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**Spatial and Temporal Analysis of
Prosopis juliflora (Swartz) DC Invasion in Amibara
woreda of the Afar NRS**

By

Getu Engda

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Dedicated to the Memory of My Beloved: Father

Who was a Source of Inspiration Throughout in my Academic career!

I really miss you and I wish you were still here to help me!

Declaration

I here by declare that the thesis entitled “Spatial and Temporal Analysis of *Prosopis juliflora* (Swartz) DC Invasion in Amibara woreda of the Afar NRS” has been carried out by me under the supervision of Dr. Mekuria Argaw and Dr. K.V. Suryabhagavan at the Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2008 as part of a Master of Sciences Programme in Remote Sensing and GIS (Earth Sciences). I further declare that this thesis is my original work and has not been submitted to any other University or Institution for the award of any degree or diploma and that all sources of material used for the thesis have been dully acknowledged.

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List of Acronyms

ANRS	Afar National Regional State
ASTER	Advanced Space borne Thermal Emission and Reflection
AVHRR	Advanced Very High Resolution Radiometer
CABI	CAB International
CSA	Central Statistics Authority of Ethiopia
EIAR	Ethiopian Institute for Agricultural Research
ENVI	Environment for Visualizing Image
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPE	Environmental Policy of Ethiopia
ERDAS	Earth Resource Data Analysis System
ETB	Ethiopian Birr
ETM +	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organisation of the United Nations
FARM Africa	Food and Agricultural Research Management-Africa, UK based International
GCP	Ground Control Point
GEF	Global Environment Facility
GIS	Geographic Information System
GLCF	Global Land Cover Facility
GPS	Global Positioning System
HDF file	hierarchical data format file
IAS	Invasive Alien Species
ILRI	International Livestock Research Institute
IUCN	International Union for Conservation of Nature and Natural Resources
LU/LC	Land-use/ Land cover
Mid-IR	Mid Infrared
MOA	Ministry of Agriculture
MSS	Multispectral Scanner
NBASP	National Biodiversity Strategy and Action Plan
NDVI	Normalized Difference of Vegetation Index
NGO	Non-governmental organization
NIR	Near Infra Red
RBIPMA	Removing Barriers to Invasive Plant Management in Africa
ROI	Region of Interest
SPOT	System Pour d'Observation de la Terre
TM	Thematic Mapper
UNDP	United Nation Development Program
UNEP	United Nation Environment Program
USGS	United States Geological Survey
UTM	Universal Transfer Mercator
VNIR	Visible Near Infrared
WGS	World Geodetic System

Abstract

Despite the harmful effects of invasive species, the mechanisms behind the invasion and dynamics of invasive alien species are poorly understood in Ethiopia. Geographical Information Systems are emerging as valuable and cost-effective tools for understanding invasion dynamics and prioritizing management efforts these days. Moreover, remote sensing is the only practical method to acquire spatially and temporal detailed data over a large area. Because images can be acquired multiple times and provides a way to directly assess changes over time. This study was done in Amibara woreda in the Afar National Regional State. The objectives were: to evaluate the land-use/land cover change in the last two decades, examine the spatial distribution of *P. juliflora* in the study area, assess the temporal dynamics of *P. juliflora* invasion and to determine the rate of invasion, and identify the land-use/land cover types which are affected by *P. juliflora* and explore the possible causes. Post classification comparison change detection scheme was employed to discriminate spatial and temporal invasion of *P. juliflora* between 1986 and 2007. The invaded land which was 769 ha in 1986 changed to 3,849 ha by 2001 and highly increased to 11,579 ha by 2007 year. During this period, almost all the land-use/land cover has been invaded by *P. juliflora*. Shrub land was the most affected land-use/land cover having 2,742 ha area invaded by *P. juliflora*. Between 2001-2007, the overall change of all other land use/land cover to *P. juliflora* invaded land have showed at least two fold increase than during 1986-2001 period except the cultivated land that was reduced by half in percent invasion. Hence, the rate of change from other land-use/land cover to invaded land has shown an increasing pattern in 0.06% area per year in 1986-2001 to 0.37% per year of the study area in 2001-2007. If this situation continues with out proper management it will not take longer to see these areas reaching at climax invasion, where it reaches impossible to think of management. The consequence will not only be of the Woreda level or Regional level but also at the National level. Hence, a GIS Model and Remote Sensing application in order to show further risk zone and its invasion driving forces should be carried out in the area. This helps to plan an immediate control and management options and strong policy to organize different stakeholders starting from lower level to regional level on the invasive species *P. juliflora*.

Key words: ASTER, Landsat, invasive species, invaded land, livelihood, land-use/land cover

1: INTRODUCTION

1.1 Background

The earth has been in a state of continuous change since a long time ago. The changes observed could be categorized into modification and total conversion of the environment. It has been proved that the transformation is mainly from forest land to cultivated land, and from grazing land to cultivated and other land use types.

Biological invasions and the presence of exotic species are a persistent and costly environmental problem that has been the focus of intense management activities over past few decades (Vitousek et al., 1996). Alien species invasion is a profuse problem in some of the most biologically sensitive zones of the world. The reason for such plants being invading and establishing themselves in regions that were once abodes of indigenous and endemic species can be attributed to various reasons such as continuing anthropogenic related disturbances, such as land conversion, grazing, and habitat fragmentation, combined with international trade and climate change, indicate that these trends are likely to continue (Zedler and Kercher, 2004).

Invasion of native plant communities by other unwanted species is one cause of modification of the environment. Now a day, alien species (also called non-indigenous species) invasion is one of the challenges to most of the rural communities of Ethiopia. The majority of the people depend on land and land resources, rural poverty has become common and natural resources are alarmingly declined and degraded from time to time. This problem is also aggravated by invasive species, through the invasion of agricultural, grazing and protected lands in Afar Nation Regional State.

A naturally aggressive plant may be especially invasive when it is introduced to a new habitat. These species can have adverse economic impacts by reducing crop yields or the quality of grazing lands and can have negative ecological impacts including reducing biodiversity, endangering rare communities and altering processes such as nutrient cycling (Higgins et al., 1999). An invasive plant is one which establishes over large areas and persists. Invasiveness is characterized by robust vegetative growth, high reproductive rate, abundant seed production, high seed germination rate, and longevity. Although the exact date and source of *P. juliflora* introduction to Ethiopia had not been documented, it was believed to be introduced from India in the 1970s by the Ministry of Agriculture for conservation purposes. Since then, the tree has rapidly invaded vast areas of agro-and silvo-pastoral lands in Afar National Regional State and eastern Harargae (Shiferaw et al., 2004).

On the contrary, the local people suggested it was introduced deliberately but unauthorized by a British man called William Ulcro who was in charge of the Middle Awash Irrigation Project (Kassahun et al., 2004). It was supposed to have been introduced in 1972. This time described that *P. juliflora* seeds were planted with the consent of the local elderly who were told about its benefit.

The invasion is threatening livelihood of pastoralists and agro-pastoralists due to loss of pasture and indigenous trees and destruction of croplands (Shiferaw et al., 2004). The government of Ethiopia identified *P. juliflora* as one of the three major invasive plant species in the country and declared as a noxious weed for eradication (Mwangi and Swallow, 2005). FARM Africa in collaboration with the local government in ANRS, Ethiopia assisted local communities to pilot a *P. juliflora* control initiative through charcoal production and marketing. This initiative was started in 2004 with the objective of clearing *P. juliflora* from pasture and croplands, and to create income generation opportunities for local people affected by the invasion. Four communities were organized into cooperatives for the intervention and advised to cut the tree at least 10cm below the ground to prevent coppicing (Shiferaw et al., 2004) and there by to contribute for the control of the spread, while using the wood for charcoal and fuel production. The cooperatives were granted licence by the government to produce and market charcoal because it is a banned activity in the country.

EIAR, Ethiopia and CABI through the UNEP/GEF Project ‘Removing Barriers to Invasive Plant Management in Africa with the local initiatives and NGOs (FARM Africa and others), has been implementing the activities since 2006 assisting the local communities, to pilot a *P. juliflora* control initiative through training, awareness creation, organizing from Kebeles to regional level for combating this invasive species using the possible means.

The Environmental Policy of Ethiopia (EPE) and the Biodiversity Strategy and Action Plan (NBSAP) have identified invasive species as posing a major threat to biodiversity and economic well being of the population. However, only little attempt to assess the status of Invasive Alien Species (IAS) has been made so far and hence those species known to be threats are already widespread.

In Ethiopia, the aggressive invasion by *P. juliflora*, which is found dominantly on the arid part and pastoral area of Ethiopia like Afar and Dire Dawa regions is displacing native tree, forming impermeable thickets and reducing grazing potential. Agricultural lands and protected areas such as the Awash National Park are threatened (Mwangi and Swallow, 2005). *P. juliflora* is highly competing for space with grazing, agricultural, forest and protected lands. In Awash basin, it is aggressively invading pastoral areas especially in the middle and upper Awash valley. Even if the farmers are benefiting from selling charcoal, being wind break and reducing salinity of the area that comes from the species, because of its many problems on pastoral farming system, state farms, farmers, development workers, researchers, ecologists and politicians are at the biggest

challenge on how to manage and eradicate this species from the area. The aim of this study is to show the spatial and temporal expansion of this species so that the stakeholders will take necessary measure and a strong policy from the government in order to get rid of the invasion risk and challenges on the livelihood and biodiversity resources.

1.2 Statement of the Problem

Prosopis juliflora has an aggressive invasive character invading pasture land, irrigated cultivated land and irrigation canals causing an irreversible displacement of natural pasture grasses as well as native tree species. The invasiveness of the species seems to have been further aggravated by overgrazing /browsing of rangelands and deforestation of native tree species.

Invasion of rangelands caused shortage of grazing land for livestock, which resulted in drastic reduction of livestock number as well as product. Thorns damage eyes and hooves of camels, donkeys, and cattle then by poisoning eventually lead to death. *P. juliflora* is invading potential croplands forcing local farmers with less capital and machinery to abandon their farmland and settlement. In general, this is a matter of serious concern for the life of the local people as pastoralists depending on livestock for their livelihood (Senayit et al., 2004).

The biggest challenge, however, comes from the invasion of the main and secondary irrigation canals by its dense stand. This limits the visibility and accessibility to the irrigation canals for supervision and maintenance resulting in flood hazard and wastage of irrigation water through seepage (Senayit et al., 2004).

In spite of the harmful effects of invasive species, the mechanisms behind invasion dynamics are poorly understood in Ethiopia. One preliminary work has already been made by Shetie, G. (2007), M.Sc Thesis. Most studies tended to focus on the Socio economic, biological and ecological distribution and identification of the target invasive species at a smaller area. In this situation, the major challenge for local government and stakeholders is how to effectively manage non-native plants to preserve native biodiversity. Therefore, being able to delineate the spatial extent and to ascertain the severity or intensity of the invasion is essential for resource management (Byers et al., 2002) and biodiversity conservation.

To understand how land-use/land cover change affect and interact with global system, information is needed on what changes occur, where and when they occur, the rate at which they occur, and the social and physical forces that drive those changes (Lambin, 1994). Hence, this research is aimed to produce an important map output that shows the spatial and temporal invasion of *P. juliflora* species by developing distribution and land cover dynamics of the area. In this regard remote sensing and GIS has an important contribution to document the actual changes in land-use/land cover of the study site in Afar NRS at Amibara Woreda.

1.3 Research Objective(s)

General Objective

The overall purpose of the study is to illustrate the degree of invasion of *P. juliflora* by assessing the distribution and expansion of the species over the study area during the past over 20 years. The assessment is expected to provide the dynamics of the land-use/land cover due to *P. juliflora* invasion and forward future research work for its effective control.

Specific Objectives:

- ✚ To evaluate the land-use/land cover change in the study area Amibara Woreda during the last two decades,
- ✚ To examine the spatial distribution of *P. juliflora* in the study area,
- ✚ To assess the temporal dynamics of *P. juliflora* invasion and to determine its rate of invasion,
- ✚ To identify the land-use/land cover types which are affected by *P. juliflora*.

1.4 Research Questions

- ✚ What is the degree of invasion of *P. juliflora* in the different and land use/land cover of the study area.
- ✚ What is the dynamics of *P. juliflora* invasion over times?
- ✚ Which type of land cover is more susceptible to *P. juliflora* invasion?
- ✚ What factors favor the invasion of *P. juliflora* invasion?

2: LITRATURE REVIEW

2.1 General Description of *Prosopis juliflora*

There is a growing concern about invasive alien trees, shrubs and grasses, and the threats they pose to livelihoods, biodiversity and water in Africa's sun-scorched, low rainfall grasslands. Kenya, Sudan and Ethiopia are increasingly worried about *P. juliflora*, a thorny, evergreen, rapidly-spreading shrub. But *P. juliflora* is a global phenomenon found beyond Africa in the Middle East, Latin America, West Indies and Australia.

P. juliflora (Swarz) DC, a native of North and Central America (Hailu et al., 2004), is a perennial thorny deciduous shrub or a small tree weed belonging to the family Leguminose. The species has large crowned evergreen tree with a deep taproot and a well-developed lateral root system; height ranges between 1-18 meters (Fig. 1), depending on the type of soil in arid and semi arid conditions.



Figure 1: *P. juliflora* invading the cultivated land, more than 12m height at Ambash

(Photo by Author)

The genus *Prosopis* comprises 44 species (Burkart, 1976) of which only one *P. juliflora* is introduced to Ethiopia. In recent decades this exotic species has attracted much attention. They are extensively planted as fast-growing and drought tolerant fuel and fodder trees, but in many countries they have also spread out of control as invasive weeds. *P. juliflora* has been introduced to and become naturalized in the tropics where it is cultivated for shade, timber, forage, food and medicine (Kassahun et al., 2004). However, contrary to the purpose of its introduction in different countries, it has escaped cultivation and proved to be a severe invader of farmlands, irrigation schemes and rangelands (Mohamed, 1997). This has been the case in Amibara Woreda during the past few decades.

2.2 Distribution, Merit and Demerit of *P. juliflora*

2.2.1 Distribution of *P. juliflora* in Ethiopia

Amibara Woreda of Afar NRS is thought to be the assumed starting point for the spread of *P. juliflora* in Ethiopia. The area represents degraded semi-arid ecosystem in the country. Contrary to the purposes of its introduction and *P. juliflora* is rapidly invading the traditional agro- and silvo-pastoral land of the Afar and Isa ethnic groups in the Afar National Regional State and has encroached hundreds of kilometres away from the initial plantation area (Senayit et al., 2004; Taye et al., 2004).

It was also pointed out that the species has spread rapidly in eastern Ethiopia, from the Middle Awash Valley in to the Upper Awash Valley and Eastern Hararghe and some localities of Raya Azebo plains of South Tigray. It is now a common sighting from Awash Arba all the way to Dire Dawa and Harar.

The naturalized extent of invasion is unknown at this stage, but (Rezene et al., 2005) has estimated to be at the order of 4000 ha, especially at Afar NRS. Invasion of *P. juliflora* is also reported in the town of Arba Minch and neighboring localities in the Southern Region of the country. However, no systematic survey and monitoring have been undertaken to determine the distribution, area coverage and density of *P. juliflora* in Ethiopia.

2.2.2 Demerit of *P. juliflora*

The species introduced to Ethiopia is known for its numerous harmful effects on the livelihood of the local people. Unfortunately, the benefits of *P. juliflora* have been dramatically outweighed by the overall loss of natural pasture (Fig. 2 to 4), displacing of native trees, reduction in stocking rate, toxicity to livestock, formation of impenetrable thickets and increased incidence of

crop pests. According to Shiferaw (2002), *P. juliflora* has been encroaching on road sides, where it is seen as a hazard due to reduced visibility and enters the cotton fields, where it has to be removed prior to planting the crop at Amibara Woreda.

Land clearance has become expensive to farmers in invaded areas in Kenya. It is only better-off people who can afford payment for land clearances, are engaged in cultivation (Mwangi and Swallow, 2005). Some of the households were also displaced due to the invasion. Incidences of malaria and challenge from predators are also caused by *P. juliflora*. It is also invading the bush land and obviously replacing the *Acacia* species. Several *Acacia nilotica* growing in the dense thickets of *P. juliflora* were found dead, presumably due to competition for water with the species.

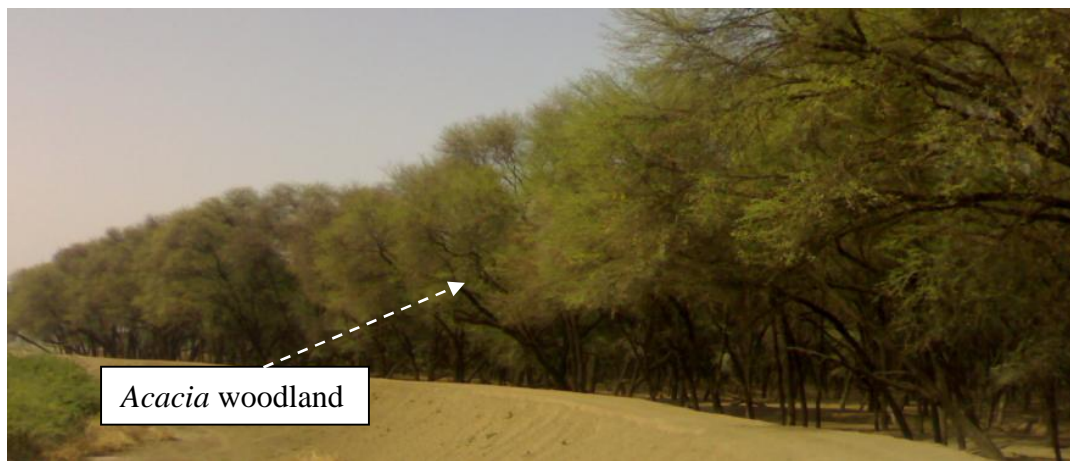


Figure 2: *Acacia* woodland found along the Awash River, Adobtelie ANRS (Photo by Author)



Figure 3: *Acacia* species start invaded by *P. juliflora*, Serkamo ANRS (Photo by Author)



Figure 4: *P. juliflora* invading the range land, Allidegie Plain (Photo by Author)

Another reported impact on the livelihood of the Afar people in that region is a negative effect on their livestock. Especially in dry years, cattle feed on the pods of *P. juliflora*. An exclusive diet of these pods poisons the cattle and many have died. The hard seed of this species inter between the gum and the teeth, leads to inflammation and eventual disfiguration of the jaw (Mwangi and Swallow, 2005; Geesing et al., 2004). As *P. juliflora* leaves contain allelochemicals including tannin, it is not palatable to animals and has allelopathic effect to crops, weeds and other trees (Pasicznic *et al.*, 2001).

According to the USFS technical assistance trip report cited by Dubale Admasu (2007), the major negative effects of *P. juliflora* in ANRS are the loss of pasture and the indigenous trees (Table 1). Similarly, Worku et al., 2004 showed that from *P. juliflora* invaded land-use/land covers; most of the native plant species were displaced or with only few in number. Those present were diseased and stunted in growth.

Table 1: Native Species threatened from *Prosopis* invasion in Gewane & Amibara Woreda

Scientific Name	Vernacular Name	Remark
<i>Acacia tortilis</i>	Eebto	Multi purpose tree
<i>Acacia senegal</i>	Adebo	Multi purpose tree
<i>Acacia nilotica</i>	Keselto	Multi purpose tree
<i>Dobera gelabera</i>	Gersaito	Multi purpose tree
<i>Chrysopogon plumulosus</i>	Durfu	Grass
<i>Cenchrus ciliaris</i>	Srdoitas	Grass
<i>Seataria acromelaena</i>	Mussa	Grass

(Source: Dubale Admasu, 2007)

2.2.3 Merit of *P. juliflora*

P. juliflora provide many of the needs of populations living in dry lands of the world, and have the potential to provide much more if knowledge on their utilization is expanded. However, their rapid growth and resilience associated with strong competitiveness and invasion of other land-use/land cover systems is causing serious dilemma. Kassahun et al. (2004) reviewed worldwide advantage of *P. juliflora*. They reported that wood from this invasive weed is an excellent as firewood and charcoal; straight branches are used for fence posts and poles in construction of shelters and homes; sawn timber has a pleasant color and grain, and shrinks little on drying. Honey produced from the trees is of the highest quality. The exudates gum produced from wounds in the bark is comparable to commercial gum arabic (from *Acacia senegal*) and can be found in large quantities.

Leaves are occasionally gathered and used as a mulch or compost on agricultural fields, with some noted fungicidal and insecticidal qualities. Moreover the bark is a source of tannins, dyes and fibers, and various plant parts are used in the preparation of medicines, mostly for eye, skin and stomach problems (Fig. 5). Soil reclamation studies indicated that soil alkalinity up to 10.4 pH can be lowered by *Prosopis* to normal level in 8 years period (Singh and Singh, 1993). It served as a wind break by preventing movement of sand-drift and typhoon. There is an indication of reducing air temperature and creating a mild weather.

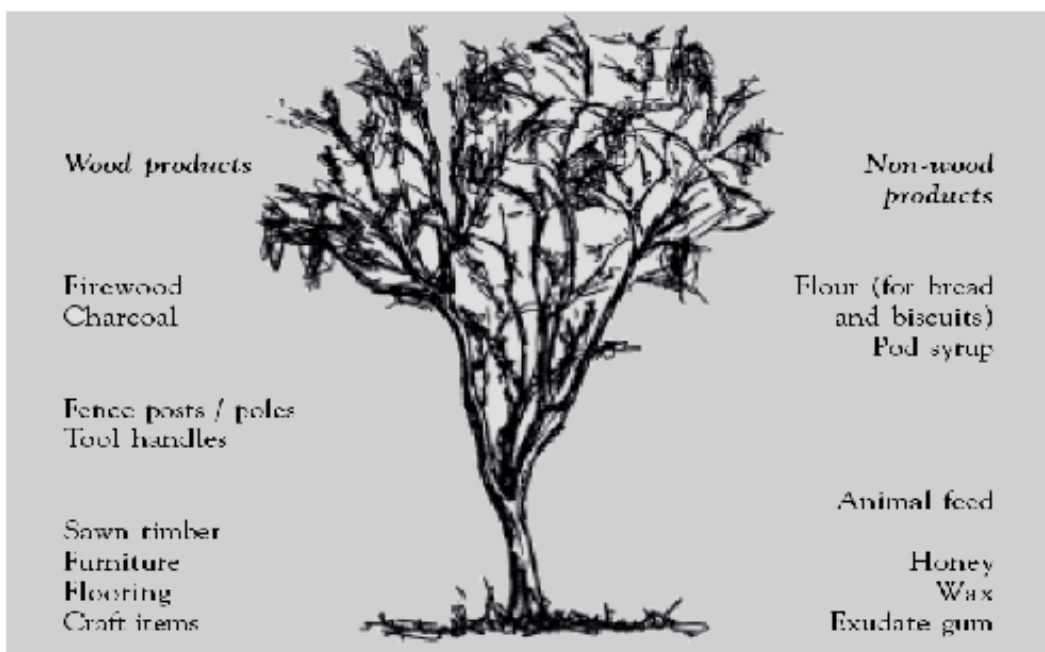


Figure 5: *Prosopis* Products commercialized in its native ranges and occasionally where introduced

(Sources: Pasiiecznik, et al., 2004)

However, the major uses of *Prosopis*, as stated by Senayit et al. (2004) in the ANRS are as fuel wood, erosion control and reducing salinity of the soil around. It is considered as one of drought resistant tree, which can serve as a supplementary feed during prolonged drought or dry seasons with its risk full for the livestock health.

2.3 Biology and Ecology of *P. juliflora*

2.3.1 Biology and Physiology

2.3.1.1 Chromosome Number

The chromosome numbers of most recognized species of *Prosopis* have been ascertained and all taxa are diploid with a haploid number of $n=14$ ($2n=28$), with the exception of *P. juliflora* which also has tetraploid forms ($2n=56$) (Hunziker et al., 1975). The formation of polyploidy forms tends to occur in rapidly expanding or hybridizing populations, both of which are observed in *P. juliflora*. Stabilization of tetraploid forms has been suggested as an evolutionary process increasing adaptability to new or changing environments.

2.3.1.2 Seed Germination

A mature *P. juliflora* tree can produce 40 kg of pods per year, from which 60,000 seeds can be obtained as stated by Pasiiecznik et al. (2004). The species is equipped with a number of biological characteristics that foster its rapid invasion of new areas (Hailu et al., 2004).

2.3.1.3 Leaf Physiology

Prosopis leaves have many adaptations to drought, such as the bipinnate, compound leaves typical of the Mimosoideae. Possession of larger numbers of smaller leaflets is considered to be a response to high temperatures, being a means of dissipating increased heat loads. Sen and Mehta (1998) found seasonal variations in *P. juliflora* leaf concentrations of proline, sugar and protein, assumed to be a response to drought which enables to survive better than any species in arid and semi arid conditions.

2.3.1.4 Phenological Variation

Prosopis species exhibit high levels of variability in morphological characters. The reproductive self incompatibility and obligate out-crossing observed in the *P. juliflora* being a combination of both clinal (continuous) variation in response to broad climatic factors and ecotypic (discontinuous) variation in response to disjunctive environmental factors (Burley et al., 1986),

both of which are seen in *Prosopis*. Such differences in continuous climatic clines such as temperature, rainfall and day length, and discrete differences in site such as soil type, salinity or depth combine to create a variety of phenological responses that also enable to outshine in desert ecosystem.

2.3.1.5 Propagation Systems

Prosopis species are generally assumed to be self incompatible (Felker and Clark, 1981). Self-incompatibility has probably been positively selected for in desert environments, with obligate out-crossing leading to high variability in progeny produced, both within and between natural populations. The maintenance of high genetic variability can be seen as a mechanism for survival in dry zones with a high variability in rainfall, temperature and soil types, and for continued evolutionary adaptations to a changing environment.

2.3.2 Ecology

The *P. juliflora* has broad ecological amplitude adapted to a very wide range of soils and site types from sand dunes to cracking clays (Pasiiecznik et al., 2001). It is noted that there is hardly any soil, if it is not habitually damp, in which the species cannot grow; no hill too rocky or broken, no flat too sandy or saline, no dune too shifting to entirely exclude it.

P. juliflora grows in arid to semi-arid environments including deserts, open woodlands, grasslands, shrublands and floodplains. They tend to establish most successfully on clay and alluvial soils that have good moisture retention. Soil moisture is more important in determining the species distribution than soil type. *Prosopis* often colonizes disturbed, eroded, over-grazed or drought-affected lands, associated with unsustainable agronomic practices (e.g. cattle ranching). *Prosopis* trees have many competitive ecological advantages and may form dense, impenetrable thickets. However, the seedlings are sensitive, rarely establishing under mature trees or in tall grass which is the case of Amibara woreda (Pasiiecznik, 1999).

2.4 Climate Change and the Spread of Invasive Species

Climate change is a natural process associated with the evolution of our planet. Historically, climate change patterns have lasted for thousands and even millions of years. The alteration in natural environment, in turn, provides opportunities for other negative phenomena to occur. One of them is the invasion of alien species (intentionally or unintentionally introduced) when the ecosystems are disturbed. The invasion of alien species brings about a number of consequences

such as competition with local species, up setting the ecological balance, negatively affecting agriculture, fishery practices, and harming social-economic development.

Invasive species, climate change and habitat loss, are three of the main threats to biodiversity. One of the impacts of climate change is likely to be an increase in invasive species problems. When native species are killed or stressed by climate change or related occurrences, they may be replaced by invasive species (Cox 2004). Groves et al., (2003) has remarked that native plants in particular are susceptible to weed invasions because of the diversity of weed species and because weeds often travel more effectively than native plants across the landscape. Areas of native vegetation, such as national parks and reserves are also surrounded by introduced species that may migrate inwards. The traits of species that make them invasive will often help them succeed under climate change.

Dukes and Mooney (1999) find that climate change is expected to worsen the world's invasive species problems. Weeds and other pests often do better if there is disruption from fire, floods, logging, livestock grazing, or hydrological changes. Disturbance events create opportunities for invasive pests to take the place of natives. Climate change has the potential to operate like a disturbance event by stressing populations. Zaveleta and Royval (2002) explained: climate change-associated diebacks of perennial vegetation communities – forests, woodlands, and shrublands – and accompanying disruption of faunal communities may provide new and widespread opportunities for disturbance-loving exotic species to colonize and spread.

Weeds often grow on roadsides where vehicles disperse them, leading to conclude that roadside weeds should be some of the earliest species to shift their ranges as climates change (Dukes and Mooney, 1999). Since climatic zones are likely to shift faster than long-lived species can track through reproduction and dispersal, communities in disequilibrium may result, with conditions that indirectly favor weedy species, many of which are likely to be aliens as explained by Cox (2004).

Weed spread from farmland into remnant vegetation is already a serious problem, exacerbated by nutrient inputs and fire events. Australia has almost 3,000 weed species (Groves et al., 2003), representing all the functional types that constitute habitats (grasses and other ground covers shrubs, vines, trees, aquatic plants). By contrast, introduced vertebrates such as frogs, reptiles and birds will not replace native species on a large scale because the pool of introduced species is very small. But large scale invasions by weeds can, on their own, profoundly alter ecosystems because nearly all animals on land ultimately depend on plants as primary producers.

As invasive species and climate change are considered two of the three main threats to biodiversity, the two operating together could be expected to produce extreme outcomes. While there are some climate change impacts that remain partly speculative, the role of extreme events in driving biological invasions is well established. For example, the New South Wales

Department of Primary Industries has a fact sheet dedicated to Weed strategies following drought, fire and flood that draws upon lessons already learned (Trounce and Dellow 2007). Because of their greater competitiveness, weed species readily invade bare areas of ground which have been denuded of vegetation. Drought, fire and even floods can create these conditions as they devastate existing ground cover, thereby removing all competition for light, nutrients, moisture and space. The devastation allows quick weed establishment when more favourable conditions arrive.

The rift valley area of Amibara Woreda in Afar NRS experienced such devastating environmental events such as flood due to overflow of Awash River, degraded lands, drought seasons coupled with alien *P. juliflora* invasion that challenge the livelihood of local communities and biodiversity. Looking in to consequence of this coupled phenomenon by analyzing the spatial, temporal and dynamics of the invasive alien species *P. juliflora* is the aim of this study.

2.5 Remote Sensing and GIS Application

2.5.1 Remote Sensing Application for IAS Mapping

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand and Kiefer, 2000). Within the scope of this study, the focus of remote sensing is the measurement of emitted or reflected electromagnetic radiation, or spectral characteristics, from a target object by a multispectral satellite sensor. Remote sensing satellite images are immensely used in natural resources monitoring and management, study the time to time changes due to its repetitive coverage especially in IAS invasion estimation and prediction.

Although, at the very beginning, Remote Sensing Technology was only for military use, recently it has been in the use for civilian applications such as agriculture, archaeology, forestry, geography, geology, planning, and mapping, decision making and in resource and inventory analyses (Hellden, 1987). Furthermore, Larsson and Stromquist (1991) reported that remote sensing could be applied within the following fields: hydrology, land-use/land cover change detection, vegetation monitoring, soil erosion, land degradation and research in environmental monitoring.

A multispectral sensor acquires multiple images of the same target object at different wavelengths (bands). Each band measures unique spectral characteristics about the target. A

spectral band is a data set collected by the sensor with information from discrete portions of the electromagnetic spectrum that is ranging from cosmic waves to radio waves (Mather, 1987).

In relation to this, spectral reflectance characteristics of common earth surface features are located within the visible and near to mid-infrared range. The reflectance of different features on the earth surface varies with the wave length of the interacting radiation. The reflectance of vegetation, soil and water, which are the three major features on the earth surface, shows different spectral reflectance characteristics. The spectral reflectance curve of the vegetation (Fig. 6) is of immense use to study the IAS invasion and future prediction in the area. The greatest reflectance is seen in the near infrared band range. Hence, the most useful image composite for the study of actively growing vegetation would be an image composite having the near infrared band (Monmonier, 2002).

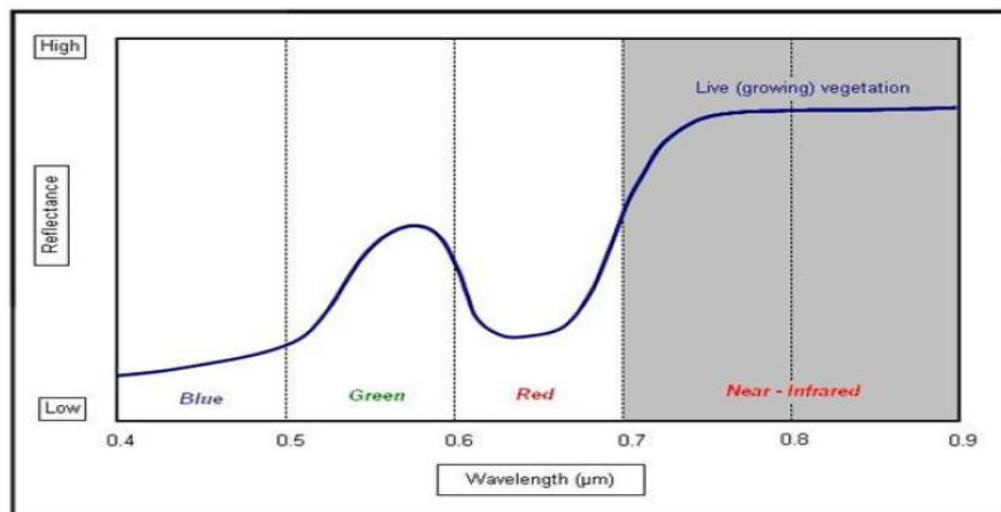


Figure 6: Actively growing vegetation curve

Source: Monmonier, 2002

The use of remote sensing techniques and, in particular, Landsat data, to map vegetation is well established (Everitt et al., 2001). Remote sensing techniques offer rapid turnaround and revisit capabilities, as well as being more cost effective than ground surveys. State-of-the-art remote sensing can potentially provide data at frequent intervals needed to quantify changes in vegetation cover.

Even though satellite imagery has been available for nearly 30 years, relatively few studies have reported its use for detecting noxious plants (Hunt et al., 2003). The relatively coarse spatial resolution of satellite sensor data, as compared to aerial photography and videography, has limited its usefulness for this application. Nonetheless, satellite sensors have shown potential for detecting relatively large stands of weeds. Richardson et al. (1981), at ARS Weslaco, conducted a pilot study to assess Landsat multispectral scanner satellite data for detecting silverleaf sunflower infestations on Texas rangelands. They reported that this annual weed could be

distinguished on Landsat imagery bands 4, 3, and 2, which agreed with an earlier study by Gausman et al. (1977). The geographic occurrence of silverleaf sunflower areas on a line-printer map generated from the Landsat image were in good agreement with their known aerial photographic locations. Additional research at Weslaco in the 1990s showed the application of the French Satellite SPOT for detecting noxious weeds.

Few researchers have tried mapping non-native plants using data other than hyperspectral. For instance, Stenback and Congalton (1990) used the Landsat Thematic Mapper Imagery to map the forest under storey vegetation. They have achieved classification results ranging from 55 to 69 percent. May et al. (1997) have proved that Landsat data as more effective as compared to SPOT for shrub vegetation classification due to its higher spectral variability.

The reflectance spectrum from remotely sensed vegetation contains information on the chlorophyll content, water content, and leaf and canopy structure. Hence, in this study remote sensing techniques was applied in order to spatially and temporally identify the invasion cover of *P. juliflora* in Amibara Woreda, which mostly grow in patches in a wide coverage in an invaded area.

Therefore, this study assisted by CABI and IUCN together with four partner agencies in four African countries: Ghana, Zambia, Uganda and Ethiopia, is part of the integrated project-Removing Barriers to Invasive Alien Plant Management in Africa (RBIPMA). The Ethiopian Institute of Agricultural Research (EIAR) is a part of it together with other three partner agencies which are assisted by UNEP/GEF-fund. Hence, the aim of this study is mapping the infestation or the invasion rate of *P. juliflora* at the pilot site called Amibara Woreda, ANRS.

2.5.2 Geographic Information System Application for IAS Mapping

The development of GIS is viewed differently by different scholars based on the perception of what GIS is. Because of lack of a single universally accepted definition provided for GIS, different authors defined it from different perspectives.

Based on Draper et al. (2003), GIS is used to identify management priorities for both endangered and invasive species in order to develop effective conservation programs. Researchers at the Lisbon University Botanical Garden used GIS to compare ecological patterns at multiple scales for the endangered bryophyte *Bruchia vogensiaca*. Habitat suitability of protected areas was compared against the impact of the invasive *Carpobrotus edulis* on a natural reserve. The application of GIS helped to optimize management efforts by identifying priority areas where potential of *C. edulis* expansion would most affect endangered and native plant diversity. The

applicability of methods is under investigation to determine use among different species and scales for conservation programs using GIS.

Moreover, many types of datasets and formats can be used in a GIS depending on the scale and scope of the study. For simple mapping, aerial photography can be a vital part of invasive species cataloging. Landsat TM is a popular form of satellite imagery used to show land cover as it changes over time or as a planning tool (Chong et al., 2001). Pixel size may include 10m or 30m depending on the dataset. IKONOS is another type of satellite imagery used when large-scale, detailed analysis is required. GIS can incorporate many environmental variables at once including climatic, topographic, and geological. Population statistics, human land-use and disturbance can be incorporated as well to better understand the relationships between the datasets and the target species.

GIS allows for a more efficient organization of spatial data, leading to enhanced interpretation and analysis. Recent studies involving GIS have shown correlations between invasive species richness and variables such as climate, habitat and anthropogenic disturbances. Such correlations will help and allow us to implement effective control and management strategies in order to conserve biodiversity. In addition, GIS technology helps us to organize the data about such problems and understand their spatial associations and provides a powerful means for analyzing and synthesizing information about them (Pino et al., 2005). Hence, GIS technology can be used to mimic the behaviour of certain aspects of the real world. It is being used to model the present, and predict the future. In addition, this technology is thoroughly used in noxious weed monitoring, weed invasion and spread susceptibility mapping studies (Aronoff, 1989).

Therefore, in this study the focus is investigating rate of spread of invasive species *P. juliflora* at the pilot site to show its spatial and temporal expansion in order to manage its future spread.

2.5.3 Integration of Remote Sensing and GIS for IAS Mapping

Remote Sensing and GIS are inherently linked technologies that in many ways share common historical roots. The problem of this planet, require information in a timely fashion at scales from local to global levels. But, data on important attributes such as population distribution and dynamics, topography, land-use/land cover and its changes, water resources and air quality are inadequate, or in some areas they simply do not exist. Remote sensing is the only practical means to acquire much of the data needed to address the wide variety of challenges we face across scales.

After the launch of landsat-1 in 1972, a tremendous progress has been made in a relatively short time in developing effective methods for processing and analyzing such a data (Hoffer, 1994).

Moreover, in the last decade it had been observed that rapid advances and significant increase in the operational use of remotely sensed data. To be effectively analyzed and employed, remotely sensed data must be combined with other data or information. The most effective way to realize this situation is within the context of geographic information system.

Over the past decade remote sensing, geographic information system (GIS), and Global Positioning System (GPS) technologies have been integrated for detecting and mapping the distribution of noxious rangeland plants (Everitt et al., 2001). Remote observations in georeferenced formats help to assess the extent of infestations, track changes, develop management strategies, and according to Hoffer (1994), much of the increased use of remotely sensed data will be due to the continued integration of Remote Sensing,

Remotely Sensed data used to provide input to new GIS database, to update existing database, and assessing and monitoring land-use/land cover changes in various types. Not only does remote sensing provide input data to GIS database, but also GIS data often can be very helpful in the analysis of remotely sensed data and enabling significant improvements in the classification accuracies. So, for GIS to be most effective, it needs to contain accurate and up-to-date data. The best way to update a number of GIS data is through the analysis of remotely sensed information.

In order to summarize, the combining of GIS with expert systems, the use of GPS technology to enhance data capture for GIS and the use of Remote sensing especially image processing, provides more rapid updating of GIS databases and as a result of this the two technologies are inherently linked.

2.6 Image Classification Techniques

Land cover classes are typically mapped from digital remotely sensed data through the process of a supervised digital image classification (Campbell, 1987). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand and Kiefer, 1994). Digital classification can be broadly categorized into two type viz. supervised and unsupervised classification. Supervised classification involves creation of training sets followed by classification step. Conversely, in the unsupervised classification approach, the image data are classified by aggregating them into the natural spectral grouping, or clusters, present in the image on the basis of clustering algorithms. Unsupervised image classification is a method in which the image interpreting software separates the pixels in an image based upon their reflectance values into classes or clusters with no direction from the analyst.

Once this process is completed, the image analyst determines the land cover type for each class based on image interpretation, ground truth information, maps, field reports, etc. and assigns each class to a specified category by aggregation. Where as Supervised image classification is a method in which the analyst defines small areas, called training sites, on the image which are representative of each desired land cover category. The delineation of training areas representative of a cover type is most effective when an image analyst has knowledge of the geography of a region and experience with the spectral properties of the cover classes (Skidmore, 1989). The image analyst then trains the software to recognize spectral values or signatures associated with the training sites. After the signatures for each land cover category have been defined, the software then uses those signatures to classify the remaining pixels (ERDAS, 2001).

The major classifiers in supervised classification are minimum distance to mean (MDM) classifier, parallelepiped classifier, and maximum likelihood classifier (MLC). The maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel so that it is considered to be one of the most accurate classifier since it is based on statistical parameters.

2.7 Land-Use/Land Cover Change

Every parcel of land on the Earth's surface is unique in the cover it possesses. Land-use and land cover are distinct yet closely linked characteristics of the Earth's surface. Land-use is the manner in which human beings employ the land and its resources. Examples of land-use include agriculture, urban development, grazing, logging, and mining. In contrast, land cover describes the physical state of the land surface its categories include cropland, forests, wetlands, pasture, roads, and urban areas.

According to Riebsame et al. (1994), land-use and land cover change includes both the conversion from one land cover category to another and the modification, or subtle within-class change, that affects the character of the land cover without changing its overall classification. The ability to detect land cover conversions is a function of the mapability of the classes themselves, the spatial extent of change, and the temporal context in which the change occurs (Singh, 1989). Addressing what cover change dynamics are expected to be detected is the first order of business.

From the temporal perspective, land cover change can be ephemeral, interannual or semi-permanent/permanent. Ephemeral changes are short-term changes in cover, such as floods or seasonal burning in a savanna setting, which do not permanently alter the dominant vegetation cover distribution of the landscape. Interannual changes are variations in land cover largely due to long-term climatic variability, such as change in the annual extent of grasslands in the Sahel or

reduction of woodland canopy cover for an area experiencing long-term drought. Semi-permanent/permanent changes are extensive land cover conversions and include new construction of impervious surface, deforestation events, or the expansion of agricultural lands. Land cover modifications, as compared to land cover conversions, are a form of semi-permanent/permanent change within a given land cover category. This is a more subtle form of change and includes examples such as rangeland degradation due to overgrazing and forest thinning due to selective logging. Using global data sets, all of these types of land cover changes can be detected.

2.7.1 Land-Use/Land Cover Change Detection

Change detection is useful in such diverse applications as land-use change analysis, monitoring of shifting cultivation, assessment of deforestation, seasonal changes in pasture production, damage assessment, disaster monitoring, day/night analysis of thermal characteristics as well as other environmental changes (Singh, 1989).

The basic principle in using satellite data for change detection is that changes in land cover result in changes in radiance values which can be remotely sensed. A wide variety of digital change detection techniques have been developed over the last two decades. Singh (1989) provide excellent and comprehensive summaries of methods and techniques of digital change detection. All digital change detection is affected by spatial, spectral, temporal, and thematic constraints. The type of method implemented can profoundly affect the qualitative and quantitative estimates of the change. Even in the same environment, different approaches may yield different change maps. Selection of the appropriate method therefore takes on considerable significance. Not all detectable changes, however, are equally important to the resource manager. On the other hand, it is also probable that some changes of interest will not be captured very well or at all by any given system.

A post-classification comparison has been implemented in this spatial and temporal change detection analysis study. According to recent research, post-classification comparison appears to perform generally better than other methods of change detection (Lu et al., 2004); and such monitoring techniques based on multispectral satellite data have demonstrated potential as a means to detect, identify, and map changes in invasive species. In this study invasion rate of *P. juliflora* between 1986 and 2007 is analyzed using three satellite imageries.

2.8 Prediction of invasion Risk Probability

Predicting the probability of biological invasion and probable invaders has been a long-standing goal of ecologists. A major challenge of invasion biology lies in the development of pre and post predictive models and understanding of the invasion processes. Introduced species vary in their invasive behavior in different regions (Krueger et al., 1998). The consequence of a given disturbance depends on the properties of the ecosystem or community.

There is a need to evaluate disturbance not in terms of the elements of a given regime, but rather in terms of ecological effect.

In this study a simple prediction system of the land-use/land cover change was carried to show the prediction risk of *p. juliflora* invasion after ten, and twenty years since 2007 in the study area.

3: MATERIAL AND METHODS

3.1 Study Site Description

3.1.1 Location

The region is part of the East Africa Great Rift Valley (Mohr, 1971); characterized by patches of scattered dry forests, *Acacia* woodlands, bush land, wooded savannah and scrubland (MOA, 1997). About 64% in the region is degraded and bare due to the harsh semi-desert climatic conditions (Shiferaw et al., 2004). The study was conducted in Amibara Woreda, zone 3 of Afar National Regional State. ANRS is located in the northeastern part of Ethiopia covering 10% and 29% of the country's total land and lowland, respectively (Yirgalem, 2001). Amibara (Fig. 7) is one of the 29 Woredas in the ANRS. It is in the middle Awash Rift Valley, located at 08°58' – 09°56' N and 40° 08'– 40° 12'E.

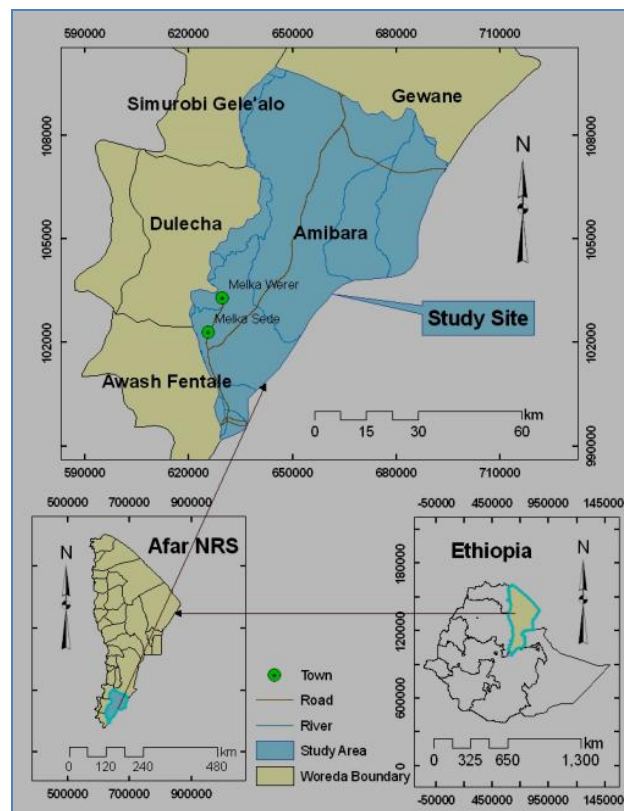


Figure 7: Location Map of the Study Area

It is bordered on the south by Awash Fentale, on the west by the Awash River, on the northwest by the Zone 5 Administrative of ANRS, on the north by Gewane, and on the east by the Oromia Region. Towns in Amibara include Awash Arba, Awash Sheleko, Melka Sedi and Melka Werer.

The selection of the study area was based on a range of vegetation types (range land, cultivated land, settlement, open bush land, shrub land, *Acacia* woodland and water) that were infested and uninfested with *P. juliflora* species. A secondary consideration was the travelling distance from Melka Werer where the project pilot site of RBIPMA was located.

3.1.2 Climate

ANRS has 1600 and 110 metres as the highest and lowest altitudes above sea level, respectively. Mean annual rainfall is 564 mm with annual evapotranspiration ranging between 1400 and 2200 mm (MOA, 1997). The study areas were characterized as hot to warm moist with mean annual temperature 27°C (Shiferaw et al., 2004).

Rain fall pattern in the study area is illustrated by data analysis from the rain fall station at Werer Agricultural Research Center station in operational since 1980. Most precipitation there falls between July and August (Fig. 8). Rainfall amount and distribution throughout the year is a major factor influencing growth and dynamics of *P. juliflora* (Elfadl and Luukkanen, 2006). Therefore, it was necessary to investigate and analyze rainfall patterns during the study period.

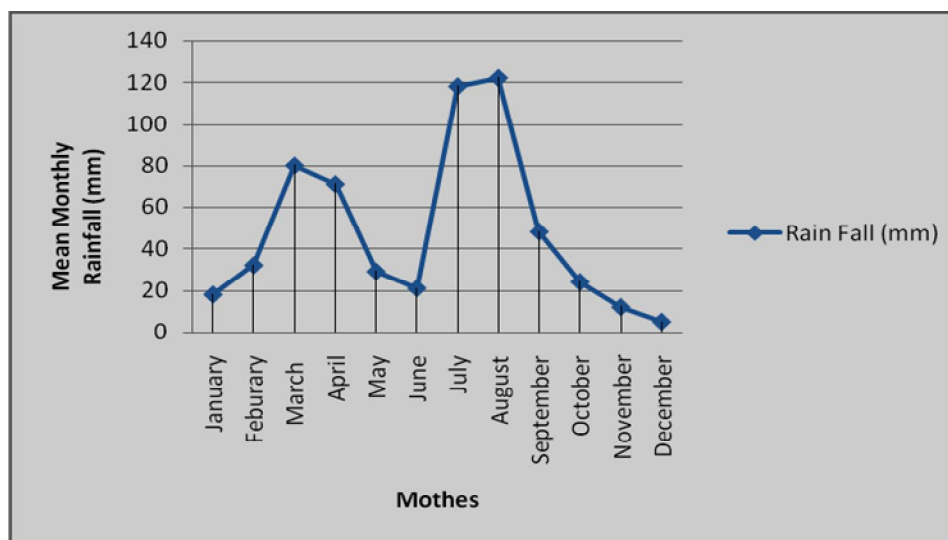


Figure 8: Mean Monthly Rain Fall Record (1980 to 2007)

The relative humidity ranges between 38 and 58%. The rainfall in the study area has a bimodal distribution July-August (main rainy season) and February-April (short rainy season). The mean annual precipitation is usually below 600mm (Abdurahaman Ame, 2002). May/June is the driest season of the year locally called Gagay (Table 2) or spring, which is unsuitable for browsing since bushes dry up except *Prosopis*.

Table 2: Seasonal Calendar of Afar NRS

No.	Period	English	Amharic	Afaregna	Season
1	September to December	Autumn	Tseday	Gilel	Dry
2	January to February	Winter	Bega	Sugum	Medium
3	March to May	Spring	Belg	Gagay	Dry
4	June to August	Summer	Kiremt	Kerma	Wet

(Sources: “Contingency Plan and Coordination System for Amibera Woreda” By Amibera Woreda Disaster Management Committee, 2007)

3.1.3 Human and Livestock

Afar region has population size of 1,106,383 and land area of 85,410 km square. The region is among the area of the country with low population density with 13 persons per km square. Amibara Woreda where the study has taken place has a population size of 40, 175 and land area of 2941 km square. Livestock population of Amibara Woreda is composed of camels, cattle, goats, sheep and donkeys; 39,995, 103,959, 122,526, 48,043 and 3,888, respectively (CSA, 2005).

Transhuman pastoralism is the major production system in the study areas where cattle, camel, goats and sheep are the dominant animals reared. Livestock were kept primarily for their products (milk, milk products and meat) and income (Abule et al., 2005). In a few pockets, pastoralists also grew crops with supplementary irrigation from permanent rivers. Some people are also engaged with other social tasks (Tibabu, 1997). The main grazing area of the southern Afar is Allaidege rangeland.

3.1.4 Vegetation Cover

The cover classes of Amibara Woreda (Table 3) can be generally classified into state farm, open bush land, bush land, shrub land, open grass land, seasonal marshland, and bare land (Abdurahman Ame, 2002), although the change over years were not well described. Hence, in this study the integration of GIS and remote sensing is used to detect the land-use/land cover changes over the last 21 years (1986-2007) due to *P. juliflora* in Amibara Woreda of the central rift valley of Ethiopia.

To know the spatial distribution of various land-use classes over years and the land cover changes, remote sensing and GIS play crucial role. The information derived from remotely sensed data, land-use/land cover changes due to *P. juliflora* and its impact is very essential to plan the management measures by the stakeholders in the study area.

Table 3: LU/LC of Amibara Woreda

No.	Description	Extent (ha)	% in the woreda
1	State Farm	7956	2.71
2	Open Bush land	40,054	13.62
3	Bush Land	25,195	8.57
4	Shrub Land	151,631	51.55
5	Open grass land	23,179	7.88
6	Seasonal Marsh Land	19,686	6.69
7	Bare land	26,405	8.98

(Source: Abdurahman Ame, 2002)

3.2 Sources of Data

Satellite imageries and ancillary data have been collected in order to identify historical and recent land-use/land cover. Materials used for this study were Landsat TM 1986, ETM+ 2001 and ASTER satellite image 2007, where all have been radiometrically calibrated and geometrically corrected.

3.2.1. Landsat TM and Landsat ETM+

The oldest available and needed datasets for the study area is Landsat TM archive data at the EROS Data Center. A two scenes, path/row 167/53 and 167/54, taken in January 1986 by TM sensor on board Landsat 5 is used. The same path/row image of Landsat ETM+ dated on 28 November 2000 and 16 February 2001 was used. All Landsat data were obtained from the online archive of the GLCF. The TM and ETM+ sensors are advanced, multispectral scanning devices designed to achieve higher image resolution, sharper spectral separation, improved geometric reliability and greater radiometric accuracy and resolution than the MSS sensor. Like the MSS, these sensors primarily detect reflected radiation from the earth's surface in the visible and near infrared (IR) wavelengths, but the TM and ETM plus sensors with their six multispectral bands and one thermal infrared band (ETM+) carries an additional panchromatic band with 15-metre ground resolution) are capable of providing more spectral information than the MSS sensor.

They also have more radiometric depth as the data are captured in 8 bits (0-255). The wavelength of the TM and ETM+ sensor ranges from the visible, through the Mid-IR, into the Thermal-IR portion of the electromagnetic spectrum. These sensors have a spatial resolution of 30 meters for bands 1 to 5, and band 7, and a spatial resolution of 120 meters for band 6 in TM. The ETM+ has an additional panchromatic band with 15 meters spatial resolution. This band may be used to increase the ground resolution of the six multispectral bands through image fusion. The satellites

orbit at an altitude of 705km and provide 16-day repletion, covering 185km swath. All Landsat imageries collect remote sensing data by detecting reflected energy from objects at the surface of the earth. The sun is thus the only energy source required in the visible and reflective infrared remote sensing. The reflectance behaviour of objects varies along the range of the electromagnetic spectrum.

3.2.2 ASTER Level-1B Image

The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) is an advanced multispectral imager that was launched on board NASA's Terra spacecraft in December, 1999. ASTER covers a wide spectral region with 14 bands from the visible to the thermal infrared with high spatial, spectral and radiometric resolution. An additional backward looking near-infrared band provides stereo coverage. The spatial resolution varies with wavelength: 15 m in the visible and near-infrared (VNIR), 30 m in the short wave infrared (SWIR), and 90 m in the thermal infrared (TIR) as in indicated by (Appendix 3). Each ASTER scene covers an area of 60 x 60 km. The ASTER instrument produces two types of Level-1 data: Level-1A (L1A) and Level-1B (L1B).

ASTER L1A data are formally defined as reconstructed, unprocessed instrument data at full resolution. They consist of the image data, the radiometric coefficients, the geometric coefficients and other auxiliary data without applying the coefficients to the image data, thus maintaining original data values. The L1B data are generated by applying these coefficients for radiometric calibration and geometric resampling. These data product is generated, by default, in UTM projection in swath orientation, and Cubic Convolution resampling. The ASTER Level-1B data are L1A data with the radiometric and geometric coefficients applied. All of these data are stored together with metadata in one HDF file.

In this study, only the VNIR bands, three scenes taken in March 2007, were used. The VNIR data at 15m resolution is currently the best resolution multispectral data available commercially from satellite with the exception of the 4metre resolution IKONOS data. Comparison of the 10m resolution SPOT Panchromatic band shows that it has much better resolution than the ASTER data while a comparison with the Panchromatic 15m band on the LANDSAT7 ETM+ shows that the ASTER image is better both spectrally and spatially.

3.3 Methods

The methodological procedure followed in this study is presented using the following flow chart (Fig. 9). It shows the steps followed beginning from the acquisition and classification of multi-temporal satellite image of the study area to the extraction of the required information both

secondary and primary data to answer the research questions. Details of activities conducted during these stages are explained in the proceeding sections.

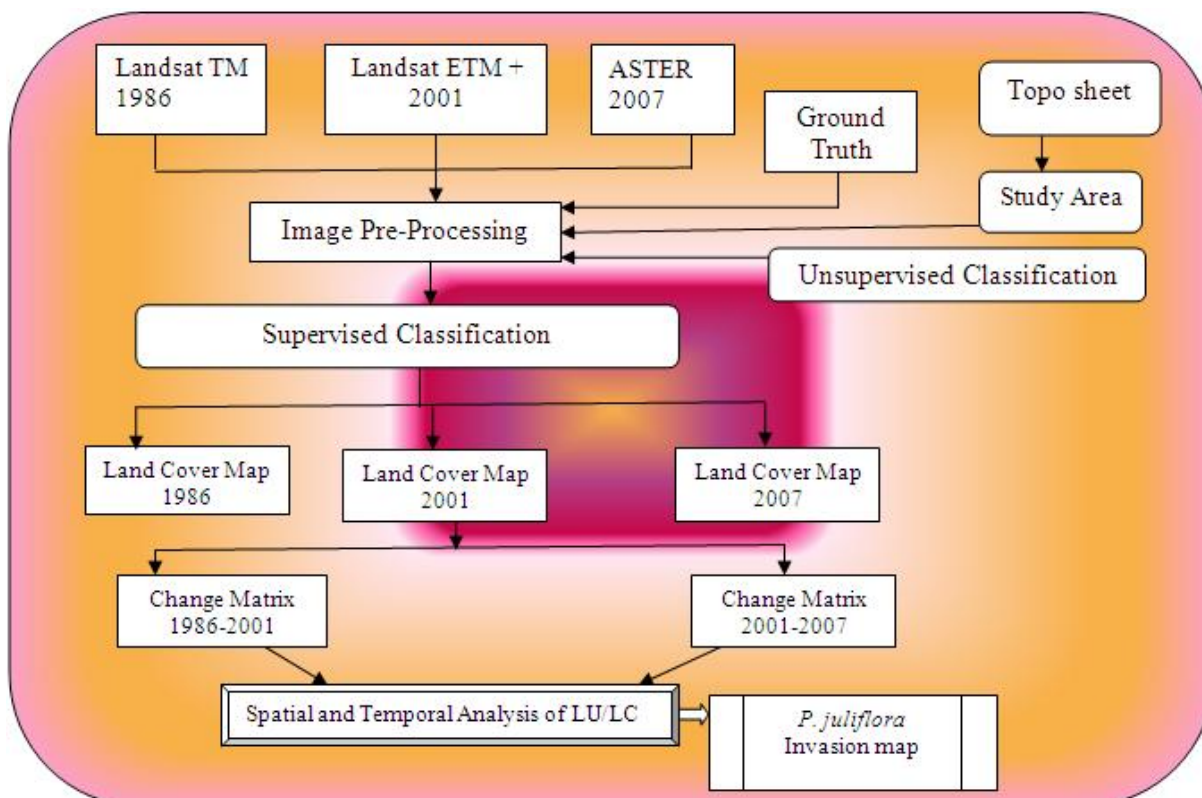


Figure 9: Flow Chart

3.4 Pre field Phase

During this stage all the available information about the study area were collected, compiled and rectified. The following steps had been carried out before the fieldwork.

3.4.1 Image Pre Processing

For this study, multi-temporal images were used from different sensors. In order to compare separate images pixel by pixel, the pixel grids of each image should match to the other images. Therefore, pre-processing techniques like geo-referencing, image to image registration and reprojection of the images, band selection and false and true colour composite for proper classification were performed.

3.4.1.1 Image Geometric Registration

Georeferencing refers to the process of assigning map coordinates to image data. All the selected four bands were opened separately by providing the required information using ENVI 4.3 software and to confirm the pixel grids and remove any geometric distortions in this imagery, it was registered to the UTM projection, map zone 37, and datum of WGS84. The RMS error is 2.04. This means that the reference pixel is 2.04 pixels away from the retransformed pixel. RMS error is the distance between the input (base image) location of a GCP and the transformed location for the same GCP (ERDAS, 2001). Points with high error were discarded before registration. Image fit was considered acceptable if the RMS error was not more than 10.0. The Overall RMS errors of less than 3.00 were achieved for each transformation. The nearest neighbor resampling method was used due to quicker computer processing time as compared to other interpolation methods.

Finally, nearest neighbor interpolation that better maintains original reflectance values of image data was used, which is the only resampling method that should be performed before image classification. Since the grid of pixels in the source image rarely matches the grid for the reference image, the pixels are re-sampled so that new data file values for the output file can be calculated. Hence the 15m pixel size of VNIR band of ASTER image was re-sampled to 28.5m resolution. The first order transformation provided sufficient accuracy and reduced potential introduction of unwanted geometric distortions in areas with no GCPs to provide precise control.

As a single ASTER image was not covering the study area, three scenes were used to cover the whole of the study area. Similarly two Landsat scenes both for TM and ETM+ were used. Thus, both the Landsat and ASTER images were subsetting, stacked and mosaiced using ENVI 4.3 in order to limit the size of the study area to Amibara Woreda.

Unsupervised classification was performed on the most recent ASTER imagery before GCPs collection (Fig. 10), where eight classes were identified. Then classification was done with these eight classes, which were identified as water=class 8, shrub land=class 7, range land=class 6, invaded land=class 4, open bush land=class 5, cultivated land=class 3, bare land=class 2 and *Acacia* woodland=class 1 (see Table 4).

3.4.1.2 Band Selection

All of the eight bands, in the Landsat ETM+ image, 3 visible, 3 infrared, 1 panchromatic, and 1 thermal band were not useful for this study. In order to reduce computer processing time and to

treat only the most important data, band selection were conducted based on the information obtained from the literature.

Reflectance of healthy vegetation is better observed at 0.52 - 0.60 μm range (green range, ~ Band 2 of ETM and TM). At 0.63 - 0.69 μm range (red range ~ Band 3 of TM and ETM+) chlorophyll absorbs a considerable portion of the incoming energy. Hence, this band is important for identification of healthy green vegetation. The near infrared spectrum ranges from 0.76 to 0.90 μm in Landsat TM and ETM+ images (known as Band 4). As opposed to the previous range, reflectance from green plants sharply increases in this range.

Table 4: Description of different LU/LC of the study area

LU/LC Lists	Description
Range land	They are characterized by having a continuous herbage layer dominated by perennial grasses and sedges. It includes land with scattered or patches of trees and it is used for grazing and browsing. It is also the major fodder resources for livestock and wildlife in semi-arid ecosystem.
<i>Acacia</i> woodland	Composed of woods or bushes found along the major perennial river, mainly Awash River.
Open bushland	It represents both natural and fragmented plantation of bushy cover area where livestock are grazing and browsing in this Woreda.
Cultivated land	Includes herbaceous (cropland) and woody (e.g., orchards, nurseries, cotton farm) cultivated lands as well as settlement areas in the study area.
Water	Water logged area surrounded by trees, shrubs, etc
Bare land	Composed of bare soil, degraded land, rocky and areas having thin vegetation cover or other earthen material with little or no vegetation
Shrub land	Areas dominated by woody vegetation less than 6 meters in height. This class includes true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions
Invaded land	Areas dominated by an evergreen <i>P. juliflora</i> species, which is an exotic species, with an average tree count of above 100 stands with minimum height of 3m with in 900 square meters (30x30m ²) area

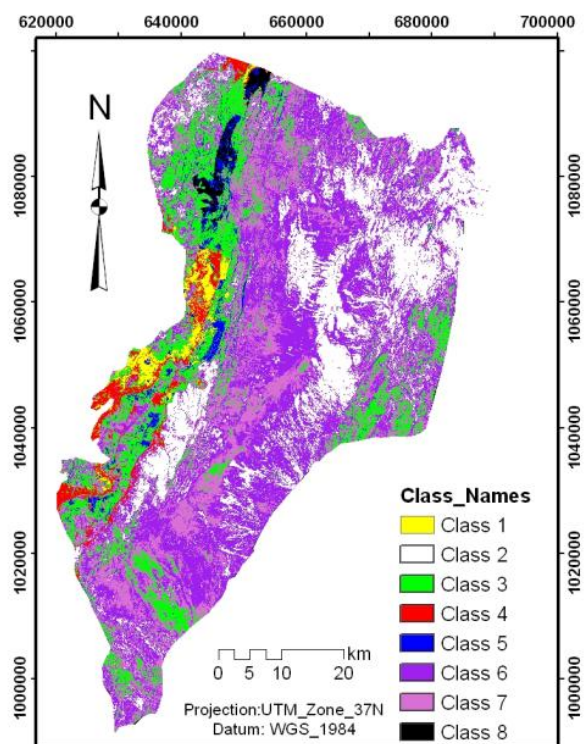


Figure 10: Unsupervised Classified Image of Amibara Woreda, ASTER 2007

Several indices, which attempt to quantify vegetation attributes, primarily use these two ranges due to this contrasting reflectance behavior of plants at these spectral ranges. At the far mid-infrared ($1.55 - 1.75 \mu\text{m} \sim$ Band 5 in TM and ETM+), the moisture content of plants is detected. This property is especially important in agricultural crop observation studies because some signs of shades in plant stress, which cannot be seen by naked eye, are readily discerned. Features those look similar in visible ranges like clouds, snow and ice are also clearly identified. At the spectral coverage gap between Band 3 and Band 4 ($0.69-0.75 \mu\text{m}$), very important chlorophyll dependant plant activities could be identified.

For some unfortunate reason, the Landsat satellites do not scan imageries at this range. Therefore, as band 6 is a thermal band; it is not used for land cover mapping. It is only used to map a surface temperature. Finally, only four bands, namely, band 2 (green), bands 3 (red), Band 4 (near infrared) and band 5 (mid infrared), were selected for this study. This is because the study is done at the dry land or in the rift valley area of ANRS. There assumed that there is a moisture difference between plant species or vegetation around; and a clear observable difference could be detected from the FCC due to the presence of band 5 and when it was not included.

3.4.1.3 True Colour and False Colour Composite

True colour composite (TCC) and false colour composite (FCC) were found to be more useful for the process of identifying the different land cover classes in the study area (Fig.11, 12 & 13).

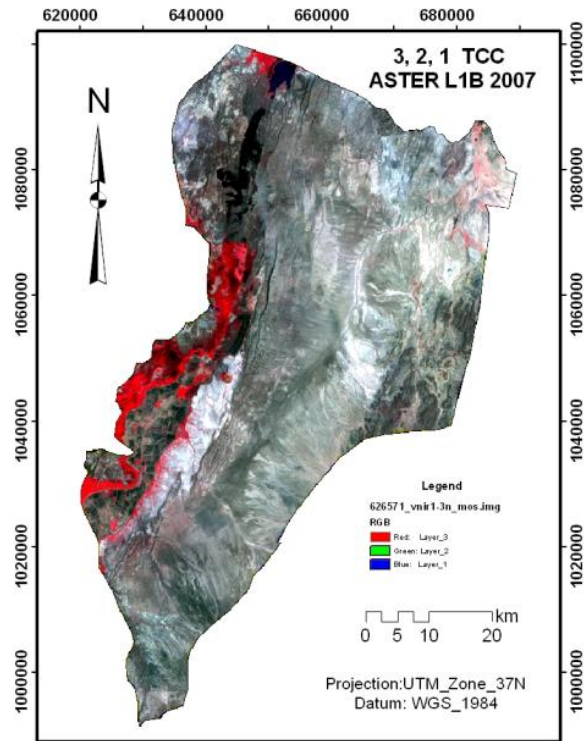


Figure 11: True Colour Composite (RGB: 321) of Amibara Woreda, ASTER 2007

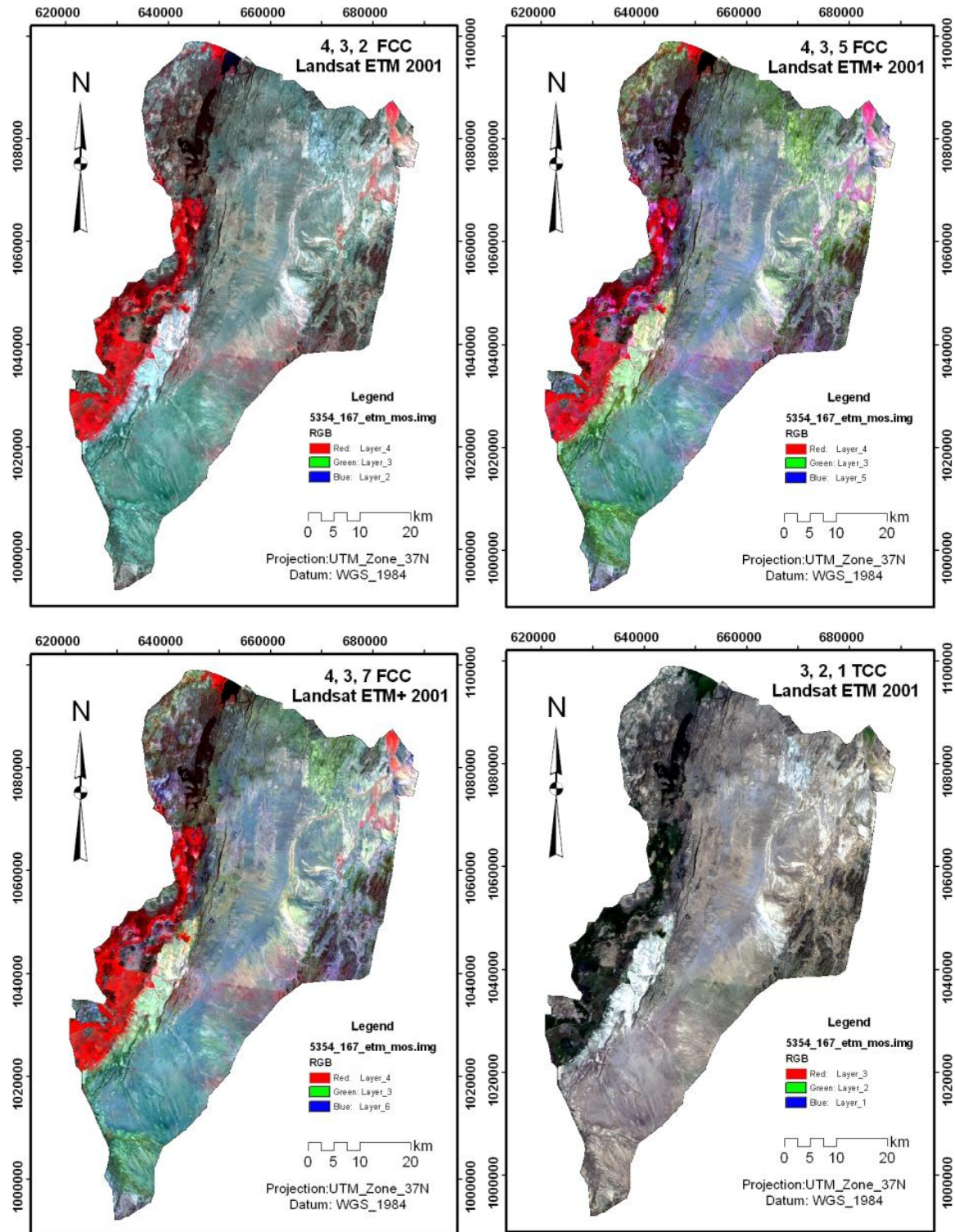


Figure 12: Different Colour Composite of Amibara Woreda, Landsat ETM+ 2001

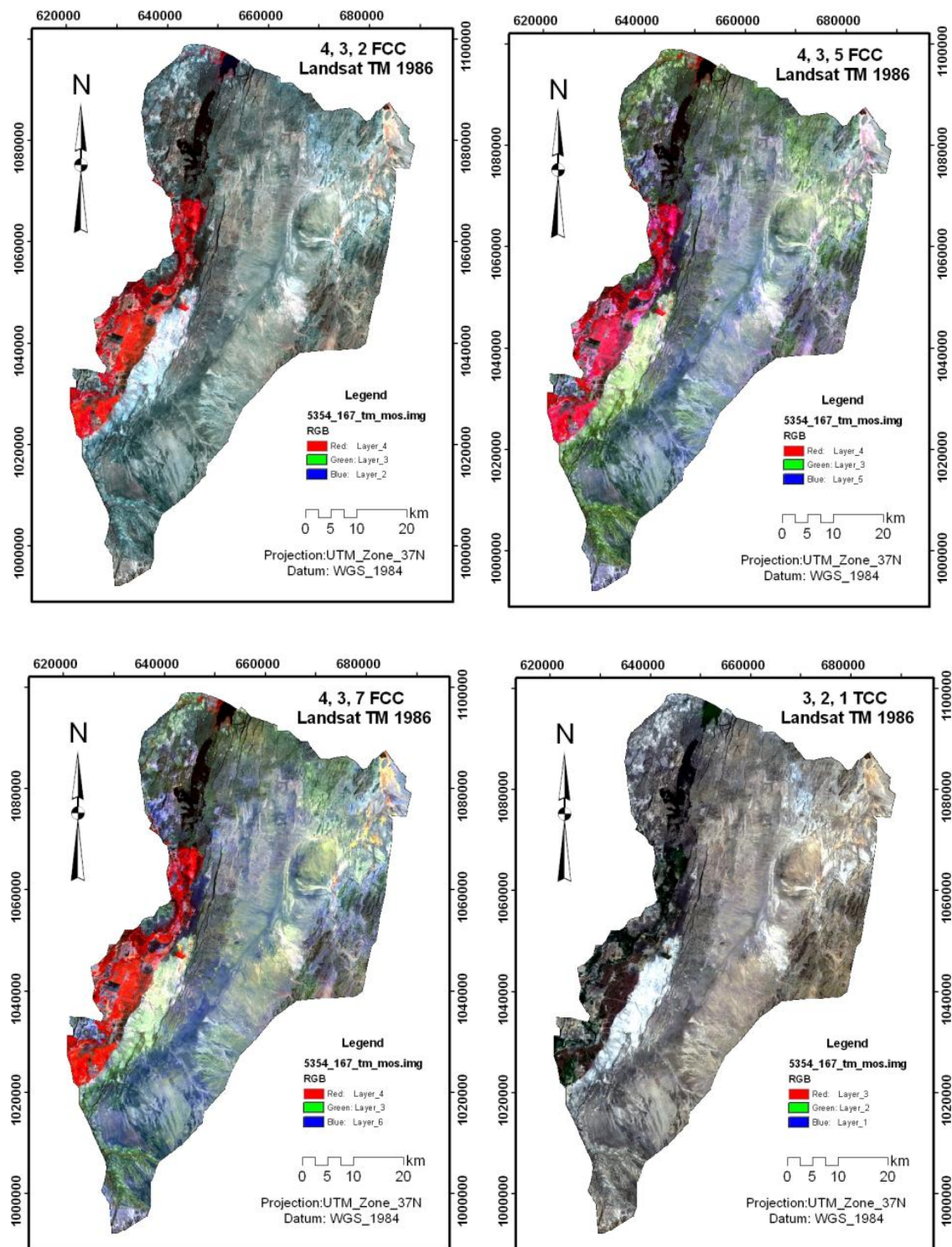


Figure 13: Different Colour Composite of Amibara Woreda, Landsat TM 1986

The applications of bands for different feature recognition were used based on the earlier information. Particularly for the supervised classification of the Landsat image different color composite of the bands were checked for better visual interpretation besides the earlier information of the study sites.

Finally, identification of most of the categories of land cover classes were possible using colour composite red 4, green 3 and blue 5, which is false colour composite (FCC). A true colour and false colour composite image helps to enhance the visualization and to prepare the image for further classification. In the NIR band (band 4) vegetation has a very high albedo since chlorophyll (the pigment in leaves that give plants their green colour) reflects energy at this wavelength. Thus, in a 4, 3, 5 NIR and MIR composite image, vegetation is intensely depicted as varying shades of red. Since different types of vegetation have different levels of chlorophyll in their leaves, each type of plant has its own shade of red. This makes a 4, 3, 5 composite very useful in determining the extent of vegetation and for classifying different vegetation types as seen from space. Water, which absorbs nearly all of the NIR energy that reaches its surface, appears very dark, nearly black, in a 4, 3, 5 NIR and MIR composite images.

For the ASTER image since the image were checked against the ground truth collected, colour composite were not tested, however, only the true colour composite were used for supervised classification of this image.

3.5 Data Collection

3.5.1 Satellite Images and Spatial Data

The major information required for the study has been extracted from satellite images. Land-use/land cover types at various times have been extracted from Landsat TM, ETM+, and ASTER images. River and road have been generated from 1:50 000 scale topographic map through manual digitizing. Towns' layer has been made from both GCPs and Topo-sheets.

3.5.2 Ground Truth Data

For ground truth collection, Global Positioning Systems (GPS) was used. GPS provide the mapping community with powerful tools for acquiring accurate and current digital data. Combined with high resolution remote sensing and GIS for land use studies, GPS can provide high accuracy ground-truth data for training-site development. The accuracy level in this case was 7 to 10m. Unsupervised classification was done on an ASTER 2007 images for the indication of the land-use cover in the area, which assist during GCPs collection from the study area. A field work was performed from June 22, 2008 to July 18, 2008 in order to collect sample

GCPs for each land-use/land cover class included in the classification scheme and for creation of training sites and for signature generation validation for classification of the ASTER 2007 imagery. From each vegetation type fifteen quadrants of 30x30m² were taken and line intercept transect method was used to record at every 100 meter interval for the presence or absence of *P. juliflora*. The invasion rate was recorded by counting the number of *P. juliflora* of > 3m height as: low invaded land (< 30 *P. juliflora*), medium invaded land (30 - 90 *P. juliflora* species), highly invaded land (> 100 *P. juliflora*) and none if there is no single count of *P. juliflora* in the sample area.

A total of 126 field observation points were collected for performing supervised classification of the ASTER imagery as shown in appendix 1. Secondary data were collected like meteorological data of the study area. Questionnaires were made and interviews were conducted with the local people in the districts, from Melka Werer and Melka Sedi for previous land-use/land cover information. In most of the areas *P. juliflora* was found growing in varying densities mixed with shrub lands; inside and surrounding the cultivated land and road sides. At some sample sites due to heavy infestation of dense impenetrable thickets of *P. juliflora* GPS data collection were inaccessible.

3.6 Post Field Phase

3.6.1 Image Analysis

During this phase, supervised classification was performed on the ASTER 2007 imagery by utilizing observation points recorded during field visit, after subsetting the image. The TM 1986, ETM 2001 and ASTER 2007 satellite images were classified using the Maximum Likelihood supervised classification using the sample training signature prepared from the GCPs collected for the recent image. For Landsat TM and ETM+ images; visual observation of the FCC Landsat image and the spectral information of the known land-use/land cover categories observed from unsupervised classified Landsat ETM+ image (Fig. 14) and from visual observation of the supervised classified ASTER image were used for supervised classification. From unsupervised classified Landsat ETM+, six classes were identified: water/bare class, range class, open bush class, cultivated/shrub class and *Acacia* class.

The software uses specific algorithm to assign all pixels in the image data set into defined land-use/land cover classes. Maximum likelihood classification is based on the probability density function that is associated with a particular training site signature. All pixels are assigned to the most likely category based on an evaluation of the subsequent probability that the pixel belongs to the signature (class) with the highest probability of membership (Jensen 2004). The same categories were obtained as in case of unsupervised classification of ASTER image (see Table 4). The classification result was also assessed using 40 validation points collected from the field in October 2008.

As already mentioned in the sub chapter 3.4.1.2 under Band Selection, false colour composite of band 4, 3 and 5 were selected for the better identification of different land-use/land cover categories of the study area from the Landsat TM and ETM+ images. Similar work has been done by Richardson et al. (1981). They conducted a pilot study to assess Landsat multispectral scanner satellite data for detecting silver leaf sunflower infestations on Texas rangelands. They reported that this annual weed could be distinguished on (bands 4, 3, and 2) Landsat imagery.

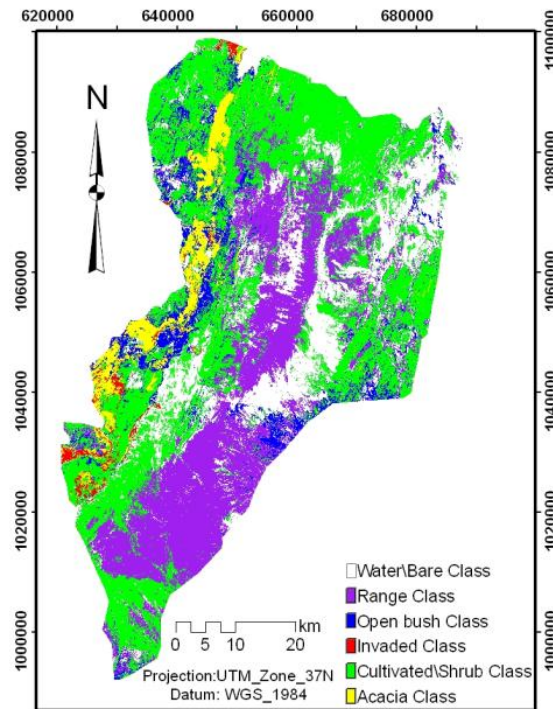


Figure 14: Unsupervised Classified Landsat ETM+ Image, 2001 of Amibara Woreda

Hence from the Landsat TM 1986 and ETM+ 2001 also eight land cover categories were identified. In this case because the 1986 Landsat TM imagery depicts a situation that existed 15 years before the recent Landsat ETM+ imagery and 21 years before ASTER L1B. Hence, these images could not be checked against the ground truth, but the available historical data from the area were used to validate the interpretation made. However, the ASTER 2007 satellite image was directly checked against the ground truths. During image interpretation *P. juliflora* was identified visually when the patch is found in dense, on the ASTER image 2007, particularly when it is found in a wide coverage covering at least more than a hectare of land at the study area where there is highest invasion. Moreover, as *P. juliflora* is an evergreen tree or shrub that is found in any season, which differ from most of the other species found in the area, which dry out or shed their leaves during the dry season in the study area, the spectral reflectance depicts more differently. *P. juliflora* invaded land have a reflectance signature colour of very bright red which

was totally different from other land-use /land cover in the study area. Above all, the satellite image used for this study was captured during January - March, which is the dry season in the area.

Hence, “post-classification comparison change detection scheme” was employed to discriminate spatial and temporal invasion of *P. juliflora* between 1986 - 2001 and 2001 - 2007 using ENVI 4.3 software. The statistics of land-use/land cover change in general and *P. juliflora* invasion cover change in particular were computed and summarized to detect the pattern and nature of the changes.

The invaded land in the study area was divided in to three categories initially as follow: highly invaded, medium invaded and low invaded, based on the GCPs already collected from the field on the ASTER image. The interest was to separately identify the invasion rate. However, all classes were merged and considered as one in the final land-use/land cover change analysis. This was done because in the Landsat images, where there were no GCPs for verification, it might not possible to classify the land-use/land cover like ASTER by assigning as highly, medium and low invaded land. Therefore, the land-use/land cover were merged and called invaded land.

3.6.2 The Jeffries-Matusita ROI Separability

The Jeffries-Matusita ROI separability measure (Table 5) was run to quantitatively evaluate the statistical separability of the training ROI of eight classes used for the multispectral image. The output separability values range from 0-2, with values falling below 1 suggesting poor or unacceptable separability and values above 1.9 indicating the classes have good separability (Richards, 1999). The separability measured for the period 2007 justify that no poor value was obtained from the classification. However, few land cover classes had mix-up, particularly for the range land and cultivated land; and cultivated land and open bush cover, having lower values.

Table 5: Jeffries- Matusita ROI Separability for the multispectral training classes (2007)

LU/LC List	Shrub land	Range land	Bare land	Water	Cultivated land	<i>Acacia</i> woodland	Open * bushland
Invaded land*	1.59	1.85	1.96	1.99	1.88	1.37	1.89
Shrub land		1.45	1.82	2.00	1.62	1.91	1.73
Range land			1.96	2.00	1.32	1.96	1.82
Bare land				2.00	1.98	1.99	1.99
Water					1.99	1.99	2.00
Cultivated land						1.92	1.32
<i>Acacia</i> woodland							1.68

*= not shown in either of the column and rows because ROI separability couldn't compare one LU/LC with itself

3.6.3 Classification Accuracy Assessment

The common means of expressing classification accuracy is the preparation of classification error matrixes. An error matrix (confusion matrix) is a square array of numbers organized in rows and columns, which express the number of sample units assigned to a particular category relative to the actual category as indicated by reference data. An error matrix was generated based on the year 2007 land-use/land cover classification and area of interest data (Table 6). The accuracy is essentially a measure of how many ground truth pixels were classified correctly.

The Kappa value is a measure of the agreement between classification and reference data with the agreement due to chance removed. None of the Kappa values in any of the images were very high. Landis and Koch (1977) ranked the Kappa values, ranging from -1 to 1 , into 3 groups: 1) those > 0.80 for strong agreement between the classification and reference data; 2) those between $0.40 - 0.80$ for moderate agreement; and 3) < 0.40 represented poor agreement. The highest users' accuracy from the vegetation classes were for invaded land followed by cultivated land. The shrub land showed relatively lower users' accuracy (75.6). The reason was the spectral signature of shrub land was mixing largely with cultivated land (Table 5). Water class was having a users' accuracy of 100%. In general, the overall accuracy of 86.026% was achieved with a Kappa coefficient of 0.8257 (Table 6).

Table 6: Confusion Matrix for ASTER image of March 2007

LU/LC List	Invaded Land	Shrub Land	Range Land	Bare Land	Water	Cultivated Land	Acacia woodland	Open Bushland
Invaded Land	83.04*	0.00	0.00	0.00	0.00	0.00	9.69	0.00
Shrub Land	4.07	82.68*	0.16	0.00	0.00	0.08	0.98	0.35
Range Land	0.00	10.85	97.4*	0.00	0.00	5.63	0.00	0.00
Bare Land	0.29	1.73	1.06	100.0*	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	100.0*	0.00	0.00	0.00
Cultivated Land	0.35	3.46	1.30	0.00	0.00	93.40*	1.21	1.48
Acacia Woodland	8.82	0.12	0.00	0.00	0.00	0.00	77.39*	0.96
Open Bushland	0.69	0.92	0.00	0.00	0.00	0.80	7.14	97.22*
Commission	9.50	24.39	12.03	18.64	0.00	9.93	11.56	23.27
Omission	16.96	17.32	2.52	0.00	0.00	6.60	22.61	2.78
Producer Accuracy	83.04	82.68	97.48	100.00	100.00	93.40	77.39	97.22
User Accuracy	90.50	75.61	87.97	81.36	100.00	90.07	88.44	76.73
Overall Classification	86.026%							
Kappa Coefficient	0.8257							

*= land-use/land cover that was not transformed

4: RESULTS AND DISCUSSION

4.1 Land-Use/Land Cover Change

Land-use/land cover map has been produced through supervised classification of the ASTER 2007 and Landsat TM, 1986 and Landsat ETM+, 2001 (Fig. 15, 16 and 17). The area under each land-use/land cover during the three periods is presented in (Table 7).

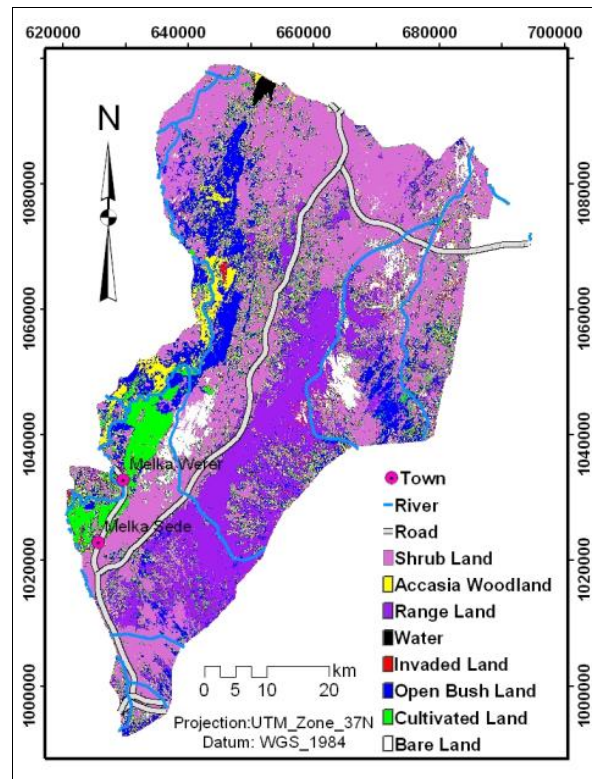


Figure 15: LU/LC Map of Amibara, 1986

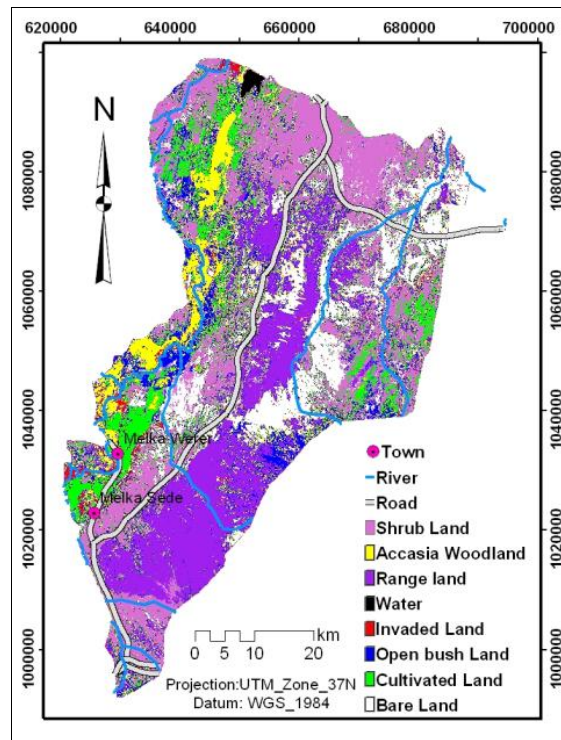


Figure 16: LU/LC Map of Amibara, 2001

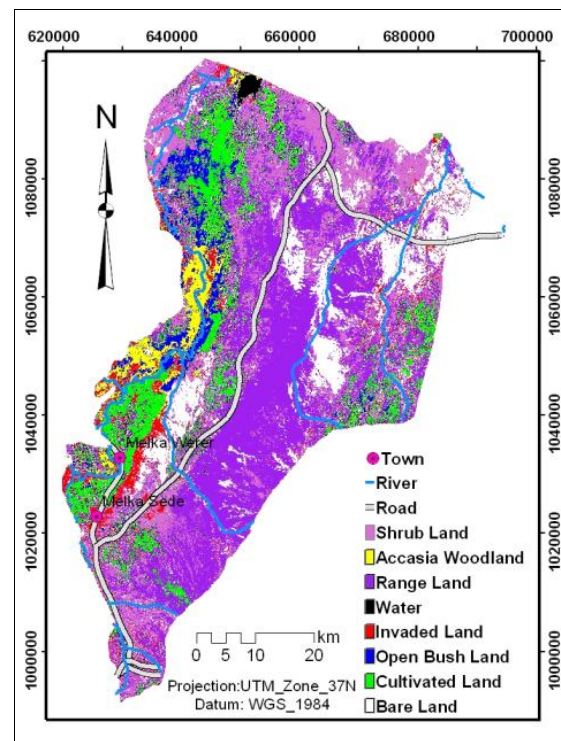


Figure 17: LU/LC Map of Amibara, 2007

4.1.2 Land-Use/Land Cover Change (1986-2001)

Out of the total change between 1986 and 2001 invaded land that was exchanged from the original 769ha in 1986 to 3849ha in 2001 in the study area. The shrub land and open bush land decreased from 50.9% and 13.8% in 1986 to 32.3% and 7.0% in 2001 respectively. In contrast, the extent of range land, cultivated land and *Acacia* woodland has increased during this period from 24.7%, 4.3% and 2.0% in 1986 to 27.0%, 8.9% and 5.2% in 2001, respectively. The land-use/land cover change to cultivated land and *Acacia* woodland was showing faster increase in the aerial coverage next to the bare land per total area in the study area. The change into bare land shown, there might be due to high rate of degradation taken place during this period in the study area, however exploring why it has been happened was not the aim of the study. The area invaded by *P. juliflora* was increased alarmingly from 1986 (0.2%) to 2001 (1.1%) at the expenses of either of the land-use/land cover listed (Table 7).

Table 7: Temporal Distribution of *P. juliflora* invasion at Amibara Woreda

LU/LC List	1986		2001		2007	
	Area (ha)	%cover	Area (ha)	%cover	Area (ha)	%cover
Invaded Land**	768.8	0.2	3848.6	1.1	11578.7	3.4
Range Land	85463	24.7	93611	27.0	121090.8	35.6
Open bushland*	47956	13.8	24421.4	7.0	17845	5.2
<i>Acacia</i> woodland	6896.1	2.0	17916.9	5.2	9978.2	2.9
Bare Land	13206.2	3.8	62715.7	18.1	48611.7	14.3
Water	1084.6	0.3	1152.3	0.3	1101.7	0.3
Cultivated Land	14962.9	4.3	30912.4	8.9	49005.9	14.4
Shrub Land*	176333.2	50.9	112092.4	32.3	80988.1	23.8
Total	346670.8	100.0	346670.7	100.0	340200.1	100.0

Land-use/land cover that has shown *= a continuous reduction in area coverage in 1986-2007

**= a continuous increase in area coverage in 1986-2007

4.1.2 Land-Use/Land Cover Change (2001-2007)

During this period, tremendous land-use/land cover changes occurred in the study area. By 2007, the extent of shrub land was reduced by about 31,104ha. This Reduction of the shrub land shows that 9.0% of the total study area was transformed into other land-use/land cover pattern. Next to shrub land, *Acacia* woodland has shown reduction by about 7,939 ha, which was almost half of the total area in 2001. Thirdly, reduction in the land-use/land cover has been observed from the open bushland by 6,576.4ha than year 2001. The bare land has been also reduced during this period. In contrast to the above land-use/land cover, the range land, cultivated land and invaded land have shown 9%, 6% and 2.3% increase, respectively between 2001 and 2007.

The shrub land has decreased in the extent continuously since 1986 (50.9%), 2001 (32.3%) and 2007 (23.8%). This was followed by open bushland that showed reduction since 1986 (13.8%) and 2007 (5.2%). In contrast, the range land and cultivated land has increased from 24.7% and 4.3% (1986) to 35.6% and 14.4 (2007), respectively. The land-use/land cover change to cultivated land has shown increase in the aerial coverage next to the bare land in the study area. The area invaded by *P. juliflora* was increased in the extent from 1986 (0.2%) to 2007 (3.4%) in the expenses of either of the land-use/land cover.

4.2 Spatial Distribution of *P. juliflora*

4.2.1 *P. juliflora* Distribution in 1986

The 1986 classified map clearly shows that *P. juliflora* invasion has started along the Awash River in the *Acacia* woodland area and open bush land (see Fig.15, see Table 7) where it was not so far from the area first detected. This was about one decade after the introduction of the species in the study area (Kassahun, 1999). By 1986, it was invaded about 769ha of the land-use/land cover in the western part of Amibara Woreda. In this year highest land-use/land coverage was occupied by shrub land (50.9%), which was half the cover percent of the study area followed by range land (24.7%), open bushland (13.8%) and then cultivated land (4.3%), *Acacia* woodland (2.0%) occupied the last but next to water area in the study area. *P. juliflora* was invaded about 0.2 % of the extent of the Woreda.

4.2.2 *P. juliflora* Distribution in 2001

The land-use/land cover map of 2001(see Fig.16, see Table 7) has revealed the extent of area invaded by this exotic species by two decades. The area along the Awash River in the *Acacia* woodland and open bushland in the western part and the northern part near the water area along the Awash River of the study area was invaded. The cultivated land near the Melka Werer and Melka Sedi state farm including the shrub land and the range land were also invaded. During 2001, higher land-use/land cover was occupied by shrub land (32.3%), followed by range land (27%), bare land (18.1%), cultivated land (8.3%) and bush land (7%) in decreasing order. The invaded land was over 1.1% of the total land-use/land cover of the study area. By this year *P. juliflora* invaded land was increased by five fold in extent as compared to the 1986 record.

4.2.2 *P. juliflora* Distribution in 2007

By 2007, (see Fig.17, see Table 7) the land-use/land cover has shown tremendous shift than before due to invasion by this invasive species. *P. juliflora* was invaded over a wide area around the cultivated land in the middle part of the study area near Melka Werer and Melka Sedi. The shrub land, bare land and the *Acacia* woodland along the Awash River and the open bushland mainly in the middle part of the study area were invaded by *P. juliflora*. The northern part along the Awash River and near the water areas were also changed to invaded land. By this year, the invasion was also spread in the north-western part in the open bushland and went down to western part along the River in the shrub land of the study area. The invasion has extended up to Melka Were and the Allidegie plain along Addis Ababa-Djibouti high way that was not observed in previous years. The extent of invaded land has increased over the last two decades to 3.4%, where as the shrub land followed by open bushland has shown a reduction in the land-use/ land cover area compared to 1986. Further, the bare land, which was covering a wide area in the eastern part of the study area in 2001, has increased by covering the eastern and north-western part of Melka Werer area and changing most of the shrub land to invaded and bare land by 2007.

4.3 Temporal Distribution of *P. juliflora*

P. juliflora has been continuously spreading to larger extents in the study area during these two decades since 1986 (Fig. 18). The percentage extent of invaded land area in 1986 was 0.2%, in 2001, it was 1.1% and in 2007 it was 3.4% of the land-use/land cover.

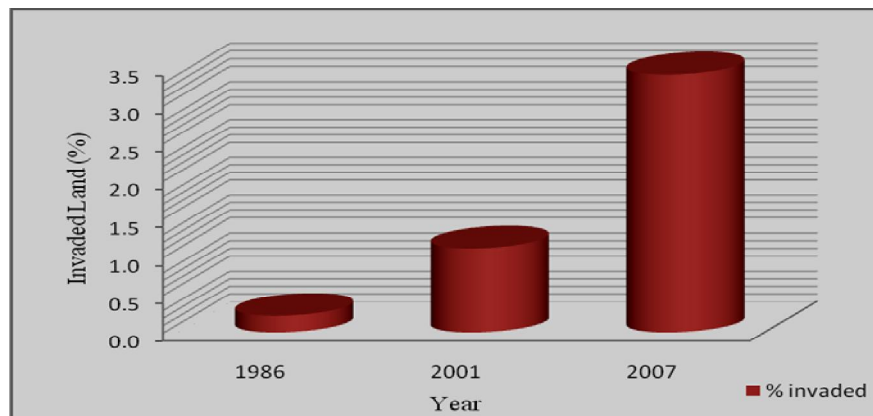


Figure 18: Temporal distribution of *P. juliflora* in Amibara woreda (Computed from Table 7)

In 1986, the invaded land has occupied about 769ha and in 2001 was increased to 3,849ha of the study area (Table 8). This land-use/land cover has shown a 205ha per year spread, which is 0.06% per year of the study area. During this time, shrub land and open bushland were reduced by 4,282ha and 1,569ha, respectively per year.

Table 8: Rate of Change of LU\ LC from 1986 to 2001(ha/year or %/year)

LU/LC List	1986	2001	Change	
	ha	ha	ha/ year	%/year
Invaded Land	768.8	3848.6	205.3	0.06
Range Land	85463	93611	543.2	0.16
Open bush Land*	47956	24421.4	-1569.0	-0.45
Acacia wood land	6896.1	17916.9	734.7	
Bare Land	13206.2	62715.7	3300.6	0.95
Water	1084.6	1152.3		
Cultivated Land	14962.9	30912.4	1063.3	0.31
Shrub Land*	176333.2	112092.4	-4282.7	-1.24
Total	346670.8	346670.7		

*= land-use/land cover that was showed a reduced rate in extent

Remark: (-) sign shows reduction in LU\LC

During the period from 1986 to 2001, *P. juliflora* has invaded 3848.6ha and during 2001 to 2007; the invaded land has reached to 11578.7ha of the study area. *P. juliflora* invasion has shown increase in spread rate of 1288.4ha per year in area coverage, which is 0.37% of the study area annually. Between 2001 and 2007 rate of expansion in hectare per year was higher than between 1986 and 2001. In the previous period, only open bushland and shrub land were reduced in area coverage. However, in 2001-2007 additional two land-use/land cover areas such as bare land and *Acacia* woodland have shown reduction (Table 9). Hence, the rate of change to invaded land has shown an increasing pattern from 0.06% area per year between 1986 and 2001 (see Table 8), while by 0.37% of the study area per year between 2001 and 2007 (Table 9).

Table 9: Rate of Change of LU\ LC (ha/year and %/year) since 2001 to 2007

LU/LC List	2001	2007	Change	
	ha	ha	ha/year	%/year
Invaded Land	3848.6	11578.7	1288.4	0.37
Range Land	93611	121091	4580.0	1.32
Open bush Land	24421.4	17845	-	-0.32
Acacia wood land	17916.9	9978.2	-	-0.38
Bare Land	62715.7	48611.7	-	-0.68
Water	1152.3	1101.7		
Cultivated Land	30912.4	49005.9	3015.6	0.87
Shrub Land	112092	80988.1	-	-1.50
Total	346671	340200		

*= land-use/land cover that was showed a reduced rate in extent

Remark: (-) sign shows reduction in LU\LC

4.3 LU/LC Dynamics and *P. juliflora*

4.3.1 Dynamics of *P. juliflora* during 1986-2001

Thus invasion of *P. juliflora* has shown an increasing pattern year to year since 1986 in the study area. Out of the total land-use/land cover changed between 1986 and 2001, the extent of invaded 769ha land in 1986 was increased to 3849ha in 2001 (Table 10).

Table 10: LU/ LC dynamics between 1986 and 2001 at Amibara Woreda (ha)

LU\LC List		Initial State (1986)								Row Total
		Invaded Land	Range Land	Open Bushland	<i>Acacia</i> woodland	Bare Land	Water	Cultivated Land	Shrub Land	
Final State (2001)	Invaded Land	219.5*	1.1	728.7	434.3	138.1	0.2	1444.8	882.0	3848.6
	Range Land	0.8	58122.	5247.3	0.3	605.5	0.0	209.2	29425.1	93611.0
	Open bush Land	84.9	2052.6	12136.8	576.3	263.7	3.2	1728.7	7575.2	24421.4
	<i>Acacia</i> woodland	264.6	12.4	9034.9	5425.9*	43.0	0.4	1990.1	1145.4	17916.9
	Bare Land	0.2	16522.	1544.7	1.4	10996.6*	0.0	706.9	32943.9	62715.7
	Water	6.7	0.0	6.3	48.3	1.0	1080.	3.0	6.4	1152.3
	Cultivated Land	190.3	121.5	12611.2	404.6	97.2	0.2	7502.8*	9984.7	30912.4
	Shrub Land	1.8	8630.6	6646.1	5.0	1061.1	0.0	1377.4	94370.5*	112092.4
	Class Total	768.8	85463	47956	6896.1	13206.2	1084.	14962.9	176333.2	0.0

*= land-use/land cover that was not transformed

Of all changes in year 2001 to invaded land; cultivated land has shown the highest change, which was 1444.8ha followed by shrub land (882ha), open bushland (729ha), *Acacia* woodland (434ha) and bare land (138ha) and least by range land and water. Rate of spread dynamics shown between 1986 and 2001 (Table 11), shows the highest invasion rate was 96.3ha per year which was from cultivated land to invaded land, where as shrub land to invaded land was the second highest (58.8ha per year) followed by open bushland, *Acacia* woodland, bare land and least from range land.

The result shows that most areas from the cultivated land has been invaded by *P. juliflora* next to *Acacia* woodland, specially areas located around western and middle part of the Woreda, where there are nearby villages and towns associated with state farm that was identified as route for livestock herd and market (Senayit et al., 2004). During the dry season (March to August), camels, goats and other livestock from different zone of Afar NRS has been migrating in search of water and fodder as well as to markets and nomadic settlements via the middle part of this Woreda following Awash River.

Table 11: Rate of Invasion from different LU/LC between 1986 and 2001(ha)

LU/LC List	Total Area Invaded	Invasion Rate per year
Range Land	1.1	0.1
Open bush Land	728.7	48.6
<i>Acacia</i> woodland	434.3	29.0
Bare Land	138.1	9.2
Water	0.2	0.0
Cultivated Land*	1444.8	96.3
Shrub Land*	882.0	58.8

*= land-use/land cover that was showed highest invasion rate in extent

These animals feed on pods of *P. juliflora* during the dry season together with other fodder species found. Hailu et al. (2004) has stated that after consumptive excretion by cattle, camels, goats and donkeys, the number of seeds recovered from 1 kg of droppings ranged between 760 – 2833, which could be source of infestation and one way of dispersal for other land-use/land cover. When these animals moved to cotton fields to utilize cotton residue from November to the end of January in the study area, especially in the state farm area around Melka Werer and Melka Sedi in the western and middle part of the study area following the Awash River basin. The above fact might have been a driving force on the dynamic spread of *P. juliflora* in the cultivated land than other land-use/land cover in the study area.

Above all, previous studies revealed that *P. juliflora* is equipped with a number of biological characteristics that foster its rapid invasion of new areas. Hailu et al. (2004) stated that production of many, small and hard seeds capable of surviving passage through the digestive system of animals, entering into the soil to form soil seed banks and remaining viable until favourable conditions are available for germination; attracting and rewarding pods for animals, containing fleshy and sweet mesocarp, that is meant for long-distance dispersal; accumulation of dormant but long-lived viable seed reserves that would serve as source of regeneration; production of a mixture of seeds, with few capable of germinating immediately after dispersal while others remain dormant; making it a very strong competitor invader combined with its sexual reproduction. Combinations of all these characteristics make *Prosopis* a powerful noxious invader.

Hence, the invasion of *P. juliflora* in the cultivated land and surrounding shrub land, open bushland in the study area might be accelerated by these factors. The spread has been also gone to flood plain *Acacia* woodland along the River Awash and range land which is of high economic importance the livelihood of local people. Thus, animals and their movement coupled with the physiological characteristics of the species might have been the primary agent of *P. juliflora* invasion dynamics in the study area.

4.3.1 Dynamics of *P. juliflora* during 2001-2007

Results of land-use/land cover change between 2001 and 2007 (Table 12) revealed that the invaded land which was 3,849ha in 2001 has been increased to 11,579ha by 2007. During this period, almost all the land-use/land cover has been invaded by *P. juliflora*. Among the land-use/land cover changed to invaded land since 2001, shrub land has the highest (2,742ha).

Next to shrub land the *Acacia* woodland (1,888ha), open bushland (1,732ha), cultivated land (1,650ha) and bare land have been changed to invaded land and showed higher invasion spread in area coverage.

Table 12: LU/ LC dynamics between 2001 and 2007 at Amibara Woreda (ha)

LU/LC List		Initial State (2001)								
		Invaded Land	Range Land	Open Bushla	<i>Acacia</i> woodla	Bare Land	Water	Cultivate d Land	Shrub Land	Total Row
Final State (2007)	Invaded Land	1401.3*	579.1	1731.6	1888.2	1551.7	35.5	1649.5	2741.7	11578.7
	Range Land	150.9	59739.4*	4262.0	604.1	18869.2	71.4	4038.9	33354.9	121090.
	Open bushland	200.5	463.5	5149.7	2996.4	434.4	45.5	5051.0	3504.1	17845.0
	<i>Acacia</i> woodland	679.3	81.5	1859.0	5488.8*	155.2	69.8	1131.6	513.0	9978.2
	Bare Land	60.3	5967.5	1216.9	38.2	28923.1*	14.6	212.2	12178.9	48611.7
	Water	29.2	0.0	117.2	158.9	0.0	711.8*	79.0	5.6	1101.7
	Cultivated Land	972.1	6142.0	5700.5	5305.7	2137.9	60.6	13911.2*	14775.8	49005.9
	Shrub Land	239.9	19666.5	4180.1	782.8	9809.7	165.5	4086.8	42056.8*	80988.1
Class Total		3733.5	92639.5	24217	17263.1	61881.2	1174.7	30160.2	109130.8	0.0

*= land-use/land cover that was transformed

Comparably lower change was observed from range land to invaded land with 579ha of the land-use/land cover which is 100% change than the previous period (1986-2001). Moreover, between 2001 and 2007, new invasion of water area by *P. juliflora* was recorded, which was almost insignificant in the previously. Between 2001 and 2007, an overall change of all land-use/land cover to invaded land were recorded with at least two fold increase than during 1986-2001 except the cultivated land that was reduced by 0.5 percent invasion.

The highest invasion dynamic was recorded from shrub land to invaded land. Shrub land was the most affected land-use/land cover in the study area during 2001-2007 periods. Rate of change of the shrub land to invaded land has been 183ha per year (Table 13) and twice of the previous period which was from shrub land to invaded land. The *Acacia* woodland transformed to invaded land was the second highest (126ha per year) followed by open bushland, cultivated land, bare land, range land and least from water area to invaded land per year. The shrub land invaded

during 2001-2007, was found near the cultivated land, which was highly invaded during 1986-2001 period.

Table 13: Rate of Invasion from different LU/LC between 2001 and 2007(ha)

LU\LC List	Total Area Invaded	Rate of Invasion per year
Range Land	579.1	38.6
Open bush Land	1731.6	115.4
<i>Acacia</i> woodland*	1888.2	125.9
Bare Land	1551.7	103.4
Water	35.5	2.4
Cultivated Land	1649.5	110.0
Shrub Land*	2741.7	182.8

*= land-use/land cover that was showed highest invasion rate in extent

The land-use/land cover dynamics revealed that the shrub land has been the most affected land-use/land cover by *P. juliflora* invasion during the study period. This could be due to movement of animals from one land-use to other after they feed on the pods of *P. juliflora*. Shrub land has been the most likely foraging area for camels in this Woreda together with the native tree found in the open bushland and *Acacia* woodland. Camels and goats browsing on the shrubs and bushy vegetation mainly on the roadside of the rangeland and around the settlement area, where they brows on scattered, large shrubs and graze the palatable forbs during the wet season in the study area (Personal communication with clan leaders and elders). Thus, invasion through seed dissemination via livestock face (goat, cattle, camel, sheep, etc.) and feed habit, trenching area, and their movement route are major means in the land-use/land cover dynamics due to *P. juliflora*.

Moreover to the above facts, the invasion dynamics become higher and higher during 1986-2007 in all land-use/land cover because Amibara Woreda could represents degraded semi-arid ecosystem in the country containing about 18% or 62,716ha of the degraded bare land and dry forest (Pasiiecznik, 1999). The reasons for rising invasion rate in all land-use/land cover in the study area might further accounted, since *P. juliflora* is drought-resistant, fast-growing and nitrogen-fixing capability that are able to grow in harsh conditions where other species may fail to grow. The species respond and survive stress conditions such as drought through changes in morphological, physiological, biochemical and metabolic processes (Pasiiecznik et al., 2001).

The cultivated land has an additional 200ha invaded area as compared in 2001, but a total increase in area coverage was shown, which might be due to deforestation of about 14,775ha of the shrub land and other land-use/land cover, after being invaded by *P. juliflora*. The deforestation was seemed for widening the cotton state farm in the area. During this period an overall change of all land-use/land cover to invaded land were showed at least two fold increase

as compared with that of during 1986-2001, except the cultivated land that was reduced by 0.5 in percent invasion.

Invasiveness of the species in this Woreda might be further induced because of poor management practices, disturbance of the open bushland and cultivated land which sometimes left fallow (Pasiiecznik, 1999). In this study area different land-use practices have been carried out, such as mechanized and local cotton-farm cultivations, irrigation facility for the farm through canals, rearing of livestock by the nomadic settlement. However, the spatial invasion of *P. juliflora* has caused many land-use/land covers to be at risk such as shrub land, open bushland, *Acacia* woodland, cultivated land and range land in the study area. In most land-use/land cover which has been invaded by *P. juliflora* observed that no species were grown underneath.

The species has been killing the native species in the surrounding like grasses and *Acacia* species (Fig.19). *Prosopis* leaves contain allelo-chemicals including tannin, which is not palatable to animals and has allelopathic effect to crops, weeds and other trees (Pasiiecznik *et al.*, 2001).

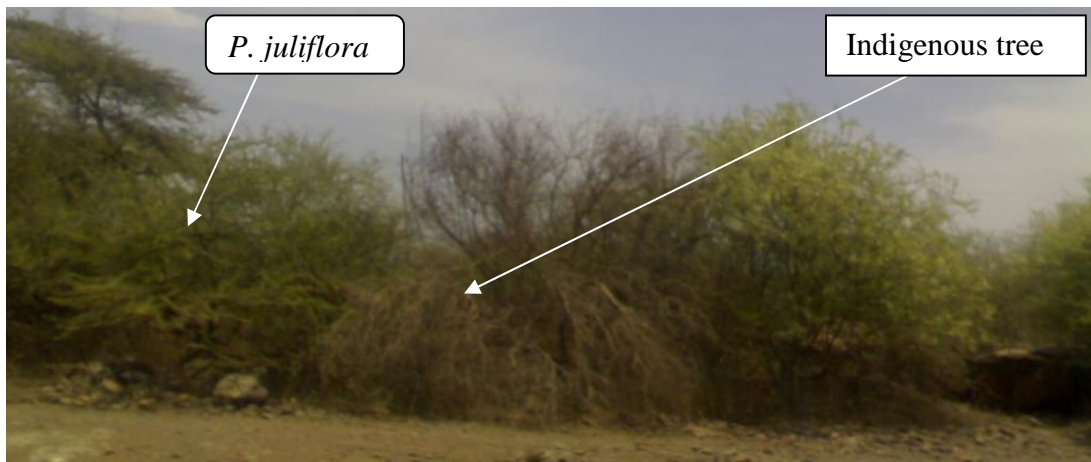


Figure 19: Indigenous trees dying out by *P. juliflora*, near Melka Sedi ANRS (Photo by Author)

Presence of strong poisonous thorns and bushy growth habit of *P. juliflora* might have made it less attractive and inconvenient for the society at the initial decade (1986-2001) in order to take intervention to reduce the impact of deforestation. If better management practices were made, the invasion rate could have been controlled and its adverse effect such as invading most economically important areas like cultivated land, shrub land, open bushland, *Acacia* woodland and range land of the study area could have brought under control.

Most of the land-use/land covers in Amibara Woreda have environmental variable factors like salinity/sodic soil problem that might have been driving forces to the spatial spread and dynamic distribution of this invasive species in the study area (Burley *et al.*, 1986). More over, *P. juliflora*

has broad ecological amplitude adapted to a very wide range of soils and site types from sand dunes to cracking clays. It is noted that there is hardly any soil, if it is not habitually damp, in which *P. juliflora* cannot grow; no hill too rocky or broken, no flat too sandy or saline, no dune too shifting to entirely exclude it (Pasicznik et al., 2001).

Furthermore, during 2001-2007 periods, new invasion was recorded in water areas in the northern part of the study area. The species has been found invading the *Acacia* woodland along the Awash River and near the cultivated land in the study area. This indicates that the species might be spread due to the presence of moisture or watercourses. The deep root system of *P. juliflora* allows competing for moisture (Mwangi and Swallow, 2005). Most irrigation canals found in the cultivated land of cotton farm could also be another means of seed dissemination, which might help in the spread of this species in the last two decades in the study area. Hence, spread of *P. juliflora* has been increased both in extent and density per unit area during 2001-2007. As a result, larger areas of potentially irrigable alluvial soil and rangeland are at risk due to invasion by *P. juliflora* (Hailu et al., 2004, Kassahun et al., 2004) in Amibara Woreda.

The rainfall pattern has also shown an increasing trend during this period, even though there were few lower records during 1984-2005 in the study area (Fig.20). Rainfall amount and distribution throughout the year is a major factor influencing growth and dynamics of *P. juliflora*. This change in rain fall amount might have favored the spatial spread of this alien species in the study area (Elfadl and Luukkanen, 2006). Weeds and other pests often do better if there is disruption from fire, floods, logging, livestock grazing, or hydrological changes (Dukes and Mooney, 1999; Trounce and Dellow, 2007).

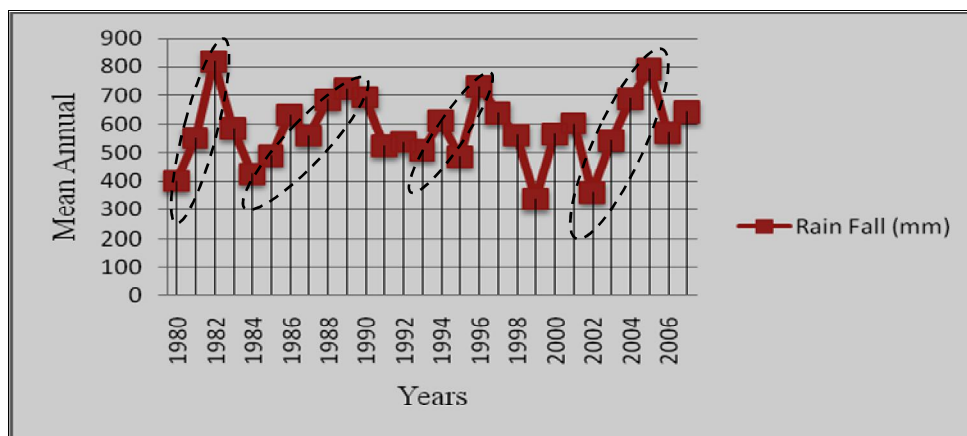


Figure 20: Mean Annual Rain Fall record

Climate change is expected to worsen the world's invasive species problems. Climate change has the potential to operate like a disturbance event by stressing population disturbance and create opportunities for invasive species to take the place of natives (Dukes and Mooney, 1999; Sutherst et al., 2007). In the study area floods of Awash River has been a common occurrence,

which carries seed of *P. juliflora* from one land-use/land cover to another to spread this species. Such spatial and temporal spread of *P. juliflora* could also be brought by the disruption of faunal communities for charcoal preparation, cattle rearing and browsing of camels in the open bushland, *Acacia* woodland and farm land in the settlement area (Cox, 2004) of the study area.

Lastly the study showed that, in Amibara Woreda for the past over two decades about 11,579ha of land-use/land covers have been totally changed to invaded land. During 1986-2001, total land-use/land covers of 3,629.2ha have been totally changed to invaded land (Table 14). During 2001-2007, 11,579ha of the land-use/land cover have been invaded by *P. juliflora* (Table 15). During this time, almost all the land-use/land covers have been changed to invaded land. The shrub land has been the most affected land-use/ land cover followed by the *Acacia* woodland during 2001-2007 periods. The unchanged land-use/land cover has shown a reduction rate by 2.3% during 2001-2007 periods being invaded by *P. juliflora*.

The rate of change of each land-use/land cover to invaded land has showed the extent in which these lands will be occupied or encroached by the invasive alien species in the study area. If this applies continuously with all other factors favouring the invasion spread being constant, thus those land-use/land covers in this Woreda, which have not been changed might be under great risk of invasion by *P. juliflora*, consequently endangering the livelihood of the local communities in the study area.

Table 14: Total LU/LC in Amibara Changed to Invaded land (ha), 1986-2001

Status	Area (ha)	Area (%)
Changed to Invaded	3,629.2	1.1
Unchanged	342,822	98.8

Table 15: Total LU/LC in Amibara Changed to Invaded land (ha), 2001-2007

Status	Area (ha)	Area (%)
Changed to Invaded	11,578.7	3.4
Unchanged	328,621	96.6

4.4 Prediction of *P. juliflora* Invasion Risk

If the invasion of *P. juliflora* proceed with the trend occurred between 2001 and 2007 (see Table 13), the land-use/land cover of the study area probability of being invaded by this alien species could be:

$$LC_n = LCo (1+nr)$$

Where, LC_n = Value of land-use/land cover in n^{th} year

n = number of years

r = rate of increase

LCo = value of land-use/land cover in previous n^{th} year

Thus, about 54, 419.89 ha the land-use/land cover of the study area could be invaded by *P. juliflora* after ten years in 2017. This is almost four fold of the invasion during 2007. Therefore, in the future research study on *P. juliflora* invasion prediction of risk should include better prediction model in the area as indicated by Krueger et al. (1998).

6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Invasive alien species can have a significant impact on development, affecting sustainability of livelihoods, food security and essential ecosystem services and processes. Invasive alien plant species, *P. juliflora* has become a great threat to biodiversity and challenge for the livelihood of the local communities in the study area. They out-compete native for space, light; nutrients and by colonizing any open gap in the land-use/land cover and form monotypic community. The species has invaded shrub land, open bushland, *Acacia* woodland, cultivated land, bare land, range land and water points respectively and has become a threat to the biodiversity in the area.

The pattern of land-use/land cover in Amibara Woreda was having tremendous difference during the study period. This can easily be recognized from the maps produced from the classification of satellite images of the study area from time to time. The 1986, land-use/land cover map represents the situation of only 6-7 years after the introduction of this species. The land-use/land cover pattern changed significantly after two decades, since then. The invasion was increased by many folds, since 1986 in the Woreda. The percentage share from each land-use/land cover revealed that invasion rate was higher in the land-use/land cover, where there is cultivated land (cotton-farm & settlements), where there are higher concentrations of the settlements. Highest invasion has been recorded in the lower eastern flood plain area along the Awash River basin in the shrub land, open bushland, *Acacia* woodland and along the road side.

Due to the above facts, *P. juliflora* has become the worst threat in Amibara Woreda. Most of the cultivated land areas have been changed to invaded land. Since, *P. juliflora* deep root system that competes for moisture has created damage on the cotton farm in the study area. The cotton-farm has much economical importance for this Woreda as well as for the region being an income sources for the livelihood of the local communities and hard currency for the country. More over, a lot of indigenous trees and pasture like *Acacia tortilis*, *Acacia Senegal*, *Acacia nilotica*, *Dobera gelabera* and *Cenchrus ciliaris* have been affected as a result of invasion of *P. juliflora*. The consequence might result in the loss of biodiversity and change in the ecosystem structure in the study area.

If such situation continued without proper management, it won't take longer time to see these areas reaching climax invasion level, where it could reaches impossible to think for the management options. The outcomes will not only be to this specific Woreda, but soon it might spread to the neighbouring Woredas and regions as well.

Thus, this study has made evident the feasibility of using integrated application of GIS and Remote Sensing to analyze the spatial and temporal invasion of *P. juliflora* from satellite image in Amibara Woreda of the Afar NRS. GIS has also provided powerful techniques by preparing a geodatabase for this invasive species visualizing the dynamics and invasion distribution of the species in the study area.

6.2 Recommendation

- ✚ The study has shown that out of the land-use/land cover in the study area invaded by *P. juliflora*, shrub land has been the most affected land. This might be due to the presence of livestock especially cattle and camel movement after they feed pods of this species. Even though, the scope of this study was not to explore invasion driving forces in the study area, future research should focus on the reason why such land-use/land cover has been susceptible for *P. juliflora* invasion.
- ✚ The spatial and temporal distributions also justify an increasing trend of invasion, both in the open bushland and *Acacia* woodland between the study periods. These land-use/land cover has been seriously affected by *P. juliflora* invasion next to shrub land. Therefore, in order to reduce further invasion, the control and management priority plan should start by looking the driving forces why these land-use/land cover became susceptible for invasion.
- ✚ The cultivated land has been the next highly invaded land-use/land cover by *P. juliflora* invasion even though reduction in total extent has not been recorded. Cultivated land (state farms + settlements) is the main economical background for peoples' livelihood in the region. Due to this, they replace the invaded cultivated land by deforestation of the nearby open bushland and shrub land. This might result in losing of the biodiversity and change the ecosystem structure of the area. Thus, Environmental Protection Agency and Biodiversity Research and Conservation shall be given high attention for the area.
- ✚ Thus, integrated application of GIS and Remote Sensing has shown the spatial, temporal and dynamic distribution of *P. juliflora* in Amibara Woreda. Further, research work using integrated application of GIS and Remote Sensing should focus in determining the risk zone using spatial modeling of this invasive species spread in the Kebele level, Woreda as well as in the region. So as to build a GIS model for the region to determine future spread of *P. juliflora*.

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Appendix

Appendix 1. *P. juliflora* Transect Survey

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDNIES EARTH SCIENCES DEPARTEMENT

REMOTE SENSING AND GIS UNIT

Enumerator: _____

Title: Spatial and Temporal Analysis of *Prosopis juliflora* (Swarz) DC Invasion in Amibara woreda of the Afar NRS

ID	Land use\land cover	GPS Reading		Altitude (meter)	<i>P. juliflora</i> Count	Location	Status
		Latitude(N)	Longitude(E)				

Appendix 2: Observation or Ground Control Points collected

ID	Land-use\land cover	Latitude (N)	Longitude (E)	Altitude (m)	<i>P. juliflora</i> count	Location	Status
1	Range Land	9.28991	40.37985	859	0	Alledgie	None
2	Range Land	9.29093	40.38038	855	0	Alledgie	None
3	Range Land	9.29204	40.38079	855	0	Alledgie	None
4	Range Land	9.29305	40.38119	851	0	Alledgie	None
5	Range Land	9.29414	40.38156	852	0	Alledgie	None
6	Range Land	9.29597	40.38211	853	0	Alledgie	None
7	Range Land	9.2969	40.38288	853	0	Alledgie	None
8	Range Land	9.2969	40.38368	851	0	Alledgie	None
9	Range Land	9.29786	40.38406	850	0	Alledgie	None
10	Range Land	9.29876	40.38462	850	0	Alledgie	None
11	Range Land	9.28373	40.31631	812	5	Alledgie	Low
12	Range Land	9.28278	40.31674	811	1	Alledgie	Low
13	Range Land	9.28188	40.31714	811	12	Alledgie	Low
14	Range Land	9.28088	40.31766	812	0	Alledgie	None
15	Range Land	9.28002	40.318	813	15	Alledgie	Low
16	Settlement	9.27717	40.30247	810	22	Alledgie	Low
17	Settlement	9.27865	40.32249	808	35	Alledgie	Low
18	Settlement	9.27954	40.30218	807	0	Alledgie	None
19	Settlement	9.28033	40.30129	806	0	Alledgie	None
20	Settlement	9.28104	40.30057	807	145	Alledgie	Highly
21	Range Land	9.28132	40.30026	808	120	Alledgie	Highly
22	Range Land	9.28226	40.30022	803	58	Alledgie	Medium
23	Range Land	9.28347	40.30016	804	13	Alledgie	Low
24	Range Land	9.28419	40.29937	809	33	Alledgie	Low
25	Range Land	9.28482	40.29861	803	30	Alledgie	Low
26	Range Land	9.2716	40.24536	810	140	Alledgie	Highly

27	Range Land	9.27208	40.24435	803	126	Alledgie	Highly
28	Range Land	9.27208	40.24318	805	123	Alledgie	Highly
29	Range Land	9.27299	40.24229	803	160	Alledgie	Highly
30	Range Land	9.2736	40.24142	802	158	Alledgie	Highly
31	Settlement	9.27686	40.22705	797	73	Berta	Medium
32	Settlement	9.27597	40.22633	799	79	Berta	Medium
33	Settlement	9.27521	40.22566	802	69	Berta	Medium
34	Settlement	9.27566	40.22501	801	89	Berta	Medium
35	Settlement	9.27633	40.22424	803	35	Berta	Low
36	Settlement	9.28499	40.21969	804	29	Berta	Low
37	Settlement	9.28417	40.21898	801	17	Berta	Low
38	Settlement	9.28507	40.2183	801	76	Berta	Medium
39	Settlement	9.28577	40.21901	798	0	Berta	None
40	Settlement	9.28655	40.21827	795	57	Berta	Medium
41	Shrub Land	9.29168	40.21635	796	35	Berta	Low
42	Shrub Land	9.29078	40.21598	793	84	Berta	Medium
43	Shrub Land	9.29003	40.21567	789	33	Berta	Low
44	Shrub Land	9.29048	40.2148	782	30	Berta	Low
45	Shrub Land	9.2912	40.21393	776	13	Berta	Low
46	Cultivated Land	9.33051	40.20029	730	0	Serkamo	None
47	Cultivated Land	9.33053	40.1992	729	0	Serkamo	None
48	Cultivated Land	9.33053	40.1982	731	0	Serkamo	None
49	Cultivated Land	9.33055	40.19715	728	0	Serkamo	None
50	Cultivated Land	9.33057	40.19617	724	0	Serkamo	None
51	Invaded Land	9.29457	40.17913	736	160	Bedula ali	Highly
52	Invaded Land	9.29411	40.17981	734	130	Bedula ali	Highly
53	Invaded Land	9.29337	40.18061	734	164	Bedula ali	Highly
54	Invaded Land	9.29393	40.17836	737	158	Bedula ali	Highly
55	Invaded Land	9.29304	40.17776	738	154	Bedula ali	Highly
56	Canal	9.28567	40.17379	734	0	Melka Sedi	None
57	Canal	9.28473	40.17341	739	0	Melka Sedi	None

58	Canal	9.28371	40.17295	736	0	Melka Sedi	None
59	Canal	9.28259	40.17246	737	0	Melka Sedi 4th	None
60	Canal	9.28167	40.17206	736	0	M Melka Sedi 4th	None
61	Saline land	9.26958	40.14999	740	0	Melka Sedi 4th	None
62	Saline land	9.27053	40.14946	737	3	Melka Sedi 4th	Low
63	Saline land	9.27153	40.149	736	4	Melka Sedi 4th	Low
64	Saline land	9.27245	40.14871	740	0	Melka Sedi 4th	None
65	Saline land	9.27352	40.14835	736	6	Melka Sedi 4th	Low
66	Settlement	9.29003	40.14203	736	0	Arategna	None
67	Settlement	9.32838	40.18052	744	0	Melka Werer	None
68	Settlement	9.32892	40.18135	739	22	Melka Werer	Low
69	Settlement	9.3299	40.18161	739	5	Melka Werer	Low
70	Settlement	9.33095	40.18148	744	4	Melka Werer	Low
71	Settlement	9.33199	40.18157	736	4	Melka Werer	Low
72	Acacia Woodland	9.38828	40.15631	717	0	Bedhamo	None
73	Acacia Woodland	9.38927	40.1562	729	0	Bedhamo	None
74	Acacia Woodland	9.39013	40.15605	757	0	Bedhamo	None
75	Acacia Woodland	9.39097	40.15595	747	12	Bedhamo	Low
76	Acacia Woodland	9.39213	40.15659	736	0	Bedhamo	None
77	Settlement	9.39635	40.17041	730	20	Sheleko	Low
78	Settlement	9.39571	40.17116	731	30	Sheleko	Low
79	Settlement	9.39575	40.17212	728	25	Sheleko	Low
80	Settlement	9.396	40.17309	728	4	Sheleko	Low
81	Settlement	9.39659	40.17386	726	28	Sheleko	Low
82	Open Bushland	9.48949	40.27516	711	0	keeliate	Low
83	Open Bushland	9.48974	40.27600	718	0	keeliate	None
84	Open Bushland	9.48933	40.27699	719	0	keeliate	None
85	Open Bushland	9.48919	40.27801	715	0	keeliate	None
86	Open Bushland	9.48882	40.27922	719	0	keeliate	None
87	Open Bushland	9.51881	40.30398	717	0	Angelleli	None
88	Open Bushland	9.51802	40.30336	719	0	Angelleli	None

89	Open Bushland	9.51692	40.30315	719	0	Angelleli	None
90	Open Bushland	9.51597	40.30291	719	0	Angelleli	None
91	Bare land	9.49955	40.31063	722	0	Buri	Bare
92	Bare land	9.49864	40.31095	723	0	Buri	Bare
93	Bare land	9.49755	40.31106	722	0	Buri	Bare
94	Bare land	9.49655	40.31108	724	0	Buri	Bare
95	Bare land	9.49551	40.31104	724	0	Buri	Bare
96	Shrub Land	9.48919	40.3044	724	0	Buri	None
97	Shrub Land	9.48998	40.30506	723	0	Buri	None
98	Shrub Land	9.49072	40.30567	724	0	Buri	None
99	Shrub Land	9.49138	40.30643	724	9	Buri	Low
100	Shrub Land	9.49189	40.30728	724	17	Buri	Low
101	Settlement	9.4978	40.30826	726	0	Bilen	None
102	Invaded Land	9.3664	40.21151	725	225	Ambash	Highly
103	Invaded Land	9.43558	40.21098	718	216	Ambash	Highly
104	Invaded Land	9.43472	40.21045	724	238	Ambash	Highly
105	Invaded Land	9.43385	40.20991	722	220	Ambash	Highly
106	Invaded Land	9.43293	40.20939	725	215	Ambash	Highly
107	Cultivated Land	9.43626	40.20448	728	0	Ambash #1	None
108	Cultivated Land	9.43609	40.20367	727	0	Ambash #1	None
109	Cultivated Land	9.43713	40.20282	725	0	Ambash #1	None
110	Cultivated Land	9.43761	40.20189	724	0	Ambash #1	None
111	Cultivated Land	9.43809	40.20096	725	0	Ambash #1	None
112	Settlement	9.43607	40.20601	727	1	Ambash	None
113	Settlement	9.43703	40.20633	732	1	Ambash	None
114	Settlement	9.4379	40.20685	728	30	Ambash	Low
115	Settlement	9.43876	40.2074	729	20	Ambash	Low
116	Settlement	9.43952	40.20786	723	50	Ambash	Low
117	Fallow Land	9.31107	40.19621	735	200	Adobetelie	Highly
118	Fallow Land	9.31042	40.19722	735	200	Adobetelie	Highly
119	Fallow Land	9.30973	40.19781	736	212	Adobetelie	Highly

120	Fallow Land	9.30911	40.19876	736	231	Adobetelie	Highly
121	Fallow Land	9.30841	40.19923	738	205	Adobetelie	Highly
122	Settlement	9.3988	40.32704	815	20	Andido	Low
123	Settlement	9.39889	40.3283	812	0	Andido	None
124	Settlement	9.39854	40.33012	813	0	Andido	None
125	Settlement	9.39751	40.33188	812	0	Andido	None
126	Settlement	9.39966	40.32623	806	15	Andido	Low

Remark: Low = low invaded land (< 30 *P. juliflora* count)

Medium = medium invaded land (30 to 90 *P. juliflora*)

Highly = highly invaded land (> 100 *P. juliflora*)

None = no single count of *P. juliflora*

Appendix 3: Characteristics of the 3 ASTER Sensor Systems. (ASTER Users Handbook)

Subsystem	Band	Spectral Range (micro	Spatial	Quantization
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

Appendix 4. Approximate distribution *P. juliflora*-*P. pallida* complex

