal	small	medium	GA+GIS	low	sectoral (on micro level)	ineligible
M7	partial	small	small	economic	medium	sectoral	ineligible
M8	minimal	small	small	GA+GIS - land suitability	high	sectoral (agriculture)	ineligible
M9	minimal	small	medium	-linear	low	sectoral (urban)	Partially eligible
M10	satisfactory	small	single	-land suitability -GIS	high	sectoral (forestry)	Partially eligible
M11	partial	small	high	-land suitability, GIS -multicriteria approach	medium	integral	Partially eligible
M12	satisfactory	small	single	-multicriteria approach, GIS, fuzzy logic	high	sectoral (agriculture)	ineligible
M13	minimal	small	medium	GA -conversion of land use	low	sectoral (urban)	ineligible
M14	partial	small	medium	-functional analysis - functional valorization - conflict analysis -cost benefit analysis	medium	integral	Partially eligible
M15	partial	medium	small	-decision support system, - macroeconomic, environmental and social model with restrictive scenarios	medium	integral	Partially eligible /ineligible for long-term planning
M16	partial	medium	small	- multicriteria evaluation, GIS - game theory, - conflict management	medium	sectoral (urban)	Eligible
M17	partial	high	small	- land capability	medium	sectoral (urban)	Partially eligible

## 5. Conclusion

The reviewed papers on the analyzed optimization models and methods, marked by the authors, clearly indicate the fact or exceptional difficulty in determining the optimal land use optimization model.

The list of terms of application therein, bearing in mind Anna's limitations in terms of ensuring accuracy and relevance respecting broad specifics and great differences, economic social and political sense concerning geographical aspects, which refer to the analyzed models, only revealed the finding that the optimization of land use is a really serious challenge for every country.

Additional geographic specifics that sometimes mean convenience, but sometimes also limit land use, economic and social conditions have a very significant place in the concept of land use.

The most of models for land use optimizations, i.e., nine (9) are assigned as ineligible, seven (7) are partially eligible and

only one (1) model could be eligible for spatial planning purpose in the country.

Thus, optimization should primarily ensure well-being, but respecting social requirements, standards and constraints. For the country in the main factors should be in harmony with political decisions, creating an optimal model is a complex and difficult task, for a long time, the optimization model should be long-term, sustainable and realistic, the power to implement within the framework of various political creations.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

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## RESEARCH ARTICLE

# Morphological and Germination Characteristics of *Alhagi maurorum* Boiss. and *Salsola richteri* Kar. Seeds Distributed in the Karakum Desert of Turkmenistan

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## ABSTRACT

The Karakum Desert is the largest desert in Turkmenistan and covers a significant part of Central Asia. This desert is home to plant species that can adapt to hot, dry, and barren conditions. During the summer months, the Karakum Desert can get extremely hot, with temperatures reaching up to 50 °C, while in winter, it can drop to -20 °C. Therefore, the desert conditions significant seasonal temperature differences. In winter, rainfall is very low, snow rarely falls, and quickly melts. Afghan winds have an impact on the desert vegetation. The desert vegetation mainly consists of short grasses and woody shrubs. Despite the scarcity of rainfall and high temperatures during the summer months, steppe plants have generally been able to adapt to the harsh conditions of the desert. There are also species that have adapted to the desert climate, such as *Alhagi maurorum* Boiss., *Haloxyton persicum* Bunge, *Haloxyton aphyllum* (Minkw.) Iljin, *Solanum nigrum* L., and *Salsola richteri* Kar. These plants are highly valuable in terms of nutrition for animals and are used as winter animal feed in rural areas. In this study, the seed and germination characteristics of *Alhagi maurorum* Boiss. and *Salsola richteri* Kar, which are tree and shrub-like plants that can adapt to Karakum Desert conditions, were examined. In laboratory study, the morphological characteristics of the seeds were determined, and vitality and germination tests were conducted. Information was obtained about the germination adaptation of these plants in desert ecosystems. As a result of the study, it was determined that *S. richteri* had a very low rate of viable seeds and no germination, while the germination process of *Alhagi maurorum* could take a considerably long time.

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## 1. Introduction

Turkmenistan is located in the center of the Asian continent and is bordered by Kazakhstan, Uzbekistan, Afghanistan, and Iran. The Caspian Sea is located to the west. Its physical geography is influenced by extremely low humidity and high summer temperatures, resulting in a harsh continental climate (Rustamov, 1994). Approximately 80% of Turkmenistan's

territory consists of deserts (Rustamov, 1994), with the largest being the Karakum Desert, covering an area of 349648 square kilometers (Monier, 2017). The Karakum Desert stretches across a wide area between Uzboy in the west, the Amu Darya River in the east, the Kopet Dag and Paropamisus Mountains in the south, and the Kwarazm (Khiva) oasis in the north. Along the eastern edge of the desert, there is a belt of sand dunes

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ranging from 10 to 50 kilometers wide, with some dune hills (barhan) reaching heights of up to 25 meters (Rustamov, 1994).

In the Karakum Desert, the average annual temperature is 15.8°C. The absolute maximum temperature reaches up to 45°C in the north and 50°C in the south. The absolute minimum temperature is -33°C in the north and -28°C in the south. The frost-free period lasts for approximately 230 days. Precipitation sharply decreases during the summer months. The average annual rainfall is 115 mm in the north and 130 mm in the south. In Southeast Karakum, there is almost no rainfall from June to September, while in Central Karakum, 4% of the annual rainfall occurs in July and August. The rainfall regime exhibits large fluctuations in both annual and monthly averages. Rainfall is generally observed from October to May, with the maximum monthly rainfall occurring in March and April. Due to the arid and hot climate, surface temperatures can sometimes reach 76-78°C in July. The average annual surface temperature ranges from 14 to 15°C in the northern Karakum and from 18 to 20°C in the Central and Southeast Karakum. During the driest period from June to September, the relative humidity ranges from 20% to 30% (Rustamov, 1994), and the average annual sunshine duration ranges from 2800 to 3095 hours (Babayev & Gurbandurdyev, 2002).

### 1.1. Vegetation of Turkmenistan and the Karakum Desert

The causes of desertification in Turkmenistan are the degradation of vegetation, water erosion, the conversion of pastures into swamps, the salinization of irrigated areas, and the formation of salt marshes due to the closure of the Kara Boğazgöl Bay in the Caspian Sea (Rustamov, 1994). In these deserts, there are plant species that adapt to extreme climatic conditions, such as drought, high temperatures, and soil salinity (D. E. Smith, 2010). These adaptations enable desert plants to survive. In the summer months, stomata shrink to minimize water loss, leaves are shed, or waxy substances are produced to cover the leaf surface. In addition, their root systems are well developed to absorb water and can reach the groundwater level (Rustamov, 1994).

The desert vegetation in Turkmenistan mainly consists of halophytic and psammophytic shrub communities, with the dominant formations being *Haloxyleta*, *Salsoleta*, *Calligoneta*, and *Artemiseta* (Rustamov, 1994). Steppes dominate in the Karakum Desert. Gandım (*Calligonum triste*) is found in the desert's hilltop areas, while shrubs called borjak (*Sambucus nigra*) are found in the lower regions. Additionally, desert plants such as sazak (*Haloxylon persicum*, *Haloxylon aphyllum*) and patlak (*Solanum nigrum*) are widespread in this region (Khan et al., 2013). The main tree and shrub species in the desert regions, along with *Haloxylon persicum* and *Haloxylon aphyllum*, are various species of *S. richteri*, *Calligonum*, *Ephedra*, *Halothamnus*, *Ammodendron*, and *Astragalus* (United Nations, 2012). The vegetation in the

Karakum Desert consists of an herbaceous cover composed of sand sedge (*Carex physodes*) and annual plants, as well as shrub species such as saksaul (*Haloxylon aphyllum*), cerkez (*S. richteri*), and gandım (*Calligonum triste*) (Rustamov, 1994). The vegetation in the desert includes trees, shrubs, and herbaceous plant species such as *Ammodendron conollyi*, *Haloxylon* spp., *Calligonum* spp., *Ephedra strobilacea*, *S. richteri*, *Stipagrostis* spp., and *Carex physodes*, which spread in sandy areas. The richest vegetation is found in the eastern Karakum region, where the massifs of *Haloxylon aphyllum* and *H. persicum* are located (Rustamov, 1994). Despite low productivity of 200 to 300 kg/ha, the vegetation in the desert is highly nutritious and widely used for grazing thousands of animals such as sheep, goats and camels (Walker, 1979). The vegetation in Turkmenistan deserts is a valuable source of fodder for the livestock sector. The desert areas are used for sheep and camel grazing throughout the year. The vegetation in the desert plays an important ecological role by stabilizing the dunes (Rustamov, 1994).

#### 1.1.1. Yandak (*Alhagi maurorum* Boiss.)

*Alhagi maurorum* Boiss. (Yandak) is generally found in hot-dry climate regions and is resistant to saline soils. It typically grows and blooms actively during spring and summer months. It can adapt well to challenging environmental conditions such as drought and salinity. Due to its thorny nature, it can hinder grazing of animals in pastures (Mandaville, 2011; Sharma, 2013). The success of adapting to salty and dry soils increases the economic and ecological significance of this species (Jones & Brown, 2015). The spread of this species, especially in agricultural fields, meadows, and pastures, can contribute to ecosystem services such as soil stabilization and erosion control (Brown & Green, 2016). It is an important resource in terms of agricultural and industrial uses (Almenova, 2021). It can be used as animal feed and can also be evaluated as a biomass source in bioethanol production (Sharma, 2013). It is also used as fuel (Khan et al., 2013).

In addition to its valuable ecological characteristics, *A. maurorum* also has medicinal properties. Its roots are widely used in traditional medicine practices (Jones & Brown, 2015). The plant has wound-healing properties (Dastyar & Lysiuk, 2023). *A. maurorum*'s antioxidant, anti-inflammatory, and antidiabetic properties have been demonstrated in various studies (Mazandarani et al., 2017; Sharifi-Rad et al., 2019). It has been used in folk medicine as a laxative, diaphoretic, expectorant, and diuretic. Its oil is used in the treatment of rheumatism, while its flowers are used in the treatment of hemorrhoids, migraines, and warts. Topically, root water extract is used to relax the kidneys and help pass kidney stones (Dafni & Lev, 2002; Mandaville, 2011; Said et al., 2014; Singh et al., 1990). Recently, extracts have been shown to be beneficial against skin hyperpigmentation (Titova et al., 2021). All *Alhagi* species are plants with nectar that are of great

importance for beekeeping. Due to its antibacterial property, its water and infusions are used in folk medicine for the treatment of colitis, dysentery, inflammation of the colon and duodenum, stomach ulcers, and gallbladder inflammation (Teshaeвна et al., 2022). It is used in traditional medicine to treat constipation and rheumatic pains (El-Sayed et al., 1993). *A. maurorum*'s seed coat is small, hard, and durable. It has a brownish color and typically resembles a small kidney bean in shape. This feature protects the seeds against external factors and enables them to maintain their germination abilities in different ecological conditions.

### 1.1.2. Çerkez (*Salsola richteri* Kar.)

*Salsola richteri* Kar, which spreads in the Karakum Desert, is classified as a halophyte due to its ability to grow in saline soils and its tolerance to high salt concentrations (Abideh, 2015). Its flowers are pale green or yellowish green in color and usually bloom between August and September (Brown & Green, 2016; J. K. Smith, 2018). Its spread is limited because it grows in drifting sand, making it highly valuable as a sand stabilizer (Kaul, 1970). This plant species plays an important role in desert ecosystems due to its ability to grow in saline soils. Additionally, it is widely used in agricultural lands due to its ability to prevent soil erosion. Due to its tolerance to high salt concentrations, it has the potential to be used in areas affected by soil salinization. *S. richteri*, a large shrub, can grow to 1.5-2 m and live for 25 to 30 years. It has a deep root system, allowing the plant to access water sources more effectively (Abideh, 2015). The main root, which grows vertically and horizontally, can reach 120 cm, while the lateral roots can extend up to 7-9 m and reach depths of 3-4 m, reaching the groundwater level (Petrov, 1935). In the *S. richteri* formation, 12 to 20 different plant species have been recorded, all of which have adapted to living in unstabilized sand (Rodin, 1963). *Salsola* roots generally grow horizontally in sands where the groundwater level is deep (20-25 m), while they primarily develop vertically in sands close to the water level (8-10 m). Like many other shrubs, *S. richteri* forms new roots from its sand-covered stems (Nechayeva et al., 1973). *Salsola* is a pioneer species for grassland regeneration, notable for its features such as sexual reproduction, seed dormancy, and seed bank formation (K. Toderich, 2008). It is a promising plant for halting the movement of sand dunes due to its ability to thrive in infertile sands, high seed yield, ability to propagate through seeds and cuttings, tolerance to salinity, and strong root system (Sarigul, 2021). It is commonly found in arid and semi-arid regions. It is a potential forage crop for semi-arid and arid environments due to its high nutritional value, abundant seed production, tolerance to extreme climatic conditions and resilience to prolonged drought conditions (Hanif et al., 2018). Its vegetation period extends from the end of March to October or November, it blooms from May to July, and produces seeds from September to October. It produces 30 to 50 kg/ha of green biomass annually (Nechayeva et al., 1973). *S. richteri* and *S.*

*paletziana* are used in sand stabilization in the desert region of Central Asia. They restrict the movement of sand layers by stopping their natural shifting (Koşak, 2009). They prevent erosion in pastures and their young shoots, leaves, and seeds are consumed by animals as fodder (Pirasteh-Anosheh et al., 2021). Plants in desert pastures are highly valuable food sources for sheep, camels and cattle. They have important ecological characteristics that indicate their suitability for growth in desert areas, such as high drought resistance, salt tolerance and good forage quality (Shamsutdinova & Shamsutdinov, 2021).

The leaves of *S. richteri* contain an alkaloid called salsolinol at a rate of 0.3%, which can lower high blood pressure. It is also recommended for headache and dizziness (Glushchenko et al., 2018). It is used in the treatment of heart and skin diseases, cough, flu and in cosmetic products (Hanif et al., 2018). Its roots contain flavonoids and tannins with diuretic effects. Its seeds, which have high fat and protein content, can be used in human nutrition. It also plays an important role in desert ecosystems and preventing soil erosion (Niknam, 2017).

The seeds of *S. richteri* stand out with their round shape, hard shell, and aesthetic edges resembling butterfly wings. This plant species living in salty habitats has the ability to adapt to the environment with its unique morphological features of seeds. Grazing, agricultural use, and mining activities cause destruction of vegetation cover and increase sand mobility. Disturbance of plant cover in the desert, particularly the decline of shrub species like *Salsola*, results in imbalance. Decrease in shrub species that can adapt to arid and saline soils negatively affects the desert ecosystem (K. H. Toderich, 2009). Therefore, preservation and restoration of vegetation cover in desert regions are necessary for sustainable environmental management. Examining the seed bank in the soil and determining the germination, seedling formation, and development characteristics of species contribute significantly to the development of management strategies for the conservation of desert ecosystems. Understanding the adaptation mechanisms of plants growing in Karakum Desert and natural areas can be achieved through laboratory studies. The obtained results can contribute to the creation of comprehensive information about the germination characteristics of plant species in this special desert ecosystem of Central Asia, as well as the development of sustainable natural resource management strategies and the conservation and restoration of the desert ecosystem.

## 2. Materials and Methods

### 2.1. Materials

The seed materials of the study were collected from the Karakum Desert in order to determine the seed and germination characteristics of the yandak (*A. maurorum*) and çerkez (*S. richteri*) shrubs that grow in and around the desert. This desert is one of the unique ecosystems of Central Asia.

The seeds were collected from the vicinity of Zahmet Village, located in Sakarçage town in the Mary province of Turkmenistan, in 2022 and 2023. The collection point is an area approximately 24 kilometers away from the village (Figure 1).

This region is significant in terms of hosting the unique plant flora of the Karakum Desert ecosystem. The collected seeds were wrapped in paper and placed in a bag, then brought to the laboratory.

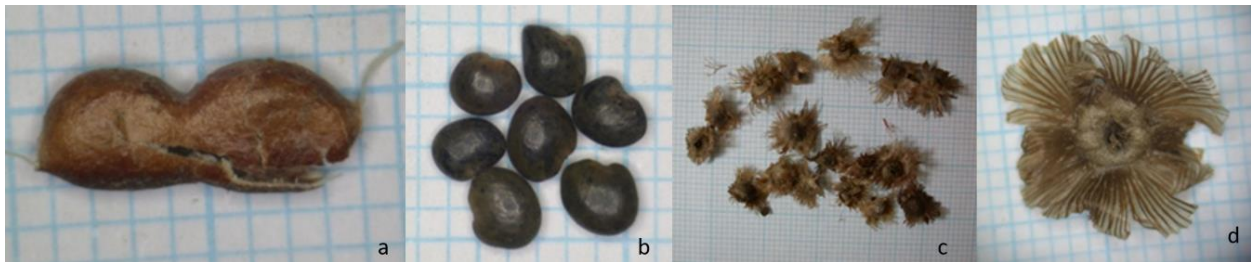


**Figure 1.** Seed collection areas of the Karakum Desert plants.

Both species of seeds were brought to the laboratory of the Department of Silviculture, Faculty of Forestry, Bursa Technical University for studies. The focus of the research is on the morphological and germination characteristics of the seeds.

### 2.1.1. Seed cleaning and storage

The collected seeds were separated from their shells in the laboratory (Figure 2) and then stored in a refrigerator until the germination tests.



**Figure 2.** (*A. maurorum*) seed (a, b) and Çerkez (*S. richteri*) seed (c, d).

Lovibond germination cabinet, precision balance, stereo microscope, digital caliper, sealed plastic bags, leak-proof plastic containers of different sizes, filter papers, nitrile gloves, Petri dishes, Maxim XL fungicide, and Tetrazolium chloride (TTC).

## 2.2. Method

### 2.2.1. Determination of seed characteristics

The weight of 1000 seeds and morphological characteristics were determined in seeds. Seed weights were determined in accordance with ISTA (1999) rules using 100 seeds and 4 replicates. For morphological characteristics, the length, width, and thickness were measured using a digital caliper in 100 seeds, then averages were taken.

### 2.2.2. Tetrazolium chloride (TTC) test in seeds

To determine seed viability, the Tetrazolium chloride (TTC) test was conducted. TTC solution is commonly used to reveal metabolic activity in seeds and determine their germination capacity. For the viability test, a 1% TTC solution was prepared and kept in light for 10 minutes. Then, 60 seeds of *A. maurorum* and *S. richteri* were wrapped in filter paper, dipped into the solution, and incubated at 40°C. To check if the seeds were stained after 24 hours of incubation, a cutting process was applied. The seeds that were not cut and remained firm were crushed by applying pressure. The stained and unstained seeds were counted to determine the viability rates.

### 2.2.3. Germination tests

Plastic Petri dishes with a diameter of 9 mm were preferred for seed germination. To prevent fungal infections, drying papers placed in the Petri dishes were sterilized by keeping

them in an oven at 105 °C for one hour. Germination tests were conducted with 4 replicates, each consisting of 100 seeds. To prevent possible fungal infections, a 0.1% Maxim XL fungicide solution was prepared and added to the Petri dishes. The Petri dishes were wrapped in cling film and incubated in a dark environment at 24°C for 200 days for germination. Germinated seeds were counted on days 3, 7, 10, 14, 21 and 28 and then for 200 days by increasing the periods, and germination rates were determined. Germination speed was determined by dividing the number of seeds germinated on day 10 by the total number of seeds. Regular observations and counts were made and

recorded in a table. Each stage of germination and development was photographed.

### 3. Results and Discussion

#### 3.1. Some Morphological Characteristics of Seeds

Determination of 1000-grain weight was done according to ISTA rules. 100 seeds were weighed in 4 replicates, and the 1000-grain weight was determined by proportioning. Thirty seeds were measured for wide, length, and thickness to determine the morphological characteristics of the seeds, and the averages are provided in Table 1.

**Table 1.** Average wide, length, and thickness of seeds (mm).

Seeds	Length (mm)	Wide (mm)	Thickness (mm)	1000 sed weight (g)
<i>A. maurorum</i>	2.6	2.1	1.1	5.7
<i>S. richteri</i>	10.2	10.0	1.9	9.6

#### 3.2. Results of Viability Testing in Seeds

TTC tests were conducted to determine the viability of the seeds. This test is a method used to assess the biological activity and viability of seeds. These data provide important information for interpreting the germination process and

determining seed quality. The TTC test conducted on *A. maurorum* and *S. richteri* seeds provided information about seed viability. The test results showed that some seeds of *A. maurorum* cracked and turned red after 24 hours. However, some seeds did not show any cracking or coloring (Figure 3).



**Figure 3.** Live seeds stained in the TTC test in *A. maurorum*.

Out of a total of 60 *A. maurorum* seeds, 25% cracked and turned red within 24 hours, 5% is empty and the remaining 70% were determined to be live and too hard when crushed. The endosperm and embryo were observed to be yellow and not stained. This may be due to impermeability of the seed coat in seeds with different coat thickness, which prevents staining and

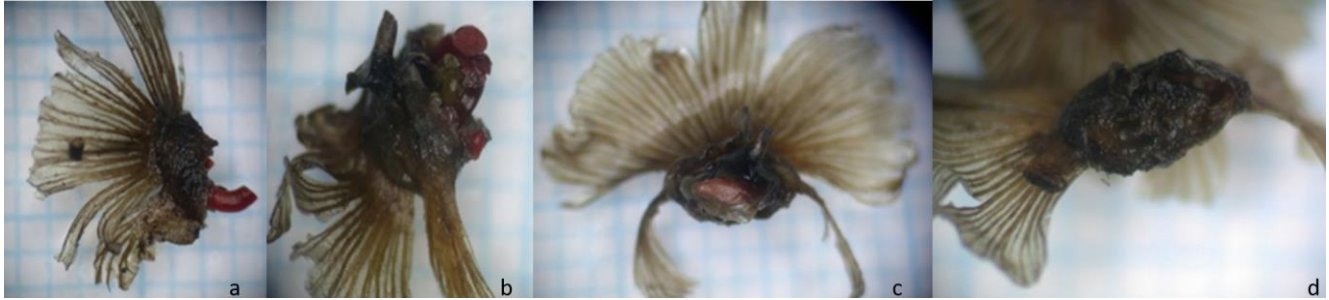
cracking. In the germination process of *A. maurorum*, the different coat structure of the seeds may lead to an extended germination period of 200 days. This demonstrates that the plant has developed a unique germination strategy to sustain its existence and adapt to desert environments (Figure 4).



**Figure 4.** Non-stained, firm and live seeds in the TTC test in *A. maurorum*

A total of 30 seeds of *S. richteri* were used in the TTC test. 13% of these seeds turned red while 87% were found to be empty (Figure 5). This indicates that *S. richteri* seeds have a lower potential for maintaining viability in their natural environment. It suggests that environmental factors in desert habitats negatively affect the germination ability of the seeds. The formation of empty seeds can also be caused by different biotic or abiotic factors. Scientific studies have observed low seed germination in *S. richteri*. Pollination and fertilization in

*Salsola*, as well as embryological findings related to embryo and fruit development are a subject of debate. The embryo of *Salsoloideae* species is curved in a spiral shape and the perisperm is almost absent. In these species, seed yield and quality are mostly dependent on the meteorological conditions of the year. Studies have shown that rainy years promote seed maturation in desert plants, while seed formation rapidly declines in dry years, and many plants do not produce seeds at all (K. Toderich, 2008).



**Figure 5.** Seeds stained in the TTC test in *S. richteri* (a, b, c) and empty and rotten seeds (d).

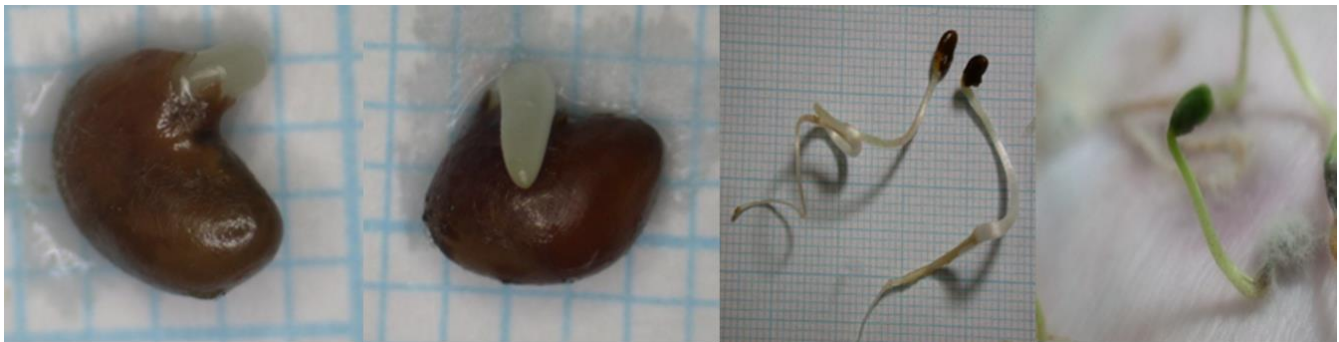
The lack of any signs of germination in the germination test of *S. richteri* and the low viability rates in the TTC test indicate problems in pollination, embryo, and endosperm formation. This situation may be due to the environmental factors created by the desert or excessive animal grazing pressure.

### 3.3. Germination Characteristics and Rates

Counts and observations were made at specific intervals to determine the germination abilities of the seeds in the study.

#### 3.3.1. *Alhagi maurorum*

In the study, it was determined that *A. maurorum* seeds began to germinate from the 2nd day. However, germination did not continue at the same rate, and it was observed that germination continued for a long period after the first germinating seeds. It was determined that there was only a small loss of around 7% in the germination rates of seeds from 2022. At the end of the 200-day period, a total germination rate of 24.2% was observed in *A. maurorum* seeds. It was observed that the seeds developed a long root structure (Figure 6) (Table 2).



**Figure 6.** Germinated seeds of *A. maurorum*.

Desert species have many adaptation mechanisms that ensure germination at the right place and time. Rapid germination strategy is the most important adaptation mechanism for reproduction in desert ecosystems where rainfall is minimal. In arid ecosystems, plants need to rapidly develop a root system after their storage reserves are depleted (Prado-Tarango et al., 2018). Rapidly germinating species in arid and semi-arid environments need to withstand prolonged

periods of drought. While fast-germinating plants germinate with the first rainfall, slow-germinating ones require long periods of wetting (Gutterman, 1993). The germination period of seeds in desert plants is quite flexible. Mechanisms such as rapid and nonsynchronous germination have developed through a long process of adaptation in the challenging desert environment (Lu et al., 2022). The prolonged germination period in *A. maurorum* seeds indicates that the plant has

developed an adaptation to adverse desert conditions. Some seeds germinate immediately, while others prolong their germination periods due to their hard shells, suggesting the production of seeds with different germination characteristics in the same environment. Similar germination characteristics can also be observed in *Arctomecon californica*, where it has been found that dormancy is broken in approximately 5% of seeds each year, allowing them to have a long-lasting seed bank (Van-Buren et al., 2021). It is believed that the same characteristic is likely present in *A. maurorum* as well.

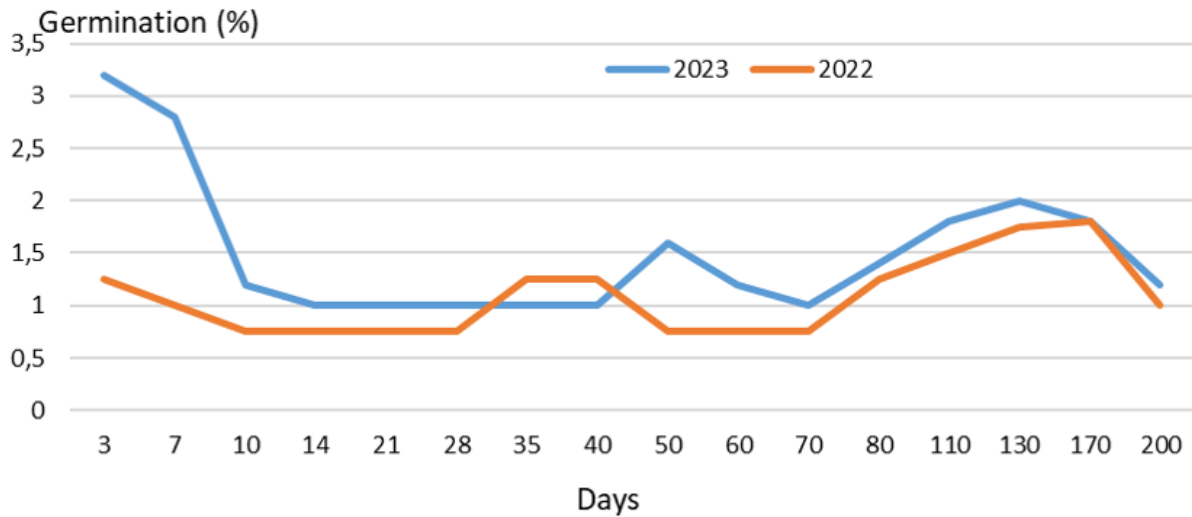
**Table 2.** Germination rates of *A. maurorum* seeds based on the year of collection.

Days	Germination (%)	
	2022 seed	2023 seed
3	1.25	3.2
7	1	2.8
10	0.75	1.2
14	0.75	1
21	0.75	1
28	0.75	1
35	1.25	1
40	1.25	1
50	0.75	1.6
60	0.75	1.2
70	0.75	1
80	1.25	1.4
110	1.5	1.8
130	1.75	2
170	1.8	1.8
200	1	1.2
Total (%)	17.3	24.2

The seeds of *A. maurorum* collected in 2022 and 2023 showed germination rates of 17.3% and 24.2%, respectively. The germination rates slowed down and decreased over the course of 200 days (Figure 7). 10 days after incubation of seeds, the germination rate was determined as 3% in 2022 seeds and 7.2% in 2023 seeds.

Similar results obtained a study conducted by Pirasteh-Anosheh (2020) that *A. maurorum* seeds continue to germinate at certain intervals. The dormancy condition in these seeds contributes to the spread of seeds to distant distances and the survival of seedlings. In addition, it was stated that *A. maurorum* has a hard shell and does not germinate easily, and chemical processes such as sulfuric acid should be used to break dormancy and increase germination rate. A study by Pirasteh-Anosheh (2020) showed that germination potential continues depending on the salinity level. According to the study by Aguado et al. (2012), rains that overlap with seed dispersal in some desert species can trigger suitable conditions for germination. In deserts with winter and summer rains,

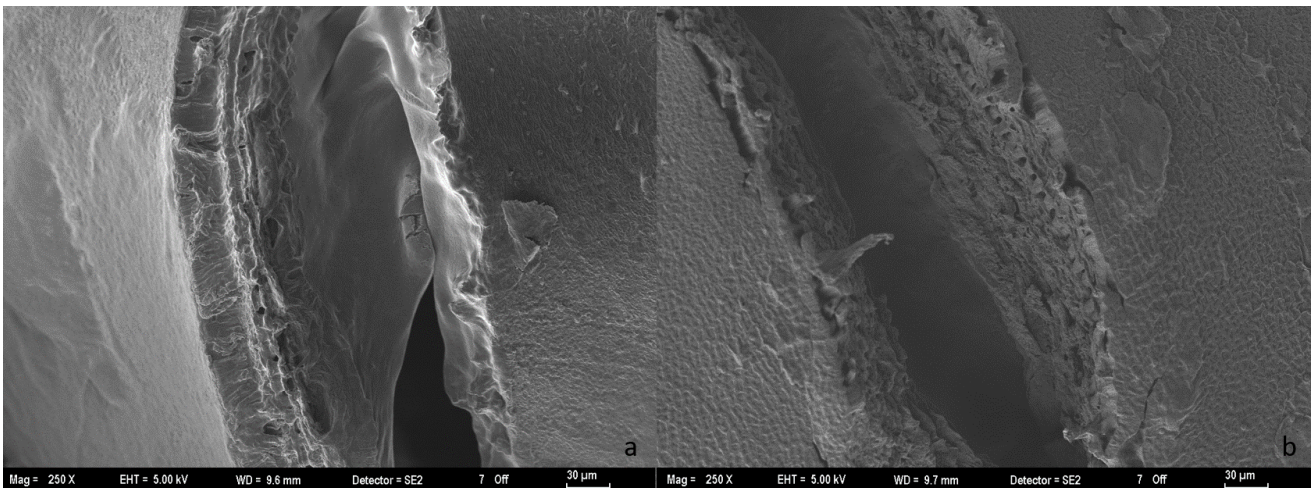
temperature determines the germination time of annual plants. Photoperiodism and thermoperiodism are important adaptation mechanisms that regulate the germination of seeds at the right time of year and season. However, there is limited information about the germination and survival mechanisms of desert plants. Therefore, more research is needed to understand how seeds determine the right time for germination (Gutterman, 1993). Desert plants have developed special adaptation abilities to reproduce. The ability to complete the life cycle in desert conditions is accomplished through the structural, physiological, and biological adaptations of halophytes in the form of half-shrubs (Shamsutdinova & Shamsutdinov, 2021). The seeds of desert plants show diversity according to the temperature requirements for germination. In extremely arid desert conditions, seeds do not germinate until there is enough water source for the survival of seedlings (Hassan et al., 2022). Long-lived plants in deserts have the characteristic of irregular flowering and fruiting to tolerate irregular rainfall. However, germination can fail in many desert plants when there is insufficient moisture. The seeds of desert plants maintain their viability in the soil for many years and ensure successful germination and seed production until the next rain (Goodin & Northington, 1985). The seeds of desert plants have adaptations such as a hard and mucilage-coated cuticle layer, specialized dormancy, and very rapid root growth (Cervantes et al., 2019). Studies have shown that some seeds can withstand surprisingly high temperatures (Ooi et al., 2009) and maintain their viability despite severe drought (Copete et al., 2021). These and similar adaptations enable desert plants to survive and reproduce in extreme conditions. One of these adaptations is seed banks in the soil, and dormancy plays an important role in this adaptation. Long-lived seed banks provide protection against unpredictable environmental changes or harsh climatic conditions, which are considered risk-aversion strategies of desert plants (Hassan et al., 2022). Residual seed banks in the soil or on the plant provide a seed source for germination and the continuation of the generation in plants in subsequent years. These seed banks are seen as an adaptation mechanism in desert ecosystems when suitable conditions for germination and seedling formation cannot be predicted (Koontz & Simpson, 2010; Meyer & Pendleton, 2005). In desert environments, most species have persistent aerial seed banks (Gunster, 1992; Hegazy et al., 2013). These seed banks allow only a portion of the seeds to germinate and maintain the populations with each rainfall (Hegazy et al., 2013). The germination rate is quite low in *A. maurorum*. In *Salsola richteri*, although 13% of the seeds are still viable, no germination occurs, indicating a dormant state that can be considered as a mechanism for adaptation to drought in these two desert plants. This adaptation strategy has also been observed in *A. maurorum*. Although some seeds start to germinate two days later, it was determined that the germination process is quite long.



**Figure 7.** Germination rates of *A. maurorum* seeds collected in 2022 and 2023.

The thickness and permeability of the seed coat affect the germination rate and duration. Different thicknesses of seed coat structures allow the plant to adapt to changing conditions in natural environment and germinate at various times. In the

SEM images, it was determined that the seed coat of late germinating seeds is 1/3 thicker at the same point compared to early germinating seeds (Figure 8).



**Figure 8.** SEM images of early (a) and late (b) germinated seed coats of *A. maurorum*.

### 3.3.2. *Salsola richteri*

In viability tests, it was determined that only a small portion of the seeds (13%) were viable and no germination occurred. It is believed that this is due to the possibility of seeds having multiple dormancies. Studies have shown that removing the seed coat is effective in increasing seed germination rate in *Salsola* plants. Depending on storage conditions, it has been determined that woody *Salsola* species enter a short dormancy period (8-10 months, rarely one to five years). Mechanical damage or chemical treatments can be used to overcome dormancy and increase germination of *Salsola* seeds (K. Toderich, 2008). For example, in *Salsola kali*, germination is faster and it was observed that some seeds started germinating after only 29 minutes of water absorption (Guterman, 1993).

Germination in Kızilkum Desert varies between 4-51% in *Salsola orientalis*, 4-50% in *S. arbuscula*, and 6-65% in *S. gemmascens* during different years (K. Toderich, 2008). Male and/or female infertility, bud and flower shedding, and lack of embryo development are considered to be the main reasons for the formation of empty seeds in desert plants. The low reproductive capacity of *S. richteri* and the difficulty of seed germination may contribute to the decrease of vegetation cover in the desert and the increase in desertification. The arid climate of the Karakum Desert has been noted to threaten the extinction of many plant and shrub species. In addition, it is stated that the unconscious habits of the local population such as animal grazing and wood stockpiling accelerate desertification (K. N. Toderich, 2001).

#### 4. Conclusions and Recommendations

In this study, the germination and morphological characteristics of *A. maurorum* and *S. richteri* desert plant species were examined. The results obtained show that the viability and germination rates of both species' seeds vary greatly. While *A. maurorum* showed germination success, the germination process lasted for a long time. On the other hand, germination did not occur in *S. richteri*. Viability tests revealed that 95% of *A. maurorum* seeds and 13% of *S. richteri* seeds were viable. Desert ecosystems are sensitive ecosystems characterized by low and irregular rainfall, extreme dryness and heat, infertile soils, and poor water retention capacities. The plant species growing in these ecosystems have developed different characteristics to adapt to extreme conditions. In particular, the long germination process of *A. maurorum* seeds is an example of this adaptation and is important for restoration efforts in desert ecosystems. The ability of an aerial seed bank to remain in the soil for a long time, the long germination period, the continuation of the plant population, and the fact that only a portion of the seeds germinate under suitable ecological conditions are all signs of good adaptation. This seed characteristic and the richness of the seed bank are important factors to consider in restoration efforts. The low viability and germination rates of some plant species' seeds indicate the sensitivity of desert ecosystems. Plants growing in the Karakum Desert and its surroundings are being indiscriminately exploited by the local population, causing harm to nature and the ecosystem. Uncontrolled grazing, irregular and excessive cutting for fuel use rapidly destroy the vegetation in the desert. As a result of this destruction, vegetation rapidly decreases, soil erosion increases in sensitive areas, ecosystem balance is disrupted, and some plant species become extinct or endangered. The results obtained from this study will provide practical benefits for the conservation and restoration of these species' habitats.

#### Conflict of Interest

The authors declare that they have no conflict of interest.

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## RESEARCH ARTICLE

# Energy Sources in Natural and Anthropogenic Ecosystems

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## ABSTRACT

This study makes an inventory, a classification and a SWOT analysis of all energy sources that support the functionality of natural and man-made systems. The analysis is carried out at the planetary level, taking into account the entire ecosphere. It is an interdisciplinary study based on literature, integrating information from the field of ecology with that of physics, chemistry, biology, meteorology, and geography. The study carries out an inventory of all types of energy sources; makes a classification of these sources according to their origin and determines which is the most advantageous source through a SWOT analysis. The entire activity of the earth is supported by two large categories of energy sources, namely solar energy and telluric energy. Currently, ten types of energy sources are used or are in the experimental stage, five sources with solar origin and five sources with telluric origin. The most advantageous energy source in terms of regeneration capacity, production costs and ecological footprint is the biofuels. The conclusions of this study are very useful in the realization of energy production strategies and the selection of the most advantageous sources in terms of cost and benefit.

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## 1. Introduction

The entire activity of the ecosphere, which is evident through many processes and phenomena, is sustained by numerous sources of energy. Without an input of energy, the activity of the ecosphere would be impossible. From the point of view of their origin, the energy sources that support the functioning of the ecosphere are of two categories: sources of solar origin and sources of telluric origin. The sources of solar origin are the following: fossil fuels, biomass, solar energy fixed by photovoltaic panels (the visible and ultraviolet spectrum radiations) and thermic solar energy (infrared spectrum radiations), wind and wave energy. The sources of telluric origin are the following: nuclear, geothermal, hydropower tidal and energy.

### 1.1. Sources with Solar Energy Origin

*Fossil fuels* represent radiant solar energy that was fixed through photosynthesis processes in the Cambrian period. This energy was stored as biomass and fossilized in the very slow geological processes that were involved in the formation of fossil fuels such as oil, coal and methane gas. We can say that the fossil fuels represent biomass from the Cambrian Era that fossilized over time (Karatzos et al., 2014). The most important sources of energy production were based on fossil fuels (mostly oil and gas but coal also – exhaustible energy resources), which caused consequences in the form of excess emission of greenhouse gasses (Ziemiński & Frąc, 2012).

*Biofuels* (biomass, biodiesel, wood, etc.) represent radiant solar energy fixed through current photosynthesis processes

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and stored as biomass. Any organic materials, living or that have been dead for a short period derived from plants or animals are classified as biomass. In plants, biomass is formed through the conversion of carbon dioxide in the atmosphere into carbohydrates in the presence of the sun's energy (Basu, 2018). Bioenergy derived from biomass is a renewable source of energy that can be utilized as an alternative to non-renewable sources of energy like coal for energy generation (and electricity production). However, biomass as provided by nature has less energy density, more moisture and the volatiles when compared to coal (Wen et al., 2014). Biofuel is a fuel that is produced by contemporary biomass processes, rather than by the very slow geological processes involved in the formation of fossil fuels, such as oil. Biofuel can be produced from plants (i.e., energy crops), or by agricultural, commercial, domestic, and/or industrial waste (if the waste has a biological origin). Biofuel generally involves contemporary carbon fixation, such as those that occur in plants or microalgae through the process of photosynthesis (Karatzos et al., 2014).

The most important biofuels are bioethanol, biodiesel, herbaceous biomass, wood and methane (gas obtained by anaerobic fermentation of plant residues). These biofuels have biomass as a precursor. Hydrothermal liquefaction (HTL) is a thermo-chemical process that converts wet biomass or organic waste into a liquid bio-oil under high temperature and pressure conditions in the presence of water (Halil, 2023). Biomass is one of the most promising alternative energy sources, because similar to carbon neutrality and availability from multiple sources (Mamvura & Danha, 2020). Biomass is an inexhaustible source of energy that regenerates at a rapid rate compared to the regeneration rate of other inexhaustible resources. It is produced naturally without the need for infrastructure and equipment; through the process of photosynthesis, it fixes, stores, and recycles the CO<sub>2</sub> from combustions. Hence, biomass is the most cost-effective source of energy for the future, having zero risk compared to nuclear energy and the lowest ecological footprint (Gheorghe & Strat, 2023).

**Solar energy** is represented by radiant light and heat from the Sun. This energy can be harnessed using a range of technologies to generate electricity and thermal energy which can be used for heating the water or the air in one's house (Gheorghe & Strat, 2023; IEA, 2012). It is an essential source of renewable energy, and its technologies are broadly characterized as either passive solar or active solar, depending on how they capture and distribute solar energy or convert it into other energy sources. Active solar techniques include the use of photovoltaic systems, concentrated solar power, and solar water heating to harness the energy. Passive solar techniques, on the other hand, include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces in which the air circulates naturally. In 2021, the Carbon Tracker Initiative

estimated the land area needed to generate all energy from solar alone was 450,000 km<sup>2</sup> or about the same as the area of Sweden, Morocco, or California (0.3% of the Earth's total land area) (Gheorghe & Strat, 2023; Walther, 2021). Photovoltaic panels predominantly absorb radiation from the visible and ultraviolet spectrum, and radiation from the infrared spectrum enhances the fixing capacity of the semiconductors in them. Energy enjoys a high level of socio-political acceptance and is preferred to other renewables, although it is unclear whether this acceptance persists if the technology is deployed on a large scale (Cousse, 2021). Radiant solar energy from the infrared spectrum can be used directly by heating water or air in different buildings, or indirectly by using wind and wave energy.

**Wind and wave energy** is due to the non-uniform heating of air and vapors in the atmosphere through the inhomogeneous absorption of infrared radiation from solar radiation. Air masses, charged or not with water vapor, have different densities, those at high temperatures being lighter, and those at lower temperatures being heavier. These different densities determine a certain air circulation either vertically or horizontally and are the basis of wind formation. In coastal areas, or on the surface of bodies of water, the wind transmits some of its energy, causing standing waves. In conclusion, winds and waves are also generated by sunlight, the radiation from the infrared spectrum being responsible. Wind power is the result of using wind turbines to generate electricity. Wind power is a popular, sustainable, and renewable energy source that has a much smaller impact on the environment than burning fossil fuels. Wind farms consist of many individual wind turbines, which are connected to the electric power transmission network. Offshore wind is more constant and stronger than the one on land and, it has a lower visual impact. Although there are fewer offshore wind farms at the present moment, and construction and maintenance costs are higher, it is expected to expand in the future (Gheorghe & Strat, 2023; Haluzan, 2011; Millborrow, 2010).

## 1.2. Sources with Telluric Energy Origin

**Nuclear energy** represents the process through which electricity is obtained from nuclear reactions. This process consists of splitting atoms in a reactor to heat water into steam, which further turns a turbine and generates electricity. There are several ways in which it can be obtained, such as nuclear fission, nuclear decay and nuclear fusion reactions (Gheorghe & Strat, 2023). The chemical elements that have radioactive isotopes used as nuclear fuels in fusion power plants to sustain a nuclear chain reaction are Thorium, Uranium and Plutonium.

These chemical elements with Z greater than or equal to 90 have large nuclear masses and present a varied number of isotopes, as follows: <sup>207-238</sup>Th <sup>214-242</sup>U and <sup>228-247</sup>Pu. The large number of isotopes indicates a large number of neutrons in the nucleus, which induces a state of instability in the nucleus of

some of these isotopes. These unstable isotopes represent the radioactive forms of the respective chemical elements. In the case of thorium, except for the radioisotope  $^{232}\text{Th}$  which is relatively stable, all others are unstable. Thorium boasts several advantages over the conventional nuclear fuel,  $^{235}\text{U}$ . Thorium can generate more fissile material ( $^{233}\text{U}$ ) than it consumes while fueling water-cooled or molten salt reactor, and it generates fewer long-lived minor actinides than plutonium fuels. It is estimated that the Earth's upper crust contains an average of 10.5 parts per million (ppm) of thorium, compared with about 3 ppm of uranium (Vlasov, 2023). These fuels are fissile, and the most common nuclear fuels are the radioactive metals  $^{235}\text{U}$  and  $^{239}\text{Pu}$ .  $^{235}\text{U}$  is used as a fuel in different concentrations. For example the CANDU reactor can use natural uranium with  $^{235}\text{U}$  concentrations of only 0.7%, while other reactors require the uranium to be slightly enriched to levels of 3% to 5%.  $^{239}\text{Pu}$  is produced and used in reactors (specifically fast breeder reactors) that contain significant amounts of  $^{238}\text{U}$ . It can also be recycled and used as a fuel in thermal reactors. Current research is being done to investigate how  $^{232}\text{Th}$  can be used as a fuel (Murray, 2008). At the present moment, the vast majority of electricity obtained from nuclear power is produced by the nuclear fission of uranium and plutonium in nuclear power plants. This type of energy is considered clean concerning greenhouse gas emissions. However, it has two major disadvantages. On one hand, the fission and fusion reactions cannot be completely controlled; hence a risk of nuclear incidents/accidents is always present. On the other hand, the nuclear waste resulting from the use of nuclear fuel cannot be neutralized, and its storage requires special conditions. Such conditions are mandatory, as the physical and radioactive cooling generates radiation with harmful effects on human health, flora and fauna. Therefore, waste storage requires special enclosures and caves in areas with low seismic risk (Galindo, 2021; Gheorghe & Strat, 2023). Ninety-three nuclear reactors in 28 states generate nearly 20 percent of the nation's electricity, all without carbon emissions because reactors use uranium and not fossil fuels. These power plants function constantly/are constantly in use: well-operated to avoid interruptions and built to withstand extreme weather (Gheorghe & Strat, 2023; Ritchie et al., 2021).

**Geothermal energy** is made up of two components, namely the thermal energy in the Earth's crust which results from the cooling of the magma and the energy which follows from the disintegration of radioactive materials. The ratio between the two components is currently uncertain but there is a possibility of roughly equal proportions in some cases (Dye, 2012). The earth's crust, the solid and cold form of the earth, has high temperatures in the deep layers. The high temperature and pressure in the Earth's core cause some rock to melt and solid mantle to behave plastically. This results in parts of the mantle converting upwards since it is lighter than the surrounding rock. Temperatures at the core-mantle boundary can reach over 4000

°C. The agent that takes the thermal energy of the deep and hot layers of the earth's crust is water from the depths. This, in the form of steam or hot liquid, reaches the surface of the earth through the various cracks or penetrations of the crust.

**Hydropower** is the energy produced by the water flow through the gravitational fall. Mountain, hill, and plain relief forms have different altitudes, and the classification of an area from a geographical point of view is closely related to the altitude. Water from watercourses located at high altitudes has a high potential energy compared to low relief areas. In free fall, the potential energy of water is transformed into kinetic energy, energy that sets the turbines of hydropower plants in motion and produces electricity. I considered the hydro energy to be of telluric origin because the oscillations of the height of the Earth's crust lead to different forms of relief, of different altitudes between which there are potential differences. Hydropower also known as water power, is the use of falling or fast-running water to produce electricity or to power machines. This is achieved through the gravitational potential or kinetic energy of a water source to produce power. Hydropower is a method of sustainable energy production. Since ancient times, hydropower from watermills has been used as a renewable energy source for irrigation and the operation of mechanical devices, such as gristmills, sawmills textile mills, trip hammers, dock cranes, domestic lifts, and ore mills (Egré & Milewski, 2002). Water energy is mainly used for hydroelectric power generation. Half of this is produced by the free gravitational fall of water and half by the pumped water in dams. Hydropower is an attractive alternative to fossil fuels as it does not directly produce carbon dioxide or other atmospheric pollutants and also provides a relatively consistent source of power. Nonetheless, it has economic, sociological, and environmental downsides and requires a sufficient power source of water, such as a river or an elevated lake (Donald, 1996).

**Tidal** is another form of hydro-energy that uses twice-daily tidal currents and waves to drive the turbines of generators. Although tidal flow is not constant (unlike some other hydro-energy sources), it is highly predictable and therefore, it can compensate for the periods when the tide is currently low (Griffin, 1992; Gheorghe & Strat, 2023).

**Hydrogen combustion:** Hydrogen is an attractive alternative fuel. However, unlike coal, gas or oil, hydrogen is not a primary energy source. Rather, its role mirrors more closely that of electricity as a secondary 'energy carrier', which must first be produced using energy from another source and then transported for future use where its latent chemical energy can be fully realized. Hydrogen can be obtained from diverse resources, both renewable (hydro, wind, wave, solar, biomass and geothermal) and non-renewable (coal, natural gas and nuclear). It can be stored as a fuel and used in transportation and distributed heat and power generation systems using fuel cells, internal combustion engines or turbines, with the only by-

product at the point of use being water. The ability of hydrogen to replace fossil fuels in the transportation sector could address one of the world's major environmental problems (Johnston et al., 2005).

Hydrogen can also be used as a storage medium for electricity generated from intermittent, renewable resources, such as solar, wind, wave and tidal power; it thereby provides the solution to one of the major issues of sustainable energy, namely the vexing problem of intermittency of supply. As long as the hydrogen is produced from non-fossil fuel feedstock, it is a genuinely 'green' fuel. Moreover, locally produced hydrogen allows for the introduction of renewable energy to the transport sector, provides potentially large economic and energy security advantages and the benefits of a new infrastructure based on distributed generation. It is this key element of the energy storage capacity of hydrogen that provides the potent link between sustainable energy technologies and a sustainable energy economy, generally placed under the umbrella of 'hydrogen economy' (Muradov & Veziroglu, 2005).

Hydrogen has an outstanding potential for becoming a major factor in catalyzing the transition of our carbon-based global energy economy ultimately to a clean, renewable and sustainable economy. The development of hydrogen production, storage and utilization technologies is set to play a central role in addressing growing concerns over carbon emissions and climate change, as well as the future availability

and security of energy supply. Hydrogen and fuel cells are considered in many countries as an important alternative energy vector and key technologies for future sustainable energy systems in the stationary power, transportation, industrial and residential sectors (Edwards et al., 2007)

## 2. Materials and Methods

It is an interdisciplinary study based on literature, integrating information from the field of ecology with that of physics, chemistry, biology, meteorology, and geography. The specialized literature was consulted; all the energy sources that are used by both humans and natural ecosystems were identified. Based on the origin of the respective source, two classes were created. For the production mode of each energy source, the strengths and weaknesses were determined by performing a SWOT analysis. Based on this analysis, the energy source that is the most advantageous for the product was identified.

## 3. Results and Discussion

The production of energy using certain sources has the same or different limitations. To conclude which is the most advantageous energy source, a SWOT-type matrix must be made, taking into account at the same time the weak points and the strong points, a multivariate analysis. The table below specifies the advantages and disadvantages that appear in the energy production process (Table 1).

**Table 1.** The advantages and disadvantages that appear in the energy production process.

No.	Source	Advantages	Disadvantages
<b>Sources with Solar Energy Origin</b>			
1	<i>Fossil fuels</i>	<ul style="list-style-type: none"> <li>- the industry that processes them is already developed</li> <li>- the industry that uses the finished products obtained through processing is already developed</li> <li>- there is a lot of know-how regarding the extraction, processing and use of the finished products</li> </ul>	<ul style="list-style-type: none"> <li>- it is an exhaustible source</li> <li>- more than 90% of the energy consumed by the world's population (electricity, home heating, transport, etc.) is provided by fossil fuels; economies of states being dependent on an exhaustible energy resource</li> <li>- it requires equipment for extraction and processing and the ecological footprint for the production of this equipment is large</li> <li>- during exploitation, transport and processing there is a risk of accidental and historical pollution.</li> <li>- in the processing process, polluting secondary products appear</li> <li>- burning them and the products obtained through processing is polluting</li> <li>- uneven distribution at the level of the globe, which generates inequities in exploitation and use for different states.</li> <li>- it does not regenerate in a reasonable time (accumulation of peat as a type of lower coal requires hundreds of years)</li> <li>- used equipment requires large amounts of energy for recycling</li> <li>- extraction and processing pose a risk to the health of those working in coal mines.</li> <li>- suspended powders and gaseous noxes resulting from combustion present an increased risk to human health</li> </ul>

		<ul style="list-style-type: none"> <li>- surface mining of coal produces the total destruction of the ecosystems that covered the deposit</li> <li>- accidental or historical oil pollutions have a destructive effect on both the marine and/or terrestrial fauna and flora where the ecological disaster occurred.</li> <li>- the transport of methane gas involves the risk of explosions and fires</li> <li>- high costs for making the constructions and equipment</li> </ul>
2	<b>Biofuels</b>	<ul style="list-style-type: none"> <li>- the industry that processes them is already developed</li> <li>- the industry that uses the finished products obtained through processing is already developed</li> <li>- by processing, products are obtained in all three states of aggregation: solid (charcoal); gaseous (methane which is produced by the anoxic fermentation of vegetable waste and liquid products (biodiesel obtained by processing oilseeds such as rape, for example)</li> <li>- there is a lot of know-how regarding the extraction, processing and use of the finished products</li> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it does NOT require equipment for fixing and storing solar energy</li> <li>- in the production process of biofuels, the CO<sub>2</sub> content in the atmosphere decreases; it is fixed in the photosynthesis process</li> <li>- in the production process, the ecological footprint is negative</li> <li>- fix and store their own atmospheric CO<sub>2</sub> produced by burning and processing them</li> <li>- captures and stores atmospheric CO<sub>2</sub> produced by burning and processing other fuels</li> <li>- it does NOT require special space for production and storage</li> <li>- DO NOT modify the natural ecosystems where they are produced (for example wood from the forest)</li> </ul> <ul style="list-style-type: none"> <li>- research interest concerning exploitation and processing into finished products has slowed down, attention is directed towards other alternative sources of energy</li> <li>- liquid products (biodiesel) are not adapted to the internal combustion engines of motor vehicles (cars, diesel locomotives), the motor vehicle industry must adapt its engines to the new fuel.</li> <li>- burning in internal combustion engines of biodiesel produces a significant amount of noxes and CO<sub>2</sub></li> </ul>
3	<b>Solar energy</b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it is a clean energy source</li> </ul> <ul style="list-style-type: none"> <li>- requires special equipment (photovoltaic panels, energy storage batteries)</li> <li>- they generate energy only during the day, they are not functional at night</li> <li>- in the production of photovoltaic panels, rare metals such as silver are used, the resource that can be limiting for production</li> <li>- copper and pure silicon are present in the photovoltaic panels, their extraction and processing are energy-consuming and polluting</li> <li>- battery production requires lithium or lead, metals that can be limiting in the case of production, and their extraction and processing is carried out by an energy-consuming and polluting industry</li> <li>- the production of equipment has a large ecological footprint</li> <li>- recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting</li> <li>- photovoltaic parks change the way land is used, reducing agricultural areas, or other types of natural ecosystems</li> <li>- high costs for making the constructions and equipment</li> </ul>
4	<b>Wind energy</b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it is a clean energy source</li> </ul> <ul style="list-style-type: none"> <li>- requires special equipment (wind turbines - blades, rotor and metal tower -, energy storage batteries)</li> <li>- battery production requires lithium or lead, metals that can be limiting in the case of production, and their extraction and processing is carried out by an energy-consuming and polluting industry</li> <li>- in the production of wind turbines, light metals such as aluminum are used, the resource that can be limiting for production</li> </ul>

		<ul style="list-style-type: none"> <li>- aluminum and iron are present in the wind turbines, their extraction and processing is energy-consuming and polluting</li> <li>- the production of equipment has a large ecological footprint</li> <li>- recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting</li> <li>- the wind blows irregularly, the production of wind energy being unpredictable</li> <li>- the winds whose regularity is greater overlap the migration routes of the birds, leading to their killing by the turbines blades</li> <li>- inside wind turbines parks change the way land is used, reducing agricultural areas, or other types of natural ecosystems</li> <li>- wind turbine parks outside, located in the coastal area, have negative effects on navigation</li> <li>- high costs for making the constructions and equipment</li> </ul>
5	<b>Wave energy</b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it is a clean energy source</li> </ul> <ul style="list-style-type: none"> <li>- the waves are produced irregularly, the production of wave energy being unpredictable</li> <li>- requires special equipment (floating platforms with wave turbines, energy storage batteries)</li> <li>- floating platforms with wave turbines located in the coastal area, have negative effects on navigation</li> <li>- the production of equipment has a large ecological footprint</li> <li>- high costs for making the constructions and equipment</li> </ul>

**Sources with Telluric Energy Origin**

		<ul style="list-style-type: none"> <li>- requires special constructions (nuclear power plants with reactors)</li> <li>- nuclear fuels (Th, U and Pu) are unevenly distributed globally, they are a limiting factor in energy production</li> <li>- extraction and processing pose a risk to the health of those working in radionuclide mining</li> <li>- exploitation in U and Pu mines have destructive effects on the ecosystems where the mining is done and on the neighboring ones</li> <li>- the waste resulting from the burning of nuclear fuels cannot be neutralized by chemical methods, and the neutralization by physical methods is at an experimental stage and with high energy consumption</li> <li>- the storage of nuclear waste requires special conditions because nuclear reactions continue in this waste, and the emission of radiation <math>\alpha</math>, <math>\beta</math>, and <math>\gamma</math>, predicts a risk to human health</li> <li>- fission and fusion reactions are insufficiently controllable reactions and there is a risk of incident and nuclear accident</li> <li>- the production of equipment has a large ecological footprint</li> <li>- recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting</li> <li>- the bars in which the nuclear fuel pellets are arranged are made of cadmium, a relatively rare metal, and the storage containers are made of lead, metals that are extracted and processed by a polluting and energy-consuming industry.</li> <li>- the use of lead, as in the case of the production of solar panels, makes the two industries competitive in terms of lead consumption</li> <li>- the production of heavy water (<math>^3\text{H}_2\text{O}</math>) used to reduce fission product emissions from the reactor requires special equipment</li> <li>- high costs for making the constructions and equipment</li> </ul>
6	<b>Nuclear energy</b>	<ul style="list-style-type: none"> <li>- it is a source with increased efficiency of converting nuclear fuel energy into electrical energy</li> <li>- the production of electrical energy from radionuclides is also accompanied by thermal energy that can be used to heat homes</li> <li>- the production of nuclear energy can be done in compacted spaces</li> </ul>
7	<b>Geothermal energy</b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> </ul> <ul style="list-style-type: none"> <li>- there are very few areas on the surface of the globe with cracks where water and vapors come to the surface</li> </ul>

		- it is a clean energy source	<ul style="list-style-type: none"> <li>- requires special equipment for capture and transport</li> <li>- the hot water has solubilized a large amount of salts and the transport pipes are corroded and obturated by the precipitation of carbonates and other salts</li> <li>- the production of equipment has a low ecological footprint</li> <li>- <b>high costs for making the constructions and equipment</b></li> </ul>
<b>8</b>	<b><i>Hydropower</i></b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it is a clean energy source</li> </ul>	<ul style="list-style-type: none"> <li>- requires special constructions (storage lake, escape tunnels, dam with turbines, power generation network)</li> <li>- the construction of the dam and the reservoir (storage lakes) have a destructive effect on the rivers and neighboring ecosystems</li> <li>- the production of equipment (turbines, cables, etc.) has a large ecological footprint</li> <li>- recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting</li> <li>- the oscillations of the water level in the river downstream of the hydropower plant induced by the various turbines have a harmful effect on the aquatic flora and fauna and the shore areas.</li> <li>- retention of water in accumulation lakes during dry periods has harmful effects on the flora and fauna of the river downstream of the dam</li> <li>- the functioning of the dam bypasses, in the case of torrential precipitations, produce abnormal increases in downstream flows with harmful effects on aquatic flora and fauna</li> <li>- <b>high costs for making the constructions and equipment</b></li> </ul>
<b>9</b>	<b><i>Tidal</i></b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it is a clean energy source</li> </ul>	<ul style="list-style-type: none"> <li>- there are very few areas where the effect of tidal is evident</li> <li>- requires special equipment (floating platforms with wave turbines, energy storage batteries)</li> <li>- the production of equipment has a large ecological footprint</li> <li>- recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting</li> <li>- <b>high costs for making the constructions and equipment</b></li> </ul>
<b>10</b>	<b><i>Hydrogen combustion</i></b>	<ul style="list-style-type: none"> <li>- it is a source of renewable energy</li> <li>- it is an inexhaustible source of energy</li> <li>- it is a clean energy source</li> <li>- the combustion of hydrogen is equivalent to “0” emissions</li> </ul>	<ul style="list-style-type: none"> <li>- it is still in the experimental stage</li> <li>- requires expensive equipment</li> <li>- the storage tanks in which it is compressed must withstand high pressures</li> <li>- during transportation and handling there is a risk of explosion</li> <li>- internal combustion engines are not adapted to this new fuel</li> <li>- the production of equipment has a large ecological footprint</li> <li>- recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting</li> <li>- <b>high costs for making the constructions and equipment</b></li> </ul>

Following the inventory of energy sources currently used, 10 types of sources were identified (Table 2). The number of sources identified for each of the two categories was perfectly

balanced (five sources with solar origin and five sources with telluric origin).

**Table 2.** Number of the advantages and disadvantages that appear in the energy production process.

No.	Source	Number of Advantages	Number of Disadvantages
1	Fossil fuels	3	15
2	Biofuels	13	3
3	Solar energy	3	9
4	Wind energy	3	11
5	Wave energy	3	5
6	Nuclear energy	3	13
7	Geothermal energy	3	5
8	Hydropower	3	8
9	Tidal	3	5
10	Hydrogen combustion	4	8

The largest number of disadvantages in energy production is the use of fossil fuels (15), followed by nuclear fuels (13). Except for the use of biofuels, as an energy source, which presents a net higher number of advantages (13) compared to disadvantages (3), the rest of the sources have a higher number of disadvantages compared to advantages (Table 1 and 2). Biofuels represent the most advantageous energy source in terms of regeneration capacity, production costs and ecological footprint. Therefore, it would be advisable for future energy research to consider this source as a priority. It is recommended that studies focus on how to transform these fuels into products that can be used in current internal combustion engines and other energy-generating systems.

#### 4. Conclusion

Although there are a relatively large number of energy sources, most of them have more disadvantages than advantages. The greatest number of inconveniences in the production of energy they have industries based on fossil fuels and nuclear ones. The energy industry with the most advantages in production is the one based on biofuels. Energy strategies designed for the future must focus research on biofuel processing technologies adapted to internal combustion engines and energy generating systems; identifying new advantageous energy sources; and equipment, internal combustion engines and systems as efficient as possible in the use of energy, leading to a saving in its consumption.

#### Conflict of Interest

The author has no conflict of interest to declare.

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## RESEARCH ARTICLE

# Monitoring Türkiye's Vegetation Cover with NDVI: Terrestrial and Temporal Perspectives

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## ABSTRACT

This study aims to monitor and analyze the temporal and spatial dynamics of Türkiye's vegetation cover from 2000 to 2023 using MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI (Normalized Difference Vegetation Index) data. The primary objective is to assess the changes in vegetation density across various geographical regions of Türkiye and determine how these changes are influenced by environmental factors such as land use and climate variability. NDVI data from July of each year were processed using ArcGIS to classify vegetation into six categories, ranging from water bodies to dense forests. The study reveals significant fluctuations in NDVI values, indicating both vegetation growth and degradation across different regions over time. Key findings include a positive correlation between NDVI values and forested areas, and a negative correlation in regions affected by drought or land use change. These results provide valuable insights into the long-term trends of vegetation dynamics in Türkiye and can help inform future conservation and land management strategies.

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## 1. Introduction

Türkiye's surrounding seas and rugged topography cause significant temporal and spatial variability in meteorological factors. The country's vegetation has undergone substantial changes over the years due to various factors such as land use practices, climate change, and anthropogenic activities. Türkiye is located at the intersection of three distinct phytogeographic regions: the Mediterranean, Euro-Siberian, and Irano-Turanian regions, hosting species from these diverse areas (Aktürk & Güney, 2021).

Traditionally, vegetation monitoring has relied on field-based observation data, which can reflect vegetation dynamics and phenological information. However, these methods often face challenges such as discontinuities in data collection and spatial gaps (Ding et al., 2012). To address these issues, remote sensing techniques have become increasingly important (Zhang et al., 2021). Among these, Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices for monitoring vegetation cover and assessing its changes over time.

NDVI is defined as a measure of surface reflectance and provides a quantitative estimate of vegetation growth and

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biomass (Y. Wu et al., 2016). This index ranges between -1 and +1, where values below zero during the growing season indicate the absence of vegetation (e.g., desert or bare soil areas), while values greater than zero represent vegetated areas (Choubin et al., 2019). The NDVI value is closely associated with the intensity of photosynthetic activity in the observed vegetation, making it an effective tool for detecting annual changes in vegetation's metabolic density and vitality (D. Wu et al., 2015). By highlighting variations in vegetation growth, NDVI can reveal the effects of temperature, precipitation, and other climatic factors, even in the absence of direct human activities or natural disasters (Ghebrezgabher et al., 2020; Jiang et al., 2021; Liu et al., 2019).

The principle behind NDVI is since green vegetation reflects more near-infrared light and less visible red light. By combining these reflections in a normalized manner, NDVI enhances the contrast between green vegetation and other land cover types (Cao et al., 2022). This capability makes NDVI particularly valuable in areas where field observations are limited or affected by discontinuities, providing crucial insights into vegetation dynamics and phenological changes (Matsushita et al., 2007).

NDVI data obtained from remote sensing methods have been crucial in eliminating errors caused by atmospheric conditions, instrument calibration, and terrain, thereby enhancing the sensitivity of vegetation monitoring efforts (Zeng et al., 2014). The broad spatial and temporal coverage of NDVI, its high sensitivity in detecting vegetation changes, low noise levels, and high comparability make it a valuable tool for assessing vegetation dynamics and phenological shifts (Alhajjar, 2024). Numerous studies have utilized NDVI to analyze trends in vegetation, detect changes in the amount of green cover, and monitor ecological changes across various ecosystems (Dai et al., 2011). Moreover, NDVI has been applied on a global scale in areas such as drought monitoring, agricultural production forecasting, land cover change detection, and ecosystem assessment (Naunyal et al., 2023).

In Kaymak (2020)'s study, the effect of morphoclimatic factors on vegetation distribution in the Sündiken Mountains was analysed. This study, which was carried out using MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI data, reveals the interaction of vegetation changes with climatic

factors in detail. The study emphasises that MODIS data are widely used to study vegetation dynamics. Such analyses are critical for understanding the impacts of climate change on vegetation.

In Ateşoğlu (2021)'s study, long-term vegetation index data in the Konya Closed Basin were monitored and trend analyses were performed. This research using MODIS data reveals the trends of vegetation changes over time and emphasises how valuable these data are for environmental monitoring. Such long-term monitoring studies contribute to a better understanding of environmental changes.

While NDVI has been widely used for monitoring vegetation cover and assessing ecological changes, many studies in Türkiye have focused on localized regions or shorter timeframes. For example, previous research by Aktürk (2024) analyzed NDVI trends over a 10-year period in specific biomes of Türkiye, providing valuable insights into regional vegetation dynamics. However, there is a notable gap in studies that assess long-term vegetation trends at the national level, using a 23-year time series to examine both temporal and spatial variations across the entire country. This study aims to fill this gap by analyzing MODIS NDVI data from 2000 to 2023, providing a comprehensive view of vegetation dynamics throughout Türkiye's diverse ecosystems. By incorporating a broader geographical scope and a longer time frame, this research contributes to a more detailed understanding of how climatic and anthropogenic factors have influenced vegetation changes across the country.

## 2. Materials and Methods

### 2.1. Material

#### 2.1.1. Study area

The study area of Türkiye is in the Northern Hemisphere, between 36°-42° north latitudes and 26°-45° east longitudes, covering an area of approximately 780,000 km<sup>2</sup> (Figure 1). Being situated in the temperate climate zone promotes rich ecological diversity. Türkiye hosts approximately 11,000 plant species, 35% of which are endemic, offering remarkable biodiversity. This ecological foundation provides an ideal environment for analyzing NDVI trends across different biomes (Aktürk, 2024).



**Figure 1.** Study area.

### 2.1.2. Satellite data

The study relies on NDVI data derived from the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Indices, specifically MOD13A3 Version 6.1 (LP DAAC, <https://lpdaac.usgs.gov/>), with a spatial resolution of 1 km and a temporal resolution of one month. These data are suitable for large-scale vegetation monitoring due to their consistent global coverage and long time series, making them valuable for observing broad trends over time. However, the relatively low spatial resolution of 1 km poses limitations, particularly when applied to regional or local-scale studies. At this resolution, fine-scale heterogeneity in vegetation cover - such as small patches of forest, agricultural land, or urban areas - may not be adequately captured. This can lead to a smoothing effect, where detailed variations within the landscape are averaged out, potentially obscuring localized changes in vegetation. Therefore, the results of this study should be interpreted with caution, particularly when drawing conclusions about smaller or more fragmented landscapes.

To address this limitation, the analysis focuses on broad-scale trends across Türkiye rather than small-scale, highly localized changes. While the MODIS data provide valuable insights into long-term and large-area vegetation dynamics, future studies aiming for higher spatial accuracy could benefit from incorporating higher-resolution satellite data (e.g., Landsat, Sentinel) or complementing NDVI with other vegetation indices, such as the Enhanced Vegetation Index (EVI), to reduce atmospheric and soil brightness effects.

By acknowledging the limitations of MODIS data and its implications for spatial analysis, this study aims to provide a comprehensive understanding of vegetation dynamics at the national scale, while recognizing the need for more localized studies to capture finer details of vegetation change.

### 2.1.3. Normalized Difference Vegetation Index (NDVI)

NDVI is calculated using the formula  $(NIR - Red) / (NIR + Red)$ , where NIR represents the near-infrared band and Red represents the red band of the electromagnetic spectrum. NDVI values range from -1 to +1, with higher values generally indicating denser and healthier vegetation. A value of -1 typically corresponds to water bodies or man-made surfaces, 0 represents bare soil, and values close to +1 suggest dense green vegetation. Based on previous studies, several NDVI classes were established for the study area (Table 1). Values between -1 and 0 are generally associated with water surfaces, and values between 0 and 0.2 represent bare soil (Essaadia et al., 2022). The ranges 0.2-0.23, 0.23-0.36, 0.36-0.45, and 0.45-1 correspond to areas with varying degrees of vegetation density (Turgut & Turgut, 2022). However, it is important to note that NDVI values can vary based on local environmental conditions, atmospheric influences, and satellite sensor characteristics, and should not be interpreted as definitive vegetation types without ground-based validation data.

**Table 1.** NDVI class values and surface characteristics.

NDVI	Surface Characteristics	Class Values
-1-0	Water surfaces	1
0-0.2	Bare soil	2
0.2-0.23	Shrub, Sparse vegetation	3
0.23-0.36	Open grassland, Annual plants	4
0.36-0.45	Sparse vegetation, Forest	5
0.45-1	Dense vegetation, Forest	6

These classifications allow for a detailed analysis of vegetation cover across different regions of Türkiye, providing insights into the varying degrees of vegetation density.

#### 2.1.4. Land use

MODIS, carried by the Terra and Aqua satellites and used to study Earth's surface, is a fundamental tool for environmental monitoring and remote sensing. MCD12Q1 is one of the MODIS data products, and MCD12Q1 V6 refers to Land Cover Type version 6 provided by the Moderate Resolution Imaging Spectroradiometer. This product includes various classification schemes to identify the surface cover of the Earth. These classifications are typically used to distinguish different land cover types such as vegetation, agricultural areas, water bodies, and urban regions. Satellite images partially downloaded from MCD12Q1 version 6 were combined using ArcGIS software to create a land use map of Türkiye, resulting in a map that depicts land use within the borders of Türkiye.

#### 2.1.5. Software used

ArcGIS, a Geographic Information Systems (GIS) software developed by Esri, was used for processing all NDVI images from 2000 to 2023. ArcGIS allows for the importation of various data types, the establishment of relationships between data, geographic queries, map creation, geostatistical analysis, and database management. Additionally, XLSTAT software was used for correlation analysis to evaluate the relationships between variables within each NDVI class.

## 2.2. Method

In this study, NDVI data within the borders of Türkiye were obtained by downloading images for each July from the MOD13A3 Version 6.1 dataset for the years 2000-2023. Each downloaded NDVI image was imported into ArcGIS software. Using the Reclassify tool available in the ArcGIS toolbox, the NDVI values were categorized into six classes (-1 to 0, 0 to 0.2, 0.2 to 0.23, 0.23 to 0.36, 0.36 to 0.45, and 0.45 to 1). This classification represents different land cover types, including water surfaces, bare soil, and varying densities of vegetation.

Classified NDVI maps for each year were created to analyze and compare annual vegetation changes. The temporal and spatial monitoring of vegetation changes across Türkiye was facilitated through NDVI maps. To determine the distribution

of the six NDVI classes over the total area from 2000 to 2023, ArcGIS software was used to extract the proportional distribution of each class. Subsequently, distribution graphs were generated in Excel to examine changes within each class for each year. Following this, correlation analysis was conducted using XLSTAT software to evaluate the relationships between variables within each NDVI class and to statistically determine the strength and significance of these relationships.

Correlation analysis is a widely used statistical method to understand the strength and direction of the relationship between two variables. Typically, the analysis is conducted using the Pearson correlation coefficient, with results ranging from -1 to +1. A positive correlation indicates a linear relationship between variables, while a negative correlation signifies an inverse relationship.

This comprehensive approach integrates geographic analysis, statistical analysis, and data visualization techniques to explore the temporal and spatial dynamics of vegetation in Türkiye using NDVI data. The use of ArcGIS for spatial analysis, Excel for data management, and XLSTAT for correlation analysis establishes a robust methodology for rigorously examining vegetation changes over time.

## 3. Results

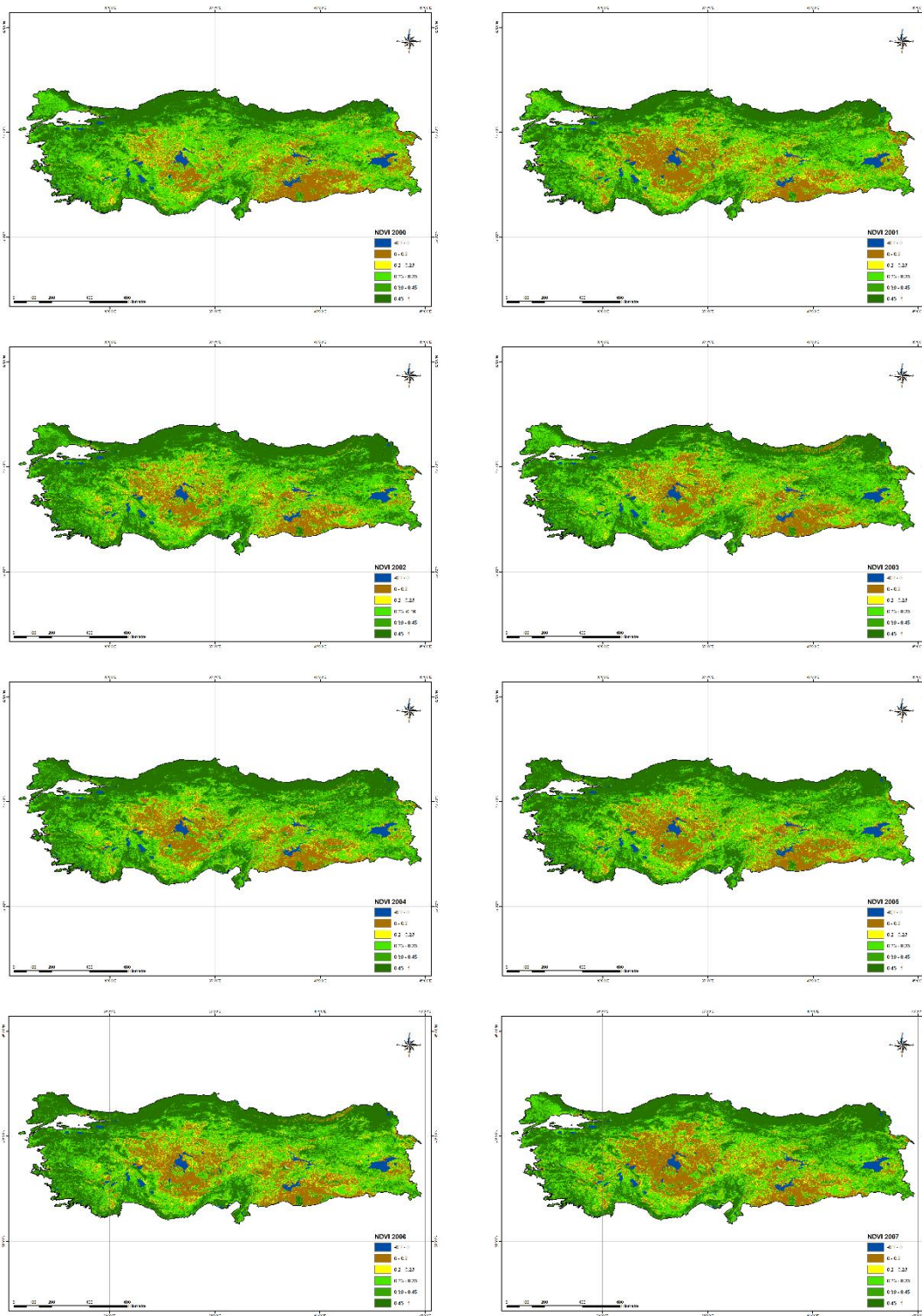
### 3.1. Temporal Variability of the NDVI in Türkiye

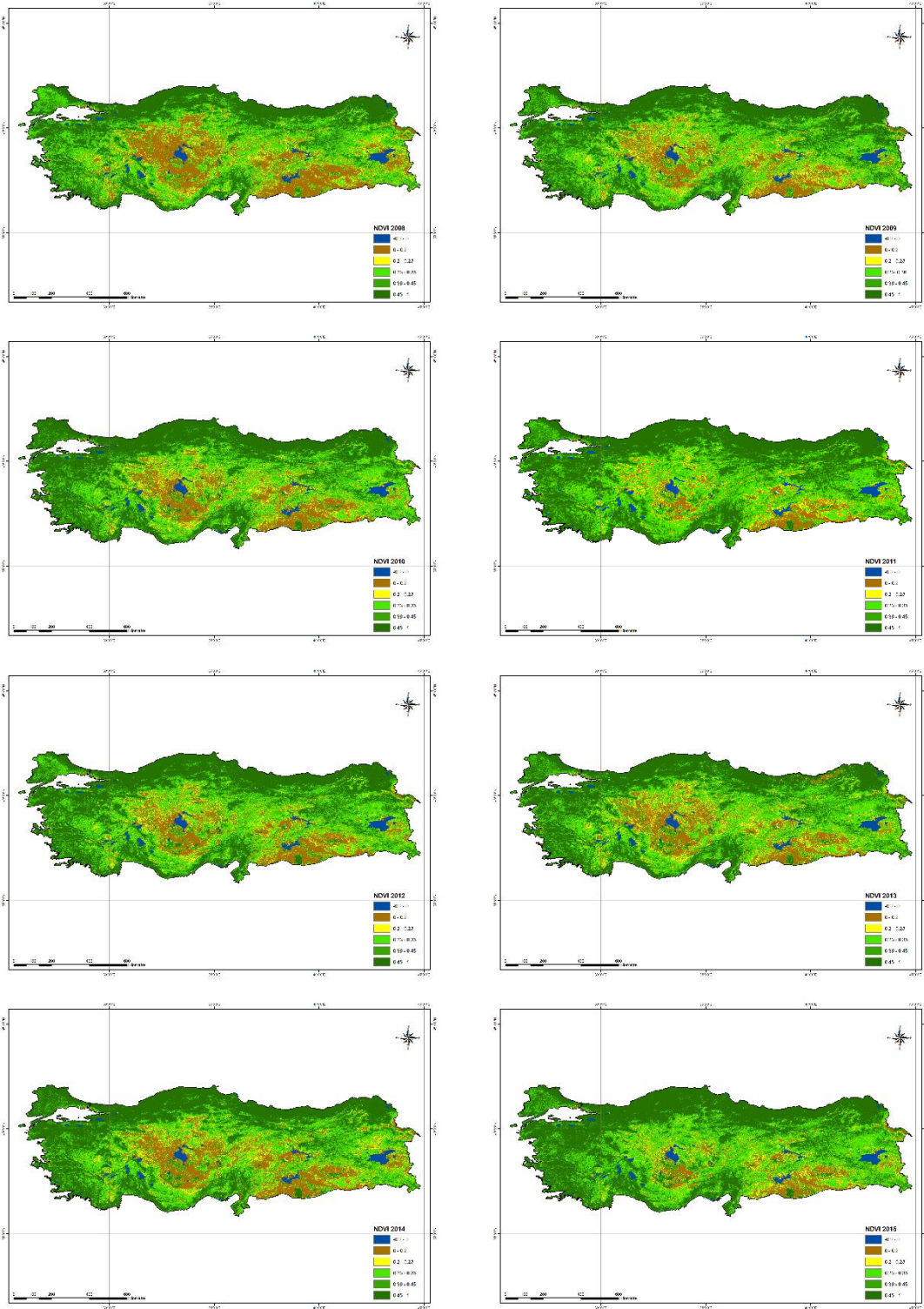
The analysis of NDVI data over the 23-year period from 2000 to 2023 reveals significant variability in vegetation density across Türkiye. NDVI serves as a crucial indicator for monitoring vegetation dynamics and environmental changes.

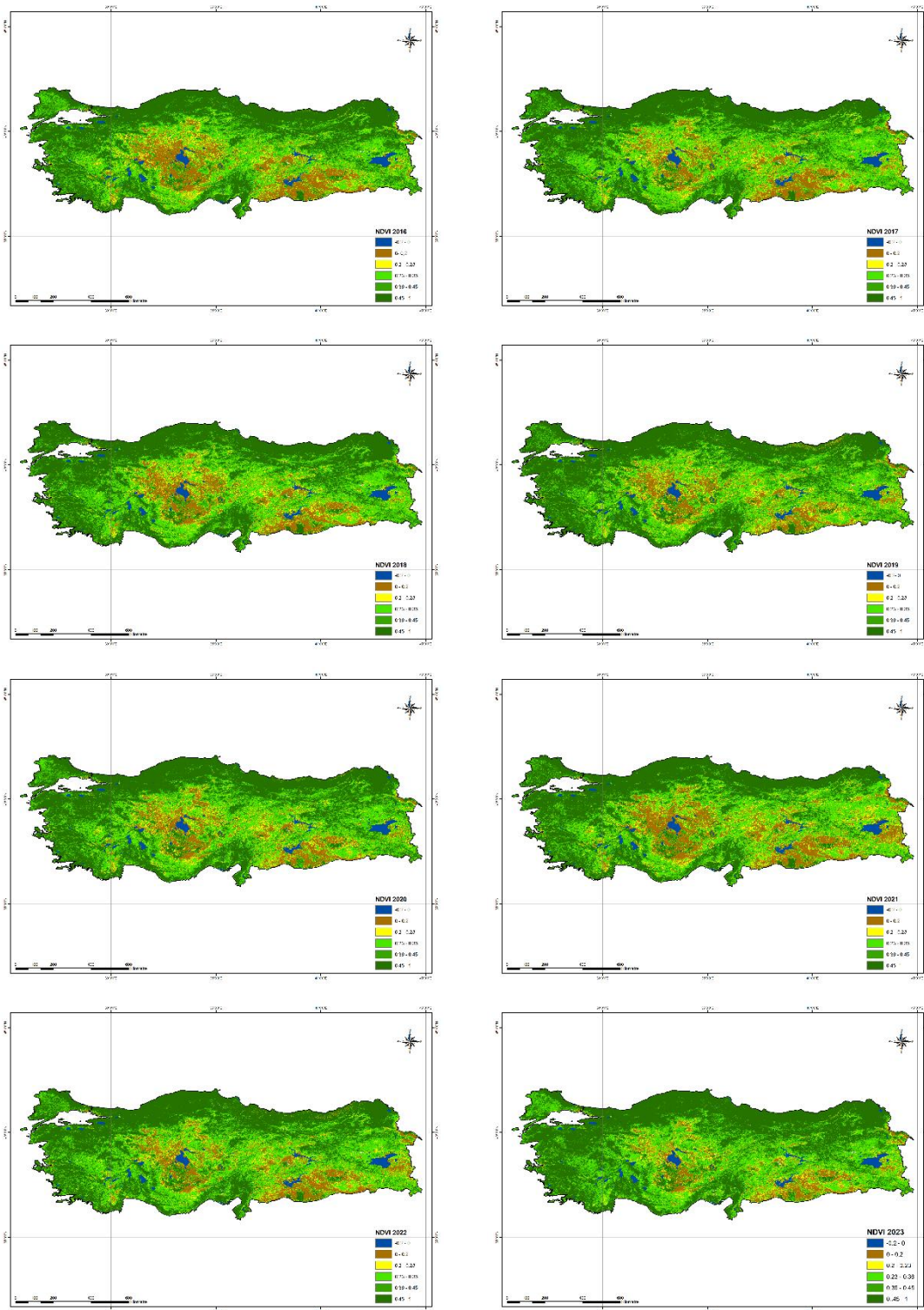
High NDVI values, typically associated with dense and healthy vegetation, are observed in areas such as forested regions, agricultural lands, and wetlands. These areas are represented in dark green on the NDVI distribution maps. Conversely, low NDVI values, indicative of declining or stressed vegetation, are observed in regions affected by desertification, drought, fire, agricultural land degradation, or loss of vegetation. These areas are depicted in brown or blue on the NDVI maps, representing barren lands or water surfaces, respectively (Figure 2).

The spatial and temporal dynamics of NDVI changes across Türkiye since 2000 have been thoroughly analyzed. The

arithmetic mean of NDVI values over the 23-year period reveals preliminary evidence of changes in vegetation density.







**Figure 2.** NDVI maps from 2000 to 2023.

When evaluating NDVI maps from 2000 to 2023 alongside land use maps, it was observed that areas with high vegetation density generally have NDVI values between 0.45 and 1. These regions are depicted in dark green on the NDVI maps. Similarly, these areas overlap with forested regions shown in

various shades of green on the land use maps. Conversely, regions with low NDVI values, ranging from -1 to 0, are typically identified as water surfaces on the NDVI maps and are represented in blue on the land use maps (Figure 3).

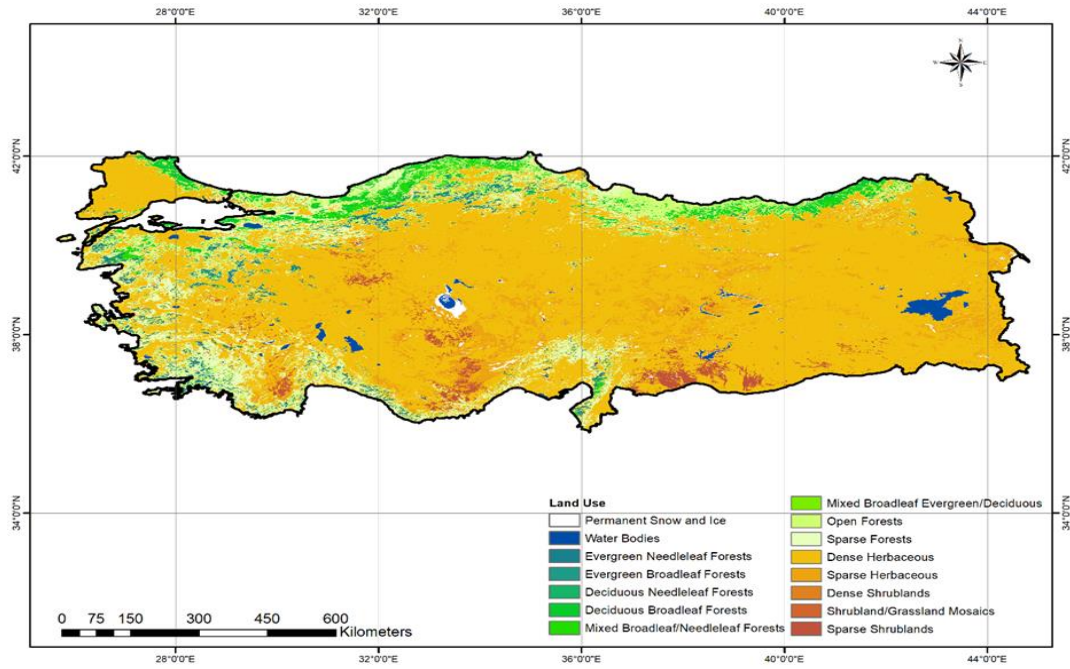


Figure 3. Land use map of Türkiye.

### 3.2. NDVI Distribution Graphs of Türkiye by Year

To track NDVI changes between 2000 and 2023, the maps presented in Figure 1 were utilized. Graphs depicting the average NDVI values for each class over the 23-year period

were employed to analyze the annual NDVI variations. These graphs visualize periodic NDVI fluctuations to provide a clearer understanding of long-term vegetation changes (Figure 4).

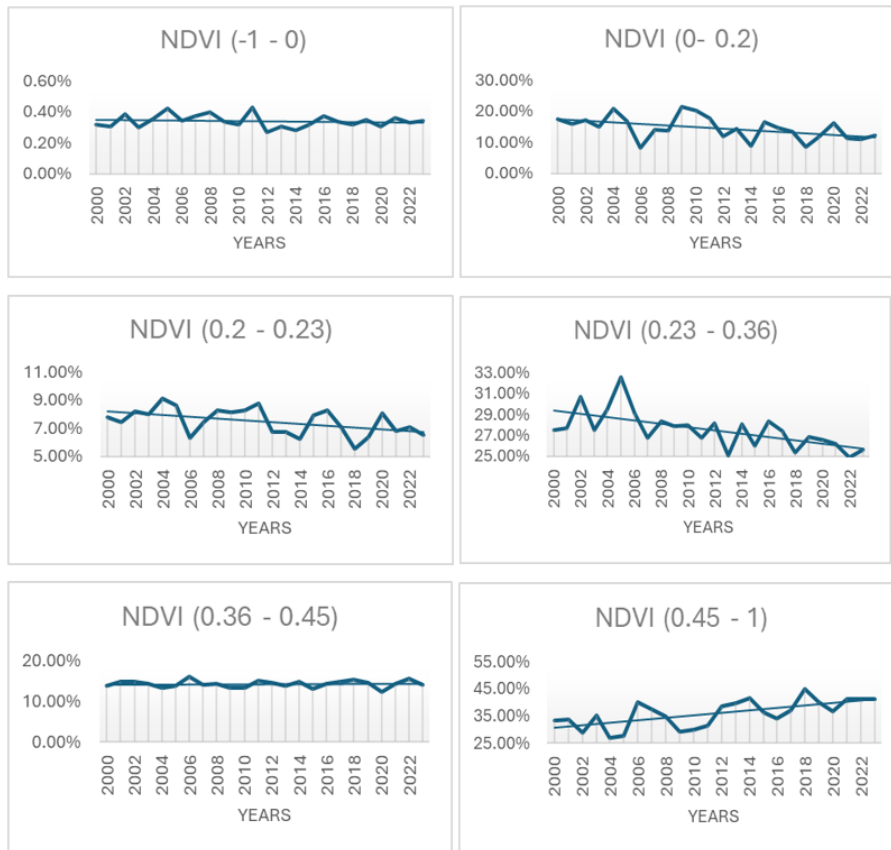


Figure 4. Annual average graphs of NDVI classes.

The presented analysis illustrates the variation in the class ranges of the Normalized Difference Vegetation Index (NDVI) over the years (-1 to 0, 0 to 0.2, 0.2 to 0.23, 0.23 to 0.36, 0.36 to 0.45, 0.45 to 1) in understanding vegetation dynamics.

The first graph represents NDVI values ranging from -1 to 0, which correspond to water surfaces. The analysis reveals a generally linear trend; however, some years exhibit increases and decreases in water surfaces, which can be associated with climatic factors such as drought or excessive rainfall.

In the analysis of NDVI data for July from 2000 to 2023, NDVI values in the 0 to 0.2 range were found to represent bare soil areas. The second graph shows a slightly decreasing trend, though not pronounced. It was observed that NDVI values exhibited irregular fluctuations, with decreases in some years and increases in others. Years with higher NDVI values may suggest the presence of annual vegetation in the environment.

The third graph indicates that the NDVI class range of 0.2 to 0.23 represents shrubs and sparse vegetation. The analysis reveals a linear decreasing trend in this graph. Similarly, the NDVI class range of 0.23 to 0.36 reflects open grasslands and annual plants, showing a similar decreasing trend as observed in the 0.2 to 0.23 range. The NDVI class range of 0.36 to 0.45 represents sparse vegetation and forest areas, showing notable changes.

When evaluating the two graphs derived from the 23-year average NDVI values for July together, it is evident that the NDVI class range of 0.2 to 0.23 corresponds to areas with shrubs and sparse vegetation, while the 0.45 to 1 range represents forested areas with dense vegetation. A distinct contrast is observed between these two graphs: a linear decreasing trend in the 0.2 to 0.23 range versus a linear increasing trend in the 0.45 to 1 range.

In the graph representing shrubs and sparse vegetation (0.2-0.23), years with increasing NDVI values correspond to years with decreasing NDVI values in the graph depicting dense vegetation (0.45-1). For example, between 2004 and 2006, there was an increase in NDVI values for shrubs and sparse vegetation, peaking in 2005 and then decreasing in 2006. During the same period, the graph for dense vegetation initially showed a decrease, followed by an increase. This pattern can be explained by increased production activities in forested areas from 2004 to 2006, leading to higher NDVI values for sparse vegetation while causing a decline in NDVI values for dense vegetation due to reduced coverage. A similar trend is observed in 2018.

This contrasting pattern indicates spatial heterogeneity in vegetation dynamics during the studied years. These observed trends reflect the dynamic nature of vegetation and underscore the importance of NDVI in monitoring and analyzing vegetation changes over time.

**Table 2.** Correlation analysis of NDVI classes.

Variables	-1-0	0-0.2	0.2-0.23	0.23-0.36	0.36-0.45	0.45-1
<b>-1-0</b>	<b>1</b>	0.225	0.472	0.395	0.101	-0.421
<b>0-0.2</b>	0.225	<b>1</b>	0.857	0.323	-0.694	-0.896
<b>0.2-0.23</b>	0.472	0.857	<b>1</b>	0.490	-0.531	<b>-0.907</b>
<b>0.23-0.36</b>	0.395	0.323	0.490	<b>1</b>	-0.031	-0.683
<b>0.36-0.45</b>	0.101	-0.694	-0.531	-0.031	<b>1</b>	0.450
<b>0.45-1</b>	-0.421	-0.896	-0.907	-0.683	0.450	<b>1</b>

The correlation analysis presented in table 2 highlights the relationships between different NDVI class ranges. The 0.2-0.23 range exhibits a strong positive correlation with both the 0-0.2 and 0.23-0.36 ranges, indicating that areas with moderate vegetation are consistent with other moderate vegetation ranges. Conversely, the highest negative correlation (-0.907) is observed between the NDVI class ranges of 0.2-0.23 (shrubs and sparse vegetation) and 0.45-1 (dense vegetation forest). The 0.45-1 range, representing the highest vegetation values, shows a negative correlation with most of the other ranges, suggesting that this range specifically represents dense and distinct types of vegetation. These correlations help in understanding how different NDVI classes reflect changes in vegetation density and how they relate to each other.

#### 4. Discussion

The findings of this study demonstrate significant temporal and spatial variations in NDVI values across Türkiye from 2000 to 2023, reflecting both vegetation growth and degradation. These results are consistent with previous studies, such as Aktürk (2024), who examined NDVI trends over a 10-year period in specific biomes of Türkiye. However, the current study extends this analysis by covering a 23-year period and encompassing a broader geographical scope, thereby providing a more comprehensive assessment of long-term vegetation changes at the national scale.

In contrast to the study by Tian et al. (2024), which analyzed NDVI trends across continental Europe over a similar timeframe, the present findings emphasize unique regional

factors influencing vegetation dynamics in Türkiye, including land use changes and climate variability in the Mediterranean and Anatolian regions. These results highlight the importance of accounting for local environmental conditions when interpreting NDVI trends, as broad-scale assessments may overlook critical regional differences.

Furthermore, the current study complements the work of Aktürk and Güney (2021), who analyzed vegetation cover changes in Türkiye's phytogeographic regions using CORINE datasets from 1990 to 2018. While their research focused on land cover changes, the NDVI trends observed in this study offer additional insights into the health and density of vegetation over time. The extended temporal range of this study provides a more nuanced understanding of long-term vegetation dynamics, particularly in response to increasing climate pressures and land use changes.

The detailed analysis of NDVI data from 2000 to 2023 offers valuable insights into the temporal and spatial dynamics of vegetation across Türkiye. Through the examination of NDVI trends and correlations, several key patterns and implications emerge. The NDVI maps and graphs indicate notable variability in vegetation density over the years. High NDVI values, representing dense and healthy vegetation, are predominantly associated with forested areas, agricultural lands, and wetlands, whereas low NDVI values correspond to water bodies and barren lands (Yasin et al., 2022). These fluctuations in NDVI values suggest that changes in vegetation density are driven by factors such as climatic conditions, land use practices, and environmental policies.

Correlation analyses reveal that the 0.2-0.23 NDVI class, which represents shrubs and sparse vegetation, shows a strong positive correlation with the 0-0.2 and 0.23-0.36 NDVI ranges, suggesting that areas with moderate vegetation are consistent across these categories. Conversely, the 0.45-1 NDVI class, representing dense vegetation, displays a significant negative correlation with the 0.2-0.23 range, indicating that dense vegetation areas are distinct from those with sparse vegetation. These correlations underscore how different NDVI classes reflect changes in vegetation density and highlight their interrelationships (Omar & Kawamukai, 2022).

Further analysis of annual NDVI graphs reveals that periods of increased NDVI in sparse vegetation categories often correspond to decreases in dense vegetation categories. For example, during 2004-2006, increased NDVI in shrubs and sparse vegetation aligned with decreased NDVI in dense vegetation. This trend may be linked to increased production activities or land use changes affecting vegetation density during that time.

The study also emphasizes the spatial heterogeneity of vegetation dynamics across Türkiye. The observed variations in NDVI trends across different regions are primarily driven by

diverse environmental conditions, land use practices, and climate variability. These findings stress the importance of localized analyses to fully capture the complexity of vegetation changes, as broader, national-level assessments may obscure critical regional dynamics.

By situating these findings within the context of previous studies, this research significantly contributes to the broader understanding of NDVI trends in Türkiye. It offers a more detailed and comprehensive analysis of how vegetation has evolved over time, shaped by both natural factors such as climate and topography, and anthropogenic influences such as land use changes. The inclusion of long-term data spanning 23 years enables the identification of key patterns and trends that may be overlooked in shorter-term studies, offering valuable insights for future research and environmental management strategies.

This study employs NDVI data from the Terra MODIS sensor to assess vegetation cover dynamics across Türkiye. While NDVI is a widely used tool for remote sensing of vegetation, its accuracy in identifying specific vegetation types can be enhanced through the integration of ground truth (in-situ) data. Ground truth data provide direct field observations that validate remote sensing classifications, thereby improving the precision of NDVI-based analyses.

However, due to the large spatial and temporal scope of this study, no ground-based validation data were available to directly confirm the association between NDVI values and specific vegetation types in the study area. The absence of in-situ data represents a methodological limitation, as NDVI values alone may not fully capture fine-scale vegetation variability or differentiate between similar land cover types.

Future studies would benefit from the integration of ground truth data to validate NDVI classifications, particularly when investigating specific vegetation types or localized ecosystems. Such data would enhance the reliability of the results and allow for more precise conclusions about the relationship between NDVI values and vegetation characteristics. Furthermore, combining NDVI with additional remote sensing indices and incorporating local environmental conditions would further strengthen the robustness of the analysis.

By acknowledging this limitation, the study highlights the importance of ground-based validation in remote sensing research and emphasizes the need for more localized and field-validated analyses in future studies.

## 5. Conclusion

This study provides a comprehensive analysis of Türkiye's vegetation cover dynamics from 2000 to 2023, utilizing MODIS NDVI data to assess temporal and spatial trends across diverse geographical regions. The findings reveal significant variations in NDVI values, highlighting both vegetation growth

in forested areas and degradation in regions impacted by factors such as land use changes and climate variability. The spatial heterogeneity observed in vegetation dynamics underscores the importance of localized analysis to understand the complex interactions between environmental conditions and anthropogenic activities.

In comparison to previous studies, this research offers a broader scope by covering a 23-year period and analyzing NDVI trends at the national scale, filling a notable gap in the literature on Türkiye's vegetation dynamics. The results align with other studies that examined shorter timeframes or specific regions, while also providing new insights into long-term trends and the drivers behind vegetation changes.

The study emphasizes the value of NDVI as a tool for monitoring vegetation health and density, while also acknowledging the limitations of using a single index. Future research should aim to incorporate additional remote sensing indices and ground-based validation data to enhance the accuracy and reliability of vegetation assessments. Furthermore, the findings from this study can contribute to the development of more effective land management and conservation strategies, particularly in regions vulnerable to climate change and unsustainable land use practices.

In conclusion, the long-term monitoring of vegetation dynamics across Türkiye provides a critical foundation for understanding how natural and human-induced factors are shaping the country's ecosystems. The insights gained from this research can inform future studies and policy decisions aimed at preserving and managing Türkiye's diverse vegetation cover in the face of environmental challenges.

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## Conflict of Interest

The authors declare that they have no conflict of interest.

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- Compliance with Ethical Standards
  - ❖ Conflict of Interest Statement
  - ❖ Statement on the Welfare of Animals (if applicable)
  - ❖ Statement of Human Rights (if applicable)

### • Main File

- Title
- Abstract (Should be between 200 and 250 words. References and abbreviations should be avoided)
- Keywords (Minimum 4, Maximum 6 keywords)
- Introduction
- Materials and Methods
- Results
- Discussion (Can be combined with Results section if appropriate)
- Conclusion (Can be combined with Discussion section if appropriate)
- References
- Table(s) with caption(s) (on appropriate location in the text)
- Figure(s) with caption(s) (on appropriate location in the text)
- and appendices (if any)

### Manuscript Formatting

Use a 12-point Times New Roman font, including the references, table headings and figure captions, double-spaced and with 25 mm margins on all sides of A4 size paper throughout the manuscript. The text should be in single-column format.

- Each page must be numbered with Arabic numerals, and lines must be continuously numbered from the start to the end of the manuscript.
- Use italics for emphasis.
- Use only SI (international system) units.
- Use “dot” for decimal points.
- Use italics for species name.

### References

*SilvaWorld* uses APA style (7<sup>th</sup> edition). Accordingly, authors must format their references as per the guidelines below. Please ensure that each reference cited in the text is also presented in the reference list. Authors should always supply DOI or URL of the work cited if available.

#### In-text citation (Narrative):

...The results of Ayan (2022) support...  
...Ayan and Yer (2020) indicated that...  
...According to the method of Ayan et al. (2021)...

#### In-text citation (In parenthesis):

...It was found to be isometric (Ayan, 2018)...  
...is highly susceptible to diseases (Ayan & Kara, 2019)...  
...have been studied (Yer et al., 2020)...

## **Two or more works in the same parenthesis:**

...extremely toxic for the environment (Ayan, 2018, 2019; Sönmez et al., 2020a; Ayan & Turgut, 2021)...

## **Citation in the reference list:**

References should be listed first alphabetically and then further sorted chronologically at the end of the article. The citation of all references should conform to the following examples:

### **Article:**

Lastname, N., Lastname, M., & Lastname, O. (Year). Title of the work. *Title of the Journal*, Volume(Issue), Page numbers. DOI

Ayan, S. (1998). Tüplü sarıçam *Pinus silvestris* L. fidanı üretiminde yavaş yavaş yararışlı gübrelerin etkileri. *Developmental & Comparative Immunology*, 35(12), 1366-1375. <https://doi.org/10.1016/j.dci.2011.07.002>

Öztürk, S., & Ayan, S. (2015). Management alternatives in national park areas: The case of Ilgaz Mountain National Park. *Eco Mont-Journal on Protected Mountain Areas Research*, 4(4), 37-44. <https://doi.org/10.1046/j.1467-2979.2003.00121.x>

Yer Çelik, E. N., Baloğlu, M. C., & Ayan, S. (2021). Gene expression profiles of Hsp family members in different poplar taxa under cadmium stress. *Turkish Journal of Agriculture and Forestry*, 45(10), 102-110. <https://doi.org/10.1111/jfd.13229>

### **Article by DOI (early access):**

Ayan, S., Çalışkan, E., Özel, H. B., Yer Çelik, E. N., Yılmaz, E., Gülseven, O., & Akın, S. S. (2022). The influence of effective microorganisms on physiological characteristics of containerized Taurus Cedar (*Cedrus libani* A. Rich.) seedlings. *Cerne*. <https://doi.org/10.1590/01047760202228013018>

### **Book:**

Lastname, N., Lastname, M., & Lastname, O. (Year). Title of the work. Publisher.

Oidtmann, K., Xao, Q., & Lloyd, A. S. (2018). *The food need by the year 2050*. Elsevier.

### **Book Chapter:**

Lastname, N., Lastname, M., & Lastname, O. (Year). Title of the chapter. In N. N. Lastname, A. Lastname & B. Lastname (Eds.), *Title of the book* (pp. Page numbers). Publisher.

Barbati, A., Mugnozza, G. S., Ayan, S., Blasi, E., Calama, R., Cicatiello, C., Canaveira, P., Collalti, A., Corona, P., Rio, M. del R., Ducci, F., & Perugini, L. (2018). Adaptation and mitigation. In G. A. E. Gall & H. Chen (Eds.), *State of Mediterranean forests* (pp. 51-63). Elsevier. <https://doi.org/10.1016/b978-0-444-81527-9.50010-5>

### **Dissertation or Thesis:**

Lastname, N. (Year). Title of dissertation/thesis (Doctoral dissertation/Master's thesis, Name of Institution).

Ayan, S. (1990). *Determination of the characteristics of growing media and production technique for containerized oriental spruce (Picea orientalis (L.) link.) seedlings* (Doctoral dissertation, Karadeniz Technical University).

Ayan, S. (1988). *Appreciation on height growth of ten years of age of norway spruce (Picea abies (L.) karst.) origins in Eastern Black Sea region* (Master's thesis, Karadeniz Technical University).

### **Conference Proceedings:**

Lastname, N., Lastname, M., & Lastname, O. (Year). Title of the work. Title of the Conference. City.

Ayan, S., Ayan, Ö., Altunel, T., & Yer, E. N. (2014). *Honey forests as an example agroforestry practices in Turkey*. World Congress of Agroforestry. New Delhi.

### **Institution Publication:**

Institution name. (Year). Title of the work. URL

FAO. (2020). *Forestry statistics 2018*. <http://www.fao.org/3/cb1213t/CB1213T.pdf>

### **Internet Source:**

Lastname, N. (Year). Title of the work. Retrieved May 15, 2020, from URL

Ayan, S. (2019). *Utilization of Zeolite as plant growing media*. Retrieved Jan 12, 2021, from <https://earsiv.kastamonu.edu.tr/>

### **Table(s)**

Tables, numbered in Arabic, should be in separate pages with a short descriptive title at the top. Place footnotes to tables below the table body and indicate them with superscript lowercase letters (or asterisks for significance values and other statistical data).

### **Figure(s)**

All illustrations should be labelled as 'Figure' and numbered in consecutive Arabic numbers, Figure 1, Figure 2 etc. in the text. If panels of a figure are labelled (a, b, etc.) use the same case when referring to these panels in the text. Figures are recommended to be in electronic formats such as PNG, JPEG, TIFF (min. 300 dpi). All figures or tables should be presented in the body of the text.

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### • Title Page File

- Title
- Full names, e-mails, and affiliation addresses of all authors
- ORCID numbers of all authors
- Corresponding author's e-mail, telephone number, and address
- Ethical statements

### • Main File

- Continuous page numbers
- Continuous line numbers
- Blinded document (no personal information is present)
- Title
- Abstract (200-250 words)
- Keywords (4-6 keywords)
- All figures and tables are numbered and cited in order in text
- Completeness and accuracy of the references have been checked
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The studies submitted to *SilvaWorld* are first evaluated by the editor. At this stage, studies that are not in line with the aim and scope of the journal, are weak in terms of language and narrative rules in English, contain scientifically critical mistakes, are not original worthy, and cannot meet publication policies are rejected. Authors of rejected studies will be notified within one month at the latest from the date of submission. Eligible studies are sent to the field editor to which the study is relevant for pre-evaluation.

### 2. Pre-Evaluation Process

In the pre-evaluation process, the field editors examine the studies, introduction and literature, methods, findings, results, evaluation and discussion sections in detail in terms of journal publication policies, scope and authenticity of study. Study which is not suitable as a result of this examination is returned to the author with the field editor's evaluation report within four weeks at the latest. The studies which are suitable for the journal are passed to the referee process.

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2. *Methodology:* The evaluation report includes information on the suitability of the method used, the choice and characteristics of the research group, validity and reliability, as well as on the data collection and analysis process.

3. *Findings:* The evaluation report includes opinions on the presentation of the findings obtained in the frame of the method, the correctness of the analysis methods, the aims of the research and the consistency of the findings, the presentation of the required tables, figures and images and the conceptual evaluation of the tests used.

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5. *Conclusion and suggestions:* The evaluation report contains the opinion on the contributions to the literature, future studies and recommendations for the applications in the area.

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# SILVAiWORLD

The logo features the text 'SILVAiWORLD' in a bold, sans-serif font. The letters 'SILVA' are in a light green color, 'i' is a small dark blue dot, 'W' is a dark blue gradient, and 'ORLD' is in a medium green color. A thick, wavy line in a blue-to-green gradient curves underneath the text.