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# TROPICAL FORESTRY REPORTS

## 52



**Badal Ahmed HASSAN**

**Trees for sustainable livelihoods in the Horn of Africa: Studies on aromatic resins and other non-wood forest products in Somalia and Kenya**

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# TROPICAL FORESTRY REPORTS

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**Trees for sustainable livelihoods in the Horn of Africa: Studies  
on aromatic resins and other non-wood forest products in  
Somalia and Kenya**

**Badal Ahmed HASSAN**

*Academic dissertation*

*For the degree of Doctor of Science (D.Sc.) in Agriculture and Forestry under the Doctoral  
Programme in Sustainable Use of Renewable Natural Resources (AGFOREE)*

To be presented, with the permission of the Faculty of Agriculture and Forestry of the  
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**Clockwise from top right:** Chief of Gayure village (Wajir, north-eastern Kenya) informing the local residents about the research purpose. Explanation of the socio-economic questionnaire to the selected respondents under *Acacia tortilis*. Researcher executing interview. Respondent expressing his opinion in focused group discussion. Recently tapped *Commiphora myrrha*. Fresh myrrh exuding from bark of tapped *Commiphora myrrha*.

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## ABSTRACT

Dryland ecosystems support the livelihood of millions of people in the Horn of Africa. However, these ecosystems have been exploited and affected by continuous overgrazing, fire and tree cutting. The general aim of the study was to find ways of improving the adaptive strategy and livelihood of the rural communities, and promoting ecosystem sustainability in the Horn of Africa, using Kenya and Somalia as specific case studies. The theoretical framework of the study was based on the conceptual framework for sustainable development or sustainability. The study examined the non-wood forest products (NWFPs), both for food and non-food commodities, harvested to overcome food insecurity.

It paid particular attention to the role of the aromatic resin bearing species of *Boswellia* and *Commiphora* in poverty alleviation and climate change adaptation in the region. It also examined the rural communities' views on the causes, effects and socio-economic impacts of resource degradation. Socio-economic field surveys were conducted in Wajir district of north-eastern Kenya and three districts in Somalia, Addado, Buhodle and Galka'ayo. A systematic literature review was also employed to identify, select and critically review the current information on socio-economic contributions of aromatic resins in the Horn of Africa. Quantitative analyses from surveys, group discussions and key informant consultations were used in processing the data.

The research identified several woody species which provide both food and non-food products which supports the livelihood of the rural communities. The results emphasised the potential for using *Boswellia* and *Commiphora* species as agroforestry trees, for not only improving the economic conditions of the farmers, but also for increasing land productivity. The study highlighted forest degradation, droughts, building of reservoirs and over-grazing as the main factors causing land degradation in the study areas. Farmers' adoption of new agroforestry management techniques in general, and those for *Boswellia* and *Commiphora* species in particular, has a distinct role in biodiversity conservation and climate change adaptation in the Horn of Africa. This would also enhance ecosystem sustainability and improve rural livelihood security and thereby facilitate poverty alleviation.

**Keywords:** *Acacia-Commiphora* woodlands, agro-pastoralists, aromatic resins, *Boswellia*, climate change adaptation, deforestation, desertification, food security, frankincense, Horn of Africa, Kenya, land-degradation, livelihoods, myrrh, non-wood forest products, non-timber forest products, pastoralists, Somalia.

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## ARAGTIDA BUUGA OO KOOBAN

Deeganada qallalan waxaa kutiirsan nolosha malaayiin dad ah oo kunool Geeska Afrika. Hasayeeshee, deegaanadan waa laxaalufiyay waxaana si xun usaameeyay daaqista xad-dhaafka ah ee xoolaha, dabka iyo jaridda geedaha. Ujeedada guud ee daraasadan waxay ahayd in la helo sidii lagu kobcin lahaa nolosha dadka reer miyiga ah, iyo in lahel qorshe ay dadku laqabsadaan, isla markaasna loo dhiiri galin lahaa bad-qabka deegaanka Geeska Africa, iyada oo Kenya iyo Somalia loo adeegsanayo saldhiga daraasadan. Qaab dhismeedka aragtiyadeed ee ay daraasadu kufadhido, waxay ku salaysan tahay figrada horumarka waara (sustainable development).

Daraasadu waxay baadhay qadhaabka/qaraabka dhirta kasoo baxa, ee ay dadku kasoo qaraabtaan kaymaha kuwo la cuno iyo kuwo aan la cuninba, si looga bad baado cunno yaraanta. Waxaa sigaar ah diirada loogu saaray doorka ay dhirta kala duwan ee dhasha xabagta carafta sida beeyada iyo Dhidinka ay kuleeyihiin yaraynta saboolnimada iyo la qabsiga isbadalka cimilada aduunka ee gobolka. Sidoo kale daraasadu waxay maan baadh ku aadan waxyaabaha keena iyo saamaynta dhaqan-dhaqaale ee burburinta khayraadka kasoo uruurisay dadka ree miyiga ah.

Macluumaadka dhaqan-dhaqaale ee daraasadan waxaa laga soo ururiyay degmada Wajeer ee waqooyi-bari Kenya iyo sadex degmo oo Somaliya kuyaala oo kala ah Buhoodle, Cadaado iyo Gaalkacayo. Sidoo kale waxaa daraasad dib u,eejis ah lagu sameeyay waxyaabihii horay looga qoray, si loo helo, loona xusho isla markaasna loo taxliiliyo macluumaadka iyo kaalinta dhaqan-dhaqaale ee ay xabagta carafta ku leedahay Geeska Afrika. Quantitative analysis ayaanu adeegsanay si aan taxliilin ugu samayno warbixininadii aan soo uruurinay, macluumaadkii aan ka dhaxehelay wadhadalkii kooxaha kaladuwan dhax maray iyo waraysiyadii aan layeelanay dadkii aqoonta gaarka ah lahaa.

Cilmi baadhistu waxay heshay geedo badan oo soo saara wax la cuno iyo waxaan la cunin oo muhiim u,ah nolosha dadka reer miyiga ah. Natiijadu waxay diirada saartay wax ku oolnimada in loo isticmaalo geedaha soo saara malmalka iyo luubaanta geedo-tacab (agroforestry), kuwaas oo wax tarkoodu uusan ku koobnayn wax ka badalka dhaqaalaha beeralayda oo kali ah, balse sidoo kale kor u qaadaya wax soo saarka dhulka. Daraasadu waxay iftiimisay in dhir xaalufinta, abaarta, dhismaha berkadaha iyo daaqista xad-dhaafka ah ee xooluhu ay yihiin waxyaabaha ugu badan ee keena burburka deeganka meelaha daraasadan lagu sameeyay. Guud ahaan adeegsiga beeralayda ee farsamooyinka iyo maaraynta cusub ee geedo-tacabka, gaar ahaan geedaha dhala luubaanta iyo malmalka door gaar ah ayay kuleeyihiin ilaalinta noolaha-kaladuwan iyo laqabsiga isbadalka cimilada aduunka ee Geeska Afrika. Tani waxay sidoo kale sare uqaadaysaa jiritaanka deegaanka iyo kobcinta amaanka nolosha dadka reer miyiga ah, taasoo fududaynaysa dhimista saboolnimada.

**Erayada ugu muhiimsan:** Geed qabka *Acacia-Commiphora*, Geedaha luubaanta dhala (*Boswellia*), xoola dhaqato, xoolodhaqato-beeraleey, xabagta carafta, hab nololeed, amaanka cuntada, laqabsiga isbadalka cimilada, qadhaab/qaraab, luubaan, malmal, nabaad guur, dhir-xaalufin, deegan-burbur, Geeska Afrika, Somaliya, Kenya.

## **PREFACE**

This study was accomplished at the University of Helsinki, Faculty of Agriculture and Forestry, Department of Forest Sciences, Viikki Tropical Resources Institute (VITRI). The study was conducted in north-eastern Kenya, and central and northern Somalia. The fieldwork was financed in part by the Viikki Tropical Resources Institute, University of Helsinki, and the World Agroforestry Centre (Global Research Project 1).

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Helsinki, June 2020  
Badal Ahmed Hassan

## DEDICATION

I dedicate my dissertation to:

My mother Haweya Farah Abdi for her endless prayers, love and continuing support, and my late father, Suldan Ahmed Hassan whose mentorship has led me to places I never thought I would go. Within my community, I am treated with dignity and respect due to the level of love, courtesy and respect accorded my father's position as a benevolent, gentle, compassionate, just and kind community leader. *May Almighty Allah admit him to dwell in Paradise.*

## LIST OF ORIGINAL PAPERS

This thesis is based on the following original articles

- I. Hassan, B.A., Glover, E.K., Luukkanen, O., Chikamai, B., Jamnadass, R., Iiyama, M. and Kanninen, M. 2011. The Role of *Boswellia* and *Commiphora* species in rural livelihood security and climate change adaptation in the Horn of Africa: Case study of northeastern Kenya. *International Journal of Social Forestry*, 4 (1):86-112.
- II. Hassan, B.A., Glover, E. K., Luukkanen, O., Chikamai, B. and Jamnadass R. 2014. An assessment of the socio-economic and ecological impacts of environmental changes on rural livelihood: A study across Addado, Buhodle and Northern Galkaayo of central and northern Somalia. *Agriculture, Forestry and Fisheries*, 3(4): 279-291
- III. Hassan, B.A., Glover, E. K., Luukkanen, O., Jamnadass, R., and Kanninen, M. 2019. *Boswellia* and *Commiphora* species as a resource base for rural livelihood security in the Horn of Africa: A systematic review. *Forests*, 10(7): 551-566.
- IV. Hassan, B. A., Glover, E.K., Luukkanen, O., Kanninen, M., and Jamnadass, R. 2019. Potential agroforestry trees and shrubs for rural household food security in Somalia. *Sustainability* (Under review).

### Authors' contributions:

Badal Hassan initiated Studies I, II and conducted the data collection and analysis for them and prepared the articles in consultation with Edinam Glover, which were revised with Olavi Luukkanen, Ramni Jamnadass and Ben Chikamai, with contributions for study I by Markku Kanninen and Iiyama Miyuki. For Study III, Olavi Luukkanen initiated the idea of a systematic review, Badal Hassan and Edinam Glover designed the research methodology, and Badal Hassan took the lead in collecting the data, analyzing and drafting the paper. Edinam Glover contributed to the interpretation of the results and the writing of the paper; Olavi Luukkanen verified the analytical method, commented and edited the paper. Markku Kanninen and Ramni Jamnadass supervised the research work and provided comments that helped shape the research, analysis and manuscript. For study IV, Edinam Glover initiated the idea; Badal Hassan collected and analysed the data and prepared the manuscript in consultation with Edinam Glover, and Olavi Luukkanen reviewed and edited the manuscript. Markku Kanninen and Ramni Jamnadass supervised the research work and provided invaluable comments that helped shape the research, analysis and manuscript.

## LIST OF MAIN ACRONYMS AND ABBREVIATIONS

AF	Agroforestry
AI	Aridity Index
ANR	Assisted Natural Regeneration
APs	Agro-pastoralist
ASALs	Arid and Semi-Arid Lands
Asl	Above sea level
CCA	Climate Change Adaptation
ELD	The Economic of Land Degradation
FAO	Food and Agricultural Organization of the United Nation
Fig.	Figure
FMNR	Farmers Managed Natural Regeneration
GHoA	Great Horn of Africa
Ha	Hectare
HH	Household
HoA	Horn of Africa
Ibid	Ibidem
ICRAF	International Council for Research in Agroforestry (World Agroforestry Centre)
IDMC	Internal Displacement Monitoring Centre
IDPs	Internally Displaced Persons
IGAD	Intergovernmental Authority on Development
IIED	International Institute for Environment and Development
ITTO	International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
KEFRI	Kenya Forestry Research Institute
LHS	Livelihood Security
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MEA	Millennium Ecosystem Assessment
MoE	Ministry of Energy
MT	Metric ton
NDMA	National Drought Management Authority
NP	Nomadic pastoralist
NR	Natural Regeneration
NTFPs	Non-Timber Forest Products
NTR	Natural Tree Regeneration
NWFPs	Non-Wood Forest Products
PRISMA	Preferred Reporting Items for Systematic reviews Analyses
RHFS	Rural Household Food Security
SLF	Sustainable Livelihoods Framework
RLS	Rural Livelihood Security
SPSS	Statistical Package for Social Sciences
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Convention on Environment and Development
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa

UNICEF<sup>1</sup> United Nations Children's Fund  
VITRI Viikki Tropical Resources Institute  
WCED World Commission on Environment and Development  
WRI World Resources Institute

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<sup>1</sup> Previously called United Nations International Children's Emergency Fund

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## 1. Introduction

### 1.1. Dryland resources for sustainable livelihoods and utilization in the Horn of Africa (HoA<sup>2</sup>)

Dryland in all its forms (hyper-arid, arid, semi-arid or dry sub-humid), is characterised by low precipitation and high evapotranspiration, which creates a phenomenon of soil moisture deficit. Globally, 41% of Earth's land surface is dryland and hosts about 33% of the global human population (MEA 2005). The United Nations Convention to Combat Desertification (UNCCD 1994) classified drylands as land areas other than polar and sub-polar regions where the aridity index "falls within the range from 0.05 to 0.65".

Between 60 and 70% of the land surface area of the Horn of Africa is classified as dryland (Awimbo et al. 2004, Babikir et al. 2015). It accommodates approximately 30% of the human population and 80% of the livestock in the region (Knips 2004; IGAD 2016) and provides a habitat for more than 2 500 species of vascular plants of which more than half are endemic (White 1983). Sustainable rural livelihood is a holistic approach of linking socio-economic and ecological development.

Livelihood sustainability depends on capacity to cope with and ability to recover from stress and shocks at household and national level and continues sustaining its capabilities and livelihood resources, and provide sustainable livelihood for the generations to come (Chambers and Conway 1991). Livelihood is a way a household or individuals secure their basic needs. Livelihood resources are "*the basic material and social, tangible, and intangible assets that people use for constructing their livelihood*" (Krantz 2001:8).

In this study, livelihood refers to a combination of activities, capacities and assets required for a means of living. Pastoralism and agro-pastoralism are the common livelihood activities in the drylands, since these areas offer little opportunity for crop production (Hesse and MacGregor 2006). The rural communities in the region depend on extensive free grazing livestock production, rainfed subsistence crop farming and harvesting of non-timber forest products.

*Acacia-Commiphora* bushland, semi-desert scrub and semi-desert grassland are the most extensive vegetation types in the drylands of the Horn of Africa region. These ecosystems play vital roles in the livelihoods of the people and the ecosystem sustainability of the region. They are the source of economically important products, including several non-wood forest products (NWFPs) for household use, livestock production and cash income. Of the NWFPs, gums and aromatic resins are economically the most important ones (Gemedo-Dalle et al. 2005; Glover 2005; Salah 2014; Adam et al. 2013; Lemenh et al. 2014).

The predominant tree species in the Horn of Africa with distinct socio-economic values are *Acacia*, *Boswellia* and *Commiphora* species. These are multipurpose trees or shrubs, with diverse socio-economic and ecological benefits, known for their edible gums such as those derived from *Acacia* species, or aromatic resins in the other two genera. While many *Acacia* spp. often form continuous dense stands, *Boswellia* and *Commiphora* species are found more

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<sup>2</sup> In this study "HoA" is defined as comprising Djibouti, Ethiopia, Eritrea, Kenya, Somalia, South Sudan, Sudan and Uganda, or all IGAD member countries. This region is also referred to as "Greater Horn of Africa", in contrast to some more narrow definitions.

scattered, often in harsh environments such as in shallow or rocky soil, steep slopes and around gullies (Gebrehiwot et al. 2003).

For the last three decades, it has been globally acknowledged that non-wood forest products (NWFPs), as a category within the larger class of non-timber forest products (NTFPs), play a significant role in sustainable rural livelihood security and ecosystem sustainability (Ros-Tonen and Wiersum 2005). Forest ecosystems provide a variety of goods for food, fodder, medicine, energy for household uses, and cash income. As the name implies, NTFPs is a collective term used to describe all tree products apart from timber, gathered or hunted from the forest ecosystem, including fuelwood and construction poles (Sorrenti 2017). Examples of NWFPs are wild fruits, edible leaves, roots, honey, medicinal plants, gums and resins, fibers, bush-meat, fish, etc.

## **1.2. Resilience and regeneration dynamics of drylands**

Drylands in the Horn of Africa face various challenges, the most serious of which is land degradation and desertification. This process is due to both climate variability and human activities, such as overgrazing and deforestation. The United Nations Convention to Combat Desertification defined dryland degradation as “reduction or loss, of the biological or economic productivity in *arid, semi-arid and dry sub-humid areas, resulting from human activities and habitation patterns*” (UNCCD 1994).

It is estimated that about 35% of drylands in the world are already degraded (IUCN 2017). In Africa, 45% of the land area is affected by land degradation and desertification, resulting in serious deterioration of ecosystem sustainability and food production systems (Tilahun et al. 2015). A resilient dryland ecosystem is able to withstand frequent disturbances such as droughts, floods, fire, overgrazing and continues to sustain its ecological functions (Lake 2013).

Either by themselves or with simple management intervention drylands have the ability to absorb impacts and to revert to their pre-disturbance condition through natural regeneration (Walker et al. 1981; Peterson et al. 1998; Gunderson 2000). Natural regeneration is the easiest, least expensive and most efficient way for dryland forests, woodlands and other vegetation to recover (Pandeya 2015). Most of the dryland woody plant species have the ability to naturally regenerate sexually and asexually following disturbances (Hoffmann 1998; Kennedy and Potgieter 2003; Vieira and Scariot 2006).

Natural regeneration occurs (FAO 2010) through seed germination (usually from a permanent soil seed bank) or vegetative regrowth of plants in the form of stump sprouts or root suckers, both in a natural environment and on cultivated lands (FAO 2010). This phenomenon is so distinct for the drylands but also so poorly recognised in dryland management that it has become necessary to highlight it with the term “underground forest” (Luukkanen 2012).

However, if not assisted, the natural regeneration may be hindered by various extrinsic factors caused by humans and livestock (Barik et al. 1996). The early stage of tree development between seed germination and the seedling establishment phase is the most vulnerable in a plant’s life cycle (Kitajima and Fenner 2000). The grazing effect on sprout mortality is relatively high especially in the first growing year (Sawadogo et al. 2002).

Assisted natural regeneration (ANR) is a term used for protection of degraded land from human and animal pressures in order to enhance natural processes of ecosystem restoration.



The purpose of ANR is to achieve healthy, productive and resilient ecosystems. Examples of ANR are closures and farmer-managed natural regeneration (FMNR), the latter being a practice of managing and protecting naturally regenerated desired woody species on farmland by individual tending (especially pruning and singling) of young trees with the objective of increasing the tree cover and the value of woody species (Pandeya 2015).

Closure is another option for rehabilitation of degraded land; in practice, it involves preventing human and animal access, with the objective of improving the natural vegetation, including both woody plants and grasses; it is especially used on communal lands (Mengistu et al. 2005; Mekuria and Aynekulu 2013).

Dryland trees produce either orthodox (desiccation tolerant) or recalcitrant (desiccation sensitive) seeds (Khurana and Sign 2001). However, most of the woody species in drylands bear small hard-coated orthodox seeds, which are able to remain dormant in the soil or on the tree for several years without losing viability; dryland trees also normally flower and produce seeds every year (Khurana and Sign 2001; Teketay 2005; Vieira et al. 2006). Forest seed dispersal is of importance in survival of seeds and tree regeneration in drylands, as most of seeds fallen under the mother trees are consumed by seed predators (Chazdon and Guariguata 2016).

The agents of seed dispersal are wind, gravity, water and animals (Gioria et al. 2012). Animals, both wild ones and livestock, also influence the process of natural regeneration of trees and shrubs by spreading the seeds and facilitating their germination by passing them through their digestive system (Tjelele et al. 2015; Egerer et al. 2018).

### **1.3. Study aims and hypotheses**

The overall objective of the study was to find ways of improving the livelihood of the rural communities and promoting ecosystem sustainability in the Horn of Africa. Another general aim was to explore the adaptive strategies for community adaptation to climate change, using Kenya and Somalia as specific cases.

The specific aims of this study were:

- 1) To examine the socio-economic and ecological effects on rural livelihoods caused by environmental changes (Study II).
- 2) To explore and compare the importance of woody plants for food security and livelihood among different community groups affected by famine and conflicts, with Somalia as a case (Study IV).
- 3) To systematically review the recent literature in terms of socio-economic and ecological relevance of aromatic resins in the Horn of Africa region (Study III).
- 4) To analyse the role of *Boswellia* and *Commiphora* species in the rural livelihood security and climate change adaptation in the Horn of Africa with a focus on north-eastern Kenya (Study I).

## ***Hypotheses***

The study was based on the general assumption that strengthening of sustainable management of dryland tree-based resources also enhances the livelihood security, ecosystem sustainability and climate change adaptation of the concerned communities and is a practical option that creates new economic incentives especially for the pastoralist and agro-pastoralist communities.

The hypotheses addressing each of the specific objectives were:

- 1) Improved management of dryland resources enhances climate change adaptation and livelihood security of the rural communities in the Horn of Africa.
- 2) The degradation of dryland resources adversely affects livelihood security of the pastoral communities in the Horn of Africa.
- 3) Development of value-chains for aromatic resins creates economic incentives for pastoralist and agro-pastoralist to sustainably manage their *Boswellia* and *Commiphora* tree resources.
- 4) There is a strong positive relationship between the availability of non-wood forest products and livelihood security in the drylands of the Horn of Africa.

## 2. Theoretical Framework

### 2.1. General considerations

The concept of sustainable development (SD) for obvious reasons is not necessarily equal to maintaining the ecological status quo. There is a growing body of empirical evidence that indicates that an interdisciplinary discourse on resilience should now pay attention to the interactions of humans and ecosystems via socio-ecological systems and to the need for shift from the maximum sustainable yield paradigm to environmental management which aims to build ecological resilience through "resilience analysis, adaptive resource management, and adaptive governance" (Walker et al. 2004).

To conceptualize the idea of SD, the term "sustainable development" needs to be defined, and perhaps the most comprehensive definition is that of the Brundtland Report published in *Our Common Future* by the World Commission on Environment and Development (WCED) in 1987 as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED 1987: 43).

According to Adamowicz and Burton (2003), the foregoing definition of sustainable development contains:

1. Equity: the future generations' right to live in an environment that is no worse than the present one (ecologically not degraded to the level that biodiversity is lost or productive and service capacity is reduced).
2. Wealth: the socio-economic function and productive capacity will be no worse in the future than its current state.

Environmental sustainability, defined as "*maintenance of natural capital*" (Goodland 1995: 10), focuses on the general viability and functioning of natural ecosystems. In terms of ecosystems, Victor (2011) defined ecological sustainability as "*a comprehensive, multi-scale, dynamic, hierarchical measure of resilience, vigour and organization*". Resilience describes the capacity of ecosystems to withstand disturbance and recover from shocks (Folke et al. 2004).

Anthropogenic factors that affect ecosystem resilience such as deforestation, natural resources exploitation, air pollution, contamination of soil and water etc., are increasingly causing ecosystem regime shifts, often leading to state of degraded conditions (Folke et al. 2004), rise in vulnerability and weakening of system health. The notions of a safe threshold and carrying capacity are of paramount importance in order to avoid catastrophic ecosystem collapse.

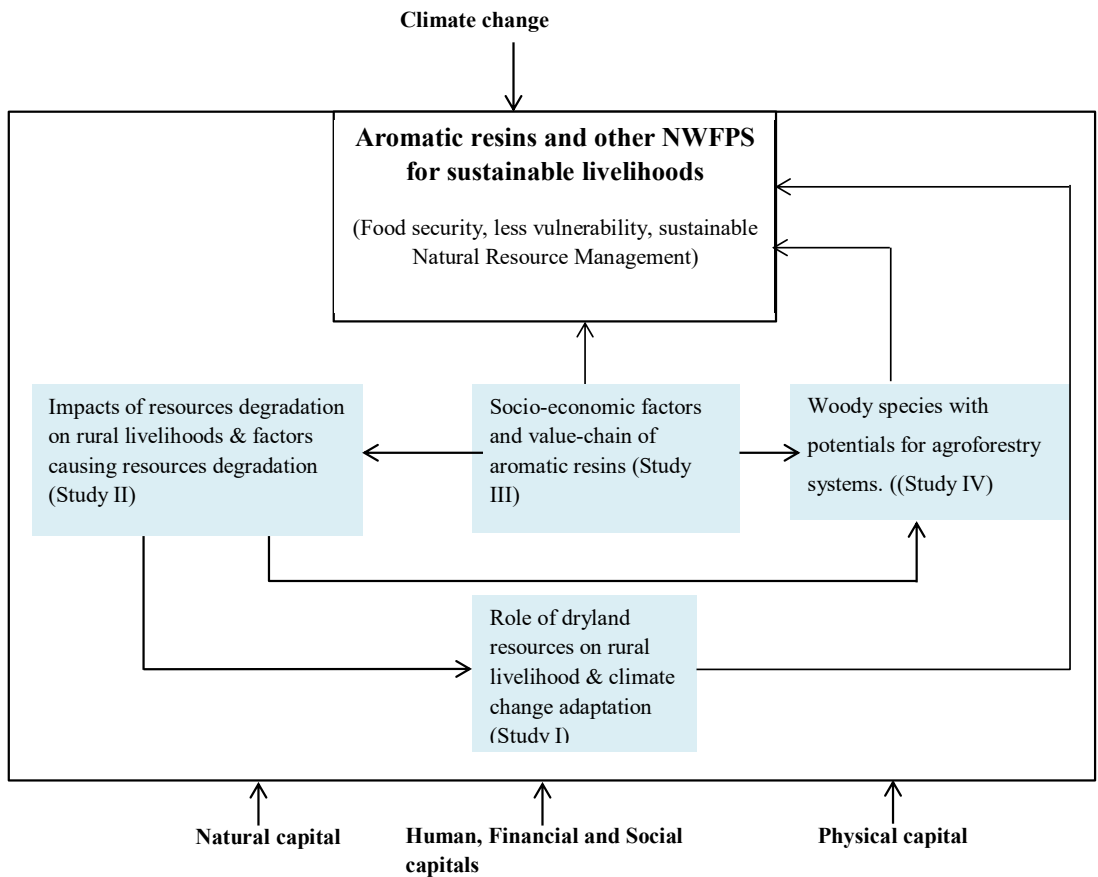
On the other hand, economic sustainability aims at maximizing the flow of income that could be generated at the same time as maintaining the stock of assets (or capital) that yields these beneficial outputs (Spangenberg 2005). A large and growing theoretical literature indicates that economic efficiency continues to optimize both production and consumption through safeguarding both effective allocations of resources in production and effective consumption choices that maximise utility (Turner and Pearce 1990; Jacobs 1995; Pinguelli-Rosa and Munasinghe 2002).

The concept of sustainable use of natural resources refers to the necessity to limit exploitation of the natural resources to such a level that the regeneration and production capacity of natural resources are not affected. This criterion is met as long as the exploitation intensity does not exceed the carrying capacity. Sustainable resource use is linked to the concept of the carrying capacity of the natural environment, according to which human activities should not irreversibly affect the ecosystem production and function (De Groot 1996; Aarts 1999; Teketay et al. 2010). Social sustainability and environmental sustainability are interlinked. Attempts to reduce vulnerability and maintain the ability of socio-cultural systems to endure shocks are also imperative (Ziadat et al. 2017).

*Social Capital* describes the social resources that people draw on in quest for livelihood objectives. These may consist of family and kinship networks, other forms of inter-household co-operation, membership of formalised groups, and the quality of leadership and the degree of cooperation within communities. The main factors contributing to social capital are enhancing human capital (through education) and strengthening social values, institutions, and governance (Davidsson and Honig 2003).

*Human Capital* describes the ability of people to work in terms of their education, health and skills. When referring to household as a unit of analysis, human capital defines also the size and quality of the ‘household labour pool’. From this perspective, safeguarding cultural capital and global cultural diversity, strengthening social cohesion, and minimizing destructive conflicts form basic elements of this approach (Hsu 2008; Murphy 2012). It is important to note that empowerment and extensive people’s involvement through subsidiarity play significant roles in terms of social capital. The social view emphasises the enhancement of human relationships and realization of individual and social aspirations.

Bearing in mind the foregoing considerations, this study analysed the role of dryland resources, in particular *Boswellia* and *Commiphora* species, in rural livelihood security (RLS) and climate change adaptation (CCA) in the HoA (Study I). A systematic review was employed to analyse the recent literature on the overall value-chain of frankincense and myrrh, and their socio-economic contribution to rural livelihood household security (RLHS) and CCA in the HoA (Study III). The study also investigated the major causes of ecosystem degradation in Somalia and its impacts on rural livelihoods (Study II). The study explored the potential agroforestry woody species for rural household food security, with special reference to food and non-food products (Study IV). Figure 1 shows a simplified theoretical framework linking the different components of the study.



**Figure 1.** A simplified theoretical framework of the study. Particular attention is placed on the environmental, economic and social context in which sustainability is discussed. These elements are assumed to be related in a variety of ways, as indicated by the arrows, all of which are highly dynamic. The study focuses on elements within the box.

The debate on the whole concept of sustainability and its components is not a novel one. The global discussion has gained significantly from organizations such as WCED (1987) and UNCED (1993).

Several scholars have contributed significantly to various aspects of sustainability as related to natural resources and their management, including Goodland (1995) on the concept of environmental sustainability; Sachs (1999) on sustainable development and the crisis of nature; Common and Stagl (2005) on ecological economics; Jabareen (2008) on environment, development and sustainability; Gesota (2008) on ecovillages as models for sustainable development; Næss and Høyer (2009) on growth, decoupling, and capitalism; Giddens (2011) on national responses to the challenge of global warming; Skrede (2013) on the issue of sustainable urban development in a neoliberal age; and Dryzek (2013) on the politics of the Earth.

Other scholars, including Chambers and Conway (1991), Chandy et al. (1991), and Chambers (1992), have also reflected on the concepts of sustainable rural livelihoods specifically focusing on poverty alleviation.

Against this backdrop, participation of people in natural resources management at local level and the relationship between the implementation of empowering strategies and successful sustainable development, are key issues to be explored (cf. Redclift 1992; Smith and McDonough 2001).

## **2.2. Sustainable forest management (SFM)**

The concept of sustainable forest management (SFM) is linked to the concept of sustainable development that has gained worldwide recognition over the last three decades (Nasi and Frost 2009). SFM is a dynamic and holistic management system that aims to enhance the socio-economic and ecological values of forest resources (UN 2008). Even though there is no internationally agreed definition of SFM, a number of scholars and institutions have sought to define SFM as a concept in different ways, as indicated by the following examples: Gale and Cordray (1991) “What should forests sustain?”; Botkin and Talbot (1992) “Biological diversity and forests”; ITTO (1992) “Criteria for the measurement of sustainable tropical forest management”; MCPFE (1993) “General Guidelines and resolutions adopted for the Sustainable Management of Forests in Europe”; Kant and Lee (2004) “A social choice approach to sustainable forest management”; and UN (2008) “Resolution adopted by the General Assembly 62/98: Non-legally binding instruments on all types of forests”.

Perhaps the most comprehensive definition is the one proposed by the Ministerial Conference on the Protection of Forests in Europe (MCPFE 1993) also known as the Helsinki Declaration, as it covers the main components of the forest principles. The MCPFE defined SFM as “*the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*” (MCPFE 1993).

Unlike traditional forest management systems that were specific and single-objective oriented, SFM recognizes the multi-functionality of forest ecosystems, multiple uses of forest products and inclusion of different stakeholders in the management and decision-making process, e.g. local resource users, civil societies etc. (Kant and Lee (2004). To implement SFM requires national policies, strategies and priorities that form the framework for sustainable development of forest resources and forest lands that foster different functionalities of forest ecosystem in the face of climate change (Bolte et al. 2010).

It acknowledges the multi-functionality of forest ecosystems such as the productive and protective function of the forest, biodiversity and forest health, as well as forest related socio-economic needs for the present and the future generations (Barbieri and Valdivia 2010; Romeiro 2015).

As a management system SFM plays a paramount role in emissions reduction from deforestation and forest degradation (REDD) (Kanninen 2009). In attempts to address the issues of deforestation, sustainable forest management has become widely accepted for the management of forest resources (Humphreys 2008; Barbieri and Valdivia 2010; Pandit et al. 2013; Mbow et al 2014). It promotes multi-functional uses of forest resources instead of forest

policies that focus on a single objective (Barbieri and Valdivia 2010; Asaah et al. 2011). SFM is an important way of integrating and achieving different objectives, such as food security, clean water, employment, biodiversity conservation, income generation and climate change mitigation (FOREST EUROPE 2009).

### **2.3. Sustainability in agroforestry systems**

The concept of sustainability in agroforestry systems plays an important role in farm productivity and profitability. The word “agroforestry” is a combination of two words: agriculture (crop cultivation and animal rearing) and forestry (practice of managing and utilising trees and caring of forest functions). Therefore, the term agroforestry involves integration of crops, pasture/animals, and woody perennials, with the objective of improving land productivity and ensuring economic diversification as well as ecosystem stability and restoration (Hillbrand et al. 2017).

Agroforestry thus comprises intentional growing of woody species on the same piece of land as used for agricultural crops and/or animals, either in spatial mixture or in sequence, to create a managed ecosystem that enhances economic and ecological interaction between the woody and non-woody components (Lundgren 1997; Nair 1993). In the present study we have adopted the revised definition of agroforestry by Leakey (2017), who described agroforestry as “*a dynamic, ecologically based, natural resource management system that, through the integration of trees in farm- and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits*” (Leakey 2017:7).

In a sequential agroforestry system, the maximum growth of the woody and herbaceous crops occurs at a different time. In this situation, the woody perennials help to increase the yields of associated agricultural crops and pastures primarily by enhancing the soil conditions (Cooper et al. 1996). In the spatial mixture of an agroforestry system, sharing of space and resources such as light, nutrients and water occurs. If one of these resources is limited in supply, competition between species occurs. Therefore, the factors creating a successful agroforestry system are the choice of species, the site and the agro-ecological zone. Other prerequisites for successful adoption of agroforestry practices are enabling socio-economic conditions (especially land tenure systems), sufficient resources available for farmers, management skills, and the short and long-term profitability of the system (Geburu et al. 2019).

Agroforestry is also described as a sustainable management system that enhances economic productivity, ecosystem sustainability and socio-cultural stability (Leakey et al. 2005; Drever et al. 2006). The ecological (or environmental) service roles of agroforestry systems include soil and water conservation, carbon sequestration, biodiversity restoration and micro climate. Agroforestry systems can be classified based on structural, functional, agro-ecological and socioeconomic factors (Nair 1987; Sinclair 1999).

A distinction can be made between agri-silviculture (the combination of crop cultivation and forestry), pastoral silviculture (or silvopastoralism, the combination of pastoralism and forestry) and agro-pastoral silviculture (or agri-silvo-pastoralism, the combination of crop cultivation, pastoralism and forestry) (Nair 1989; Harwood 1996; Wiersum 1999). An agroforestry system is noted for spreading the risk of crop failure due to its potential to strengthen the economic and ecological basis of the agricultural production system. Important product roles of agroforestry consist of supply of fuelwood, domestic timber, fodder, food, oils, gums and

resins, and materials for handicrafts (FAO 1987; Luukkanen et al. 1999; Wiersum 1999; Jose 2009; Wekesa et al. 2010).

Many farmers are more interested in diversification of household income than in the ecological aspects; however, the ecological benefits also form the basis of the economic advantages (Leakey et al. 2005; Jose 2012). The integration of agricultural crops with trees may generate a higher profit margin than mono-planting of either component alone. The same applies for the ecological benefits (Leaky 2010; Sharma et al. 2016). The factors influencing the economic success of agroforestry system includes the accessibility to markets.

There is more biodiversity in agroforestry systems (both above and below the ground) compared to crop or forest plantation monocultures (Lavelle and Pashanasi 1989; Sanchez 1995; Leakey 1999; Huang et al. 2002; Pandey 2002; Jose 2012). Agroforestry helps significantly in conserving plant and animal biodiversity through its preventive value, i.e. the savings in current biodiversity attained by reducing tree cutting and further conversion of forest land to agriculture (Lavelle and Pashanasi 1989; Sanchez 1995; Schroeder 2009 and Pedroni et al. 2009).

Agroforestry is also an effective tool for rehabilitating and reclaiming of degraded lands (Dagar and Gupta 2016). Agroforestry systems help to improve the physical and chemical conditions and biological processes of the soil. Trees act as sources of additional nitrogen inputs through the fixation of atmospheric  $N_2$  and deep-soil nutrient capture. Many leguminous trees are especially efficient in supplying nitrogen for agricultural crops through  $N_2$ , particularly to soils sufficiently enriched with phosphorus (Young 1987; Shepherd et al. 1995; Sanchez 1995; Narain et al. 1997; Deng et al. 2017).

Trees, with their extensive root systems, accumulate nutrients from large quantities of soil, while litterfall then increases the soil organic matter content and enhances the soil water holding capacity; (Fisher 1995; Garrity 1996; Glover 1998; Luukkanen et al. 1999; Pandey 2002). Integration of woody perennials into agroforestry systems also helps to control wind and water erosion. Various studies have shown that wind erosion can be reduced with boundary plantings (Wallace et al. 1990; Young 1987; Wolfe and Nickling 1993; Whisenant 2005; Zhao et al. 2006; Mansourian 2016).

There is also a growing body of empirical evidence that shows that contour hedges and alley cropping efficiently combat erosion as hedges provide barriers (Garrity 1996; Luukkanen et al. 1999; Mutegi et al. 2008; Ravenscroft et al. 2010; Aerts and Honnay 2011). Agroforestry systems help retain carbon (C) in the terrestrial ecosystem and remove it from the atmosphere. This is achieved both by curtailing further deforestation and by accumulation of biomass and soil carbon (Dixon 1995; Pandey 2002; Albrecht and Kandji 2003; Schoeneberger 2009; Tiwari et al. 2017). Oelbeman et al. (2004) and Nair et al. (2009) reported that tropical agroforestry systems contribute considerably to sequestering atmospheric C owing to their high return of organic material to the soil.



## 2.4. Livelihood sustainability and food security

In 1991, Chambers and Conway published a paper in which they defined a livelihood as comprising the “*capabilities, assets and activities required for a means of living*”. A capability was defined as a person’s, or household’s ability to cope with stresses and shocks, and the ability to find and make use of livelihood opportunities (Chambers and Conway 1991). In this context, assets mean the basic material and social resources that people have in their possession. Activities are described as the ways in which capabilities and assets are joined to attain livelihood results. A livelihood is referred to as sustainable when it can “*cope with and recover from stresses and shocks, and maintain or enhance its capabilities and assets, in the present and in the future, without undermining the natural resource base*” (Scoones 1998:5).

Livelihood assets are the basic building blocks on which livelihoods are built. They may also be referred to as capitals or even more generally as resources. The existence of, and degree of access to, livelihood assets are therefore important in influencing people’s choice of livelihood strategies. Some combination of these assets is essential in improving people’s quality of life significantly on sustainable basis. Although there is some debate concerning the categorisation of livelihood assets, the sustainable livelihoods framework (SLF) alludes assets in terms of the five distinct forms of capitals (Chambers and Conway 1991; Scoones 1998; Scoones 2009), namely, natural capital, human capital, financial capital, physical capital and social capital.

Livelihood strategies describe a variety and combination of activities that people embark on in order to attain their livelihood objectives. The different kinds of livelihood preferences that are available to people are thought to be determined by the vulnerability context (i.e. shocks, trends and seasonality), the extent of livelihood assets and the nature of transforming structures and processes. Accordingly, environmental sustainability should be operationalised as a set of constraints on the activities of the human economic subsystem in order to preserve the natural capital (Wu 2013).

### ***Food security***

Food security is an essential concept when addressing livelihood sustainability. Food security has four dimensions: availability (focusing on supply side), access (focusing on income, price and market), utilization (focusing on nutritional status) and stability; they focus on the sustainability aspects of socio-economic and ecological conditions (FAO 2008). The global declaration on hunger eradication adopted by the UN in the World Food Conference in 1974 emphasised the need to ensure globally adequate food availability at all times (UN 1975).

The World Food Summit in 1996 defined food security as a situation when people have continuous access both physically and economically to sufficient and nutritious food, to meet their nutritional needs for a healthy life (FAO 1996). On the other hand, a state of food insecurity occurs when people do not have sufficient physical, social or economic access to food (Diouf and Sheeran 2010). It is crucial to differentiate between food security on the one hand and famine and hunger on the other. Food security is defined based on socio-economic (financial and cultural) condition and the availability of food, whereas famine and hunger are referred to as temporary periods of food scarcity in which households experience food insecurity (Tarasuk 2001).

The Agenda 21 (UNCED 1993), adopted at the UNCED (1992) held in Rio de Janeiro, describes sustainable development to include three dimensions: the social, economic and the environmental. The ultimate goal of sustainability is to find a balance between the three pillars -- economic, social and environmental sustainability aspects of communities (Sneddon (2000). However, much of the scholarship on sustainability argues for using ‘sustainable livelihood security’ as an integrating concept, emphasizing that sustainability of the resource base is of no use in situations where it is separated from the human agents who manage the environment.

## 2.5. Characteristics of aromatic resin producing trees

### 2.5.1. Morphology and geographical distribution of *Boswellia* and *Commiphora* species

*Boswellia* and *Commiphora* spp. (family Burseraceae) are multipurpose tropical trees that grow naturally in the dry areas of the Horn of Africa and southern Arabia. (Farah 1994; Chikamai and Casadei 2005). The main characteristic of the family is the presence of resin ducts in the bark, and it includes the principal producers of the commercial frankincense and myrrh resins. Frankincense is an aromatic resin obtained from different species of *Boswellia*, mainly *B. frereana* Birdw, *B. sacra* Flueck, *B.papyrifera* (Del.) Hochst., *B. neglecta* S. Moore and *B. rivae* Engl.

Substantial morphological variation exist within the *Boswellia* species: e.g. *Boswellia neglecta*, *B. rivae*, and *B. ogadensis* are much-branched stunted trees of up to 3-4 m tall with dark-grey bark that is not peeling, whereas *B. frereana*, *B. papyrifera* and *B. sacra* are evergreen trees of up to 12 m tall with a spreading crown, grey trunk and peeling outer bark. The highest species diversity of *Boswellia* species is found in Somalia; within the entire Horn of Africa region, *B. frereana* and *B. sacra* are found only in this country (Chikamai et al. 2009).

On the other hand, *Commiphora* species are small perennial tropical trees or shrubs of up to 3 m tall, widely distributed in the Horn of Africa, with concentrations in areas closer to the Kenya, Ethiopia and Somalia borders. The *Commiphora* species are multi-branched trees which start branching from the base or from about one metre above the ground and recognised by their peeling outer bark, compound leaves and a fleshy fruit that splits when ripe into two (Farah 1994; Chikamai and Odera 2002).

Myrrh is obtained from number of *Commiphora* species. The commercially important real myrrh (syn. Malmal) is obtained from *Commiphora myrrha* which is endemic in Somalia, Ethiopia and Kenya. Among other species -- that yield low quality myrrh (syn. Opopanax) -- are *C. holtziana* Engl., *C. habessinica* (Berg) Engl., *C. guidotti* Chiov. and *C. erythraea* (Ehrenb.) Engl. (Chikamai and Casadei 2005). *Boswellia* and *Commiphora* species are among the economically most important dryland trees, with diverse ecological and socio-economic importance and sometimes considered as a lifeline for pastoral communities in the region. They are slow-growing dryland species that can be propagated through cuttings, root sprouts (suckers) or from seeds (Lemenih and Kassa 2011; Bekele 2016).

### 2.5.2. Value chains of aromatic resins

As defined by Kaplinsky and Morris (2001) and Lugusa et al. (2016), a value chain is a sequence or series of activities necessary to make a product or service that starts from the production phase and continues through processing phases up to the end-use; it includes different stakeholders along the chain. The value chains for frankincense and myrrh (both included in the product category of aromatic resins), involves six distinct phases of operations: tapping, harvesting, sorting, transport, assembling (by local buyers) and marketing, variously occurring at local, national or international market levels (Ribot 1998; Sturgeon 2001; Leakey et al. 2005; Abteu et al. 2012; Luukkanen et al. 2017).

The global demand for aromatic resins is hard to quantify as the products are aggregated as “other natural gums, resins and balsams” (Luvanda et al. 2017), but International Trade Center (ITC) estimated the world trade value of lac, gums, resins and other vegetable saps and extracts approximately 8 billion<sup>3</sup> US dollars in 2018. In the Horn of Africa, the largest producers and exporters of aromatic resins are Somalia, Ethiopia, and Kenya; the total average annual production is about 10,000 MT (Chikamai et al. 2009; Karaba 2011; Lemenih 2011).

The major buyers of aromatic resins are China, the EU, Japan, Middle East, North Africa and the USA. The volume of exports of aromatic resins from the Horn of Africa region is considered small when compared to the existing potential (Lemenih and Kassa 2011). The main markets and end-uses for frankincense and myrrh are found under three main categories, comprising culture and religion, fragrances and cosmetics, and pharmaceuticals and flavours (Chikamai and Casadei 2005).

Some of the pharmacological uses of frankincense and myrrh are ointments for curing tumours; medicines against stomach and intestinal disorders, dysentery, fevers, leprosy and cancer; wound plasters and toothpaste. In cosmetics, aromatic resins are used as ingredients in lotions, soaps, perfumes, detergents and other scented preparations. In addition, aromatic resins are used in paints, adhesives, varnishes, fumigation powders, dyes and beverages (El Ashry 2003; Chikamai and Casadei 2005; Lemenih et al. 2007).

### 2.6. Land-use rights and aromatic resins

In most parts of the Horn of Africa, land administration and land management in rural areas are in the hands of the local government. However, as is the case in Somalia, land titles can be granted exceptionally to those who have developed the land (Norton 2008). As discussed by Fitzpatrick (2005), community-controlled traditional rights are maintained by traditional leaders, and kinship-related or territory-based criteria exist for this regulation. In the African drylands in general, activities that form the safety nets for communities, such as fuelwood collection or food plant use, are usually not under customary tenure (HLPE 2017).

In particular, the pastoral communities in the Horn of Africa practice customary communal tenure systems, while the governments in the region mostly recognize rangelands as state land; this situation creates uncertainty regarding tenure rights of the resources users (Chikamai and Odera 2002). In his much quoted study, Hardin (1968) introduced the concept of “the tragedy of the commons”, which described the gradual degradation of natural resources left without defined managers.

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<sup>3</sup> Figure calculated from the database of ITC: <https://www.trademap.org/Index.aspx>

Later research, especially well highlighted by Elinor Ostrom, has made a clearer distinction between communal resources under defined management regimes and truly open-access resources which are free for anyone to exploit; for the resource to be sustainably managed, the users should have a common view of its management and use (Ostrom 1999). Specifically with reference to Somalia, Shepherd and Soule (1998) also criticized the model presented by Harding and supported the view that customary tenure can well support sustainable use of natural resources. Bruce (2000) also emphasized that, in Africa, different tenure niches may also be overlapping.

Katila (2008) has analyzed the concept of property right in the African context and emphasized that it cannot be dealt with as one particular right but must, instead, be divided into components, such as use right, management right, transfer right and exclusion right. In the case of aromatic resins in the Horn of Africa region, it is known that the ownership and use of these resources are mainly under customary regime. Obviously, additional research is needed to properly understand the present local patterns of rights related to these resources (Luukkanen et al. 2017).

### 3. Materials and Methods

#### 3.1. Study area and research sites

The field research for Study I was conducted in north-eastern Kenya (Fig. 3); while that for Studies II and IV was carried out in central parts of Somalia (Fig. 4 and Fig. 5). The socio-economic situation, culture and the ecological characteristics of the study areas in both countries were similar, much because of the fact that the population in both cases consisted of the Somali ethnic group depending on similar sets of natural resources. For Study III, a systematic literature review was conducted at the Viikki Tropical Resources Institute (VITRI), University of Helsinki. Agro-ecologically, the study areas in both Kenya and Somalia lie within the arid zone<sup>4</sup>, where the rainfall is scarce and irregular, and the whole region is susceptible to drought.

The Horn of Africa region at large has a biannual rainfall regime with spring and autumn rains. The spring rain is the main rainy season and lasts from April to June, while the autumn rain lasts from October to November. The annual average rainfall in the study areas is about 300 mm; however, due to a relatively high altitude; Buhodle in north-eastern Somalia receives a slightly higher rainfall ranging between 400 and 500 mm per annum. The study areas have no perennial rivers; therefore, local people rely on boreholes and rainwater harvesting as sources of water.

The average annual temperature of the study sites in both Kenya and Somalia is around 28° (Mahony 1990, Orindi et al. 2007). The vegetation types are generally woodland, semi-desert scrub or semi-desert grassland. These particular vegetation types are characterised by deciduous trees with open crown cover, stunted trees, spiny bushes and shrub-like perennial herbs (Greenway 1973). Especially in Wajir and Buhodle, a typical *Acacia-Commiphora* woodland is observed. The most commonly observed woody species in the study areas represent the genera *Acacia*, *Boswellia*, *Commiphora*, *Grewia* and *Boscia*.

Over 60% of the study area residents are nomadic pastoralists or agro-pastoralist of the Somali ethnic group in both Kenya and Somalia. In this study, as nomadic pastoralists are considered households which derive more than 50% of their gross revenue from livestock production. On the other hand, agro-pastoralists are defined as households deriving more than 50% of their gross revenue from crop farming and at least 10% of that from livestock (Swift 1988). Due to frequent droughts in the Horn of Africa region and a prolonged civil war in Somalia, a large number of the nomadic pastoralists in the study areas lost their livestock and now live sedentary life. These people are settled in camps in outskirts of cities and villages as internally displaced persons (IDPs) and generally rely on humanitarian aid.

Consequently, this study refers to IDPs as persons who have been displaced from their place of habitual residence without their will, because of natural or man-made disasters, such as droughts, floods, diseases, situations of generalised violence and violation of human rights, and who have not crossed an internationally recognised political border (IDMC 2019). Villagers in the study areas obtain their living from other sources than pastoralism or crop farming. They are either formal employees earning salary, or self-employed, e.g. traders, labourers or NWFPs collectors. Therefore, in this study, villagers are defined as those households which secure

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<sup>4</sup> According to Kenya Forestry Research Institute's climatic classification of Kenya, the arid zone receives an annual mean rainfall of 300-550 mm and has a potential evapotranspiration of 1900-2400 mm/year.

more than 50% of their livelihood from other sources than crop production, livestock rearing or humanitarian aid.

### 3.2. Data collection and analysis

Before the survey started, the researcher consulted with the local elders/administration in the respective study areas on the research purpose, the contents of the questionnaires, population figures, the socio-economic strata, cultural sensitivities in relation to the study, potential key informants and, most importantly, the sample selection procedures (Fig. 2). Four different livelihood groups (strata) were then identified based on household income and livelihood activities, namely, Agro-pastoralists (AP), Internally Displaced Persons (IDPs), Nomadic Pastoralists (NP), and Villagers (V).

Data were obtained from two different sources namely: primary data, collected from the field, and secondary data, obtained from existing literature. Primary data for Studies I, II and IV were gathered in the field based on quantitative and qualitative structured questionnaire (Table 1) using closed ended questions as well as group discussions and key informants.

Simple Random Sampling (SRS) was employed to obtain a representative sample of the different livelihood groups for Study I, and Proportional Stratified Random Sampling (PSRS) for Studies II and IV (see Table 4). These methods were used in order to confirm that each livelihood group had a chance of being selected. PSRS is effective in obtaining a representative sample of the farming system categories in the study area as the number of variables drawn from each livelihood group is proportionate to the relative number of variables (Marshall 1996, Meng 2013).

Quantitative descriptive analyses were employed in Studies I, II and IV to describe the households' socio-economic characteristics, livelihood activities, land tenure systems and environmental degradation. Percentages were used as a method for interpreting the qualitative data. Descriptive statistics is a valuable analytical method that allows the researcher to investigate the characteristics, perception and experiences of the respondents (Polit and Hungler 1999). Market survey was also conducted (in Study I) to investigate the potential commercialisation of *Boswellia* and *Commiphora* products in the study area. Statistical Package for Social Sciences (SPSS) for Windows, version 21 was used as a tool for analysis. According to Polit and Hungler (1999), "*statistical procedures allow the researcher to reduce, summarize, organize, evaluate, interpret, and communicate numeric information*".

In Study III, systematic literature review was used to critically review the current literature on aromatic resins in the HoA, in relation to LHS, VC and CCA. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline was followed. Only literature published between 2003 and 2017 was considered, which led to the use of 51 articles for assessment (see Table 1).

**Table 1.** Summary of methods of data collection

<b>Study</b>	<b>Study area</b>	<b>Method used</b>	<b>Sample size</b>	<b>Comments</b>
I	Wajir, north-eastern Kenya	Standardised as well as open-ended questions, Key informants and group discussion was also used	N= 45 HHs	The selection of the respondents was based on SRS procedure. A representative sample of the different farming categories were selected as follows: 31% NP, 33% V, 20% IDPs and 16% AP.
II	Somalia (Addado, Buhodle and Galka,ayo districts)	Standardised as well as open-ended questions, Key informants and group discussion was also used	N = 90 HHs	Proportional Stratified random sampling (SRS) was used as sampling method to select 20% of 450 households (HH) in the study area. A total number of 90 HH comprising of 30 HHs in each study area, comprising of different livelihood groups as follows: 33 NP, 9 AP, 19 V & 20 IDPs.
III	Systematic literature review	Preferred Reporting Items for Systematic Reviews Analyses (PRISMA) checklist was used for selecting the criteria for this study	N = 51 articles	Electronic databases utilized for the literature search were Web of Science, Social Science Citation Index and Google Scholar; on-going projects reported in national forest programmes, conference proceedings and university publications were also investigated.
IV	Somalia, Godanlabe village located in the south of Addado district,	Standardised as well as open-ended questions; key informants and group discussion were also used	N = 80 HHs	Proportionate stratified random sampling method was employed to choose 20% of 400 HH in the study area. A total number of 80 HH comprising of different livelihood groups in study area was selected as follow: 18% AP, 20% IDPs, 30% NP and 32% V.



**Figure 2. a-f.** Overview of the survey procedure: a) Researcher consulting with the local elders in Addado, Somalia; b) Sub-chief of Gayure (Wajir, Kenya) telling the local residents about the research; c) Researcher discussing with the local authority at Halobokhad (Galka’ayo, Somalia) about the research; d) Group discussion<sup>5</sup> conducted in Gayure sub-location (Wajir, Kenya); e) The researcher conducting socio-economic survey at Gayure location in Wajir district]; f) The researcher consulting with the local authority in Buhodle, Somalia.

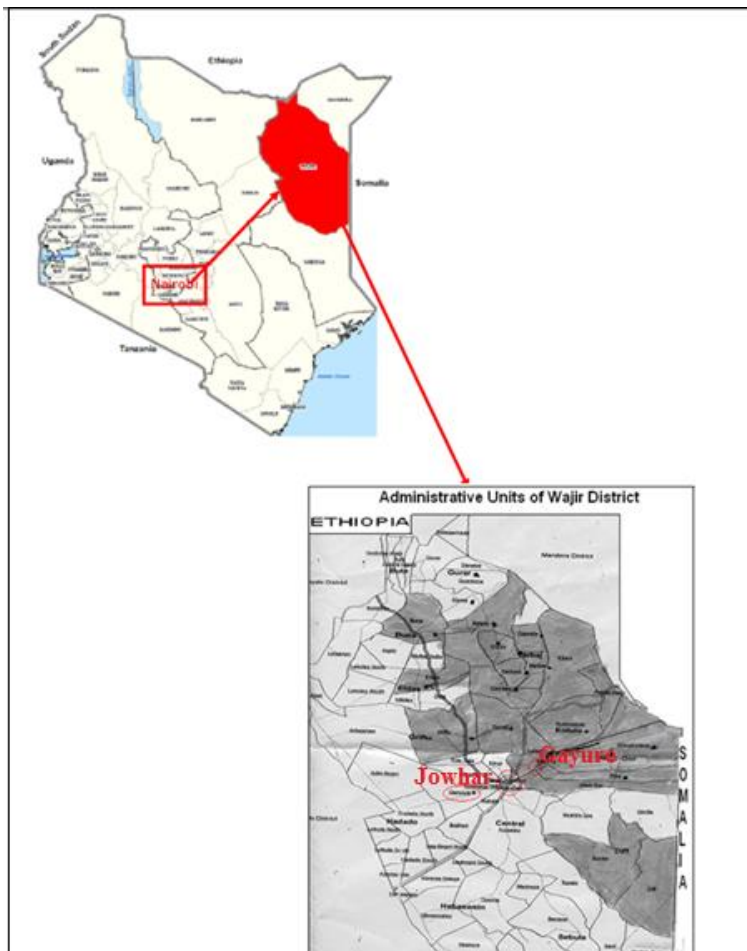
<sup>5</sup> As the group discussion proceeded, more people usually joined the event for curiosity, but they were not interfering with the meeting.



### 3.3. Study I: The role of *Boswellia* and *Commiphora* species in rural livelihood security and climate change adaptation

A survey on climate change adaptation and socio-economic contributions of *Boswellia* and *Commiphora* species on rural livelihood security was carried out at two sites in Wajir, north-eastern Kenya, namely, Gayure and Jowhar. These locations are situated about 490 km north-east of Nairobi; Gayure lies at latitude 01° 42' N and longitude 39° 56' E, west of Wajir town; and Jowhar at latitude 01° 47' N and longitude 40° 6' E northeast of Wajir (Fig. 3). Data collection consisted of both closed and open-ended questions.

A survey of 45 households, representing the different livelihood groups in the study area, was randomly selected. Of the 45 respondents, 31% were nomadic pastoralists, 33% villagers, 20% IDPs and 16% agro-pastoralist.



**Figure 3.** Map of Kenya showing the area of Study I. Dark colour indicates the distribution range of *Boswellia* and *Commiphora* species. (Modified from a map sourced from the office of the Wajir District Commissioner 2007.)

### **3.4. Studies II & IV: The socio-economic and ecological impacts of environmental changes on rural livelihood security**

Studies II and IV were linked to the SAHANSAHO project<sup>6</sup>. They focused on aims 1 & 2 and were conducted in Somalia, in three different districts (Fig. 4):

- (i) Addado district, which lies 590 km north of Mogadishu, at latitude 05° 53' N and longitude 46° 37' E;
- (ii) Galka'ayo district, 720 km north of Mogadishu, at latitude 06° 50' N and longitude 47° 26' E; and
- (iii) Buhodle district, 1 120 km north-west of Mogadishu, at latitude 08° 13' N and longitude 46° 21' E.

A survey of 90 households (i.e. 30 HH at each study site) was conducted in Addado, Buhodle and Galkaayo in 2012. A study sample of 9 APs, 29 IDPs, 33 NPs and 19 villagers were randomly selected for the survey. Socio-economic and natural resources management/exploitation data were gathered by using structured and open-ended questionnaires. Descriptive statistics was employed for the interpretation of the qualitative information obtained from the respondents.

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<sup>6</sup> The SAHANSAHO Project Against Desertification is financed by the Ministry for Foreign Affairs of Finland. It is jointly implemented, since 2012, by three local NGOs based in Addado, Buhodle and Galka'ayo in Somalia, three NGOs based in Finland, and the Finnish Somalia Network coordinating the project. The Viikki Tropical Resources Institute (VITRI), University of Helsinki, provides the technical and scientific backstopping of the projects, participates in local technical training and conducts field surveys, including those in Somalia on which the present research was based.



Figure 4. Map of Somalia showing the study area (Source: modified from OCHA<sup>7</sup> Somalia reference map)

<sup>7</sup> United Nations Office for Coordination of Humanitarian Affairs.

### **3.5. Study III. *Boswellia* and *Commiphora* species as a resource base for rural livelihood security in the Horn of Africa: A systematic review**

Study (III) covers a systematic literature review. This particular study critically assessed the recent literature on aromatic resins in the Horn of Africa region in relation to factors such as socio-economic situation, livelihood security, climate change adaptation and ecological relevance. The Preferred Reporting Items for Systematic reviews Analyses (PRISMA) checklist (Moher et al. 2009) was used for selecting the criteria for this study. A systematic identification of electronic publications was carried out in 2017 using different sources including scientific journals and databases.

### **3.6. Study IV: The importance of forest-based products for food insecurity**

This study was carried out in Godenlabe village near Addado district, in Galgudud region of central Somalia (Fig.5). The village is located approximately 1 500 km north of Mogadishu and lies at latitude 05° 48' N and longitude 46° 39' E. Based on information received from the local authority, the study area had a population of about 400 households (HH). Based on this study area population ( $N$ ), a sample size ( $n$ ) of 20%, covering all livelihood type groups, was selected. Accordingly, a total sample of 80 HHs was thus randomly selected.



Figure 5. Political map of Somalia showing the Study IV area. (map modified from: Azilon.com<sup>8</sup>)

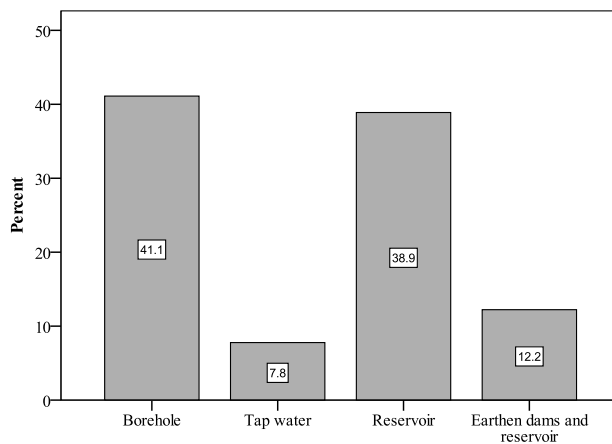
<sup>8</sup> <https://www.ezilon.com/maps/africa/somalia-maps.html>

## 4. Results

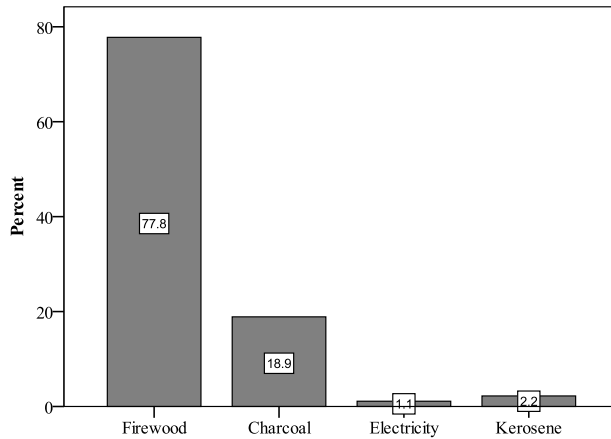
### 4.1. Causes and impacts of resources degradation on rural livelihoods in Somalia (Study II)

#### 4.1.1. Sources of energy and water

With reference to the sources of energy and water, results indicate that 41% of the HHs interviewed use boreholes as primary sources of water, approximately 51% rely on rainwater harvesting using different methods e.g. reservoir or dams, and only about 8% receive water through tap (Fig 6). As sources of energy, about 78% of the HHs rely on firewood, approximately 19% use charcoal, 2% kerosene and only 1% use electricity (Fig. 7).



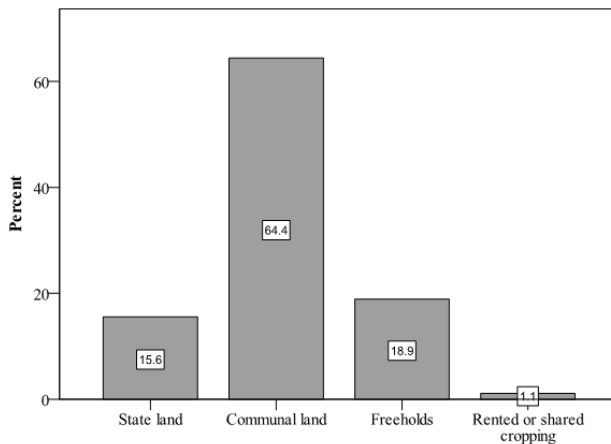
**Figure 6.** General sources of water as indicated by the respondents.



**Fig. 7.** Sources of Energy as indicated by the respondents

#### **4.1.2. Causes of resource degradation and existing natural resources management practices in the study areas in Somalia**

The study shows that four land tenure regimes exist in the study areas, namely, CL<sup>9</sup> (64.4 %), FH<sup>10</sup> (18.9 %), SL<sup>11</sup> (15.6 %) and rented land (1.1 %) (Fig.8).



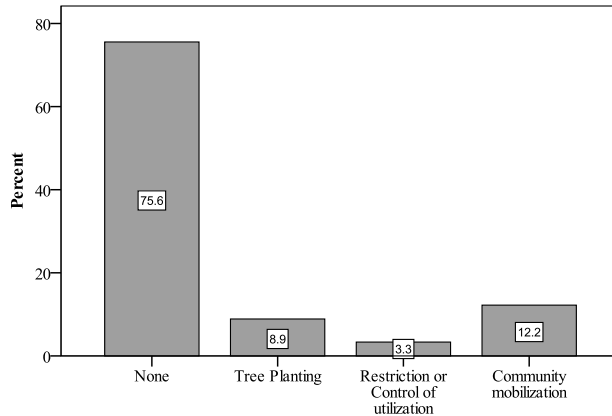
**Figure 8.** Land tenureship in the study areas in Somalia.

<sup>9</sup> CL= Communal land: land owned by specific community or clans which is free access for all members.

<sup>10</sup> FH= Freehold: Land owned as real estate by individual or HH just by investing or clearing the land.

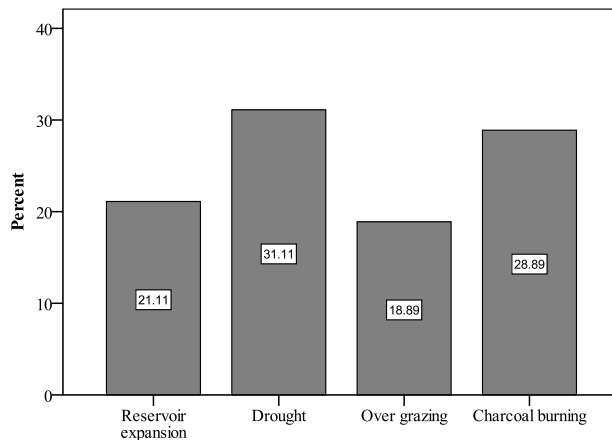
<sup>11</sup> ST = State's land = Land that belongs to the state

Figure 9 indicates the local peoples' views on existing natural resources management in response to environmental changes. They suggest that about 76 % of the respondents believe there are no ongoing environmental management activities, 12% indicated that environmental awareness and community mobilization activities exist, 9% mentioned that tree planting projects were on-going and (3%) indicated that a locally approved environmental law is enforced as a tool of management.



**Figure 9.** Natural resource management practices in the study areas.

As shown in Figure 10, the respondents indicated the following factors as main factors causing land degradation in the study area. Results revealed that 31% of all land degradation in the area is due to drought, 29% to charcoal production, 21 %, to rainwater harvesting and 19% to overgrazing.



**Figure 10.** Main agents of environmental changes in the study area



## **4.2. Potential agroforestry trees and shrubs for rural household food security (Study IV)**

### *Coping strategies*

Table 2 shows coping strategies adopted by local households in response to famine. Different households adopted different strategies as safety nets (cf. Table 2). In total, 44% of the study residents mentioned that NWFPs are used as means of safety net, while approximately 29% mentioned humanitarian food aid and 16% remittance as a safety net for survival.

Tables 3 and Table 4 show lists of preferred agroforestry trees and shrubs as indicated by the respondents. The study covered ten most important woody plants that were used as sources of food during famine and ten most important ones used as sources of income, apart from their other uses during drought or famine periods. Rankings were based on the availability of a given species during the dry season and its contribution to household dietary and income diversification needs.

**Table 2.** Coping strategies adopted by households in response to famine in the study area.

Group type	Coping mechanism							Total
	NWFPs	Humanitarian Aid	Food Aid	Sale of Assets	Remittances	Migration	Other	
Count	12	3	3	2	3	3	1	24
Pastoralist								
% within type of group	50.0%	12.5%	12.5%	8.3%	12.5%	12.5%	4.2%	100.0%
% within coping mechanism	34.3%	13.0%	13.0%	50.0%	23.0%	75.0%	100.0%	30.0%
Count	7	3	3	0	4	0	0	14
Agro-pastoralist								
% within type of group	50.0%	21.4%	21.4%	0.0%	28.6%	0.0%	0.0%	100.0%
% within coping mechanism	20.0%	13.0%	13.0%	0.0%	30.8%	0.0%	0.0%	17.5%
Count	12	9	9	1	4	0	0	26
Villager								
% within type of group	46.2%	34.6%	34.6%	3.9%	15.4%	0.0%	0.0%	100.0%
% within coping mechanism	34.3%	39.0%	39.0%	25.0%	30.8%	0.0%	0.0%	32.5%
Count	4	8	8	1	2	1	0	16
Internally Displaced Persons (IDPs)								
% within type of group	25.0%	50.0%	50.0%	6.3%	12.5%	6.3%	0.0%	100.0%
% within coping mechanism	11.4%	35.0%	35.0%	25.0%	15.4%	25.0%	0.0%	20.0%
Count	35	23	23	4	13	4	1	80
Total								
% within type of group	43.8%	28.8%	28.8%	5.0%	16.3%	5.0%	1.3%	100.0%
% within coping mechanism	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

N = 80 respondents;

**Table 3.** Ten locally most valued woody species used in response to food insecurity and with potential agroforestry use.

No	Scientific name	Species type	Local names (Somali)	Parts used	Description of specific uses
1	<i>Cordia alliodora</i> <i>edulis</i> Hemsl.	Shrub	Gud (shrub) Yi,ib (fruit)	Fruits, wood and leaves +*****	Fruits are used for food, leaves for fodder and branches for construction. The fruits are consumed as soup or nuts at home, but also sold in the market for cash exchange.
2	<i>Dobera glabra</i> Forssk.	Tree	Garas	Fruits, wood, leaves +*****	Food, fodder; wood is used to make mortars and pestles; beehives. The fruit is consumed cooked but the fleshy part of the fruit is also eaten fresh (uncooked). It flushes new shoots in the dry season and is thus an excellent source of fodder.
3	<i>Berchemia discolor</i> (Klotzsch) Hemsl.	Tree/shrub	Dheen	Fruits, leaves, fruits, bark, wood, roots +*****	Fruits are used for food; leaves for fodder and medicine; wood for construction and walking canes. Both the fruit pulp and seed are edible (fruits are dried and stored for later use). Fruits are also sold in the local market. Wood is used for construction and making walking canes for sale. Leaves and bark are used for medicine. Bark is used for tanning and medicinal purposes, roots for medicine.
4	<i>Ziziphus mauritiana</i> Lam.	Tree/Shrub	Gob	Fruits, leaves, branches +*****	Food, fodder, fence, cosmetics and medicine. The fruits ripen in the dry seasons (winter and summer). They are mostly harvested by children and women and eaten fresh (uncooked). Nutritionally, it is among the most valuable fruits in the region, rich in vitamin C.

+\*\* = somewhat useful, +\*\*\*= useful, +\*\*\*\* = very useful, +\*\*\*\*\* = extremely useful.

(Continued next page)

No	Scientific species name	Species type	Local names (Somali)	Parts used	Description of specific uses
5	<i>Grewia penicillata</i> Chiov.	Shrub	Hohob	Fruits, leaves, branches +****	Food, fodder and construction of hut houses. It is an important source of food, used as food supplement. Fruits are eaten fresh when ripe, they are also brought to the local market for sale.
6	<i>Grewia tenax</i> (Forssk.) Fiori	Shrub	Dhafarur	Fruits, leaves, branches and flowers + ***	Edible flowers appear at the beginning of the rainy season. Children eat it as a vegetable; the fruits are also eaten fresh when ripe in the dry season, they are used for home consumption only.
7	<i>Givottia gosai</i> A.R. Smith	Tree/Shrub	Goosay	Leaves, fruits and branches +****	The fruits are nutritionally very important; local people eat them during famine. The fruits ripen during the dry season, both the pulp and seeds are eaten. Seeds are very nutritious. Wood is used for making tool handles and utensils for sale.
8	<i>Acacia edgeworthii</i> T.Anderson	Shrub	Jeerin/Quule	Fruits, leaves, bark and braches +****	Food, fodder and for medicine; branches are used for fencing. Seeds are used for food and medicine, pod husks used for animal feed.
9	<i>Grewia villosa</i> Boivin ex Baill.	Shrub	Gomoshaa	Fruits, leaves, branches, flowers + ***	Food, fodder and construction of hut houses. Flowers are edible, children eat them as a vegetable; fruits are also eaten fresh when ripe in the dry season. Fruits are eaten as a food supplement.
10	<i>Grewia erythraea</i> Schweinf.	Shrub	Midha cas, ciid, xajjin	Leaves, fruits, poles +****	Food, fodder and construction of hut houses. Flowers are edible, children eat them as a vegetable; fruits are also eaten fresh when ripe in the dry season. Fruits are eaten as a food supplement.

Note: This table is a continuation of Table 3.

**Table 4.** Ten locally most valued woody species that provide household income in Somalia.

No	Scientific name	Species type	Local names (Somali)	Parts used	Description of specific uses
1	<i>Boswellia frereana</i> Birdw.	Tree	Maidi	Resin (frankincense), leaves +*****	Resin for cash exchange, leaves for fodder during the dry season. It is a source of job opportunity for poor and especially women-headed HHs. Women participate in frankincense sorting, as labourers to earn income.
2	<i>Boswellia sacra</i> Flueck..	Tree	Mohor (Moxor)	Resin (frankincense), leaves +*****	Resin for cash exchange, leaves for fodder during the dry season. It is a source of job opportunity for poor and especially women-headed HHs. Women participate in frankincense sorting, as labourers to earn income.
3	<i>Commiphora malmal</i> (Nees) Engl.	Tree/shrub	Dhidim/malmal	Resin, leaves, wood, branches +*****	Resin (myrrh) for cash exchange, dry leaves for animal feed and medicines. The trees exude only in the dry season. Wood for carving and utensils for sale; trees used for live fences.
4	<i>Acacia senegal</i> (L.) Willd.	Shrub	Addad/Caddad	Stem, branches, pods, leaves and gum +*****	Food, cash income, fodder, firewood, charcoal, dead fencing. It is the source of gum arabic exported for use globally as food supplement and in medicinal and cosmetic products and in printing. The dry pods are important fodder for animals.

+\*\* = somewhat useful, +\*\*\* = useful, +\*\*\*\* = very useful, +\*\*\*\*\* = extremely useful.

(Continued next page)

No	Scientific name	Species type	Local names (Somali)	Parts used	Description of specific uses
5	<i>Acacia tortilis</i> (Forssk.) Hayne	Tree	Qurac/Abaq	Stems, branches, pods, and leaves, fibres and roots, wood +****	Food, fodder, energy, medicine, tool handles, beehives. It has high energy content; trunks are used for charcoal production, while branches are used for firewood and tool handles; pods are used as food during severe famine and as fodder for animals.
6	<i>Boswellia neglecta</i> S.Moore	Tree/shrub	Mirafur	Resin, leaves, branches +***	The frankincense resin is used for cash exchange and fumigation, leaves for fodder, firewood and dyes. It exudes the resin only in the dry season.
7	<i>Salvadora persica</i> L. (Meswak)	Shrub	Aday/Caday	Roots, twigs, leaves +****	Roots and twigs are used for toothbrush. It is sold in the market throughout the year for this purpose. It is evergreen, and juvenile leaves are used for fodder.
8	<i>Commiphora holtziana</i> Engl.	Tree/shrub	Hagar	Resins, leaves, wood, +****	Resin (myrrh) for cash exchange, dry leaves for animal feed and medicines. The trees exude only in the dry season. Wood for carving and utensils for sale; trees used for live fences.
9	<i>Commiphora guidoti</i> Chiov.	Tree or dwarf tree	Hadi	Resin, leaves, wood +****	Resin (myrrh) for cash exchange, dry leaves for animal feed and medicines. The trees exude only in the dry season. Wood for carving and utensils for sale; trees used for live fences.
10	<i>Juniperus procera</i> Hochst. ex Endl.	Tree	Dayib	Wood +**	Construction, boat building, furniture. Local carpenters listed it as the most important timber tree.

Note: This table is a continuation of Table 4.

### 4.3. The role of *Boswellia* and *Commiphora* species in rural livelihood security and climate change adaptation (Studies I and IV)

#### 4.3.1. Local Uses of *Boswellia* and *Commiphora* species

The study found that all parts of *Boswellia* and *Commiphora* trees are used for a range of different purposes (Table 5 and Table 6). Their leaves are palatable with high nutritional value and serve as fodder for browsing animals, especially goats and camels. The wood is used for craftwork and tool handles, barks for tannin, flowers for bee forage and resins for commercial purposes.

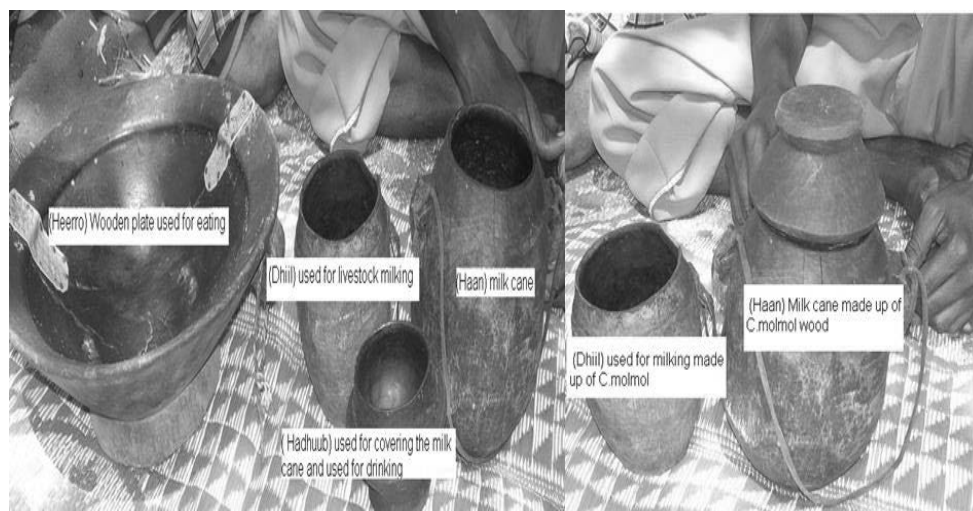
**Table 5.** Parts of *Boswellia* tree and their uses.

Part of tree	Local uses/Home consumption	Commercial uses
Leaves	Fodder for browsing animals	None
Flowers	Bee forage (honey production)	By-product (honey)
Bark	Dyes/tannin used for skin care and hide processing, feed for goats and antelopes	None
Branches	Tool handles; dry branches used for fuelwood	None
Resin	Chewed as gum; incense, local perfumes,	Cash exchange

**Table 6.** Parts of *Commiphora* trees and their uses.

Part of tree	Local uses/Home consumption	Commercial uses
Leaves	Fodder for browsing animals	None
Flower	Bee forage (honey production)	By-product (honey)
Stem	Wood carving, beehives	Wood utensils for sale
Branches	Tool handles; dry branches used for fuelwood	None
Bark	Dyes/tanning used for ski care and hide processing,	Non
Myrrh	Medicine, ink for Quranic schools, insect and snake repellent, medicine.	Cash exchange

In particular *Commiphora* species such as *C. myrrha* (syn. *C. malma*), *C. holiziana* and *C. giodotti* are used to make household utensils such as wooden plates, milk cans, milk jugs, wooden spoons and many more items (Fig. 11.).

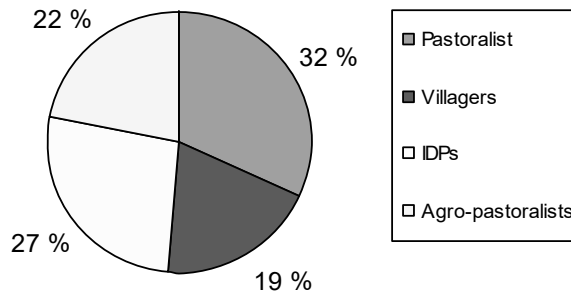


**Figure 11.** Household utensils made from *Commiphora myrrha*. From left to right: *Heerro* (wooden plate); *Dhiil* (milk bucket) used for milking cows, camels, goats and sheep; *Haan* (milk can) used for keeping and transporting milk to the market; *Hadhuub/haruub* (milk can lid) used as lid but also as a cup for drinking milk.



### 4.3.2. Aromatic resin value chains

Results of the present study confirm that the commodity chain for aromatic resins consists of five distinct steps, namely, tapping and harvesting, sorting, transporting, storage, and marketing at the village, district and national levels. The main collectors of frankincense and myrrh in the study area were found to be nomadic pastoralists (32 %), IDPs (27 %), agro-pastoralists (22 %) and villagers (19 %), as shown in Figure 12.



**Figure 12.** The main collectors of frankincense and myrrh in the study area.

The systematic literature review of the present study identified the following challenges constraining the aromatic resin management and production in the region:

- Lack of proper tapping methods.
- Labour intensiveness in collecting and transporting the products.
- Environmental challenges.
- Low prices, lack of market regulation, and inaccessibility of bank credit.

The results also indicate that local and international pharmaceutical industries and fragrance manufacturing were the principal actors in the end use of aromatic resins (Table 7).

**Table 7.** The end-uses of frankincense and myrrh in local and international markets (modified from Chikamai et al. 1996).

<b>Pharmaceutical</b>	<b>Fragrances and cosmetics</b>	<b>Flavours</b>	<b>Culture and religion</b>
<ul style="list-style-type: none"> <li>• Ointments for curing tumours</li> <li>• Medicines for curing vomiting, fever and leprosy</li> <li>• Wound plasters</li> <li>• Toothpaste and mouth wash</li> </ul>	<ul style="list-style-type: none"> <li>• Lotions</li> <li>• Soaps</li> <li>• Creams</li> <li>• Oriental powder</li> <li>• Perfumes</li> <li>• Floral perfumes</li> <li>• Citrus colognes</li> <li>• Spice blends</li> <li>• Male fragrances</li> <li>• Other scented preparations</li> </ul>	<ul style="list-style-type: none"> <li>• Chewing gum</li> <li>• Chewing without processing</li> <li>• As flavour agent</li> </ul>	<ul style="list-style-type: none"> <li>• Social functions, including coffee ceremonies</li> <li>• Religious rituals (Orthodox, Roman Catholic and Muslim)</li> <li>• Fumigation to repel bad odour</li> <li>• Use as snake repellent</li> <li>• Traditional ink</li> </ul>

## 5. Discussion

### 5.1. The role of aromatic resins in rural livelihood security and climate change adaptation

Frankincense and myrrh have been harvested and traded for centuries by the rural households in the Horn of Africa. These products are used in various industries and for cultural and religious ceremonies (Study I and Study III), and they provide significant incomes to households. Our findings confirmed that rural communities in the Horn of Africa harvest and sell aromatic resins specifically as a household income diversification and climate change adaptation strategy.

Aromatic resins are seasonal products available during the dry seasons; therefore, the pastoral and agro-pastoral communities in Somalia and north-eastern Kenya harvest them for off-farm wage employment. Earlier studies have shown that these resources can support rural households in coping with food insecurity, reducing extreme poverty, and in adaptation to climate-driven social and environmental changes (Laird et al. 2011, Teshome et al. 2015). The present study is also in line with the findings by Adilo et al. (2005) and FAO (2013), which concluded that national governments in the region generate considerable revenues from the export of aromatic resin products.

Muga et al. (2016) estimated the potential annual production of aromatic resins in Kenya as 8000 MT, with an export value of 5.2 million USD. Our similar study conducted in Wajir, north-eastern Kenya, found that, between December and February (i.e. in the winter season), about 180 MT of frankincense and myrrh is transported out of the district per month, while between June and August (in the summer season) the corresponding amount is between 70 and 80 MT (Study I).

However, proper development of the *Boswellia* and *Commiphora* aromatic resin sub-sector is hindered by lack of appropriate policies to support the industry. Little effort has been paid to the development of the sector, in terms of yields, adding value to the product, or marketing (Luvanda et al. 2007). The present study concluded that inappropriate technology, lack of sustainable resource management systems and policies, and weak value chain development are limiting the production and profitability of the aromatic resin economic sector.

Currently, local harvesters sell these products to few local retailers, which result in low commodity market price (Study III). Besides, these resources are under threat of being exploited due to poor tapping techniques and tools. Similar constraints have earlier been observed by Luvada et al. (2017) in Kenya and by Lemenih et al. (2007) in Ethiopia.

### 5.2. Resource degradation and rural livelihoods: Impacts and the way forward

In the Horn of Africa, the dryland ecosystem is fragile and exposed to intertwined challenges such as desertification and land degradation, food insecurity, climatic uncertainty, increased water scarcity and biodiversity reduction. All these factors increase the social vulnerability in the region. Resource degradation affects the rural livelihoods as they primarily depend on ecosystem products and services. Regarding to particular factors causing ecosystem

degradation, the study found that *recurring and severe droughts, overgrazing and deforestation are the main causes of environmental degradation of the drylands in the region.*

This result is consistent with the findings of Geist and Lambin (2004), who observed that extensive grazing and crop farming impacts coupled with prolonged droughts are the main causes of desertification and land degradation on drylands. Several scholars, including Reardon and Vosti (1995), Grepperud (1997), Vlek et al. (2010) and Ostrom (1999), have stated that land degradation is caused by lacking or inappropriate policies and the socioeconomic situation of the land users.

Forest resource degradation threatens, in particular, open-access land where neither resource users nor governing authorities have developed effective governance system to regulate the access to forest products or develop a sustainable harvesting system, e.g. in relation to timing of utilisation or the technology used (Ostrom 1999). Land-use right is the key issue on drylands, both in regard to management and to forms of exploitation. The present study found that communal land ownership regulated by customary regimes (i.e. open access) and freeholdings are the most common forms of land tenure (cf. Fig. 9).

The customary or traditional tenure system is predominant in Africa (Cotula 2007). The tenure system related to developed land in the Horn of Africa is mainly based on freehold under a customary system (Obeikol 2014). It was confirmed in the present study that in order to overcome water scarcity, the pastoral and agro-pastoral communities in Somalia practice rainwater harvesting by constructing cemented underground reservoirs in the grazing area. These communities also maintain closures on freehold land for fodder production. However, such activities tend to lead to land fragmentation and increased desertification (Study II). Thereby pastoralism is often perceived, by government and development agencies, as a primitive and destructive form of land use, responsible for communal rangeland degradation through overgrazing (Ayantunde et al. 2011; Nyberg et al. 2015).

Deforestation on drylands occurs in two forms: conversion of forest land to other uses, mainly crop cultivation and settlements, and harvesting of trees for cash exchange or household consumption, e.g. for wood-based energy (firewood and charcoal), construction, fencing etc. (Sola et al. 2017). Unsustainable harvesting of non-wood forest products (NWFPs) may also be a driver for forest degradation and resource depletion in the region (Ticktin 2004). In the tropics, over fifteen million hectares of forest land are still cleared per year for fuelwood or agricultural production (cf. Bishaw 2001, Otieno and Anyah 2012, Chidumayo and Gumbo 2013, Rudel 2013).

In the case of Somalia, charcoal is one of the most important export commodities and one of the main causes of deforestation (Rembold et al. 2013, Farah and Luukkanen 2015). Charcoal burning becomes an option of survival for poor households in due to lack of other employment opportunities but, at the same time, contributes to resource over-utilization.

This study revealed that the land tenure systems in the region were becoming increasingly more complicated due to disputes over the right of land use between crop farmers and pastoralists, and between neighbouring pastoral communities. This being the case, there were also mutual compromises on land disputes between neighbouring pastoral communities; for instance, in case of unexpected natural events, an affected community could migrate to the area of a neighbouring community to graze their animals and vice versa for the host in time of need.

The situation of pastoralists in both Kenya and Somalia is deteriorating at a high rate caused by persistent droughts and overgrazing, and that continue to affect the productivity of pasture lands. Overgrazing is a common constraint to sustainable development of drylands, requiring inputs to improve the animal husbandry and integration of grazing control with water development (Davies 2008). The situation of overgrazing is worsened by influx of livestock from neighbouring districts as well as from neighbouring countries.

Our findings show that many people were destitute as they faced shortages of food, fodder for livestock and fuelwood, and had limited incomes. Droughts endangered especially the livelihoods of the pastoralists and exacerbated the living conditions of impoverished households. This results in progressively higher rate of land degradation and in drastic reduction of the water resources, particularly for the pastoral communities.

The inhabitants of the Horn of Africa region now studied primarily depend on man-made water sources like boreholes and temporary structures for rainwater harvesting such as underground reservoirs and earthen dams. However, during the missions of the present study it was observed that reservoirs also have negative environmental and social impacts. Reservoirs are owned by private households and are scattered across the grazing lands and cause desertification in their vicinity because of the large herds of animals gathering around them.

In the present study, it was observed that reservoir owners commonly fence an area of about 1 ha around their reservoir as water harvesting area using dead fences which eventually result deforestation. In addition, they use tree branches and grasses, e.g. *Andropogon kelleri* Hack. (*Duur* in Somali), used to cover the reservoirs in order to reduce evaporation, which further cause fodder shortage and soil erosion. In response to land degradation, local communities have imposed restrictions on felling of *Acacia tortilis* and *Acacia busei* trees. However, the illegal felling of these species continues because of weak law enforcement.

Managed regeneration of trees on farms for agroforestry purposes is recognized as an important intervention option on drylands. There is now an increasing willingness in the Horn of Africa region to adopt such techniques, as documented in Study I and earlier confirmed, for the case of Sudan, by Glover and Elsiddig (2012) and Fahmi (2017). Results from the successful application of the Farmer Managed Natural Regeneration (FMNR) approach that has especially been developed and adopted in western Sahel (cf. Rinaudo et al. 2019) now encourages further attempts for similar action also in the Horn of Africa region.

### **5.3. The significance role of NWFPs in rural livelihood security and climate change adaptation**

Most of the population in the Horn of Africa lives in rural areas and rely on subsistence crop and extensive livestock production as principal means of living (Chidumayo and Gumbo 2013). Non-wood forest products are another livelihood asset that contributes to rural livelihoods and alleviating rural poverty. The rural communities living in the drylands of the Horn of the Africa are highly dependent on products obtained from the natural vegetation mainly through harvesting of NWFPs (Studies I, II and IV) and on extensive livestock farming based on free ranging system (Knips 2004).

Our research indicated that the local communities have good knowledge of their resources because of intergenerational knowledge transfer. *In Somalia and north-eastern Kenya, the pastoral communities have developed a number of adaptation mechanisms to cope with the climate variability.* Harvesting and use of NWFPs is one of the most important adaptation strategies. NWFPs are therefore viewed as one of the major participatory survival options for pastoral communities in the Horn of Africa.

Even though the exact economic implications are not documented in detail, households obtain from forests and trees a large variety of goods, including products for household consumption and for sale, or for manufacturing at the household or village level (cf. Table 7 and Table 8). The contribution of trees and shrubs to household security is not confined only to household consumption/sale of NWFPs as a food, fodder, medicine, aromatic resins, gums and honey; also wood products harvested from the forest contribute to income generation/home consumption through sale of fuelwood and construction poles.

The study also found that *households use the safety-net function of NWFPs in response to food crises* (Study IV). This is consistent with the concluding statement in a report by Diouf and Sheeran (2010) which recognises that “dryland forests of sub-Saharan Africa play a significant role in providing essential ecosystem goods and services that are essential to rural livelihoods and ecosystem sustainability”. Atmadja et al. (2019) also confirmed that dryland resources are important sources of income for rural households living in drylands. Therefore, management and development of dryland resources are viewed as major participatory survival options for rural communities under the changing scenarios for forest resources in the region now studied. Globally, the World Bank (2003) has estimated that approximately 20% of the world’s population depend on drylands for their essential forest product needs.

#### **5.4. Coping strategies and adoption of agroforestry system to address food insecurity**

Food insecurity is a major concern in the Horn of Africa. To cope with adjustment to the scarcity of food availability, the rural households in the region adapt “*self-squeeze*” by developing different internal strategies that allow them to survive (Ghimire 1994).

The study identified five major coping strategies in response to famine and food deficiency, i.e. *harvesting of non-wood forest products (NWFPs), appealing for humanitarian food assistance, sales of assets, remittances, and migration* (cf. Table 6). Of course, some of the strategies are for a short-time survival option and do not improve the long-term welfare of people.

The socio-economic analysis of the present study shows that rural households depend heavily on NWFPs, i.e. food, fodder and medicines, as well as on wood-based energy and construction materials obtained from dryland forests. The study is in line with the findings of Leakey et al. (2012), who also stated that rural communities in the drylands of sub-Saharan Africa benefit greatly from the local tree resources. Several indigenous multi-purpose trees and shrubs were now identified in the study area that the local people heavily rely on.

Studies by Feyssa et al. (2012) and Pandey et al. (2016) also indicated that most of the rural communities in the developing world at least to some extent depend on NWFPs for meeting

their subsistence needs. Another study by Abdulla (2013) in Ethiopia also found that 65% of households who harvest NWFPs for dietary supplements were more food-secured compared to households that do not utilize NWFPs for food.

Specifically, the present study identified twenty useful woody species that have potential value for domestication; they are already used for broadening the range of sources for food and for economic diversification during famine or economic hardship. They include, for instance, *Cordeauxia edulis*, *Dobera glabra*, *Ziziphus mauritiana* and *Berchemia discolor* (cf. Table 7 and Table 8). *Farmers' preferences for species were now based on the availability of the particular tree products during periods of famine or severe droughts, as well as on their nutritional value, preservability and income generation potential.* Similar studies by other researchers have confirmed this observation and further clarified the role of indigenous fruits for filling the seasonal and nutritional gaps in food availability (cf. McMullin et al. 2019).

Hence, coping with the increasing food insecurity and the problematic rural livelihood conditions in the Horn of Africa requires new national and international efforts to promote sustainable utilisation and management of the local resources (El-Lakany 2004). Domestication of wild multi-purpose trees and shrubs, especially those used as food sources, through use in agroforestry systems can substantially help in building livelihood resilience and improving food security (Barrett and Swallow 2006). Much international work on the domestication of local edible woody plants is already ongoing in the Horn of Africa region, especially through an ICRAF-coordinated programme for domestication of “orphan crops”, i.e. food-providing woody species that earlier have mainly been harvested in the wild (cf. Dawson et al. 2018).

In many cases, the populations of the presently used multipurpose woody plants in the Horn of Africa region are endangered, which makes their domestication as well as germplasm management and conservation all the more urgent. Several local fruit tree species have already been improved through repeated selection, and their yields, in terms of fruit size and fruit yield per tree, have been increased. Some early introductions of exotic fruit trees to the present study region (e.g. mangoes and *Ziziphus mauritiana*) have resulted in development of numerous land races and local varieties in the Horn of Africa region. Local fruits seem to be especially important for securing a year-round supply of nutrient-rich food (McMullin et al. 2019). Unfortunately, the dryland areas in the region have not yet benefited much from this development.

For gene conservation, in the case of endangered or threatened woody plant species, two approaches are commonly applied, *in situ* gene conservation, where the population is protected and managed within the natural range of that species, and *ex situ* conservation, which refers to maintaining the genetic diversity by establishing and managing artificially established populations outside the natural range of the species. A third approach, *circa situm* gene conservation is not as commonly practiced, but it refers to maintaining the genetic diversity by cultivating and managing the woody plant species in question within its natural range (Boshier et al. 2004). In (humid tropical) West Africa, this approach has been shown to be very successful (even if the term *circa situm* conservation was not explicitly used), in incorporation of Iroko (*Milicia excelsa*) into smallholder agroforestry systems in Ghana (Appiah 2003).

When developing aromatic resin management in the Horn of Africa in the future, the benefits offered by *circa situm* gene conservation, especially in terms of maintaining the germplasm diversity of trees and shrubs by local communities should be seriously considered. This has been earlier suggested for *Boswellia* and *Commiphora* species (Luukkanen et al. 2017), but the lack of distinct land and forest tenure regimes on the drylands of this region obviously hinders this development.

However, despite the obvious benefits of agroforestry systems, studies show that adoption of agroforestry among poor households may also become less successful for different reasons (Palte 1989; Mulongoy and Akobundu 1992; Glover et al. 2013; Gebru et al. 2019). Therefore, to promote the socio-economically potential trees and shrubs and enhance adoption of agroforestry technology among poor farmers, earlier studies have suggested that the socio-economic challenges, such as “*household security, access to capital and incentives, labour, gender, land tenure and knowledge for management*” (Glover et al. 2013:180), which presently often hinder the participation of rural households in agroforestry practices, be tackled (cf. Gebru et al. 2019).

In response to frequent droughts and resource degradation that threaten the traditional rural livelihood systems, the present study also found that *households may abandon their settlements* in agricultural frontiers in order to cope with the changing environmental circumstances. For survival option in the harsh dryland environment and following its seasonal dynamics *pastoralists migrate with their livestock, sometimes across international borders*; such a pattern has also been found in previous studies (IUCN 2011). However, strong family links and community networks (cf. World Bank 2006) were also observed that help community adaptation to climate and environmental changes.



## 6. Conclusions and Recommendations

The present study examined the goods and services derived from *Acacia-Commiphora* woodlands by local communities engaged in livestock husbandry and farming in the Horn of Africa, particularly north-eastern Kenya and central Somalia. The focus was on coping strategies during periods of unfavourable weather conditions or conflicts. This particular region is well endowed with natural capital, especially livestock, land, and high-value trees, notably *Acacia*, *Boswellia* and *Commiphora* species.

There are various products available from tree-based systems for household consumption, and among the most valuable commercial products are the aromatic resins, frankincense and myrrh. In contrast to previous studies on gum arabic, the resins market was found to be still underdeveloped and constrained by technical, policy and socioeconomic factors. Most of the forest products in the region are derived, traded and consumed outside the formal cash economy or for other reasons not adequately captured in national economic statistics.

The situation demands empowering the local communities through formation of community based associations to coordinate the trade, especially in the potentially high-valued resins, as well as the public awareness of the importance of quality, standards and product development (packing and marketing). Uncertainties in the production of aromatic resins, as in other forest-based commodities owing to environmental changes and human-induced events such as conflicts, affect the livelihoods of many poor rural households.

Increasing pressure on the natural vegetation caused by overgrazing, drought and deforestation has resulted in large-scale degradation of its environmental and social foundation, calling for seeking new approaches in land-use systems to meet the basic needs of people. A mobile lifestyle, the resilience of local communities and strong social networks were all found as part of an indigenous knowledge system that helps a community cope with and adapt to the environment.

Adoption of more diversified agroforestry practices and especially integration of new multipurpose trees through domestication and management of lesser-known woody plant species are ways for achieving the above objectives. Agroforestry has the prospects of enhancing food security, increasing fodder and fuelwood production and protecting the ecosystem. The most preferred trees in the study area were *Acacia*, *Commiphora* and *Boswellia* species. Therefore, integrating these particular local tree species into well-managed productive and resilient agroforestry systems with livestock and/or food crops has a potential not only for fulfilling a subsistence requirement but also for increasing land productivity and improving the economic conditions of local communities.

Participation of local communities and their organisations, as well as that of representatives of local and central government, is a necessity in planning and implementing new, concerted agroforestry actions. Economic as well as social considerations are needed for the adoption of new agroforestry technologies, in addition to the conditions set by the environment. Traditional practices and indigenous knowledge must be thoroughly examined before any new policy or management action is initiated.

By acting through a joint work programme, local people can leverage their own efforts and organise and amplify their actions according to their respective comparative advantages in resource management.

On the basis of the present study, the following recommendations can be given:

1. New sustainable, managed silvo-pastoral and agro-silvo-pastoral agroforestry systems based on indigenous multipurpose trees and shrubs should be developed in north-eastern Kenya and Somalia for improved land-use practices and for reversing the excessive exploitation of tree-based natural resources.
2. Care should be taken for sustainable utilisation of the woody plant resources and priority should be given to assisted natural regeneration of trees and shrubs instead of tree planting.
3. Participation of local people in forest management should be made a leading guideline.
4. User rights to tree-based resources should be guaranteed for the local people with appropriate policy and legislative actions.
5. Improvement of already cultivated woody plants and domestication of existing lesser-known and poorly commercialised woody species for improved varieties should be supported with the available research and development tools; this should be combined with ethnobotanical research for urgently documenting the existing traditional knowledge on various uses of woody plant species among different communities.
6. New markets and value added for tree-based products should be opened through improvement of harvesting methods, efficient processing and shortened marketing chains, and by exploring new markets through market research and development initiatives.
7. Microcredit systems and other economic incentives should be created, especially for improving the trade in aromatic resins for the benefit of the local communities and to enhance employment creation.
8. Attention should be given to creation of public awareness of the value and importance of *Acacia-Commiphora* woodlands both in environmental conservation and as a source of livelihoods.
9. Promotion of new, more sustainable aromatic resin harvesting techniques should be explored and introduced.
10. Local human resource capacities should be improved and the involvement of local communities in the development of new policy guidelines and management interventions for dryland resource management and conservation encouraged.
11. The role of drylands in watersheds for maintaining the supply of water for domestic and agricultural uses should be properly recognised.

## 7. References

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