Chapter

Combating Desertification through Enhancement of Woody Floral Diversity in the Drylands of Kenya: Analysis, Milestones, and Strategies

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Abstract

Desertification remains one of the most challenging phenomena in the drylands of Kenya, where it affects about 80% of the country. This is because of persistent degradation of these areas by climatic variations, human activities, and overgrazing by livestock and wildlife. In these areas, inhabitants suffer from widespread acute poverty and other adverse effects of drought. In order to effectively and efficiently combat desertification and reduce the impacts of further degradation, the Government of Kenya and partners are committed to developing and implementing methods, approaches, strategies, and mechanisms that would slow down or reverse this phenomenon. This chapter covers an in-depth review of advances made so far in the area of woody resources restoration and sustainable management in the drylands of Kenya through biodiversity assessments, conservation, rehabilitation, afforestation, and reafforestation initiatives and research. Achievements, challenges, and opportunities encountered are highlighted for sustainable development and wise utilization of dryland woody and allied resources.

Keywords: degradation, desertification, drylands, floral diversity, natural resources, species adaptability

1. Introduction

Desertification is one of the most important challenges to livelihoods and development in the drylands [1, 2]. Traditionally, the drylands of Kenya are vast and rich in biodiversity and natural resources [3]. However, recent decades have seen increased human pressure on forests and woodlands that has created conditions conducive to degradation, deforestation, and desertification, thus reducing national tree cover to all time unacceptable levels. Deforestation leads to the deterioration of soil fertility, which occurs rapidly under tropical climates. However, it also offers a great potential for intensified afforestation toward achieving the national objective of 10% tree cover [2, 4]. This chapter provides an in-depth analysis of the problem including the extent, genesis, impacts, and remedies instituted by the Government of Kenya, her citizens, and development partners. The authors present an in-depth review of relevant reports and case studies and share original data and maps in view to present a favorable case toward promoting greening of drylands in Kenya.

2. Desertification process and Kenya's context

Drylands occupy 41% of the earth's land surface and are home to 35% of its population. They occur in every continent but are most extensive in Africa. The drylands include desert, grassland, and savanna woodland biomes. In Kenya, the drylands make up 84% of its total land surface, support about 9.9 million Kenyans (about 34% of the country's population), and account for more than 80% of the country's ecotourism interests, 60% of the nation's livestock, and up to 75% of the national wildlife population [5, 6]. Although rich in natural resources, the increased human pressure on forests and woodlands has created conditions conducive to degradation, deforestation, and desertification. The drylands environment poses formidable problems for sustainable development. Among these are unpredictable and severe drought, desiccation or aridification due to persistent drought, and dryland degradation or desertification [7]. However, drylands in Kenya are vast and offer a great potential for intensified afforestation toward achieving the national objective of 10% tree cover.

Desertification is defined as land degradation in arid, semiarid, and dry subhumid areas resulting from many factors, including climatic variations and human activities. These areas are characterized by low and erratic rainfall, high evapotranspiration, shallow soils with low water-holding capacity, and low soil fertility [8]. Drought is a common occurrence in the Arid and Semi-Arid Lands (ASALs) and is exacerbated by climate change [9]. It is caused by rainfall deficit; it leads to shortage of water and unusually high temperatures. Anthropogenic causes of desertification include overgrazing, deforestation, and removal of the natural vegetation cover by taking too much fuelwood, the build-up of salt in irrigated soils, topsoil erosion, and agricultural activities in the vulnerable ecosystems of arid and semiarid areas that are thus strained beyond their capacity. These activities are triggered by population growth, the impact of the market economy, and poverty. The phenomenon reduces agricultural output, contributes to droughts, and increases human vulnerability to climate change.

The differences and interlinkages between desertification, drought, desiccation, and climate change and their causal factors have been outlined in many texts [7]. Desertification is a type of land degradation in drylands in which biological productivity is lost due to natural processes or induced by human activities whereby fertile areas become increasingly arid [10]. Land degradation is a process in which the value of the biophysical environment is affected by a combination of human-induced processes acting upon the land [11]. It is viewed as any change or disturbance to the land perceived to be deleterious or undesirable. Permanent changes in climate, particularly rainfall, are responsible for natural desertification. Desertification may alter the living conditions of the local flora and fauna that makes it impossible for animals and plants to sustain their populations. After desertification, regions suffer from water shortages due to climate change and animals may suffer and die since water is vital for all life on the planet. Desertification results in persistent degradation of dryland and fragile ecosystems due to man-made activities and variations in climate. Desertification, in short, is when land that was of another type of biome turns into a desert biome because of changes of all sorts.

Desertification affects topsoil, groundwater reserves, surface runoff, human, animal, and plant populations. A study conducted in the Mutomo District, Kenya, confirmed that the main use of selectively harvested trees was charcoal production [12]. This consequently led to degradation of the woodlands through reduction in tree species richness, diversity, and density. Water scarcity in drylands limits the production of wood, crops, forage, and other services that ecosystems provide to our local communities. The United Nations Convention to Combat Desertification states on its website that, globally, more than 12 million hectares of land are lost annually to desertification, drought, and degradation and that over 1.5 billion people are directly dependent on land that is being degraded, leading to loss of US dollars-equivalent billions of earnings each year [13]. In Africa, three million hectares of forest along with an estimated 3% of Gross Domestic Product (GDP) are lost annually due to depleted soils. The result is that two-thirds of Africa's forests, farmlands, and pastures are now degraded.

The dry lands on average receive an annual rainfall of between 250 and 1000 mm. **Figure 1** shows the extent and levels of aridity in Kenya. The rains are typically of short duration but of high intensity and therefore highly erosive. The rate of evapotranspiration is also high. The aridity values on the map legend are based on the generalized climate classification scheme for Aridity Index values [15] as follows (**Table 1**). No region in Kenya is classified as Hyperarid (Aridity Index Value <0.03).

The main challenge in developing dry lands is how to increase availability and access to information and technology for the development and management of natural resources.

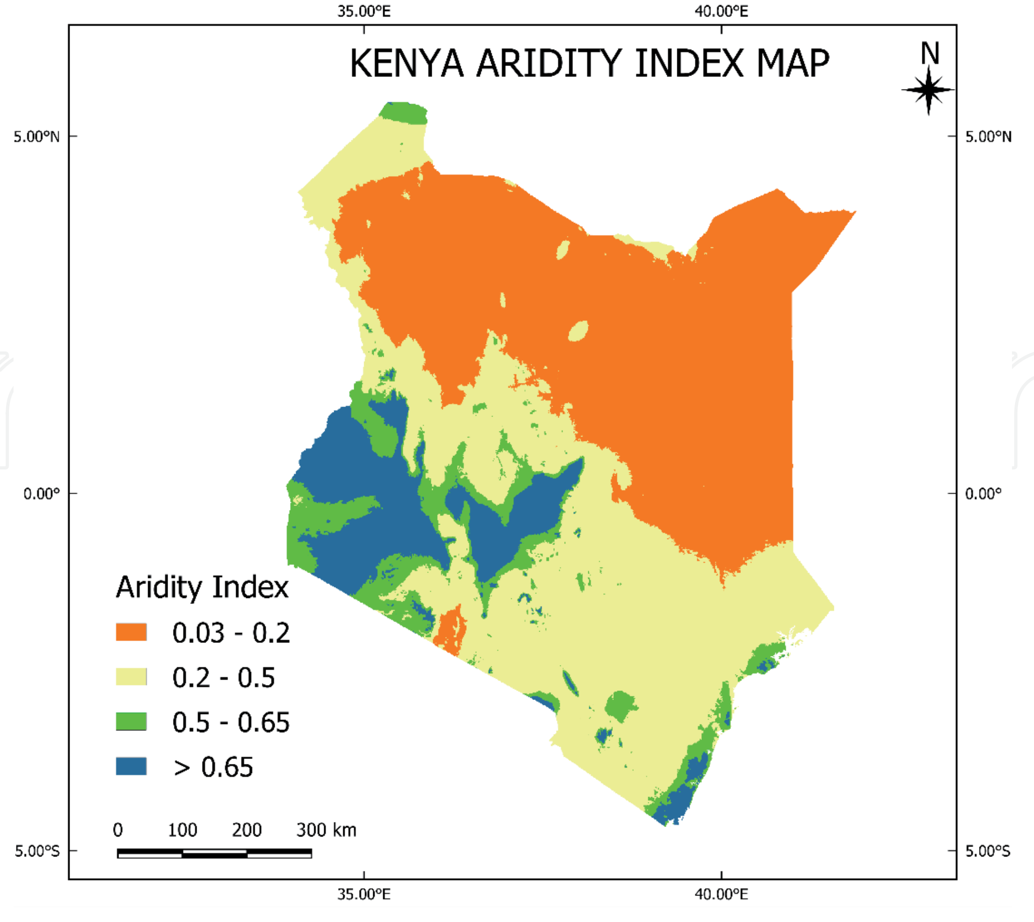

Figure 1.
Kenya aridity index map produced based on the Global Aridity Index and Potential Evapotranspiration (ETo) Climate Database v2 [14].

Aridity Index Value	Climate	Extent coverage (km^2)
0.03–0.2	Arid	255,800.11
0.2–0.5	Semiarid	220,704.78
0.5–0.65	Dry subhumid	46,483.89
>0.65	Humid	57,378.22

Table 1.
Aridity context in Kenya.

3. Land use, cover, and natural water resources

Overgrazing is the major cause of desertification in the dry lands [16]. Other factors that cause desertification include urbanization, climate change, overuse of ground water, deforestation, natural disasters, and tillage practices in agriculture that make soils more vulnerable to wind [16, 17].

3.1 Contextualized land uses in Kenya

A land-use map represents the physical and biological cover over the land surface, consisting of vegetation, bare soil, water, and artificial structures. Land-use and land-cover information is significant in understanding the socioeconomic and environmental implications linked to the utilization of the available natural resources in a region. In Kenya, land use is classified into agriculture, forest, bushland, grassland, plantation, built-up and urban area, barren land, woodland, plantation, swamp, and water bodies (**Figure 2**).

Agriculture is estimated to occupy 48% of the total land area, out of which 9.8% is considered arable land, 37.4% is covered by permanent pasture, and 0.9% by permanent crops such as tea and coffee plantations. Tree cover is estimated at 6% while other land uses, such as urban areas and bare land, occupy about 45.8% [19]. Urbanization and expansion of agricultural land have increased the rate of conversion and fragmentation of the natural forest ecosystems leading to deforestation and eventually land degradation. Land-use/land-cover change is considered the primary causal agent of climate change due to environmental changes that lead to increased greenhouse gas emissions. However, the effects of climate change, viz. increased temperature and variability in precipitation, prompt the change in land use as communities try to adapt to the changing climate [20]. Therefore, the development of effective land-use management plans is crucial to ensuring Kenya's goals toward environmental sustainability under future climate scenarios. There is a need to assess the vulnerability and adaptive capacity of local communities so as to prioritize the solutions that will enable communities to cope and adapt to climate change.

3.2 Contextualized tree cover types in Kenya

Kenya's forest areas constitute a wide range of vegetation, viz. trees, shrubs, and grass species. The Kenya Tree Cover Types map (**Figure 3**) gives a detailed visual representation of the categories of different tree cover types found in Kenya. The tree cover types are mainly classified as open canopy, closed canopy, multilayered trees, and mangrove trees. Open canopy refers to a collection of relatively tall trees that are spaced and allow easy penetration of sunlight to the ground surface. Closed canopy forest is a thicket of mature trees whose leaves and branches are densely spaced

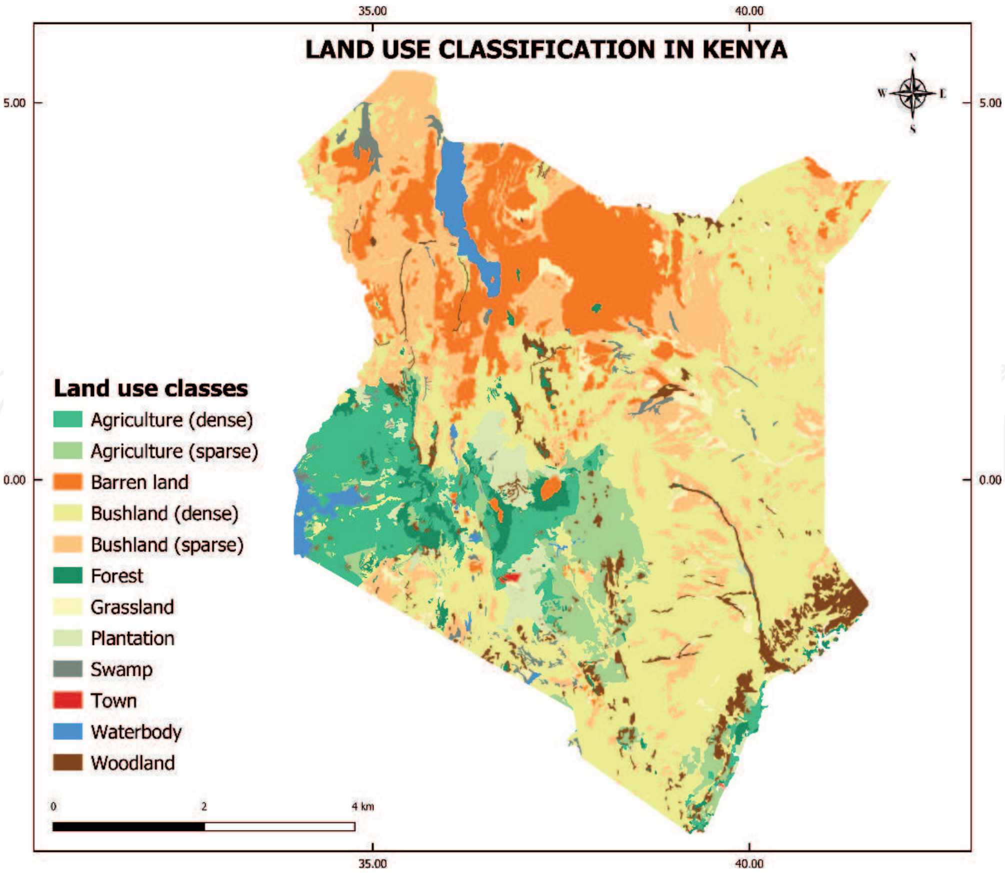

Figure 2.
Mapped land-use classification for Kenya based on Kenya's geospatial data provided by the World Resources Institute [18].

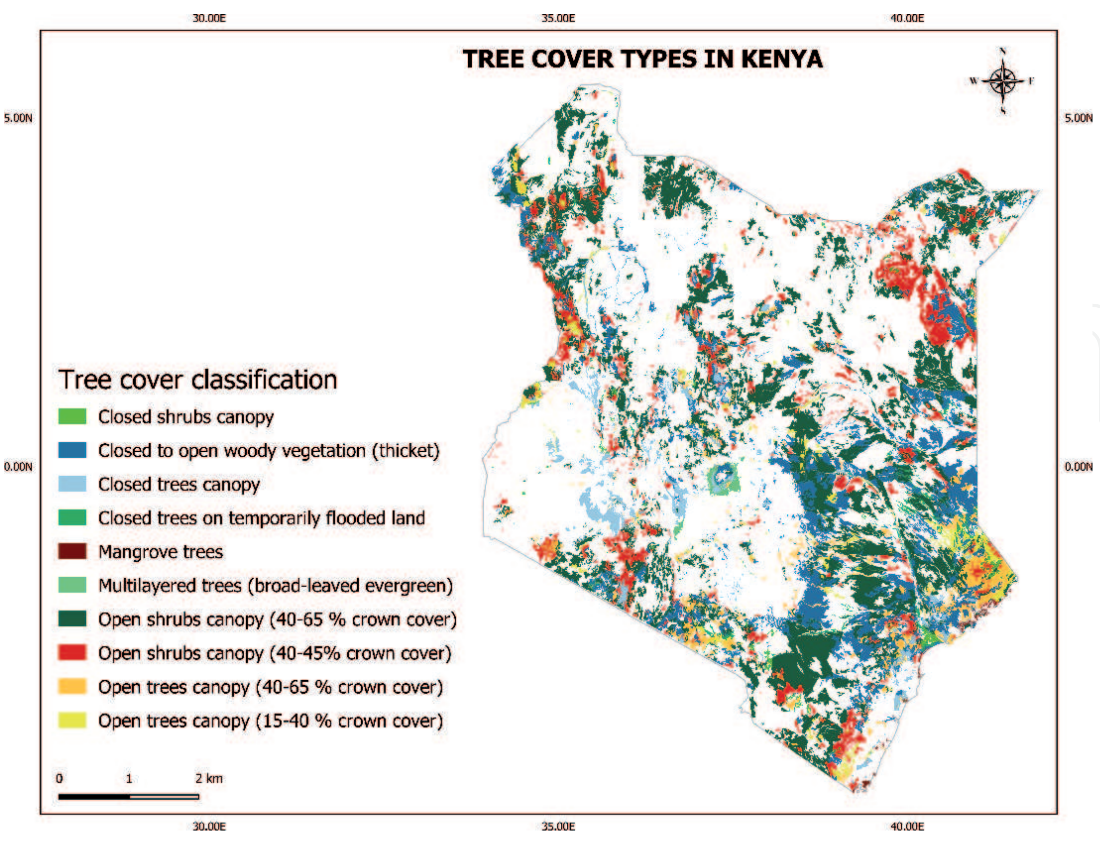

Figure 3.
Spatial distribution of different types of tree cover in Kenya produced from the Environmental Systems Research Institute Kenya GIS data [21].

creating a crown that encloses the understory and the forest floor. The canopy types are also distinguished based on the percentage of crown cover, that is, the proportion of the ground covered by the vertical projection of the tree canopy. The multilayered trees generally refer to the dense tropical evergreen forests having the appearance of structured layers that differ in the amount of sunlight penetration, ground cover, and water availability. The mangrove trees, which occupy about 1% of the land area in Kenya, include thickets along the coastlines, tidal estuaries, and salt marshes of Kenya. *Rhizophora mucronata* Lam is the principal species in most sites dominated by mangroves along the Kenyan Coast [22].

The closed canopy and multilayered trees each cover about 2% of Kenya's total land area and are mainly restricted to areas below an altitude of 3000 meters. Tree species dominance within this area is according to the Agro-Ecological Zone (AEZ) [23]. Moist forests occurring at 2100–3300 m above sea level, with rainfall above 1500 mm, are dominated by a variety of broad-leaved species that include *Tabernaemontana stapfiana* (Britten), *Dombeya goetzenii* (K. Schum), *Dracaena afromontana* (Mildbr), *Hagenia abyssinica* (Bruce J. F. Gmel), *Nuxia congesta* (Fresen), *Croton macrostachyus* (Delile), and *Podocarpus latifolius* (Thunb. Mirb) [23]. The drier montane forests occurring at 1800–2900 m a.s.l. with an annual rainfall of 700–1350 mm are characterized by species such as *Juniperus procera* (Endl), *Olea europaea ssp. africana* (Mill. P. Green), *Podocarpus falcatus* (Mirb.), *Cassipourea malosana* (Baker. Alston), *Acokanthera schimperi* (A. DC. Schweinf), *Ekebergia capensis* (Sparrm.), *Olinia rochetiana* (A. Juss.), *Teclea nobilis* (Delile), *Croton megalocarpus* (Hutch), and *Calodendrum capense* (L. f. Thunb) [23].

The open canopy trees and shrubs, woodland, and grassland vegetation are estimated to cover 65% of the total land area and represent the dominant vegetation type in the Arid and Semi-Arid Lands of Kenya [24, 25], with the dominant tree species being *Acacia mellifera*, *Acacia senegal*, *Acacia reficiens*, *Acacia tortilis*, and *Commiphora* sp. [26]. Presently, climate change is a major driver of the rate of encroachment into forested areas and the destruction of grasslands in the country. Climate change has led to competition for arable land resources due to declining water resources coupled with droughts and scarcity of arable land.

Evidence of climate change in Kenya has been manifested in the increased frequency of droughts and floods, changes in rainfall intensity and distribution patterns, and increased minimum and maximum temperatures. Future climate projections estimate that most regions in Kenya will experience a 100-mm decrease in long-season (March–May) rainfall by 2025 [27]. Increased climatic variability poses a threat to the trees and associated vegetation cover with regions such as the ASALs being most vulnerable to the adverse impacts. The projected climatic impacts are likely to exacerbate the rate of land degradation and desertification in the country.

3.3 Contextualized water resources in Kenya

Figure 4 shows the distribution of Kenya water resources. The country relies mainly on freshwater resources represented by lakes, rivers, swamps, and springs as well as dams, water pans, and groundwater. Kenya's annual freshwater resources endowment is estimated to be 20.2 BCM (billion cubic meters) or 548 m^3 per capita per year [28]. These surface water resources are highly dependent on the country's forested areas and highland ecosystems that serve as water catchments. The watersheds depicted on the map include the Ewaso-Samburu, Mt. Kenya and Aberdares, Mau and Western, Amboseli and Chyulu, and the Coastal forest and Marine watersheds. The major lakes in the country include, inter alia, Lake Victoria, Lake Nakuru, Lake Naivasha, and Lake Elementaita. Some of the major rivers include the Tana River, Mara River, Athi-Galana-Sabaki River, Tsavo River, Ewaso Ng'iro River,

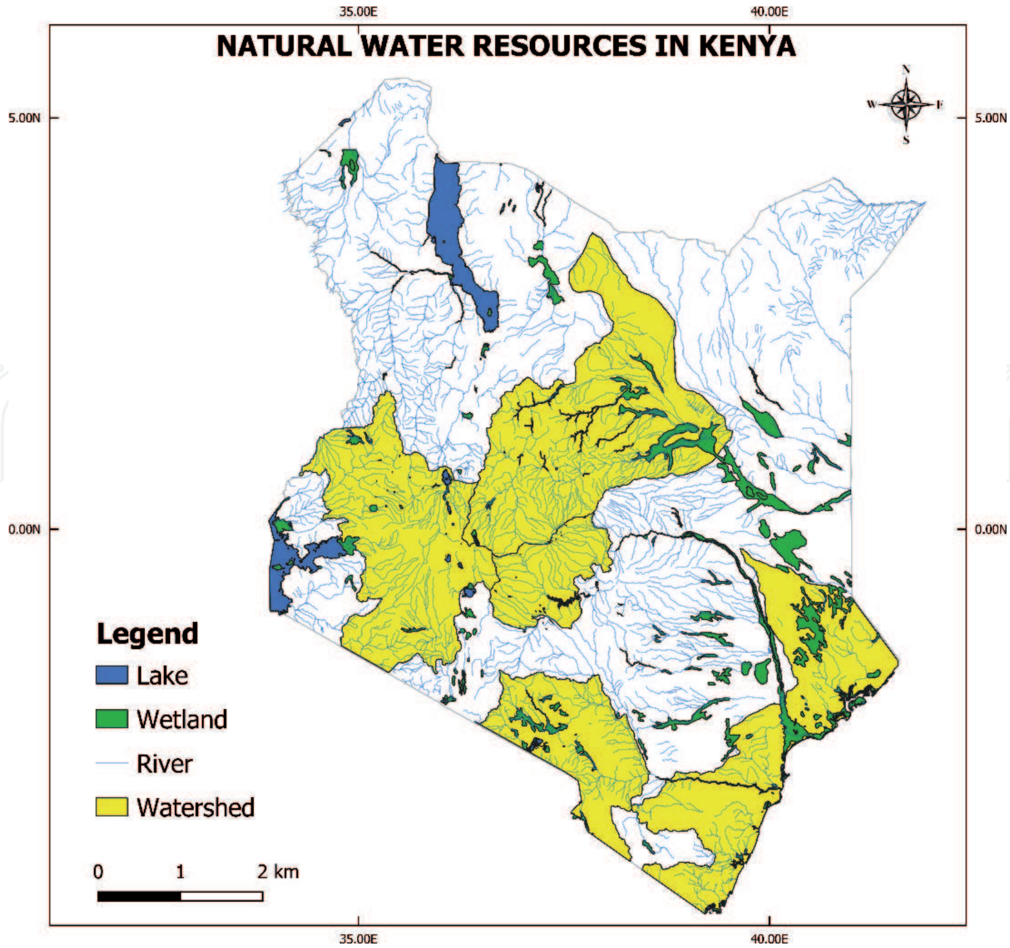

Figure 4.
Map of natural water resources in Kenya based on Kenya GIS data provided by the Environmental Systems Research Institute Kenya GIS data [26].

and Nzoia Rivers. The wetlands represented on the map are classified into fresh water marshes, saline/alkaline marshes, mangrove, lake shorelines, and saltpans [29]. Despite harboring some of the great water towers of East Africa, Kenya is among water-scarce countries, with its per capita renewable freshwater potential being 235 m^3 per annum [30].

Coupled with extreme climatic events, such as droughts and floods, the water resources in the country continue to show a declining trend and threaten the availability of water for economic and domestic use. In the past, prolonged dry seasons have led to 37% decline in the water levels in dams and other reservoirs subsequently causing crop failure, loss of livestock, and limited access to freshwater [31]. Additionally, increased frequency of floods has led to the destruction of land resources due to soil erosion, disruption of water supply systems, and the contamination of freshwater resources. Overall, climate change, destruction of water catchment areas and deforestation continue to increase water scarcity in Kenya.

4. Preventive and corrective initiatives

4.1 Background on combating desertification in Kenya

Like many other nations around the world, Kenya is threatened by desertification, land degradation, and drought. In some of the dryland areas such as in the North and North-Eastern Kenya, the deserts have eaten the once-potential landscapes turning them into inhabitable landscapes that cannot support humans, livestock, and even wildlife [3]. The government of Kenya, recognizing the importance of the country's dry lands to the country's socioeconomic development and realizing that they are being degraded fast, has sought ways of restoring and rehabilitating dry forests and woodlands, among other ecosystems in these lands. These ecosystems are comprised of trees that are specially adapted to the harsh climatic and edaphic conditions, providing important ecosystem services for communities in an environment where other types of tropical tree species would not survive. These trees are threatened and call for restoration and rehabilitation initiatives by the government through support and participation in thematic forestry research and development activities. These activities include restoration and sustainable management of woody resources through biodiversity assessments, conservation, rehabilitation, afforestation, and reafforestation in order to enhance plant diversity.

4.2 Role of enhancement of woody floral diversity in the drylands

Floral diversity refers to the diversity of plants occurring in a specific region during a particular era. It generally refers to the diversity of naturally occurring indigenous or native plants. The word "Flora" comes from the Latin word Flora, which means the goddess of plants. As Kenya has a limited area covered by indigenous timber-producing forests, plantations of exotic trees, mainly eucalypts, were established in the country in the early 1900s. These species were suitable to small-scale farmers and provided overall support to key sectors of the economy. The demand for timber had exceeded the supply available from indigenous forests; hence, the exotic species were preferred for afforestation because none of the indigenous tree species that yielded useful timber grew at rates considered profitable. Efforts to rehabilitate the dry lands are in place and include the promotion and establishment of suitable multipurpose tree species in the ASALs as well as water harvesting and conservation measures.

As rangelands, areas in ASALs have a relatively low production potential, are fragile, and are easily degradable through overutilization or use of inappropriate technologies [32]. There is a need to develop suitable ASAL rehabilitation technologies and to uphold efforts employed in providing solutions that sustainably improve the lands' productivity and combat desertification. Woody vegetation is one such renewable resource with an exceptional potential to provide the dry season's forage for livestock and serve as soil cover. Forests and woodlands are also biologically important because of the diverse fauna and flora associated with them. They, therefore, contribute significantly to the livelihoods and welfare of inhabitants of dry lands [33].

4.3 Restoration initiatives

4.3.1 Baseline studies/surveys such as biodiversity assessments

Baseline surveys are studies that are done at the beginning of projects to collect information on project status before any types of intervention are implemented. Information obtained from such surveys later inform decision-makers on what impacts the projects have on target communities. For instance, the first step in protecting and managing biodiversity in any ecosystem is to understand what species exist by documenting these species and their environments through biodiversity surveys. Biodiversity is the biological variety and variability of life on Earth, a measure of variation at the genetic, species, and ecosystem levels.

Biodiversity performs multiple roles in the daily lives of people in the drylands through the supply of ecosystem services, food security, tourism, wealth creation and aiding a range of cultural services. As such, the value of Kenya's biodiversity resources cuts across the economic and social and, ultimately, the political pillars of Vision 2030. Direct benefits from plant diversity include food, medicine, honey, forage, vegetables, and other raw materials that play a vital role in the lives of poor people in rural and remote places [34]. Indirect benefits that flow from plant biodiversity's environmental services include employment, income, nitrogen fixation, maintenance of water cycles, regulation of climate, photosynthetic fixation of carbon dioxide, soil protection, storage, and cycling of essential nutrients as well as absorption and breakdown of pollutants [35]. Kenya's forests, for instance, play a vital role in rural livelihoods by providing food and energy for domestic consumption and watershed regulation. In Kitui and Mwingi districts of Kenya, plant species recorded during a survey of five hilltop sites were noted as important sources of medicine, fiber, food, fodder or forage, timber, and fuelwood [36]. Some of the much-sought species, especially for medicine, included *Warburgia ugandensis*, *Pittosporum viridiflorum*, *Securidaca longipedunculata*, *Zanthoxylum*, and *Strychnos*.

Overall, Kenya's known floral biodiversity assets include 7000 plants among other life forms [37]. However, the status of plant species' diversity in the dry lands is poorly documented [3]. In order to remain ahead in efforts to conserve dryland ecosystems, restore degraded sites, and reverse or halt desertification, the Government of Kenya gathers information from various sources to understand the prevailing circumstances and prescribe restoration measures using various tools and strategies. For instance, a study conducted in the Mutomo district, Kenya, evaluated the nature of degradation caused by selective logging for charcoal production and provided information on how this could be addressed to ensure the woodlands recovery without impacting negatively on the producers' livelihoods [38]. Restoring the dryland landscapes can help mitigate climate change, support sustainable livelihoods, and maintain biodiversity. Restoration aims to reestablish a previous ecosystem state and all its functions and services, while rehabilitation seeks to repair specific parts of the systems, in order to regain ecosystem productivity [39]. Effective restoration and rehabilitation of degraded drylands require a combination of policies and technologies and the close involvement of local communities. There are two categories of landscape-restoration methods that are commonly applied in the drylands: active restoration and passive restoration [40, 41].

4.3.2 Active-versus passive-restoration approaches

4.3.2.1 Active-restoration methods

These are methods involving management techniques, such as planting of seeds or seedlings. They are needed to restore severely degraded lands and are particularly relevant for water-limited environments, where self-restoration processes of severely degraded lands may be limited. One such method is the Framework Species Approach developed in Queensland, Australia [42]. The method involves a single planting of both early and late successional species. Planted species must survive in the harsh conditions of an open site as well as fulfill the functions of (i) fast growth of a broad dense canopy to shade out weeds and reduce the chance of forest fire and (ii) early production of flowers or fleshy fruits to attract seed dispersers and kickstart animal-mediated seed distribution to the degraded site [43]. Framework trees are indigenous, non-domesticated, forest tree species, which, when planted on deforested land, help to reestablish the natural mechanisms of forest regeneration and accelerate biodiversity recovery. A rainforest-restoration experiment established on abandoned pasture in northeastern Queensland to examine the effectiveness of five different restoration-planting frameworks concluded that some restoration success measures increased with planting diversity, but overall the rate of recovery was similar in framework species and maximum diversity method [44].

Active restorations, using afforestation and reforestation methods, are effective biological approaches with the potential to help restore and rehabilitate degraded dryland ecosystems and halt desertification [45]. Among other benefits, rehabilitation improves the soil biological activities where high rates of soil organic matter, organic C and N, suitable soil acidity range, and abundance of forest litter are considered the predisposing factors promoting higher microbial populations in enrichment planting as compared to secondary forest [46].

Afforestation is the planting of forests on land that historically had no forests [47]. The main purpose of afforestation is to reduce soil erosion by planting trees, which increases soil stability and enables forest regrowth. Other purposes include improving the potential wood extraction in the future and improving the visual landscape. However, there have been concerns that conversion of "natural" drylands to dryland forestry may have adverse ecological and environmental impacts on the environment, thus risking a wide range of ecosystem functions and services. Attempts have been made to demonstrate the potentially adverse implications of dryland forestry and highlight the caution needed when planning and establishing such systems [45]. For instance, in order to negate suppression of understory vegetation and sustain plant species' richness and diversity, low-density savanization by non-allelopathic tree species is preferred over high-density forestry systems by allelopathic species. According to the author, and wherever possible, it is preferable to plant native tree species rather than introduced or exotic species, in order to prevent genetic pollution and species invasion. In addition, mixed-species forestry systems should be favored over single-species plantations, as they are less susceptible to infestation by pests and diseases. In addition, drought-tolerant, fire-resistant, and less-flammable tree species should be preferred over drought-prone, fire-susceptible, and more flammable species.

4.3.2.2 Passive-restoration methods

These are methods in which no action is taken except to cease environmental stressors, such as agriculture or grazing, and are effective for restoring moderately degraded lands. In Eastern Kenya, for instance, the results of a study involving passive restoration show that woodlands have a high potential to recover if put under a suitable management regime since they have a high number of saplings [12]. The most commonly used of these approaches is the Assisted Natural Regeneration (ANR) approach, which acts on natural regenerates that are already present in deforested sites. The word "assist" in ANR refers to helping the naturally growing young trees to grow faster [48]. Assisted Natural Regeneration accelerates the natural succession process by protecting against disturbances, such as fire, stray domestic animals, and humans, and by reducing competition from grasses, bushes, and vines that would hinder the growth of naturally regenerated trees [48]. Forest restoration using ANR has advantages over conventional reforestation through planting by being cheaper to implement as costs associated with seedling production, site preparation, and planting are greatly reduced. The plant community that is established is well adapted to the site conditions, and the naturally regenerating plant community typically comprises a mixture of species that result in more diverse, multilayered vegetative cover [48].

Assisted Natural Regeneration is a flexible and adaptable approach that can be applied in a variety of contexts. It can, for instance, be combined with enrichment planting for various reasons including to fill in patches that may not have enough wildlings to establish tree canopy cover within the desired time frame, enhance the success and quality of forest restoration, and restore ecologically and/or economically valuable species to meet specific restoration objectives [48]. Enrichment planting may be defined as the introduction of valuable species to degraded forests without the elimination of valuable individuals who already existed at that particular site [49]. In this technique, trees are planted in gaps, lines, or open sites as plantations of mixed species or under canopies of young dryland forests. In a study to identify the optimal enrichment planting method vis-à-vis gap and line planting, and to evaluate the performance of two dipterocarps and three legumes planted in logged-over mixed deciduous forest of Laos, the diameter and height growth were favored more in gaps than in planting lines [50]. Furthermore, the use of logged-over gaps for enrichment planting was recommended given the difficulty to maintain constant line width and even light condition, the cost of annual clean operation, and the rigid geometric patterns of planting lines [50]. In Indonesia, gap planting with *Anthocephalus macrophyllus* to rehabilitate degraded natural forests increased soil density, although its value was categorized as a very loose soil class [51]. In another study from Malaysia, the total mean microbial enzymatic activity, as well as biomass carbon (C) and nitrogen (N) content, was significantly higher under enrichment planting than under secondary forest [46].

There is little consensus on whether active or passive restoration strategies are more successful for recovering biodiversity because few studies make adequate comparisons [41]. In some studies, recovery of species' richness and composition is similar in active- and passive-restoration sites, while in others, recovery of forest specialists is enhanced through active restoration [40, 41]. While both restoration strategies may lead to different vegetation structures, they may support similar biomass of foliage-dwelling arthropods and be similarly used by foraging insectivorous birds [40]. Passive restoration is generally less costly than active restoration and, if local and landscape characteristics do not impede recovery, may be a viable alternative. Where active restoration is adopted, it should be implemented using mixed plantations of native tree species and, whenever possible, select sites close to mature forest to accelerate the recovery of tropical forest biodiversity [41]. Because active restoration is more expensive than passive restoration, both strategies should be used in complementarity at the landscape level for cost-effectiveness and optimization of the different land management objectives for the wider landscape [40, 41].

4.3.3 Challenges of tree growing in drylands

Tree planting in the drylands poses challenges to land users, which are brought about by a combination of edaphic, ecological, and socioeconomic factors in these areas. These include, among others, moisture stress, termite infestation, animal damage, and competition from weeds [8, 52]. Although the farmers and tree growers have developed interest in tree planting as an investment activity, they are discouraged by the continuous low tree survival rate and thus are not able to reap the maximum benefits from their tree crop. In a guideline intended for farmers and tree growers living in the drylands of Kenya, the common factors contributing to tree mortality at all stages of tree growing have been presented [8]. They also provide interventions that can be applied during species' selection, raising seedlings in the nursery, out-planting, and tree management to enhance tree growing in the drylands. The Kenya Forestry Research Institute (KEFRI), through the dryland forest research program, has identified major factors contributing to low tree survival and developed mitigation measures, which include the selection of appropriate tree species and development of suitable methods for propagating, establishing, and managing trees [8]. KEFRI has demonstrated better ways of re-afforestation especially in areas under limited water availability [52], proposed species-site matching as a key consideration, especially with drought tolerance, and found mycorrhizal inoculation to greatly enhance the survival of trees planted in degraded areas, which have low mycorrhizal inoculum potential [53]. Inoculated trees have been used to restore the soil inoculum and to enhance the growth of interplanted agricultural crops. There are also opportunities to exploit tree/crop symbiotic associations in agroforestry systems, using trees selected both for their own attributes and for soil-improving qualities [53]. Farmers and tree growers need to adhere to these measures to improve tree survival and thus realize maximum profits from tree-planting activities.

4.3.4 Biodiversity policy and management in Kenya

4.3.4.1 Biodiversity law and policy

A number of legal and policy instruments have been put in place to enhance conservation and regulate utilization of biodiversity resources. Among these instruments are the Constitution of Kenya 2010, which entrenches a range of environmental imperatives and provides an avenue for remedying the land tenure, land use, and gender-inequity issues that have negatively affected the country's biodiversity. The Constitution also decentralized the management of a range of natural resources to the devolved units known as County Governments. Other biodiversity-related instruments include the Revised Kenya National Biodiversity Strategy and Action Plan (2010), Integrated Coastal Zone Management Policy (2010), Environment Management and Coordination Act (1999), National Water Policy (1999), Water Act (2002), Draft Forest Policy (2004), Draft ASALs Policy (2004), Forest Act (2005), Fisheries Policy (2008), Heritage Sites (2006), National Land Policy (2009), Energy Act (2006), Biodiversity Regulation (2006), Draft Wildlife Policy (2007), and the draft of Minerals and Mining Policy. Any initiative that directly or indirectly helps to conserve the country's biodiversity helps to meet the specific Vision 2030 poverty-alleviation objectives as well as the goal of improving the general welfare of citizens. A national biodiversity policy and law would be a useful complement to the above operative instruments.

4.3.4.2 Biodiversity research and development agenda for drylands

The Natural Resource Management (NRM) has been defined to mean *inter alia* the sustainable utilization of major natural resources, including forests, wild flora, and fauna [54]. Natural resources play an important role in providing fundamental life support, by proving a diversity of products and services, both social and ecological. Sustainable management of these resources is challenged by increasing demands, climate change, pollution, and economic development needs. These pressures have led to dwindling availability of natural resources, especially in the ASALs. The national research priorities that have been identified in Kenya to address the above challenges include, among others, the following [55]:

- Balance between productivity and environmental services
- Environmental protection for sustainable agriculture, livestock management, and aquaculture
- Studies on ecosystem services (including provisioning)
- Biodiversity and conservation of genetic resources

Biodiversity is also a key component of KEFRI's research and development agenda as articulated in the Institute's 2018–2022 Strategic Plan [56]. The current KEFRI Strategic Plan aims to achieve the following seven strategic objectives:

- Generating technologies for the establishment and management of forest plantations and trees on farms and enhance the production of superior germplasm for priority tree species for different agroecological zones
- Generating rehabilitation technologies for adaptation to climate change, sustainable forest landscapes, woodlands, wetlands, and riparian ecosystems
- Developing technologies for efficient processing and utilization of wood and non-wood forest products
- Formulating forestry policies for sustainable forest management and improved livelihoods
- Disseminating forestry research technologies and enhancing institutional research and development capacity
- Strengthening institutional capacity for research and development
- Enhancing corporate communication and publicity

KEFRI's specific actions in the development of technologies for rehabilitation and restoration of forests and allied natural resources in drylands target the following [56]:

- To develop guidelines on rehabilitation and restoration technologies and train stakeholders
- To establish permanent sample plots in forests and woodlands ecosystems for collection of data on ecological trends and dynamics
- To develop strategies for in-situ and ex-situ conservation for threatened and endangered species
- To perform ecological studies for various forest types to secure a broad range of goods and environmental services
- To develop technologies for sustainable natural forest and woodland management
- To quantify the impact of animal damage on forest ecosystems

4.3.5 Biodiversity conservation in Kenya

Although Kenya's biodiversity remains highly protected, declines are common phenomena due to a number of anthropogenic threats that have led to numerous conservation challenges [57]. Nevertheless, the country explores all avenues to ensure that efforts to win the war against biodiversity losses are sustained. Examples of progress made in research and development for drylands afforestation in Kenya include the following:

4.3.5.1 Selection of appropriate tree species

Until the 1980s–90s, when it became a government policy in Kenya to promote the replanting of indigenous rather than exotic tree species, most of the work on the selection of trees of arid and semiarid lands in Kenya was with exotic fast-growing species [53]. Since then, selection criteria have continued to evolve with consideration around preferences of local communities, availability of quality genetic material for propagation, and site biophysical conditions. Currently, a large number of tree species have been recommended for the drylands of Kenya [52, 53]. In the dryland areas of Kitui and Kibwezi (Eastern Kenya), tree species grown and recommended include *Azadirachta indica*, *Jatropha curcas*, *Senna siamea*, *Leucaena leucocephala*, *Croton megalocarpus*, *Casuarina equisetifolia*, *Melia volkensii*, *Eucalyptus camaldulensis*, and *Dovyalis caffra* [4].

In Kenya, the area under *Eucalyptus* is likely to increase as a result of high demand for transmission poles, for construction, fuelwood, carbon sequestration, and mitigation of the effects of climate change [58]. However, there is much unease about Eucalyptus water consumption as compared to other woody flora. On a positive note, studies have established that Eucalypts exhibit high efficiency in water use for biomass accumulation. It has been established that eucalyptus requires less water to produce one (1) kg of biomass than most crops [59].

Melia volkensii, an important timber species that grows well in well-drained soils, is a promising indigenous tree species found in the drylands of Kenya. It is fast growing, drought tolerant, and produces high-quality hardwood timber for furniture. However, this species is heavily exploited in its natural stands and the trend has been worsening over the last decade owing to shortage of alternative hardwood species in drylands. As a result, programs promoting domestication of the species as a plantation species are ongoing [60–62].

4.3.5.2 Development of suitable methods for propagation

Poor propagation of some promising tree species in the drylands of Kenya has slowed down the country's efforts to increase its forest cover to the targeted 10%. For example, lack of seedlings attributed to poor seed germination is experienced with *Terminalia brownii*, a drought-tolerant species, which can be used to rehabilitate degraded drylands through reforestation and agroforestry approaches [63]. The current demand for Terminalia seedlings is higher than the supply. Research has focused on development of technologies ranging from breakage of dormancy to plant-tissue cultures to improve germination propagation of such species. Studies have been conducted to investigate the dormancy and germination of *T. brownii* seeds collected from various dryland sites in Kitui, Makueni, Tharaka-Nithi, and Baringo Counties of Kenya. Extracted seeds recorded the highest germination with the best at 76% compared to nipped seeds (13%) and those subjected to other treatments [63]. *Melia volkensii* Gurke is another drought-tolerant tree native to the drylands, of which cultivation is limited by difficulties in propagation via conventional means. Full exploitation of the ability of thidiazuron to elicit regeneration in plant-tissue cultures, as a sole plant growth regulator, was found to be hampered by high costs. Alternative effective and low-cost agrochemical thidiazuron for in vitro propagation of *M. volkensii* was found to be Kingtai-TDZ, which has a high potency and suitability for use in tissue culture of the species [61]. Because of difficulties in seed germination, land users sometimes go for the use of plants produced from root and stem cuttings, rather than from seedlings, and researchers have focused on the possibility that root and stem cuttings may be used for propagation, rather than seedlings [62]. However, if cuttings are used to circumvent the problems of seed germination, alternative methods of controlling competition, such as root pruning, need to be considered.

4.3.5.3 Establishment and management of trees

In systems where trees are promoted for on-farm planting or in agroforestry systems, challenges associated with tree–crop interactions, and likely competition such as that for nutrient and water resources, are sometimes experienced. Researchers, for instance, find below-ground competition to be a major problem in simultaneous agroforestry systems and a focus of much research in recent decades [64]. Considering that trees raised from seed may differ in their competitiveness from those raised from cuttings, studies have been conducted to evaluate differences in root system architecture of plants raised from seed, stem, or root cuttings and the relationships between the competitivity index (CI) and crop yield [62]. From such studies, more shallowly rooted cuttings than seedlings, higher competitivity indices, and a negative relationship between CI and crop yield in *Melia volkensii* under integrated land-use systems have been observed. Therefore, to reduce tree–crop competition, the use of seedlings rather than cuttings should be recommended when promoting the use of this species on dryland farms [62].

4.3.5.4 Management of invasive plant species

Invasive plants are capable of penetrating and replacing the existing indigenous vegetation of a location [65]. These are mostly exotic plants that have been introduced in a location, either intentionally or unintentionally, and that reproduce and spread on their own [66]. In the late 1970s and the early 1980s, the East African dry lands witnessed the introduction of various alien species. They include the 10 key invasive plant species that affect the drylands of Kenya and Tanzania [65], namely *Lantana camara* (Lantana), *Prosopis juliflora* (Mesquite), *Prosopis pallida* (Mesquite), *Opuntia ficus-indica* (Prickly pear cactus), *Caesalpinia decapetala* (Mauritius thorn), *Psidium guajava* (Guava), *Senna spectabilis* (Cassia), *Acacia farnesiana* (Sweet acacia), *Acacia mearnsii* (Black wattle), and *Acacia polyacantha* (White thorn).

Invasive plants are a hazard in the tropical dry forests and rangelands of East Africa, having increasingly created disasters that have affected the environment and socioeconomic well-being of communities inhabiting these dry regions. Some of the negative effects of invasive species include causing the death of livestock by poisoning and destroying livestock foliage, accelerating biodiversity loss via suppression of native plants, and increasing diseases by offering a breeding ground for mosquitoes and other insects that carry ailments such as nagana and sleeping sickness [65]. Of the 10 invasive species identified in East Africa, 90% suppressed native plant species and reduced biodiversity. Because invasive species could cause food insecurity and slow economic growth, their potential to derail attainment of the Country's Vision 2030 targets cannot be underestimated [67]. In addition, there is a need to explore and exploit the range of livelihood opportunities that invasive alien species, such as *P. juliflora*, present in drylands. In this regard, KEFRI and other partners have, for many years, conducted research and developed technologies for the control and management of this species through utilization.

4.3.5.5 Extension services and outreach

Forestry extension is the art and science of converting information from research and past experiences to a practical level for use by local people who may not be specifically trained in forestry techniques [68]. There are two approaches to forestry extension, namely top-down approach and bottom-up/participatory approach. The bottom-up approach is a two-way information flow system that considers prior consultation with target beneficiaries about their needs/problems and aspirations for effective planning. The top-down approach is a one-way information delivery system that reinforces the hierarchical relationship between the extension agent and the client [69]. The aim of forestry extension in the drylands is to help the pastoral people manage their livelihoods and their environment and to involve them in forestry development activities. Although forestry activities remain the main concern of the forestry sector, pastoralists look at their management activities in totality. For this reason, an integrated approach to extension involving relevant National and County Ministries usually strengthens extension services in the ASALs.

The drylands of Kenya are extensive, with low productivity and sparse populations, thus calling for appropriate forestry extension methods. The extension techniques appropriate for the ASALs and methods of developing them have been outlined [68, 69]. Some of the most commonly used extension methods include exploratory seminars, small meetings, public meetings, individual visits, and field exercises [70]. Efforts are made to establish the two-way flow of information from the forestry extension agents to the target groups in order to explore local problems and their solutions in the context of local traditions, knowledge, needs, and priorities. Common extension tools used include the media (radio, film, television, print manuals, and posters), field demonstrations complemented by video and audio tapes, slide shows, local actors, and direct discussions.

5. Conclusion

This chapter provides an in-depth review of "desertification" as one of the most important challenges to livelihoods and development in the drylands of Kenya. The phenomenon results from climatic variations and human activities, such as destructions of water catchments and deforestation, that exert pressure on forests and woodlands leading to degradation, deforestation, and desertification. Desertification is, thus, a precursor to increased water scarcity. Overall, it causes reduced tree cover, reduces agricultural productivity, and increases water scarcity, climate change, destruction of water catchment areas and deforestation, which continue to increase water scarcity in Kenya. However, opportunities for remedial measures offer potential for intensified afforestation toward achieving the national target of 10% tree cover. More investment is needed for active and well-coordinated research toward rehabilitation and restoration of dryland resource systems. A significant impetus in combating desertification and drought is to devolve power to the people who are affected and to link environmental degradation to economic policies. Devolved action will attract local support to initiated programs. For sustainable development strategies to work, policies should put the welfare of the people in drylands at the center of the development agenda, uphold local people's rights, and empower the same people to adopt adaptive strategies to ascertain sustainable livelihoods. This review demonstrated the role of research and development in availing afforestation technologies in drylands to increase biodiversity and avert advancement of desertification in Kenya.

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Conflict of interest

The authors declare no conflict of interest.

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