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Sustainable Management of Natural Resources

Edited by Mohd Nazip Suratman,
Engku Azlin Rahayu Engku Ariff
and Seca Gandaseca

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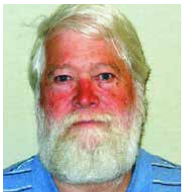
Aims and Scope of the Series

Scientists have long researched to understand the environment and man's place in it. The search for this knowledge grows in importance as rapid increases in population and economic development intensify humans' stresses on ecosystems. Fortunately, rapid increases in multiple scientific areas are advancing our understanding of environmental sciences. Breakthroughs in computing, molecular biology, ecology, and sustainability science are enhancing our ability to utilize environmental sciences to address real-world problems.

The four topics of this book series - Pollution; Environmental Resilience and Management; Ecosystems and Biodiversity; and Water Science - will address important areas of advancement in the environmental sciences. They will represent an excellent initial grouping of published works on these critical topics.

Meet the Series Editor



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Contents

Preface

Natural resource management involves the management of forests, environment, land, water resources, biodiversity, soil, plants, and animals. This book highlights sustainable management of natural resources with a specific focus on how this management influences the quality of life for both present and future generations. It also discusses managing these resources the way in which human beings and natural landscapes interact, how they rely upon the health and productivity of our landscapes, and their critical role in maintaining health and productivity. The book is organized into six sections: (1) "Introduction", (2) "Environmental Resources Management", (3) "Agriculture Resources Management", (4) "Water Resources Management", (5) "Ecotourism Resources Management", and (6) "Community-Based Natural Resources Management".

Section 1 analyzes the relationship between environmental education and community-based natural resources management in Zambia. It examines the roles they could play in the management of natural resources and recommends that environmental education be incorporated into the sustainable management of natural resources in the country. It also highlights the use of phosphate-solubilizing rhizobacteria as biofertilizers in Pakistan, which are reported to be capable of solubilizing soil phosphate from an insoluble to soluble form that can be taken up by plants easily.

Section 2 looks at the impact of large-scale agricultural investment expansions on natural resources and factors affecting it in the drylands of Ethiopia. The section also highlights how agroforestry can be practiced for better land management to climate adaptation and mitigation in Savannah West Africa Burkina Faso, and how environmental sustainability and safety could be ensured while intensifying crop production.

Based on a study conducted in the Mississippi River floodplain in a portion of the state of Missouri, USA, Section 3 summarizes the key soil and soil features and elaborates on ecosystem site descriptions to support the assessment of land management's influence on ecosystem services.

Section 4 discusses that the mutual benefits of society and the environment can be achieved by keeping to the principles of sustainable development, which is the development that satisfies the present situation without compromising the ability of future generations to satisfy their needs.

Finally, Section 5 presents a study in Eastern Africa on the importance of stakeholders' participation in eradicating alien species.

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Section 1

Introduction

Chapter 1

Introductory Chapter: Why Is Sustainable Management of Natural Resources Necessary?

Mohd Nazip Suratman, Seca Gandaseca and Engku Azlin Rahayu Engku Ariff

1. Introduction

Natural resources are sources that are drawn from nature which are used to support life and meet people's desires, and used with few changes. Any natural substance that human beings use can be considered a natural resource. Oil, coal, natural gasoline, metals, stone, and sand are natural resources. A component of environmental putting embraces the totality of *substances,* functions, and processes of landscapes [1], and these settings provide unique and specific features that offer various possibilities for the transformation of materials and energy. As Mitchell [2] noted, sources in this context refer to the abiotic, biotic, and cultural attributes that exist on, in, or above the Earth. These sources play a critical role in shaping environmental settings and determining how they can be utilized by humans and other living organisms.

Barsch and Burger [3] defined natural resources as materials created by nature such as soil, water, land, minerals, vegetation, and wildlife, as well as power resources like coal, gas, and sunlight that fulfill human needs and desires. These materials are considered "natural matter" until humans recognize their presence, attach value to them, and find ways to utilize them. When humans utilize these resources, they give them a new purpose and turn them into a source of subsistence, or a herbal resource. As a result, these natural materials fulfill a new function in human society [2, 3].

Natural resources provide benefits that are essential for meeting basic human needs such as air, shelter, food, and clothing. They are considered a part of humanity's natural heritage and are often protected in nature reserves. Barsch and Burger [3] suggested that natural resources can be classified in various ways, and one common classification is based on their exhaustibility and regenerative power. At their most fundamental level, every man-made product is made up of natural resources.

Barsch and Burger [3] categorized natural resources into two categories; renewable and non-renewable resources. Renewable resources refer to a natural resources that can profile rate in that period relevant for human planning such as forests or water. However, they can still be depleted. Whereas for non-renewable resources, the stock provided by each is constant in the period relevant for human planning which includes traditional energy sources such as gasoline or coal.

Natural resources management is the management of natural resources such as land, water, soil, plants, and animals, with a specific focus on how management influences the quality of life for both present and future generations (stewardship). Natural resources management involves managing the interaction of various fields such as natural heritage management, land use planning, water management, biodiversity conservation, and sustainability of industries such as agriculture, mining, tourism, fisheries, and forestry. This approach recognizes that human livelihoods depend on the health and productivity of our landscape and that humans have a responsibility to act as stewards of the land to maintain its health and productivity [4].

According to Environmental Law, sustainable management of natural resources involves utilizing these resources in a way that maintains and improves the resilience of ecosystems and the benefits they provide. This approach aims to meet the needs of current generations without compromising the ability of future generations to meet their own needs, while also supporting the achievement of welfare goals outlined in the Act on the Wellbeing of Future Generations [5].

2. The need for sustainable management of natural resources

All sources that are used and consumed by humans are ultimately derived from natural resources. However, due to factors such as population growth, industrialization, and urbanization, the demand for these resources is steadily increasing while their availability is limited. This has to concerns about the sustainability of resource use and the need for more responsible management practices to ensure that these resources are available for future generations. Therefore, there is a need for sustainable management of natural resources. These include:

- Judicious use of natural resources and avoiding wastage of natural resources.

- Long-term planning is essential for the sustainable use of natural resources, ensuring that they are available not only for the present but also for future generations.

- The exploitation of natural resources should not be limited to benefiting only a few people or groups but should be distributed equitably for the benefit of all.

- When extracting and using natural resources, it is important to plan for the safe disposal of waste to prevent damage to the environment.

Natural resources are closely linked to the global agenda of Sustainable Development Goals (SDGs), a principle that forms a basis for land management and environmental practices worldwide. Sustainable management of natural resources involves a scientific and technical understanding of resources and ecology, as well as an understanding of the supportive capacity of those resources. This approach aims to meet the needs of the current generation without compromising the ability of future generations to meet their own needs. This concept helps in sustainably managing natural resources as they resources are utilized and saved [6].

According to Tayagi [7], sustainable management of natural resources demands the following:

- Using resources carefully and wisely as these resources are limited and finite.

- A long-term perspective that takes into account the needs of future generations, so that these resources will last for the generations to return and cannot merely be exploited for short-term gains.

- Minimize the damage caused to the environment during the extraction and use of these resources.

- Planning for the safe disposal of the waste which is generated during the extraction and use of these resources.

3. Forest resources: the Malaysian perspective

Malaysia is home to some of the most precious natural resources in the world, including its tropical rainforests. These forests are incredibly diverse and complex and are known for their high productivity and ecological significance. Malaysia's climate is characterized by high temperatures and heavy rainfall, which creates ideal conditions for the growth of tropical rainforests, as well as other forest types such as hill dipterocarp forests, peat swamp forests, freshwater swamp forests, and mangrove forests. These forests provide a range of benefits to both humans and the environment, including regulating the climate, supporting biodiversity, and providing valuable ecosystem services such as water purification and soil conservation.

Malaysia has a total land area of 32.94 million hectares, of which 18.23 million hectares are classified as forest areas. Peninsular Malaysia, Sarawak, and Sabah are the three main regions of Malaysia, and they occupy 5.69, 7.79, and 4.75 million hectares of forest cover, respectively. This translates into 43.5, 62.6, and 64.3% of the forest cover in each region, respectively (**Table 1**).

The Malaysian Government is committed to its effort to maintain natural forest cover of more than 50% of its land base, as declared at the 1992 United Nations Earth Summit. Forestry departments in Peninsular Malaysia, Sabah, and Sarawak have been using remote sensing technology for mapping monitoring and inventory purposes in order to effectively monitor forest resources. Geographical Information Systems (GIS) have been integrated with advanced technologies such as hyperspectral imaging

Region	Forest Cover (ha)			Total Forest Cover (ha)	Land Area (ha)	Total Forest Cover (%)
	Inland Forest	Peat Swamp Forest	Mangrove Forest			
Peninsular Malaysia	5,338,082	243,504	110,953	5,692,539	13,100,367	43.5
Sarawak	7,328,029	320,207	139,890	7,788,126	12,444,951	62.6
Sabah	4,273,536	97,276	378,195	4,749,007	7,390,224	64.3
Total	**16,939,647**	**660,987**	**629,038**	**18,229,673**	**32,935,542**	**55.3**

Source: [8].

Table 1.
Forest cover in Malaysia (2020).

and Light Detection and Ranging (LIDAR) have been used with the integration of Geographical Information Systems (GIS) to facilitate the departments to carry out the management and monitoring responsibilities.

4. Sustainable management of natural resources in Malaysian

Malaysia has benefited from the abundant natural resources that have made a significant economic contribution. Environmental services provide these natural resources. It is crucial to ensure proper management of environmental performance, especially with regard to conservation and sustainable use, as natural resources are one of the nation's greatest strengths and assets. Sustainable management of natural resources is important to ensure that present and future generations enjoy the benefit of the natural bounty while striving for green growth.

4.1 Sustainable forest management

Diverse initiatives have been made in Malaysia to manage natural resources sustainably. Since 1901, Malaysia has been using Sustainable Forest Management (SFM) in the forestry industry. SFM refers to the process of managing permanent forests and achieving one or more clearly defined management objectives with regard to the production of a continuous flow of desired forest products without having an excessively negative impact on the physical and social environment.

4.2 Main pillars of sustainable forest management

According to Lye [9], SFM is based on three main pillars: (1) economically viable, which means that the forestry sectors benefit the economic development of the nation and its people; (2) environmentally sound, which means that the forestry sectors implement the environmental friendly forestry practices and keep the ecosystem support the healthy organisms while preserving its productivity, adaptability, and capacity for renewal; (3) socially acceptable, which reflects the relationship between development and social norms, an activity is socially sustainable if it conforms to these norms.

4.3 Permanent reserved forest

Permanent Reserved Forests (PRFs) have been established throughout Malaysia as a result of the National Forestry Act (1984). Malaysia PRFs manage four categories of forests, i.e., Production Forests, Protection Forests, Education Forests, Reserved and Education Forests, and Amenity Forests [10].

Protection forests are established to ensure favorable climatic and physical conditions in the nation, protect water resources, and maintain soil fertility, environmental quality, and biological diversity of the forests. Production forests are necessary for the nation's economic development and for the nation's agricultural, domestic industries, and export needs. Research and education forests are introduced for forestry education, publicity services, and development to better convey the advantages of forests. Amenity forests are established based on the forest's attractiveness and its natural environment that serve as areas for ecotourism and to stay away from the noise and busy city life.

5. Conclusion

Natural resources on the earth are limited. The proper management of natural resources takes into attention long-term perspective and prevents their exploitation to the hilt for short-term goals. Because the human population is increasing rapidly, the demand for sources will increase day by day. Sustainable management can ensure the equitable distribution of natural sources, therefore, all humans can benefit from the development of those resources.

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Section 2

Environmental Resources Management

Chapter 2

Environmental Education and Community-Based Natural Resource Management in Zambia

Delphine Inonge Milupi, Liberty Mweemba and Kaiko Mubita

Abstract

This chapter analyses the relationship between Environmental Education (EE) and Community-Based Natural Resources Management (CBNRM) in Zambia. It examines the roles that EE could play in the management of natural resources. The chapter begins with the general introduction on CBNRM. It further analyses the concept of Environmental Education by explaining its aims and objectives. The chapter further deliberates on the history of CBNRM as an approach to natural resource management in Africa and Zambia in particular. The chapter concludes by giving an analysis of the roles played by EE in CBNRM in Zambia and recommends the incorporation of EE in the sustainable management of natural resources in the country. Doing so would provide every person with opportunities to acquire the knowledge, values, attitudes, commitment and skills needed to protect and improve the environment.

Keywords: community participation, community resource boards and game management areas, environmental education, rural community development, community-based natural resource management (CBNRM)

1. Introduction

There is a growing interest in rural community development and conservation of natural resources in Africa in recent years that has led to the development of the community-based natural resources management [1]. This is as a consequence of recognised general failures of centralised approaches to natural resources management to arrest lasting losses of biodiversity all over the world during colonial and post-independence periods led to a search for an alternative 'Community-Based Natural Resources Management' (CBNRM). The concept of CBNRM rose specifically to address the objectives of environmental, social, economic as well as social justice. CBNRM has been adopted as a positive approach to the management of natural resources management in many countries. This is because the approach integrates wildlife conservation and rural development goals [2, 3].

The concept of CBNRM rose specifically to address the objectives of environmental, social, economic as well as social justice. CBNRM has been adopted as a positive approach to the management of natural resources management in many countries.

This is because the approach integrates wildlife conservation and rural development goals [2, 4, 5] noted that benefits to natural resource reliant on communities that are closely dependent on wildlife management. The approach according to [5] identifies that local communities could be motivated to embrace sustainable practices to natural resource management. According to the assumption of the foundation of CBNRM, the local communities are interested and willing to adopt and implement conservation programmes so as long as they are legally entitled to ownership of resources and its related benefits [6]. In view of these benefits, CBNRM stresses social fencing as a tool for conserving the natural resources in question and perpetuating the flow of benefits associated with it. In this context, the natural environment is treated as part of the community and perceives the community as part of the landscape. There is gratitude of the interdependence of physical environments with the community. Identifying the interdependence of community well-being and ecosystem health, there is need to strengthen the capacity of communities to have the ability to speak in decisions about planning and design of conservation initiatives affecting them at local level.

The natural environment plays a huge role in supporting peoples' livelihoods, the health and welfare at large and people in turn have faith in their source of income, food and other resources. This is the case for many across the world who live in inaccessible villages with little access to outside markets. They depend on the land to offer them with enough food to feed their families through the year and enough money so that they can meet the expense of medical care, clothing and shelter.

In Zambia, the rural livelihoods depend significantly on the use of wildlife and other natural resources, harvesting forest community and on small-scale agriculture [7]. Further observation by [7] indicates that Zambia is one of Africa's most resource-rich countries with its two-thirds of land area being forested and nearly 40% of the land area being restricted within a network of national parks and forest reserves, as well as co-managed areas that overlap with customary community lands. These resources have to be sustainably managed. The local people who are in direct use of these resources have to be involved in planning and sustained yield practices. One of the most influential strategies to use to engage the local communities in sustainable use of natural resources is through Environmental Education (EE). It is against this background that this chapter emphases on the role of Environmental Education in Community-Based Natural Resource Management in Zambia. This is because the local communities have to be educated about the importance of sustainable management of natural resources in the country.

2. What is environmental education (EE)?

In order to understand how environmental education can be used as a strategy to natural resources management amongst the local communities in Zambia, there is need to clarify the concept. Environmental Education (EE) is a process that allows individuals to discover environmental issues, engage in problem solving and take action to improve the environment. EE refers to organised efforts to teach about how natural environments function and, particularly, how human beings can manage their behaviour and ecosystems in order to live sustainably. EE is sometimes used more broadly to include all efforts to educate the public and other audiences, including print materials, websites, media campaigns, etc. Related disciplines include outdoor education and experiential education [8]. One of the most important definition of EE given by UNESCO states that EE is a process that increases people's knowledge and consciousness about the environment and related challenges, advances the necessary skills and expertise to address the challenges, advances the essential skills and expertise to address the challenges and fosters attitudes, motivations and obligations to make informed decisions and take responsible action [8].

The visibility of environmental problems and amplified awareness of their consequences have made environmental issues prominent in Zambia. At the beginning of the twenty-first century, EE, conservation and management emerged on the global policy stage [9, 10]. Most international declarations and conventions to combat environmental problems call for amplified environmental awareness among the population through EE [11]. Global environmental politics will only be successful if decision-makers are backed by an environmentally aware population. The concept of sustainable development needs to be decisively anchored in people's consciousness in order to effect behavioural change. This calls for EE that is an important tool to eliminate environmentally harmful forms of behaviour and learn how to safeguard the earth [11, 12]. Sound EE consists of learning from personal and conveyed experience in everyday situations (situational orientation), learning in connection with one's own direct action (action orientation) and incorporation of the subject matter into the socio-political context (problem orientation) [12]. Many ecosystems are controlled by human activity, and none is free from human influence [13, 14].

For individuals to worry themselves with environmental issues, they must first be aware that environmental problems occur. Without such awareness, society will not understand the need for change; will tend not to support it and maybe reluctant to participate in the process. The result of the insensible activity of economic systems according to [15, 16] often leads to environmental degradation. Awareness of environmental risks and the importance of responding to reduce or eliminate such risks is crucial to society. Awareness helps in achieving environmental literacy across economic sectors in all regions. The magnitude of environmental degradation or the sense of how environmental problems were becoming worse was not known for many years by most people. This let to continued contribution to the problem by society inadvertently [17]. As a result, society inadvertently continued to contribute to the problem [17]. Environmental literacy achieved through EE which is part of an effective strategy to protect the earth's resources therefore helps us learn from our mistakes [13]. This chapter therefore analyses the links between EE and CBNRM in Zambia. It examines the roles that EE could play in natural resources management.

The concept of Environmental Education can also be made clear through its aims, objectives and principles.

3. Environmental education aims, objectives and principles

Environmental education is a concept incorporating a vision of education that seeks to empower people of all ages to undertake responsibility for creating a sustainable future, an understanding of and concern for stewardship of the environment in its broadest sense and the knowledge to contribute to ecologically sustainable development. The overall goals of EE are to increase people's knowledge about the environment and environmental issues and to influence attitudes and behaviours [18]. The term is often used to indicate education within the school system; however, it is used more broadly to include all effort to educate the public and other audiences, including the print materials, websites, media campaigns and many other efforts used in education.

4. Environmental education aims

The aim of EE according to UNESCO [19] clearly shows the economic, social, political as well as ecological interdependence of the modern world, in which decisions and actions by different countries can have international repercussions. EE therefore helps to spread a sense of responsibility and unity among countries and regions as a base for a new international order which will warranty the conservation and improvement of the environment.

At the grass root level, the main aim of EE is to engage individuals and communities in appreciating the complex nature of the natural and the built environments. In addition, EE aims to accelerate citizens to acquire knowledge, values, attitudes and practical skills to contribute in a responsible and effective way in solving social problems and in the management of the environment.

Therefore, the necessary steps for Environmental Education include:

a. **Awareness:** To help social groups and individuals to acquire knowledge of pollution and environmental degradation.

b. **Knowledge**: To help social groups and individuals to acquire knowledge of the environment beyond the immediate environment.

c. **Attitude building for motivating to protect environment**: To help social groups and individuals to acquire a set of values for environmental protection.

d. **Participation:** To provide social groups and individuals with an opportunity to be actively involved at all levels of environmental decision making.

e. **Skill and capacity building:** To help social groups and individuals to develop skills required for making discriminations in form, shape, sound, touch, habits and habitats. Further, to assist people to develop ability to draw unbiased inferences and conclusions.

4.1 Important outcomes of environmental education

An Effective Environmental Education programme requires the regular use of learner-centred, interactive teaching and learning strategies in various educational systems that may include the informal, formal and non-formal. The outcome of this type of education is the:

a. Clarification of environmental attitudes and commitments and

b. Development of critical thinking skills as well as learning how to work collaboratively to improve human and environmental well-being.

4.2 Main goals of environmental education

UNESCO [19] outlines the goals of EE as follows:

a. Nurture clear awareness of and concern about, economic, social, political and ecological interdependence in urban and rural areas;

b. Provide every person with opportunities to obtain the knowledge, values, attitudes, commitment and skills needed to protect and improve the environment and

c. Generate new patterns of behaviour of individuals, groups and society as a whole towards the environment.

These goals can lead to successful educational process that promotes enhanced awareness, expression of interest and behavioural changes. Positive attitudinal change is one of the most important objectives of education. Next we examine one approach where EE may find relevance.

4.3 Origin of community-based natural resource management (CBNRM)

Global biodiversity is endangered by several factors such as extensive biodiversity loss, over exploitation of species, pollution, invasive species and climate change. Biodiversity loss appears to be severe in the equatorial region of the world where the world's greatest biodiversity and species endemism are intense [20]. In order to prevent biodiversity loss, conservationists have tried finding ways of inhibiting biodiversity loss including the fences-and-fines approach which failed because of excluding the human dimension aspects of wildlife management [21]. This steered the search for a viable and sustainable alternative approach to wildlife management by conservationists [22]. The approach whereby rural communities are given ownership rights, custodianship and management responsibilities for the resource became popular in the 1960s, and it was named BNRM, also called community-based conservation (CBC) [21].

Community-based natural resource management (CBNRM) is an approach to environmental protection in rural areas that attempts to integrate the goals of conservation, sustainable development and community participation [21, 23], further define CBNRM as the management of resources that include forest, land, water as well as wildlife by resource users in order for them to benefit. Projects of CBNRM, particularly in eastern and southern Africa, frequently focus on conservation of wildlife, but in principle the method may be used for management of a range of natural resources [24]. The concept of CBNRM arose and gained popularity in the early 1980s as an alternative to resource regimes that were generally perceived to be failing [25]. The approach has been applied widely in the developing world, including Zambia. As an approach that seeks to achieve both biodiversity conservation and socioeconomic objectives, CBNRM has received much support in the past years because of its attempt to integrate the goals of conservation, sustainable development and community participation [21]. Since then CBNRM has been extensively promoted in recent years as an approach for pursuing biological conservation and socioeconomic objectives.

Nabane and Matzke [22] noted that CBNRM approach gives communities full or partial control over resolutions concerning natural resources, such as water, forests, pastures, communal lands, protected areas and fisheries. The degree of CBNRM control ranges from community consultations to joint management or to full obligation for decision making and benefit collection, using tools such as joint management plans, community management plans, stakeholder consultations and workshops and communal land tenure rights. Community-based institutions are key to any CBNRM project, and selecting and building the capacity of local institutions are critical [22]. The selection process in these local institutions must always try to ensure transparency and accountability and minimise conflict at all cost. Together with decentralisation reforms, CBNRM approach guarantees stakeholder participation, increases sustainability and provides a forum for conflict resolution and as such the approach often leads to more equitable and more sustainable natural resource management than one that does not have stakeholder participation [21].

4.4 Understanding CBNRM

CBNRM approach is based on the idea that if conservation and development can be concurrently achieved, the benefits of both are served [26]. The main objective for CBNRM approach was to create, through the bottom-up participatory approach, conditions whereby a maximum number of community members stand to benefit from a sustainable management and utilisation of wildlife resources [25]. According to a typology by [27], community participation in natural resource management has a variety of approaches that range from passive to active participation (**Table 1**). Community and participation are therefore fundamental concepts underlying the theory of CBNRM. The participation also includes education which promotes active participation of the local communities in managing their natural resource [28]. Participation in CBNRM can take the form of direct democracy, in which all individuals belonging to a community participate themselves, or in the form of representative democracy, in which elected leaders speak for their constituents [29, 30].

In wildlife management, a combination of active form of participation which includes functional participation, interactive participation as well as self-mobilisation

Type of participation	Description
1. Passive participation	People being told what is going to happen or has already happened. Unilateral announcement without any listening to people's responses. The information being shared belong only to external professionals
2. Participation in information giving	People answering questions; questionnaire surveys or similar approaches. People do not have the opportunities to influence proceedings; findings are neither shared checked for accuracy.
3. Participation by consultation	People are being consulted and external agents listen to views. External agents define both problems and solutions; may modify these in the light of the people's responses. Does not concede any share in in decision making; professionals are under no obligations.
4. Participation for material incentives	People provide resources for example labour in return for food, cash or other material incentives. Much in –situ research and bio prospecting falls in this category
5. Functional participation	People form groups to meet predetermined objectives; can involve the development of externally initiated committees, etc. Does not tend to be at early stages of project cycles or planning; rather, it occurs after major decisions have been made. Initially dependent upon external initiators and facilitators; may become self- dependent.
6. Interactive participation	Joint analysis leading to action plans and the formation of new local groups or the strengthening of the existing ones. Involves interdisplinary methodologies, multiple perspectives and learning processes. Groups take control over local decisions; people have a stake in maintaining structures.
7. Self-mobilisation	Initiatives taken independently of external institutions. May challenge existing inequitable distributions.

Source: Adapted from [27].

Table 1.
Showing typology of participation.

and passive participation (participation for material incentives, participation by consultation and participation in information giving and passive participation) is encouraged. Active participation involves all stakeholders in decision making process at all the stages of the project, whereas passive participation does not [29]. In passive participation people participate by being told what is going to happen or has already happened [31]. The active participation of stakeholders in natural resource decision-making and use increases economic and environmental benefits and, therefore, leads to a sustainable management of natural resources.

4.5 Community-based natural resources management in Zambia

In Zambia, CBNRM programme was introduced by the Zambian Government in 1987, and it comprised wildlife in game management areas and National Parks [32]. The idea was to improve the livelihood of local people in rural communities living in national parks and game management areas and also to create awareness in the local communities regarding the importance of conserving wildlife resources [33]. The CBNRM initiative in Zambia was initiated in Lupande Game Management Area (LGMA) under the project called Lupande Integrated Resource Development Project (LIRDP). There are 35 Game Management Areas (GMAs) and 20 national parks in Zambia (**Figure 1**), representing 30% of the total territory of protected areas. National parks are intended for the protection and enhancement of wildlife, ecosystems and biodiversity [34]. No human settlements are allowed in the national park, only photographic safaris, also known as non-consumptive wildlife use, are allowed.

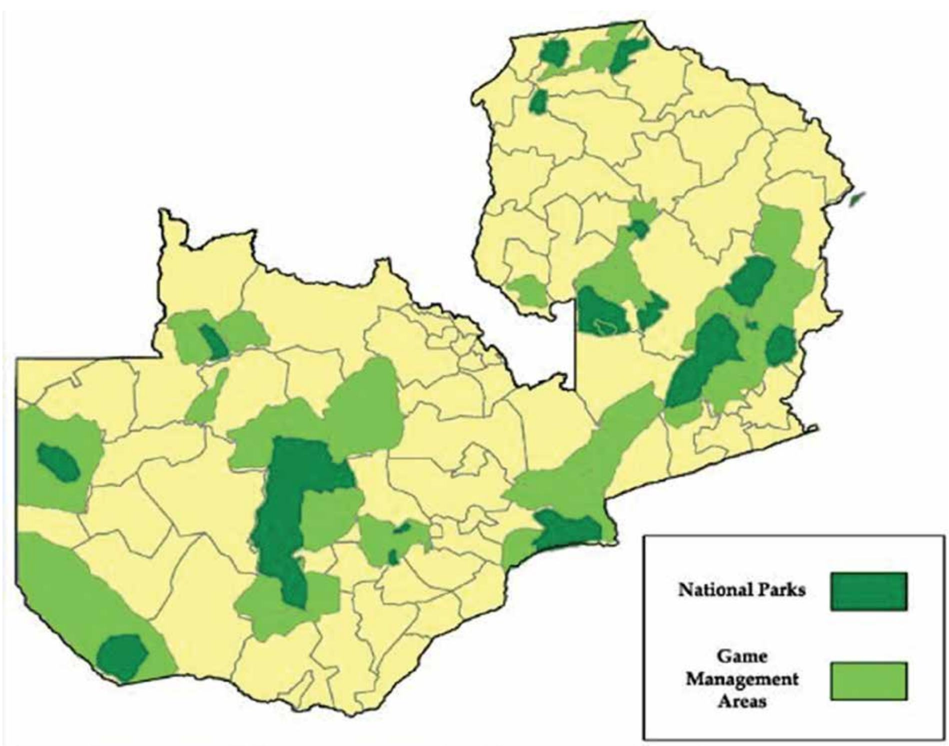

Figure 1.
National Parks and Game Management Areas of Zambia. Source: Adapted from [34].

GMAs act as buffer zones between the national parks and farming areas [30]). GMAs are intended to promote sustainable harvest of wildlife through hunting as an alternative to other economic activities not compatible with wildlife protection. GMAs also offer wildlife viewing but allow human settlements and licensed hunting (consumptive wildlife use). The LIRDP project promoted the sustainable use of fisheries, water, wildlife, forestry and agriculture. Later on, the initiative evolved into Administration Management Design (ADMADE) that was replicated in other GMAs [35], and today a total of 63 Community Resource Boards (CRBs) have been formed country-wide [36]. The CRBs are a form of co-management model currently active in the wildlife sector in Zambia where local communities have been given opportunity to actively participate in and benefit from natural resource management [37].

4.6 The role of environmental education in CBNRM

Community participation is one of the key principles of CBNRM. This, therefore, confirms that participation of local resource users in the management of their resources could lead to sustainable management of natural resources [30]. In Zambia however, a large proportion of community participation in wildlife resource management lacks necessary knowledge and understanding of the world [38]. Some scholars such as [38] suggested the need to purposefully put in place a new, open, transparent and robust participatory approach called 'EE in CBNRM' in the GMAs so as to improve capacity building available in rural areas. The introduction of EE in natural resource management according to [38] would improve the nature of participation currently prevailing in the natural resource programme which lacks the necessary tools of understanding the world.

The introduction of EE would further enhance positive community participation in wildlife resource management in the GMAs. This is because EE is a vision of knowledge that allows community participants in natural resource management to have sufficient knowledge that will allow them to contribute to the sustainable management of natural resources. Furthermore, EE promotes behavioural change in learners by motivating people to act in a responsible way that does not exploit the resource base. In other words, EE helps to create a sense of empathy for the environment [38].

The introduction of EE in wildlife resource management in the GMA would also enable the local community to have a broader and a more complete understanding of reality. EE would also help decrease uncertainty and unlikelihood of unpremeditated consequences [38]. Finally, the incorporation of EE in Zambia would further strengthen the weak CBNRM of wildlife resources being experienced in the country and reduce loss of biodiversity experienced in most areas of the country [39]. This is because the main objective of EE is to help individuals acquire the knowledge, values, attitudes and practical skills that will assist them to participate in a responsible and effective way in solving social problems, as well as in the management of the environment. Hence, individuals and communities would appreciate complex nature and the built environment.

5. Conclusion

The above account demonstrates a link between EE and CBNRM in that while EE on the one hand aims to raise environmental awareness among human populations and to provide opportunities to acquire the knowledge, values, attitudes and skills needed to protect the environment, CBNRM on the other hand is expected to provide a scientific basis about environmental management decisions. This is because EE is a disseminator of ecological concepts [40]. EE plays an important role in natural resource management as it is a facilitator of the use of ecological knowledge that could promote sustainable utilisation of natural resources. People's preferences for action and their social and cognitive features must be considered for the successful environmental policies that activate action on environmental degradation. Worldwide environmental politics will therefore only fulfil its tasks if policy-makers in different nations are sustained by a population whose environmental awareness and willingness to behave in an environmentally appropriate manner permits them to demand solutions to global environmental problems.

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Chapter 3

Phosphate Solubilizing Rhizobacteria as Sustainable Management Strategy in Agrobiology

Aqsa Tariq and Ambreen Ahmed

Abstract

Phosphorous limits agricultural productivity due to its limited plant availability. Use of synthetic phosphate fertilizers disturbs soil fertility and ecosystem ecology as it contaminates environment. Plants have developed certain mechanisms to respond to P-scarcity, which involve release of specific chemical messengers through root exudates that attract rhizospheric phosphorbacteria to colonize plant root vicinity. Thus, use of phosphate-solubilizing bacteria/rhizobacteria (PSB/PSR) as biofertilizers is a safer approach toward sustainable agrobiology. These PSR are capable of solubilizing soil phosphate from insoluble to plant available form. Due to instability and slow movement of available phosphates in soils, they readily get incorporated with soil particles or chelates as metal complexes. In this scenario, PSR provide continuous chain of soluble phosphate to plants. PSR direct plant root system architecture toward available phosphate zones in soils. Moreover, there is an increased number of roots, root hair and lateral root, increase root absorbing surface area by increasing contact to soil particles. Hence, PSR-based root system morphology is a significant trait in measuring their agronomic efficiency. Moreover, PSB also possess phytostimulatory properties that significantly contribute to agricultural efficiency. Hence, the use of phosphate-solubilizing bacteria can improve crop productivity by increasing soil P-mobility and soil fertility.

Keywords: biofertilizers, phosphate solubilizing rhizobacteria, inorganic phosphorus, plant growth promotion, agrobiology

1. Introduction

Global food security greatly depends on soil fertility and agricultural sustainability. Most of the soils with high sorption capacity have finite phosphorous (P) resources which is far away from meeting the agricultural P demand, thereby, limiting agricultural fertility and productivity [1]. On the average, 0.05% (w/w) phosphorous is present in agricultural soils out of which only 0.1% is available to plants. Mostly inorganic phosphates (Pi) are present in higher concentrations but due to highly reactive nature of P-anions, it readily gets immobilized via complex formation with various mineral cations (Fe_3^+, Mg_2^+, Ca_2^+, and Al_3^+) [2]. Hence, application of animal manure in traditional farming technique solves P-deficiency problems to some extend but this leads towards an unbalance ratio between various nutrients especially nitrogen and phosphorous in relation to relative crop demand and results in overfertilization [1]. Lower plant accessible P-concentrations and higher immobility in soils make it an essential mineral needed to be applied exogenously in the form of fertilizers. Therefore, conventional agricultural practices rely on high input of chemical fertilizers to boost crop productivity. Among various fertilizers, phosphate fertilizers are the major contributor to environmental contamination. Concentration of various metals in potassium and nitrogen fertilizers is significantly low as compared to phosphate fertilizers therefore, these are not regarded as serious threat to soil and environmental [3]. On the other hand, phosphate fertilizers contain traces of various metals including heavy metals i.e., cadmium (Cd), lead (Pb), arsenic (As), strontium (Sr), chromium (Cr), zinc (Zn) and radioactive metals such as thorium (Th), uranium (U), radium (Ra) etc. [4]. Consumption of such crops deteriorate our ecosystem by accumulating in agricultural soils and becoming part of food chain. Moreover, soil erosion facilitates the entry of P in waterbodies where it causes uncontrolled growth of algal blooms, deplete oxygen and cause risk to aquatic life. Even very low P- concentrations (10–20 μgPL^{-1}) can support luxurious growth of algal bloom. In addition, drinking highly eutrophicated water adversely affects human health [4].

Rock phosphate is the naturally occurring source of phosphate used for the manufacturing of various phosphate (P) fertilizers such as triple superphosphate (TSP), monoammonium phosphate (MAP), diammonium phosphate (DAP), and NPK mixtures [5]. Apatite, basic constituent of phosphate rock, is incorporated with various metals and radionuclides which later become distributed in environment by the application and formation of these fertilizers. Sometimes, besides commercially available P- fertilizers, its by-product phosphogypsum (PG) is also used to fertilize agricultural lands having potential environmental risk [6]. This uneven distribution of various metals in soil adversely affects its physiological properties which, in turn, affect nutrient availability to plants. This, in the longer run, reduces soil biodiversity and fertility by disrupting soil microbiota as these are very sensitive to environmental variations. The soil microorganisms play crucial role in regulating soil fertility as they are involved in nutrient cycling (particularly P- cycle) hence, maintaining plant health and crop productivity. Hence, keeping in view all the agrobiologically and environmental sustainability concerns, a greener and cleaner approach should be needed to compete this challenge. In this regards, utilization of phosphate solubilizing microbes (PSM) is the best possible solution. Phosphorous solubilization capacity of soil microbes have been extensively studied from the perspective of their utilization in agro-ecosystems and development of biological fertilizers. For this purpose, molecular prospects of bacterial transformation of organic phosphates through various mechanisms have received a great deal of attention. First ever report on plant growth improvement via. Inoculation using phosphate solubilizing microorganisms was published in 1948. Since then, after so many decades, there is no general agreement among the scientific communities on the benefits of these microbes in crop production, hence, their use is still limited. The current chapter summarizes the agricultural accountability and significance of phosphate solubilizing rhizobacteria (PSR) and the strategies acquired by these microscopic creatures to solubilize phosphate and the genetic aspects for better understanding of phosphate mineralizing mechanisms. This would lead scientific community to understand their nature that would be beneficial for the development of commercially available formulations used in agriculture.

2. Soil phosphorous dynamics and accessibility

Phosphorous is an important macronutrient constituting about 0.2–0.8% of plant dry weight [7]. Phosphorus is crucial in various plant metabolic processes including energy generation and transformation during developmental processes such as germination, flowering, root expansion, photosynthetic activities, nitrogen fixation, carbohydrate metabolism, enzymatic activities etc. In addition, it is integral part of various structural and functional macromolecules such as adenosine triphosphate, proteins, nucleic acids, lipoproteins etc. [8]. In soil, phosphorous is present in two basic chemical forms i.e., organic (P_o) and inorganic forms (Pi). Primary sources of inorganic phosphates include stable P minerals such as apatite ($Ca_5[PO_4]_3(OH,F,Cl)$), variscite ($AlPO_4\ 2H_2O$) and strengite ($FePO_4\ 2H_2O$). These minerals have P structural element and are very stable and considered as huge P- reservoirs existing naturally in soils. However, the phosphate liberation from these minerals is a gradual process, regulated particularly by soil pH [9]. Optimum pH for P availability to plants is 5.5–7. At high or low pHs', it forms chelates and become unavailable for plants [10, 11]. Under acidic conditions, adsorption of P on Fe and Al oxides and hydroxides (gibbsite and goethite) is increased. On the other hand, in alkaline conditions, Ca serves as primary P precipitated site. P can also readily bound with soil particles or adsorbed with cations to form complexes such as aluminum phosphate ($AlPO_4$), iron phosphate ($FePO_4$), and calcium phosphate ($Ca_3(PO_4)_2$) etc. These secondary sources of Pi are the major phosphorus sources for young plants [12, 13].

In addition, compounds originated mainly from soil organic matter (plant and animal residues and manure) are the source of organic phosphates. They include wide range of compounds varying in terms of their bioavailability and solubility. These compounds are categorized as various phosphate esters such as phospholipids, sugar phosphates, inositol phosphates, nucleic acids; phosphonatases such as C–P bonded compounds; and phosphoric acid anhydrides (adenosine di- and tri- phosphates) [14, 15]. Important organic source of P is soil microorganisms. Soil microbes have potential to inlock soil phosphorous by absorbing and incorporating in their cellular structures such as nucleic acids, coenzymes) or stored as polyphosphates which temporarily act as immobilized P-pool. This temporarily locked P can later be released into soil solutions through mineralization process [16]. Rhizobacteria accumulate polyphosphates or polymers of phosphoric acids under unfavorable conditions which serves as P-reserves within bacterial cells. These P-reserves are considered as high energy reserves providing anhydrides and can easily be used as energy source by releasing Pi [17]. Various enzymes are involved in consumption and degradation of accumulated polyphosphates. Poly P kinase catalyzes the synthesis of polyphosphates within microbes. Similarly, polypases (exopolypase (PPX)) and polyphosphate-specific kinases (polyP-fructokinase and polyP-glucokinase) are involved in phosphate utilization and degradation [9]. Bacterially mediated P-cycling process releases accumulated phosphorous back to the soil. However, the P- liberation from biomass is highly dependent on available soil carbon and phosphorous and composition of microbial communities [18, 19]. P_o constitute almost 30–65% of the soil out of which 3–14% become immobilized into soil microbial biomass [20]. Plant roots can efficiently uptake Orthophosphates ($H_2PO_4^-/HPO_4^{2-}$) but due to its weak stability and highly reactive nature, it loses its efficiency and becomes yield limiting factor in most of the agricultural soils [21, 22]. In addition to the microbial, plant and animal residues, a large quantity of xenobiotics (detergents, pesticides, antibiotics etc.) released in the environment also serves as source of organic P. These high molecular weight organic compounds are resistant to chemical hydrolysis or biological degradation, thereby, the locked P within them is useless for plants unless converted to Pi or orthophosphates. However, some PSR studied have ability to degrade such complex compounds and release P from these sources [23].

Strong P- fixing capacity of soils and immobilization of soil P pool via precipitation, chelation or complex formation causes P scarcity in soils. Despite all these factors, P availability is generally a balanced process including desorption and adsorption mechanisms. Various rhizospheric phenomena particularly biological processes play critical role in soil P dynamics and its availability to plants. Both plants and rhizospheric biota contribute to bioavailability of P at root-soil interference by regulating specific signaling molecules such as release of H^+, chelation and ligand exchange etc. All these rhizospheric activities contribute to P-cycling process to improve P availability in agricultural soils [24].

3. Plant starvation responses

Plants uptake P- through roots by simple diffusion. The absorbed P- ions actively move across the plasmalemma against concentration gradient developed by existence of low orthophosphates. Plant response vary greatly from species to species in P-deficiency response. Generally, plants cannot respond and absorb soil P efficiently (plant P uptake rate: 10–12 to 10–15 m^2s^{-1}) due to its low mobility. This causes the formation of phosphate depleted areas adjacent to plant roots. Therefore, plants need subsidiary system that can help plants to receive optimum P requirement by developing nutrient pool around the plant roots [25]. Plants have developed generally various physiological, biochemical and morphological adaptations to respond P- scarcity and to endeavor P acquisition efficiency. These genetic modifications acquire by plants can be categorized as plant P- acquisition efficiency: capacity to absorb soluble P and P-utilization efficiency: capacity to utilize and assimilate the absorbed P. These include high expression of P transporters, carbon metabolism, secretion of various organic acids such as oxalate, citrate and malate), modification in root architecture, enhanced production of acid phosphatases and phytases. Modifications in root architecture is foremost response substantially studied in plants [26, 27]. A preferential allocations metabolic budget towards roots undoubtedly results in greater root hair formation and clustering of roots, providing greater surface area for P absorption but, on the other hand, it decreases root to shoot ratio resulting in reduced plant growth. However, greater root system allows plants for greater and easier nutrient acquisition [28]. Besides modifications in root architecture, root signaling is also significantly important parameter affecting P- acquisition efficiency. Under P-scarcity, release of organic acids by plant roots help to solubilize the nearby immobilized P-pool. Moreover, plants also release P- scavenging enzymes that also help in soil P- cycling mechanism. For instance, release of acid phosphatase catalyzes Pi hydrolysis process to release Pi from P_o residues [29]. In addition, plants enhance cellular P utilization efficiency by increasing activity of high affinity Pi/H^+ symporters (PHT1 gene family) associated with plasma membranes [30, 31]. Plants also regulate alternate metabolic pathways e.g., glycolysis pathways, tonoplast pyrophosphatase, and various respiratory electron transport pathways [32]. Despite of all these modifications in plants for improved P acquisition efficiency under P stress conditions, plants still are unable to full fil their P- demand, therefore, plants tend to establish symbiotic interactions with soil microbiota especially rhizobacteria to cope up with P- scarcity.

4. Phosphate solubilizing rhizobacteria (PSR): biological revolution

Rhizosphere is hotspot for various plant beneficial bacteria with potential to solubilize immobilized P sources (di- and tricalcium phosphates, hydroxyapatite, and rock phosphate). These rhizobacteria are known as phosphate solubilizing rhizobacteria (PSR). PSR are copious in nature. Various rhizobacteria belonging to genera *Paraburkholderia*, *Ralstonia*, *Burkholderia*, *Curtobacterium*, *Arthrobacter*, *Cronobacter*, *Massilia*, *Pseudomonas*, *Enterobacter*, *Bacillus*, *Serratia*, *Pantoea*, *Rhizobium*, *Klebsiella*, *Ochrobactrum*, *Staphylococcus*, *Arthrobacter*, *Acinetobacter* have phosphate solubilizing potential [33–40]. Visualizing the formation of clear halo zones around bacterial colonies on various phosphate media indicates their phosphate solubilizing ability. Quantitative analysis of P-solubilizing potential of PSR using rock phosphates (RP) and various Al-, Ca- and Fe- complexes revealed their efficiency to mobilize soil Phosphate for plant use. However, the extent to solubilize phosphorous is highly dependent on bacterial species. Agronomic efficiency of RP significantly increased using suitable PSR. This improvement is attributed to the positive effects of PSR on soil P-availability [20]. These microbes play significant role in P acquisition and nutrient management in soils and hence, serve as potential biofertilizers [41]. In addition, PSR exhibit diverse abilities and exert synergistic effect on plant growth and development besides solubilizing soil phosphate. They enhance plant growth by various plant growth promoting mechanisms including production of plant growth stimulating phytohormones such as auxins, gibberellins, cytokinins and various compounds such as siderophores, 1-aminocyclopropane-1-carboxylate (ACC) lytic enzymes, hydrogen cyanide (HCN), exopolysaccharides that lock up soil nutrients for plant availability and protect them from various unfavorable conditions [42]. Moreover, PSR also act as biocontrol agents protecting plants from pathogenic attacks by producing wide variety of antifungal compounds including certain phenolics and flavonoids [43]. The phosphate solubilization mechanisms are summarized in **Figure 1**.

4.1 Unearthing the mechanisms of P-solubilization: molecular insight

a. Inorganic phosphate solubilization

Principle mechanism of inorganic phosphate solubilization acquired by PSR is release of mineral dissolving compounds such as protons (H^+), siderophores, organic acids (OAs), carbon dioxide (CO_2) and hydroxyl ions (OH^-). Production of low molecular weight organic acids is common mechanism shared by PSR. Rhizobacteria produce these organic acids either during carbon metabolism through intercellular phosphorylation or through direct oxidation of glucose to gluconic acid and sometimes to 2-ketogluconic acid via quinoprotein glucose dehydrogenase (GDH), an enzyme involved in direct oxidation pathway in periplasmic space [44]. Pyrrolo quinoline quinine (PQQ) (product of pqq) acts as a cofactor which is essential for the activity of GDH. These organic acids lower down soil pH. Under alkaline conditions, soil P precipitates as Ca^{2+} phosphates and its solubility increase with decreasing soil pH. Increase in soil pH causes the formation of di- and tri- Pi (PO_4^{3-} and HPO_4^{2-}) [45]. The production of organic acids acidifies the surroundings and cellular environment by liberating H^+ in the vicinity of plants which regulates the accumulation of other cations that directs to P solubilization by substitution of H^+ for Ca^{2+}. For instance, assimilation of NH_4^+ along with H^+ causes P solubilization [46]. Moreover, there is no evidence of a correlation between pH and solubilized P [47]. The P- solubilizing efficiency of

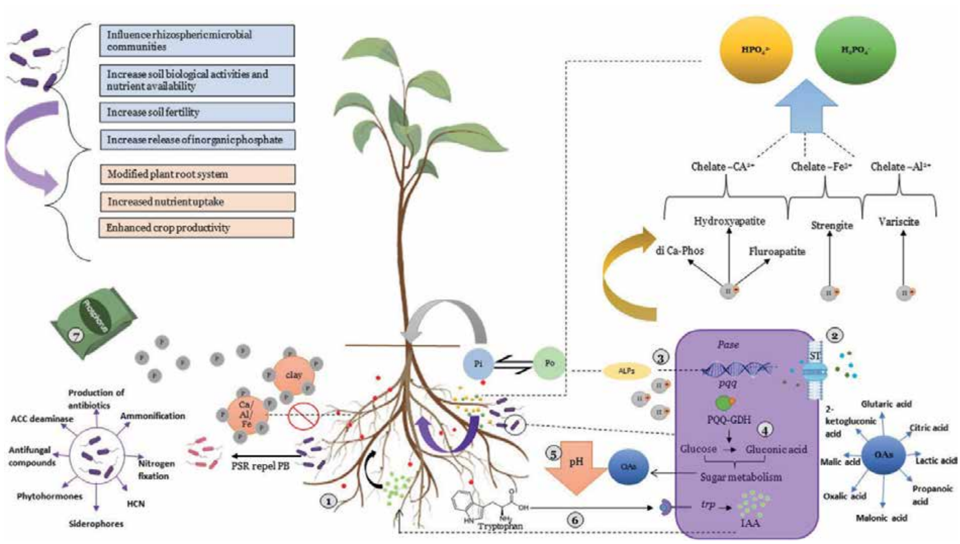

Figure 1.
Rhizospheric interactions between PSR and plants and their impact on plant growth. 1- Plant releases certain chemical messengers ( ) that attract beneficial PSR which in turn colonize plant roots and fight off pathogenic bacteria (PB). 2- Bacteria receive sugar chemical messengers (-glucose, -fructose) by sugar transporters (ST) which activate synthesis of phosphatases (Pase). 3- Synthesis of ALPs solubilize organic phosphate to inorganic phosphate that can be taken up by plants. Moreover, accumulation of H+ on bacterial surface also facilitates P-solubilization process by releasing Pi from various soil minerals. 4- Chemical messengers also activate pqq involved in sugar metabolism as a result of which it forms various organic acids (OAs). 5- Synthesized OAs lower soil pH which favors P-solubilization by PSR. 6- PSR also utilizes tryptophan released in root exudates to synthesize bacterial Indole acetic acid (IAA) that is released in the vicinity of plant roots and taken up by plants. 7- Pi present in phosphate fertilizers interacts with soil particles and form chelates before it is taken up by plants thus minimizing the advantage taken by the plants from the application of phosphate fertilizers.

PSR greatly depends on the strength and type of acid production. Variable nature of OAs leads them to respond differently. For example, di- and tri forms of carboxylic acids are more efficient as compared to monobasic or aromatic acids. In the same way. Aliphatic acids are more efficient as compared to fumaric, phenolic, or citric acids [48]. Moreover, the quantity of OAs produced is correlated to the concentration of soluble P. Hence, OAs production in P-deficit soils is greater as compared to the P- sufficient soils [49]. OAs produced by majority of PSR are glutaric, citric, propionic, lactic, glyoxalic, malonic, glicolic, 2-ketogluconic, oxalic acid, glyconic acid, acetic acid, malic acid, fumaric acid, succinic acid, tartaric acid, butyric acid, and adipic acids [50]. Among these OAs, gluconic and 2-ketogluconic acid are most commonly produced OAs. Gram-negative bacteria oxidize glucose to gluconic acids for mineral P- solubilization. Gluconic acids chelate the cations bounded with phosphate via OH^- or carboxyl (–COOH) groups making phosphate accessible to plants [51]. Pyrroloquinoline quinone-dependent periplasmic glucose dehydrogenase (PQQ-GDH), is responsible for the production of gluconic acid from glucose. PQQ-GDH is also responsible to produce gluconic acid. In most of the Gram-negative bacterial species, biosynthesis of PQQ is regulated by five genes comprising pqq operon (pqqA-BCDE) [52]. Until now, 11 pqq genes have discovered so far in various bacterial genera, however, pqqF and pqqG existing at proximal or distil end of operon are commonly found [53]. Various PSR genera exhibit this mechanism including *Pseudomonas*, *Enterobacter*, *Acinetobacter*, *Pantoea*, *Klebsiella*, *Rahnella*, *Serratia*, *Erwinia*, *Citrobacter*, *Burkholderia* and *Gluconobacter* [54, 55]. Another P-solubilizing mechanism acquired by some PSR is release of H^+ microbes which release H^+ at their surfaces helping cation exchange via H^+ translocation or ATPase leading to the release of P from inorganic minerals (Ca-P) [9]. Production of chelating compounds and inorganic acid by some bacteria is also source of mineral P solubilization, however, effectiveness of these compounds is very less compared to other mechanisms of P-solubilization [43].

b. Organic phosphate mineralization

Mineralization of organophosphates highly depends on the environmental conditions. Alkaline conditions favor this process. Phosphate decomposition by PSR from organic substances is correlated with P- content of their biomass. This biological event plays an important role in solubilization of organic P and regulating P-cycling events in nature. These phosphate solubilizing bacteria secrete various enzymes responsible for organic P mineralization. Among these enzymes, phosphatases and phytases are important. Phosphatases (phosphohydrolases) belonging to the class phosphomonoesterases, dephosphorylate phosphoester or phosphoanhydride bonds present in organic compounds [56]. They can either be alkaline or acidic phosphomonoesterases (ALPs), however, acidic phosphatases are important and play significant role in decomposition having optimum catalytic activity. ALPs can mineralize up to 90% of organophosphatases, however, phytate is resistant to them [57]. The key ALPs encoding gene found in phosphorbacteria is *pho* (phoX, phoA, and phoD). Among these phoD is widely distributed among various PSR. However, phoD abundance has shown no correlation with the P-availability. phoD can mineralize phosphate even under low concentrations but causes immobilization of P in bacterial biomass under application of P fertilizers [58]. ALPs are categorized as specific acid phosphatases (SAP) and non-specific acid phosphatases (NSAP). Examples of SAP with different activites are: nucleotidases, hexose phosphatases, and phytases [59]. Several bacterial species have been known for their potential to produce phosphatases such as Pseudomonas sp., *Klebsiella aerogenes*, *Burkholderia cepacia*, *Enterobacter cloacae*, *Pseudomonas fluorescens*, *Enterobacter aerogenes*, *Proteus mirabalis*, *Citrobacter freundi*, and *Serratia marcenscens* [9].

The enzyme phytase is responsible for releasing phosphorous locked in soil organic compounds such as seeds or pollens that were stored as phytate (inositol polyphosphate). Phytates are great source of phosphorous containing 60–80% of soil P. Phytates contain strong and stable ester bonds that can easily be hydrolyzed by PSR. They completely hydrolyzed phytates to lower molecular weight isomers of inositol polyphosphate and inorganic phosphates [60]. Several phosphorbacteria have been known for having their potential to produce phytases such as *Bacillus*, *Pseudomonas*, *Enterobacter*, *Pantoea*, and *Escherichia coli* [61, 62]. Four types of phytases identified so far from PSR are: β-propeller phytase (BPP; alkaline phytases), histidine acid phosphatase (HAP; acid phytases), protein tyrosine phytase (PTP; cysteine phytase) and purple acid phosphates (PAP; metalloenzyme) [63]. Acidic nature of these enzymes enhances their efficiency under various pH conditions. Some rhizospheric P- solubilizing *Bacillus* and *Streptomyces* also tend to produce phosphoesterases, phosphodiesterases and phospholipases to mineralize organophosphates [64].

4.2 Impact of exogenous P on phosphobacterial activities.

Soil phosphorous status directly influences plant metabolic activities, root exudates and carbon availability for rhizospheric microbes. Low soil P levels causes plants to activate P- stress responsive mechanisms involving various transcriptional and physiological changes that indirectly affect its associated rhizobacterial communities [65, 66]. P- fertilizers are the yield limiting determinants of soil fertility which influence by disturbing soil nutrient equilibrium. The aggressive use of these fertilizers affects nutrient availability for biological processes and plant uptake [67]. Application of P- fertilizer significantly changes phosphorous turnover efficiency by recruiting rhizobacterial families and regulating bacterial genes involved in P cycling [68, 69]. P-fertilizers can shift soil microbial communities affecting soil biodiversity [70]. Environmental phosphate affects all the phenomena of inorganic P- solubilization, organic P mineralization, P-uptake and transport and plant responses. Phosphorbacteria respond differently to available phosphate conditions. Shifting of various phosphorbacteria in response to P fertilizer indicates their P- availability based selection criteria. Some bacteria such as Actinobacteria prefer high P areas whereas *Moraxellaceae* and *Pseudomonadaceae* prefer low phosphate soils. Similarly, bacterial genera *Bacillus*, *Clostrodium* and *Alicyclobacillus* have shown negative correlation with soil P-content [71]. Moreover, besides affecting rhizospheric bacterial taxonomy, soil nutrient also affects bacterial potential to solubilize immobilized phosphate. *Burkholderia* and *Collimonas* exhibit nutrient poor soils having efficiency for mineral decomposition to fulfill their nutritional demand [72]. *Burkholderia* is described as low phosphate responsive taxon. It is abundantly present in P deficient soils where it switches its interactions with plants i.e., commensal to opportunistic and utilize the stored inorganic shoot phosphate [73]. Nutrient acquisition ability of phosphate solubilizing bacteria makes them more competitive in nutrient poor soils [73].

Soil P-status leads to the upregulation of various P-solubilizing enzymes. Expression of gene (gcd) responsible for glucose dehydrogenase synthesis is suppressed under greater soil P levels through feedback mechanism. Moreover, plants growing under P-deficit conditions release certain signals through root exudates that influence P-solubilizing activity of PSR. The expression of pqq genes is increased by detecting root signals of plant growing under P-deficient conditions [74]. Moreover, the production of phosphatases is regulated by the availability of nitrogen and phosphorous. In the presence of sufficient nitrogen, their production is enhanced. On the other hand, phosphorous supply decreases their production [75]. This negative feedback creates strong correlation between exogenous P and phosphatases to increase P mineralization. Similarly, inorganic phosphate supply reduces the activity of phoD [76]. Under acidic conditions activity of acidic phosphatases and abundance of phoC are negatively correlated with P availability, whereas exogenous P- supply exceeds no significant effect on abundance and activity of alkaline phosphatases [77]. In some cases, long term P- fertilization causes bacterial dormancy leading to inactivation of bacterial P-solubilizing potential [74]. However, there are some controversies in bacterial response to available phosphorous. Sometimes PSR show no response to P-fertilization and the composition of soil bacterial communities remain uninterrupted [78]. Moreover, shift in bacterial communities in response to exogenous P supply is controlled by various biotic and abiotic factors such as nutrient level, drought, pH etc. hence, it is considered that rhizospheric microbial communities are initially determined by soil conditions, then scrutinized by root exudates and finally shaped by alterations in soil physiology [79].

5. Agronomic efficiency of phosphobacteria

Various plant traits have been extensively studied to develop an agronomic framework for the evaluation of PSR effects on crop yield parameters. These traits serve as applicable indicators for evaluating the efficiency and potential of phosphorbacterial biofertilizers in agricultural fields (**Table 1**).

5.1 Plant-phosphobacterial interactions

Various plant physiological activities are involved in efficient use of soil phosphorous. Release of ions, organic acids and enzymes through root exudates favors plant, to recruit microbial communities especially PSR beneficial for their growth [88]. Soil microbes have affiliation with C-containing compounds, target plant root exudates and response chemotactically to plant chemical messengers. Several rhizobacteria especially phosphate solubilizing bacteria prefer to occupy the plant root zones. For instance, *Oceanobacillus*, *Massilia*, *Arthrobacter*, *Lactococcus* and *Bacillus* are recruited in the vicinity of wheat root zone to get benefit from organic acids released in the form of root exudated [89]. Similarly, some phosphorbacteria such as *Bacillus* sp. enhance root colonization in response to plant secreted organic acids. Plant root exudates activate root colonizing genes present in phophobacteria. This, in turn, significant in establishing plant-PSR interactions which is crucial in P-acquisition by plants [90, 91].

Phosphate solubilizing bacterial strains	Expected mechanism	Experimental Plant	Agronomic efficiency	References
Bacillus, *Pseudomonas*, *Massilia*, *Citrobacter*, *Arthrobacter* and *Acinetobacter*	Presence of P cycling related genes (gcd, bpp)	Chinese cabbage (*Brassica rapa*)	Increased plant fresh weight, dry weight, and plant height	[80]
Phosphate solubilizing bacteria (PSB)	Enhanced soil P content	Kasumbha (*Carthamus tinctorius*)	Increased number of leaves per plant, leaf area, number of seeds per capitulum, increased plant height, number of branches, number of capitulum per plant, seed oil and phenolic content	[81]
Bacillus siamensis, Rahnella aceris, Pantoea hericii, Bacillus paramycoides (Single and consortium)	Phosphate hydrolyzing enzymes (acid phosphatase and pyrophosphatase) and organic acids (glycolic acid)	Wheat (*Triticum aestivum*)	Modified root architecture (enhanced root hairs length, root length, root inorganic P content, plant biomass plant organic phosphate content, P translocation and soil phosphatases	[82]
Bacillus thuringiensis and *Pantoea ananatis*	Decreased soil Pb phytoavailability through dissolution of insoluble inorganic P and increase water-soluble phosphate concentrations	*Lactuca sativa* L.	Promoted plant growth and reduced shoot Pb concentrations	[22]

Phosphate solubilizing bacterial strains	Expected mechanism	Experimental Plant	Agronomic efficiency	References
Pseudomonas sp. (UC_1), *Klebsiella* sp. (UC_M), *Burkholderia* sp. (UC_J), *Chryseobacterium* sp. (UC_3)	Regulation of soil microbial communities	*Ulmus chenmoui*	Improved plant growth	[83]
Enterobacter sp. (J49) *Serratia* sp. (S119)	Interactions of P solubilizing activity and plant root exudation causes increased pectinase and cellulase activities	Soybean (*Glycine max*) and maize (*Zea mays*)	Improved plant growth	[84]
Bacillus mojavensis (B1), *Bacillus megaterium* (B2)	Enhanced soil P-solubilization	Sugarcane (*Saccharum officinarum*)	Increased yielding components such as increased stem height, internode, weight and diameter	[85]
Burkholderia sp. (N3)	Interactions with plant immune system by upregulating 129 genes and downregulating 33 genes involved in plant resistance against pathogen	Melon	Enhanced plant height, dry weight, leaf area, and uptake of nutrients of melon seedlings increased and suppression of bacterial fruit blotch in melon	[86]
Pseudomonas mallei, *Pseudomonas cepaceae* (Consortium)	Promotes soil biological activities, nutrient availability, enhanced productivity of calcareous soils	*Phaseolus vulgaris*	Increased fresh and dry weight of pods and seeds per plant, increases shoot fresh weight per plant, shoot dry weight per plant	[87]

Table 1.
Phosphate solubilizing rhizobacterial efficiency in agriculture.

5.2 PSR mediated regulation of phosphate related genes in plants

Phosphate solubilizing bacteria can either directly or indirectly trigger the expression genes responsible for Pi movement. These PSR regulate the expression of P transporters either by modulating the expression of plant metabolic genes (pheromone producing genes) or sometimes by increased P-supply in the vicinity of plant roots. Plants have two types of phosphate transporters (PHT) for the regulation of intracellular optimum phosphate concentrations. The high affinity transporter (PHT1) activates in roots whereas, low affinity transporter (PHT2) is responsible for Pi transfer in shoots, flowers, leaves etc. [92]. Phosphorbacteria regulate various phosphate related genes within plants in response to environmental conditions especially during low P supply. Plants growing in P deficit soils have shown upregulation of PHT1. The PSR *Pseudomonas putida* increased the expression of AT5G43350 gene responsible of the production of PHT1 in *Arabidopsis thaliana* [93]. Under combination of P and salt deficiency, PSR upregulated the expression of AT1G80050 gene responsible for the production of PHT2 in A.

thaliana. Contrary to this, the expression of gene (PHO2) responsible for Pi accumulation in shoots was down regulated. This phenomenon is referred to the fact that PHO2 is responsible for Pi signaling under low P supply [93]. Similarly, phosphate solubilizing *Bacillus* sp. enhanced P-acquisition in wheat plant by upregulating PHT1 transporter [94]. On the other hand, P solubilizing *Pseudomonas* sp., *Klebsiella* sp., *Stenotrophomonas* sp., *Serratia* sp. and *Enterobacter* sp. have been shown to down regulate the expression of Pi transporter in inoculated plants, however, plant growth is enhanced with improved P acquisition and biomass [95]. These changes in molecular patterns positively influence plant P acquisition that ultimately improved crop yield and productivity.

5.3 Effect of PSR on root system architecture

Root system is a paramount, fitness determining component of a plant. Phosphobacteria can modulate root system architecture through various mechanisms in favor of P acquisition. Modified root system stimulate enhanced root absorptive capacity for nutrients uptake [96]. Generally, under P scarcity, plants have adopted root modifications such as increased root biomass, greater number of roots, enhanced root length and surface area. This extensive, denser root system with larger surface area help plants in detecting localized higher phosphate content [97]. Moreover, spatial parameters in root architecture are important under P- stress. Sometimes for the P- acquisition, PSR affect plant roots to develop shallow root system by decreasing primary root growth and inducing laterals root formation. Thus, development of shallow and more proximate roots favor plants to acquire P from topsoil [98]. This phenomenon of detecting local phosphate concentration by modifying root system is termed as 'P-mining'. Under low P supply, inoculation of phosphate solubilizing *Bacillus megaterium* and *P. fluorescens* inhibited primary root formation and initiated lateral root and root hair formation in *A. thaliana* [99]. PSR also have positive influence on the development of root hair of inoculated plants. Plants with longer root hair are found to be more efficient in P- acquisition under P deficiency. Plants treated with phosphate solubilizing *Pseudomonas* sp. strongly influence root hair formation by increasing number of root hair and length of root hair [100]. Root functions related to phosphate foraging such as number of roots, root hair, lateral roots, frequency of root tips, branching intensity etc. have shown to be increased under the influence of PSR [101].

5.4 Mechanisms adopted by PSR for plant growth promotion

Phosphate solubilizing bacteria follow several other mechanisms influencing plant growth directly or indirectly such as production of phytohormones, quorum sensing signals, production of various enzymes etc. These mechanisms act synergistically, helping plant to better adopt the environmental conditions with improved growth yield. Some of these mechanisms affecting directly are described below.

5.4.1 Nitrogen fixation

Some phosphate solubilizing *Rhizobia* spp. with nitrogenase (nif) gene have potential to fix nitrogen. N is important macromolecule so PSR with potential N-fixing ability can significantly help plants to cope with its nitrogen demand having improved nitrogen acquisition [82]. Leguminous plants have developed symbiotic relation with nitrogen fixing rhizobacteria and modify plant roots by developing root nodules where these bacteria convert environmental nitrogen into ammonia (plant available form of N) [102]. However, some non-nodule forming N-fixing phosphate solubilizing bacterial species such as Pseudomonas sp. also regulate legume-rhizobia symbiosis for improving the plant nitrogen levels. Increased ACC activity in Pseudomonas sp. trigger nodulation process in rhizobia [103, 104].

5.4.2 Siderophore production

These are iron chelating compounds secreted by some PSR bacteria to reduce inter- or intra-cellular iron that can be utilized by the associated plants. Due to iron scarcity, Phosphate solubilizing e.g., *Pseudomonas fluorescence,* can produce different kinds of siderophores i.e., pyoverdine pyochelin, and pseudobactin [105]. This phenomenon positively influences plant growth. For instance, Pseudomonas fluorescence produce pyoverdine which form complex with iron (pyoverdine-Fe) that can be easily taken up by plants. Iron acquisition is more important under stress conditions. Siderophores also help to alleviate the stress imposed on plants [106].

5.4.3 Phytohormone production

Phosphate solubilizing bacteria have potential of producing various plant hormones such as auxins, cytokinins, gibberellins, and ethylene. PSR release these hormones via interconnected series of signaling network and affect plant physiological activities [107]. Tryptophan present in plant root exudates acts as principle signaling molecule to produce bacterial Indole Acetic Acid (IAA). PSR generally detoxify tryptophan, or its analogs present in root exudates that cause IAA production [108]. Bacterial phytohormones can alter plant hormonal balance which is positively correlated with plant health. Many species of phosphate solubilizing *Bacillus* and *Pseudomonas* exhibit potential to produce auxin that triggers formation of lateral root and root hair in inoculated plants [109]. Moreover, auxin stimulates seed germination, enhance photosynthetic rate and produce other plant growth related metabolites [110, 111]. Similarly, gibberellins and cytokinins stimulate wide variety of plant processes such as seed germination, cell elongation etc. which play important role in plant growth and development. Various genera of phosphate solubilizing bacteria can produce phytohormones such as *Rhizobium*, *Pantoea*, *Azotobacter*, *Paenibacillus*, *Rhodospirillum*, *Bacillus*, *Pseudomonas*, *Microbacterium*, *Plantibacter*, *Sanguibacter*, *Buttiauxella*, *Microbacterium*, *Erwinia* [96, 112–114].

5.4.4 ACC-deaminase production

Sometimes bacterial IAA stimulate ACC synthase enabling the of 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase using S-adenosyl methionine precursor which is also the intermediate of ethylene production in higher plats. ACC deaminases have potential to cleave ACC to ammonia and α-ketobutyrate that act as nutrient for plants. This enzyme is also responsible for the reduction of plant stress ethylene, thus alleviating stress effects imposed on plants. Plants inoculated with ACC producing PSR have shown increased shoot system [115]. Moreover, ACC deaminase producing PSR can also stimulate nodulation process. Various PSR have potential to produce ACC such as *Achromobacter*, *Azospirillum*, *Enterobacter*, *Acinetobacter*, *Serratia*, *Bacillus*, *Burkholderia*, *Pseudomonas* etc. [105].

5.4.5 Bacterial cyanide biosynthesis

Some phosphate solubilizing bacterial have hydrogen cyanide (HCN) production potential which is a volatile compound and protect plants from various biotic stresses including allelopathic effects. Moreover, they also protect other harmful rhizobcateria by colonizing plant roots. Most of the phosphate solubilizing *Pseudomonas*, *Bacillus*, *Serratia*, *Enterobacter*, *Pantoea* can produce HCN [116, 117].

5.4.6 Indirect methods of plant growth promotion

Various indirect mechanisms are also adopted by phosphate solubilizing rhizobacteria such as production of various antifungal compounds, antibiotics and lytic enzymes. Different antifungal compounds such as proteases, lipases, cellulases and chitinases degrade cell wall of pathogens. Different P solubilizing *Pseudomonas* and *Bacillus* species can produce antifungal compounds. These compounds can protect plant from various plant pathogens [118]. Hence, these phosphorbacteria can also act as biocontrol agents in agricultural fields. Moreover, some PSR can also release enzymes that act as antibiotics, protecting plants from other pathogenic bacteria. Thus, inducing plant systemic responses (ISR). *Bacillus* sp. can produce various compounds such as difficidin, bacillaene, rhizocticinsn chlorotetain, bacilysin, and mycobacillin. ISR positive plants can response stronger and faster to pathogenic attack due to their induced defense system [119, 120].

6. Future perspectives

Efficiency of phosphate solubilizing rhizobacteria as biofertilizer, biopesticides, phytostimulaors and bioremidiators have now become research priority owing to their importances as environmentally safe plant growth promoting agents. Various genera of rhizospheric bacteria are capable of solubilizing soil phosphate by either releasing organic acids or enzymes. But there is a need to investigate further indepth mechanisms for bacterial phosphate solubilization and their interactions with root exudates for the development of suitable biofertilizer. Also, study about the knowledge of impact of these biofertilizers on soil microbiota is necessary as the rhizobacteria are important candidate of P-cycling mechanism. Moreover, plant growth promotion by rhizobacteria is a complex network of mechanisms functioning synergistically, thereby particular interaction between phosphate solubilization and its influence on root morphology needs to be investigated. In addition, the interactions and coordination between various rhizobacterial traits and their impact on agronomic parameters should be considered as top priority research for sustainable agriculture economically. Hence, commercializing these biofertilizers can be a promising tool for agricultural sustainability.

Conflict of interest

Authors declare no conflict of interest.

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Section 3

Agriculture Resources Management

Chapter 4

The Impact of the Expansion of Large-Scale Agriculture in Drylands of Ethiopia; Implications for Sustainable Natural Resources Management

Getnet Bitew, Alebel Melaku and Haileyesus Gelaw

Abstract

Dryland areas in Ethiopia encompass pastoral and agro-pastoral areas in the country and have long been regarded as peripheries especially in economic terms. Expansion of large-scale agricultural investments (land grabbing) in these areas is the current government's focus and resulting in the loss and unsustainable utilization of natural resources. For instance, foreign investment in Ethiopia's forestry sector is currently limited, but agricultural investments that affect forests largely through forest clearing are common in the country. Therefore, the objective of this review paper looks at the impact of large-scale agricultural investment expansions on natural resources and factors affecting it in drylands of Ethiopia. A literature search was conducted through the use of different search engines to organize this paper. Natural resource degradations such as rangelands fragmentation, soil salinity, water scarcity, deforestation, and seasonal wildlife migrations are the main problems resulting from large agricultural investments in dryland areas of Ethiopia. Government policies, climate variability and the weakening of customary rules are the main factors causing natural resources degradation in dryland Ethiopia. Large agricultural expansion investment in dryland areas of Ethiopia is currently affecting not only natural resources but also cannot improve people's livelihood by far. Given the key roles forests play in rural livelihoods, new tenure arrangements will have significant implications for communities located at the forest farm interface in its dryland areas. Therefore, development of sound strategic policy that contributes to environmentally more sustainable and socially inclusive large-scale agricultural expansion in dryland areas of Ethiopia should be recommended.

Keywords: drylands, Ethiopia, government policy, large-scale agriculture, natural resource degradation

1. Introduction

About 75% of Ethiopia's landmass is categorized as dryland, experiencing moisture stress during most months of the year [1]. In recent decades, agricultural growth in the country has been progressing with the establishment of large scale investments in dryland areas. However, the growth is not as such increasing land productivity but mainly through the expansion of the cultivated area onto the regions where relatively abundant land is assumed to be available i.e. in dry areas [2].

The Ethiopian government and international bodies have presented the commercialization of land and the shift to large-scale agriculture as being an essential measure for agricultural modernization and improvement of production efficiency which leads to huge food production and economic growth as part of their five-year Growth and Transformation Plan. This plan envisages that Ethiopia will be food secure and a middle-income country by 2025 [3–5], Since the 1990s, the government formulated a long-term economic development strategy called Agriculture Development Led Industrialization (ADLI) which is the government's overarching policy response to Ethiopia's food security and agricultural productivity challenge focuses primarily on the expansion of large-scale commercial farms and improved productivity in smallholdings [6, 7]. The government also promotes large-scale agricultural investment as a way to improve food security at the national level, through foreign exchange revenues from farm outputs, higher crop production in the country, and increased incomes from farm jobs [5, 8].

According to World Bank [3], population growth in developing countries like Ethiopia will lead to increased demand for food products, expanding urbanization, and rising incomes which needs to be met by bringing more land to large investors for farming and thereby improving productivity. In line with this argument, the Ethiopian government confirms that there is plenty of unused land for investors to operate efficiently without posing a threat to the environment and its natural resources as well as the livelihood of smallholder farmers in dryland areas of the country. However, facts on the ground show on the contrary, as sustainable natural resource utilization and rights of smallholder farmers to land have been ignored during investment implementations in dryland regions of the country. This expansion strategy reflects the relative availability and lowers costs of land relative to capital inputs required for agricultural intensification, such as fertilizer, credit, and irrigation etc. without considering natural resource degradations. Therefore, land grabbers cause unsustainable natural resources utilization with little account for agricultural growths [7, 9–11].

As long as drylands areas are becoming a center of government attention in current Ethiopia for the expansion of large-scale agricultural investments, natural resource degradation caused by its expansion aggravated by climate change and variability are common problems in these regions. Some of its impacts on natural resources include increasing rangeland degradations, soil salinity due to irrigation schemes, water overexploitation, and deforestation that leads to various forms of land degradations in dryland regions of the country [11, 12]. Changing land-use patterns and disturbances to the environment and its natural resources is common. Thus, the livelihoods of many pastoralists are affected in the drylands of Ethiopia. Pastoral and agro-pastoral communities, who live in these emerging areas of investment and who engage in subsistence economies within larger socio-economic networks will continue to be significantly affected by domestic and foreign agricultural investors by resettlement schemes, increasing landholding and land-use changes [13, 14].

Sustainable use of natural resources refers to use patterns that meet the basic human needs of current generations without destroying or degrading the natural environment to the resource needs of future generations can be met [15]. However, many of the current trends in rural dryland areas exert varying pressure on water, soil, forests, ecosystems, and biodiversity, threatening the resilience and sustainability of the complex environmental systems. These rushes to land, water, and other essential natural resources in the region particularly have negative effects on indigenous and local people's livelihoods and increasing food insecurity. An environmentally sustainable rural transformation is not only a technical challenge but also a political question, because root causes for the degradation of natural resources and the measures to be adopted are mainly policy issues [11]. In locations where irrigated agriculture is viable, mobile pastoralists, sedentary agro-pastoralists, and commercial investors are increasingly competing for land and water resources. Balancing competing land use and livelihood systems while also safeguarding natural resources continue to be important problems for Ethiopia's development program, which is centered on greater agricultural output. In light of this, the question of whether sustainable resource management can remain a viable strategy in the future and what structural changes are required to increase environmental resilience arises.

The principal objective of this review paper is to investigate the impacts of large-scale agricultural expansion on natural resources and systematically assessing policy and other affecting factors to its sustainable management.

2. Materials and methods

A literature search was conducted through the use of different search engines and options such as the Web of Science (apps.webofknowledge.com), Google Scholar (scholar.google.com), Research Gate (https://www.researchgate.net), altavista.com, and www.freefull.pdf.com, the Science of policy aspects in natural resource management in Ethiopian. The majority of the searched works of literature were published research articles that are highly related with the expansion of large scale agriculture in drylands of Ethiopia and sub-Saharan Africa having a policy focus were retrieved, the author of this review paper focused on those reporting the general descriptions and results on the impact of expanding large scale agricultural investments in dryland natural resources such as rangelands, soils, forests, water, and wildlife. Thus, about21 published scientific papers were used to develop this review paper. Individual articles from the collected literature were grouped for research objectives to the impacts of large-scale agricultural investments on natural resources in drylands. Research objectives were further sub-categorized into articles focusing on rangelands, soils, forests, and water resources.

3. The development of large-scale agricultural investments

Around the mid-1990s, the Ethiopian government developed a development strategy that prioritized small-holder agriculture and agricultural production as the engine of growth for the country's overall development. The concept relied on small-holder farmers to provide not just a stimulus for development but also a surplus for food self-sufficiency. During this time, domestic and donor aid, resource management methods and improved farming, credit services, and many types of human capacity development programs were provided to small-holder farmers. New technological packages were also offered to some extent. At the time, the land system was skewed in favor of small-holder farmers [16]. The government's 2001 paper with revised rural development policies and strategies signified the beginning of the shift away from this method [11]. Despite the fact that smallholder farmers continue to play a significant role, the agreement includes an essential role for big scale agricultural firms and foreign investors [17].

"Private investors are already contributing significantly to agricultural growth." Experiences from developed countries reveal that as an economy grows, some small farmers leave the industry to seek employment in other areas, while others gather enough capital to go big in the sector.

"There appear to be two investment areas in the agricultural industry that appear to be particularly favorable for foreign investment." The first is to develop previously undeveloped huge area with considerable irrigation potential. The second investment opportunity is to develop high-value agricultural items for export (such as flowers and vegetables).

We can see here that investors who export their products are given more support than those who do not. This suggests that the primary goal of the shift to large-scale agriculture is foreign exchange gains, rather than domestic food security, and that it is causing natural resource degradation in pastoral areas.

3.1 Transfers and distributions of land

Despite the fact that farmland has been allocated to investors since the mid-1990s, up until 2002, those requesting property were primarily local investors, and the land released was mostly modest, no larger than 500 hectares. The growth of foreign investors is inextricably linked to the passage of the investment declaration and the success of the floriculture industry. Between 2003 and 2007, the cut flower sector was expanding, with a growing market to Europe and internationally. Beginning in 2006, foreign investors' desire for land increased, resulting in a land rush in 2008. The sizes of property requested were no longer minor, with several applicants requesting vast swaths of 10,000 hectares or more. According to Ministry of Agriculture and Rural Development (MoARD) and government officials, foreign investors are given much bigger land in size with the justification that they are better endowed in capital and technology and are more likely to be successful in their operations. The total land area given for both foreign and domestic investors large scale agriculture in 2008 is 1, 133, 000 hectares. Such large scale land transfers are over 2000 hectares for each investor [11].

4. Result and discussions

4.1 Impacts of large scale agriculture on natural resources

4.1.1 Environmental dynamics in dryland areas of Ethiopia

Changing patterns in the accessibility and availability of natural resources is closely linked to processes of rural transformation by the expansion of large agricultural investments. An expanding rural population relies on natural resources for a living. With rising food demands at the national and worldwide levels, two options for increasing food production emerge: intensifying the utilization of existing natural resources or expanding the area cultivated through large-scale agricultural investments. Both options raise environmental and social risks if context-specific conditions are not sufficiently considered [18].

Furthermore, dryland regions in Ethiopia are characterized by climate uncertainty due to spatially and temporally highly variable rainfall. Under these unpredictable climatic conditions, the broad and opportunistic use of communally held land rangelands and mobile forms of pastoralism is the most fitted land-use system [19, 20]. Pastoralists' extensive understanding of the sustainable use of animal fodder and water resources is reflected in the careful selection of livestock breeds and the temporally limited usage of rangelands. Besides, functional customary institutions for natural resource management in which collective action and resource sharing (social capital) are of major importance [21].

4.1.2 Rangeland deterioration

Vegetation and soil degradation is a serious issue in the dry and semi-arid lowlands, where various types of savanna, grasslands, and deserts dominate the majority of the area [22, 23]. Rangeland degradation caused by major agricultural investment development in dryland areas results in altered grass species composition and a general loss of biodiversity and vegetation cover, resulting in a permanent decrease in biological and economic productivity. Seasonally flooded plains are the hardest hit, as they provide the best pastures during the dry season while also having the largest irrigation potential for agricultural projects [24]. The main feed source for grazers like cattle and sheep, nutrient-rich palatable grasses, is increasingly being out-competed by invasive plant species (*Prosopis juliflora*, *Parthenium hysterophorus*, *Lantana camara*, *Acacia melifera*, *Acacia nubica*) or grassy floodplains are being converted into irrigated farmland. *P. juliflora*, which was purposely introduced to the lowlands as an ecosystem engineer for soil and water conservation, has infiltrated significant sections of grazing land in Ethiopia's dryland areas, particularly in the Afar Region [25, 26].

Although irrigation occupies a relatively small quantity of land, there are far-reaching implications and ramifications of siting irrigation projects in direct competition with pastoral grazing needs during the dry season. This is especially evident in the Afar region's Awash River valley irrigation system. In the Valley, the cost of pastoral output is correspondingly high [27].

4.1.3 Soil degradation and salinity effect

Soil salinity is a major problem for agricultural production in dryland areas of arid and semi-arid parts of Ethiopia where evapotranspiration rates exceed precipitation. According to Azeb and Wolfram [7], since the mid-2000s, the government has awarded thousands of hectares of the Gambella Region's most fertile lands to foreign companies and some of the world's wealthiest individuals to export rice, cotton, sesame, and other commodities, often on long-term leases and at low prices. Similarly, salt-affected soils are common in Somali Region's Awash Valley and the Wabi Shebele River Basin as a result of large-scale irrigated farm operations. In these areas, soil salinity is high due to poor drainage systems and inappropriate water management practices. Increasing salinity is now one of the major reasons for decreasing agricultural productivity on irrigated cotton and sugarcane plantations along the Awash River for small-scale agro-pastoralists cultivating maize and vegetables. Under current conditions of an ongoing expansion of irrigation farming in lowland areas, soil salinity becomes a major problem in the future that can jeopardize sustainable agricultural production and natural resource management [28].

4.1.4 Forest degradation and deforestation

Customary laws in dryland areas of Ethiopia for instance among Afar and Somali people prohibit the cutting of trees. When deemed necessary, branches are collected as feed for animals or lactating cows. This is done in a way that ensures the regenerative capacity of the plants. Within the last decade, deforestation of indigenous trees has increased, especially due to the growth of large scale domestic and foreign agricultural investments as well as charcoal traders in Afar and Somali dryland areas [29, 30].

Foreign investments in the forestry industry differ from agriculture investments that have an impact on forests. Forest clearing for farm enterprises is one of the latter, with a decades-long history fueled by a variety of government policies affecting land use, resettlement, and investment incentives. Forest clearing for agricultural purposes is a frequent practice in Ethiopia's lowland regions. Most modern forests are cleared with fire, leaving forest products generally unexploited [31]. Clearing dryland deciduous woodlands for cash crops (mainly sugarcane and cotton) occurs often in lowland areas [32]. Forest encroachment for agricultural expansion (including tea and coffee cultivation) by both large scale agricultural investors and rural people generally leads to contemporary highland forest clearing [33, 34].

Land used for large-scale agricultural investment (such as coffee and tea plantations, irrigated farming, and so on) may occasionally contain natural forestlands and woodlands, resulting in substantial conversions of forestland to non-forest land. Regardless of their economic importance, such investments exacerbate deforestation. As an example, that of the Jardaga Jarte District in oromia region, large-scale agriculture investment and expansion is the main cause of deforestation, particularly for commercial sugarcane production [35]. With regard to the underlying drivers of deforestation and forest degradation, the report suggested that commercial agriculture and national policies are the main drivers where other factors are also under consideration. Forest policies, proclamations, related laws, and regulations are poorly implemented for a variety of reasons. Some of the barriers could be a lack of financial and human resources, as well as a lack of institutional capacity; the absence of proper implementation guidelines; and, for a long time, the structuring and restructuring of the forest governance system at the national and regional levels, limiting forest sector representation at the department or expert level.

The expansion of large-scale commercial agriculture and other development activities, such as road networks and megaprojects are the direct causes of deforestation in Ethiopia. The magnitude of such large-scale agricultural expansion on the forest resource of the country is very huge [36].

Unpredictable agricultural investment, which began shortly after 2010, is the most recent phenomenon causing widespread forest cover degradation in the area. According to respondents and key sources, this is the most pressing issue putting a strain on the remaining forests and the environment. According to Othow et al. [37] observations in the field, most farmlands were located near forests, allowing the farm owner access to surrounding forests. This issue is also consistent with Rahmato's [11] report, which said that land leased to investors is located near national parks, protected regions, and forests. The primary causes of forest cover change in Gog district

Gambella region is farm land expansion. It accounted about 33.4% over other causes (such as forest fire, population growth, illegal logging, charcoal and fuel production and poor governance) of forest cover change in this study area [37]. For instance, a recent report by Bekele et al. [38] looked that commercial agriculture as a major driver of deforestation and forest degradation in Ethiopia. Similarly, Getachew et al. [39] found that landscape changes in southwest Ethiopia have been rapid over the last 37 years. These changes included expansion of agricultural areas (including coffee farms, tea and Eucalyptus plantations, and small-scale cultivated lands) and decline of forest cover (**Figure 1**) [39].

4.1.4.1 Biofuel development

According to a biofuel strategy document produced by the Ministry of Mines and Energy (MME), the 24 million hectares of unutilized land suitable for growing bio ethanol and biodiesel can be leased out without interfering with food crop production or undermining the country's food security goals. Its main goal is to employ indigenous resources to permit adequate biofuel production to replace imported petroleum and export excess goods. As a result, the government's objective is for foreign and domestic investors to produce bioenergy, with the government providing land, financial incentives, and other assistance [40, 41].

The method utilized to estimate available land for such purposes is unclear, which is an issue. The amounts of land stated to be accessible for biofuels development in several regions were abnormally vast in comparison to the size of the regions. According to Anderson and Belay [40], the stated accessible acreage for production of biofuels crops in Gambela and Benshangul Gumuz was around 88% and 60% of the entire size of the regions, respectively. In such cases, there is the likelihood of allocating fertile lands or preserved forest areas for large-scale cultivation of energy crops.

According to the law, no project can start operation without approval given by the environmental protection authority. It had the responsibility of following up and supervising with the help of its subunits in the regions that contractual obligations were met about environmental considerations. But since 2009, even though the technical and institutional capacity of the ministry of agriculture and rural development to carry out the duties involved is questionable, the responsibility of environmental protection authority was transferred to the ministry of agriculture and rural development [11].

Figure 1.
Rapid forest conversions for commercial tea, agricultures, settlements and infrastructure development in Southwest Ethiopia [39].

4.1.5 Increasing water resource supply and demand

The naturally limited supply of water resources in dryland regions of Ethiopia is a severe constraint for rural inhabitants. The GTP's lofty governmental aims for agricultural intensification and hydropower development, with the ambition of becoming a middle-income country and developing a Climate Resilient Green Economy (CRGE), resulted into the construction of numerous large-scale dams in lowland regions. The increasing agricultural water off-take from a large-scale sugarcane plantation in Tendaho, Afar Region, built in 2009, has resulted in increased water scarcity for local pastoralists and agro-pastoralists, as well as disturbed discharge patterns and floodplain ecology, and has left downstream communities with insufficient water to irrigate their plots [42–44].

Ethiopia's government is optimistic about the future excavation of huge aquifers in the lowlands. The lowlands of Amhara, Tigray, Afar, and Somalia are where the majority of unusable groundwater is suspected and somewhat studied. However, it is unclear if long-term aquifer exploitation would be sustainable and financially viable. Groundwater table declines have been documented in the Afar and Somali dryland regions [45].

4.1.6 Increasing water pollution

Water pollution due to pesticides, fertilizers, and insecticides, and the disposal of industrial waste has become a growing concern in dryland areas particularly for those pastoralists who use the river water for human consumption, for watering of their livestock, and irrigation. Most affected by the harmful consequences of this agro-industrial contamination are highly developed by commercialized farms and industries dryland Ethiopia particularly in the Awash central rift valley. The fluoride levels in the waters of the Ethiopian central rift valley are among the highest in the world, putting some 8 million people at risk of developing skeletal or dental fluorosis [46].

4.1.7 Impacts on wildlife

A considerable body of ecological research in arid and semi-arid areas in eastern Africa shows that the extensive land-use practices of pastoralists also have a major bearing on the conservation of savannah wildlife populations and ecosystems [47]. Aspects of sustainability enter the picture here. Pastoralism is crucial not just for conserving forest regions, but also for wildlife populations and the savannah plains they inhabit, due to the overall ecological compatibility of pastoralist livestock and wild large mammals [48]. As an example, the diversified wildlife is Gambella's most valuable treasure, with over twenty wild animal species, some of which are of international value. Experts estimate the seasonal wildlife migration that occurs between Gambella and South Sudan to be Africa's second-largest wildlife migration [49, 50].

4.1.8 Underutilization of land that is not covered by irrigation programs

This occurs when a small region along the river is made unavailable for dry season grazing, rendering a much larger area distant from the river worthless. If current development trends continue, the complete exploitation of the Awash Valley's 200,000 irrigable hectares will leave many millions of hectares of desert and semi-desert unused since the only people or culture capable of using such land will no longer exist [42].

4.2 Factors influencing natural resources degradation

4.2.1 Governmental policies

The Ethiopian government has escalated its efforts to harness the lowlands' natural riches by expanding large-scale irrigation agriculture and mining. The notion of the lowlands' 'untapped resources,' enormous land resources, minerals, and underutilized irrigation potential, particularly from groundwater aquifers, is a significant rhetorical factor among political stakeholders in this regard. With global food costs rising since 2008 and rising national demands from a growing population, the conversion of communal dry season pastures into agricultural land has gained traction. This resulted in livestock exclusion from prime pastures and subsequent overstocking in less productive locations, resulting in disrupted livestock Spatio-temporal movement patterns [11, 51].

Water-led development is the overarching policy guiding government actions aimed directly at the rural population. It has been in effect in Afar and Somalia since 2010/11. Deep wells and water pipelines have been significant initiatives in this regard. The major strategic entry point for creating incentives for voluntary settlement of pastoralists and their subsequent transformation to agro-pastoralism is better water supplies. Through villagization and the construction of irrigated farmland, it intends to significantly alter land use and settlement patterns in arid and semi-arid regions. The government's quest for sedentarization is rooted in a prevalent rhetoric among governmental stakeholders that sees pastoralist mobility as a cause of conflict and overgrazing. It is also considered that dryland areas have significant energy resources such as gas, oil, and geothermal sources, as well as minerals such as salt, gold, and potash.

International corporations (Australia, USA) are already mining gold and potash in the northern Afar Region, while Tigrayan investors control salt mining in the Danakil desert. Russian oil explorations in the Middle Awash region are ongoing, with the chance of enormous pasture fields being transformed if oil is discovered. Several oil explorations are also taking place in the Somali region. A Chinese corporation has just begun significant gas investigations in the Somali Region with the goal of addressing China's expanding energy demands.

Generally, Ethiopia's ill-designed development policy highly affects its natural resources particularly in dryland areas in which many development projects are established.

4.2.2 Increasing climate variability

Drought and floods are normal phenomena in arid and semi-arid regions of Ethiopia which affect reproduction rates of livestock and agricultural output significantly [52–54]. The drought in 2016 severely reduced the amount of water in the Awash River, jeopardizing large-scale sugarcane plantations, whose command area had to be reduced from 24,000 ha to 8000 ha, as observed during the field study by Rettberg, et al. [55]. As Fantini et al. [42] note out, "the lack of a systematic strategy to rangeland decision-making has done more to weaken prior levels of rangeland production than cyclical droughts could ever achieve."

4.2.3 Weakening of customary rules

Pastoralists in the Afar and Somali Region stated that customary institutions which regulate the use of natural resources, for instance prohibitions of cutting of trees is becoming weaker. In Afar, for example, government officials recently restricted the use of Desso, exclusive clan-based grazing areas, to limit grazing intensity and protect access to feed during the dry season. At the same time, elders and clan leaders who are in charge of enforcing the rules are not as revered as they once were, particularly by the younger generation. The government is undercutting clan leaders but cannot replace these culturally ingrained organizations [55].

On the other hand, the increasing fragmentation and privatization of communal rangelands displaces pastoralists from valuable grazing areas onto less productive pastures and limits the mobility of livestock [56]. Under such conditions, uncontrolled, intensive grazing without appropriate rest of the rangelands has increased [41, 51, 57].

5. Conclusion

In general, the Ethiopian government has only vaguely recognized the support of the expansions of large-scale agricultural investments in dryland areas under the current policy of the country resulting in unsustainable natural resource utilization and accounted for a cause for its degradations. It is closely linked to and supported by policies aimed at expanding large-scale agricultural investment in dryland areas to increase production and productivity. The Ethiopian government has not yet accepted such policy support for the expansion of large agricultural investments without considering sustainable natural resource management. Factors accounting for natural resource degradation in these regions other than government policy are also climate variability and weakening of customary rules as well. The degradation and increasing scarcity of critical natural resources such as rangelands, soils, forests, water, and wildlife in dryland areas of Ethiopia is exacerbated due to the expansion of large agricultural investments. For instance, pastoral rangelands continue to be encroached upon by commercial irrigation schemes run by investors and increasing natural resource exploitation particularly in dryland areas of Afar Awash Valley, and at the same time affecting pastoralists' livelihood. If Ethiopia's rising population is to be fed and the natural resource base that underpins food production is to be sustained, agriculture must undergo a paradigm shift at all levels of research and development. The status quo is no longer an option. Agriculture, rather than just extending big agricultural investments in the country's fragile dryland areas, can become part of the solution to sustainable development and natural resource management by transitioning to climate-resilient, low-emitting production systems. An integrated approach for agricultural production is the key to increased production on a sustainable basis. Finally, it is recommended that the development of sound strategic policy that contributes to environmentally more sustainable and socially inclusive large scale agricultural expansion in the drylands of Ethiopia should be operationalized in the current and future plans.

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Chapter 5

Climate Smart Agriculture: Threshold Number of Trees in Agroforestry Parkland for Better Land Management to Climate Adaptation and Mitigation in West Africa Burkina Faso

Tiga Neya, Oblé Neya, Galine Yanon and Akwasi A. Abunyewa

Abstract

Agroforestry system is the most climate smart agriculture practices in West Africa. Because perennials are generally more resistant to climate extremes, such as drought, flood, and heat, than annual crops. Park land may appear to be competitive with crop on farm. To elucidate that, trees number and their canopy cover on farming system were assessed through tree inventory in three municipalities and compared with normal trees canopy cover. More than 3000 trees which spreading was 1154 in Bouroum-Bourom, 884 in Ouahigouya, and 1054 in Sapouy were used. Trees density and mean tree canopy cover in farms were calculated. Trees density on farm were about the double of trees threshold number in Soudanian zone, one and half both in Soudan Sahel and Sahel strict zones. Tree canopy cover were 66.25, 59.92, and 42.1 m^2, respectively in Bouroum-Bourom, Sapouy, and Ouahigouya. The average tree cover was 23.99, 18.23, and 14.88%, respectively, the Municipality. Agroforestry system as more trees that it should be, to optimize the positive impact of agroforestry system to increase crop yield and restore land fertility the number of trees on parkland system should be 15, 17, and 24 trees/ha, respectively in Bouroum-Bouroum, Sapouy, and Ouahigouya.

Keywords: smallholders, soil fertility, crop integration, threshold of tree, crown cover

1. Introduction

In Sahelian countries, the most widely spread farming system is agroforestry parkland land system and is composed by scattered trees sharing the same space with underwood crops and livestock [1]. Parkland management system is function of farmers socio-ecological knowledges and their needs dealing with the variability of climate, to cope with climate change and to recover land degradation and soil fertility improving crop productivity [2–5]. In Burkina Faso, the economy is basically based on natural resources, and agriculture which occupied more than 80% people [6]. Agroforestry parkland is the most broadly spread farming system throughout the country. But, nearby climate change and variability, soil erosion and land degradation continue to be the keys barriers limiting crop production [7–9]. Several studies have shown the importance of agroforestry parkland trees for food security [1, 10, 11] and sustainable soil management [12–14]. It is shown that crop under trees crown cover were more protected to extremely increase of temperature, wind speed increase, scarcity of water and to diurnal temperature changing during drought spell than in open area [15–18]. These stress adaptation indicators show the adaptability of parkland system to climate change for crop production. Several authors have shown important soil porosity and water infiltration under tree compared to adjacent open area in the Sahel zones where the lake of water is the key limiting factor of crop production [19, 20]. Furthermore, soil under trees has shown higher water infiltration and increased soil nutrients migration capacity leading to soil vitality and improving crop production. According to Sanou [20], soil properties modification and the microclimate created by agroforestry parklands system could be due to trees species morphological characteristics such as trees height, density, crown and shape.

Nevertheless, on farm trees improve positively crop productivity and it has been widely reported that trees and crops compete for above-ground growth resources such as light, heat, air relative humidity, and rain interception [21, 22]. The below-ground, competition is specifically link to water and nutrients, although it is generally expected that the roots of trees and crops occupy different soil layers, at least to some extent [23, 24]. Base on the above, it seems that there are different schools of thought according the impact of trees on farmlands. While one group of researchers appreciate and encourage agroforestry parklands promotion, a second put much more emphasis on the negative effect of trees in smallholders farming system. Therefore, it is needed to come out with a good insight into these apparently contradictory positions. The few studies done on trade-off between tree keeping and crop production were mainly in research stations and covered limited agroforestry trees species [1, 14, 25]. Moreover, most of these studies failed to determine the threshold number of tree per hectare to be kept in the farm to maximize the ecosystem services provided by trees and to reduce the trade-off that trees can occur. However, it has been argued and reported that trade-off resulting from tree keeping and crop production is raise up to 109.5 kg/ha in Sahel strict zone, 247.6 kg/ha in Soudan- Sahel zone and 252.8 kg/ha in Soudanian zone [5]. This study, aim to determine the thresholds number of trees to be kept in the farms for agroforestry parkland promotion and management in the Sahel zone. More specifically, the threshold number of trees was investigated, through (i) evaluation of tree diameter in farms (ii) tree crown cover assessment within farms, and (iii) estimation of threshold number of trees.

2. Materials and method

2.1 Study area

The work was done in three municipality of Burkina Faso such as Bouroum-Bouroum (10° 32′ N, 3° 14′ W), Sapouy (11° 33′ N, 1° 46′ W) and Ouahigouya (13° 35′ 00″ N, 2° 25′ 00″ W) located in three different climatic zones of Burkina Faso (**Figure 1**).

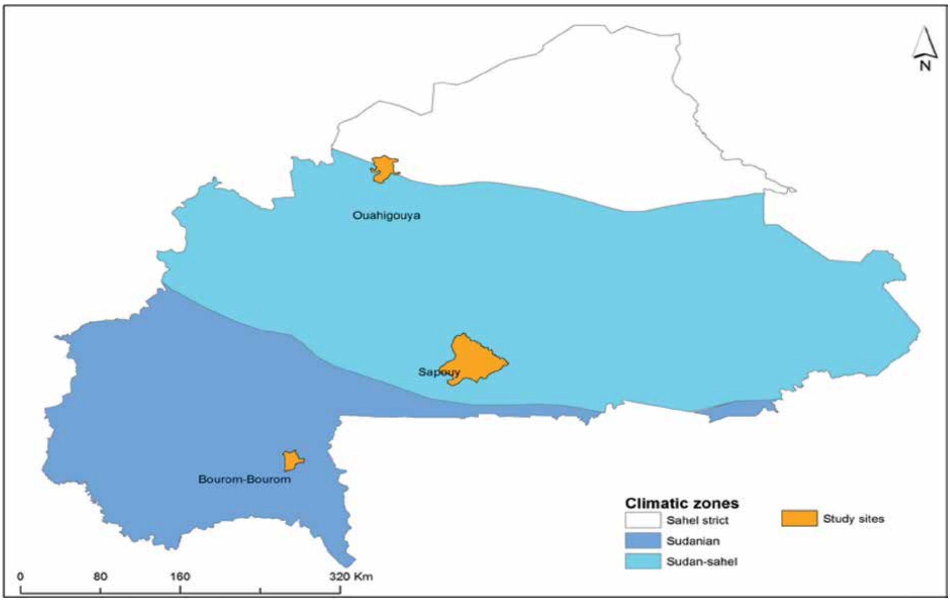

Figure 1.
Studies sites Ouahigouya (Sahel strict), Sapouy (Sudan -Sahel) and Bouroum-Bouroum (Sudanian) in Burkina Faso.

Three municipalities were randomly chosen, and 30 households were randomly selected among farmers covered around 35 ha per municipality.

2.2 Mean diameter of woody species (D)

The average of woody species diameter (D) was computed using the sum of total DBH over the total number of individual woody species found. Before, computing (D), all the individual woody species which have more than one trunk at 1.3 meter, the equivalent diameter (d_{eq}) has been estimated using Eq. (1) below.

$$d_{eq} = \left(d_1^2 + ..d_n^2\right)^{\frac{1}{2}} \qquad (1)$$

Where d_1 is the diameter of trunk 1first and d_n: is the last diameter of the trunk (n).

2.3 Mean height of woody species

The average of woody species diameter (h) was computed using the sum of total H over the total number of individual woody species found.

2.4 Trees crown cover

According to Jennings et al. [26] crown cover is the vertical projection of a tree's outmost perimeter and constitutes the potential shaded area which can influence crop production. To estimate crown area all, the trees are inventoried and the big radius of crown cover (R_b) and the small radius of canopy cover (R_s) were recorded with Ruben meter. The formula of ellipse Eq. (1) was applied to obtain the area of crown (C_a).

$$C_a = \pi \; x \; R_b x \; R_s \tag{2}$$

Total canopy area under trees (TC_a) of each farm was obtained by summing up the crown cover areas of all trees within the farm Eq. (2).

$$TCa = \sum_{i=1}^{n} Ca_i \tag{3}$$

The average tree crown cover is the sum of crown cover in m^2 of the agroforestry parkland tree divided by the total number of trees in the parkland Eq. (3).

$$m = \frac{TCa}{N} \tag{4}$$

With m: average crown cover.
TCa: total crown cover of agroforestry parkland.
N: total number of trees in the agroforestry parkland.

2.5 Trees number

United Nations Food and Agriculture Organization [27] has defined forest as land with a tree canopy cover higher than 10% in an area larger than 0.5 ha. Based on this definition the threshold number of trees (T_t) in the farms has computed using the Eq. (4).

$$T_t = 1000^{-3} \frac{TCa}{N}$$

With.
T_t: Threshold number of trees.
TCa: total crown cover of agroforestry parkland.
N: total number of trees in the agroforestry parkland.

2.6 Data analysis

Minitab 17, Excel and Sigma plot 13.0 software were used for statistical analysis. One-way Fisher Pairwise Comparisons and Tukey Pairwise Comparisons tests using One way Anova were utilized to see how tree crown cover and tree cover differed within the three climatic zones and the significance level was stablished at 95 percent for all tests done in this study.

3. Results and discussion

3.1 Mean diameter

Average diameters observed in Soudan-Sahel zone were significantly higher than average diameter observed in Sahel strict zone and Soudanian zone (**Table 1**).

Climatic zone	Individual number	Density (tree/ha)	Mean diameter (cm)	p-value
Soudanian zone	1154	37	26.490 ± 0.819	0.001
Soudan-Sahel	1054	30	27.697 ± 0.935*	0.001
Sahel strict	884	35	24.010 ± 0.857	0.001

Table 1.
Individual woody species number, tree density and average diameters per climatic zone.

3.2 Mean height

Tree height in agroforestry system decrease from Soudanian to Sahel Strict zone (**Figure 2**).

This decrease can be explained by the fact that in Sahel Strict zone natural forest is very scarce trees on farm should play multiple role to cover firewood need through tree pruning.

3.3 Trees crown cover

The results revealed a mean tree crown cover of 66.25 m^2, 59.92 m^2 and 42.1 m^2 respectively in Soudanian zone, Soudan-Sahel zone and Sahel strict zone, respectively. The mean tree crown cover was significantly different at ($p < 0.05$) from one climatic zone to another (**Figure 3**).

The differences detected between mean tree canopy cover in the three climatic zones can be explained by different dominant tree species in the three sites of study. Indeed, individual tree crown cover varies significantly from one species to another (**Table 2**). Also, farm management practices such as tree pruning (**Figure 4**) can have a lot of influence on tree crown cover.

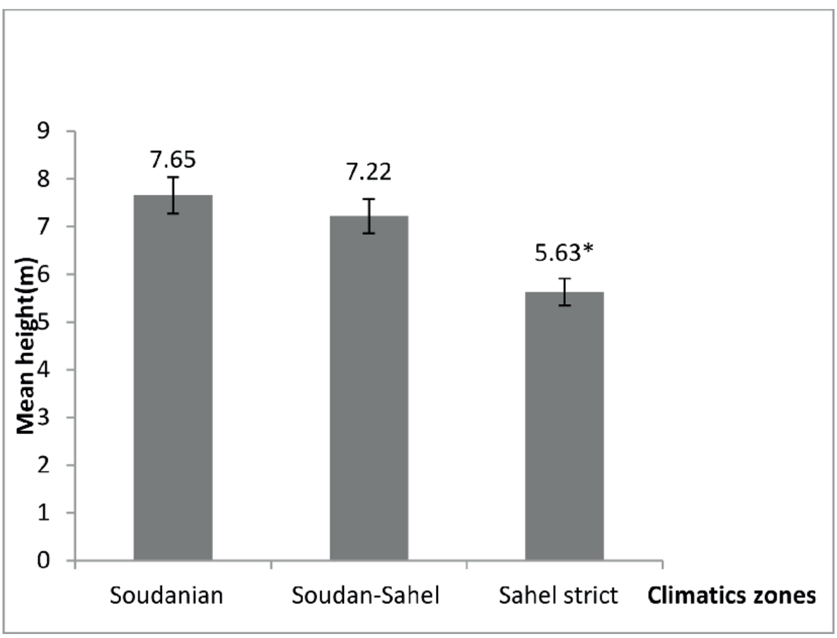

Figure 2.
Mean height of tree in the climatic zones in Burkina Faso.

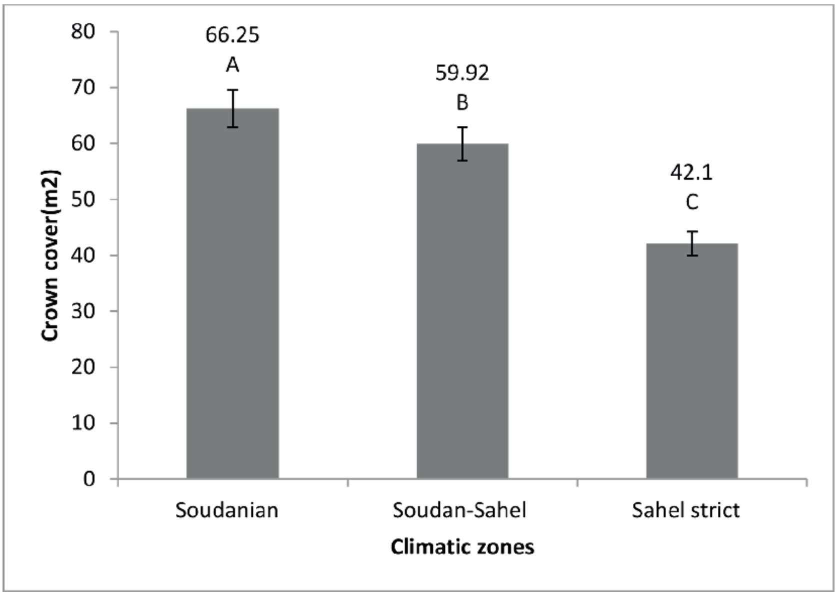

Figure 3.
Mean tree canopy cover in the study sites located in three different climatic zones in Burkina Faso, A Sudanian zone, B = Sudan-Sahel zone and C = Sahel strict zone.

Among the six major species found in the agroforestry parkland in Sahel-Strict zone, statistical analysis revealed significant difference in crown cover (p-v = 0.01) with high value of 63 ± 12.5 for *Lannea microcarpum* and low value of 8.99 ± 11.8 for *Adensonia digitata*. The lower crown cover of *Adansonia digitata* observed in this area can be explained by the fact that its leaves are usually harvested by farmers for stew/sauce preparation. However, the fruit of *Lannea microcarpum* is the most sought for ecosystem service by farmers. Therefore, a big canopy cover of this species augurs a promising fructification capacity. The type of ecosystem service provided by each tree species guide it crown cover management by farmers.

Climatic zones	Trees species	Average crown cover (m^2)	IVI (%)
Sahel strict	*Lannea microcarpum*	$63.71 + 12.5^{a}$	19
	Sclerocarya birrea	$53.86 + 11.18^{a}$	15
	Azadiratha indica	$48.49 + 11.18^{ab}$	13
	Balanites aegyptyaca	$25.99 + 11.19b^{c}$	11
	Adensonia digitata	$8.99 + 11.18^{c}$	8
	Feiderbia albida	$47.81 + 11.18^{ab}$	7
Soudan-sahel	*Vitellaria paradoxa*	$60.57 + 23.45^{ab}$	61
	Parkia biglobosa	$96 + 23.5^{a}$	6
	Bombax constatum	$48.7 + 26.21^{b}$	4
Soudanian	*V. paradoxa*	55.51 + 4.54	78

Table 2.
Average tree canopy cover (TCC) of trees in three municipalities in the three climatic zones of Burkina Faso.

Figure 4.
Tree management affecting tree crown cover in Sahel-Strict zone in Burkina Faso.

The funding of this work are comparable to Nelson et al. [28] results who shown that, the morphological characteristic of agroforestry tree species determined their canopy cover shape. Moreover, the morphological characteristic of the species and trees management practices developed by farmers also contributed to shape the canopy cover [1, 5, 8, 29]. According to Bationo et al. [1, 5], farming system should play various roles to cover farmers' needs in term of wood and non-timber products where the forest resources are scarces. According to DIFOR [30] on forest resources

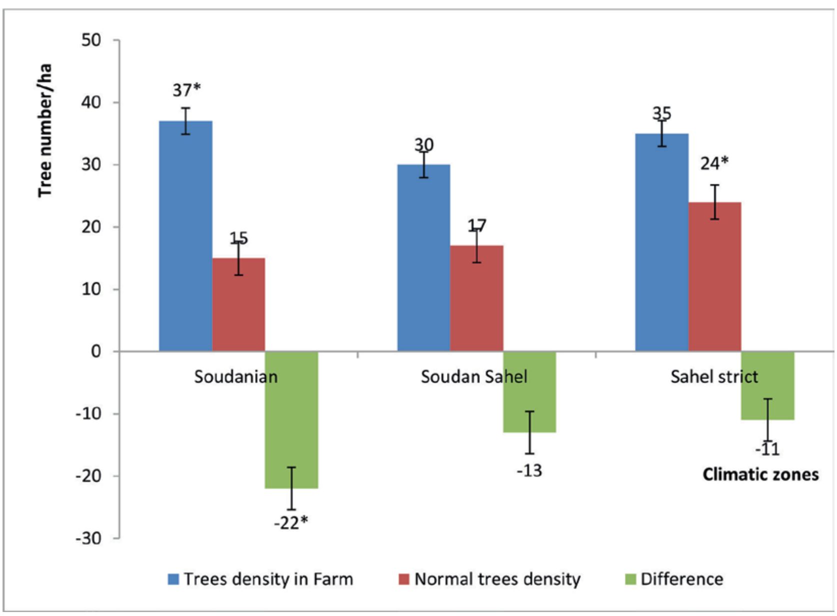

Figure 5.
Maximum tree number per hectare for the three climatic zones in Burkina Faso.

availability, it has been argued that in Burkina Faso, forest resources decreased from the southern to the northern region of the country.

3.4 Trees number

Trees density on farm were about the double of trees threshold number in Soudanian zone (37 trees/ha vs. 15 trees/ha), one and half both in Soudan Sahel and Sahel strict zones (30 trees/ha vs. 17trees/ha and 35 trees/ha vs. 24 trees/ha). The threshold number decrease from Sahel-strict zone to Soudanian zone (**Figure 5**).

The decrease of threshold number can be explained by the higher crown cover observed in Soudanian zone compare to the smaller crown cover in Sahel-strict zone (**Figure 5**).

4. Conclusions

The investigation has revealed that tree number threshold is a function of tree species and climatic zone. Based on the study data, average trees number threshold increased from high rainfall area (Sudanian zone) to low rainfall area (Sahel-Strict zone). One farm trees density were 37 trees/ha, 30 trees/ha and 35trees/ha respectively. However the average tree number threshold is 15 trees/ha, 17trees/ha an 24trees/ha are in Soudanian zone, Soudan Sahel and Sahel strict zones respectively. The difference of tree number/ha compare to normal were also 22 trees/ha; 13trees/ha and 11trees/ha in Soudanian zone, Soudan Sahel and Sahel strict zones respectively. To encourage trees conservation in agroforestry parklands, it is highly recommended that in addition to other ecosystem services, trees carbon stock in agroforestry system be assessed to determine the benefit that could be gained by smallholder farmers in carbon payment using REED+ initiative.

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Chapter 6

Efficient Management of Environmental Resources through Sustainable Crop Production Intensification

Chris Adegoke Fayose

Abstract

Agriculture is crucial to the survival and well-being of the populations of most nations. It is the single most important means of livelihood and foreign exchange earnings for many nations globally. Crop Production is the bedrock of agriculture on which most other agricultural activities depend, because of the ability of plants to manufacture their food via photosynthesis, which is an essential phenomenon for the sustenance of the natural system. Thus, most other agricultural activities depend directly or indirectly on crop production. As a result of the exponential increase in world population, leading to a significant reduction in agricultural land due to urbanization; deforestation, air pollution, erosion, climate change, and consequently, food insecurity; measures must be put in place to ensure crop production intensification via sustainable and environmentally safe methods that guarantee food security. The principles of sustainable crop production intensification discussed in this Chapter include optimum tillage method, land and water resources management practices, suitable choice of agricultural system, precise crop management techniques, and bioremediation, in an already contaminate environment.

Keywords: agriculture, climate change, food security, integrated pest management, organic farming, precision agriculture, production intensification, soil and land resource management, sustainable agriculture, urbanization

1. Introduction

Agriculture is the global largest industry. It provides employment for more than a billion people and generates in excess of $1.3 trillion dollars' worth of food annually [1]. Pasture and cropland occupy about half of the Earth's habitable land and provide habitat and food for a good number of organisms [2]. Most agricultural activities are dependent on environmental resources which must be properly managed to ensure food security. When agricultural operations are sustainably managed, they can preserve and restore delicate habitats, protect water resources, and improve soil health and water quality. Conversely, poor management practices have potentially grave negative impacts on the environment and the ecosystem.

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This fact is even truer for crop production. Crops occupy the primary producers' level of the food chain. Thus, they manufacture their food using environmental resources, i.e., soil nutrients and sunlight. As a result, all other life forms depend directly or indirectly on plants for food and survival. Crop production is therefore considered the bedrock of agriculture [3].

Among others, factors which are social, economic and biological in nature; environmental factors, especially edaphic and climatic factors are of utmost importance in crop production. The soil provides anchorage, and a growth medium for plants. It supplies the necessary nourishment needed for crop growth and also houses essential organisms and micro-organisms which are responsible for the recycling of nutrients necessary for crop growth [4].

The rate of partitioning of photosynthetic assimilates for dry matter production also depends in no small measures, on the amount of nutrient and moisture in the soil, as well as favorable climatic conditions including humidity, temperature, and most importantly solar radiation [5]. Unfortunately, there are several modern socio-economic and environmental challenges to overcome in our bid to optimize agricultural productivity especially in the area of crop production. Such challenges include, industrialization leading to increased environmental pollution, urbanization causing reduced access to fertile land for agricultural activities, fast declining soil fertility from continuous cultivation of the same area of land as a result of urbanization, poor management practices on the limited land, indiscriminate use of agricultural input to compensate for the aforementioned problems leading to more dangerous environmental and hydrological pollutions, deforestation interacting with environmental pollution to force excessive warming of the environment and consequently, climate change, among a number of other challenges [6].

It is a fact that the world's population is increasing. The rate of increase is projected to intensify in the coming decades [7]. As a result, the level of food production must increase to meet the need of the teaming population despite the significant decrease in available land resources which is expected to further decline as the population increases. Production intensification on the available environmental resources is therefore of critical importance in order to ensure optimum crop growth. This involves social, cultural and environmental modifications which must be carefully done in ways that are environmentally and ecologically safe in order to preserve the delicate ecosystem.

This Chapter highlights the principles that should be considered to ensure sustainable and ecological intensification to guarantee optimum food production in a safe and friendly environment in light of the myriad of contemporary challenges facing agricultural, especially crop production.

2. Crop production intensification and sustainable/ecological intensification

2.1 Crop production intensification

These are the method employed to increase crop yield output per unit area of land in time and space.

2.2 Sustainable/ecological intensification

This is production intensification carried out using methods that ensure environmental health and safety. This involves increased production without leaving any harmful effect on the biotic and abiotic factors of the environment including land and water resources. It also ensures continued or sustainable production.

3. Tillage operations

The necessary conditions for optimum seedling emergence and proper growth after sowing include adequate moisture availability in the growth medium, favorable temperature, proper soil aeration, favorable soil structure, and for some crops, light availability. To provide the necessary conditions for seed germination and emergence, appropriate seedbed must be prepared according to the requirements of each crop. This is achieved through tillage. The purpose of the seedbed is to provide optimum conditions for seed germination, seedling emergence and growth [8]. Tillage also eliminates competition from weeds; and could increase soil nutrient availability to the seed/seedling. Tillage is the act of land preparation prior to planting. It involves a series of activities carried out in sequence to get the agricultural land ready for crop cultivation. The type and level of tillage depends on a number of factors including soil and the crop intended for cultivation. For any given location, the choice of tillage will depend on any of the following (**Table 1**) [9].

Thus the right tillage for specific crop must be done to ensure optimum performance. There are three broad tillage methods used for seedbed preparation. They are conventional, minimum, and conservation tillage [10]. The goal here is to carry out tillage operations in a manner that helps conserve the precious soil resources and prevents damage to the structure of the soil or open up the soil to erosion and other forms of disturbances [11]. In conventional tillage, heavy machineries like the tractor are used to open up the land and get it to the desired seedbed conditions. The compaction that often results from the movement of these machines is capable of causing a potentially dangerous alteration to the soils structure via compaction which reduces aeration and affects the soil microorganisms and eventually disrupts the addition of organic matter to the soil. It is therefore very important to minimize the exposure of agricultural land to such heavy equipment where possible. Different crops also require different levels of soil preparation. For instance,

Soil factor Relief/slope Erodibility Erosivity Rooting depth Texture and structure Organic matter content Minerology	**Climatic factor** Rainfall amount and distribution Water balance Length of growing season Air and soil temperature Length of raining/rainless period
Crop factor Duration of growth Root characteristics Water requirement Seed	**Socio-economic factors** Farm size Availability of power Family structure and composition Labour situation Access to cash and credit
Other government policies	**Objectives and priorities**

Table 1.
Factors affecting choice of tillage [9].

Crop	No-till (t/ha)	Conventional till (t/ha)	Soil type
Maize	3.64	2.58	Clay loam
Soybean	2.36	1.97	Clay loam
Sorghum	3.30	3.42	Sandy clay loam
Groundnut	4.66	4.61	Sandy clay loam

Table 2.
Yield of some arable crops under two tillage methods [14].

maize (*Zea mays* L.) performs well irrespective of the tillage method used as long as important crop management practices are deployed. Cowpea [*Vigna unguiculate* L. (Walp)] often requires a well pulverized soil to do appreciably well. Vegetables such as green amaranth (*Amaranthus* sp.), African jute mallow (*Corchorus olitorus* L.) and *Celocia agentea* require a high level of soil pulverization to ensure optimum seedling emergence and growth. The tuber crops like potato (*Ipomoea batatas* (L) Poir), yam (*Dioscorea* sp.) and cassava [*Manihot esculenta* L. (Crantz)] require hips and ridges for optimum tuber production. It is generally recommended that Conservation tillage be done or tillage be kept to the minimum level that supports proper growth of specific crops [10, 12]. This reduces the disposition of the cultivated land to soil compaction from excessive use of heavy machineries, soil erosion, and excessive nutrient leaching beyond crop root-zone, nutrient volatilization, and excessive loss of soil moisture due to evaporation. It also conserves energy expended in land preparation [11] and reduces carbon emission, thereby, in part, mitigating climate change in the process. According to Li et al. [13] conservation tillage can improve soil physical structure and water storage, protect moisture, and increase crop yield. However, the long-term adoption of a single tillage method may have some adverse effects on soil and ecological environment, even though it favors increased crop yield. They therefore recommended integrating conservative tillage methods with other methods to ensure long term sustainability (**Table 2**).

Result of the study by Thiagalingam et al. [14] revealed that yield for all crops were higher under the no-till condition than in conventional tillage over a four year period of maize-cowpea and sorghum-groundnut rotations.

3.1 Conservation tillage methods

a. **Mulch tillage:** this is based on the principle of causing least disturbance to the soil and leaving the maximum of crop residue on the soil surface, while obtaining a quick germination and adequate stand in the process. A chisel plow is often used for this purpose.

b. **No tillage:** this is a specialized method of tillage where planting is done in the soil with minimal disturbance. The surface residue of such system is important for soil and water conservation. Weed control is generally achieved by the use of herbicides and crop rotation.

c. **Strip/zonal tillage:** this divides the land into the planting zone and the soil nutrient/water management zones. The planting zone about 10 cm long is tilled while the inter-row spaces are left untilled to conserve resources.

d. **Ridge tillage:** ridges are cultivated at planting to optimize soil nutrient for seedling growth and reduce erosion.

e. **Minimum tillage:** Minimum tillage minimizes tillage operation to the lowest level that supports the desired crop.

As earlier mentioned, it is also very important to consider the soil type and physical characteristics before deciding on the tillage method to use to ensure maximum conservation of resources. Different soils have different proportion of silt, sand, clay and organic matter which impact their water and nutrient holding capacity, hence, different levels of tolerance to tillage. Tillage must be minimized on soil with high proportion of silt and sand. Soils with a high proportion of clay and organic matter could tolerate higher level of tillage without a major risk of loss of soil resources through leaching, deep percolation and surface runoff [15]. Where conventional tillage is necessary, tillage must account for land topography and slope. According to Oost et al. [16], in areas with high gradient, there is a high tendency of movement of water downslope. Erosion and nutrient movement is also expected to follow the slope. It is therefore expected in most case, that the lower areas of the field would be more fertile than the higher area. The direction of tillage must therefore be that which ensures the control of erosion i.e., tillage must be done across slope, and not along it [17].

4. Land and water resources management

Land, healthy soils, water and plant genetic resources are key inputs for food production. Their growing scarcity in many parts of the world makes it imperative to use and manage them sustainably. Boosting yields on existing agricultural lands, including restoration of degraded lands, through sustainable agricultural practices would also relieve pressure to clear forests for agricultural production. Wise management of scarce water through improved irrigation and storage technologies, combined with development of new drought-tolerant crop varieties, can contribute to the sustenance of dry land productivity.

Halting and reversing land degradation will also be critical to meeting future food needs. Given the current extent of land degradation globally, the potential benefits from land restoration for food security and for mitigating climate change are enormous. However, there is also recognition that scientific understanding of the drivers of desertification, land degradation and drought is still evolving [18].

4.1 Land management

4.1.1 Agricultural systems

The agricultural systems may seem like an old practice, but the concept is still relevant even in contemporary agriculture. As highlighted above, one of the major limiting factors in the modern day agriculture is access to land amidst the exponential increase in population. As population increases, the demand for food and other social infrastructures increase. These require opening up the precious forest reserves. This is often done without any plan to replace the forest reserves that are being displaced. Deforestation is one of the major causes of the significant increase in the amount of greenhouse gases (GHGs) in the atmosphere [19]. This results in global warming leading eventually to the prevalent and imminent climate change impacts. Trees are major sinks for some GHGs especially CO_2, which is one of the gases easily emitted as a result of anthropogenic activities in the environment. CO_2 has an atmospheric resident time (ART) of upwards of 50 years and will remain in the atmosphere for that period if not removed somehow from the atmosphere. Plants, especially trees, serve as major sinks for CO_2 by using it as a raw material in the synthesis of glucose via photosynthesis. Therefore, when deforestation is done without afforestation, the precious environmental purification tendencies of the heavy vegetation are also nullified thus leading to a harmful concentration of the gases in the atmosphere, hence, global warming and climate change. Therefore, managing the current land resources available for agricultural production without necessarily destroying the forest reserves is expedient for a healthy environment.

Mixed farming, arable farming, crop rotation, Shifting cultivation and bush fallowing are some of the farming systems that have been used in agriculture.

4.1.1.1 Bush fallowing versus shifting cultivation

Bush fallowing and shifting cultivation have a subtle difference between them. The basis of both systems is to give enough time for a depleted agricultural land to recover while continuing crop cultivation on a different, more fertile piece of land. Shifting cultivation is becoming less friendly because it involves the opening up of fresh land area, as a result of the continuous reduction in agricultural land due to urbanization [20]. This destroys forests and opens the environment up to adverse effects including climate change. Bush fallowing, on the other hand does not open up a new land or destroy forest. It only rotates on the existing agricultural land, such that a depleted area is given enough time to fallow and recover its resources. While it is necessary to stress that the destruction of forest reserved is not encouraged as explained above, it is important to note that a fallow period is necessary where alternative agricultural land exists where production intensification could be safely done while the depleted agricultural land is allowed time to recover through bush fallowing [21].

4.1.1.2 Mixed farming, arable farming and crop rotation

Mixed farming is simply a system where crop production is coupled with animal husbandry. This is a complementary system where crop and animal bye-products each support the other and plays a major role in the conservation of the precious environmental resources; and such is crucial for sustainable intensification and therefore, highly encouraged.

Arable farming which involves production of short duration crops alone, either on a subsistence or commercial level must be accompanied with crop rotation where crops that supplement the soil nutrient e.g., legumes and pulses are rotated with crops that deplete soil nutrients such as the cereals. By so doing the level of soil nutrient and overall soil health could be maintained.

4.1.2 Fertilization

This involves every measure taken to supplement the natural nutrient present in the soil. This is done by the addition of compounds to the soil which are capable of increasing the levels of essential nutrients in the soil needed for crop growth. Such compounds added to the soil for the aforementioned purpose are known as fertilizers. Fertilizers could either be organic or inorganic (synthetic) in nature. Both organic and inorganic fertilizers have their pros and cons. For instance, inorganic fertilizers are formulated to contain special blend of nutrients for specific crop growth and developmental requirements and for unique soil requirements. They are also highly soluble and nutrients are readily available for crop growth [22].

For this reasons, inorganic fertilizers become an easy choice for most farmers especially as pressure increases on agricultural produce from rising population. Unfortunately, application of inorganic fertilizers for an extended period significantly alters soil physical and chemical properties and often leads to extensive soil degradation [23]. The high solubility of this group of fertilizers also means that their nutrients are easily leached beyond the root zone in the event of a heavy rainfall for instance. They also pose a risk to the environment as they are easily eroded to non-intended targets such as nearby water bodies where they often cause water pollution and endanger aquatic species. Organic fertilizers or manures on the other hand are usually too bulky and messy compared to their inorganic relatives and the release of nutrients usually takes a while sequel to the breakdown and release of organic matter by natural processes which also depend on other environmental factors both biotic (soil micro-organisms) and abiotic or climatic (e.g., temperature) factors. These make inorganic manures immediately unattractive to many stakeholders. Yet, organic fertilizers are highly environmentally friendly and ensure soil health and conservation, and are therefore highly recommended for sustainable crop production intensification [23]. Organic manures are also cheaply available especially as the costs of inorganic fertilizers continue to increase globally. The benefits of organic fertilizers therefore outweigh their disadvantages and should be the main source of soil nutrient supplement. Inorganic fertilizers should be used only when absolutely necessary, and as precisely as possible (i.e., the exact quantity needed per unit area of land should be applied and not more [24].

4.2 Water resources management

Water is a critical input for agricultural production and plays an important role in food security. Irrigated agriculture represents 20 percent of the total cultivated land and contributes 40 percent of the total food produced worldwide. Irrigated agriculture is, on average, at least twice as productive per unit of land as rain-fed agriculture, thereby allowing for more production intensification and crop diversification [25].

Due to population growth, urbanization, and climate change, competition for water resources is expected to increase, with particular impact on agriculture. Population is expected to increase to over 10 billion by 2050 [7], and whether urban or rural, populations will need food and fiber to meet their basic needs. Combined with the increased consumption of calories and more complex foods, which accompany income growth in the developing world, it is estimated that agricultural production will need to expand by approximately 70% by 2050.

Agriculture accounts (on average) for 70 percent of all freshwater use globally, and an even higher share of "consumptive water use" due to the evapotranspiration from crops [26]. Therefore ensuring efficient use of water in agriculture would go a long way to ensure conservation of the precious environmental resource.

Conservation of water resources starts from the tillage method used in crop production. Employing conservation tillage ensures as much soil moisture is conserved as possible. Mulching, planting of cover crops, irrigation especially smart irrigation, water harvesting and storage are measures that could conserver water resources.

4.2.1 Mulching

Mulching involves the use of plant materials from weeding; or other materials such as plastic or polythene to achieve different agronomic purposes including conservation of soil water, reduction of soil surface temperature to favor optimum growth, addition of nutrient to the soil and sometimes weed control and crop protection from harmful pests and environmental conditions. This process is relevant both for soil and soil water resources conservation [27].

4.2.2 Cover crops

According to Delgado et al. [28], cover crops are key tools that could contribute to increased yields, conservation of surface and ground water quality, reduced erosion potential, sequestration of atmospheric carbon and improved soil quality and health. Cover crops are usually leguminous plants which form branches and twine over and essentially cover and screen the land from direct atmospheric impact from sunlight or rainfall. The leguminous plants used as cover crop add precious nutrients like nitrogen to the soil in addition to the protection of soil from erosion and excessive water loss from evaporation.

4.2.3 Irrigation

This should be done to supplement the natural soil moisture. Some environments receive very little amount of annual rainfall as a result of which irrigation is the main source of water to the soil. Other environments receive significant amount of rainfall and only need irrigation as a supplement where there is either cessation of rainfall or during dry spells. It is crucial for irrigation to be as precise as possible. That is, the exact amount of water needed for the soil and crop requirement should be applied. Addition of too much amount of water amounts to wastage of the precious water resources and could lead to undesirable conditions such as surface flooding, lodging, nutrient leaching or worse still contamination of non-target areas in the case of washing of agricultural chemicals to location where they are not intended. There have been advents of technologies that monitor soil and crop water requirements and trigger the release of the precise amount of water to the area based on the specific requirements of the crop in modern day agriculture. This process is termed Precision Irrigation which is a component of a group of modern and more efficient techniques of agriculture and crop production known as Precision Agriculture (PA) [29]. The use of remote sensing technologies and Internet of Things (IoT) sensors is becoming widespread in this regard [30]. Where there is no access to sophisticated facilities, irrigation technologies such as the drip setup should be promoted to ensure more efficient supply of water to crops.

In addition to drip irrigation mentioned above, subsurface soil irrigation where pipes are installed beneath the soil, thereby supplying water to the root zone of the crop is also highly efficient. This ensures that the crop receives the needed amount of water while protecting soil moisture from excessive surface heat, thereby significantly reducing water loss through evaporation. The soil surface is also freed up for other agronomic/crop management activities.

The benefits of the old gated pipe irrigation method could also be harnessed in the modern day agriculture to conserve water. This process spread water into unlined ditches and allowed it to saturate the soil, while preventing waste by limiting its flow into those ditches. It's a very simple technique that can easily be upgraded by incorporating IoT sensors in the soil and remote or autonomous gates in each of the pipes.

4.2.4 Reservoir for water

Where there is good amount of annual rainfall, and even in environments with low rainfall, efforts must be made to develop storage facilities to collect and store water from every rainfall which could then be processed and applied accordingly, for different agricultural operations [31–33].

4.2.5 Importance of level field for resource conservation

Fields with higher gradient are likely to experience higher water loss via runoff and higher nutrient erosion [34]. One of the biggest sources of water waste is runoff because the fields or gardens where planting is done aren't perfectly level, so any water that does not soak into the soil immediately flows away. Crop production site must be carefully selected such that it is on a level plane free of major slope, and where there are slopes, effort should be made at leveling the land out before planting operations. Laser land leveling reduces or even eliminates the problem of runoff by using lasers and other tools to make the field perfectly level before crops are planted, reducing runoff and, by proxy, preventing waste and promoting conservation.

4.2.6 Water reclamation from runoff

It is important to reduce water loss from runoff by selecting or leveling the agricultural land as much as possible. However, this may not completely stop runoff especially in places that experience frequent heavy rainfall concentrated in certain periods of the year. Therefore, setting up means of reclaiming water loss from runoff usually referred to as the tail water can be very useful. This is especially useful in farm enterprises that practice organic farming as there will be less likelihood of water pollution from agro-chemicals and the reclaimed water could be used for irrigation and other purposes [35].

5. Crop management/agronomic practices

5.1 Cropping methods

There are different cropping systems to consider prior to cultivation depending on the intended crop(s) and environment.

Sole cropping involves growing only one crop at any particular time. This can take the form of monocropping, growing a single crop of choice on a piece of land at any particular time; or monoculture: Growing a single crop over and over in an area for a long time. In the sole cropping system, crops must be rotated so that the soil nutrient level could be maintained. Crops that deplete environmental resources, maize for example could be rotated with those which are capable of replenishing the soil such as groundnut or soybean. Monoculture should be discourages unless the crop in such system is one that can maintain nutrients in the soil.

Multiple cropping on the other hand involves growing more than one type of crop with different patterns such as inter cropping – planting two or more crop species on a piece of land at the same time with a specific spatial arrangement; mixed cropping – growing two or more crop species randomly on a piece of land at once with no specific arrangement; sequential cropping/crop rotation – growing two or more crop in succession from one planting period to another; and relay cropping – planting another crop "b" before the initial crop "a" is harvested. Multiple cropping, with a smart choice of the right combination of crops based on nutrient requirements, physiology, gross morphology etc., could aid intensification of crop production while preserving soil and other precious environmental resources.

5.2 Planting material

Not all crops may grow and successfully complete their life cycle in an environment. A good knowledge of the suitability and adaptability of the crop to the area is needed prior to cultivation. Subsequently, decision must also be made on the right crop cultivar/variety to be grown with respect to environment and season. Crops must be carefully selected to reflect the capacity of the environment to support such crop without any adverse effect on the environment. Environmental resources efficient crop cultivars that have been improved for drought tolerance, higher yield, increased levels of essential nutrients, short generation time and disease resistance/tolerance should be selected to ensure conservation of environmental resources and sustainable production intensification.

5.3 Timing of planting

Planting at the optimum planting dates (DOP) could optimize environmental resources and ensure optimum crop yield [36].

The study in **Figure 1** investigated the effect of planting dates on maize grain yield evaluated over 42 weekly planting dates in 2 years under natural field conditions. Results showed that planting early each year, with the first few rains optimized grain yield. A steady decrease in grain yield was observed as planting was delayed [36].

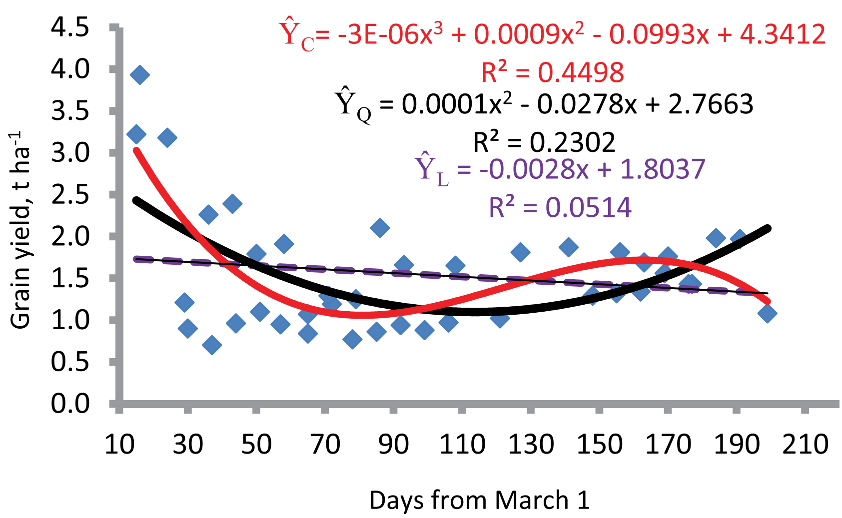

Figure 1.
Mean grain yield (t ha^{-1}) by DOPs of five maize varieties evaluated over 42 different planting dates at the OAU T&R farm in 2016 and 2017.

A good number of investigations and recommendation can be found in the literature on the optimum DOPs for different crops in different environments. Environmental resources that could be optimized include soil resources, solar radiation and soil moisture. Planting at the optimum planting period ensures maximum crop yield and avoidance of crop failure from unpredictable weather condition in case of agricultural production that is dependent on the natural environmental conditions. This is even more important in light of the prevailing and imminent climate change scenarios.

5.4 Planting density

This is simply the population of cultivated crop per unit area of land. The number of plants per stand (in crops with the possibility of multiple plants per stand e.g., maize) and the spacing between each stand determine the plant population. Planting at the optimum density ensures optimum crop efficiency and performance [24].

Planting at a density too high for the land area could deplete soil resources from excessive competition and cause poor crop performance. Planting at a density lower than the soil capacity also results in low yield per unit area of land and input. For instance with a higher spacing and low plant population, weed could be a bigger problem. Planting at the optimum density ensure optimum supply of nutrient from the soil and maximum interception of solar radiation for photosynthesis while also controlling weeds in part, when canopies touch and shade the soil surface from sunlight thereby starving the weeds of solar radiation and reducing their growth in the process [3].

Agro-climatic zone		Planting density	Grain yield Kg/ha
Rainforest		66,666	2477a
		88,888	2594a
		133,333	2186b
	$LSD_{0.05}$		138
Marginal rainforest		66,666	2734a
		88,888	2595a
		133,333	2277b
	$LSD_{0.05}$		176
Southern Guinea Savannah		66,666	3162a
		88,888	3098a
		133,333	3015a
	$LSD_{0.05}$		236
Northern Guinea Savannah		66,666	3032a
		88,888	3029a
		133,333	3095a
	$LSD_{0.05}$		311

Table 3.
Means of grain yield and some agronomic traits of extra-early and early hybrids evaluated under varying plant densities in five agroclimatic zones of Nigeria in 2015 [24].

Table 3 adapted from a study by Ajayo et al. [24] showed the yield performances of maize varieties under different densities in different agro-climatic zones of Nigeria. In the rainforest/marginal rainforest zones where there was significant difference in yield performance under different densities (i.e., in the 66,666 vs. 88,888 vs. 133,333 plants/ha density contrasts), the density level that guaranteed the highest grain yield should be used i.e., 88, 888 plants/ha. In the savannah where there was no significant difference in yield, the highest density (133,333 plants/ha) is then ideal for intensification purposes.

5.5 Fertilization

In addition to the general soil management practices which have been covered earlier in this Chapter starting with tillage, soil fertilization in response to crop demand is an essential crop management/agronomic practice. It is important to supply the needed level of fertilization to each crop when necessary, no more no less! This ensures optimum crop growth and avoids waste of agricultural input and minimizes environmental pollution. Studies have suggested the optimum rate of organic and inorganic fertilizer needed by different crops at separate growth and developmental stages [37].

5.6 Management of Pests and diseases

Diseases and pest management is achieved by several methods that have been described earlier in this Chapter. These include choice of suitable agricultural land, correct tillage operation, suitable crop/crop cultivar selection, right choice of cropping system, and timing of planting operations to avoid specific periods of higher diseases and pest occurrences among other measures. These help manage diseases even before they occur. Carefully observing the aforementioned procedures could reduce the incidences of diseases during the crop growth cycle thereby decreasing the need for special control measures. Consequently, resources for pesticides are conserved and environmental pollution from synthetic pesticides is reduced.

Where application of pesticide is necessary, the choice and concentration must be precise for the specific pest or disease situation, avoiding injury to non-target and even potentially beneficial organisms and the environment must be of utmost consideration. The general methods for pest management and control are mechanical - physical objects such as traps, machines, and devices including manual weeding; Cultural – modification to agricultural practices and techniques, planting pests/diseases resistant/tolerant hybrids etc.; Biological – using natural enemies of pests (prey or diseases), genetics, and natural chemicals such as pheromones; Chemical – applying substances that are poisonous to the pests, such as sprays, dusts, and baits. Cultural and biological methods of pest and diseases control should be amplified as they are more environmentally friendly. Chemical method should be employed only when absolutely necessary and the indiscriminate application of chemicals should be avoided because such often comes at a great danger to the environment by polluting land and water resources and destruction of non-target organisms [38].

5.6.1 Integrated pest management (IPM)

This has been well discussed in the literature to involve an integration or synchronization of all the method of pest control to ensure optimum and efficient pests and diseases management. It involves selecting the control method(s) that are best for the disease/crop. This is important in ensuring ecological/sustainable intensification [38].

5.7 Harvest operation

Harvesting must be timely and done as recommended for each crop. Timely harvesting conserves resources and prevents crop deterioration due to precocious germination and other phenomena. It also frees up the land as quickly as possible to pave way for further cultivation.

6. Precision agriculture (PA)

There are many elements of traditional farmer knowledge that, enriched by the latest scientific knowledge, can support productive food systems through sound and sustainable soil, land, water, nutrient and pest management, and the more extensive and safe use of organic fertilizers. An increase in integrated decision-making processes at the national and regional levels is needed to achieve synergies and adequately strike a balance among agriculture, water, energy, land and climate change. This can be achieved through PA. PA is the science of improving crop yields and assisting management decisions using high technology sensor (Remote Sensors, RS) and analytical tools (Geographic Information System, GIS) [39]. PA is a relatively new concept adopted throughout the world to increase production, reduce labor time, and ensure the effective management of fertilizers and irrigation processes. It uses a large amount of data and information to improve the use of agricultural resources, yields, and the quality of crops [40]. PA is an advanced innovation and optimized field level management strategy used in agriculture that aims to improve the productivity of resources on agriculture fields. Thus PA is a new advanced method in which farmers provide optimized inputs such as water and fertilizer to enhance productivity, quality, and yield. It requires a huge amount of information about the crop condition or crop health in the growing season at high spatial resolution. Independently of the data source, the most crucial objective of PA is to provide support to farmers in managing their business. Such support comes in diverse ways, but the end result is typically a decrease of the necessary resources.

Modern agricultural production relies on monitoring crop status by observing and measuring variables such as soil condition, plant health, fertilizer and pesticide effect, irrigation, and crop yield. Managing all of these factors is a considerable challenge for crop producers. The rapid enhancement of precise monitoring of agricultural growth and its health assessment is important for sensible use of farming resources and as well as in managing crop yields. Such challenges can be addressed by implementing remote sensing (RS) systems such as hyperspectral imaging to produce precise biophysical indicator maps across the various cycles of crop development [40]. Such indicators are analyzed and used for precise crop management. This leads to more efficient use and management of environmental resources thereby enhancing safe and environmentally sound crop production intensification.

6.1 Modeling

Different models have been developed with good levels of accuracy to predict the growth and development of different crops in relation to different environmental conditions such as soil climate and health cum general atmospheric conditions. Such models are used to forecast the performance and yield of crops before planting, given a set of environmental and ecological conditions [41]. This is important in deciding the level of intensification required to reach a desired level of production and at what cost to the environment. This budding area of research is even more valuable with the prevailing climate change scenarios, as crop production could be better adapted to climate change with the development and utilization of models capable of predicting the impact of a plethora of simulated extreme weather scenarios on crop production and devising means of adapting crop production to such scenarios in order to ensure food security while also securing the environment in the process. This would eventually lead in part to climate change mitigation [41].

7. Remediation

This is the term used to describe a group of processes used to consume and break down environmental pollutants, in order to clean up the environment after pollution. Agrochemicals are one of the major sources of pollution to the environment. Other sources of environmental pollution include nuclear and radiological accident and non-nuclear industries, such as petrochemical and mining, as well as harmful wastes generated as a result of a myriad of anthropogenic activities [42].

There are three main categories of remediation. They include soil remediation, ground/surface water remediation and sediment remediation. Remediation in the different categories is usually achieved by different techniques each with its own advantages and disadvantages. These remedial techniques can be physical, chemical, thermal or biological in nature depending on the contaminant that is being dealt with. Biological remediation also known as bioremediation is the use of either naturally occurring or deliberately introduced biological organisms to consume and break down environmental pollutants, in order to clean up an environmental pollution. According to Palansooriya et al. [43], it is a process where biological organisms are used to remove or neutralize an environmental pollutant by metabolic process.

Despite the strengths of physicochemical remediation, bioremediation is fast gaining advantage and wider approval over the physicochemical methods for environmental remediation despite being significantly slower. This is because it cleans up water sources, creates healthier soil, and improves air quality with much less disruption and intrusion; and can facilitate remediation of environmental impacts without damaging the delicate ecosystems. The agrarian environment should be evaluated from time to time for possible pollution from chemicals with the view to bio-remediate the environment where significant pollution is detected.

8. Conclusion

Environmental resource conservation, especially via agriculture is a key area that concerns all nations of the world irrespective of the level of development. Currently, some countries are more conscious and shrewd with the utilization of environmental resources especially for agricultural purpose, while others are not at the same level of consciousness. It is necessary therefore to increase awareness via conferences like the United Nation (UN). Each country should be encouraged to treat this subject with the same manner of seriousness as climate change, and stakeholder should take urgent steps to develop policies and programs to ensure that agricultural production is intensified to ensure food security in an environmentally and ecologically sound manner which preserves precious environmental resources.

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Section 4

Water Resources Management

Chapter 7

Analysis of Missouri Floodplain Soils Along the Mississippi River and an Assessment of Ecosystem Services

Michael Aide and Indi Braden

Abstract

Floodplain ecosystems have been substantially altered because of land management decisions. Land management decisions have been made primarily for economic development, increased food demand, and reducing flood risks. Recently, increased attention has been devoted to restoring selected floodplain ecosystem services that have important benefits for habitat and wildlife, water purification, forest restoration, and carbon sequestration. Considering the Mississippi River floodplain as a portion of the state of Missouri, we summarize the key soil and soil features and elaborate on ecosystem site descriptions to support assessment of land management's influence on ecosystem services. Given the significant government investment in detailed soil mapping and development of the ecosystem site descriptions, the fusion of these two advancements is critical for evaluating ecosystem service restoration.

Keywords: soil genesis, forest soils, ecological site descriptions, soil health, ecosystem services

1. Introduction

The Mississippi River is the world's fourth largest river system, with the lower portion of the river supporting 10 million ha of floodplain forest wetlands. The establishment of 3500 km of levees has improved river navigation, barge transport, agriculture, and economic development. Although the economic savings from flood risk is substantial, a large portion of the floodplain (75–90%) is no longer influenced by flooding and its ecosystem services similarly altered [1].

Lewin reviewed floodplain evolution and geomorphology [2]. With an emphasis on the Mississippi River, Lewin noted the following typical characteristics: (i) the shallow floodplain gradient is approximately 0.1 m km^{-1}, (ii) the floodplain width varies between 40,000 and 200,000 m, (iii) the channel width is centered around 1000 m, and (iv) the channel width to floodplain width ratio varies from 0.025 to 0.005. Landform features include the presence of sandbars and an abundance of abandoned channels, levees, and scroll bars (scroll bars are a series of ridges formed from continuous lateral meander migration). Lewin further stressed that the average flow regime may be misleading when describing floodplain dynamics. Magilligan et al. [3] studied the historic flood of 1993 in the upper Mississippi River, documenting only minor overbank deposition and suggesting that substantial flow regimes may not result in significant soil disturbance. Because the soil maintained their textural and structural stability during the 1993 flood, the lack of significant soil disturbances reduced stream sediment transport.

Hupp et al. [4] documented changes in ecosystem services in North Carolina, western Tennessee, and Louisiana because of land management. Alterations to river dynamics because of dams, stream channelization, and levee and canal construction increase sediment transport and stream velocities. Mungai et al. [5] studied soil landforms in the Lake Victoria basin of east Africa. Soil analysis tended to show that ß-glucosidase activities, clay abundances, and phosphorus levels were more available or abundant in soils experiencing flood, whereas organic carbon and exchangeable potassium levels were more abundant or available in flood-protected soils.

Price and Berkowitz [1] investigated the Mississippi River flood of 2019, wherein there was more than 150 days of floodwater inundation. The study was concentrated along the states of Missouri, Arkansas, and Tennessee. The floodwater increased the abundance of woody debris and forest floor litter; however, many other hydrogeomorphic features were not significantly altered. The change in the abundances of woody debris and forest floor litter decreased the wetland's ability to detain floodwater, retain precipitation, recycle nutrients, and export organic carbon.

Guo et al. [6] investigated soil organic and inorganic carbon contents in the upper Yellow River Delta in China. The typical soil organic carbon contents centered at 9.3 g kg^{-1} for the surface horizons and 2.4 g kg^{-1} at the 80–100 cm soil depth. Soil inorganic carbon varied from 10.5 to 12.7 g kg^{-1}. The authors concluded that soil organic carbon increases influenced soil inorganic carbon accumulation. Along the Yellow River in China, Hou et al. [7] investigated reclamation efforts to improve soil organic carbon and soil inorganic carbon. Over the considerable timetable of this study, the authors documented that soil organic carbon increased by 2.7 Mg carbon ha^{-1} $yr.^{-1}$. The increase of soil organic carbon was greater for the 0–20 cm soil layer than the 80–100 cm layer. The inorganic carbon content increase was more modest and showed that the soil profile accumulation distribution differed across regions.

Using the lower Missouri River floodplain, Moore et al. [8] developed a factorial experimental design involving soil columns collected from sites having: (i) long-term agroforestry, (ii) row crop, and (iii) riparian forests. Nitrogen treatments were incorporated into the experimental design. The objective of the study was to discern if the greenhouse gas emissions of CH_4, N_2O, and CO_2 were influenced by vegetation and nitrogen fertilization practices. The long-term agroforestry plots exhibited the smallest CO_2 and N_2O emissions. In a central European forest, Valtera et al. [9] investigated anthropogenic changes to water regimes, documenting that human-altered water regimes frequently threaten the stability and existence of floodplain forests. Soil organic carbon and microbial biomass deceased on transition from pristine natural floodplain forests to plantation forests.

For Central European floodplains, Hornung et al. [10] developed a matrix that considered linkages of management options with the preservation of identified ecosystem services. Of interest to this manuscript, specific management options included: (i) reduction of pollution because of agricultural practices, (ii) establishing buffer zones, (iii) limiting soil acidity attainment, (iv) restoration of the natural river flow regime, (v) floodplain vegetation and habitat restoration, (vi) restoration of longitudinal connectivity, (vii) prevention of adverse land drainage impacts, and (viii) limiting introduction and spread of invasive species. In Germany, Fischer et al. [11] developed a habitat provisional index to facilitate decision makers' ability to sustain or improve floodplain biodiversity.

In humid climates, flooding regimes support elevated N_2O and CH_4 emissions. Limpert et al. [12] added water to a degraded semi-arid floodplain and observed reduced CH_4 and CO_2 emissions by 28 to 84%. The reduced carbon emissions were attributed to reduced mineralization of soil organic matter, greater CO_2 sequestration, and increased plant growth.

In the United Kingdom, Lawson et al. [13] extended the natural capital concept to define it as an accounting protocol for estimating the quantity of a resource (stocks) and the services provided (flows). Resources are partitioned as: (i) renewable if the benefits are exploited sustainably, and (ii) non-renewable or non-sustainable if the resource regeneration time interval is excessive. Lawson et al. [13] envisioned researchers assessing the resource serially as: (i) its extent, (ii) its condition, (iii) the physical and monetary ecosystem service flow, and (iv) providing the resource with a monetary value. Rajib et al. [14] proposed that long-term floodplain land use data may quantify floodplain services and provide sustainable land management options. Additionally, land area changes in the Mississippi floodplain show an expanding agriculture domain.

In Germany, Stammel et al. [15], in a compelling manuscript, provided an integrated river and floodplain management protocol, wherein ecosystem services and their respective indicators were modeled to reveal advantageous management options. In addition to the ecosystem services stipulated by Lawson [13], Stammel et al. [15] provided or prioritized nitrogen retention, phosphorus retention, drought risk mitigation, and mass flow and sediment mitigation. Employing ecosystem mapping of the floodplain's area of interest, synergistic or antagonistic relationships among the ecosystem services are more evident.

2. Ecosystem services of floodplains

In the United States, the ecological site concept embodies principles and site data derived from physiographic features, climate assessments, hydrologic features, soil properties and their distribution, and existing and ancestral vegetation to create a framework for predicting ecological dynamics resulting from land management. Ecological sites provide a consistent framework for classifying and describing rangeland and forestland soils and vegetation, thereby delineating land units that share similar capabilities to respond to management activities or disturbance. Aide et al. [16] presented the status of ecosystem site descriptions development in Missouri, showing how landowners may anticipate land management impacts.

Talbot et al. [17] reviewed the impact of flooding on aquatic ecosystem services. They identified ten ecosystem services and associated processes: (i) net primary production influenced by nutrients or physical conditions; (ii) soil formation involving sediment transport and deposition; (iii) water regulation supporting anthropogenic use; (iv) water quality with an emphasis on nitrogen and phosphorus; (v) regulation of human disease; (vi) climate regulation involving CO_2 and methane emissions; (vii) drinking water and pollution; (viii) food supply as influenced by crops, fish, and livestock; (ix) esthetic values including housing values because of flood risk; and (x) recreation and tourism. Importantly, Talbot et al. [17] evaluated these ecosystem service gains and losses in response to frequently occurring and extreme flooding.

The United Nations Department of Economic and Social Affairs developed 17 Sustainable Development Goals [18]. These goals include ending poverty, zero hunger, good health and well-being, good education, climate education, and others. The sustainable development goals are partitioned into three domains: (i) environmental, (ii) social, and (iii) economic. Visser et al. [18] remarked that the three development goals are sufficiently linked such that the attainment of any one domain is dependent on attainment of the other two domains. They further discussed the role of the soil-water system on the achievement of the 17 sustainable achievement goals. Keesstra et al. [19] supported "nature-based solutions" as a cost-effective and long-term solution in coastal or fluvial land management in order to enhance ecosystem services. Soil-based solutions attempt to support soil health and restore or maintain soil processes that provide environmental stewardship for water quality and availability, soil fertility, and multi-use landscapes.

Lawson et al. [13] and Petsch et al. [20] provided listings of ecosystem services associated with floodplains (**Table 1**). Similarly, Jose [21] provided a listing of ecosystems associated with agroforestry, some of which may also be important for floodplain environments. In addition to the ecosystem service listing provided by Larson [13], Jose [21] provided two additional ecosystem services: (i) a mosaic of net primary production sites across the floodplain forest and (ii) clean air. Birkhofer et al. [22] presented a substantial literature base with narratives discussing the current challenges and opportunities for evaluating ecosystem services. Noting that assessment of ecosystem services requires a spanning set of indicators to indicate the extent and intensity of the ecosystem services and their provisioning services, Birkhofer and his colleagues [22] provided four sequential challenges when evaluating ecosystem services: (i) understanding anthropogenically modified systems, (ii) assessing ecosystem services, (iii) analyzing relationships between ecosystem services, and (iv) considering appropriate spatial and temporal scales. Evaluating these four challenges provides

Ecosystem Service	Examples of Environmental or Social Attributes
Food	Crop and livestock production
Fiber	Timber, reed production
Mitigation climate change	Carbon sequestration and storage
Pollination	Habitats for pollinating insects
Biocontrol	Nesting habitats for birds, bats, and others
Water quality	Sediment trapping
Flood risk alleviation	Flood water storage
Conservation genetic resources	High diversity and species rich habitats
Pollution abatement	Nutrient management
Maintenance of soil fertility	Soil development
Cultural history	Historical context, heritage, and sense of place
Esthetics	Enhancement of landscape appeal
Recreation and health	Access to nature
Source*: Lawson et al. [13] and Petsch et al. [20].*	

Table 1.
Ecosystem services of Mississippi river floodplains.

a multifaceted understanding of human-ecosystem interaction to support resource sustainability.

Jose [21] conducted a review and synthesis of recent investigations involving agroforestry and their provision of ecosystem services and environmental benefits. Jose classified ecosystem services in agroforestry into four categories: (i) carbon sequestration, (ii) soil enrichment, (iii) biodiversity conservation, and (iv) air-water quality. Many of the items in these categories are apropos to floodplain ecosystems. The quantity of carbon sequestered is a complex function of vegetation composition, stand age, location, environmental and climatic factors, and land management. Jose reported that 630 million ha of unproductive croplands and grasslands when converted to agroforestry would likely result in soil carbon increases of 586,000 Mg C $yr.^{-1}$. Soil enrichment could be attributed to forest species having biological nitrogen fixation capacity, incorporation of canopy and soil organic carbon, nutrient recycling, soil water infiltration and storage improvement, increased aggregate stability of soil structures, and more robust microbial activities. Biodiversity conservation was manifested as (i) habitat provisions, (ii) preservation of germplasm, (iii) habitat connectivity, and (iv) erosion control and water recharge. Air and water quality improvements include: (i) tree barriers and shelterbelts to reduce odor movement, (ii) reduced nitrate and phosphate transport, and (iii) enhanced nutrient and other element biocycling.

The objectives of this manuscript are: (i) to provide general soil descriptions of typical Mississippi River floodplain soils in Missouri; (ii) to provide an introduction to floodplain ecological site descriptions to focus on key ecosystem services, including carbon sequestration and forest productivity; and (iii) to estimate future research needs to better evaluate floodplain soils and their influence on ecosystem services. We also desire to support the development of ecological site descriptions and the important role they play in allowing landowners to understand the consequences of land management decisions.

3. Climate, physiography, and geology of the Mississippi River in East Central Missouri

The ecological site concept correlates principles and site data derived from physiographic features, climate assessments, hydrologic features, soil properties and distribution, and existing and ancestral vegetation to create a framework for predicting ecological dynamics resulting from land management [16]. Ecological sites provide a consistent framework for classifying and describing rangeland and forestland soils and vegetation, thereby delineating land units that share similar capabilities to respond to management activities or natural disturbances. The study area is within the Major Land Resource Area 115X-Central Mississippi Valley Wooded Slopes. The selected ecological site descriptions include: (i) F115XB015MO (sandy/loamy floodplain forest) [23], (ii) F115XB041MO (clayey floodplain forest) [24], and (iii) F115XB042MO (ponded floodplain prairie) [25]. These sites are in the riverine wetlands class of the hydrogeomorphic classification system [26].

The sandy and loamy floodplain forest ecological sites possess soils that are very deep and exhibit sandy to loamy soil textures and have evolved under eastern cottonwood (*Populus deltoides*) and black willow (*Salix nigra*) forest [23]. These soils are located where comparatively swift flood currents preferentially deposit sandy to silty sediments. Over time, these soils accumulated a more diverse vegetation and subsequently deposited fine-textured alluvium. Forest vegetation altered in response to landscape elevation with a greater presence of shade-tolerant forest species, such as American elm (*Ulmus americana*), ash (*Fraxinus pennsylvanica*), and hackberry (*Celtis occidentalis*). Catastrophic flooding may reestablish a willow and eastern cottonwood-dominated forest. Typical soils include Blake, Haynie, Caruthersville, and Commerce.

The clayey floodplain ecological sites are not usually adjacent to perennial rivers and streams; rather these sites reside in lower landscape positions. Given the clayey floodplain soils are positioned in low-lying and depressional areas, they are thoroughly influenced by a seasonal high-water table and often show typical backswamp features such as a fine texture, slickensides, and gleization. The clayey floodplain forest is generally supported by a silver maple (*Acer saccharinum*), American elm (*U. americana*), and eastern cottonwood (*P. deltoides*) forest [24]. The ponded floodplain prairie is in the floodplains of perennial streams and backswamp environments that are not adjacent to the Mississippi River channel. Typical soils include Alligator, Bowdre, Darwin, Nameoki, Parkville, Sharkey, and Waldron. The ponded floodplain prairie possesses a high-water table and soils exhibiting fine textures and enriched soil organic matter contents that have evolved under herbaceous wetland vegetation, including graminoids, sedges, and wetland forbs [25].

Forest species associated with the Mississippi River floodplain include northern red oak (*Quercus rubra*), eastern cottonwood (*P. deltoides*), American elm (*U. americana*), white oak (*Quercus alba*), black walnut (*Juglans nigra*), silver maple (*A. saccharinum*), yellow poplar (*Liriodendron tulipifera*), pin oak (*Quercus palustris*), American sycamore (*Platanus occidentalis*), green ash (*F. pennsylvanica*), sweetgum (*Liquidambar styraciflua*), black willow (*S. nigra*), red maple (*Acer rubrum*), nuttall oak (*Quercus texana*), water oak (*Quercus nigra*), pecan (*Carya illinoinensis*), common hackberry (*C. occidentalis*), river birch (*Betula nigra*), boxelder (*Acer negundo*), and bald cypress (*Taxodium distichum*).

Most Mississippi River floodplain soils are from Holocene age and include the soil orders Entisol, Inceptisol, Mollisol, and Vertisol [27]. The reference plant community is forested with black willow, eastern cottonwood, hackberry, river birch, sycamore, silver maple, and American elm. In the absence of levees, occasional to frequent flooding is generally very brief (less than 48 hours) to brief (2 to 7 days). During flood events, water is accumulated by overland flow and baseflow from the channel to shallow unconfined aquifers.

4. The study area section of the Mississippi River in Missouri

The study area resides in Mississippi River floodplains in the Missouri counties of Ste. Genevieve County, Perry County, Cape Girardeau County, Mississippi County, and New Madrid County. In Cape Girardeau County, the January average temperature is 1.6°C (35°F), whereas the July average temperature is 26°C (79°F) [28]. The total annual precipitation ranges from less than 0.97 meters (38 inches) to more than 1.42 meters (56 inches), with an average of 1.19 meters (47 inches). Rainfall varies seasonally, with spring having typically greater rainfall totals and autumn having typically smaller rainfall totals. Where levees are not present, flooding ranges from short (a few days) to medium (several weeks) durations, with spring flooding corresponding to more northern snow melt conditions; however, flooding may occur at any time during the year, and long-term flood events have occurred. The surrounding geologic setting generally has Ordovician dolomites and sandstones overlain with thick loess deposits. Bottomland expanses have massive alluvium, with textures ranging from sand to fine clay [28–30].

5. Laboratory protocols

Soil pH in water, exchangeable cations, total neutralizable acidity, and organic matter content by loss on ignition are routine procedures [31]. The clay, silt, and sand fractions were separated by Na-saturation of the exchange complex, washing with water–methanol mixtures, dispersion in Na_2CO_3 (pH 9.2), followed by centrifuge fractionation and wet sieving [31]. Two *M* acetic acid extractable SO_4-S were determined by the soil testing laboratory at the University of Missouri-Columbia Delta Center (Portageville, MO).

An aqua-regia digestion was performed to estimate elemental concentrations associated with whole soil soluble, exchangeable, organically complexed, and adsorbed/co-precipitated with oxyhydroxide environments and the partial degradation of phyllosilicates. In this procedure, 0.25 g of finely ground fine earth fraction was digested in 0.01 liter of aqua regia (1 HCl:3HNO_3) for 1 hour, followed by 0.45 μm filtering with an aliquot analyzed using inductively coupled plasma – atomic emission spectrometry (ICP-AES) [32].

6. Soil descriptions across the study area

We selected 22 soil series that occur in the Mississippi River floodplain or in levee-protected land areas. The parent materials are (i) Mississippi River alluvium with soil textures ranging from coarse to fine and (ii) stream alluvium transporting silty materials from the surrounding loess mantled uplands. The Alligator, Commerce, Caruthersville, Sharkey, and Steele are examples of soils whose parent materials mostly are derived from the Mississippi River, whereas the soils Falaya, Haymond, Mhoon, Wakeland, and Wilbur have parent materials derived from loess that were stream transported onto the floodplains. In the study area, the soils and their taxonomic classification are listed in **Table 2**, and the appropriate soil horizons and diagnostic horizons for each soil are listed in **Table 3**.

Soil Name	Taxonomy Description
Alligator	Very-fine, smectitic, thermic Chromic Dystraquerts
Beaucoup	Fine-silty, mixed, superactive, mesic Fluvaquentic Endoaquolls
Bowdre	Clayey over loamy, smectitic, thermic Fluvaquentic Hapludolls
Commerce	Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts
Caruthersville	Coarse-silty, mixed, superactive, calcareous, thermic Typic Udifluvents
Darwin	Fine, smectitic, mesic Fluvaquentic Vertic Endoaquolls
Dupo	Coarse-silty over clayey, mixed over smectitic, superactive, nonacid, mesic Aquic Udifluvents
Elsah	Loamy-skeletal, mixed, superactive, nonacid, mesic Typic Udifluvents
Falaya	Coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents
Haynie	Coarse-silty, mixed, superactive, calcareous, mesic Mollic Udifluvents
Jackport	Fine, smectitic, thermic Chromic Epiaquerts
Haymond	Coarse-silty, mixed, superactive, mesic Dystric Fluventic Eutrudepts
Leta	Clayey over loamy, smectitic, mesic Fluvaquentic Hapludolls

Soil Name	Taxonomy Description
Mhoon	Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts
Nameoki	Fine, smectitic, mesic Aquertic Hapludolls
Parkville	Clayey over loamy, smectitic, mesic Fluvaquentic Hapludolls
Sharkey	Very-fine, smectitic, thermic Chromic Epiaquerts
Steele	Sandy over clayey, mixed, superactive, nonacid, thermic Aquic Udifluvents
Wakeland	Coarse-silty, mixed, superactive, nonacid, mesic Aeric Fluvaquents
Walbash	Fine, smectitic, mesic Cumulic Vertic Endoaquolls
Waldron	Fine, smectitic, calcareous, mesic Aeric Fluvaquents
Wilbur	Coarse-silty, mixed, superactive, mesic Fluvaquentic Eutrudepts

Table 2.
Taxonomic classification of selected Mississippi river floodplain soils.

Soil Name	Horizon Sequence	Diagnostic Horizons
Alligator	A-Bg-Bssg-Bssycg-Cg	Ochric, cambic
Beaucoup	A-Bg-Cg	Mollic
Bowdre	A-Bw-2C	Mollic
Commerce	A-Bw-Bg-Bssg	Ochric, cambic
Caruthersville	A-C-Cg	Ochric
Darwin	A-Bg-Cg	Mollic, cambic
Dupo	A-Bg-2Ab-2Bgb-Cg	Ochric
Elsah	A-C	Ochric
Falaya	A-Bw-Cg	Ochric, cambic
Haynie	A-C	Ochric
Jackport	A-Bg-Bssg	Ochric, cambic with slickensides
Haymond	A-Bw-C	Ochric, cambic
Leta	A-Bg-2Cg	Mollic, cambic
Mhoon	A-Bg-Cg	Ochric, cambic
Nameoki	A-Bw-2Btg-Cg	Mollic, cambic
Parkville	A-2Cg	Mollic
Sharkey	A-Bssg-Bssyg	Ochric, cambic with slickensides
Steele	A-C2g-2Abg-2Cg	Ochric
Wakeland	A-Cg	Ochric
Walbash	A-A1-Bg	Mollic, cambic
Waldron	A-C-Cg	Ochric
Wilbur	A-Bw-Cg	Ochric, cambic

Table 3.
Soil horizon sequences and diagnostic horizons.

In soil taxonomy, soil diagnostic horizons are soil horizons having characteristics that indicate pedogenic development and are discerned in the field without additional laboratory data [33]. With considerable generalization, mollic epipedons are surface horizons that are not acidic, have high-base saturations, and possess significant soil organic matter abundances [34]. Mollic epipedons are presumed to have had prairie vegetations; however, all mollic epipedons in this study have significant smectite clay contents that limit microbial soil organic matter decomposition. Ochric epipedons are like mollic epipedons but lack significant soil organic matter contents. The cambic horizons are subsurface soil horizons that show some pedogenic development but not to the extent of other subsurface diagnostic horizons (**Table 3**).

7. Soil properties across the study area

Table 4 provides value ranges for the selected soils by soil depth and includes typical soil profile permeabilities, volumetric available water contents (AWC), soil textures, soil pH levels, and soil organic matter (SOM) contents. The values are provided by the soil surveys for the study area [28–30]. Permeability (Perm) on an hourly basis is vs. for very slow (<0.15 cm), s for slow (0.15 to 0.51 cm), ms for moderately slow ((0.51 to 1.5 cm), and m for moderate ((1.5 to 5 cm). mr is moderately rapid (5 to 15 cm), r is rapid (16 to 50 cm), and vr is very rapid (>50 cm).

The Alligator, Darwin, Sharkey, and Walbash soils have moderately slow to very slow permeabilities and silty clay to clayey textures. To some extent, the soils Jackport, Leta, Nameoki, and Waldron share these attributes. Conversely, the soils Caruthersville, Elsah, and Steele have coarse-textured surface horizons and moderate to moderately rapid permeabilities. In general, soils having very slow to slow permeabilities have very high to high shrink-swell capacities, whereas soils with rapid to very rapid permeabilities have low shrink-swell capacities.

The volumetric available water contents (AWC) when adjusted for a 1.83 m (6 ft) soil profile depth show a moderate available water content for the Walbash soil, high available water contents for the Darwin and Waldron soils, and very high available water contents for the Haymond and Wilbur soils. Virtually all soils in the floodplain support high to very high volumetric available water provision. Soil pH levels range from very strongly acidic to slightly alkaline.

Floodplain ecosystem evolution because of land management is an area of active research. The soil profile values by soil depth for permeability, available water contents, textures, pH, and soil organic matter contents (**Table 4**) will almost certainly be leading indicators for documenting soil changes because of land management. These indicators permit an estimation of forest species suitability and growth potential. Other indicators will likely be required, and their values will be experimentally determined. Soil indicators and the ecosystem site descriptions collectively are integral to assessing soil health potential and evaluating ecosystem service functions.

The Sharkey soil series belongs to the Vertisol order and is representative of soils in the clayey floodplain forested ecological site. The pedon has an Ap – Ap2 – Bssg horizon sequence where the ss represents slickensides caused by repeated soil expansion attributed to the large content of smectite (montmorillonite) clay, and g represents gleization (**Table 5**). The pedon shows a clay loam – silty clay loam transitioning to a clay texture, resulting in the very high shrink-swell capacities and the large cation exchange capacity. The phosphorus and sulfate concentrations are considered low. The effective rooting depth was less than 1 meter because of the shrink-swell capacity,

	Depth		Perm		AWC	
	cm	cm/hr	cm/cm	Texture	pH	SOM
Alligator	15	ms	0.19	sicl	4.5–6.0	1 to 3
	117	vs	0.16	clay	4.5–5.5	
	152	vs	0.16	clay	6.5–7.3	
Beaucoup	48	ms	0.22	sicl	5.6–7.8	5 to 6
	112	ms	0.19	sicl	5.6–7.8	
	152	ms	0.2	sicl	5.6–7.9	
Bowdre	15	s	0.17	sicl	5.6–7.3	1 to 3
	113	ms	0.21	sil	6.1–8.4	
	137	m	0.18	sandy loam	6.1–8.4	
	152	mr	0.1	loamy sand	6.1–8.4	
Commerce	30	ms	0.21	sicl	5.6–7.8	0.5 to 2
	58	ms	0.21	sicl to sil	6.1–8.4	
	152	ms	0.21	sl to sic	6.6–8.4	
Caruthersville	71	m	0.2	sandy loam	6.6–7.8	1 to 2
	152	m	0.17	sand-sil	6.6–8.4	
Darwin	38	vs	0.13	sic	6.1–7.8	4 to 5
	152	vs	0.13	sic	6.1–7.8	
Dupo	18	m	0.23	sil	5.6–7.3	1 to 2
	71	m	0.21	sil	5.6–8.4	
	152	s	0.14	sicl to sic	6.6–7.8	
Elsah	30	m	0.21	loam	5.6–7.3	1 to 3
	132	mr	0.11	cherty loam	5.6–7.3	
	152	m	0.03	cherty sand	5.6–7.3	
Falaya	15	m	0.21	sil	4.5–6.5	0.5–3
	152	s	0.18	sil to sic	4.5–5.5	
Haynie	23	m	0.21	sil to sic	7.8–8.4	1 to 3
	152	m	0.2	sil to sic	7.8–8.4	
Jackport	13	ms	0.2	sicl	4.5–7.3	1 to 3
	147	vs	0.15	clay	4.5–5.5	
	160	s	0.19	sic to sil	6.1–7.8	
Haymond	23	m	0.23	sil	5.6–7.3	1 to 3
	150	m	0.21	sil	5.6–7.3	
	183	m	0.21	sil	5.6–7.3	
Leta	38	s	0.13	sic	6.6–7.8	2 to 4
	69	s	0.15	sicl	6.6–7.8	
	152	m	0.18	sil	6.6–8.4	
Mhoon	10	m	0.22	sil	6.1–7.8	0.5 to 2

	Depth		Perm		AWC	
	152	s	0.2	sil to sic	6.1–8.4	
Nameoki	38	vs	0.16	sicl	6.1–7.3	2 to 4
	76	vs	0.13	sicl	5.1–7.3	
	132	m	0.16	sil	5.1–7.8	
	178	m	0.1	sl to sil	5.6–7.8	
Parkville	43	vs	0.12	sic	6.6–8.4	1 to 3
	104	m	0.2	sil	7.4–8.4	
	152	mr	0.13	sandy loam	7.4–8.4	
Sharkey	18	vs	0.19	sicl	5.1–8.4	0.5 to 2
	137	vs	0.19	clay	5.6–8.4	
	183	s	0.2	clay	6.6–8.4	
Steele	20	r	0.08	sand	5.6–7.3	0.5–1
	56	r	0.11	loamy sand	5.6–7.3	
	66	r	0.11	loamy sand	5.6–7.3	
	152	s	0.18	sicl	5.6–7.3	
Wakeland	30	m	0.23	sil	5.6–7.3	1 to 3
	152	m	0.21	sil	5.6–7.3	
Walbash	15	vs	0.13	sic	5.6–7.3	2 to 4
	185	vs	0.09	sic	5.6–7.3	
Waldron	20	vs	0.13	sic	6.6–7.8	2 to 4
	152	s	0.17	sicl	7.4–8.4	
Wilbur	23	m	0.23	sil	5.6 to 7.3	1 to 3
	152	m	0.21	sil	5.6 to 7.3	

Perm is permeability: vs. is very slow, s is slow, ms is moderately slow. m is moderate, mr is moderate rapid, r is rapid. Texture: sil is silt loam, sicl is silty clay loam, sic is silty clay.

Table 4.
Representitive soil depth, permeability, available water content (AWC), texture, pH, and soil organic matter (SOM) content.

clay contents, and the lack of soil structure. The pH is slightly alkaline. Aqua-regia digestion of this pedon for Fe, Mn, Cr, Co, Ni, Cu, Zn, Pb, and Cd reveals that all elements have typical abundances [35] and does not indicate significant heavy metal impact (**Table 6**).

The Commerce soil series belongs to the Inceptisol order and is representative of soils in the sandy and loamy forested floodplain ecological site. The pedon has an Ap – Bw-Cg horizon sequence where the w represents a slightly altered subsoil parent material, and g represents gleization (**Table 7**). The pedon shows a silt loam profile, with the cambic horizon having a silty clay loam texture. The phosphorus and SO_4-S concentrations are considered low. The effective rooting depth was more than 2 meter. The Ap and Bw horizon pH activities are neutral, whereas the Cg horizon sequence is acidic. Aqua-regia digestion values for Fe, Mn, Cr, Co, Ni, Cu, Zn, Pb, and

Horizon	Depth	Texture	pH	SOM	P	CEC	SO_4-S
		cm	water	%	ppm	cmol kg^{-1}	ppm
Ap	15	clay loam	7.9	2.1	22	24.2	6.6
Ap2	30	silty clay loam	7.8	1.8	31	23.6	5.6
Bssg1	46	silty clay loam	7.9	2.6	15	26.0	4.5
Bssg2	61	clay	7.6	2.3	7	29.4	6.7
Bssg3	91	clay	7.8	1.5	4	27.9	6.7
Bssg4	122	clay	7.3	1.7	3	28.0	6.2
Bssg5	153	clay	7.9	1.4	10	28.2	8.3

SOM is soil organic matter and CEC is the cation exchange capacity.

Table 5.
Routine characterization of the Sharkey pedon.

Horizon	Fe	Mn	Cr	Co	Ni	Cu	Zn	Pb	Cd
	---------------------mg kg^{-1}---------------------								
Ap	18,300	258	28	4.8	16.3	11.4	64	17.3	0.15
Ap2	18,300	350	29	5.5	17.2	13.7	69	22.9	0.19
Bssg1	22,600	308	33	5.7	18.2	12.3	73	16.4	0.07
Bssg2	23,800	447	22	6.8	17.7	11.3	69	14.7	0.07
Bssg3	29,600	1160	36	9.7	25.2	10.2	83	15.3	0.13
Bssg4	24,400	417	34	6.5	20.7	12.5	75	15.2	0.08
Bssg5	23,200	252	36	5.6	22.2	11.5	76	15.7	0.09
Typical values for the selected transition elements in soil (*Source*: Kabata-Pendias)									
Soil	35,000	488	60	8	29	39	70	27	0.3

Table 6.
Aqua regia digestion for selected transition metals for the Sharkey pedon.

Horizon	Depth	Texture	pH	SOM	P	CEC	SO4-S
	cm	water	%	ppm	cmol kg^{-1}	ppm	
Ap	15	silt loam	7.0	4.6	28	22.0	4.6
Bw1	30	silty clay loam	7.1	1.9	8	19.9	2.8
Bw2	45	silty clay loam	6.1	0.9	14	14.3	8.8
Cg1	60	silt loam	5.7	0.6	16	10.9	20.7
Cg2	90	silt loam	5.5	0.6	7	9.7	29.7
Cg3	120	silt loam	5.5	0.5	8	10.1	55.3
Cg4	150	silt loam	5.4	0.5	8	10.9	68.3

Table 7.
Routine characterization of the Commerce pedon.

Horizon	Fe	Mn	Cr	Co	Ni	Cu	Zn	Pb	Cd
	————————————mg kg^{-1}————————————								
Ap	24,200	560	32	10.5	26.9	20.7	90	23.2	0.30
Bw1	23,300	615	32	8.9	26.1	19.2	89	30.1	0.31
Bw2	17,700	277	25	6.5	13.8	13.7	44	11.8	0.04
Cg1	15,300	567	21	8.8	14.1	14.4	35	9.3	0.03
Cg2	15,500	636	21	8.3	15.7	12.0	39	10.9	0.04
Cg3	16,700	626	23	8.0	19.2	17.1	38	10.2	0.08
Cg4	14,600	567	20	7.7	16.8	12.7	40	9.6	0.08
Typical values for the selected transition elements in soil (*Source*: Kabata-Pendias)									
Soil	35,000	488	60	8	29	39	70	27	0.3

Table 8.
Aqua regia digestion for selected transition metals for the Commerce pedon.

Cd reveal that all elements have typical abundances and do not indicate significant heavy metal impact [35] (**Table 8**).

The Wilbur and Haymond soils are Inceptisols whose parent materials are derived from loess-mantled upland erosion and subsequently deposited in the floodplains. The Wakeland soil is an Entisol and shares an evolutional history like that of the Wilbur and Haymond. All soils have uniform silt loam textures (**Table 9**). Wilbur, Haymond, and Wakeland are somewhat poorly drained, moderately well-drained, and poorly drained pedons, respectively. The upper portion of the Wilbur and Wakeland pedons are slightly acidic, whereas the deeper horizons are very strongly acidic. The cation exchange capacity is generally medium, and the soil organic matter contents show a decreasing abundance on progression through the soil profiles. The Wilbur pedon shows typical transition metal contents and do not indicate any heavy metal impact [35] (**Table 10**). The Haymond and Wakeland heavy metal soil profile concentrations are similar to that of the Wilbur pedon.

8. Employing soil data and the ecosystem site descriptions to advance sustainable land management

Ecological site descriptions are intended for conservation planning and implementation of sophisticated land management. Within the ecological site description, a "State" is largely the dominant vegetation status, whereas the transition involves a natural event (flooding, fire) or land management that fosters vegetational changes. The sandy/loamy floodplain forest provides a State and transition model, wherein the reference States include: (i) eastern cottonwood and hackberry/willow and (ii) sycamore and eastern cottonwood/willow. The transition from the eastern cottonwood and hackberry/willow State to the sycamore and eastern cottonwood/willow State involves flood disturbance. The reverse transition involves no flooding disturbance or sedimentation. Non-reference States include: (i) cropland and (ii) cool season grasslands, with appropriate events or activities promoting the respective transitions. The clayey floodplain forest provides a State and transition model, wherein the reference

Horizon	Depth	pH	Acidity	SOM	CEC	BS
	cm	cmol kg^{-1}	%	cm kg^{-1}	%	
			Wilbur			
Ap	13	6.4	5.7	2.0	17.2	80
A	25	6.4	3.6	1.2	16.6	83
Bw1	41	6.1	3.8	1.0	14.1	79
Bw2	56	5.4	5.3	0.8	13.3	65
Bw3	74	4.7	5.2	0.4	11.0	53
Cg1	89	4.2	4.1	0.2	5.7	44
Cg2	104	4.3	4.6	0.2	8.8	55
Cg3	152	4.9	3.1	0.2	10.8	78
Cg4	183	5.1	3.0	0.2	10.4	78
Cg5	203	5.2	3.0	0.2	10.5	78
			Haymond			
Ap	15	4.9	5.2	1.5	12.9	64
A	28	5.2	4.6	0.8	13.2	69
Bw1	41	5.0	4.4	0.7	11.4	73
Bw2	74	4.4	3.6	0.3	6.9	65
C	97	3.9	5.4	0.2	6.6	41
C2	124	4.1	4.0	0.2	6.7	55
C3	145	4.5	3.1	0.2	7.8	72
C4	170	5.3	2.5	0.2	7.5	78
			Wakeland			
Ap1	8	6.0	1.4	1.5	7.9	90
Ap2	20	6.0	1.4	0.5	7.9	90
Cg1	43	6.0	2.5	0.7	9.5	83
Cg2	66	6.1	2.7	0.7	8.7	88
Cg3	91	6.2	2.8	0.5	8.6	81
Cg4	122	5.8	4.9	1.2	15.5	76
Cg5	145	4.8	5.3	0.5	9.2	60

All soil profiles have a uniform silt loam texture. SOM is soil organic matter, CEC is cation exchange capacity, BS is percent base saturation. Acidity is the total acidity attributed to titratable H and Al

Table 9.
Routine characterization of three soils along drainageways to the Mississippi River floodplain.

states include: (i) Hackberry American Elm, and (ii) Hackberry-American Elm/Pin Oak. The transition from Hackberry American Elm to Hackberry-American Elm/Pin Oak involves an absence of disturbance events. The reverse transition involves natural disturbances every 2 to 5 years. Other States include: (i) low disturbance/logged woodland, (ii) cool season grassland, and (iii) cropland, with each transition between the states specified.

Horizon	Fe	Mn	Cr	Co	Ni	Cu	Zn	Pb	Cd
	--mg kg^{-1}--								
					Wilbur Soil #1				
Mean	16,940	832	21.8	7.2	17.2	15.4	43	12.3	0.14
Coeff. Var.	23	79	13	56	29	24	33	37	62
					Wilbur Soil #2				
Mean	17,720	906	22.0	8.4	17.5	13.5	45	12.1	0.10
Coeff. Var.	15	55	7	42	23	14	25	27	81

Coeff. Var. is the percent coefficient of variation.

Table 10.
Aqua regia digestion for selected transition metals for the Wilbur pedon.

Effectively evaluating the ecosystem services for these floodplain soils require: (i) select the ecosystem services to be evaluated, (ii) determine the indicators that will be used to infer the effectiveness of the ecosystem service, and (iii) given the reference and non-reference States for each ecological site provide field work that infers the benchmark rating and variance for the selected indicators. Specifically, provision for each ecosystem service for each reference State needs to be clarified. Suppose carbon sequestration is selected as a vital ecosystem service, then the following needs elucidation: (i) the initial and long-term carbon sequestration potential for each soil, (ii) determination of the intensity of the transitions to improve or degrade the desired outcomes, (iii) determination of any synergistic or antagonistic correlations. Thus, future research needs to determine which ecosystem services are deemed to have the greatest need to support using land management.

Conflicts of interest

The authors have no conflicts of interest.

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Section 5

Ecotourism Resources Management

Chapter 8

Role of Ecotourism in Sustainable Development

Jubril Akanni Soaga

Abstract

This chapter examines ecotourism as responsible travel to natural areas. Climate change issue or more succinctly global warming has brought ecotourism to the front burner of conservation in twenty-first century. It involves economic development and conservation to ensure sustainable development. Natural resources are the focal point in ecotourism with the broad division into renewable and non-renewable natural resources. The non-renewable resources are the physical attractions which are abiotic that are formed through geological processes, and renewable resources are biotic that are capable of regeneration through reproduction. These resources are also referred to as environmental resources. The interaction among biodiversity ensures a good sightseeing for tourists which encourages visitors to make payment for conservation because of utility derived. Thus, ecotourism has two arms in conservation, the willingness to pay (WTP) on the part of tourists and the willingness to accept if the locals must surrender their rights and privileges over land areas accommodating biodiversity and their habitats. Therefore, the instrument mostly used in evaluating ecotourism is contingent valuation though with some reservations. Ecotourism thus manages people, resources and protects the environment to reduce the effect of climate change and promote sustainable development.

Keywords: travel, natural resources, climate change, biodiversity, contingent valuation

1. Introduction

Ecological tourism or simply referred to as ecotourism mostly among renewable resources experts and scientists is increasingly attracting global attention in the twenty-first century because of climate change phenomenon and conservation issues. Ecotourism is an age-long practice across the world but never considered as a conservation measure because of abundant natural resources and low population in early civilisation. People have related with nature in a positive way by allowing natural phenomena to dictate the rhythms of nature and thus promote conservation through cultural practices unconsciously. Therefore, sustainability at the early stages of man civilisation was a natural arrangement without any concern, care or caution for the environment. However, man's greed for uncontrollable request for natural resources brought the concern for sustainable development. Thus, ecotourism as a tool for sustainable growth involves managing people, natural resources – renewable and non-renewable and the environment to ensure sustainable development. Ecotourism

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in twenty-first century is protecting man and at the same time generating income and employment with substantial contribution to the GDP of most countries as well as promoting conservation through habitat restoration and protection. The summary of it all is that the environment is maintained by reducing the effect of climate change.

2. Ecotourism

Ecotourism is nature tourism and can also be referred to as alternative tourism or bio-tourism. Ecotourism depends on available natural physical attractions, namely hills, waterfalls, springs, caves, lakes and mountains across the length and breadth of any country. The fascinating features and beautiful scenes provide interesting sites for leisure, adventure and other tourism-related activities. Ecotourism therefore combines two things to make it more attractive today, conservation and welfare of residents. The natural physical attractions mostly exist in local communities either as a geo-heritage or natural features supporting and promoting settlement of locals. Ecotourism can therefore be defined along the school of thought of 'The international Ecotourism Centre' as responsible travel to natural areas that protect the environment and sustain the welfare of indigenous communities or rural population with interpretation and education.

Figure 1 illustrates ecotourism and derivable benefits by man and the environment. Conservation is ensured through market-linked approach as well as the protection of the natural and cultural heritage of the earth. Also, local communities' well-being is boosted through employment, capacity development and poverty reduction. The market-linked approach and welfare of the people create adequate environmental awareness to achieve sustainable development. Ecotourism ensures that the carrying capacity of the environment is not exceeded in any location based on the principles of ecotourism by limiting the population to a site at a given time to reduce impact and protect the environment. The advantage of ecotourism outweighs

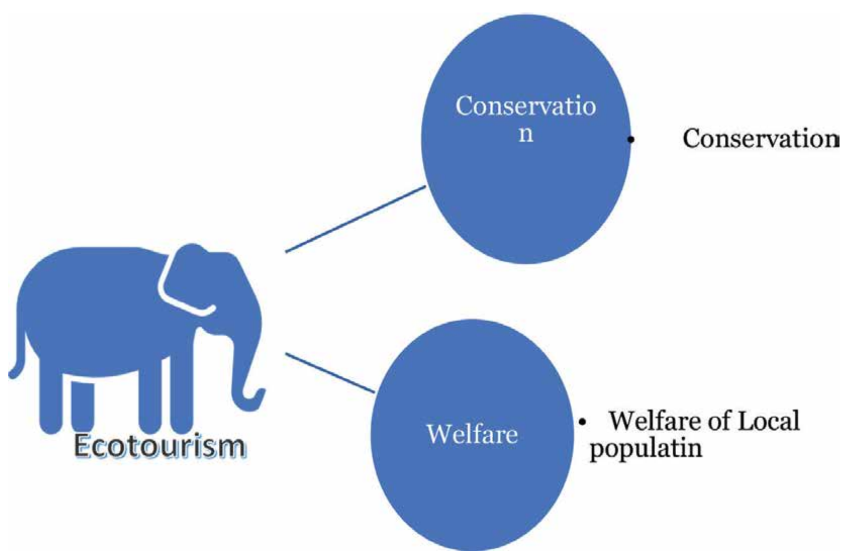

Figure 1.
Ecotourism benefits.

any known or unknown negative impact. Consequently, in 2002, United Nations celebrated the 'International Year of Ecotourism'. The meeting brought ecotourism to the front burner of tourism with global acceptance of the concept and meaning of ecotourism. It was a watershed event. Since then, ecotourism became one of the largest global economic activities of paying for nature conservation and reducing the pressure of land conversion that has naturally fascinating features for agriculture and infrastructural provision under the context of development [1].

The definition of ecotourism identifies three main characteristics.

1. Nature-based physically fascinating features

2. Environmental education

3. Sustainability

The nature-based physically fascinating features are mostly geographical heritage existing in nature in various locations. These features promote settlement, and consequently communities mostly spring up around the features. The reason is not far-fetched, living is made easy and convenient especially around waterfalls and rivers. However, other features such as rocks offer protection to adverse environmental conditions and war for the early settlers of the communities. It is therefore common to note that most of these features are named after the early settlers or circumstances surrounding the community migration to the location. For example, in Canada, the famous Stanley Park in British Columbia was named after a Governor-General as far back as 1886, and the Park exists on 405 hectares of indigenous land of Salish First nation. Also, in Nigeria, 'Erin-Ijesha', that is, 'Elephant of Ijesha' in Osun State was so named by the people in line with the narrative of the early settlers as far back as 1140 A.D. as 'Olumirin' meaning 'another deity' because of the appearance of mysterious figure. The naming pattern applies to all other locations of ecotourism.

Environmental education came with physical features through the relationship between man and nature. The natural features convey messages. These messages were documented, and they became the aspect of environmental education so cherished today. A good example of this is the 'Erin-Ijesha' waterfalls that the people believed could purify their souls because it was a sacred altar, thus, indicating the therapeutic significance of nature. Sustainability was also borne out of the relationship of man with nature. The locals in various geographical areas where the natural features exist were conscious of the fact that the resources must be maintained in perpetuity for the communities to continue to exist in those locations. Any alternatives to these resources could not sustain the existence of the locals. This is commonly observed in some locations where historical evidence shows that previous settlements had existed, but due to the mismanagement of the natural resources, the communities or settlements had collapsed leaving footprints of human existence in such locations. This is mostly revealed through archaeological findings where footprints of previous settlers existed.

3. Resources

The term 'resource' was used to describe the nature-based physically fascinating features under the classification of natural resources. Resources have been used to

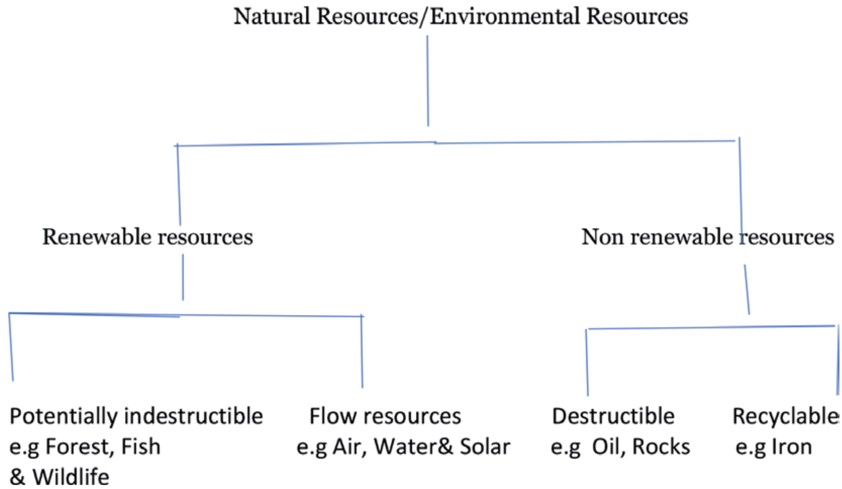

Figure 2.
Classification of natural resources.

show that they are natural endowment given or created by God in different locations. Some locations are more endowed than others – location-specific, while value addition in terms of amenities has made less endowed areas to become more prominent and attractive and therefore attract more tourists than highly endowed locations. This is the situation between developing countries in Africa and Asia with other Western countries such as Europe and North America. This chapter will not cover the comparative advantage of the regions in terms of nature endowment as this is also a broad area for further discussion.

Natural resources are 'gift of nature'. They are living and non-living endowment of the earth. They are therefore exploited by man as resources because they are known and accessible and can be used under foreseeable technological and economic conditions. The living aspect of the resources is the biotic components that describe the biodiversity in terms of plants and animals in ecotourism. However, the non-living endowment is the physical features and beautiful scenes of nature.

Figure 2 shows the broad division of resources into renewable and non-renewable categories. There is distinction between the biotic and abiotic components of the natural resources. The renewable resources are capable of regeneration or biologically reproduce off-springs through the process of reproduction. Consequently, 'bio-tourism' originated from the biologically renewable resources of ecotourism simply referring to biological tourism. Flow resources sustain life such as air, water and solar mostly through photosynthesis, water cycle and carbon sink. The non-renewable resources are the physical features of hills, rocks, mountains that have come into existence through various natural processes such as rock metamorphosis, volcanic eruptions and perhaps landslides. Therefore, man has not contributed anything or did not shape any structure in the formation of these resources. Thus, it is imperative that the resources must be used sustainably as the reproductive cycle and geological processes take time to complete. Though reproduction may take a short period of time, the geological aspect takes a longer time to complete. Therefore, the characteristics of these resources are significant in their management.

I will briefly describe the characteristics for better understanding of these resources:

1. Natural endowment – It is the 'gift of nature'. They are naturally existing in different ecological zones across the world. The globe has heterogeneous ecological zones; therefore, some exist in the tropics and others in the temperate regions. This promotes ecotourism by encouraging people to move from one region to another to appreciate nature. This is more common with biological resources

2. Location specific – As mentioned earlier, these resources are location-specific. Most plants and animals have different tolerance level of the environment in terms of climatic factors. Temperate plants and animals do not reproduce and adapt properly in tropical locations despite all progeny trials carried out in science for acclimatisation. The same applies to tropical plants and animals not doing well in temperate conditions. Biodiversity of plants and animals mostly has restrictions and limitations of weather conditions. Thus, tourists will have to travel to ecological sites – natural habitats of these resources to appreciate nature, and this makes it responsible travel specifically for a purpose

3. Uneven distribution – The resources are not evenly distributed across the regions of the world. There is no concentration of the resources in a particular region of the world. Despite this, some locations are not naturally endowed. Tourists from such locations will have to travel to endowed locations.

4. Versatility – Natural resources are versatile. The value of resources increases over time. Resources appreciate over time. This explains the regeneration potential of the resources. Offspring of animals will grow to maturity with time, and the population of some species continues to rise due to extinction of other species that cannot cope with changing climatic conditions and competition among the diversity of biological resources. Further, resources earlier categorised as lesser economic significance are now becoming very important far from the understanding of early scientists, and a good example is ecotourism in the twenty-first century.

5. Finiteness – Natural resources are finite. Natural resources are limited in supply. If the rate of exploitation is greater than the rate of regeneration, then the resources will dwindle. Therefore, natural resources must be managed in way that will ensure that regeneration is greater than exploitation for sustainability. The natural process of food web takes care of this, but interference creates catastrophic situation for nature.

6. Destructibility – Natural resources must be converted from the natural state through processing into other products that is not reversible to make it more useful. The conversion process is the destructibility. Elephants' trophies are very good examples of the conversion.

7. Common property – Natural resources are common property of any society or community where they exist. Since they are gift of nature, all inhabitants of a geographical area own the resources. All water bodies, forests and mineral deposits belong to the global society but demarcated by political and geographical boundaries for easy management.

8. Importance of time – Time is a crucial aspect of the natural resources. Unlike production process that can easily be manipulated, it takes time for these

resources to regenerate naturally – biological resources may take a short period, but it takes longer time for geological resources.

9. Part of the environment – Natural resources are part of the environment. In a geographical location, any removal of a particular species will always create imbalance within the ecosystem. This may lead to ugly landscape that may not be attractive to man. Any areas of mining for any resource's deposits will clearly give a good picture.

4. Biodiversity

Biodiversity is the most important component of the biotic aspect of natural resources. Previous studies have described biodiversity as the variety and variability among living organisms and the ecological complexes in which they occur [2, 3]. Current estimates of global biodiversity have been estimated to range from 10 to 100 million species of plants and animals including fungi and microorganisms. However, in ecotourism plants and animals are the most important biotic component of biodiversity. Thus, biodiversity occurs at three levels – genes, species and ecosystems. Therefore, biodiversity supports human life and the systems that support it. Clearly, the value of biodiversity to humanity is to protect and ensure that sundry services of provisioning are discharged. Man depends on biodiversity for food, fibres, medicines and drugs as well as raw materials for manufacturing technologies and purposes. The crucial aspect of biodiversity in ecosystem stability is to protect humanity through services.

The three levels of ecosystem occurrence will be briefly explained.

Genes – The genes as the name implies provide genetic information contained in individual plants and animals. The genetic make-up of various plants and animals and the regeneration potential of the species capable of surviving in varying ecological conditions.

Species – The populations of plants and animals within which genes flow occur in natural conditions. Species allow normal individuals to breed within the population among members of opposite sex for population increase.

Ecosystems – These refer to habitats, biotic communities and various ecological processes to protect and sustain the populations and the genes in the environment. Therefore, ecosystem stability through ecological processes is very important for biodiversity to be value-laden. Ecosystem stability and resilience promote heterogeneity among species.

The three levels of occurrence are interwoven and cannot be separated to fully understand the concept of biodiversity in life sustaining processes. However, recent climatic trends in terms of climate change have brought biodiversity conservation to the front burner in twenty-first century to protect the environment and save humanity from destruction. Therefore, biological diversity in various ecosystems across the world is important to man and the environment. A relationship exists between man the environment. This relationship must be sustained on the positive side for man to co-exist with the environment. However, development activities in terms of agricultural revolution for food and infrastructural provision for modern life have tilted the relationship in the negative direction and alter the balance between man and the environment. It has been noted that 40% of world economy is based on biological products and processes, but this is not sufficient as man wants more because of expanding population and rising cities. The excesses of man on the environment are now generating issues of climate change with the survival of man, biodiversity and environment threatened with destruction. The GDP – Gross Domestic Product of any country may not reflect the value of biodiversity because it is difficult to calculate, yet it contributes to the GDP.

Looking critically at biodiversity from plants and animals' perspective within the scope of this chapter, the plants can be described in terms of vegetation pattern such as grassland, shrub and forest with all other biomes subsumed in the three broad vegetation types. Plants life forms (vegetation) depend on climatic factors of temperature and moisture of a region. On the other hand, animals can be broadly divided

Figure 3.
Biodiversity in a forest ecosystem – adapted from Pixabay.

Figure 4.
Human activities, habitat destruction and biodiversity loss in forest ecosystem – adapted from Pixabay.

into fish, mammals, birds, reptiles, amphibians, as well as invertebrates and other categories subsumed within the broad classes. Insects are also not left out with broad classes. These descriptions reveal the diversity of plants and animals which is very significant in ecotourism. When tourists make responsible travel to various destinations, it is the diversity of plants and animals and interactions among them and the environment that the tourists are trying to catch a glimpse of nature's endowment to humanity. Ecotourism is sightseeing of the beauty, diversity and interaction of

Figure 5.
Infrastructure for expanding population destroying biodiversity, habitats and promoting climate change – adapted from Pixabay.

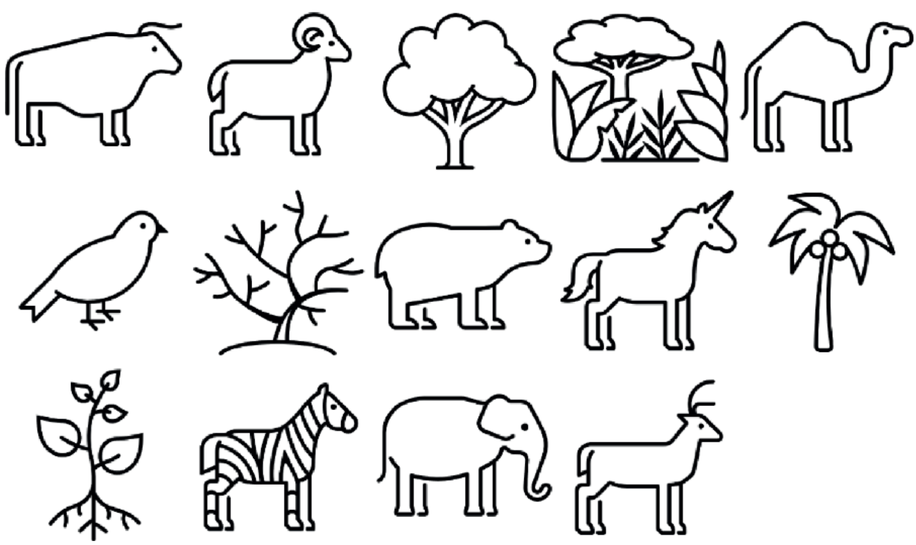

Figure 6.
Biodiversity interaction.

biodiversity. **Figure 3** shows the forest ecosystem with diversity of animals revealing the richness of forest ecosystem in terms of biodiversity.

Figure 4 shows human activities within the ecosystem with the destruction of habitats to provide shelter for man and consequently, loss of biodiversity. Also, there is emission of carbon dioxide through fossil fuels use and waste disposal into the environment.

Figure 5 shows road construction through the forest for expanding population to allow easy access and movement within a location. Such road construction promotes biodiversity loss through disturbance, habitat destruction and biodiversity loss. This is very common in growing communities and cities and locations that are gradually becoming metropolitan. Again, the vegetation of the constructed sites will always be permanently destroyed, and such situation reduces the ability of the forest to absorb more carbon dioxide from the atmosphere, thus leading to excessive carbon dioxide that promotes global warming (**Figure 6**).

5. Ecotourism and in-situ conservation

Ecotourism promotes in-situ conservation and allows plant and animal species to exist in natural geographical location. This contrasts with zoo where animals are caged for sightseeing/game, and the animals remain in captivity throughout their lifetime and therefore perform poorly in the cage, this is ex-situ conservation. In-situ conservation allows plants and animals to exist in favourable geographical vegetation zones without any alteration or modification to the natural habitats. Consequently, the natural protocol regulates plant and animal species population through the food chain in the ecosystem – over-population of a particular species is controlled within the food chain, and under-population is also corrected within the food chain. This allows energy flow within the ecosystem in a natural pattern. Therefore, natural protocol checks either over-population or under-population. The various categories of animals and plants exist naturally within the in-situ population range of an ecosystem. Thus, the natural order ensures there are herbivores, carnivores, omnivores, detritus feeders and the microorganisms to balance the natural equation of co-existence among the species. This enables animals to perform optimally in such a situation. This situation is mostly common in national parks, sanctuaries, sacred grooves (mostly protected by the locals through indigenous knowledge and cultural believes), biosphere reserves and others. Countries such as Kenya, Tanzania and South Africa are good locations where in-situ conservation can be observed. Thus, tourists from different regions will have to make responsible travel to these locations to observe species in their natural range with interactions among the various groups. Thus, plant species of the same genus may exist along a vegetation zone in conformity with the dictates of nature or co-exist with other plant species if they are able to survive competition from the simple principle of succession.

The ex-situ conservation is not acceptable in ecotourism as plants and animals population are affected through transportation, captivity, poor feeding and bad management. However, botanical garden in ex-situ conservation can be a mixture of both in-situ and ex-situ if it is established through enrichment planting.

Figure 7 shows the diversity of animals and the interaction between the animals and the environment. This is what mostly interests tourists in any responsible travel to derive satisfaction from nature's endowment.

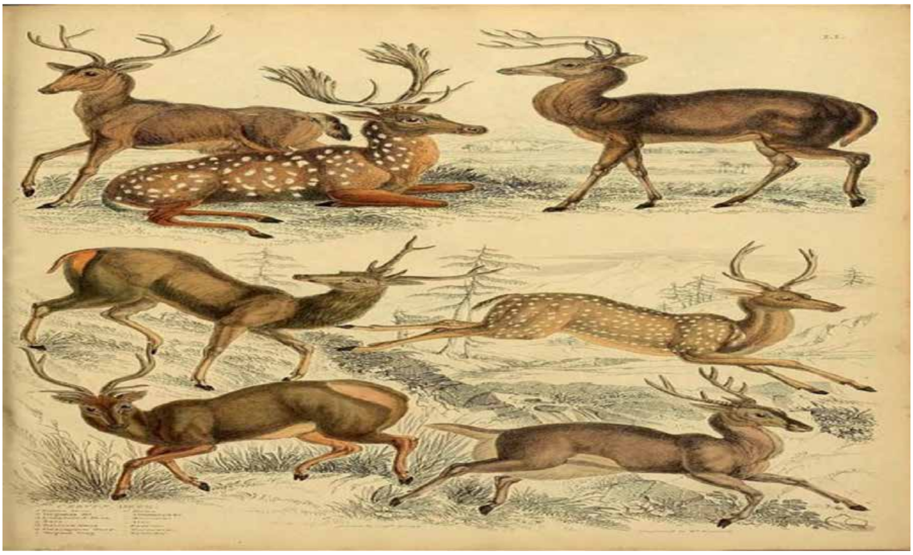

Figure 7.
Animal diversity showing nature's endowment in ecosystem – adapted from biodiversity heritage library.

6. Contingent valuation

Contingent valuation method (CVM) is a means of estimating the value of unpriced goods and services. This is very important in ecotourism. Nature's endowment is mostly goods and services without existing market price. CVM is a stated preference approach with two arms involving respondents' responses for their willingness to pay (or willingness to accept compensation) for a hypothetical change in the level of provisioning of a non-market good. CVM has a wide range of applications especially to changes involving non-use values as well as future changes. Contingent valuation method was introduced in 1947 by von Ciriacy-Wantrup [4], a German academic, but the practical application in ecotourism was done by Davis in 1963 when the principles were applied to value the benefits attached to outdoor recreation. Further application of CVM was observed in water and air quality, species preservation, forest protection, biodiversity conservation, natural resources damage, cultural heritage, waste management and sanitation improvement, just to mention a few of areas of application. Consequently, CVM has been widely applied in ecotourism since 1963. Despite the acceptance and application in ecotourism, CVM has a major shortcoming in terms of results validity due to responses associated with human behaviour. Further information on the criticism of CVM can be found in Diamond and Hausman [5] publication. However, CVM remains the most adequate tool for measuring satisfaction in outdoor recreation through maximum WTP and minimum WTA for hypothetical change in the level of provisioning for non-market-based goods and services to sustain natural resources.

Willingness to pay (WTP) involves asking people maximum value they are willing to pay to obtain a good not currently possessed and, on the other hand, the locals are asked the minimum value they are willing to accept (WTA) compensation for conservation of natural resources in their domain. Perhaps, it is important to mention that the two arms of CVM- WTP and WTA are often used in eliciting monetary values, but WTP is widely used than WTA. In WTA, people tend to give monetary values that are outrageous and therefore making it difficult to arrive at a positive conclusion in resources conservation. On the other hand, WTP is associated with income of the people or respondents, and thus, people are restricted to provide information that can be supported by their income. Thus, WTP is more informative and positive for resource conservation since it depends on income. However, where local communities will surrender their privileges and rights on land for conservation in a geographical area, then WTA compensation for conservation will have to be used due to a change in land use to prevent converting natural habitats into others uses such as agriculture and infrastructural development.

Such conversion of land cover leads to vegetation loss, habitat destruction and loss of biodiversity at three levels of existence of biodiversity. This indirectly leads to a reduction in carbon storage and contributes to greenhouse gases mostly carbon dioxide that threaten the life support base of man and the environment, a condition now known as climate change. Therefore, WTA in CVM is very important in eliciting monetary value from the locals as the consent of local communities in conservation as a way of participatory approach and thus prevents intra and inter-community future conflicts. In WTA, locals have the advantage of specifying what they are willing to accept to voluntarily give up what they currently possess. The stakeholders in ecotourism are the tourists and the community or locals where the resources are located. In this condition, the issue has to do with land use, the tourists must be prepared to pay certain amounts to sustain the resources and the locals also ready to allow the resources to continue to exist in the natural habitat without destroying the regeneration niche of biodiversity through converting the land to other uses by the acceptance of compensation.

Contingent valuation method (CVM) is a survey-based stated preference technique that elicits people's intended future behaviour in constructed markets. Respondents' behaviours were assumed to be under real market situation.

6.1 CVM concepts

Contingent valuation method relies on the significance of non-market-oriented natural resources to the society. The positive impact of the goods and services on human welfare measured in monetary terms is the focal point in CVM. From the economic point of view, utility is derived by the people expressed as satisfaction. As a result of utility derived from sightseeing, people are willing to pay certain value to express their satisfaction. This payment is mostly dependent on the income of the people. However, other socio-economic variables may affect the payment such as age, literacy level, family size, etc. This is better understood with Hicksian welfare measures and Marshallian consumer surplus.

6.2 CVM Questionnaire

Data collection method in CVM is a well-structured questionnaire. The document will contain questions that can elicit the necessary information from the people. However, caution must be exercised to prevent eliciting information that is biased through inappropriate questions which is the root cause of bias in contingent valuation. Therefore, it is important to let people have a better understanding of the situation to be able to provide relevant, reliable and positive information. The questionnaire will elicit individual preferences in monetary terms. Individual preferences in monetary terms will indicate the maximum willingness to pay (WTP) or minimum willingness to accept (WTA) for conservation of natural resources through positive changes in the future. The questionnaire is premised on the fact that the items under consideration are non-marketed goods and services, that is, there is no existing market for the products. Three major components of the questionnaire will be:

1. Socio-economic and demographic information

2. Income evaluation of the respondents

3. Attitude and behaviour of the respondents towards the goods and services for positive future changes. This is very important for hypothetical change

6.3 Constructed market

The elements of the constructed market are as follows:

1. The institution responsible for the goods and services such as government, local council or non-governmental organisation (NGO), Research Institute, Industry, etc.

2. Payment – The respondents may need to know the conditions for payment. This is crucial as the mean WTP is what is mostly accepted and not the various amounts stated by individuals. Thus, it is imperative to design the questionnaire in such a way that respondents give adequate monetary information towards conservation

3. Time – the length of period that the goods and services will be provided

6.4 Payment

The payment vehicle may be divided into two:

1. Voluntary payment such as donations, gifts or annual subscription. It can be a one-time payment or for a period. This payment vehicle may sometimes introduce bias in CV as respondents may not fulfil obligations. A very good example of this is presently in use in Stanley Park in British Columbia, Canada. Members of the society and lovers of nature are encouraged to donate generously annually for the care of a particular species of interest in the park

2. Coercive payment includes taxes, levies, rates, fees or charges. This is more reliable but requires incentive to encourage payment. This is where accountability and trust on the part of government may be crucial.

Further information on CVM can be obtained from textbooks on contingent valuation method.

7. Ecological implication and sustainability

The ecological implication of ecotourism is rooted in the historical emergence of tourism. Ecotourism as an age-long activity predates modern tourism practice. In the solitary lifestyle of early settlers across the globe in various geographical locations, man depended on available and attractive physical features such as rocks and caves for protection from harsh weather conditions. At that time, man affected the environment, and the environment affected man, but there was a balance and no threat to the environment or man. People were able to co-exist with nature. The preservation of these rocks, caves, hills, etc. as well as the biodiversity to generate utility or satisfaction to man is what ecotourism is bringing to the front burner to save the earth. Ecotourism is gradually providing the much-needed change to suppress a repeat of the nineteenth century industrial revolution of Great Britain. That period saw the beginning of the present global crisis of climate change. There was major economic break through but with catastrophic consequences for the environment – the earth was damaged, and it marked the beginning of emission of carbon dioxide to the atmosphere. Industries and human societies were built recklessly on biodiversity. It revealed the relationship between environment and economy. Wildlife and natural habitats or, more succinctly put, diversity of plants and animals at that time was considered irrelevant to economic growth and human development. However, the emerging discipline of ecological economics now provides methods of assessing the economic value of wildlife that was considered irrelevant during the industrial revolution. This is strengthening the case for conservation as the contribution of biodiversity and the existing physical features play significant role in GDP of most countries. Kirkby et al. [6] reported on annual revenue flow to developing countries from ecotourism to be as large as US$ 210 x 10^{12}, thus, indicating incentives against habitat loss and exploitation. In the social cost-benefit analysis of land for ecotourism in Tambopata region of Amazonian Peru, it was revealed that the net present value of ecotourism-controlled land given by the producer surplus (profits plus fixed costs of ecotourism lodges) was as large as US$1158 ha-^{1}. Therefore, the significance of ecotourism in economic transformation of nations cannot be ignored. Further, man benefits from biodiversity from the diversity of organisms used for medicines, food, fibres and other products. Biodiversity has been an integral part of the human experience because it influences human well-being including access to flow resources and basic materials for a satisfactory life and security in the face of environmental challenges.

In view of the importance of ecotourism to man and the environment, the sustainability of the industry is very important. Both the society and the environment will benefit tremendously by keeping to the principles of sustainable development which is the development that satisfies the present situation without compromising the ability of future generation to satisfy their needs. With ecotourism the principle of sustainable development is put in practice. The United Nations agenda for sustainable development as contained in the 2030 agenda blueprint identified relevant points under the following:

1. No poverty – Agenda 1

2. Clean water and sanitation – Agenda 6

3. Sustainable cities and communities – Agenda 11

4. Responsible consumption and production – Agenda 12

5. Climate action – Agenda 13

6. Life below water – Agenda 14

7. Life on Land – Agenda 15

8. All the above are common features of ecotourism.

8. Conclusion

This chapter has revealed that ecotourism is an age-long conservation tool contributing to economic development and protecting the environment. Ecotourism utilises natural resources both renewable and non-renewable to protect the environment and reduce the impact of climate change. Thus, ecotourism contributes to the GDP of most countries through ecological economics approach, but the percentage contribution is still difficult to measure. Ecotourism has shown the significance of wildlife and natural habitats in economic transformation, conservation and sustainability across the globe in the twenty-first century mostly in countries and regions endowed with natural resources. Total dependence on science for solution on conservation has failed man with the experience of the nineteenth century industrial revolution in Europe through reckless economic transformation of building industries and cities on biodiversity and natural habitats. Ecotourism manages man and resources and promotes positive relationship with the environment in perpetuity. Resources of lesser-known economic value in early development are now playing significant roles in sustaining the environment. The issue of climate change, expanding population and land carrying capacity is embedded in principles of ecotourism as contained in the United Nations blueprint of agenda 2030.

Conflict of interest

The author declares no conflict.

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Section 6

Community-Based Natural Resources Management

Chapter 9

A Stakeholder's Participation Process to Combat Water Hyacinth in Eastern Africa: The Case of Lake Tana

Mekonnen Hailemariam Zikargae

Abstract

Alien species are a challenge to developing countries in Africa. Ethiopia is the most affected. Lake Tana is diseased with weeds. The study aimed to analyze how stakeholders participated in the campaign and mobilized against water hyacinth. Professionals promoted, advocated and combated the challenges through different scenarios. A qualitative design was selected to obtain data through cross-sectional online web-based scientific documents. Data were analyzed using analytical discussions. The length of shoreline infested by the weed has increased alarmingly and is a major cause of the loss of biodiversity in the lake. However, the multifaceted efforts to save Tana are the greatest endeavor to protect it against the water hyacinth. The efforts are opportunities to undermine the enlargement of the weeds in and out of the lake. The finding indicates the identification of the water hyacinth problem was delayed. The findings show that most of the campaigns are not based on participatory planning. Participation was not well institutionalized in Ethiopia. The stakeholders' role in environmental management was limited, and minimal attention was given. Inclusive planning and community-based management are indispensable to combating water hyacinth. The planning and participation of the campaign should be prolonged and repeatedly used to eradicate alien species.

Keywords: biological invasions, alien species, stakeholders' participation, environmental management, Lake Tana, Ethiopia

1. Introduction

1.1 Background

Literature has been reported that invasive alien species are a major global challenge requiring urgent action as they are considered as one of the major problems in the world's biodiversity. The species were reported to alter ecosystem services, reduce species richness and abundance, and decrease genetic diversity of the habitats. In addition, they also cause substantial economic losses.

This chapter describes an alien species in Eastern Africa with special reference to water hyacinth (*Eichhornia crassipes*). The focus of this chapter is on how people of the local community members communicate, interact, and manage among themselves to solve the problems. Community problems could be solved by the local community but requires support from different stakeholders [1]. It has also relied on how stakeholders, at the grassroots level, can articulate their views, needs, interests, and actions to the district, regional, national, and international level [2]. In addition, the practice of the stakeholders in this context could be considered. In the context of the practice, the stakeholders who had participated in the removal of water hyacinth (*E. crassipes*), alien species, in Lake Tana are critically considered in the chapter. In the water ecosystem, the availability of water weed at Lake Tana was discovered by Ayalew Wonde, who is a Bahir Dar University colleague [3]. Researchers, journalists, environmentalists, individuals, and practitioners in environmental protection have also begun promoting, in different media, the serious problem of Lake Tana and its basin based on deliberative motives. A deliberative motive is that stakeholders make decisions on their own minds without any communication with others. It is difficult to tackle this problem in isolation from each other. The campaign started through media, and stakeholders mobilized to physically remove the water hyacinth. Besides, fundraising events were conducted through social media by some stakeholders from abroad. The funders bought machine to remove water hyacinth. Moreover, youths came and joined the campaign from different areas.

Weed expansion in the Lake is becoming worse. It has risks on the ecosystem. In addition, the release of untreated wastewater from industries around the lake adds to the deterioration of the lake's ecosystem. Several aggravating factors identified a widespread of the weed in Lake Tana. Pollutants that originated out of farming as well as urban sites were the primary sources. Scholars confirmed that there were extensive agricultural activities at water basin of the lake in its surrounding districts, which rushed out and drained used pesticides and fertilizers to the buffer zone where the weed received nutrients for growing. A water hyacinth is difficult to eradicate, but aquatic wetland researchers indicated its removal through chemical spraying and biological control methods.

Recently, the challenge of the hyacinth infestation was the driving force that motivated the stakeholders to participate in the campaign. However, it was not institutionalized. The stakeholders' participation could be institutionalized [4]. The local and state government, politicians, academicians, and researchers assisted in disseminating information regarding water hyacinth. It will take a concerted effort by many stakeholders and other participants. As a result, different media, government organizations, NGOs, donors, civil organizations, and partners were involved in the campaign, to save Lake Tana in the year 2017 and 2018. Attempts of removing water hyacinth by machine failed during 2019. Research indicates that "the area covered by water hyacinth was increasing significantly" [5]. Specifically, the stakeholders from the lake's neighboring region have been directing their efforts to preserve Lake Tana. To ensure participation, genuine participatory communication is a basic tool. However, the major drawback of the campaigns was that it was not based on strategic planning. Hence, communication is not participatory and genuine. In general, the multifaceted efforts to save Lake Tana are the highest endeavor to protect it from the invasive water hyacinth in the north-eastern part of Ethiopia. However, stakeholders' participation has not been well institutionalized in Ethiopia, and as a result, the stakeholders' role in environmental management is limited. The major idea is that the identification of the water hyacinth challenge was delayed, and no more attention was given to involving stakeholders. In Ethiopia, policies of environmental protection, development, and climate change are aimed at presenting key environmental and developmental sustainability challenges and opportunities. Both issues are linked to poverty reduction and socioeconomic development in the era of sustainable development. The main aim of this research is to analyze how stakeholders are participating in the campaign of fighting water hyacinth on Lake Tana. Accordingly, the study seeks to answer the following two questions: Q1: How do the stakeholders participate to solve the challenge of water hyacinth in Lake Tana? Q2: What are the roles community members play in the planning and implementation of programs of water hyacinth?

Any global research activities with regard to environmental issues can support current global environmental challenges, climate change, and developmental problems. It can contribute and provide information for intervention to different parts of the society. It was enabled to strengthen the participation and decision-making in environmental management [6]. Moreover, the results could bridge and enhance the existing gap of lake issues among different stakeholders in the country. Besides, it provides practical experiences for the teaching-learning process, research, and community services. This research, then, is an initial step and part of future academic discourses. Above all, the findings provide credibility and integrity among the stakeholders [7]. In summary, the research findings will be employed as resources in research, community services, teaching-learning processes, scientific communities, varied organizations, and stakeholders, as well as program and policy formulations and potential sources of public dialog.

1.2 Description of the study area

Lake Tana is the first largest in Ethiopia and the second largest among the African lakes. Owing to its rich biodiversity and significant cultural heritage, UNESCO recorded it as the World Network of Biosphere Reserves in June 2015 [8]. Lake Tana accounts 50% of the freshwater of Ethiopia. The lake has 3111 km^2 surface area, 284 km3 volume, 90 km length, and 65 km width. The Blue Nile River flows from Lake Tana, and it is the source of the Blue Nile River. There are 37 islands in the lake. They are ancient and artistic monasteries. They provide esthetic beauty with their historical, cultural, religious, and tourism values. The communities are dependent on untreated water for drinking, cattle watering, fishing, irrigation, and recreation. Besides, Lake Tana has been providing ecosystem services through fishing, water supplying, transporting, electric power supplying, water irrigation, heritage/religious practices, ecological diversity, tourism, a breath for Bahir Dar residents, livelihood for a marginalized ethnic group (Negede Woyto), mining (sand), and wetland products. However, according to [9], the Lake Tana basin suffers from:

> *land, soil, and water degradation which are manifested in different forms such as sedimentation, clearing of wetland, canalization of the tributaries, increased trend of eutrophication, toxigenic cyanobacteria, occurrence of invasive species like water hyacinth, stakeholders' conflict, improper damming, construction of buildings in the lake shore areas that are natural breeding and feeding grounds for some fish and bird species, poor waste management, and an increased prevalence of water-borne diseases.*

Even if these problems persist, the Tana basin has been connecting about 2 million inhabitants, the majority of whom depended on agriculture, while the two largest cities (Bahir Dar and Gondar) in the Amhara regional state are found within the lake basin [10]. The Bahir Dar city is found on the lake shore. The Lake monasteries including Bahir Dar are among the highest tourist destinations [11] found in Amhara regional state and Ethiopia.

2. Methodology

2.1 Approach

Qualitative research is a type of scientific research approach to obtain information regarding awareness, knowledge, skills, occurrence, process, actions, experiences, behaviors, and social contexts of a particular population [12]. An in-depth description, accounts, opinions, and feelings were emphasized to make reiteration and interpretation easier. In-depth description is the hallmark of qualitative research [12–14]. A qualitative research approach has to be determined in terms of orientation uses and inductive approaches to generate theories [15]. It is "concerned with life as it is lived, things as they happen, and situations as they are constructed in the day-to-day, moment-to-moment course of events" [16]. Qualitative researchers study people within naturally occurring settings to describe, explore, and possibly explain lived experiences. In this regard, deep familiarity of the scene and people inside it are desirable components of the study. Hence, deep digging and involvement in the natural setting are crucial. Natural settings, meanings, processes, perspectives, and understandings were the focus of this qualitative research [16, 17].

The settings are the natural open system wherein stakeholders interact within and ongoing changes maintained. Therefore, the settings and things inside are in a state of change—they are not static. Environmental context and situations are very important to qualitative research [18]. To understand this phenomenon, a case study design was selected.

2.2 Case study

A qualitative research methodology dependent on the topic, aims, intentions, philosophy, researcher competence, purpose of the enquiry, and the availability of the resources. Some scholars also emphasize that accessibility of issues can determine methodological choices [19]. Therefore, this study primarily focuses on case studies. This enquiry is followed with intensive investigations of a study subject in its natural settings.

Case studies are described as a common way to conduct qualitative research. In addition, case studies are able to illustrate the type of study. Case study is a "methodological approach" [20] that uses different data-gathering measures. Data gathering takes a holistic, analytic, entirely by repeated measures to get valid data [17, 18, 21]. A study considered data from diverse sources and triangulated to gain an in-depth understanding of the study. In addition, case study research works on an intensive and holistic investigation that uses voracious sources of evidence as of a single phenomenon within its social context [19].

It used different data collection methods and data analysis techniques to enrich the study with different perspectives. Case studies provide an analysis of the relationship between a challenge and a solution and the cause-effect relationship [20, 22–24]. A case study is "…ideally suited to the needs and resources of the small-scale researcher and used to illustrate problems or indicate good practices" [23]. Therefore, a case study starts with an introduction the analysis of a situation.

In addition, a case study is a systematic and intensive examination, gathering, or investigation of information using multiple sources, which considers comprehensive investigation of social unit under the study [17–20, 22, 24]. It considers [24] the role and functions in the case of stakeholder participants, media, and communicators. In addition, the case study "investigates and reports the complex dynamic and unfolding interactions of events, human-environment relationships and other factors in unique instances" [24]. Thus, careful observation of each unit is very important. From the case data, generalizations and inference are drawn [17, 21–24]. Case studies for letting incidents and circumstances speak for themselves [24]. Therefore, a case study is a systematic and rigorous field research technique.

Case design types are exploratory case study. These may consider single or multiple cases [17, 20, 22–24]. The multiple cases are actual replication but not sampled. In addition, there are three stages to write up case studies: research, analysis, and the actual writing. The researcher repeats to gather additional information after the writing had started. Therefore, convince sampling strategy is appropriate for this study that ensures the availability and accessibility of data. The sampling strategy should aim at an unbiased selection of stations, contexts, or situations where the relevant encounters, transactions, processes, experiences, or behavioral responses are likely to be found with acceptable frequency [12].

2.3 Collecting data

Qualitative researchers seek data that represent personal and lived experiences in particular situations and contexts [18, 25]. According to Stake, to study the case researchers gather data all at once. Therefore, three most common qualitative methods of collecting data were used for this research. These were in-depth interviews, observations, and documents [20, 23, 24, 26]. The majority of the data were collected using documents. The secondary sources were written, video, and photographic sources that interpret or record [13]. Each and every study project used and analyzed documents. The researcher used different documented and archived resources [23]. In addition, [27] organizational manuals, educative documents, federal regulation, meeting hand-outs, policy documents, and environment impact assessments were considered in the current research. Thus, documents were considered valuable methodological tools. Media sources were also important to elicit data. Observation was a technique that is used to elicit primary data. In this procedure [12], reflection, observation, and analysis were repeated throughout the research process until the theoretical and conceptual formulations exhausted through the available data.

2.4 Data analysis

This study employed analytical discussions based on the emerging themes from the collected data. Qualitative analysis was dependent on the researcher's analytical and integrative skills and personal knowledge, as well as experience of the social context where the data were collected. Qualitative research findings were constituted through the subjects' categories of meaning and experience. The emphasis in qualitative analysis is "sense-making" or understanding a phenomenon, rather than predicting or exploring [25]. Qualitative analysis was organized on key ideas. Coding helped researcher to rearrange and organize data. Coding was analytical. It requires researchers to review, select, interpret, and summarize the data. It provided a first step in conceptualization of a phenomenon [13]. With qualitative studies, there was usually a constant interplay between collection and analysis that produced a gradual growth of understanding.

3. Theoretical framework

3.1 Stakeholders' participation

The term stakeholders can be used as public interchangeably. This article predominantly uses stakeholders in lieu of using the word public. In this regard, this theoretical part notes some concepts of stakeholders' participation by defining the concept and identifying the benefits of participation. It also considers some concepts of stakeholders' involvement and discusses their participation level. In addition, the discussion also considers the incorporation of stakeholders' interest in environmental law. This research explores how citizens are involved in quality environmental decision-making with regard to sustainable development [6]. It strives to understand the extent to which stakeholders' participation in environmental issues occurs in the decision-making process, particularly in cases involving stakeholders in using any channels of environmental communication so that they can empower themselves. Allowing citizens to comment to decisions that have already been made is very different from inviting individuals to contribute knowledge about how a policy will affect their community from the beginning of a decision-making process [27]. Stakeholders' participation in policy decision involves two dimensions [27] including the extent of decentralization of power and the participant interaction. On the one hand, a pseudo-participation approach to participatory communication practices is often adopted for the purpose of appearing to be actively involved citizens. On the other hand, full participation requires every member of the community a vested power to determine the result of decision-making. Ultimately, stakeholders' participation is an input for decision-makers [28] and incorporates different aspects, such as a provision of information, filling information gaps, problem-solving, social learning and information contestability, empowering marginalized groups. Democratic practice and capacity are also noted. Stakeholders' participation consists of three overlapping issues [29] including information dissemination, consultation, and stakeholder participation.

The term stakeholders can be used instead of the public. The stakeholders are those who are directly or indirectly concerned about the environmental issues. Different scholars define stakeholders' participation in the context of environmental decision-making. They define stakeholders' participation in terms of involvement of all parties (stakeholders) who may have an interest and/or are affected in both environmental and development decision-making at all levels [27, 30, 31]. Stakeholder participation is a technique used to include stakeholders' values, needs, and concerns in commercial and governmental decision-making. It entails participation and two-way communication, with the end goal being to reach conclusions that the stakeholders will support. The Planning Commission indicated the importance of stakeholders' participations to empower them. To make an effective stakeholder participation in the planning level, interested and affected individuals, organizations, agencies, and government entities are consulted, collaborated with, and included in the decision-making process to bring their empowerments and legitimacy [29]. Planning is also an organized process to involve stakeholders.

3.2 Benefit of stakeholders' participation

Broad stakeholder participation is indispensable part of democratic response of responsible governance. Besides, it is mandatory to achieve sustainable development through responsive and curious management of environmental challenges. It creates opportunities for the democratic exchange of ideas, transparency, mutual learning, and informed and representative decision-making processes. Stakeholders' participation in environmental agendas and issues could have different benefits. First, it strengthening democratic approach and practice through engaging the stakeholders in the impact assessment of environmental and other processes as stakeholders have been encouraged to use their democratic rights. Second, it has increasing accountability. Stakeholders have been contributing to healthy social, economic, and environmental impacts of the development process. It also shows how the risks and hazards could affect different parts of the society. Third, it can improve process quality. Meaningful participation could allow stakeholders to be well informed of different concerns and engagements about the implementation of policies at the grassroots level [32]. Fourth, it manages social and environmental conflicts. Stakeholders can alleviate social and environmental conflicts by engaging stakeholders to assess the impacts of environmental activities and policies. Fifth, it safeguards against externalities. Active stakeholders' participation can identify environmental and other externalities that might otherwise be overlooked. By paying attention to, for instance, the impact assessment of environmental processes in advance, stakeholders' scrutiny can prevent future problems from arising. Finally, it enhances process legitimacy. Meaningful stakeholders' participation in the impact assessment of environmental policy and international environment agreements will legitimize the quality of decision-making process and reduce the level of conflict [30]. Without significant stakeholders' participation, citizens may feel manipulated and suspicious, which undermines an effective dialog and can create distrust.

3.3 Principles and types of participation

The idea of stakeholders' participation principle is considered according to the pillars of the Aarhus Convention [33] that includes access to information vital for stakeholders' participation. It is an engagement in designing, decision-making process, and access to justice [34]. The World Bank listed out the types of stakeholders' participation such as information sharing, consultation, collaboration, and empowerment. The former two are the low-level forms of participation, while the latter two are considered high-level forms. These types are consistent with other forms of participation by [35], which include passive participation, consultation, functional participation, empowerment on which stakeholders have an equal influence on the decision-making process.

3.4 Participatory communication

Participation of the stakeholders uses a recently developed approach of communication, which is known as participatory communication. What is participatory communication? [34]. The World Bank came up with the working definitions as participatory communication that provides a platform the voices to be heard by and allows for the genuine participation of the targeted audiences by the aim of addressing their challenges and transformational power. As stated above, it is merely a deliberative action of the stakeholders. There was no institutional responsibility at the time of the public campaign. Therefore, participation for action is the motive of the stakeholders.

Participatory communication will contribute to the formulation of *communication strategies* that can enhance dynamic, engaging, and sustainable change processes. The focus of participatory communication is on dialogical communication rather than on linear communication. The emphasis is on participatory and collective processes in research, problem identification, decision-making, implementation, and evaluation of change. The participatory approaches to communication have reinforced the emphasis on structural and social change. Participation entails that the communities are part of the development process and initiatives, and it could be fruitful by themselves [35, 36]. In general, this alternative paradigm of development communication is advocating the changes that emphasized a dialogical participatory environmental communication. In addition, participatory communication emphasizes the crucially of the cultures of the communities, democratization, and participation.

The most important governing principles include dialog, voice (role of media), and liberating pedagogy—for dialogical communication to happen something has to articulate the process. Action-reflection-action: Key results of participatory communication are the articulation of awareness raising and commitment to action. First and foremost, it becomes a process of empowerment for involved communities that feel a commitment to, and ownership of, the problem.

3.5 Participatory spaces: the role of the media

Participatory communication strategies and approaches require the role of media, which could be indispensable in the developing nations [36]. The dialog among stakeholders is useful to promote and empower their participation. It is used to build capacities and involve stakeholders. In addition, it can probe, assess, and analyze issues and prevent conflicts. An expansive role for communication—participation-as-end—is appropriate in projects aimed at organizing movements, transforming social relations, and empowering individuals. In this regard, participatory communication is about visibility and voice in the mediated public sphere [36]. Scholars argued that in communication interventions the more participatory strategies emphasize media that allows more dialog [36]. The media serves as a channel of communication whether they become catalysts of social mobilization and change in themselves or not. The community-based media are a dialogical instrument for change. Community radio, for instance, has the participatory potential. In developing participatory communication strategies issues such as accessibility, reachability, and manageability of media could be given much emphasis [36]. At the local level, the main goal of media is to enlighten and inspire local residents through a variety of media in order to maintain their active engagement [37]. The role of media is the center of the campaign for mobilizing the stakeholders.

3.6 Sustainability and public participation

Citizen can participate in genuine decision-making process through different sustainability platform discourses. In that case, it provides the democratic legitimacy for the stakeholders [38]. Different stakeholders highly used sustainable development and sustainability in their program vision, plan, and empowerment strategies [38, 39]. The two concepts accommodate different mandate groups and are attractive in building a coalition among different stakeholders. Citizen engagement can provide concrete ideas and make them inclusive to ensure the sustainability of policies and initiatives.

4. Results

The findings of the current study indicate that efforts were fine and several stakeholders participated. However, a short period of campaign that was ended without fruitful outcomes. It was a dystopia to the participants. A scenario that ended itself with a short period of campaign followed with a low outcome.

4.1 The major role of stakeholder participation

The purpose of this research is to analyze how public, media, government, donors, partners, nongovernmental organizations, and civil society or the stakeholders, participated in the process of designing and implementing the campaign to fight water hyacinth on Lake Tana. In the objective part, two questions are designed. The questions are: How do the stakeholders participate to solve the problem of water hyacinth on Lake Tana? What are the sole roles expected from community members in the life cycle of programs designed to combat water hyacinth? Accordingly, the result of the study shows that stakeholders' role before and during the campaign includes mobilizing the community, financial contributions, material provisions, establishing charity organization, conducting research and dissemination of information, and expertise in the dissemination of information through the media and planning campaigns.

Stakeholders' participation has voracious in alleviating deep-rooted environmental challenges on the Lake and its surroundings. The current research found varieties of participation to combat water hyacinth on Lake Tana. These participations include media communication and mobilization, youth's movement, farmers' movement, researchers, government, NGOs, and charitable organizations. Therefore, the participation of stakeholders can take different forms. The researcher finds out and emphasizes that the participatory communication was based on a deliberative motive. However, it was not as such progressive.

5. Discussion

5.1 Review of research conducted on Lake Tana

First, the study conducted focused on wetlands surrounding the Lake Tana. Its aim was to: (1) study the vegetation wetland communities of surrounding the lake; (2) assess and evaluate vegetation types of the wetlands as well as bird species; and (3) provide reliable information regarding biodiversity, disturbance, and threats. The finding indicates that there were many losses and damages [40]:

> *the wetlands adjacent to the lake are seriously threatened by habitat degradation and loss, over-grazing, over-harvesting, agricultural practices, sand mining, man-made modifications of the lake, irrigation, sedimentation, soil erosion, siltation and the spread of the invasive species Eichhornia crassipes.*

Second, there are 33 research projects [41] conducted on the Lake Tana basin and its surroundings, which basically focus on regional challenges, problems of the Lake, growth and ecology, climate of the basin and its variability, hydrology, and groundwater occurrence, agricultural landscape, plankton, birds diversity, wetland, forest resources, exotic and invasive plants, demographic characteristics, gender and livelihood, characteristics of stakeholders, urban areas and planning, and environmental security and its basin.

At the end, another study conducted using biological approach [42] showed that water hyacinth swiftly grows due to climate conditions. The climate condition on the lake shore becomes cold and rain. A survey report on water hyacinth on the lake was also compiled [15, 43] by the Bahir Dar University academic staff.

5.2 Water hyacinth

Government authorities, academics, and consultants develop several techniques for public involvements. Governmental and nonprofit organizations, activists, researchers, media, and other scholars tried to impose information regarding the hallmark of multiple problems of Lake Tana. For instance, on the website of the Charitable Organization for Integrated Tana Basin Development, it indicates its multiple causes, dangers, and its distribution.

The most recent invasion of water hyacinth (*E. crassipes*) is the most pressing issue Lake Tana has encountered, and it has caused an immediate threat to the lake's water quality and quantity as well as its biodiversity. The most notorious and invasive aquatic plant, known as water hyacinth, has been named one of the top 10 worst weeds in the world and one of the top 100 most aggressive invasive species. Although this weed is not new to Ethiopian rivers since it has existed in the Koka Lake and Awash River since 1965, the first reports of its invasion of Lake Tana were made in September 2011.

The drawdown of the lake led to the loss of breeding habitat for fishes. It is also difficult for transportation on the lake. Several boats were damaged and others have sunk. The papyrus beds were seriously damaged and difficult to grow around the lake. It could be a resource for the livelihood of the Negede Weyto community. They produce baskets, canons, and mats. Still, the wetlands around the lake were diminished. Discourage wetlands rice farming. The crisis reached its climax, which was highly invaded by the weeds. Scholars [44, 45] confirmed that water hyacinth, as an aquatic invasive weed, has received wider stakeholders' attention lately in Ethiopia due to the infestation of the country's largest lake—Lake Tana. Water hyacinth spreads in the fragmentation of plants and may re-sprout out of rhizomes or germinate from seeds [46]. Besides, seed dispersal occurred through water-borne seeds and by feet of birds. Migratory birds are agents for long distance dispersal. People are the major dispersal agents. Humans also contribute to its spread in some areas by using the plant as a packing material and as cushions in boats.

Water hyacinth: What is it, and what are its effects?

Water hyacinth is an aggressive invasive weed that invades water bodies (**Figure 1**). It could be reproduced very swiftly on the water body. It was not well known for other purposes. It further forms thick floating mats. The matured water hyacinth mats block different activities on the water body. Besides, it adversely affected the ecology of freshwater on Lake Tana. It reduces the oxygen level by limiting the circulation of water and air inside the water bodies that in turn hinder the survival of aquatic ecosystems. It affects the photosynthesis process by

Figure 1.
The aquatic weed, the water hyacinth, is causing major problems at Ethiopia's Lake Tana.

blocking the passage of sunlight. Ultimately, it disturbs the natural ecology of the water. Moreover, the livelihoods of the surrounding dwellers have been affected seriously. The lake size was contracted by the invasion. Above all, it interferes with the surrounding farming system around Lake Tana.

Lake Tana is the largest lake found in Ethiopia. It is the source of the Blue Nile. It has been the home of cultural heritages and biodiversity of the Amhara regional state. The Lake has 37 islands. Twenty islands host Ethiopian Orthodox churches and monasteries. These religious sites are considered reach in biodiversity, which have been considered as local and international significance. Both the lake and wetlands have ecological value and means of existence for many people in Bahir Dar city and the surrounding farmers [46–48]. The lake and its wetlands have been considered as an important habitat for both endemic and migratory birds and endemic fish species. However, the increasing pressure on the ecosystems had resulted in land degradation, erosion, and the eutrophication of the lake that affected the floral and faunal resources. In general, water hyacinth causes significant issues for the neighborhood near Lake Tana by adversely harming the ecology, farms, cattle, and the fishing industry [46]. In light of the above deep-rooted problems and other related matters, there have been many motivations and efforts contributed by different concerned communities. The problems are serious and require many efforts. Even though continuous efforts have been undertaken by farmers and all levels of government, due to the biological nature of water hyacinth, over the last 5 years there have been frequent re-infestations of the lake by water hyacinth, and it could also expand to cover thousands of hectares in the coming decades. From the experiences of other countries and the water hyacinth management efforts of Lake Tana, full control and eradication seem to be difficult, which indicates the need for integrated and sustainable management. This includes integrated water hyacinth management, integrated watershed management, and integrated community development works in the Tana basin. All these contributions should be marked by different stakeholders. The stakeholders include media, charity organizations, government, NGOs, youth, researchers, businesspeople, and innovators. The stakeholders are volunteer groups who are concerned about the environs in Lake Tana and its surroundings.

It is well known that environmental mobilization campaigns such as political mobilization campaigns are more effective and legitimate if they engage citizens in a sustained dialog rather than treating them as a mass opinion to be manipulated [49, 50]. The crucial importance of stakeholders' participation in establishing and developing decisions that include concern about the natural environment has been stressed by numerous researchers. Broad-based civil participation cannot be brought about by expert advocacy. Instead, individuals need to actively participate in the creation and maintenance of their civic institutions. As scholar [51] notes: "the task of putting stakeholders' awareness of environmental issues into practice is inseparable from that of working to enhance political solidarity." Another scholar [52] also emphasizes the need of "civic engagement and stakeholders' dialogue" [52].

5.3 Media as stakeholders and how they framed the issue

Environmental education and public awareness are assumed to be the major components to reduce the effect of water hyacinth on ecology of water [53]. Research suggested as the media are the major sources for the stakeholders to turn into for information about environmental security [54]. The mass media provide stakeholders' education concerning environmental challenges Thus, the media portrayed the seriousness of the water hyacinth on the lake. Specifically, media such as BBC, Addis Standard, Sudan Tribune, Southworld, and CGTN framed and reported the issue of water hyacinth as "aggressive," "invasive," "threatening," "infested," and "damaging."

In addition, the media educates people to improve knowledge and awareness of environmental issues. There are many local media and their respective social media platforms (Amhara television, Ethiopian television, Ethiopian News Agency, Fana Broadcasting, Ethiopian radio, Amhara FM radio, Walta information center), foreign media (BBC, Al Jazeera, VOA), social media (Facebook, Twitter, YouTube), and other personal and organizational websites participated in the campaigns by holding fora, conferences, meetings, and discussions. Some instances how some media framed the problem of water hyacinth. BBC framed it as follows: "Ethiopia's largest lake, Lake Tana, is being lost to an invasive South American weed, the water hyacinth", (BBC 30 Jan 2018). A newspaper framed the issue as "Water hyacinth is not Ebola: It has challenges and opportunities" (The Reporter 5 August 2017). Ethiopia: Lake Tana at jeopardy was how the water hyacinth issue was presented in German media. Others framed the issue as Ethiopia's largest lake nearing extinction. Lake Tana, Ethiopia's largest lake and the source of the Blue Nile, is being choked out by the toxic plant species known as the water hyacinth, prompting concerns about the federal government's response and the effectiveness of local efforts to eradicate it. In summary, the media are placing more coverage on problems of the weed on the Lake and its surrounds.

5.4 Youth from Bahir Dar city and neighboring cities as stakeholders

5.5 Farmers as stakeholders

Local authorities and city dwellers mobilized an estimated 162 000 people to remove the weed by hand (**Figures 2** and **3**). This happens only when the lake shores are accessible and when farmers have time.

5.6 Oromo youth as stakeholders

More than 200 youth from Oromia regional state joined the campaign at Bahir Dar city of Amhara regional state. They used a slogan regardless of belongings stated on a banner as "Tanan Kaygna"; literally, it means that Tana is ours. The youth used this slogan to show a unity, reconciliation, mutual respect, mutual understanding between Oromo and Amhara people. Oromo youth joined the campaign in Amhara region to combat water hyacinth on the Lake.

In support of the motivation of Oromo youth, the Ethiopian musician Mehari Defefaw released, on October 28, 2017, a new single "Tana Kegna." It was meant to support efforts to fight water hyacinth from Lake Tana. Literally, it means that "Tana is ours." The youth are geographically far away from the lake region. However, the youth's movement minimized and reinforced the ethnic and political segregation between the Oromo and Amhara people. The lake maintained the relationship between Oromo and Amhara people in the country and what is interesting here is that the hardship of Lake Tana has not been left to the Amhara Regional State alone. Youth from the Oromia Regional State have joined the march, going to Bahir Dar to fight the good fight. This exemplary unity between the two large regions, it seems, was just a prelude to the next meeting between the leaders of the Oromia and Amhara regional state. It was held in Bahir Dar. The very idea of having conducted the conference indicates progress both for the lake and the political environment of Ethiopia. The weed has to be eradicated, just as the political tensions in the country have to be resolved. Saving Lake Tana will go down as one of the most crucial events in the country's

Figure 2.
Bahir Dar city youth participation on removing water hyacinth.

Figure 3.
Farmers' participation on removing water hyacinth (source: Ethiopian today, 2017).

history. It is an experiment signaling that unity is possible and could help save it from falling apart. But improving the political situation will not be as easy as clearing the weed from Lake Tana. But it is an effort worth expending if democracy is to rein in the country, and the nation's unity is to continue. Some participants witnessed the participation as the best example for the solidarity of the two ethnic peoples.

5.7 Charitable organizations as stakeholders

One of the dominant local charitable organizations as a stakeholder to protect Lake Tana was established in 2017 at Bahir Dar University. The "Charitable Organization for Integrated Tana Basin Development" [55] (COITBD) is a charity organization working in Ethiopia. COITBD has been supporting the removal of the weed from the lake. The watershed management of the lake basin supported by COITBD to improve the livelihoods of the community living in the sub-basin.

Founders of the organization are composed of multidisciplinary stakeholders that include 15 professors of Bahir Dar University (BDU), over 15 engineers, lecturers, economists, lawyers, and political scientists, 11 journalists, and businessmen. The charity comprises 51 passionate young professionals who want to contribute their share in the protection of Lake Tana and its watershed. Since its establishment, hundreds of members have joined the charity. Several prominent international scholars are also supporting this charity (http://savetana.org 2018).

5.8 NGOs as stakeholders

In addition to the local charitable organization, the Global Coalition for Lake Tana Restoration (GCLTR), formed and based in America in support of environmental activities and watershed development to restore the lake ecosystem in Amhara Regional state. GCLTR has been facilitating the participation of individuals from United States, Canada, Europe, Australia, and the rest of the world to protect the Lake Tana from weeds infestation. GCLTR is mainly concerned about environmental issues around Lake Tana through research-proven and training environmental management system of Amhara Regional State Environmental Protection Authority. Besides, it aimed to establish and strengthen an effective water hyacinth monitoring and evaluation. To establish sustainable and integrated watershed management system; to mobilize financial resources among Ethiopians diaspora and international funding; and to advocate and create community awareness [55]. In summary, GCLTR is aimed to provide four major supports to the ongoing water hyacinth management efforts in Amhara regional state. These include capacity building, logistic support, supporting monitoring, evaluation activities, and research and assessment.

5.9 Regional government as stakeholders

The Amhara regional government has been calling up on the stakeholders to participate on fighting water hyacinth. The government representative emphasized that "unless measurements can be taken to control the invasive water hyacinth in Lake Tana, it might occur in other areas of the country and cause destruction" [56]. Besides, the authority added that "Unless it can be controlled by any means, the water hyacinth may also affect the Great Ethiopian Renaissance Dam (GERD)" [56]. Well-established national institutions were suggested tackle the challenges of water hyacinth on the Lake Tana. The government call for the cooperation had got attention by the University of Gondar, which was followed by an immediate workshop. Some workshops enhanced the call for the campaign to fight and are described as follows (http://www.uog.edu.et):

> *On June 14, 2017, at the Florida Hotel in Gondar, a workshop that effects the nation of Ethiopia was held. The joint workshop concentrated on progressing efforts to control water hyacinth in Lake Tana. Some of the event's organizers were the Ethiopian Environment and Forest Research Institute, the University of Gondar, and the Forest and Wildlife Conservation and Protection Authority. The University of Gondar's higher officials, staff, faculty and individuals from various organizational entities were present to brainstorm constructively about the issue at hand.*

The regional government call to collaboration not only got support from the university but also got attention from different government offices.

5.10 Researchers as stakeholders

Researchers' participation as stakeholders to identify the nature, extent, impact, and severity of the water hyacinth is crucial. In addition, they consider different mechanisms to eradicate the water hyacinth. The mechanisms include biological control (beetles, Faba bean fungus), removal, and chemical spraying (using herbicides). The first attempt to identify what happening in the Lake Tana is the study of Ayalew Wondie. He identified the problem of environmental issues related to Lake Tana in his research in 2011. Following this year, scholar [57] indicated the severity of the weed on the Lake. The researcher described the growth of the weed as a paradox. In the first place, "water hyacinth can cover lakes entirely, with dramatic impacts on water flow. It blocks sunlight from reaching native aquatic plants and hampers oxygen supply to the water body." On the contrary, "it can have a positive influence, if managed properly. The plant is extremely tolerant to and has a high capacity for the uptake of heavy metals which could make it suitable for the bio-cleaning of industrial wastewater. They can also enhance nitrification in waste water treatment cells of living technology" [57]. The native aquatic plant could not get sunlight. As a result, the water body will not get oxygen. A field survey result shows native fungal pathogens found in association with the weed.

Scholars suggest that "biological control is the most economical and effective approach to manage water hyacinth in the long term" [39] through the natural enemies and little cost. This strategy was not without environmental impact. It had reduced the weed coverage on the water surface. Besides, it was effective by controlling the spread in 33 countries. This was implemented in the United States, Uganda, Nigeria, Ghana, India, and Australia. The major shortcoming was that it took several years [39]. Moreover, this participation could be adopted from the Ugandan experience to the Lake Tana case. For instance, Bahir Dar University coordinated experts to bring and adapt the Uganda's experience carried out on Lake Victoria. However, the challenge of applying that experience was not yet implemented. In fact, it was evidenced that Uganda controlled the invasive weed by applying biological methods. Therefore, the biological control is going to spoil out without applying it to the Lake Tana Water Hyacinth. Nonetheless, this effort will take many years to be effective on a mass-based breeding and application plan. The researchers confirmed that biological mechanism applying natural enemies is cheap and can sustain, but comparatively slow.

5.11 Constraints in participation

Citizens' engagement in the environmental decision-making process is considered a situation where they got legitimacy on decisions and an opportunity to improve the quality and effectiveness of the decisions [6]. The difficulty of removing the weed was Heralded that "The spread of an invasive alien species is neither easy to manage nor easy to reverse, threatening not only biodiversity but also economic development and human wellbeing" [58]. The campaign of removing water hyacinth started without these goals in place. Recently, stakeholders used several methods to eradicate the weed through biological and technological techniques. These strategies were planned to eradicate the water hyacinth as much as possible. The effort was not well planned to gear all efforts toward removing water hyacinth. It was a huge challenge to achieve through small and unorganized efforts. It was also difficult to eradicate the weed using machines from the lake. In addition, the stakeholders' involvement efforts are weakened by unplanned strategic efforts. The agenda of water hyacinth removal has ceased among the surrounding people, the media, either domestic or foreign, researchers, and governments. Scholar suggests a community media for the stakeholders' mobilization [59]. This aimed to ensure a two-way communication to combat water hyacinth on the Lake Tana as the previous timely campaigns phased out. Water hyacinth removal, after the campaign, has no more media and public agenda. Currently, it has been criticized for being neglected among the stakeholders. As a result, the weed has been expanding and spreading.

Many efforts were implemented and used to eradicate the weed through human labor. Despite the very extensive campaigns to eradicate the weed, the water hyacinth had been continued to spread over the lake since it had an ability to revive and spread quickly. Two scholars showed their evidence of how water hyacinth disturbed the whole system of the lake.

The most frequently reported effects of water hyacinth on aquatic ecosystems include: i) massive water loss through evapotranspiration, which changes the water balance of the water body; (ii) decreases dissolved oxygen concentrations beneath its mats by preventing oxygen from reaching the water's surface and by obstructing sunlight used for photosynthesis by phytoplankton and submerged vegetation; and (iii) creates obstruction to water flow, which increases sediment concentration; vi) decreases electrical power plant output, endangering the nation's power supply; and vii) poses a major threat to agricultural production due to the clogging of irrigation canals and drainage systems.

Thus, the efforts utilized by the stakeholders were not yet brought about any significant impact. Moreover, the biggest problem was that the weed revives quickly unless it could be chopped, dried, and burned out. It was argued that it could take more than 30 years to eradicate the weed. It covered a large body of the water. Social media has seen a significant public outcry calling for swift action. The expansion of the weed is currently hurting the local farmers. It has resulted in decreased output of fish and crops [58].

The water hyacinth availability is indicated by some researchers. However, no one planned for further intervention and removal of the weeds immediately following on the discovery of the water hyacinth on the lake. Consequently, still water hyacinth is remaining problematic among the stakeholders.

6. Conclusion

The study shows that the drastic negative impacts of water hyacinth in Eastern Africa, inside and outside the water ecosystem, are enormous. Several challenges were manifested on the lake, such as decreasing water levels due to evapo-transpiration, decreased oxygen levels that prevented the entrance of oxygen to the water body, and blocked sunlight used for photosynthesis. It also affected the flow of water by increasing sedimentation and worsening soil erosion. Moreover, it stopped the process of fishing activities on the lake. Moreover, the condition of the lake reduces the livelihood income of the local population. It also changed the physicochemical properties of the water, which created a threat to agricultural practices. Above all, it has been affecting the farming system due to the outflow of water hyacinth by flooding. As a result, various stakeholders were called to a campaign by unorganized individuals through the media and other public discussions. Based on unstructured calls, various volunteer stakeholders participated in the fight to remove water hyacinth from the lake. The stakeholder participation did not incorporate different types of participation such as communication, consultation, deliberation, and co-production. For this participation, the most important contributors were researchers. The researchers conducted different research based on their interests. The researchers from different universities (e.g., Bahir Dar University, Gondar University) tried to identify the causes of water hyacinth and the extent of its problems. They used different journals to disseminate their findings to the wider community. These stakeholders agreed and concluded that the weed has been a major challenge since there were no effective programs implemented by the stakeholders. Ordinary citizens also disseminated information through various social media. They sensitized the issue to local and global audiences. Journalists contributed by disseminating information through mass media. Some others agreed on the understanding of the biology of water hyacinth (through longitudinal research). And it was suggested that a well-established local institution is needed to coordinate, execute, and monitor the process of all efforts to manage the lake resources. The participation of different media was initiated, and they were involved in the campaign to remove water hyacinth. Still others, such as musicians, activists, and charity organizations, locally and abroad, promoted the serious effects of water hyacinth on the lake and its basins. Afterward, no more media and public agendas have been posed by the concerned bodies, and media professionals still exist. It has no advocacy. Ultimately, as far as participatory communication used to motivate stakeholders' participation is concerned, the researcher suggests that long-term and well-planned genuine participatory eradication measures have to be designed and could be in place.

7. Limitations of the current study

The limitation of the study is that it lacks exploratory studies that did not integrate scientific investigation from all relevant disciplines such as science, the environment, and social sciences. It is important to get the details of a problem by considering a grassroots level study. This kind of study requires an institutional-based study. Besides, it lacks comparative studies of alien species removal efforts on the African continent. The current study shows a regional study limited to Lake Tana, and in fact, similar mobilization is needed to scientifically remove the water hyacinth. Still, other studies are also required to show every status after the campaign.

Conflict of interest

The authors declare no conflict of interest.

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Natural resources are necessary for meeting simple human needs such as food, water, clothing, shelter, and air. They are part of humanity's natural heritage or protected in nature reserves. Therefore, sustainable management of natural resources is crucial to ensure the stability of the ecosystem, prevent further damage to the environment, and avoid over-consumption of the resources. For the United Nations' Sustainable Development Goals (SDGs) to be achieved, it is crucial that natural resources be protected from being destroyed or overused. In addition, proper care of these resources will help them sustain for a long period of time to meet the needs of future generations. The global community has become increasingly aware of the importance of sustainable natural resources management. As highlighted in this book, it can be achieved through multiple approaches of top-down, adaptive management, integrated natural resources management, and community-based resources management. This book discusses the theories, practices, and findings on effective natural resource management being practiced in many parts of the world.

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