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Mesquite Trees Infestation of the Gash Spate Irrigation system in Kassala state, Sudan

Impacts and Remedial Measures

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Abstract

Mesquite *(Prosopis spp.)* are ever green leguminous trees or shrubs. These species are native to North and South America. They were introduced to Sudan in 1917 from South Africa and Egypt and planted in Khartoum state in central Sudan. In Kassala state mesquite was even broadcasted by plane to be planted in early 1970's. It is then becoming a problem in 1990's when the government stopped planting the trees in Sudan. Mesquite was originally favored as sand dunes stabilizer and as fodder for livestock. However, sparse stands often formed impenetrable thickets formations that hindered the movement of water ways, human, animals. Many infestations in Kassala state in eastern Sudan are along the waterways, especially in irrigation canals and river banks. However mesquite trees can also grow in drier areas away from water sites. Even in natural rangelands it is an aggressive competitor and can quickly invade the upland country. Mesquite thickets can out compete other vegetations; interfere with mustering and blocking the access to watering places and irrigation systems.

This research evaluated the impact of Mesquite trees infestation in Gash Spate Irrigation system in Kassala state in Sudan from 1979 to 2013. Randomly GCP's (Ground Control Points) collected and by using Garmin GPS (Global Positioning System), the coordinates were exported to identify the study area. Remote sensing imageries of Landsat 1-3 MSS of 1979, Landsat 4-5 TM of 1985, 1998 and Landsat 8 OLI of 2013 with the combination of the supervised and unsupervised classifications was used along the Principal Components Analysis (PCA) spectral transformations technique. This was to produce five land cover classes, namely as Mesquite trees, other vegetations, Agricultural areas, Bare land and Urban/stabilized sand areas, which reveal that the increment of mesquite trees infestations in Gash is at large. Using ArcGis and Remote sensing tools, five research questions were answered and recommend the alternative ways to get rid out of this invasive species. The questions were meant to evaluate how are the mesquite tree has changed over the years, what are the factors which contributed to that trend, what are the impacts of mesquite trees on agricultural production in Gash agriculture area, the effectiveness of the existing measure to eradicate the mesquite and to recommend the possible best way to get rid out of it. . Additionally an accuracy assessment was done and reported that a producer's accuracy of 98% and a user's accuracy of 64% for mesquite trees. An overall Kappa statistics of 66% and overall accurate assessment of 76% was observed during the classifications.

My results suggest that mesquite trees are heavily infested in the delta and the all area around for many years but from mid 1990 to 2013 infestation were much increased because of movement of animals each year and water from Gash river which is transferring the seeds from upstream to downstream areas and finally to the farms. However mesquite has a tendecy of growing along the river and canal banks hence inhabiting favourable condtions for fast growth. Mesquites is also found on road sides, irrigated crop lands, riverine forest and even in the areas which are away from the river.

The total areas of 141,942 ha out of the total Gash delta area of 371,870 ha have been gained from May 1979 to April 2013.This area of mesquite trees invaded only in the delta. The trend of mesquite increament has been so fast that it threatens the life of livestock keepers, farmers and all citizens in general. From may 1979 mesquite covered around 89,428 ha out of total area with low reductions on water and crop yield, in 1985 it increased to 104,483 ha and still there were no any program to deal with the weed. Recently in 2008 ten years after other study which shows that in 1998 (117,076 ha) the massive weed were already affecting the irrigation canals and cause many impacts on the river Gash, and its irrigation facilities then authourities started observing its impacts.

There are so many factors which contribute to the trends of mesquite infestation in GAS, animal movement and poor water management among others. When animal moves from one area to another due to search for water and food they normally drops the dung with seeds. Seeds are exposed to enzyme action in the stomach which promotes fast germination after expulsion during the plant growth process. Poor water management and flood system contribute a lot to the transportations of mesquite pods and seeds to downstream areas that invade the farms. Animals like eating mesquite pods because they contain a high sugar content (16%) and protein (12%) which is palatable to animals. Other factors like air movement, ability of the trees to adapt to different environment also contributed a lot. The Kassala state government stopped planting Mesquite in the year 1990 and launched a campaign to get rid out of it. In 2005 there were several government intervations some of which included creation of a management mesquite team but all failed to stop the weed due to several reasons. Year after year the density of mesquite is increasing and threatens the agricultural productions, water sources and life of livestock keepers.

In this study it suggests that mesquite trees contribute a lot on the crop yield reductions and blockage the water passage to irrigation canals. Its ability to remain viable in the soil up to ten years, adaptation to different environment and high resistance to drought compared to other vegetations/trees suggest that much water is consumed by the mesquite especially in desert area like Sudan. However there are so many factors which contributed to the crop yield reduction in Gash, but due to Mesquite characteristics of rooting up to 50m down the ground and 6m root wide then there are enough possibility that mesquite trees affect the crop productions. The estimated calculations from this study shows that 730,285,714 litre/day is consumed by mesquite in the total area of 42,600 ha which is only for agricultural purposes. It is also suggests that the total amount of water consumed by the mesquite for the Gash delta infestated area by mesquite is 2,433,291,428litres/day.Evapotranspiration was considered to be 2/3 of the total discharge by mesquite. Seepage, deep percolation and other factors were not considered as the area is desert and flood water is per season. Therefore, a large amount goes to evaporation and irrigation.

Though for this study only Sorghum crop were considered for the evaluation. The results show that at the current application rate of 823 to 987 mm, a yield of about 5 ton/ha is obtained, which is considered to be optimum by FAO recomendations. Should as informed by the farmers, a 50% reduction in application happens, the yield will sigificantly reduce by up to 50% to 2.5 ton/ha. It was further be inferered that, assuming that farmers continue to utilize 987 mm or about 9870 m^3/ha, a total of 493,500,000 m^3 of water will be required to sufficiently irrigate approximate 50,000 ha currently irrigable land in Gash Agricultural Scheme. If the irrigation application of 9,870 m^3/ha is maintained while the actual supply is redcued to 6170 m^3/ha (scenario 2) and 4940 m^3/ha , the irrigable area will be reduced from 50,000 ha to 31,500 ha and 25,000 ha respectively. Assuming a maxium yield of 5 ton/ha and market price of sorghum is 3000 SDG/ton (412.5 USD/ton) then a farmer can get a cash back of 2062.50 USD

Despite several negative impacts of mesquite tree in GAS, it has so many advantageous and if implemented wisely it can increase the economic value of the people around Kassala. Mesquite can be processed for timber, charcoal productions, the edible pods with high protein and large amount of sugar can be converted to flour for making bread, juice,honey and even medication for eractile disfunction. In this reasearch only charcoal production were evaluated using cost benefit analysis with total infested agricultural area (42,600 ha) were considered. The analysis results shows that if the total agricultural area infested (42,600ha) were to be cleared and produced charcoal,the benefit is 36,818,571 USD for selling charcoal and the same area if cleared and harvesting sorghum the total amount of 73,218,750 USD will be the benefit. The analysis was estimated into Sudanese currency and then converted to USD. It is advisible to start using mesquite as a resource and benefit from it especially eradication on agricultural areas.

A number of recommendations have been put in this study in order to benefit from the trees including charcoal making, honey productions, electrical power supply from mesquite logs etc. The Sudanese federal government has the role to play to make sure that mesquite trees becoming benefit to rural people of Kassala. Moreover, New Halfa agriculture scheme could be a pilot study on the campaign to eradicate mesquite trees in Gash, for two years 2008-2010, the ministry of agriculture in New Halfa started the eradication program which was later adopted by farmers themselves and it was successfully removed from the farm areas.

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DEDICATION

To my little handsome Rayhanhson, you're born to serve people and *Al Kaaba* is the way to follow son, dad love's you very much

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Abbreviations

ETM	Enhanced Thermatic Mapper
ENVI	Environment for Visualizing Images
FAO	Food Agriculture Organization
GAS	Gash Agriculture Scheme
GPS	Global Positioning System
GLCF	Global Land Cover Facility
GCP	Geographic Control Points
GRTU	Gas River Training Unit
GDP	Gross Domestic Product
HRC	Hydraulic Research Center
HDRA	Henry Doubleday Research Association
IHE	Institute of Hydraulic Engineering
IFAD	International Fund for Agricultural Development
IFAD	International Fund for Agricultural Development
LULC	Land Use and Land Cover
MLC	Maximum Likelihood Classifications
MSS	Multispectral Scanner
ND	Not Defined
NDII	Normalized Difference Infrared Index
OLI	Operational Land Imager
RGB	Red Green Blue
SUST	Sudan University of Science and Technology
SDG	Sudanese Pound
TM	Thermatic Mapper
UTM	Universal Transverse Mercator

CHAPTER 1

INTRODUCTION

1.1. Background

Agriculture is considered as the mainstay of the Sudanese economy which contributes for about 38.9 % of the GDP provides about 80 % of the country's export and about 80 % of the population depends on agriculture for livelihood (Mohammed et al., ND). The Gash Agricultural Scheme (GAS) is considered as one of the pilot projects that contribute to the rural development and population settlement in eastern Sudan, particularly towards local population around the Gash River area. The Gash River is a torrential stream originates from the Eritrea/Ethiopian Plateau and ends up in a flat delta within the eastern part of Sudan. The length of the river is about 110 km from the Eritrea/Ethiopian border to the end at the Gash Delta. The flow is seasonal, and occurs between June and October. It varies significantly between the years, from a minimum of 200 to a maximum of 1200 Mm^3/year (Mohammed et al., ND).

According to Abualgasim[1] et al., (ND), the river irrigates the large Gash delta through Gash Irrigation Scheme (120,000 feddans), which was constructed at the beginning of the 20th century. The Gash River is also the main source of water for the Kassala Town. Kassala town in Eastern Sudan, a huge blasted land of some 300,000 square kilometers, is home to an estimated 3 - 4 million of Sudan‘s poorest people. The region is made up of three states: Red Sea, Gadaref and Kassala. In each of these states the living conditions are so rough that the local population has been facing with intensive poverty, persistent drought, in addition to land degradation and shrinking pasture areas, for a very long time (Ayoub 2004). Following increased desertification in eastern Sudan, especially in Kassala State, studies have been conducted to investigate the causes and impacts of the desertification.

The large part of the area (Kassala state) is semi arid with average annual rainfall of about 50-200mm/yr (Helldén 1984). According to Helldén (1984), Gash River is rises above 2000 m in the Eritrean – Ethiopian high lands and has a catchment area of 21,000 km^2, with intense flood flows of 60 – 70 days and average annual discharge of about 1000 million m^3. The design of scheme is typical of flush irrigation system. Water is directed through basic off take structures into the main canals leading to about 280 blocks in Gash Delta (GAS). Crop cultivation usually starts about one week after irrigation. The net command area served by the river is around 240,000 feddans (1 feddan = 4200m^2), managed under a three year rotation, up to

80,000 feddans of crop is grown each year. In the Gash Delta, the percentage of farmers is high, but cultivated land is small and land allocation for cultivation depends on the size of the seasonal flooded area. Agricultural output in the Gash Delta is way below its potential (Mohammed et al., ND).

The aim of the scheme is to settle poor nomadic people to grow cotton as a cash crop so that to be economically self-sufficient. In the last decade, the scheme has undergone serious deterioration, invasion of unfavorable Mesquite trees. This factor leads to acceleration of the degradation process in the study area,(Hinderson,2004).

1.2. Problem Statement and Major Threat

According to Van Steenbergen (2010),poor field and land management as a results of the absence of permanent land ownership in the systems cause tens of thousands of hectares were invaded in the GAS by mesquite trees which affecting the spate irrigation systems. Because of its hardiness it has become an invasive weed and a problem in many areas. It spreads rapidly by seed along water-courses and across grazing lands and, being thorny and shrubby, can quickly form impenetrable thickets, blocking tracks and preventing access to water. The mesquite has a very problematic spreading which threatens agriculture in huge area of eastern Sudan. Its invasion into crop land, together with irrigation channels and water courses cause huge impacts to the area. In most of the infested sites, mesquite forms impenetrable thickets that smothered and excluded native vegetation and substantially changed community structure. Mesquite trees is regarded as one of the worst weeds in Sudan because of its invasiveness, potential for spread and economic and environmental impacts (Hamza 2010).

Figure 1-1 Mesquite trees on either side of the diversion channel for irrigation (Bokrezion 2008)

In Gash Irrigation Scheme (GAS), Mesquites reduce the agriculture productivity by taking over the grasslands and using valuable water resources. The environmental impacts of mesquite include land erosion resulting from the loss of grassland habitat that supports native plants. This study has considered problem mainly on low production of agriculture and its measure to remediate and advise the best solution to eradicate/control in an economic manner the mesquite infestation in Gash Agriculture Scheme.

1.2.1. Control and or eradication

Most eradication programmes have proved unsuccessful. Improved knowledge and understanding on its management and uses provides a way of keeping it under control whilst benefiting resource-poor communities. To eradicate the tree completely it has been a very huge task for poor country like Sudan. Only Australia has an eradication programme which is going on, where huge budget of funds has been put aside to this end (Department of Natural Resources and Mines 2003).
In a country like Sudan the eradication campaign doesn't seems neither economically nor technically viable but in any case the plant should be controlled and used to prevent its further spread to unwanted area. This project research emphasized on explore the hypothesis that there are certain vital areas like in canals and irrigation channels, land for agricultures where mesquite tree should be eradicated and other area where it will be allowed and serve as good source for productive biomass etc.

1.2.2. The impacts of Mesquite on water for agriculture

According to DC Le Maitre (1999c) , Water for agriculture, and especially groundwater use, by mesquite trees has a major impact. Mesquite can develop a wide root systems that can reach water tables at depths of at least 15m and sometimes can go up to more than 50m (Phillips 1963). Mesquite forms its densest stands in floodplains where groundwater is potentially accessible Transpiration is limited by available soil moisture, but the trees can sustain high transpiration rates despite high moisture stress levels (D Le Maitre

1999a), therefore it is necessary to look onto how mesquite is affecting the water especially for agriculture production. The agriculture systems mostly irrigation which is practiced in Gash Delta is affected much by this exotic tree. It affects the irrigation canals, where its existence and growth hinders the correct flow of water and reduces the crop productions. According to Angelo State University (June 19, 2001), 130 million mesquite trees can consume up to 2 million acre feet of water annually, and an acre foot of water is equivalent of 325,850 gallons (1,481,344 Litres).

1.3. Research objective

The overall objective of the research is to analyze the impact of mesquite tree infestation on the agricultural production in Gash Spate irrigation scheme and recommend the possible technically and economically viable remedial measures.

Specific Objectives

1. To examine spatial and temporal land cover changes of the Mesquite tree coverage in Gash Spate Irrigation scheme using satellite imageries from year 1970's to 2013.
2. To study the impact of the Mesquite tree on water supply for canal capacities and reduction of command area for irrigation in Gash Spate irrigation area.
3. To assess the effectiveness of measures used to control Mesquite tree in Gash Spate Irrigation area.
4. To recommend the alternative technical and economical feasible control measures of mesquite tree infestation in Gash Spate irrigation area.

1.4. Research Questions

To achieve the research objectives the following questions were answered:

1. How the Mesquite tree infestation has changes over the years?
2. What has the factors that contribute to that trend?
3. What are the impacts of Mesquite trees infestation on the agriculture production of Gash Irrigation Scheme in Kassala region, north-east of Sudan?
4. How effective are the existing measures to reduce or eradicate the infestation of mesquite trees has been done
5. What alternative measures, (if any) could be recommended

CHAPTER 2

MESQUITE TREES (*Prosopis spp*.)

2.1. Mesquite Trees *(Prosopis spp.)*

The Prosopis spp., namely the mesquite tree was deliberately introduced 1917 on a large scale into northern and eastern parts of Sudan for the purposes of dune stabilization (Hoshino et al., 2012). Furthermore Hoshino et al., (ND) states that mesquite has since then spread in an uncontrolled manner and become a serious weed in many parts of the country.

Prosopis, as it is much known as Mesquite in Sudan is a perennial woody plant, characterized by a strong root system, and with the ability to grow under a wide range of environmental conditions. In the 1970s and 1980s it was widely disseminated in Sudan for the purpose of addressing the problems of Sudan's arid and semi-arid areas, summarized as: fuel wood production; pods for fodder; soil stabilization; and as a means for stopping the desertification process. However there is great controversy surrounding the Mesquite shrub. When unmanaged, it often colonizes disturbed, eroded and over-grazed lands, forming dense impenetrable thickets alarming pastoralists, farmers and conservationists alike. Its spreading and growth are extremely difficult to control and it negatively affects Sudan's agriculture productivity (Brown and Massey 1929b).

The invasion of mesquite in Gash Agriculture scheme (GAS) in the region of Kassala ,Sudan is considered one of the major issues threatening the productivity of the scheme and lead to poor field and marginal land management arrangements, loss of productive crop lands, recession of water table and many threat to the famers of Kassala region. Various manual and mechanical methods were deployed and at considerable cost to eradicate it or at least keep it under control. Most of the methods applied had their inherent strengths and weaknesses. They were all faced by the looming threat of mesquite return from coppice, soil seed bank, animal droppings etc.(Brown and Massey 1929b).

Due to these reasons Sudan decided to declare Mesquite as noxious weed and launched a national program for its eradication. This is a brave task as it continues to spread quickly into agricultural lands and irrigation canal, (Babiker,2006) Therefore the purpose of this research is to see the impacts of mesquite tree infestation, review the eradication which has been done in the past and introduce or promote the measure to reduce or control the infestation and comes with Mesquite control that can improve livelihoods through resource exploitation and advise the core measure to be taken or entertained by farmers to make use of this exotic tree

The study will also look on the economic way of solving the problem by considering the community in the Gash Agriculture area, to participate onto charcoal production using mesquite as raw materials, finding the possibility of covering the cleared area with farming activities and since the seeds are the main vehicle of transport and spread of the weed, there is a need to avoid glazing the livestock from mesquite tree. It is possible to make more use of it, developing these trees economically and helping those who live in Gash Irrigation project area where it is found.

2.2. What is *Prosopis spp.* known as Mesquite?

According to Rachele Osmond et al., (2003), defined Mesquite (Prosopis species) as an exotic plant that has been recognized as a weed of any country invaded significance due to its invasiveness and subsequent ecological, economic and social impacts. The ecological situation of Mesquite can be either a multi-stemmed shrub with branches drooping to surface level, or a single-stemmed tree with a spreading canopy that can grow to 15 m in height. Mesquite is often a single-stemmed tree with area on the ground, while the remaining species and hybrids are generally multi-stemmed shrubs that can grow to 10 m, but are more commonly3–5 m high. This is the most extensive root system of any plant in the world (Thorp et al., 2000).

Figure 2-1 Mesquite tree can grow up to 15m (Thorp et al., 2000)

Pods

The seed pods are 5–20 cm long, straight to slightly curved, smooth, and with slight constrictions between the seeds. Ripe pods are straw-colored or sometimes purplish. Normally it contains from 5 to 20 hard seeds of each pod with round or oval in shape. *(see appendixes)*

Thorns
Mostly Mesquite found in Kassala are thorny, variations can occur. Thorns usually occur in pairs above each leaf stalk or along the main stem. They usually range in length from 4 to more than 75mm. *(see appendixes)*

Flowers
According to Rachele Osmond et al., (2003), the mesquite flowers come with greenish yellow in color. They are grouped in spike-like clusters on short stalks giving the general appearance of a cylinder-shaped they so called 'lamb's tail'. It goes from 5–12 cm long. The lamb's tail appearance of the flowers is a unique characteristic of the Prosopis species**.** *(see appendixes)*

Leaves
Leaves of mesquite are fernlike in appearance. Each leaf has 1–4 pairs of leaf branches (pinnae), with each branch having 6–18 pairs of individual leaflets (leaves). Leaf characteristics of the different mesquite species vary. *(see appendixes)*

2.3. Life of Mesquite

One thing that is clearly evident about mesquite is that, once established, it can be very long-lived, even in the harshest of environments. In the United States, one of the countries of origin, were believed to have an average age of 33–44 years, with the oldest trees estimated to be over 170years old. This longevity may help explain why very few dead plants are ever observed in mesquite infestations. This has serious implications for controlling, as it means that once established, a plant will continue reproducing and spread all over the area if not controlled.(Golubov et al., 1999)

Its roots can grow down to 50m with ability to adapt a very wide range of soil conditions. Mesquite can extend the root up to 30m which makes to be a very most extensive root system of any plant in the world (R Osmond, March, N, Campbell, S, Klinken, R, Cobon, R & Jeffrey 2003). With large carbohydrates stored in the root act as a buffer against environmental stress and serve as a carbohydrate source for new growth following defoliation, allowing mesquite trees (and even seedlings) to survive repeated top-kills and many years of constant defoliation. Mesquite has the ability to extract soil water and actively photosynthesis when soil moisture is so low that most other desert plants shut down or die. Mesquite can actively grow even during prolonged drought (Rachele Osmond et al., 2003).

Figure 2-2 Mesquite tree roots of three month old with 5m depth in New Halfa Irrigation Scheme (Source-Author)

Prosopis has many uses including livestock fodder, human food from the pods and honey from the flowers, wood for fuel, timber for furniture and construction, livestock fencing, charcoal, medicines, pest control, shade, soil stabilization, soil fertility improvement and so many other uses. According to Abdelgadi Hajj Ali (*Chairman, Kassala Mesquite Management Team*), mesquite trees has shallow and deep root, it has 10-30 seed for just one pod. The seed itself coated with kainite (brown colour) material which is difficult to be demolish by animal when they eat. Animal likes to eat these seed because they have sweet test. Seeds takes 5 -10 years to grow/germinate with growing of the root is three (3) time the grow of the stem. Mesquite trees does not depend on the condition of soil or water nature, it grow wherever with any kind of water sources even salty water.

CHAPTER 3

LITERATURE REVIEW

3.1. Mesquite Tree, Origin and spread

According to Bokrezion (2008), mesquites were native to central and south America and started to spread from southern Mexico to Panama and from Caribbean Islands to Venezuela and northern Peru.

It has been introduced worldwide over the last 200 years. Nowadays, it can be found in various semi arid and arid climate zones including further parts of southern America, India and Pakistan, Australia and the Pacific Islands and several countries in Africa, the Arabic and the middle east, (Bokrezion 2008), According to Sharma and Dakshini (1998) the mesquite tree known as Prosopis was then introduced in India during the late 19th century, possibly from Mexico or Jamaica. The proper time as when exactly the mesquite has been transferred is not yet clear,(Sharma and Dakshini 1998).

3.2. Mesquite in Sudan

According to Broun and Massey (1929) Mesquite (P. juliflora) was introduced into Sudan in 1917 from South Africa and Egypt and planted in Khartoum .The success attained in establishment of the mesquite it is because of its abilities to tolerate drought and fix sand dunes (Brown and Massey 1929a). In 1938 the plant was introduced into Sinar, Fwar, EL foung (central Sudan), Elghaba, Lietti basin (northern Sudan), Sinkat, ELgalabat, Portsudan (eastern Sudan), Kordofan and Darfur (western Sudan). And in the late 1947 and later on in 1965 mesquite was re-introduced into eastern Sudan, where it was planted in Kassala area, (Abd El Bari and Ahmed 1986) . In New Halfa mesquite was introduced to protect the research farm at inception in 1966 (El Tayeb, et al., 2001). The dominant drought in the 1970 s restored the interest in tree and further introductions, into eastern Sudan, were made to protect residential and cultivated areas. According to ElSiddig et al., (1998), in 1974 mesquite seeds were broadcast by airplanes in around Kassala and further planted in protected forests and then in the period 1978-1981 the tree was planted as shelterbelts at Port Sudan and Tokar.

It was then introduce into the land of Africa in 1822 to Senegal, South Africa around 1880 and Egypt around 1900 as it has been documented by (Nick M Pasiecznik et al., 2001a)

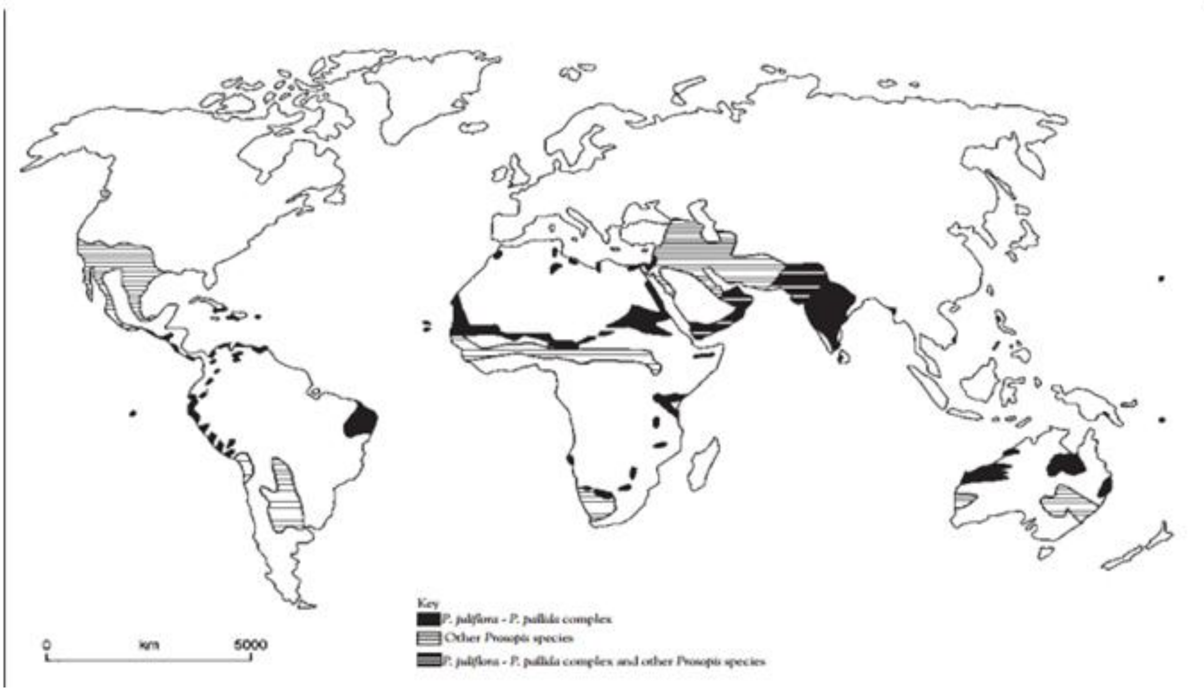


Figure 3-1 The spread of Mesquite tree to Africa in the year 2000 (Source: Pasiecznik et al., 2001

Moreover, introductions were made into the White Nile province, western and central Sudan. The tree was planted in shelterbelts around farms, irrigated schemes and along the Nile (Luukkanen et al., 1983).

Mesquite has become a noxious weed in Sudan (Broun and Massey 1929). It has invaded both natural and managed habitats, including watercourses, floodplains, highways, degraded abandoned land and irrigated areas. The weed is more of a problem within central, northern and eastern Sudan. Mesquite tends to establish, successfully, on clay or alluvial soils which have good water retention. Currently mesquite infestations cover over 230 thousand hectare (Luukkanen et al., 1983),(before this study conducted). The bulk of mesquite infestation (>90%) is in eastern Sudan where Gash Irrigation scheme is located. (Elfadl and Luukkanen 2003).

The Mesquite is found in the Gash delta from Kassala northwards passing Wagali ward and southwards up to the borders with Eritrea, in Atbara River, extending from the delta up to 130 kilometers upstream and in water collection pits a long Kassala-Gadarif and Portsudan highway (Department of Natural Resources and Mines 2003). Rate of spread of the weed in eastern Sudan, as revealed by aerial photographs, successively taken, in 1962, 1978 and 1992 and a survey undertaken in 1996 was initially low (ElSiddig et al., 1998) as cited by FAO (2006). However, a substantial increase in rate of spread, 371 hectares per annum, was observed during 1978-1992. In 1992-1996 the average rate of spread increased to 460 hectares per annum (Elsidig et al., 1998). And from 1979 to 2013 the increment goes to more than 1,000Ha per annum.

3.3. Impacts on Economy

Case study in India

In India the primary objective of brought the mesquite was to protect the environmental and rural economy. Mesquite has received so much appreciation mainly for fire wood value. The wood is an important source of domestic fuel for the many people in rural areas. The fuel wood availability ranges from 40kg/tree from

fourth year of planting and varies up to 139Kg/tree until ten years after plantation (Muthana and Arora 1983)
For small scale industries wood is also used as industrial fuel for kilns. Rather than firewood, the wood is also used for making charcoal and adds up the energy and economic value of the product, compared to firewood.
Charcoal is burnt from bigger trunks and upper root stocks of mesquite. The wood of mesquite is also used as timber. Fence posts, poles, particle boards and cardboard are manufactured using wood of mesquite. Furniture is also made with bigger boles tree. Pods of mesquite have been used as animal feed for cattle, sheep, goats, Camels and horses. The pods are generally consumed raw by animals. In India the average mesquite pod production was assessed to be around 20kg/tree (Tewari et al., 2001). Animal feed with 10% protein, 14% fibre, 55% soluble carbohydrates, 0.20% Calcium and 0.15% Phosphorus of the nutritive source from pods.
Apart from other uses, mesquite tree pods are also processed in a disc-mill to prepare for flour inclusion in livestock ration. Much finer pod flour has also been reported to be used in the manufacturing of confectionary items like bread and biscuits for human consumption.
During the summer and winter time the gum exuded from the sapwood is used in the textiles mills for sizing and for making adhesives. The *polysaccharide(class of carbohydrates)* present in the seeds of mesquite has been reported by (Tewari et al., 2001), to be used as in products like ice creams, sauces, cheese and yoghurt. Several medicinal uses of mesquite tree as syrup, and as coffee prepared from pods are also reported. The leaves are consumed by cattle as green fodder in the absence of alternative fodder and dry leaves are consumed freely by livestock. The leaves are also used for mulching and composted manure. Flowers of the species are useful in yielding good quality honey. The plant is also used for live fencing and soil conservation (Nick M Pasiecznik et al., 2001a).

3.4. Case study of Yemen

In the paper published by FAO (2006) explained in details how mesquite tree infestation can be controlled to make benefit out of it and at the same time eradicate them. According to that paper, in Yemen Mesquite fodder and wood products has so many potentials which should constitute positive attributes everywhere in dry land regions. The tree provides large quantities of wood, charcoal and fuel-wood and if it will be managed, it will greatly contribute to save significant area of natural range and woodlands from degradation.

Mechanical and manual removal is the methods used to remove the mesquite. A farmer will increase his productivity for Prosopis removal having a simple chainsaw instead of using a machete. In unwanted arable areas the farmer is compelled to eliminate the stand of the plant by ploughing combined with successive control of new shoots, where rational and direct-applied low toxic herbicide may be useful. All these tasks required labour and enormous efforts from farmers. Since the agriculture of Yemen is mainly irrigated, there is a need to establish effective ways of Prosopis control in irrigation canals. Here mechanical removal would be the most productive and effective way for controlling it. Fast removal is a need when the canals are heavily infested. It may happen that rain may start at the time when canals are still infested by Prosopis (FAO, 2006).

Since the large amount removed of Prosopis may become a problem for disposal. Therefore the promotion of products as fuel-wood, timber and processed fodder for livestock would be very good alternatives for business of mesquite products. The possibility of Collecting and grinding the pods with seeds would greatly reduce the spread of the plants. On this case, the solution of the problem is at present only possible by implementing an integrated approach, which should include mechanical and manual control, rational and limited chemical control, use of biological control agents for preventing spread of the plant and utilization of pods and wood. Preventing spread of the plant also means avoiding the introduction of any new species of mesquite into the Yemen and prohibiting its planting as is at present recommended in several countries like Sudan, Ethiopia and South Africa (Herzog 2006). Farmers' communities should be aware of the need to control and prevent the spread of Prosopis, and also its usefulness in wastelands.

3.5. Cost Benefit of Mesquite

A case study in Kenya

The survey conducted by Kenyan Environmental agency in 2002, came with the report which classify mesquite in Kenya is a tree with the potential of providing a range of products. The survey findings showed that these uses contribute significantly to the livelihood of local communities in areas where the tree is growing, both at domestic and commercial scales. Some of the major uses of mesquite by the communities at household level documented during the survey in the order of importance, include livestock fodder, source of firewood, poles for construction of houses, fencing materials, rehabilitation of degraded land, provision of shade, making of charcoal, medicinal uses, production of honey and other human food supplements, ornamental, making of sawn timber, wood carving and making of ropes. Other members expressed outrage and indicated that mesquite has no use at all, only losses as other trees could provide the same uses (Choge et al., 2002).

The table 3.1 below shows the quantities and value of mesquite products used within the household and those traded per household per year among rural communities in Kenya.

Table 3.1 Quantities and value of *Prosopis spp.* products used within the household and among rural communities in Kenya as it was cited by FAO, (2006)

Use	Quantities of products used	Value of products used(Ksh)	Quantities of products traded	Value of products traded (Ksh)	Value of products used(Ksh)
Fodder	252 bags	13,800	440 bags	44,000	13,800
Fuelwood	138 bundles	8,280	-	-	8,280
Charcoal	30 bags	4,500	427 bags	63,982	4,500
Poles	982 pieces	9,820	1050 pieces	10,500	9,820
Total Values		36,400	-	118,482	36,400
Grand Total (Domestic and traded)				154,882	

Table 3.2 The contribution of *Prosopis spp*. to household losses per year among the rural communities in Kenya, Source: (FAO, 2006).

Category of loss per household	**Value of loss per household per year (KSh)**
Thorns (Human)	2,144
Thorns (Bicycle)	3,711
Labor to remove (Farming areas)	3,383
Livestock death (Teeth decay)	46,063
Crop losses (due to invasion)	8,860
Fishing losses	48,000
Total Losses	112,160
Total benefits	154,882
Net Benefits	42,722

The preliminary studies of that study findings that the benefits derived from Mesquite outweigh the total losses by a margin of Ksh 42,722 per household per year. However the study noted the gap between the benefits and losses is closing in gradually as deaths of livestock are increasingly being reported; this is due to the effect of mesquite to animals.

Table 3.3. Cost Benefit analysis for Prosopis

Cost	**Year**			
	0	**1**	**2**	**3**
Machine purchase	20,000	-	-	-
Pods purchase	138 bundles	454	1063.20	30,000
Operating Cost	30 bags	454	1063.20	30,000
Fuel Cost	982 pieces	192.60	451.86	12,750
Total Costs		1100.60	2578.26	72,750
Benefits		1982.75	3987.00	131,250

Source: *Farm Africa -Experiences on Prosopis Management (Case of Afar region, 2008)*

From Table 3.3, the benefit calculated from the financial analysis of this study shows that the proposed idea of Prosopis pods collection, transport and crushing for supplementary animal feed production in the Afar region is a promising investment option which in the long run can help control the further spread of prosopis.

3.6. The Cost Benefit of Mesquite in Ethiopia

A case of Afar Region

Farm Africa has come with a compiled report on different areas where mesquite tree was converted to benefits from its cost. According to GG Tegegn (2008a), the financial feasibility of Prosopis pod collection, transport and crushing based on the costs incurred and benefits gained by the pastoral community in adopting it within a specified period of time. With the aim to limit the analysis of financial feasibility of the program by focusing on privately incurred costs and benefits gained by cooperatives or even farmers, and evaluated at market prices. The cooperatives fix the buying cost of raw Prosopis and the selling price of crushed Prosopis pods at 0.4ETB/kg and 1.75ETB/kg, respectively. The focus of the study was on crushed Prosopis pods only. The pods price was taken from local market. The cooperatives also incur costs, which include the costs of labor, raw pod purchases, crushing and fuel.

Three things happened here:

• Controlling further expansion of Prosopis into farmlands and rangelands, by crushing the seeds which otherwise would intensify the invasion;

• Animals fed on crushed pods shoed positive response in growth rate. Crushed pod marketing provided alternative feed supply for livestock keepers. Herders buy crushed pod to supplement sheep and goats kept for selling to add value and for rental animals such as donkeys for loading. Crushing also improves feed value of the pods by availing protein rich seed to the animals;

• Earning money at house hold level by supplying pods to the pod crushing locations; organizing the community into cooperatives to process and sale pods to the local community of the area.

In Afar, Farm Africa an organization which had been supporting the local communities through provision of hand tools and organizing mass campaigns to clear the mesquite trees from agriculture plots and farms. However the approach could not get wider acceptance as there was no immediate benefit to the people,Steenbergen (2014).

3.7. Charcoal Production from Mesquite

In the year 2008, Farm Africa produced the paper which emphasized on supporting local communities through provision of hand tools and organizing mass campaign to clear prosopis from pasturelands and cultivable areas. Utilization of Prosopis tree for charcoal by clearing the stumps is assumed to restore the land, and the collection and crushing of the pods will also prevent further spread of the invasion to new locations. Charcoal production was banned activity in Afar region with a view to conserving indigenous tree species. But it was again allowed for few cooperative to make sure the spread of the tree is minimize and making better life to community around Afar region. The following were the purpose of the tree cutting for charcoal

• Clear Prosopis from invaded land;
• Use the wood for charcoal and fuel wood production; and
• Restore cleared land.

Agriculture and cooperative offices were responsible to provide technical support to the cooperatives, to ensure the cooperatives abide by the by-laws, and to issue pass permits for Prosopis charcoal transportation. Few private agencies like Farm Africa also participated in building the technical and administrative capacity of the cooperatives and government offices to better manage the initiatives. These includes training on improved charcoal production techniques, introducing improved metal kilns, carrying out market study for charcoal and fuel wood, training on business management and leadership, and provision of startup capital (G.G. Tegegn 2008b)

Figure 3-2 Charcoal production ready to sell, source: (Hoshino et al., 2012)

This was observed especially after when individuals and investors started to be involved in charcoal production and marketing. The wholesalers sell a bag of charcoal on average at ETB50 rate to the retailers while the retailers sell on average ETB66/bag. This shows that on average the cooperatives, the wholesalers and the retailers get profit margins of ETB6.9, 13.68 and 16/bag of charcoal sold respectively (G.G. Tegegn 2008b).

3.8. Management and Control of Mesquite tree

Several efforts have been put to complete eradication of the established mesquite in Sudan. Unfortunately this is virtually impossible, especially under the current situation of limited knowledge on its management. It is somehow possible in rich countries like Australia and developed countries. So the best way to move with mesquite infestation problem is to make use of its huge growing potentiality by make use of the mesquite products more effectively and therefore to help to control its spread. Some of the options which will be preferred are as follows

3.8.1. Mechanical removal

Mechanical control of Prosopis has been found not to be economically viable, except on land of high conservation and bio-diversity value. Mechanical techniques can be either by ranging the blade ploughing to grubbing and chaining of mesquite tree from important habitats. This will depend much on the size of the tree and species of the plant. According to Australian Department of Natural Resources and Mines (2003), mechanical control is very expensive compared to other methods. Ploughing and even chain cost more than $200/Ha in grabbing one dense of infestation. In Sudan from the study done by Khalil (Oct, 2005) eradication cost in New Halfa, scheme which is located near Gash Irrigation Scheme, the cost on high density is 72.000SD per feddan and low density it goes up to 42.000SD per feddan (2.000.000 feddan = 0.42Ha, 1Euro = 10SD).

Figure 3-3 Mechanical rake for mesquite removal (Source: (Department of Natural Resources and Mines 2003)

3.8.2. Chemical control

Mesquite control using chemical ways/methods are being tried in other parts of the world, and encouraging results have since been reported. In Australia, herbicides is applied direct to all around the circumference of lower stem for up to a height of 750 mm for mature mesquite and it dies after few days (Department of Natural Resources and Mines 2003).

Figure 3-4 showing chemical mesquite control using chemical spray; Source:(photo aafopted from Babiker archive)

3.8.1. Remote Sensing as a tool for detecting land cover change

Remote sensing is the process of obtaining information of a distant located object or area using a device which is not in contact with the object or area under investigation, involving the process of collection and interpretation of acquired data. Data are acquired using sensors mounted on platforms (satellites, aircrafts) positioned at a considerable distance from the earth's surface.

As sunlight strikes earth's surface some of the light is absorbed and some of it is reflected back into space. Satellite sensors work by detecting electromagnetic energy reflected or emitted from the earth's surface (Congalton and Green 2008). Objects have different reflectance patterns a feature that makes them to be easily identified on the satellite images. Vegetation has a peculiar feature of reflecting green and absorbing red and blue in the visible spectrum as well as reflecting near infrared (NIR) energy. Remote sensing technology has been applied in the study of mesquite tree (Wise et al., 2012) , monitoring of land use change (Seto et al., 2002)
Application of remote sensing technology on studying the land cover change has been used in many parts of the world in detecting and monitoring vegetation covers, Afify (2011) compares remote sensing images from Landsat TM and Landsat ETM+ satellite and aerial photographs to study the dynamics of mesquite tree in Eritrea and Egypt where it shows that the mesquite area generally increasing rapidly year after year (Abualgasim[1] et al., ND). This study will be the pillar for the development of the GAS area and Sudan as a country.

3.9. Remote Sensing as a Tool on Monitoring the Impact of Mesquite

According to Abualgasim et al., (ND), remote sensing data imageries system was used to monitor and assess the impacts of changes in land use and land cover and also the detection process on the area. In determine the images, four cloud free multi-temporal Landsat images (path 171/row 49) acquired from the global Land Cover Facility (GLCF) by Maryland University, were used to represent the period of years 1979.1987,1999 and Aster data of the year 2010 covering the study area were selected for analysis. The data were selected at the same period to minimize the effect of seasonal variation on the images analysis. The Landsat images of MSS, TM and ETM+ were rectified and registered to the Aster 2010 using ground control points.

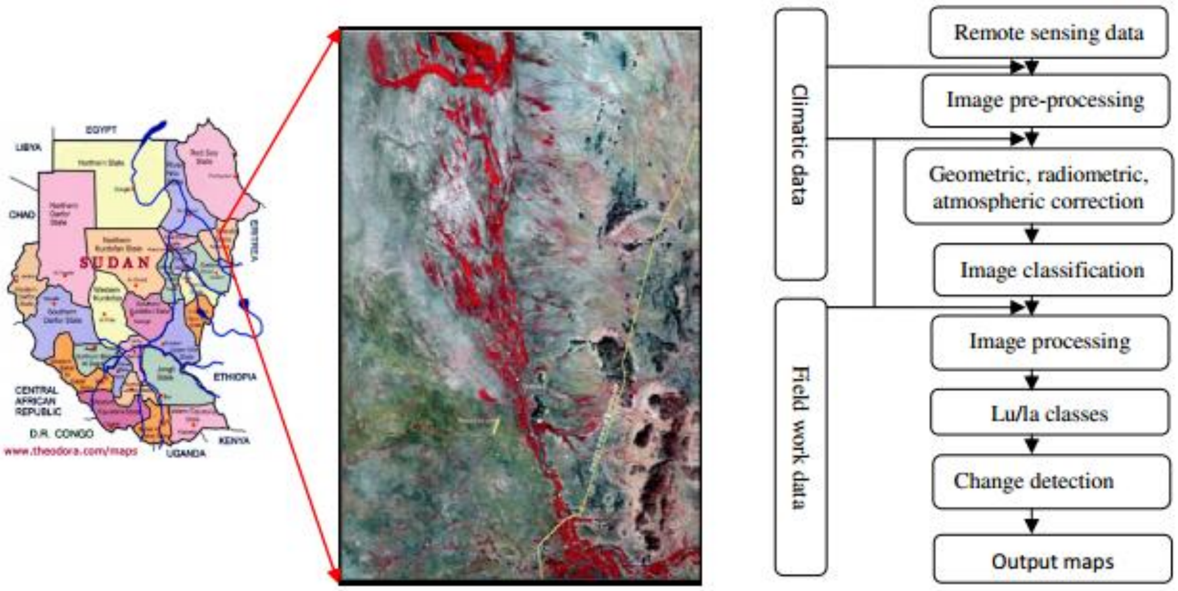


Figure 3-5 The location of the study area left side and the flow chart of research methodology

Source: (Abualgasim[1] et al., ND)

Supervised classification was carried out by training samples for each information class by visual interpretation of imagery supported by training samples measurement. The classification supervised training was followed instead of classification unsupervised signature to avoid the misclassification errors. There are so many land cover classes which could not be obvious classified especially mesquite tree and even the scattered trees and some spp. of glasses (Mohammed et al., ND)

In total five land cover/land use classes were identified explicitly as Mesquite tree, grass land, clay soil, stabilized sand and mobile sand. Visual and statistical change detection was also carried out for the periods 1979- 1987, 1987-1999 and 1999-2010 to detect the land use and land cover changes for the area. And the results show that the stabilized sand and mobile sand are the most dominant classes in the study area. They definitely affect the agricultural and residential areas as well as threaten the Gash Irrigation scheme especially during the dry season. The mesquite trees, grass land and clay soil cover 19.15%, 10.05% and

19.25% respectively.

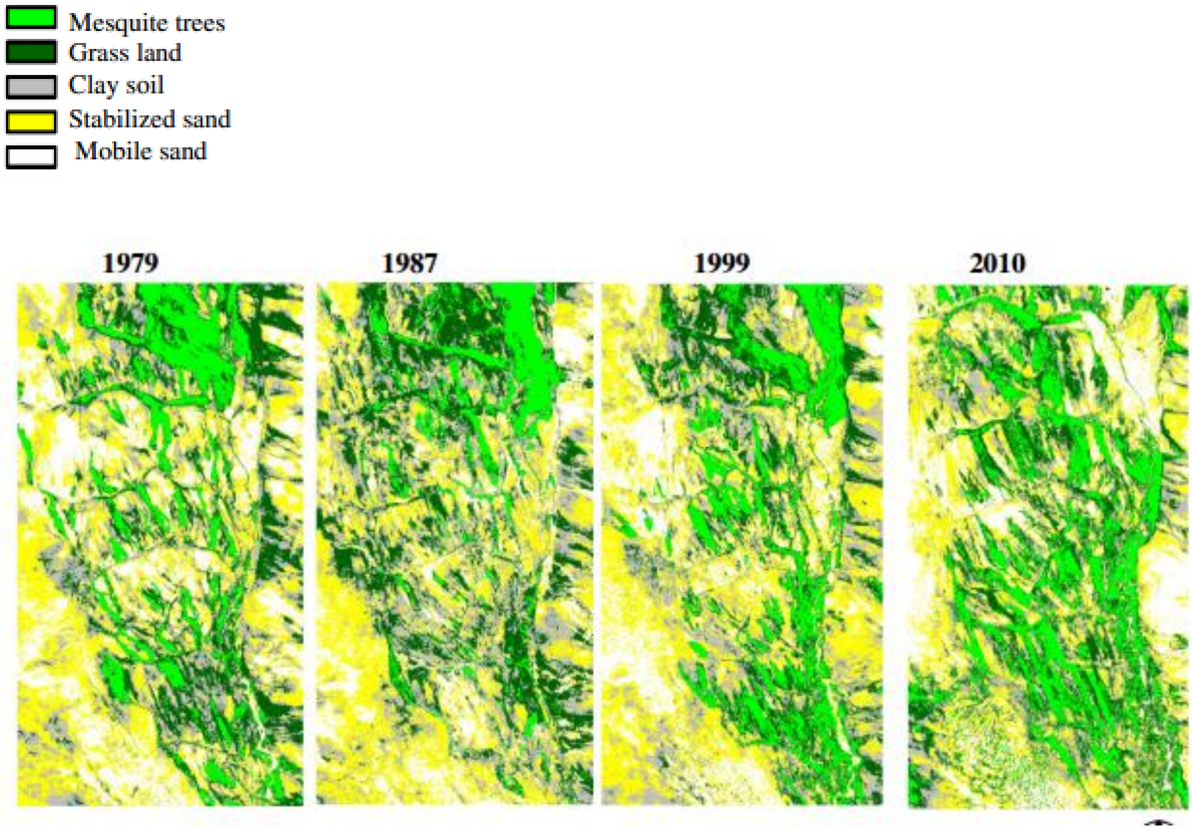


Figure 3-6 Classified images of MSS (1979), TM (1987), ETM+ (1999) and Aster (2010) for Agricultural Scheme, Source : (Abualgasim et al., ND)

Table 3.4 Land cover/use classes' distributions during 1979-2010

Classes	1979 (%)	1979(ha)	1987(%)	1987(ha)	1999(%)	1999(ha)	2010(%)	2010(ha)
Mesquite trees	8.68	6611.94	12.04	36655.65	13.32	162172.9	19.15	60022.3
Grass land	21.73	16552.53	17.36	52856.64	16.23	197529.8	10.05	142321.1
Clay soil	28.97	2206494	22.44	68326.11	23.47	285732.2	19.25	50215.15
Stabilized sand	27.8	21104.55	28.4	86453.82	29.94	364413.4	31.75	52312.54
Mobile sand	12.91	9829.89	19.75	60134.13	17.04	207365.9	19.88	723541.3

Remote sensing provides important tools for generating and analyzing information on land degradation status and its geographical extent in the eastern Sudan especially in Gash Delta. It is also recommended as a most suitable approach to periodically monitor land degradation process in the semi arid and area of the GAS of eastern Sudan. The technology offers and innovative potential avenue to acquire, analyze and visualize land use and land cover dynamics to address the related issues (Abualgasim et al., ND). The challenge we have from this study is how the impact of mesquite infestation affecting the crop production for those years from 1979 to 2013.In this research, the aim is to evaluate the impact on the crop production especially the irrigation practices and see the remedial measures on how the farmers can use mesquite to change their life and able to increase the yield.

3.9.1. How to detect mesquite tree route using Remote Sensing

Remote sensing method is very useful to detect the invasion route of mesquite trees in a very wide area, (Hoshino et al., 2012), Since the plants leaf absorbs red light energy and reflect near infrared (NIR) light energy of sunlight, therefore smartly growing healthy vegetation has low red light reflectance, this is due to its chlorophyll and high near-infrared reflectance this is due to total biomass. Mesquite tree has low red light reflectance and has higher near infrared reflectance. The comparisons of the trees absorption of red light and the reflectance of NIR light with those of the other native plants showed that the mesquite was more healthy and smartly growing (Hoshino et al., 2012).
In the Figure 3-7, it shows the native plants in the same habitat of mesquite have higher water stressed growing situation.

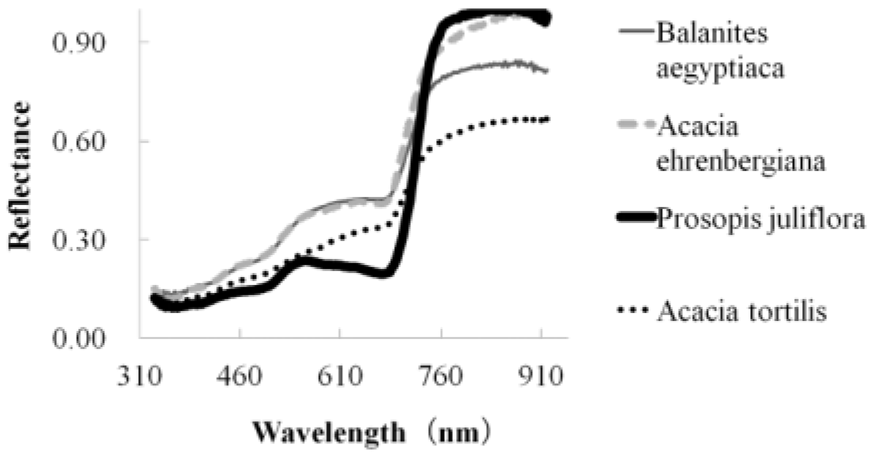


Figure 3-7. The spectral reflectance between Mesquite and other native plants in semi arid region in Sudan, 2010 Source:(Hoshino et al., 2012)

3.9.2. Mesquite Water Efficiency

According to Hoshino et al., (2012), mesquite can control the leaf water evaporation and survive in any condition regardless of the weather. This is because water efficiency is more than those of native plants. The figure below shows the parameters of the stomata conductance (mmol m-2 s-2) in native plants and mesquite tree. From 11am most of the native plants goes into midday depression of photosynthesis and reduce evapotranspiration when air temperature are near 40^0C, However mesquite is slightly reducing evapotranspiration from 9am and remained low evapotranspiration during the whole day.

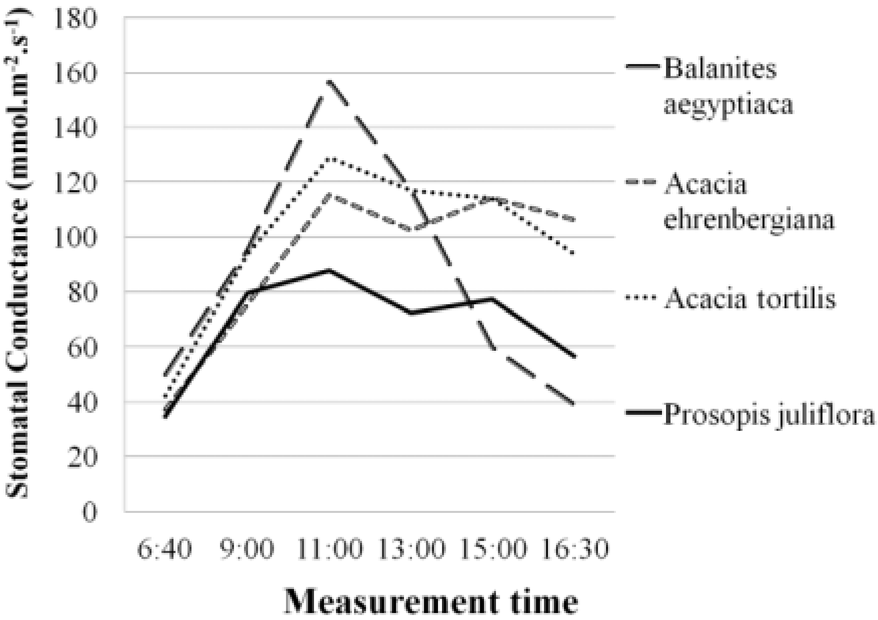


Figure 3-8 Comparison of the stomata conductance (mmol/m^2/s) in native plants and mesquite tree at semi arid area of Sudan, in 2010) , Source: (Hoshino et al., 2012)

Normalized Difference Infrared index (NDII) which is defined as the ratio of actual to foliar water content was used to identify the vegetation and distribution based on spectral values in the study done by Hoshino et al., (2012). The ratio of near-infrared and red bands is going to be used to map vegetation because plants tend to strongly reflect the near-infrared bands and absorbed the red bands. A high ratio represents presence of healthy vegetation, while a low ratio indicates stressed as well as non-vegetation conditions. The measurement can be calculated from remotely sensed data (NIR and SWIR). The calculation equation is:

$$NDII = \frac{(NIR-SWIR)}{(NIR+SWIR)} = (Band\ 2 - Band\ 6)/(Band\ 2 + Band\ 6) \quad (3.1)$$

Hardisky et al., (1983)

Where NIR is reflectance radiated in the near-infrared wave band and RED is reflectance radiated in the visible red wave band of the satellite radiometer. Where the NIR is reflectance of near infrared and SWIR is the reflectance of short wav infrared. This can be calculated from Landsat5 Thematic Mapper (TM) band 4 as (NIR) and 7 as (SWIR).The figure below shows the NDII image calculated from Landsat5 spectral band 4 and 7. This index displays the ability to evaluate the invasion strategic of mesquite. As shown from the figure below.The mesquite tree expansion followed high soil moisture area along the bank of the river.

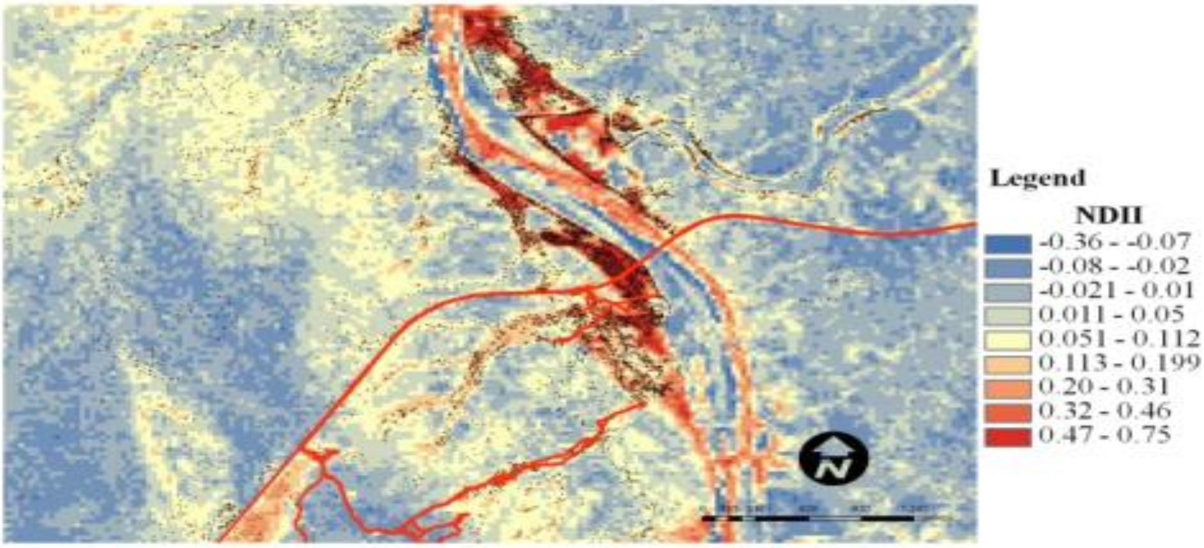


Figure 3-9. NDII map calculated from Landsat 5-TM data, where red colour shows the satellite extraction of mesquite tree pixels, Source: (Hardisky et al., 1983)

Georeferencing Process

Georeferencing is the process of assigning real world coordinates to each pixel of the raster. The coordinates will normally be obtained by doing the field surveys-collecting coordinates with a GPS (Global Positioning System), device for few easily and identifiable features in the image or map (which is already indicated (see scanned map of Gash Delta)). In these cases, where I am looking to digitize scanned maps, I can obtain the coordinates from the markings on the map image itself. Using these coordinates or GCP's (Ground Control Points), the image will be warped (buckled) and made to fit within the chosen coordinate system. The data which will be used is from Gash Delta site plan, which is scanned and fixed the coordinates.

The Landsat images of MSS, TM and ETM+ will be rectified and geo referenced (registered) to the arc-GIS tool using ground control points (zone 37 N). And later on the overlying process of the images will be determined to compare with the scanned one.

CHAPTER 4

RESEARCH METHODOLOGY

4.1. Study area

The Gash irrigation scheme is located in Kassala province, Eastern part of the Republic of the Sudan. This large irrigation scheme of 100,800 ha was set up by the government in the 1920s to settle poor nomadic people into a cash economy growing cotton. The scheme went into serious decline in the 1970s, and further drought spells and security problems have led to increased pressure on thin resources. Many of the poorest farmers now rely on small plots of land occasionally allocated to them. Furthermore, the organization managing the scheme has changed often, and has not demonstrated effective management of the scheme (Cleveringa et al., ND)

Gash Agriculture Scheme (GAS) is located in the Kassala State between latitudes 15 30 31 and 16 04 06 N and longitude 36 05 26 and 36 05 20 E. The crop production is depending entirely (since the beginning of the season) on the annual flood of the Gash River, in addition to a little amount of rainfall at the end of the season. The mean annual flooding of the Gash River (between July to August) is about 560 Mm^3 and only 17% (Abualgasim et al., ND), of this amount is effectively used for the agricultural purposes, Great Basin (plods) and furrows irrigation are the main irrigation systems in the scheme. The major crops are cotton, sorghum, sun flower and cluster. However, recently sorghum is considered as the main cash crop (Abualgasim[1] et al., ND).
The Gash Agricultural Scheme consists of six (6) main blocks, Kassala, Makali, Degeni, Tendelai Metateip and Hadaliya.

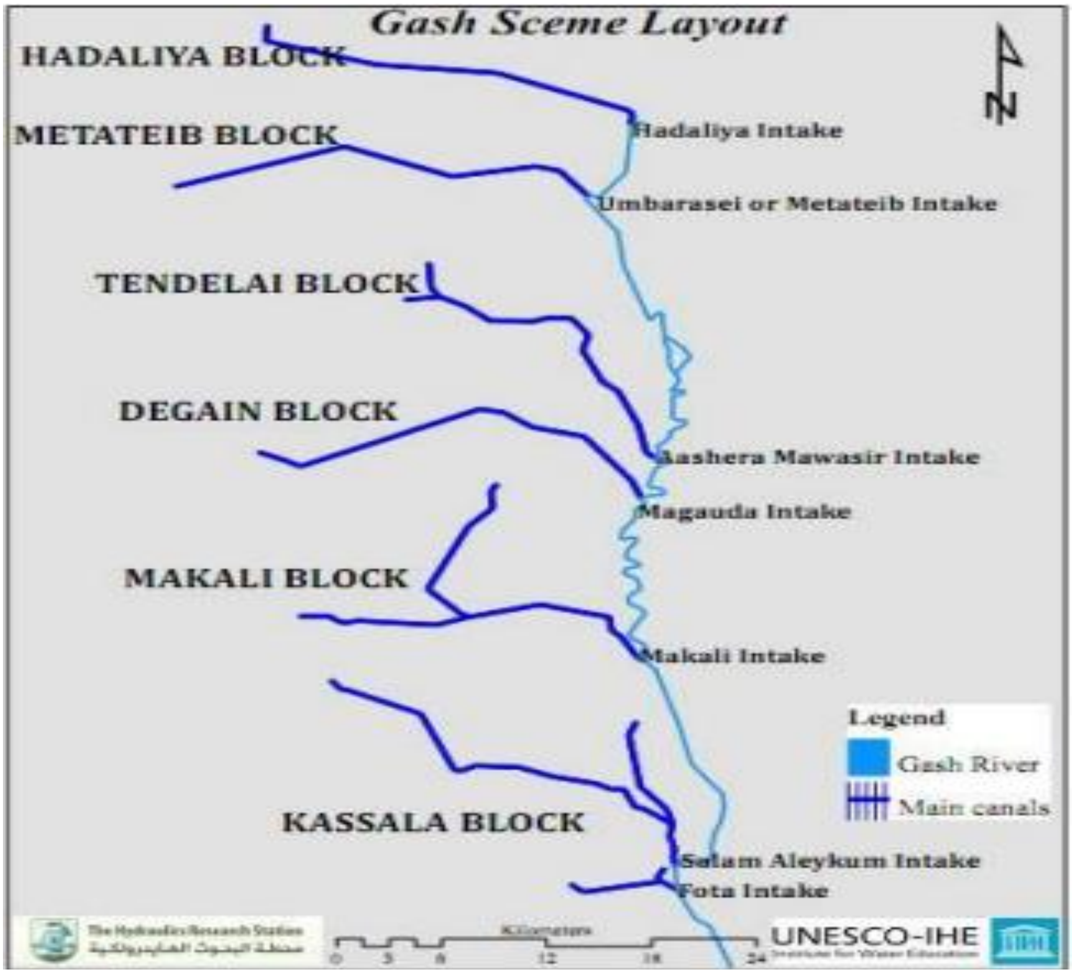


Figure 4.1 Shows the irrigation canals,block network in GAS ;Source (Avelino,2012)

According to Abualgasim¹ et al., (ND), The river irrigates the large Gash delta, in which the Gash Irrigation Scheme (120,000 feddans), which was constructed at the beginning of the 20th century is benefited. The Gash River is also the main supply of water for the Kassala Town. Kassala town in Eastern Sudan, is a huge blasted land of some 300,000 square kilometers, is home to an estimated three to four million of Sudan's poorest people. The region is made up of three states: Red Sea, Gadaref and Kassala. In each of these states the living conditions are so rough that the local population has been facing intensive poverty, persistent drought, in addition to land degradation and shrinking pasture areas, for a very long time (Ayoub 2004). The process of desertification in eastern Sudan, especially in Kassala State, Gash agricultural Scheme (GAS) has increased rapidly and much effort has been investigated to define and study its causes and impacts. Kassala State is a region which is characterized by drought and desertification. The greater part of the area is semiarid with a small portion of rainfall ranges between 50-200 mm annually (Helldén 1984).

Figure 4-2 Map showing the Gash Delta in Kassala state, Source: Researcher images, 2013)

Description of Methodology

The research methodology involved both quantitative and qualitative analysis based on available primary and secondary data obtained through field data collection and observation, measurements, and interviews of various irrigation stakeholders. Arc map GIS 9.3.1 were also used to evaluate the changes of the mesquite tree infestation over years. The field data collection was conducted on the area which represents the gross area of the Gash delta about 371,870 Ha with 294,000 Ha (potential area) of which 100,800 Ha are irrigated by spate irrigation with 60% for cash crops irrigated and 40% is for sorghum (Janeiro A.C., 2012), the remaining 193,200Ha are not irrigated at all, *Ministry of Agriculture Kassala state, (State 2013).*

Table 4.1 : Methodology to be used to answer Research Questions

No.	Research Question	Method to be used	Data needed	Source of Data
1	What are the impacts of Mesquite trees infestation on the agriculture production of Gash Irrigation Scheme in Kassala region, north-east of Sudan	Literature review, RS imageries data with Landsat4-5 TM, and ground truthing method, Image will be processed using the ENVI 4.7 (Environmental for Visualizing Images Version 4.7)	Gash Delta Remote sensing imageries (1980's -2010)	Satellites, images, Landsat 4-5 ETM/TM, Scientific articles, journals, publications, USGS-EROS, books etc.
2	How has the Mesquite tree infestation has changes over the years	Literature review, Analysis Remote Sensing land cover imageries of mesquite infestation trends/Changing detection methods	Mesquite tree RS maps (1970 - 2013's) Changing detective series analysis (area coverage)	Land cover maps Changing detection analysis Satellite images (Landsat 4-5ETM Band combinations, RGB) (1980 - 2010's)
3	What has the factor that contributes to that trend	Literature review RS data analysis Interview with local farmers	Historical of mesquite regime of Gash Agriculture area (1980 - 2010's)-farmers interview	Scientific articles, Gash spate irrigation farmers, Journals, publications, books etc. on Mesquite tree infestation regimes
4	What are the existing measures, inputs has been done, and what to improve those measures?	Literature reviews References from articles and consultants consultation Researcher results on the measure to improve	Literature reviews References from articles &consultants consultation Researcher results on the measure to improve	Scientific articles, journals, publications, books Farmers, Stakeholders and
5	To what extend that the mesquite tree infestation affected the crop production?	RS data analysis GPS survey data from the area	Secondary data from study area References from articles and consultants consultation	Scientific articles, journals, publications, books Stakeholders *eg* ministry of agriculture, research institutes etc RS imageries from project area

The methods of analyzing the change detection of mesquite tree infestation have been done for so various processes and finally the results come up positive. It has to start with downloading the satellites images from year May 1979, May 1985, May 1998 and April 2013. The following Table 4.2 summarizes the details of satellites used.

Table 4.2 Summary of Landsat imagery used

	Landsat 1 - 3 (MSS)	**Landsat 4-5 (TM)**	**Landsat 4-5 TM**	**Landsat 8 OLI**
Date acquired	13/05/1979	13/05/1985	13/05/1998	26/04/2013
Path	184	171	171	171
Row	49	49	49	49
Spatial resolution (m)	60	30	30	30
Temporal resolution (days)	18	16	16	16
Number of bands	4	7	7	11
Image size (swath-km^2)	180 x180	185 x185	185X185	185x185
Cloud cover (%)	0		0	0

All the images were downloaded on the same period of time between April and May to ensure consistency of the results. Moreover the study area has three seasons, dry season which is from March to May and Flood season from June to October and agriculture season from July to December. Landsat 1-3 Multispectral Scanner System (MSS), Landsat 4-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) acquired in May 1979, 1985, 1998 and April 2013 was obtained from the USGS archive (http://glovis.usgs.gov/). These data had been processed to the ENVI 4.7. The data were selected due to their open accessibility, historical record and suitable processing levels, cloud coverage, swath, spatial,spectral and temporal resolution as described in the Table 4.2

.

The data downloaded were unzipped and six (6) bands images using ENVI 4.7 program with band combinations of 654 (RGB). Then the multi band images were re-projected to the Universal Transverse Mercator grid (Zone 37N, WGS84) and finally OLI RGB (Red, Green, Blue) composite bands with RGB 654 bands was chosen to be the benchmark of other images as it showed more sign of mesquite trees before pre processing, at processing and post processing classifications. This band combination shows the green colour as reflected from the satellite which basically the presentation of mesquite and other trees like Taleh *(accasia)* and Kormot *(Latin name)* trees which can survive during dry season in Kassala region. Mesquite trees have the ability to shine and reflect all season regardless of the climatic conditions. Apart from those trees, there are also plant trees like Mango, Orange, Lemon, Neem trees and others like Sonut *(Acasia nilotica)* and Sorub *(Latin name)* trees especially on downstream areas. Other vegetation were seeing reflecting because during that period the farmers use ground water to irrigate and therefore they were also seeing in the image.

Furthermore the band combinations of 742 RGB for Landsat 4-5 TM for the year 1985 and 1998 were used to acquire other information's from the images. This combination provides a natural-like rendition, Healthy vegetation will be a bright green and can saturate in seasons of heavy growth, grasslands will appear green, pink areas represent barren soil, oranges and dark /light green represent sparsely vegetated areas and dry vegetation will be orange and water will be blue . Sands, bare soil come with whitish colour and unplanted land shows the brown colour. But for this study the colour were changed depending on the image processing results. The bands combination provides striking imagery for desert regions so it is very useful to area like Kassala in Sudan. It is useful for geological, agricultural and wetland studies. If there were any fires in the image then they would appear red. Urban areas/residential areas appear in varying shades of magenta, light purple and browns. In this study, urban areas are defined as residential areas, roads, villages, animal huts, schools, irrigation infrastructures, stabilized soil, mobile soil and the likes.

To have mixed up pixels the results for urban areas is very much dynamic. Grasslands appear as light green and the light-green spots inside the city indicate grassy land cover - parks, cemeteries, golf courses. Olive-green to bright-green hues normally indicate forested areas with coniferous forest being darker green than deciduous. River sand indicated by the light purple and mixes up with dark purple and Rock Mountain and clay soil shown by dark/black colour.The satellite imageries were captured of May 1985 and 1998 from the same source. Only image from Landsat MSS of the year 1979 were downloaded and processed differently as it has different format and resolutions from the other satellites. For 1979 Landsat 1-3 MSS, Band combinations to make RGB need four bands which are 4, 5, 6, and 7. Then refer to Landsat 4-5 TM / OLI as a base to see the wavelength.. It lacks the wavelength range of Band 7 and Band 5 to compare the wavelength with Landsat 4-5 TM as the base combinations. It also does not have the Band 3 as the true color for Landsat 4-5 TM (7 5 3). For its False color RGB comes of 6 5 4 (red, green, blue) as its wavelength (0.7nm - 0.8nm) corresponding to RGB 4 3 2 from the base LT 4-5TM.Hence for Landsat 1-3 MSS, RGB, 6 5 4 (0.7-0.8), (0.6-0.7), (0.5-0.6) and For Landsat 8 RGB is 6 5 4 for True color and false color is 5 4 3.Band combinations of 6 5 4 were used for these landsat data. All imageries were to follow several processing to finally come up with results.

After downloading all imageries were processed onto layer stacking from ENVI4.7 programme. Then the enhancement of the image onto 2% to have clear seen of the images was used. Georeferencing was done after the PCA (Principal Components Analysis) of the images and later on the image was brought to arc map 9.3.1 tool to classify them onto supervised and unsupervised classifications. The unsupervised classification was done before the field data collection to have understanding of the study area. However for this research the only supervised classification was considered with knowledge of the ground truthing data information's to classify the image and finally having the change detections. A supervised maximum likelihood classification (MLC) algorithm were used of which previously demonstrated to obtain the best results from a remotely sensed data.

Moreover the results of urban areas/stabilized sand/Mobile sand which are heterogeneous and composed of complex combinations of features e.g. building, trees, small gardens, roads, grass, trees, soil, water etc GIS tools such as Regional of Interest (ROI) were used to draw polygons, using visual analysis, reference data as well as local knowledge, to split and recode these covers so that they become more closely reflected to their true classes. This process was also repeated for classes like mesquite trees as within this classification the results comes with other features like other trees which were not be classified. By applying all these methods the results obtained could be considered as the best results and to finally reduce the salty and pepper effect the majority filter was applied to the classified land covers.

The following figure demostrate the satelites bands with corresponding wavelength as taken from the literatures. There is always the variation in atmospheric transmission with wavelength of electromagnetic radiation due to wavelength selection absorption by atmospheric gases. Only wavelenghth ranges with moderate to high transmission values are considered in remote sensing.

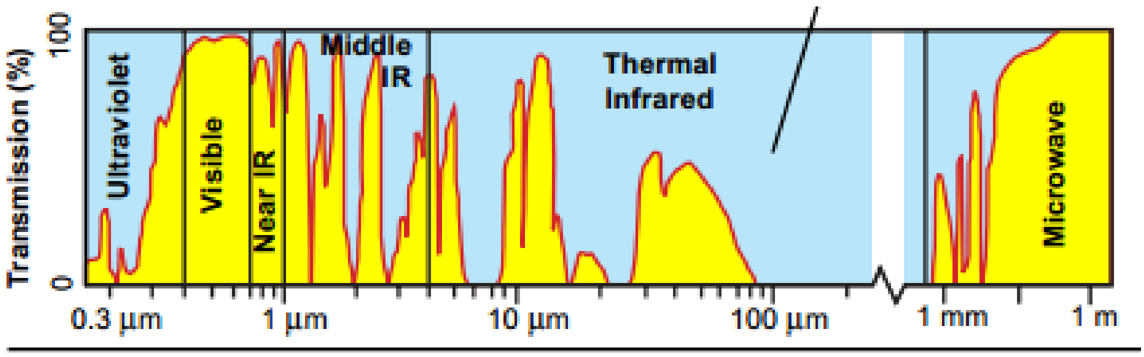


Figure 4.3 Spectral signature of different wavelength with corresponding transimission in percentage, Source ((Smith,2001)

Further description was explaing from the **Figure 4.4** as the only visble energy which we were able to generate our images. From the visible infrared its where the RGB-Red, Green and Blue has been observed to generate the classification from Landsat imagery data acquired.

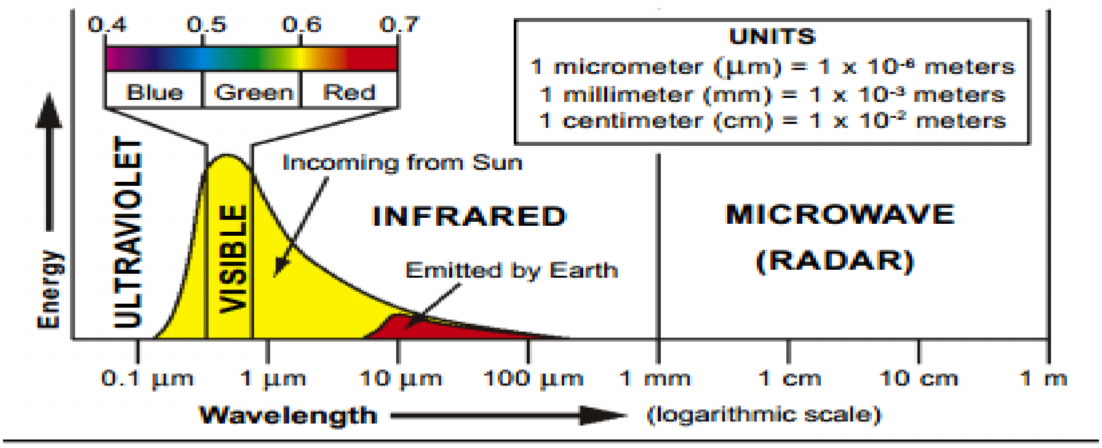


Figure 4.4 The wavelength vs energy with only visible near infrared we able to use with 0.4 to 0.7 RGB (Smith,2001)

In GAS the observation and reflectances of the images were considered during band combination and classifcations. The bare land was much more reflectance compared with vegetation however the only challenge were to differentiate and identify the mesquite alone from a group of other vegetation.

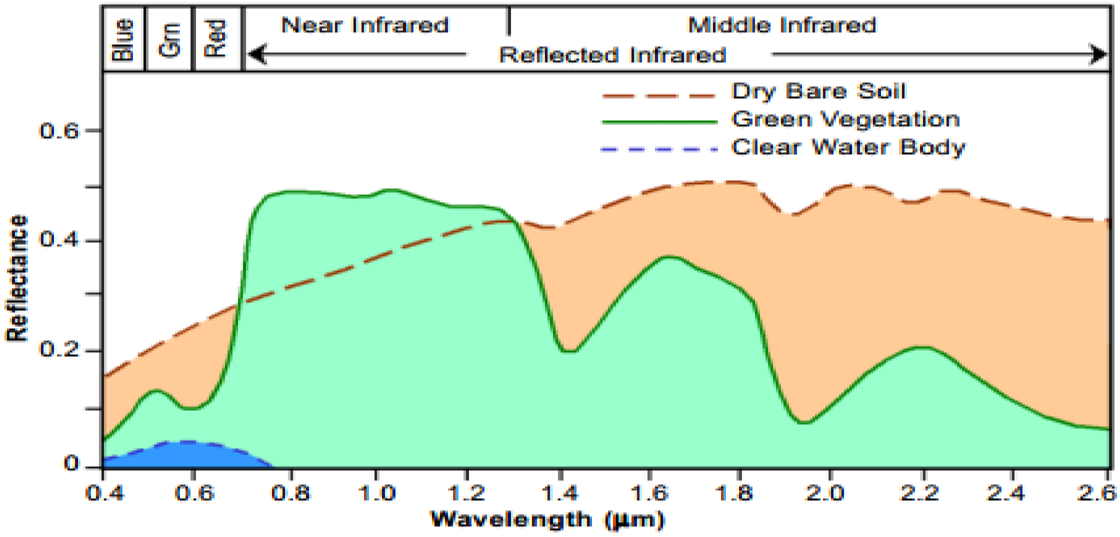


Figure 4.5 Dry bare soil and green vegetation reflections(Smith,2001)

Apart from the description above, the classification were defined well in **Table 4.3**. Mesquite trees have been defined in such away that easily to be identified compared with other classifications.

Table 4.3 Description of different land cover classes of the study area

Land Cover Classes	Descriptions and definitions
Mesquite trees	Areas covered by (i)>60% natural or planted woody vegetation which are >8m tall and have a similar nature of natural trees. Mesquite is ever green leguminous trees or shrubs. The plants of the study area can be classified into nine life forms: annuals, perennial grasses, perennial herbs, evergreen succulent perennial sub-shrubs, evergreen non-succulent perennial sub-shrubs, partially deciduous perennial sub-shrubs, evergreen succulent, perennial shrubs, evergreen non-succulent perennial shrubs and deciduous perennial shrubs
Other Vegetations	Areas where growing herbaceous crops account for>60% of the cover, trees like orange, lemon, Neem, Mangoes etc
Agriculture fields	Area dominated by >65 % crop lands like, have been ploughed for planting crops, animal feed, etc. Areas cultivated with annual crops, vegetables, or fruit. (Were et al., 2013).
Bare Land	Areas characterized by>60% soils (gravel, sand, silt, clay), with or without vegetation (<10%), Land areas of exposed soil surface as influenced by human impacts and/or natural causes. It contains sparse vegetation with very low plant cover value as a result of overgrazing, woodcutting, etc. (Were et al., 2013).
Urban areas/stabilized sand (Abualgasim et al., ND)	Areas characterized by>60% constructed or impervious materials eg asphalt, concrete, building, roads, villages, irrigation structures, schools, animal hut etc and materials, as well as houses of the within the local villages and some governmental buildings as well as the main cities of Kassala state. As well as Stabilized sand (soil are not movable due to weather conditions). It is also include the shade trees which are planted within the residential areas and during the image processing were not able to be classified including mesquite trees within the residential area.

4.2. Data used on the impacts of Mesquite in GAS

Remote sensing application to the study area

To analyze the change and impacts of mesquite tree in the delta of Gash in Sudan remote sensing technique was applied to obtain imageries of the delta and its changes. The analysis was done on imagery from the period of 1979 to 2013 with similar seasons to minimize the image errors. The main data sources was satellite images from Landsat 1-3 MSS, 4-5 TM and Landsat 8 OLI, covering a period of 1979's to 2013.

Landsat is a satellite sensor with temporal resolution of 16 days and 30 m (medium to course) spatial resolution (Landsat TM and OLI). Landsat satellite has a large continuous record of earth observation for over 35 years which are important information for monitoring, management and scientific activities at regional level (Franklin & Wulder, 2002) as cited by (Wulder et al., 2008).

The imageries data of the study area were downloaded freely from http://glovis.usgs.gov/Landsat images was used because it has some advantageous, some of them are

(i) availability- free access,
(ii) cloud cover percentage-will be assessed during the study but mostly 0% was taken,
(iii) correspondence with years of major events in the study area.

Landsat images were accessed free of charge from the US Geological Survey (USGS) through Center for Earth Resources Observation and Science (EROS) from ***http://glovis.usgs.gov/.*** Generally the resolution of Landsat satellite is more clearly compared to other sources apart from its advantageous of freely access. Landsat 4-5 TM and Landsat 8 OLI with spatial resolution of 30x30 m was used together with Landsat MSS 1-3 with spatial resolution of 60x60 m..

Landsat data (MSS, TM and OLI) were acquired and used to evaluate LULC changes. Geometric correction was performed on all the images using Landsat TM image of the same area from 1998 as reference. At least 91 ground control points (GCP's) were used to register the images to the Universal Transverse Mercator (UTM) systems then converted to World Geographic System 84 to have the same coordinate of all imageries.

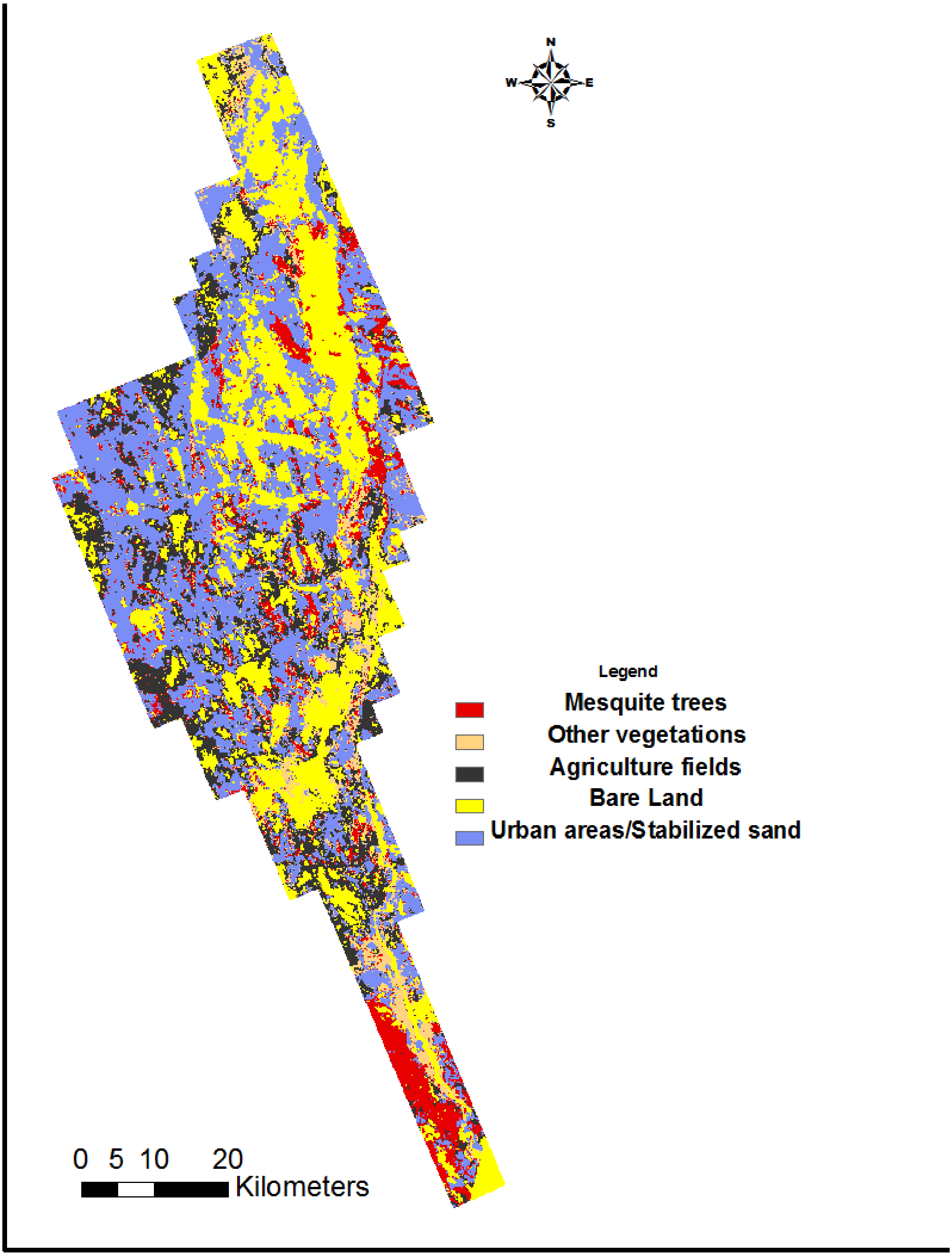


Figure 4-6 Supervised Classification image for five classes in 1979-Landsat MSS (1-3)

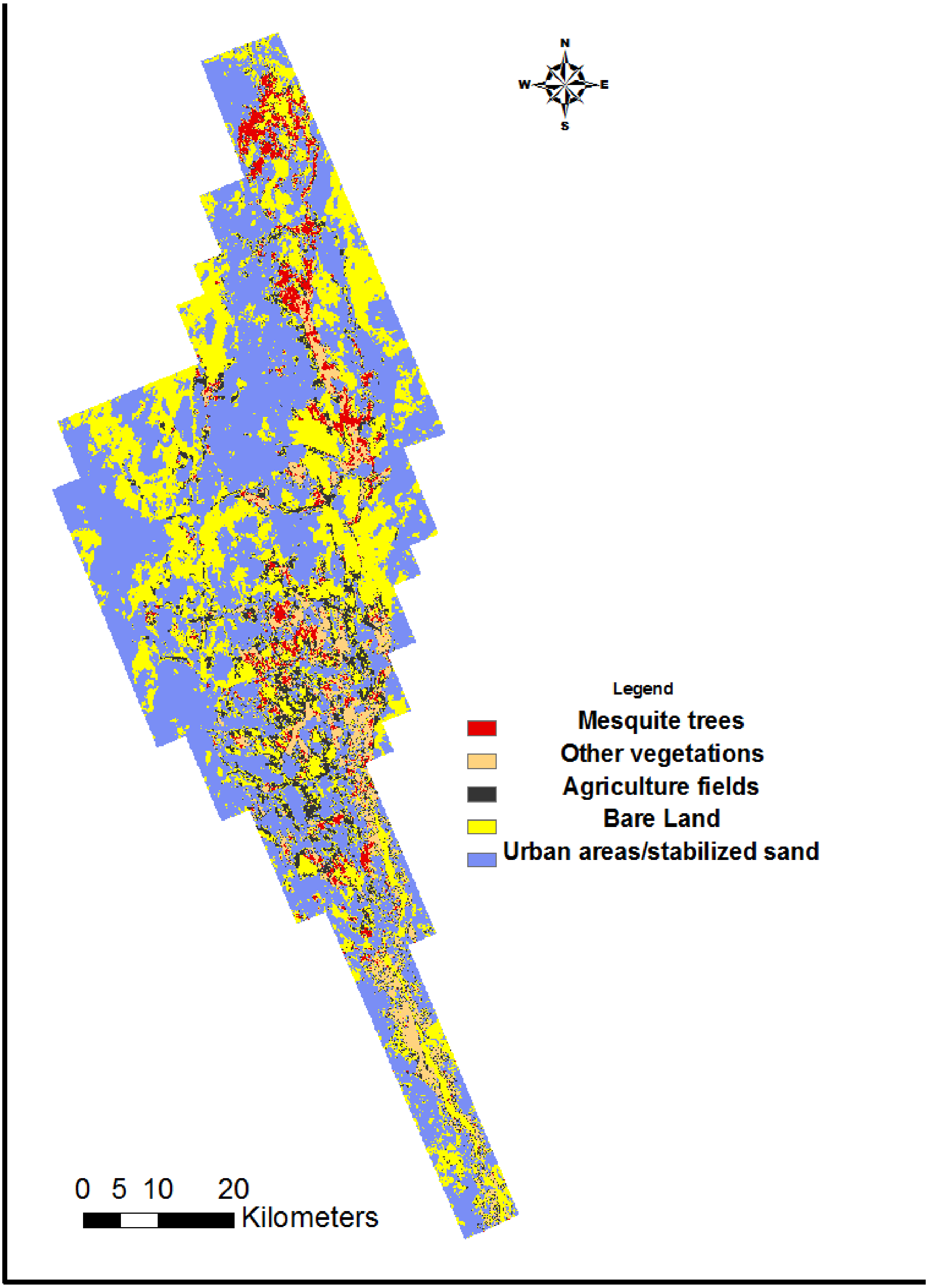


Figure 4-7 Supervised Classification showing the five classes in 2013 for Landsat 8 OLI

4.3. Secondary data and Primary data

In carrying out this study the other method which was employed were to reviewing literature of the history, development, and control and eradication measures of infestation of mesquite trees. Collection of existing secondary data and primary data were also used to carry out the studies. On secondary data (unstructured interviews) were conducted from government administrations and community based group while the primary data (semi structured interview) were conducted by administered individuals who were selected with assistance of GAS project manager, farmers, and random people who are living in the area to observe the factors that contributes the mesquite trends. The agriculture impacts were also assessed by considering the canal interventions with mesquite. That is how much canal capacity to convey water before and after the infestation.

4.4. Ground Truthing

Apart from using the satellite imagery data, the collection of various coordinates from Gash Spate Irrigation area was done and then compared with the satellite ones. The coordinates of the study area was determined on site by selecting 4-5 points each with its coordinates and classify them in terms of cultivation area, river, forest; mesquite spread area, mesquite tree areas, Bank River and agriculture area for the land use and land cover classification purpose. This is known as the ground truthing with each area were recorded with its coordinates. Apart from comparisons of data imageries this process helped the researcher to determine how the mesquite tree infestation has affected the area for crop production. The coordinates were then taken from the scanned map within the agricultural area and therefore was able to see the extension of mesquite tree infestations.

Intensive field work was done from 23rd November 2013 to 24th December 2013 to collect data for ground truthing at randomly selection coordinates prior to field work. A hardcopy with pleliminary image of Landsat 8 OLI was classified and used as the benchmark for data collected. The image was processed in arc map 9.3.1 with band composite of 11 5 3 RGB which was then improved to 6 5 4 RGB after the field work. This image depicting different LULC which was used in the field to identify different land cover features with special consideration was given to spectrally similar features. Based on this field work, a ground truth map was prepared for locating the training pixels on the image and 91 reference data points were collected using a global positioning system (GPS). The Garmin-GPS information was then overlaid with the image in GIS to select training areas and area of study for accurate assessment and 89 point were considered for evaluations with two points appeared to be out of the study area.

4.5. Accuracy Assessment

Foody (2002) define accuracy assessment as the correctness of a map or classification which provides an unbiased representation of the land cover of the region it portrays. It is the degree to which the derived image classification agrees with reality or confirms the truth (ground truth). It normally quantitatively compares satellite images and reference map of spatial information's using a common accuracy assessment. For this study, accuracy assessment of Landsat 8 (OLI) image of 2013 was processed in an arcGIS then to an excel sheet with error matrix method. An error matrix summarizes the relationship between two datasets a classified satellite image (with the mapped land cover) and a reference map of land cover or areference satellite image. The major diagonal of the error matrix showing the agreement between the reference data and the interpreted land cover types, (Congalton 1991)

Congalton (2005) stated that the accuracy assessment or thematic accuracy is looking into the accuracy of a mapped land cover category at a particular time compared to what was actually on the ground at the time. *"Although no reference data set may be completely accurate, it is important that the reference data set may be completely accurate, it is important that the reference data have high accuracy or else it is not a fair assessment. Therefore it is critical that the ground or reference data collection be carefully considered in any accuracy assessment"* , (Congalton 1991)

Using arc GIS several steps have been followed to create the matrix at the end. To start with the two images, one from classified which was considered as the map2 or satellite image data and were indicated on the row side and other image is the satellite enhanced image from column side which is known as map 1 or reference image data. More than 50 polygons were identified on the reference image from each class with more polygons collected from mesquite trees as the intended biased class. The images collected are the same from landsat 8 OLI, 26th April 2013. Each class was then classified in the attribute table and the field calculator. By using the spatial analyst tool to convert the polygon to raster and then the classified raster were then processed and combined the two images so that the programme give us the confusion matrix. The pivot table created then was exported to excel for further process to fill the error matrix. The table were to be in text file to read and processed in the excel sheet.

4.5.1. Descriptive Techniques of Accuracy Assessment

Congalton (1991), states that the overall accuracy which is computed by dividing the total correct (the sum of the major diagonal) by the total number of pixels in the error matrix, it is also summarizes the total/disagreement between the maps, only incorporates the major diagonal and excludes the omission and commission errors. Basically the total accuracy number of individual classes will indicate the probability of the cell value in the reference data being the same as in satellite image. Simply are the total correct number cells in a class divide by the sum of the cell values in the column and change into percentage. It is known as the producer's accuracy or omission error.

User's accuracy or commission error is opposite of the omission error, it is defined as the accuracy of individuals classes which indicates the probability of the cell value in satellite image being the same as in reference image. Simply is the total number correct cells in a class divide by the sum of cell values in the row and convert to percentages. However the results obtained from an error matrix will be interpreted with much caution as the error matrix measures the degree of agreement between the reference data and the map data, which is not necessarily equivalent to the degree of agreement between the map product and the fact on the ground (Powell and Matzke 2004) as quoted from (Foody 2002). The error matrix is useful for both visualizing image classification results and for statistically measuring the results. According to Congalton (2005), the error matrix is the only way to effectively compare two maps quantitatively

The assessment of this study was done by error matrix, as this is the most common way to represent the classification accuracy of remotely sensed data. Using error matrix has been recommended by many researchers and should be considered as the standard reporting convention, (Congalton 1991).

4.5.2. Error Matrix (Confusion Matrix)

According to Congalton (1991) the error matrix as the square array of numbers set out in rows and columns which agree or express the number of sample units which are pixels, clusters of pixels or polygons. For this study it is polygons which assigned to a particular landcover class relative to the actual landcover class as verified on the ground. From the table below the column represent the reference data and the rows represent the satellite image data which was generated from remotely sensed data. An error matrix is one of the effective ways to represent the accuracies of each category.

4.5.3. Overall or Total Accuracy

Can be defined as the total number of correctly classified points (which is the sum cells of the major diagonal) by the total number of reference points

4.5.4. Producer's Accuracy

Are the results of dividing the number of correctly classified points for each particular class on the major diagonal by the number of reference points known to be of that category (Column total). This is simply showing how well the reference points of the ground cover type are classified.

4.5.5. User's Accuracy

Calculated by dividing the number of correctly classified points in each class by the total number of points that was classified in that particular class (the row total). This is normally representing the probability that a point classified into a given class actually represent that class on the ground.

Kappa analysis (K_{hat})

KAPPA statistics analysis were first employed by (Cohen 1960),It is useful for comparing the images of similar nature/categories to determine if they are significantly different. (UofA 2004). It is always given by the following expression

$$\boldsymbol{Khat} = \frac{\mathbf{N}\sum_{i=1}^{\infty}\left(\boldsymbol{X_{ii}} - \sum_{i=1}^{\infty}(\boldsymbol{X_{i+}} * \boldsymbol{X_{+i}})\right)}{\mathbf{N^2} - (\sum_{i=1}^{\infty}(\boldsymbol{X_{i+}} * \boldsymbol{X_{+i}})} \tag{4.1}$$

Xii= total number of rows in the matrix
Xi+ = total for row i
X+i = total for column i
N = total number of cells in the error matrix **(Bishop et al., 1975)**
This formula was then proposed to be used in remotely sensed data by Congalton et al., (1983). Kappa is also powerful technique in its ability to provide information about a single matrix as well as to statistically compare matrices.
Kappa calculates a Khat value (Congalton 2005) as he quotes from (Cohen 1960) which is a measure of the actual agreement of the cell values minus the chance i.e random agreement. and can be viewed as a measure of accuracy.

4.6. Change detection

Change detection is the process of identifying differences in the state of an object (Hinderson,2004), or phenomenon by observing it at different times (Singh 1989). According to Radke et al., (2005), It is also known that detecting changes in an images of the same scene taken at different times is of widespread interest. This due to a large number of applications in diverse disciplines including remote sensing, surveillance, medical diagnosis and treatment, civil infrastructure, and underwater sensing. Changes in land cover and land use in cultivated areas are dynamic processes, such that transitions and changes occur at varying rates and in different locations within the constraints of, or in response to, increase or decrease or social, economic and environmental factors, (Radke et al., 2005). A change detection analysis was conducted to determine the mesquite trees coverage trend in the area over the years. Mesquite has been in Kassala for a number of years and various methods have been used to eradicate or control this exotic tree but all failed. According to Macleod and Congalton (1998) change detection is a technique used to determine the change between two or more time periods of a particular object of study. They further explained that change detection is an important process in monitoring and managing natural resources and urban development because it provides quantities analysis of the spatial distribution in the population of interest. In this study post classification and principal components change detection was not used and only image differencing was used to determine the changes in mesquite trees infestation over 28 years from 1979 to 2013 in Kassala state in eastern Sudan with Landsat satellite images as references data.

4.6.1. Image differencing

Image differencing is performed by subtracting the digital number (DN) value of one date for a given band from the DN value of the same pixel for the same band of another date (Macleod and Congalton 1998).The two images of 1998 and 1985 or 2013 and 1998 were subtracted from each other resulting in a new image. Two classes observed which are *no change* and a *change* in the area occupied by mesquite trees. The classified changed and unchanged image were determined by the number of pixels of each subclass and the changes in pixels and then in areas.
This study employed the post classification change detection method, which is efficient in detecting the nature, rate and location of changes and has been successfully used by a number of researchers in the past (Singh 1989),(Teferi et al., 2013), (Congalton 1991) The method of image differencing was used to detect the changes in each year.

4.7. Data from Farmers

This study was also discussing in detail the factors which contributed to the trend of mesquite infestation by using the collected data information from local farmers. Simple questions were asked to the farmers and local people who involved onto mesquite management practices. The information's which were determined and the factors which are contributing the infestation to the area were also identified. Though from the literature there are so many factors but this study will concentrate on the irrigation areas. Sample of questionnaires were introduced to the farmers and analysis of the results was done to get the best results.Finally the analyses on land and water development of GAS were done by considering the effect of the area. By comparing the data from satellite imageries and all other information's from all stakeholders, it revealed the extent on how the mesquite tree infestation has been affecting the crop production. Moreover the analysis of impacts on Land and water development of GAS will also used and finally the optimum recommendation control measures were recommended accordingly.

CHAPTER 5

RESULTS AND DISCUSSION

5.1. RESULTS

Based on the methodology in chapter four, the different research questions were answered as stated below.

How the Mesquite tree infestation has has changed over the years?

There were continuous changes in the areas occupied by mesquite trees over the study area from 1979 to 2013. The Table 5.1 above shows that in 1979 mesquite tree were covering 24% (89,428 ha) of the study area and nearly six (6) years after (1985) the area under mesquite trees increased by 4% reaching 104,483 ha. From the literatures, mesquite trees have been introduced in early 1970's and 1980's started to extend covering large areas.

Table 5.1 also shows that the area under mesquite increased by 3.4% in the period of 1985-1998 reaching 117,076 ha which is almost 32% of the total area of the Gash delta. In the period 1998 to 2013 the area covered by mesquite increased dramatically to 141,942 ha of land which is almost 48% of the total area of Gash delta. The effort to control and eradicate mesquite including mechanical removal and awarenesss campaign were implemented from 1995/1996, however, mesquite is still spreading. Some of the Mazigies (Plots for agriculture area) have been cleared from mesquite trees but areas downstream *viz* Makali, Hadalia and Matetaip blocks are still heavily infested.

Table 5.1 Five classes' trends of area from 1979 to 2013

	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
	1979		1985		1998		2013	
Mesquite trees	89,428	24.0	104,483	28.1	117,076	31.5	141,942	38.2
Agricultural areas	32,125	8.6	11,777	3.2	11,326	3.0	23,538	6.3
Other vegetations	62,652	16.8	80,445	21.6	48,971	13.2	27,210	7.3
Bared Land	107,443	28.9	79,455	21.4	82,914	22.3	58,572	15.8
Urban areas/Stabilized sand	80,217	21.6	95,710	25.7	111,583	30.0	120,608	32.4

Figure 5-1 shows population density of mesquite trees increased with time from 1979 to 2013 as displayed in the Figure 5-2, observed increaments were positively correlated with time (r = 99.07%). In 1979 the agriculture areas was 8.6% (32,125 ha) of the total land but progressively decreased to 3.2% (11,777 ha) in 1995-1998. Thus coinciding with the pattern of mesquite expansion in the same year, there is strong correlation between the mesquite infestation areas (ha) versus the number of years. Though in 1998 to 2013 the mesquite trees maintained its consistent advancement the area under annual field and horticultural crops, mainly onions,sorghum and water melon, together with folders, increase from 3.0% (11.326 ha) to 6.3% (23,538 ha).

The other vegetations classified from present the study, include orange ,lemon, neem, banana, palm, sorob, sonut, kormot and citrus trees increased from 16.8% (62,652 ha) in 1979 to 21.6% (80,445ha) in 2013. Natural vegetations, however, dramatically decreased from 21.6 % (80,445ha) in 1998 to 7.3% (27,210ha) in 2013. This is, mainly, because of the fast spreading of mesquite.

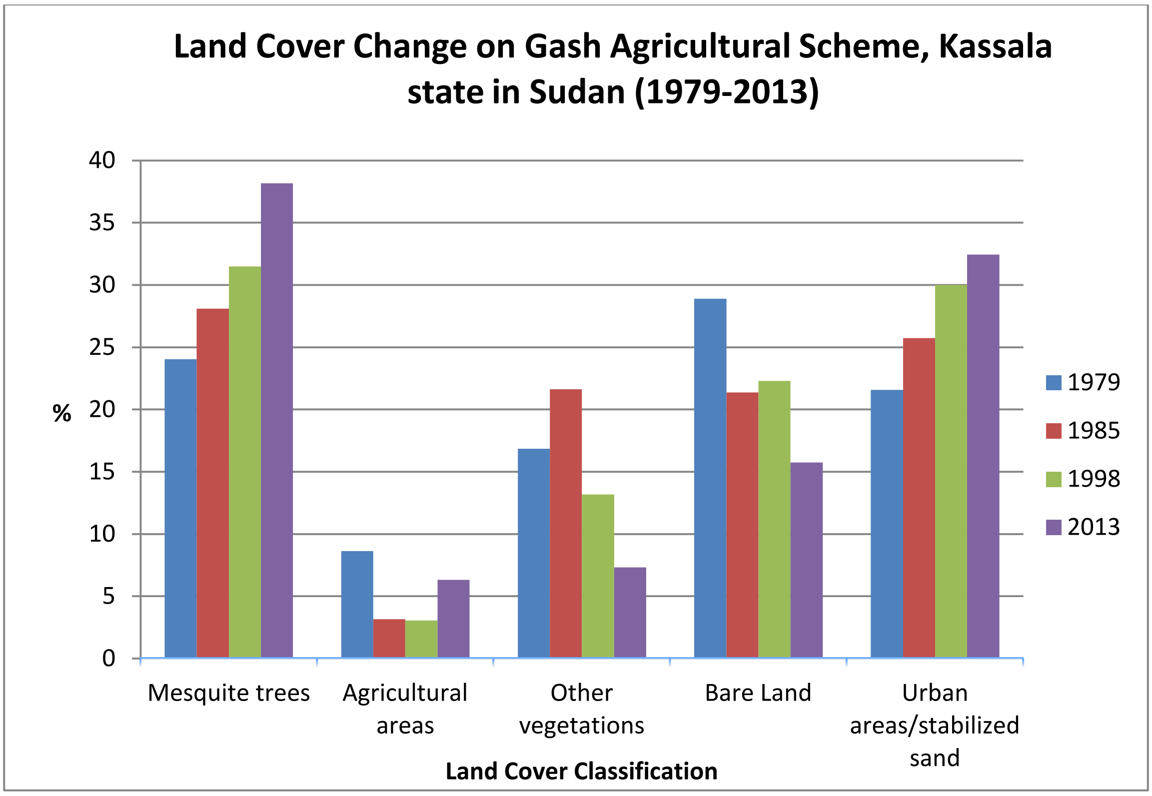


Figure 5-1 The graph shows the Mesquite trees changes against other classes in Kassala region in Sudan

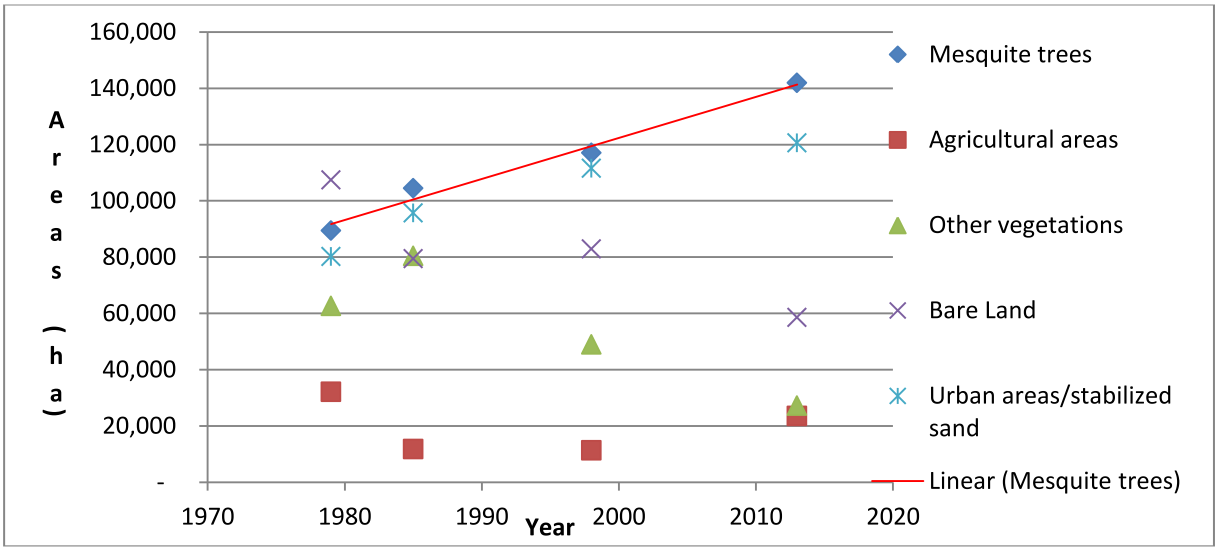


Figure 5-2 Correlation coefficient between mesquite infestation (ha) and number of years, r = 99.07%

On the other hand bare land which includes bare land from farms (unplanted plots), bare land from river bed and mountain or hills and uncovered with open area, places where there is typical desert areas these areas they are deteriorated and decreased as urban/stabilized sand and mesquite occupied areas dominate the delta. In the period 1985-1998 deteroration in bare land was slow at only about 1% change (22.3% (82.92ha) to 21.45% (79.45ha)) was observed. However, in period 1998-2013 the bare land was reduced to almost half (15.8%) of the total area.

5.1.1. Image Classification Accuracy assessment

In order to assess the accuarcy of classification conducted, the confusion matrix 9error matrix) was used. Accuracy assessment for classification was conducted using the image of 2013. The overall accuracy of the classification obtained is 76% and the Kappa Coefficient for the classfication is 66%. The User's and Producer's accuracy for each class is presented in the **Table 5.2**.

Table 5.2. Error matrix, overall accuracy and Kappa statistics of land cover classifications of Landsat 8 OLI of April 2013

	Reference Map						
Satellite Classified Map	**Mesquite trees**	**Other Vegetations**	**Agriculture Fields**	**Bared Land**	**Urban areas**	**Total**	**User's accuracy(%)**
Mesquite Trees	12,035	830	0	6,027	6	18,898	64
Other Vegetations	**0**	5,036	200	0	0	5,236	96
Agriculture Fields	**0**	421	10,589	0	0	11,010	96
Bared Land	**229**	0	0	30,099	20,664	50,992	59
Urban areas	**12**	2,027	6	0	37,704	39,749	95
Total	**12,276**	**8,314**	**10,795**	**36,126**	**58,374**	**125,885**	
Producer's accuracy(%)	**98**	61	98	83	65		
Overall accuracy(%)	76						
sum diagonal	95,463						
Part A	95,463	N*A-B	7,460,537,735				
Part B	4,556,822,020		11,290,211,205				
N	125,885						
Kappa	66						

A= the sum of total number correct cells in a class i.e value in row i and column i

B= Total sum of the product of total row i and total column i

From the Table 5.2 above, by dividing the mesquite tree class which is 12,035 pixels by total 12,276 pixels, the results are 98% which means the mesquite trees was correctly identified as mesquite trees by producer's accuracy of 98% of the time of the study and at that particular year and month in Gash. On the other hand the by dividing correctly the 12,035 by 18,898 results is 64% which is indicating that only 64% of the areas mapped as mesquite trees are actually mesquite trees on the ground. However because each producers accuracy from the correct category is a users accuracy to the wrong category, it is critical that both producers and users accuracies are considered, since reporting one value can be misleading, (Congalton 2005).

Similarly, the other vegetations from producer's accuracy is 61% which indicates the correct other vegetations was only 61% compared with user's accuracy which is higher to 96%, means the 96% of the other vegetations are correctly identified in the map are actually found on the ground. Agriculture fields has been identified correctly on both hands as in the producer's accuracy calculated to be 98% which simply showing the 98% of the actual agriculture field was identified correctly and in user's accuracy , 96% is identified as actual agriculture fields on the ground.

On the other hand the bare land is 83% in producer's accuracy and 59% in user's accuracy. This means that only 59% of the areas mapped as bare land are actually bare land on the ground. And only 83% of the reference data are in fact the bare land at that particular time. The last class to be discussed is the urban areas/stabilized sand. This class feature has 65% in producer's accuracy which means only urban areas/stabilized sand is 65% identified as urban areas/stabilized sand in classified reference data while the user's accuracy is 95% of the urban areas/stabilized sand is actually urban areas/stabilized sand on the ground. That is only 95% of the areas mapped as urban areas/stabilized sand are actually urban areas/stabilized sand on the ground. This class gave us several pixels around the region which shows that different features of pixels were also included and results in a wide range of region compared to other ones. Stabilized sand /soil is also found in bared land, mesquite and other trees are also found in urban and used as shade. During the reflectance of the sensors, on the area results with so many feature which conclude its diversity and complexity on the classifications

" Finally the information used to assess the accuracy of remotely sensed maps should be of the same general vintage as those originally used in map classification. The greater the time period between the imagery used in map classification and the data used in assessing map accuracy, the greater the likelihood that differences are due to change in vegetation rather than misclassification. Therefore the ground data collections should occur as close as possible to the date of remotely sensed data".(Macleod and Congalton 1998).

The results from Kappa calculation were compared to overall accuracy to see if there are significance differences and for this study only the overall accuracy gave us 76% and Kappa results were 66%. Although the overall assessment and Kappa differ by 10%, yet the results are considered the best on the classification of LULC. The selection of the pixels during the classification especially the classified map might not have been identified correctly as the similarity of the feature for Landsat sensor becomes difficulty to differentiate. High sensor resolution might have correctly identified the pixels correctly and results in a higher accuracy.

An overlay procedure using the GIS was adopted in order to obtain the spatial changes in LULC during three intervals of 1985-1998, 1998-2013 and 1985 -2013. The image of 1979 though was classified but since the resolution of landsat MSS (1979) and landsat TM (1985, 1998) and OLI 2013 differ then it will not be discussed in details. In post classification the results were further classified onto two main classes which are mesquite trees and non mesquite trees and therefore the change detection method were used in arc-GIS by using the raster calculation to observe the changes and trends of mesquite tree infestation on the study areas. From 1985 to 1998 mesquite trees of 51,293 ha were grown over the areas and only 7,290 ha were disappeared while from 1998 to 2013 only 38,134 ha were grown. In general the mesquite trees which grown over 28 years from 1985 to 2013 were 89,427 ha of which all these data are net gain/grown within the delta.

The Table 5.3 shows the change detection on the year 1985 to 2013 in number of pixels and the corresponding areas coverage. Mesquite trees has gained 58,583 ha and only 7,290 ha had disappeared and the net gain which is the differences between the mesquite trees gained/grown over the same period minus the mesquite trees which had disappeared is equal to 51,293 ha.

Table 5.3 Change detection analysis of mesquite trees infestations

	Areas (Ha)			
Years	Mesquite trees Disappeared	no change	Mesquite trees Gain	Net gain
1998 vs 1985	7,290	305,998	58,583	51,293
2013 vs 1998	18,841	296,054	56,975	38,134
2013 vs 1985	10,708	261,028	100,135	89,427

The images for change detected for year 1985, 1998 and 2013 with each other is shown on appendixes.

In the year 1998 to 2013 there was less area compared to 1985. Area of 56,975 ha was gained during the time and only 18,841 ha were disappeared from the area. This means that the amount of both bare land and cultivated land had been taken by mesquite trees and therefore reduces the production rate. The huge changes appeared on the year 1985 to 2013. Mesquite trees have changed to negatively up to 89,427 ha. However the mesquite trees have kept increasing from 1970's to date for various reasons as explained from previous chapters. Below is the graph of mesquite tree infestation in percentages. It increased gradually on 1979 to 1985 and keeps increasing continuously to 2013.

In contrast the mesquite trees while growing fast year after year the agriculture fields decreasing and this is showing how the agriculture productions is reducing tremendously. Although there were slight changes in the year 2013 but because of agricultural season then the changes were not significant to express its disappearing.

What are the impacts of Mesquite trees infestation on the agriculture production of Gash Irrigation Scheme in Kassala region, north-east of Sudan?

5.1.2. Crop Yield Reductions Using Aquacrop, Cropwat and Climwat Modelling For Spate Irrigation in Gash Agriculture Scheme

The mesquite tree infestation has reduced the main canal capacity by 25 to 50%. The impacts of these reductions on the major crop (sorghum) were analysed using AquaCrop model. These analyses were done in the Fota offtake, within one field canal that has a dicharge of 1.6 m^3/s that supplies a plot with command area of 420 ha. Under the current irrigation application practise, a plot is considered fully irrigated if it recieved water for 25 to 30 days continuously.

The yield simulation was conducted under three scenarious:

1) Current condition - full irrigation application: 823 to 987 mm - this is calacutated assuming 25 and 30 days irrigation duration and the field canal operates continuously at full capacity (1.6 m3/s)
2) Reduced application depth: 617 and 741 mm - this calculated assuming 25 and 30 days irrigation duration and the field canal operates continously at 75% of its full capacity (1.2 m3/s)
3) Reduced application depth: 494 and 411 mm - this calculated assuming 25 and 30 days irrigation duration and the field canal operates continously at 50% of its full capacity (0.8 m3/s).

The results are displayed in **Table 5.4** At the current application rate of 823 to 987 mm, a yield of about 5 ton/ha is obtained, which is considered to be optimum (FAO,2012) by (Steduto et al., 2012). Should as informed by the farmers, a 50% reduction in application happens, the yield will sigificantly reduce by upto 50% to 2.5 ton/ha.

It can further be inferered that, assuming that farmers continue to utilize 987 mm or about 9870 m^3/ha, a total of 493,500,000 m^3 of water will be required to sufficiently irrigate the 50,000 ha currently irrigable land in Gash Agricultural Scheme. If the irrigation application of 9,870 m^3/ha is maintained while the actual supply is reduced to 6170 m^3/ha (scenario 2) and 4940 m^3/ha (scenario 3), the irrigable area will be reduced from 50,000 ha to 31,500 ha and 25,000 ha respectively. Assuming a maximum yield of 5 ton/ha and market price of sorghum is 3000 SDG/ton (412.5 USD/ton) and therefore;

$$scenario\ 1(50{,}000\ ha) = 5 * 50{,}000 * 412.5 = 103{,}125{,}000\ USD \tag{5.1}$$

$$scenario\ 2\ (37{,}500\ ha) = 5 * 31{,}500 * 412.5 = 77{,}343{,}750\ USD \tag{5.2}$$

$$Scenario\ 3\ (25{,}000\ ha) = 5 * 25{,}000 * 412.5 = 51{,}562{,}500\ USD \tag{5.3}$$

The supply application has been done but mesquite tree is also absorbing more water from the canal banks using the deep root system.

Table 5.4 Impact of mesquite induced reduction in water supply on sorghum yieldin Fota field canal, Gash Agricultural scheme

Soil type/crop scenario	Applications (Days)	Mesga intake capacity (m3/s)	Existing scenario(mm)	25% Discharge reductions (mm)	50% Discharge reductions (mm)
Silt Clay	25	1.6	823	617	411
Crop Productions(Ton/ha)			4.98	4.98	3.5
Loam	25	1.6	823	617	411
Crop Productions(Ton/ha)			4.02	4.02	2.5
Silt Clay	30	1.6	987	741	494
Crop Productions(Ton/ha)			4.98	4.98	3.5
Loam	30	1.6	987	741	494
Crop Productions (Ton/ha)			4.02	4.02	2.5

This condition can be achieved by changing the irrigation schedule and the soil type. It is known that Gash delta has been characterized by diverse soils types, from alluvial deposits to cracking clay. The two common soils types which were considered in this study GAS, are Silty clay and loam soil (Avelino.,2012) With designed discharge of the intake capacity of 1.6m^3/s, the available irrigation depth can be achieved with regarding the two soils

Using Aqua crop applications on yield productions the following details prevail the differences of crop productions with regarding to the Mesquite infestation to Gash. Since the main focus is to know the crop productions of Sorghum with respect to soil type, water application and the Mesquite infestation then the Table 5.4 shows the changes of crop productions with regarding the soil type and amount of water taken bymesquite trees. Mesquite trees water consumption/ reductions were calculated in 25% and 50% *(GAS director oral interview, 2013).*

There are no significant changes on the productions even if more water is applied to the 25% reductions. The effect of water logging could be arising up if more water applied to the plots (Mesga).
The more effect is on the 50% reductions as lesser production obtained on Loam soil and on contrary the same 50% with Silty clay, the productions is higher to (4.98 Ton/ha) . There no effect of irrigation event for 25 and 30 days on silty clay for 25% reduction. The effects of crop productions revealed on 50% reduction by 411mm net application depth for both silt clay and loam with crop productions of 3.5 Ton/ha and 2.5 Ton/ha. These results suggesting that the application of water to the plots (*Mesga*) has been excessive, therefore causing water logging and ineffectiveness of water.This is also means that though water application has been done but mesquite trees is also absorbing more water from the canal banks using the deep root system.

Figure 5.3 Mesquite invade sorghum farm,causing water and crop yield reductions Source; (Hoshino et al., 2012)

5.1.1. Mesquite Impact on Water

Accoding to (D Le Maitre 1999b), mesquite trees affecting much water table and ground water and cause major impacts on irrigation, water sources and agriculture productions.The trees which can develop excessive rooting systems and reach water table with more than 50m and 6m wide.

According to (Scott et al., 2006, Wise et al., 2012, Scott et al., 2004, D Le Maitre 1999b) in a study conducted in different part of the world with classifying the invasion in flood plains and uplands, it is known that mesquite trees can consume much water from fully floodplains in a range of 543 to 663 m^3/ha/yr. In fully invaded uplands areas the consumptions of the trees goes to 64 to 78 m^3/ha/yr. This estimation were made using the assumptions that the upper limit of evapotransirations was based on the review of the measurements of the interceptions and transipirations in native mesquite woodlands in the USA and other areas around the world.

The Kassala government *hydrological office* stated that, in 1984 they were able to dig down for 7m to 8m and found enough water for irrigation and drinking water but recently 2013 they dug down and reach 36m to find water for their wells and irrigation purposes. Mesquite trees (with age of 3-9 months) can consume up to 18Litres/day with 1/3rd consumed by tree and 2/3rd by Evapotransipiration. In 1984 and 1988 the drop of water table was estimated to be 3m because of the deposition of sand and blocking by mesquite trees. It is expected that by the end of 2020 ground water in Kassala will be scarse and only dam will be the solution for the drought in the area.It worth mentioning that fruits and vegetables farms approximately 1600ha, in Kassala depend solely on underground water. and vegetables in Kassala they depend on ground water. From the interviews with six farmers from each blocks in Gash scheme, in one day a farmer can draw about 6000 liters and there are about 500 diesel pump machines in all Kassala area, *(Source; Hydrology and Ground water office director-Kassala state)* (the figure counted during the field work in a rough estimation depending on the *GPS* points reached).

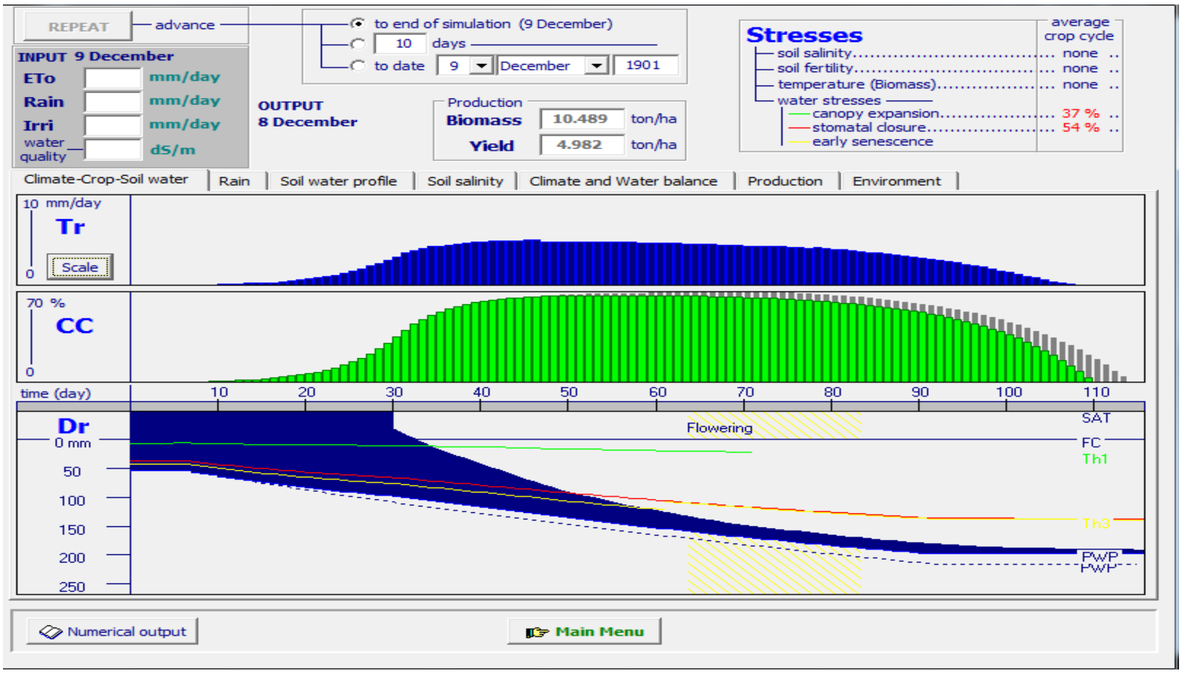
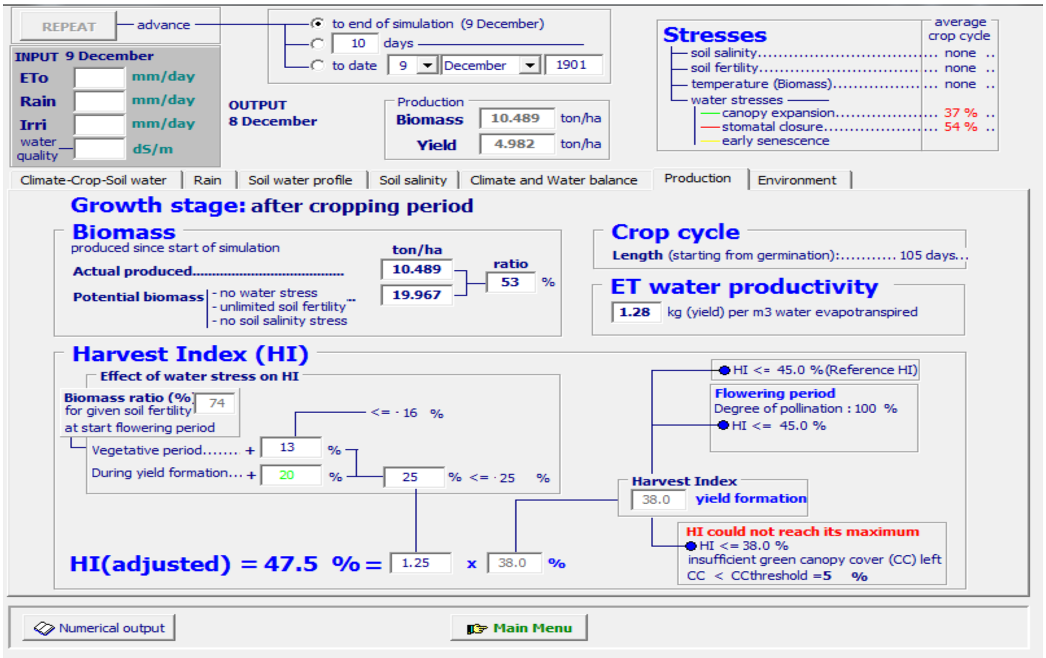


Figure 5.4 Crop productions under 25% discharge reductions and 25 days water applications



Based on the existing scenario for Sorghum crop planted on 15th August for one month flood over the area, a variety grown under spate irrigation (Basin) with a net application generated from CROPWAT8.0 and calculation of 1.6m^3/s discharge intake capacity to the 1000 feddans = (420ha), the productions of Sorghum is 4.98 Ton/ha and the water productivity with respect to the evapotranspiration is calculated as 1.23Kg/m3. This production is under Silty clay soils.

These results are subjected to the infestations of mesquite trees. The effect of reduction of water to the productions is clearly indicated to the effect of water applied to the plots (Mesga). The change of crop productions can be translated to the crop yield by 25% and 50% water reduction by mesquite. Mesquite tree is known by consuming more water (18 liters/day) hence within 30days (0.54m^3) and 25days (0.45m^3) scenarios were taken by mesquite trees. This is causing direct effect on productions as in each 1.6 m^3 /s of water applied for 30 days for example then 4,147,200 m^3 then in each 4147200 m^3, 0.54 m^3 is taken by mesquite trees on the same plot *(Mesga)* of 420 ha.

$$V = 1.6 * 24 * 30 * 60 * 60 = 4{,}147{,}200m^3$$

However during the interview with famers and stakehloders in Gash and New Halfa, it was revealed that one feddan (0.42 ha) of mesquite trees consists about 400 trees. From this figure then the amount of water taken/consumed by mesquite tree can be calculated as follows.

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The age of the tree is unknown for this case but during the interview local study done by ministry of forest in Kassala it was revealed that the amount of water consumed by mesquite tree is approximate to be 18litres/day with only mesquite tree of the age 3-9months. From this data, the total amount of water consumed by mesquite under agricultural areas can be calculated.

In Gash, the total area infested by mesquite is 141.942 ha, in one feddan (0.42ha) there is 400 trees ,so

$$Trees = 141{,}942 * \frac{400}{0.42} = 135{,}182{,}857 \tag{5.4}$$

$$Amount\ of\ water\ consumed\ in\ the\ whole\ infested\ area = 18 * 135{,}182{,}857 \\ = 2{,}433{,}291{,}428\ litres/day \tag{5.5}$$

$$Amount\ consumed\ by\ mesquite\ in\ irrrigated\ areas(agriculture) = 42{,}600 * \left(\frac{400}{0.42}\right) \\ = 40{,}571{,}429 * 18 = 730{,}285{,}714\ Litres/day \tag{5.6}$$

By considering that 2/3 *(source,department of hydrology Kassala state)* of consumption of water is by evapotransipiration then the net amount water taken by mesquite is as follows

$$Net\ Mesquite\ water\ consuption(whole\ area) = 2{,}433{,}291{,}428 - \frac{2}{3} * 2{,}433{,}291{,}428 \\ = 1{,}622{,}194{,}285 = 811{,}097{,}143\ Litres/day \tag{5.7}$$

$$\textit{Net Mesquite water consuption}(\textit{agricultural areas}) = 730{,}285{,}714 - \frac{2}{3} * 730{,}285{,}714 = 1{,}622{,}194{,}285 = 243{,}428{,}571\ \textit{Litres/day} \quad (5.8)$$

From Angelo State University (June 19, 2001), 130 million mesquite trees can consume up to 2 million acre feet of water annually, and an acre foot of water is equivalent of 325,850 gallons (1,481,344 Litres). Using this data it can be calculated that the 2million acre consume 2,962,688,000,000litres of water. For 130,000,000 trees equal to 2,962,688,000,000 litres then one tree consume 22,789.91 litres of water per day

Furthermore the total irrigated land for each year is 80,000 feddans (33,600 ha) but in particular Fota intake has three flood event which are 1m^3/s, 1.6m^3/s and 2.4m^3/s as small, medium and high flood consecutively (Avelino.,2012). For this study medium flood which is very common (nearly average figure) in the area was taken for finding the crop productions requirement

Table 5.5 Total Irrigation area for Fota intake

Soil types	Fota intake area total area(ha)	intake capacity(m 3/s)	25% discharge reductions(25days)-(mm)	25% discharge reductions (30days) (mm)
	705	1.6	368	852
Productions(Ton /ha) under Silty clay			2.1	3.1
Productions (Ton/ha) under Loam			2.1	3

Table 5.5 is showing the total area irrigated with 1.6m^3/s discharge from Fota canal and the productions from two scenarios. The first scenarios is showing the same discharge with loam soil (2.1 Ton/ha) for 25 days irrigation events and silty clay soils productions (2.1Ton/ha) for 25 days. On the other hand showing the crop productions of 3.1 ton/ha for Silty clay soils for 30 days spate irrigation and 3.0Ton/ha for loam soil with 30days spate irrigation. From the calculation above the discharge is too much that the net application depth for 368mm and 852mm causing water logging. (FAO et al., 2013) (irrigation and drainage paper 33, states that the basin irrigation expected yield reductions under good irrigation practices is 3.5 ton/ha to 15% moisture content with water productivity from 0.6 to 1.0 kg/m^3.

In spate irrigation practices the grain (Sorghum) yield under spate irrigation with little or no rainfall at all then the productions can reach up to 800kg/ha (minimum) and maximum reaches up to 1300kg/ha with 90 days total growing period. The ETm is ranges from 425 to 450 mm and net depth applied of an about 300 mm. The growing period for the other varieties of Sorghum like *Tabat* and *Aklamoi* which is mainly in Gash agriculture scheme is about 110 to 140 days depend on the temperature.

5.2. DISCUSSION

What are the factors that contribute to that trend?

(i) Animal cause

From the history and various literature studies that mesquite was introduced from different sources (Babiker, 1996). In 1974 mesquite seeds were broadcasted by planes around Kassala and further planted as protected forests (Elsidig *et al.* 1998). At present mesquite has become an invasive weed which has invaded natural and managed habitats watercourses, floodplains, and highways, degraded abandoned land and irrigated areas (Babiker and Eltayeb 2007).

Figure 5-5 Cow eat the branch of mesquite in Gash area *(Photo-Author)*

The major factor contributing to the spreading of mesquite tree is animal's movements (Babiker, 2006). In Kassala 40 % of the farmers *(Ministry of Agriclture, Kassala state office)* also having animals like castles, goats, camels' sheep, donkey for transportation and even the horses *(oral interview with Gash director)*. To large extend these animals spread the seed of mesquites over all the areas especially in the agriculture fields. Normally farmers in Kassala are nomadic and therefore they move from one place to \another seeking food, feed, water and better area to establish themselves. Animals eat and spread the seeds when going to water sources. The dung, characterised by high water retention capacity, ensures rapid germination and esttablishment of mesquite. The root are normally, grow faster than the shoot and it can grow anywhere with minimal amount of moisture.

During the dry season animal eat mesquite pods transport the seeds to other places including Gash river, river bank, ponds and other sources of water and therefore during the rainy season water comes and flush the seeds or remainder of the animal dung and moves to the other places. This process is ongoing, repetitively and spread the seeds of mesquite annually. It is noteworthy that irrigation methods in Gash scheme are by flood. The flood inaddition to seed dissemination disturbs the habitat and makes it more prone to invasion (Babiker,2006), (Congalton et al., 1983) and (Babiker et al., ND)

Figure 5-6 Animal dung spread the mesquite trees by deposits

The invasion of mesquite trees pods and seeds corresponds with the movement of animals being driven to markets and nomadic settlements. Once they move from one place to another on the way via the dung of the animal then it spread the seeds and extend to the areas. Mesquite pods are also float and normally transported easily by flood water.

The seeds, characterized by coat imposed dormancy, germinate in flushes and establish a huge persistent seed bank in soil. Seed remain in a well-protected seedpod with dormancy imposed by a thick seed coat. Seedpods remain unbroken when matured and do not release seed until minimal growing conditions are met, this results in a huge and persistent seed bank in the soil (Babiker and El Tayeb, 2009). Flood and/or overland flow of seasonal waters can transfer viable seeds many hundreds of kilometers from the mother tree as seeds are well-adapted to endozoichry (Living within a living animal usually as a parasite) or spreading by water. Grazing livestock help further spread the plant, with seeds passing undamaged through the digestive tract of the animals. Goats, sheep, cows and feral animals, attracted by the green foliage, eat ripened pods and liberate the seeds. The seeds encapsulated in animal droppings, are spread into new sites over long distances. The pods are also transported by floodwaters and run-off. Following germination mesquite seedlings grow vigorously (Mohamed, 2001). The rapidly growing root system and unpalatability of the foliage increase seedling survival rate and competitiveness particularly in heavy grazed areas and/or on uncultivated fallows (Mohamed, 2001).

(ii) Poor Management

The lack of follow up programs, inadequate management and weak enforcement of regulations played a major role in re infestation of and spread of mesquite trees in Gash area. Despite the effort of the state government of Kassala in 1995 to have a campaign on mesquite eradication, the program did not remove the problem. In the practical note from *MetaMeta 2014* stated that during the last 15 years different programs under the government were employed but all fail to overcome the invasive weed. In 1996 for instance the Kassala state government raised a campaign to eradicate the mesquite, the programme was under the Gash Livelihoods Project, and land was titled to farmers on the condition that it would be taken back if they could not control the emergence of the shrub.

In 2005, same government made contracts with private companies with the target of eradicating 63,000 ha in Gash area, Although the effort made by the government were very positive but poor management, poor follow up and even poor commitment to the programmes cause the mesquite to re infested the area. It is known that when you cut mesquite trees poorly then it will come and grow with five to seven (5-7) branches and multiply the amount which was existing *(Chairperson, Mesquite Eradication Unit-Kassala).*

Several factors have contributed to the success of *Prosopis* in the Sudan. Among these factors are

1. Repeated introductions of prosopis from unknown sources (Nick M Pasiecznik et al., 2001a). Introduction pressure is expected to enhance naturalization (the more often an introduction is repeated in time and space the greater the chance of the release into environmental conditions suitable for establishment).
2. *P. juliflora* is claimed weedy in its own native range and invasive in many parts of the world. Ease of spread of mesquite is consistent with its invasive nature, ease of adaptations to novel environments, lack of natural enemies and underutilization and mismanagements (Babiker,2006).
3. The fact that *Prosopis* was deliberately distributed within the country contributed to the plant invasiveness. In the period 1978-1981 the tree was planted as shelterbelts on premises of towns (ElSiddig et al., 1998) prevailing drought, livestock and feral animal's movement coupled with decreased land-use, land tenure practices, under utilization of the plant, mismanagement and over exploitation of natural vegetation have led to spread of mesquite into various locations where it has become a national pest (Babiker, 2008).
4. While prosopis leaves are unpalatable, pods are renowned for high sugar (16%) and protein (12%) contents, are attractive to animals (Mohamed,2001)
5. Flowering was observed to take place between October and April (Abdel Bari, 19(Abd El Bari and Ahmed 1986)). The tree is a copious seed producer. In the Sudan one plant produces more than 768 g of seeds annually (El Tayeb et al., 2001)
6. In the Sudan *Prosopis* grows on all soil types from sand, heavy clay to the shore line of the highly saline Red Sea but deep loose soils are preferred (ElSiddig et al., 1998)In some locations in the Sudan it occurs where there is a 10 month dry season with temperatures routinely greater than 40 degree ^{0}C. It was reported to tolerate soil temperatures in full sunlight as high as 70 ^{0}C (El-Fadl 1997)
7. Regarding water requirements *Prosopis* has a wide range of tolerance. If the root system is able to find water during drought, the plant will stay green otherwise the above-ground part is stunted (Mustafa, 1986; Salih, 1998). The tree height depends on the water availability ranges 3-13 m but can reach up to 20 m (Laxén,2007)

8. *Prosopis* coppices well, the high coppicing ability of mesquite ensures recovery of the plant when cut, burned or chemically controlled and often results in a multi- stem tree.

How effective are the existing measures to reduce or eradicate the infestation of mesquite trees has been done

In 1996 Kassala state through Sudan Federal government started a one year project on mesquite trees eradication. An organizing board Mesquite Trees Eradication Unit, the name later 2012 changed to Mesquite Trees Management Unit. One of the major targets was to eradicate mesquite infestation. They started with awareness of the people to explain the disadvantages of mesquite, how to cut them incase needed and controlling animals grazing.

Later on the team decided to change the methodology of employing farmers and individuals to eradicate mesquites. Though the turn up was very poor as farmers themselves do not have permanent plots to cultivate then they tend to ignore any movement of eradication programme. Farmers advised to cut the mesquite and make charcoal out of it and plant different crops on the cleared areas as part of controlling the mesquite trees infestation. Mobilizing the communities and school pupils to participate under the Gash Livelihoods Project (IFAD 2004), land was titled to farmers on the condition that it would be taken back if they could not control the emergence of the shrub. This condition was also used in New Halfa, a scheme nearby Gash, but in New Halfa successful they used heavy equipment rather than manpower from local community to remove the mesquite trees.

Steenbergen (2014) stated that in 2005 the Kassala government made contract with private firms to eradicate the mesquite trees from 150,000 feddan (63,000 ha) in Gash area. The cost of clearing mesquite trees by mechanical removal was 350 Sudanese pounds (35 Euros) per feddan (0.42 ha) and the cost for manual removal of mesquite trees was about 150 Sudanese pounds (15 Euros) per feddan (0.42 ha). He further stated that all firms did their work properly but yet after one year complete regeneration of mesquite trees occured. The reasons were lack of follow up programmes, inadequate management and weak enforcement of regulations.

However from the field information conducted in this study on November to December 2013, the major reasons on the failure of eliminations of mesquite trees in Gash area were the poor management from the team/committee appointed by the government. Despite the hardness and mesquite characteristics of its roots going deep down to sometimes 50m but yet the effort were not sufficient enough to eradicate the trees. According to farmers themselves from the several interviews conducted in Gash from each block, there were no heavy machine employed and only local manual labour and chemical control were employed. Though the report to the government was to use the companies and contract work so to have the proper way to remove the trees. The team also decided to use diesel and 2-4 D to eradicate and control mesquite. Other herbicides used were *round up* like round up and clinic graivosade were also used to control the tree but with no success (*Chairman, Kassala Mesquite Management Team*).

There were also natural methods like cutting the tree for 1feet deep and put chemicals and burn it but yet mesquite overcome the efforts and grows stronger. For some part of the Delta the method of removing the cover from a stem tree and allow the flowers and bees to come and produces honey from the mesquite. All these method prove failure of the programme to eradicate mesquite trees. The government injected so many amounts of funds for the course. The amount was disclosed for this research from the ministry of agriculture though from the mesquite committee said to be around 3-4 millions SDG (3-4 hundreds thousands euro). Apart from above various alternative on control and eradication there were other as follows.

- Several control and eradication efforts have been made but often not successful. Effort like cutting the mesquite trees and applying chemicals and bioagents viz bacteria.
- Sudanese government approved a bill for mesquite eradication in 1995 though the effort was not successful. The plant proved to be difficult to eradicate a huge amount of money-over 50million USD
- Hand puling, hoeing, tilling up to 10 weeks
- Grabbing, chaining and bulldozing
- Cutting mesquite with no further treatment. However this proved to be futile and mesquite trees regenerate rapidly. According to the Mesquite Tree Management team chairperson, improper cutting of mesquite trees worsten and induce more branching (5-7 new branches).

Figure 5.7 Shows the effect of improper cutting of the mesquite trees and how rapidly the trees regerated .

What alternative measures, (if any) could be recommended

Alternative method which under the capacity of the government would be very possible is of using the mechanical machines like bulldozers, excavators and others. It was very much successful in New Halfa. In New Halfa scheme were 98% control was achieved. New Halfa is an agriculture scheme which is located to the west side of the Kassala state. It has total area of 3,300 feddans (1,386 ha) and was affected much with mesquite but same year when the Sudanese government decided to have a programme on eradication. It was that much successful as the programme was supervised and controlled, planned and implemented in a way that Kassala state was supposed to follow. Before the programme the area covered by mesquite was more than 200,000 feddans (84,000 ha) of potential area. The government of New Halfa decided to hire the contractor (Swish) with class one (1) grade. It took two years to clear all the areas covered by mesquite trees. Using heavy machine and closed supervision the mesquite eradicated. After the programme and handling the project to the government then the whole 330,000 feddans were divided to farmers with registration and closely look up by the authority so to make sure no farmers will be allowed to take animals onto the agriculture fields even after the growing seasons. Establishment of new regulations to control the mesquite trees in Kassala.

Figure 5.8 Mechanical and heavy equipment method can be used as in New Halfa scheme

Biological control

Figure 5.9 Bacteria attacking the Mesquite trees pods, source (Babiker,2006)

Figure 5.10 *Algarobus prosopis* (An insect which is very specific, it destroy seed of mesquite)

5.2.1. Mesquite infestations and Benefits

Eradication of Mesquite trees-A case study of New Halfa Scheme

New Halfa irrigation scheme which is located about 30 kms south of Gash Agriculture Scheme has about 138,600 ha. New Halfa had the same problem of mesquite trees but after huge effort to eradicate them, then successful in 2011 mesquite trees has disappeared from the farm and small plots for irrigation. The management has the program to supervise the farmers and livestock keepers to avoid them coming into the farms after clearing. According to Ministry of Agriculture in New Halfa crop production has improved to the extent that farmers get benefit from their cultivations. For example in 2012 about 0.42 ha of sorghum produced approximately 10 bags of raw sorghum, same size of the area can produces 33bags of nuts,10 bags of wheat and 33 bags of cotton compared to five) years before the mesquite eradication campaign started in New Halfa. It was 20 % of the current production. New Halfa management decided to provide each farmer with the 6.3 ha with three crops per year, namely cotton, sorghum and groundnuts or wheat with 2.1 ha each crops.

For two years New Halfa using the heavy machines likes the excavators and bulldozers which were contracted by the government and supervised by the Ministry of Agriculture. While in Gash scheme the same programme was employed but with different approach using farmers and individuals to eradicate the mesquite trees. Kassala native people also known by drinking tea and coffee, Mesquite tree can be converted to charcoal and help the indigenous and tea/coffee maker to use charcoal from mesquite trees as

their main sources of energy. Although preferences of which charcoal type to use is very challenging. People in Kassala prefer *Taleh* tree for charcoal making rather than mesquite trees. The huge problem and challenge is to have awareness on how to use the mesquite trees for charcoal making. One bag of charcoal from mesquite tree is sold for 4 euro on site and goes to 7 euro in Kassala town yet farmers think that this price is minimal and it does not make any profit for them, Few charcoal maker admit that the charcoal business is payable and can be used for charcoal making and benefit them from mesquite trees.
Despite of injecting the eradication programme there are other ways to get rid of these trees.

- ✓ The uprooting of the mesquite trees on the area and then rapidly converts the cleared area with agricultural area so not to allow a comeback.
- ✓ To have constant management on the area of study to make sure that the mesquite trees can be used to benefit the farmers.
- ✓ To reflect the other countries what they did on the programme of eradication process
- ✓ To find the way on how the mesquite trees can be of benefit out the treesbenefit out of the trees.
- ✓ Use the mesquite as the source of energy for charcoal making and wood for hotels, restaurant and other events.
- ✓ To prevent the weed invasion in new places
- ✓ To keep the Maziga, irrigation canals and Gash river free from mesquite trees
- ✓ Eradicate and destroy the high value area and leave the low value areas of high area for economic purposes. Mesquite can be used by indigenous people to increase their income.
- ✓ Use chemicals recommended by specialist like Triclopyr at 1.67 % in diesel (Babiker, 2013)
- ✓ Initiate a National Coordination management committee that selects appropriate management procedures depend on the site.
- ✓ To prevent the introduction of the weed by cost effective manner as the essential component of a noxious weed management strategy. Prevention programme for introductions, containment and eradication will help to control and remove the trees.
- ✓ Develop effective education materials and reduce the susceptibility of the ecosystem to invasion and prevent the weed invasion along the transportation corridors including roadsides, waterways and railways.
- ✓ Whenever possible these management options should integrate mechanical, biological and chemical techniques.
- ✓ With regular monitoring and annual evaluations determine adequacy of the plan and long term commitment which will deplete the seed bank
- ✓ Charcoal production can be more encouraged to the area but it should be in a regulated and through a number of co operatives. Create the cooperatives so as to have a common go on how to get benefit. Water users association can be more considered as the best way to start with.
- ✓ According to GG Tegegn (2008a) the best systematic way to control the mesquite is to collect the pods crush them and use in a proper ration as animal feed with the aim of depleting the seed bank and turn the pods into an economic asset.With time the mesquite will not grow more and spread around.

5.2.2. Mesquite Management control Method

According to the *HDRA-the Organic Organizations, (2005),* the Sudan government is looking to improve rural life without high expenditure. There is a virtually free resource in the area invaded by mesquite and potentially much to be earned by its wise and equitable exploitation. Cost benefit analysis of different management and processing operations were discussed and propose the best way on how to use the mesquite to get good living standards. As firewood and charcoal or pots and poles mesquite can provide a living. The effort of controlling the infestation of mesquite via management which involves clearing the mesquite and making charcoal out of it, reclaiming the land which were cleared for agriculture production and try to emphasize on the use of crushed pods for animal feed.

5.2.3. Existing scenarios to control or eradicate the mesquite

It is reported by ElSiddig et al., (1998) that the mesquite has prominent benefit of daily life, in additional to sand dune stabilization and fixation, is the provision of wood fuel for the households, charcoal making and other important traditional activities. Farmers have been selling the mesquite products such as charcoal, firewood which is very important economic activity. In 1996/97 report from Gash rivers records the commercial production of charcoal and firewood were 600,000 sacks and 135,000 m^3 respectively, (ElSiddig et al., 1998). All these method were deployed to make sure the trees eradicated from the area but, it is very far from controlling it. Cutting the trees and use the area for house construction or farm management, using as livestock huts were also tried but yet the *devil tree* as they call it from indigenous farmers in Gash area never gone away. Livestock keepers in eastern Sudan regard mesquite as a liability for over 90% of them all. Mesquite pods are not used as animal feed, mesquite thorns are injurious to animal and dense mesquite thickets reduce productivity of grazing enterprises and therefore with mustering of stock this was stated by ElSiddig et al., (1998).

Figure 5-11 Mesquite wood fuel transported to market and mesquite thicket on the background (Source-FAO, 2006)

5.2.4. Cost Benefit Analysis

Benefits of Mesquite

Despite its so many disadvantages, Mesquite has several benefits such as honey production (support honey production by providing forage bees wood to generate steam power), using pods for livestock consumption and for medicinal purposes, and the use of wood for various products and as firewood as well, (Wise et al., 2012). It can also used to provide shade for farmers, according to Wise et al., (2012), this benefit is lost when the trees form impenetrable stands and it is not possible to approximate the economic value of this use. Apart from these benefit Mesquite has other benefits including improvement in soil fertility, preventing erosion, improvement of saline lands, creating cooler microclimate and reduction of wind damage, charcoal and fuel wood making (GG Tegegn 2008a).

This study discussed few benefits of charcoal and analyses them in an economical way to increase the living standard of the people of Kassala region. Since eradication of mesquite has been a long time agenda and has not been that easy, expensive and need modern technology to overcome the trees. Using these benefits farmers can convert the mesquite onto fuel wood, pods for animal feed, fencing, and house construction and promote in high rate the use of charcoal businesses. Making charcoal and promote worldwide will not benefit people who are living in the Gash delta area but world as a whole. Selling the poles will also make them having sustainable life greater than that before.

According to (Wise et al., 2012) the net economic contribution of mesquite trees in both sides of uplands and floodplains were estimated to be USD 6.2/ha and USD 23.8/ha. This benefit is coming with various incomes from mesquite including on the pods, honey, furniture making, charcoal and firewood. In Kassala (Gash area) the economic analysis for mesquite were estimated only for crop (Sorghum) with consideration on the benefit from selling Sorghum and Charcoal. The costs were estimated with consideration of removal of mesquite in one feddan (0.42ha). This estimation was accurate only for these few factors. If other factors included then the estimation might change accordingly. Other cost eg, water discharged during the flood and transportations were factorise to achieve to the conclusions.

In achieving the cost benefit analysis for Sorghum, charcoal and mesquite trees area cleared, simple calculations have to be done. The ammount of charcoal produced in one feddan depend much on the density of the mesquite. In high density one feddan can produce up to 100 bag (sag) of charcoal while in medium density the productiins can be 60 bag (sag) in one feddan. The figure used is the majority of farmers' experiences which is similar to the average. It is also known that 400 mesquite trees *(farmer's interview, chairperson of mesquite eradication and New Halfa ministry of Agriculture)* can be found in one feddan in Kassala; in this study only 400 trees were taken for consideration into the calculationa of amount of water taken by mesquite in the previous chapter. The following **Table 5.6** illustrates the rate of each item as collected during the interview with farmers.

Table 5.6 Rate of each item used for calculation of cost benefit analysis; Source (Farmers interview)

	ha	time (hours)	Ton	SDG	USD	Trees	Remarks
Clearing/removing	1	1		715	100		hiring cost
hectares	1		0.04				capacity
Ton			0.001	300	41		sale
Charcoal (sag)			1	90	12	5	used
Charcoal produces(sag)			1	30	4		making on site
Feddan (0.42ha)	1		80			400	Amount

Table 5.7 Table shows the Cost Benefit analysis in hiring the Excavator/Bullzoer machine

	Item	Feddans	Quantities (ha)	Cost (SDG)	Cost rate (Eur)	Total Cost (SDG)	Total Cost (Eur)	Total Cost (USD)
A	**Mesquite Tree removal ,grabbing and pulling heavily (Mechanical removal by bulldozer or excavators)**	101,429	42,600			60,857,100	6,085,710	8,367,851
	Feddan rate	1.00	0.42	600	60.0			83
	Rate for (ha)	2.38	1.00	1,428	142.8			196

Table 5.8 Charcoal cost and benefit analysis

		unit	Charcoal Cost						
			ha	**sags (bag)**	**Rate (SDG/bag)**	**Rate (Eur/bag)**	**Cost(SDG)**	**Cost(Eur)**	**Cost(USD)**
	Charcoal making (cost)	**L/S**	42,600.00	10,142,857	40.00	4.0	405,714,286	40,571,429	55,785,714
	Transportation	**L/S**	42,600.00	10,142,857	9.00	0.9	91,285,714	9,128,571	12,551,786
	Market store Tax		42,600.00	10,142,857	2.60	0.30	26,371,429	2,637,143	3,626,071
	Loading and Unloading	**L/S**	42,600.00	10,142,857	3.00	0.30	30,428,571	3,042,857	4,183,929
	Empty bag for charcoal seal	**L/S**	42,600.00	10,142,857	3.00	0.30	30,428,571	3,042,857	4,183,929
	Labour work	**15% of charcoal produce**							8,367,857
B	**Cost subtotal**								88,699,286
C	**Market price (Benefit)**		42,600.00	10,142,857	90.00	7.0	912,857,143	91,285,714	125,517,857

Kassala and Sorghum selling.The charcoal from mesquite trees and Sorghum produced from the area which was occupied by mesquite trees.

The rate used was calculated based on the rough estimates of curent amount.

Table 5.9 Currency rate

1 Euro	10 SDG
1 Euro	1.375 USD

The rate used for hiring the removal machine is 300 SDG for one hour. It needed two hours to clear one feddan and therefore 600 SDG needed to clear one feddan. The hurrowing process was ingored as mostly spate irrigation does not need much of tracting process in harrowing process (case of GAS). The analysis above can be taken as the pilot to other areas as the informations were collected from different farmers as part of the interview for this study including six blocks of irrigation, stakeholders of mesquite and New Halfa experinces on removing the weed.

Table 5.10 Cost and benefit analysis for Sorghum crop

	Sorghum cost								
		feddan	**ha**	**sag (bag)**	**Rate (SDG/bag)**	**Rate (Eur/bag)**	**Cost(SDG)**	**Cost(Eur)**	**Cost(USD)**
D	**Sorghum Benefits**	1	0.42	15	350	35	5,250	525	722
	Sorghum Benefits	101,428	42,600	1,521,429	350	35	532,500,000	53,250,000	73,218,750
	Sorghum Benefits	2.38	1	36	350	35	12,500	1,250	1,719
E	**Sorghum cost**	**feddan**	**ha**	**sag(bag)**	**SDG/feddan**	**EUR/feddan**	**Cost(SDG)**	**Cost(Eur)**	**Cost(USD)**
1	**Cleaning the farm**	101,429	42,600		150	15	15,214,286	1,521,429	2,091,964
2	**Cultivating**	101,429	42,600		250	25	25,357,143	2,535,714	3,486,607
3	**Furrowing/Basin**	101,429	42,600		50	5	5,071,429	507,143	697,321
4	***Seluka****	101,429	42,600		50	5	5,071,429	507,143	697,321
5	**Planting**	101,429	42,600		10	1	1,014,286	101,429	139,464
6	**Weeding**	101,429	42,600		250	25	25,357,143	2,535,714	3,486,607
7	**Farm keepers**	-					-	-	-
	animals	101,429	42,600		20	2	2,028,571	202,857	278,929
	birds	101,429	42,600		75	7.5	7,607,143	760,714	1,045,982
8	**Harvesting**	101,429	42,600		200	20	20,285,714	2,028,571	2,789,286
9	***Flower****	101,429	42,600		185	18.5	18,764,286	1,876,429	2,580,089
10	**Grinding**	101,429	42,600		185	18.5	18,764,286	1,876,429	2,580,089
11	**Empty sag**	101,429	42,600		195	1.3	19,778,571	1,977,857	2,719,554
12	***Ropti *****	101,429	42,600		1,050	105	106,500,000	10,650,000	14,643,750
13	**Stem collection**	101,429	42,600		50	5	5,071,429	507,143	697,321
14	**Wster fee**	101,429	42,600		40	4	4,057,143	405,714	557,857
15	**Transport**	101,429	42,600		150	15	15,214,286	1,521,429	2,091,964
	Sorghum Cost subtotal								37,236,964
	Total Cost (A+B+E)								**134,304,101**
	Total Benefit (C+D)								**198,736,607**
	Total Net benefits								**64,432,506**

Seluka(creating the holes ready for sowing); flower**(cutting and gathering dry flowers); Ropti***(Tieing the sag)*

As the invasion and spread of mesquite tree in Kassala area have become a threat to agriculture and well being of the citizens as more hectares have been infested then several ways should be implemented to remove, eradicate or benefit from the trees. Although many effort has been done to eradicate and control the mesquite especially from agriculture areas but still the invasion of the mesquite is increasing in number of hectares. It is easy to categorize the control or management of mesquite in Gash area into three (3) methods;

- ✓ **Physical;**
  The plants can be removed by machine or by people mechanically by hand pulling, cutting, hand digging or mechanical uprooting. This is the best and mostly preferred method and is strongly recomended.
- ✓ **Chemical;**
  The Large trees and shrubs are killed by cutting them at ground level and spraying or painting the freshly cut stumps with suitable herbicide. The chemical herbicides like round up, 2-4 D, Glenside Kerosene and diesel oil are the best to be used.
- ✓ **Biological;**
  Predators and /or pathogens can be used to control the mesquite trees infestation. Sudanese researchers from Sudan University of Technology (SUST) have found some predators insects that can attack the seeds and leaves that can demolish the trees.

  Moreover the burning of mesquite trees from the cutting on the ground level can also be used. In New Halfa irrigation scheme they used the same method, firstly by using the physical method, cutting and bulldozing the mesquite trees and burn them. However this is possible if the roots are not very much long, in case the roots are long to more than 10m down the ground then the excavating process should be applied instead of bulldozing it. Mesquite trees are invasive nature and eradication need commitment and aggressive management. It need time to maintain the process of keeping the land clean from mesquite after eradication. Without any clear policies, organization, open management budget and regulations maintenance it will not be easy to fight against mesquite trees in Gash. For example in New Halfa, after the shrubs and stumps were cleared and uprooted the seeds for land clearance, farmers were not allowed to allow their animals to pass through the farm nearby. Not allowed to leave the farm plots un culvated and not allowed to use animal manure as fertilizers from farm to avoid germination of the seeds. This is controlling and supervised by New Halfa ministry of Agriculture /Irrigation and Local government.

5.2.5. Mesquite Used as Benefit to farmers

In making use of mesquite trees by converting the weed into a valuable resource will benefit the communities on socio-economic aspects improve the living standards of the communities of Gash and Kassala in general. However to manage, control and utilize Mesquite trees need full commitment and participation of local communities. The appropriate control measures and follow up management activities need to be done.(N Pasiecznik 2002).

The government could have strategic development plan and encouragement of the private sector and other stakeholders to establish a market for mesquite products. With market policies could help the improvement of living standard and increase the economic status of the country.

Charcoal making

In Kassala the production of charcoal was not very much encouraged. The farmers in Kassala however do practice charcoal making in small amounts. This is because the income from charcoal making was not enough to make their daily life for instance 1bag called sucks is sold for four (4) euro in the production area and goes up to 7 euro in Kassala town while the production cost and transport is nearly the same cost. Users preferred to use charcoal from Taleh *(Acacia)* trees rather than mesquite trees. However the huge problem was that the mesquite charcoal as explained earlier is inferior to the one from Taleh trees which is much processed from the area.

According to Admasu (2008) mesquite wood is very hardy, burns slowly and has excellent heating characteristics. The charcoal produced has good properties and can easily trade on urban markets. In Ethiopia farmers were trained in labour efficient charcoal productions techniques using metal kilns instead of traditional kilns. The mesquite wood can also be used for making furniture, parquet flooring wood and housing.

Wood Chips

Though this is not very common in Kassala but mesquite wood residue can be chipped off and used in garden and little vegetable gardens. The mulch is also effective in reducing evapotransipiration and, thus reduces plant water consumptions.(Nick M Pasiecznik et al., 2001a)

Fodder

According to (Nick M Pasiecznik et al., 2001b) Free ranging animals can eat mesquite pods directly from the tree. But it is possible to collect the pods and ground them to produce flour which will be included to animals' diet. This process produces the percentages of the flour in the mix should be kept below 50% in order to avoid digestion disorders among the livestock. This is also noted from MetaMeta 2014-Practical note on Controlling and /or using mesquite trees in spate irrigation scheme.

Land reclamation

Charcoal improves the physical, biological, physical and chemical properties of the soil by releasing and storing nutrients, increasing also the bulk density of the soil, improving the overall porosity and creating favorable conditions for micro biological activities for farm practices. It can be applied in conjunction with farm yard manure and or soil microbes (MetaMeta 2014) as quoted from Sai Bhaskar, 2009.

Bio Fuel

Nick M Pasiecznik et al., (2001b) stated that, mesquite is underestimated source of sugar that can be converted into ethanol. Trials in the USA have shown that up to 80% of the pods carbohydrates can be converted in the process. However this process is still in experimental stage.

Figure 5.12 Benefit of mesquite trees, charcoal in Sudan and India

Biomass to generate power

In Kenya, the private electricity producer Tower Power is planning to develop the two biomass power plant in Baringo and Kwale to produce electricity by suing the mesquite trees. The project is set to transform the tree from noxious weeds to a cash crop when about 2000 households are supplying the company with the trees stems. The trees stem will be cut into chips and dried then reacted at high temperature under controlled oxygen to avoid complete combustion. The resulting gas will be used to run specialized generators which in turn produce electricity. Baringo has a mesquite infestation forest for about 30,000 ha which is the highest invasive trees in Kenya. It is estimated that the company Tower Power can serve its power plant for 10 years (Daily 2014a, b)

Honey and Gum

Mesquite trees have abundant amount of pollen which can be transformed to high quality of honey. This is also proven by researchers in Sudan (SUST).One of the big obstacles is the lack of water sources for the bees especially during dry season or off flood period. The gum that exuded from mesquite is comparable to gum Arabica and can be used in the food cosmetic industry. Its use is constrained by the absence of toxicological tests necessary for it to enter the industrial market. Researchers in SUST stated that the honey from mesquite can be used for medical reason erectile dysfunction (Babiker, 2009).

Pods

According to Wise et al., (2012), are very highy nutritious as refered by (Felker et al., 2003), the production of pods from different area in the world can be observed by (Felker 1979), which states that that pods can produce up to 20,000kg/ha/year. Famers can therefore be advised to use pods of mesquite for animal feed productions. In Kenya studies shows that the productions of pod can reach up to 12,000kg/ha (Choge et al., 2007). No studies /estimates exist from Sudan so far. The advised to farmers and stakeholders in Sudan is to convert this resources to animal feed as it will benefit not only livestock keepers which are many and very normadic but also farmers who are struggling to get rid out of it. It also have medicinal purposes as stated by (Choge et al., 2007).

5.2.6. Other Benefit of Mesquite trees

- ✓ In Peru the collection of pods can be up to 150kg/day/one collector and he/she can earn 3.7 euro during the production season. In February the pods sell in the market at 20 Euro/Ton .
- ✓ In Gash area, Kassala in Sudan, the clearance of mesquite tree in 85euro/1feddan (0.42 ha) by manual removal with the cost of charcoal goes for about 10euro/stuck in urban areas.
- ✓ In Kassala 15% of population depend on charcoal for the daily life cooking energy in urban and 55% from the remote areas depend on charcoal for their cooking energy.
- ✓ In India Mesquite wood is sold at INR.80 (1Euro)/Kg and charcoal is sold at Rs 14 (0.2euro/Kg (Sai Bhaskar, 2009)
- ✓ Clearing one acre of infested land can cost up to 185euro/ha (MetaMeta, 2009)
- ✓ The use of mesquite biochar plus manure is known to have brought about a 30% to 40% increase in cotton yield (Sai Bhaskar, 2009)
- ✓ For a small scale charcoal producer it is possible to earn 1410 euro/year (CSDI, 2009)

A table below summarizes the pros and cons of mesquite trees in Gash. Despite many negative impacts mesquite trees, there is also the positive part from mesquite trees.

The following strategy can be used to control the mesquite trees infestations

1) Removal of mesquite on the water ways, highly productive areas like in the *Mesga* and keep close vigilance and intense use of these lands
2) Communities especially farmers, should be encouraged to uproot the mesquite when they are still very small, will easy to remove.
3) The Kassala state government, Central government, stakeholders, private sector and communal land have to say to mesquite and establish new program management team with given all the resources to fight against mesquite or to convert the mesquite biomass like in Kenya convert it to energy.
4) A new body regulation is required to facilitate the commercialization of mesquite trees products. Policies must promote the productions of charcoal and poles for fencing and construction which until now is discourage.
5) After the clearance and make benefit out of it the new regulation should be entertain to make sure no more mesquite within the area for instance in New Halfa whereby the ministry of agriculture decided to have bylaws and regulations to manage the new invasive and animal glazing on the Maziga.

Despite the effort to control and eradicate the mesquite trees in Kassala there are so many benefits if it is used in a proper way. Mesquite tree can have benefits from wood, as its wood is very hard and used in making furniture and tool handles. The flowers from mesquite trees species provides bee with nectar to produce honey, this is practically workable in India. They grow rapidly and a shade source for animals. In Kassala 40% of the farmers are also livestock keepers and therefore they can use mesquite trees for shading their animal's hut. The bean produced by the trees can be turned into flour and used for baking (Babiker, 2009). Mesquite has the negative part in its growing stage.

Although the mesquite trees have very big negative impacts on the agricultural areas and social communities yet the shrub has some benefits to the users in Gash. It is all the time source of fodder and river bank stabilizations. It also has been used for covering the grazing area and timber productions. According to IFAD (2011), the poor and landless people are able to generate their income from charcoal making and fuel wood. In Wagari, Makali, Matetaip and many areas in downstream of the Gash river poor nomadic people use charcoal making as their main source of income especially during the dry season. In Hadalia village where hadandawa tribe found, the mesquite tree has been used as not only for charcoal making but also for their house construction, firewood, medicine and even for animal boundary areas.

Table 5.11 Pros and Cons aspects of mesquite trees in Gash area *(Source; MetaMeta 2014)*

PROS	CONS
Can play a role in sustaining the livelihood of poor rural households	Lack of traditional knowledge on how to manage and control the plant
Source of fuel and dry season animal feed	Obstructs paths and roads
Wood does not spit, spark of smoke excessively	Hard and costly to remove
Often in the commonly owned areas where they are freely available to the whole community	Expands quickly even in the harshest condition
High quality and hard timber	Thorns can injure animals and people
Good animal feed especially for dairy cows	Depletes the water moisture and limits availability to local plants
Wood can be processed into furniture or construction material	Few plants are able to grow under its crown shade
Can act as vegetative fencing to delimit and protect properties	Can favor the breeding of malaria spreading mosquitoes
Produces good charcoal	Causes pastoralist communal lands to shrink

CHAPTER 6

CONCLUSSION AND RECOMMENDATIONS

6.1. CONCLUSSIONS

1. Generally the mesquite trees infestation has been a huge problem in Gash agriculture scheme and Kassala state. As a whole and covering the large amount of hectares with approximately more than 89,000 ha reported in 1979 and recently in 2013 data shows that the total coverage area for mesquite trees are 141,942 ha. The processing and analysis of four satellite images in the period 1979-2013 confirm the global trend of increament in mesquite infestation. However the increament takes place with different rates and in different periods for the different parts of the Gash Delta which makes it possible to identify different main drivers for this increament per area.The Gash delta shows a continuing increament trend in mesquite trees from during 1979-1985 followed by 1985 -1998.In the year 1998-2013 the trend continue with the big changes of coverages (117,076 ha to 141,942 ha), it can be forecasted that in 2020 the trend could reach 200,000 ha of infestations.

   (a) This study was discussing the Land Use Cover of Gash Agriculture Scheme (GAS) with emphasize on the Mesquite trees infestation over the area. The total area of Gash Delta is more than 294,000Ha. To identify the trends of the Mesquite infestation on Gash area in Kassala, several methods have been implemented. ArcGis 9.3.1 and ENVI 4.7 were the major tools to come up with the results. The results show that a total of 141,942 ha of mesquite tree have been infested during the year 1979 to 2013.Mesquite infestation has increased from 89,000ha in 1979 to 142,000 ha in 2013. Most of the infestations appeared in recently years especially from 1995 to 2013, the trends keep growing as many factors contributed to the trends. On contrary an Agriculture areas has been decreasing from 1979 (32,125 ha) which is 8.6% of the total study area (294,000 ha). This has caused a major effect on both land and water development. Land has reduced for other activities including agriculture land.

   (b) Infestation is also caused by animals especially when they come to the river and canal banks to drink water. Animal movement and water management have been key issues causing the infestation of mesquite trees in Gash. When animal moves from one area to another they normally drops dung which then by its germniation from animal stomach generates growing conditions and grows stronger a a tree.One drop fro an animal can grow more than ten branches at once.Water has been important for agriculture activities in Gash. Flood is the only source of water from Gash river for irrigation but, when the flood comes in July to September it transport dried pods which carry mesquite seeds and leaves to another area downstream. Flood water also crosses the river and canal banks, mesquite forest areas, with poor management then mesquite activated and grows stronger.

(c) In this research, crop production has also been considered. Only Sorghum crop was taken into consideration and Fota Canal as intake capacity discharge. However the capacity of the canal was calculated during the field work and also aquacrop model 4.1 was used to estimate the crop productions and how mesquite is affecting the productions. Three scenarios were developed i.e,

(i) Current condition - full irrigation application: 823 to 987 mm - this is calacutated assuming 25 and 30 days irrigation duration and the field canal operates continuously at full capacity (1.6 m3/s),

(ii) Reduced application depth: 617 and 741 mm - this calculated assuming 25 and 30 days irrigation duration and the field canal operates continously at 75% of its full capacity (1.2 m3/s),

(iii) Reduced application depth: 494 and 411 mm - this calculated assuming 25 and 30 days irrigation duration and the field canal operates continously at 50% of its full capacity (0.8 m3/s).

The three scenarios concluded that with crop productions under full discharge of 1.6m^3/s, is enough to be used, with current application rate of 823 to 987 mma yield of 5ton/ha is obtained, which is considered to be optimum condition as per FAO,2012 (Under spate irrigation the productions is 5.5to/ha). As been informed by farmers,a 50% reduction in application happens, the yield will significantly reduce by up to 50% to 2.5ton/ha.

(d) On the water consumption by the trees it was revealed that the amount of 243,428,571 litres/day out of the total agricultural area (42,600 ha) is consumed.This amount is only after evapotranspiration has been taken out of the total amount 811,097,143 litres/day per total infested area. With the consideration that study area is irrigated by flood seasonal river then the effect on the production is very high. The water is consumed by tap root of mesquite tree and its widening root of about 6m. Other factors can also contribute to the water loss and crop yield reductions eg climate changes, low rainfall, improper agriculture ptactices and also the poor infrastructure to allow proper flow of water without seepage.

(e) Mesquite eradication/ controlling can be used to change the life of Kassala indigeneous people if used in a proper way. So far there is nothing concrete on using the tree for benefit. The ammount of 52,876,902 USD/ha can be achieved as benefit for only selling charcoal. However other research questions were also answered depend on the ground truthing and data collection in the field. The existing measure have been ineffective with lack of land ownership(land tenure),lack of institutional backing fro central government to local government and even the control has been disappointed due to lack of commitment and follow up from the state government.

6.2. RECOMMENDATIONS

Due to high infestation particulary in Gash area, in summary the following are the keympoint on recommendations to Sudan government and stakeholders of agriculture, water and irrigation, institutional and also scientist/researchers.

(a) More research should strongly recommend evaluating the impacts of these trees on water and cropping productions on other crops like cotton and fruits. Thios studwas done on the emphasiz on sorghum crop only. There is a room for othe researchers to look onto other crops in Gash even in different perspective. It could also emphasize on the 6 blocks irrigation canals, sedimentation with all crops cultivated in the area into considerations.Such programs of control and eradication should maximize the income to citizens.

(b) Cost benefit analysis is an essential component of a noxious mesquite management strategy with focus on productive land. Mesquite has caused and continued to cause huge problems in irrigation facilities and Gash River. Despite various efforts to deal with it still, the problem is unsolved. There is a need for the institutional (government) to look very closely to the mesquite and put first agenda so that to come up with alternative way on how to benefit from this weed. So many ways has been mention in this study could be implemented. New Halfa project can be used as a pilot study for removing the Mesquite and have the prper control structure for animals and normadic people. With clear bylaws for water user association which will enable and put in place, it is mostly of the the farm areas to be mesquite free zone. Whenever possible, management options should integrate mechanical, cultural, biological, and chemical technique. Regular monitoring and annual evaluations determine adequacy of the plan (a case study of New Halfa scheme).

(c) Though in this study cost benefit analysis was discussed in details for Sorghum, Charcoal and Mesquite removal yet there are so many ways to utilise the trees for the benefit of the citizens. By preventing the introduction of the weed (cost-effective) is an essential component of a noxious weed management strategy. Not only the management but also increasing the income of the people

(d) Since mesquite tree infestation has been in Sudan for such along time, Further studies can be recommended with high resolution (ALOS,GeoEye, RapidEye,Meteosat,DigitalGlobeERDAS, MODIS, ASTEL‘s) satellite software to add what has been studied so far and to find the effectiveness of monitoring and expansion of mesquite.

CHAPTER 7

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Appendix A Mesquite Trees branches

Figure A.1 Shape and color of the mesquite pod; Source: (*Control and management options for mesquite in Australia, 2003*)

Figure A.2 Thorns originate just above the leaf axis; Source: (*Control and management options for mesquite in Australia, 2003*)

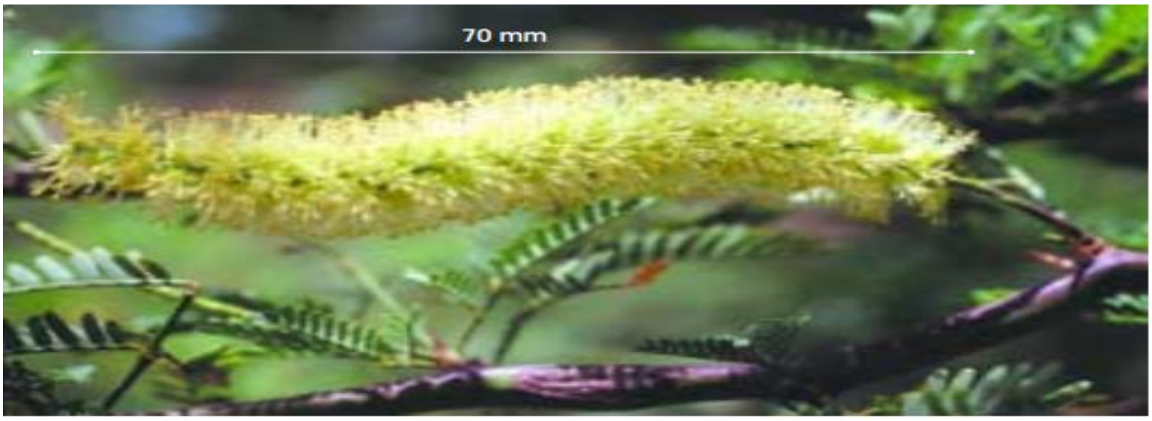

Figure A.3 Lamb's tail flower of mesquite. Source: (*Control and management options for mesquite in Australia, 2003*)

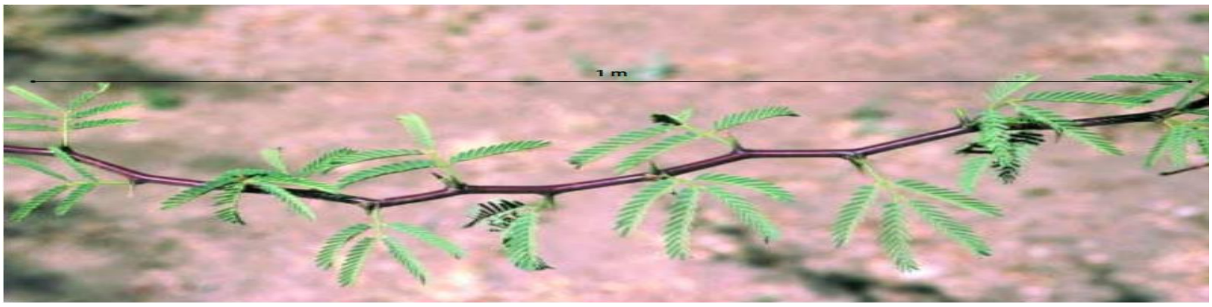

Figure A.4 Mesquite Leave; Source; (*Control and management options for mesquite in Australia, 2003*)

Figure A.5 30 to 40m long root in this photo taken from Australia.

Source; (*Control and management options for mesquite in Australia, 2003*

Appendix B Supervised Classification Images

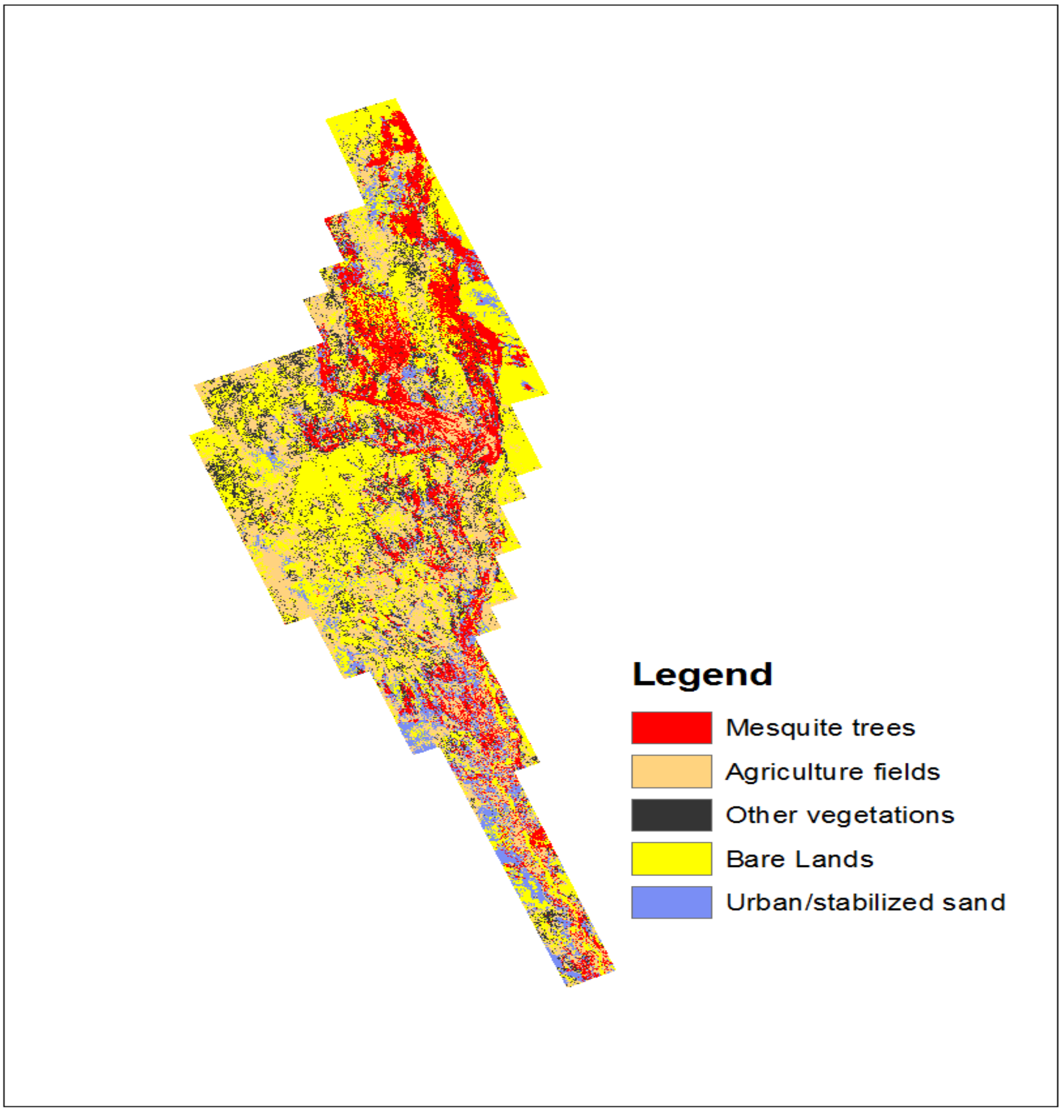

Figure B.1 Supervised Classification for Landsat 4-5TM of April, 1998

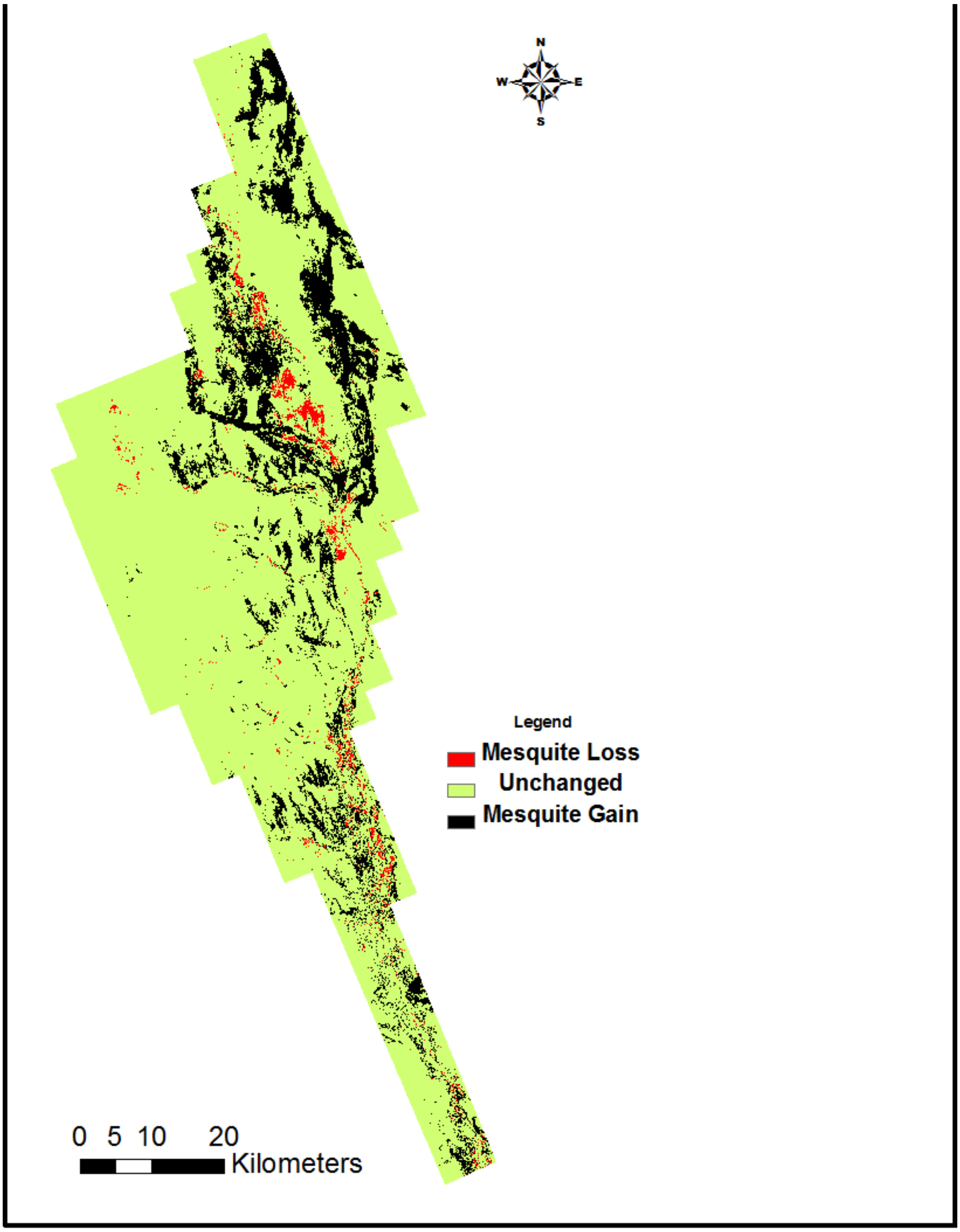

Figure B.2 change detection 2013 vs 1985

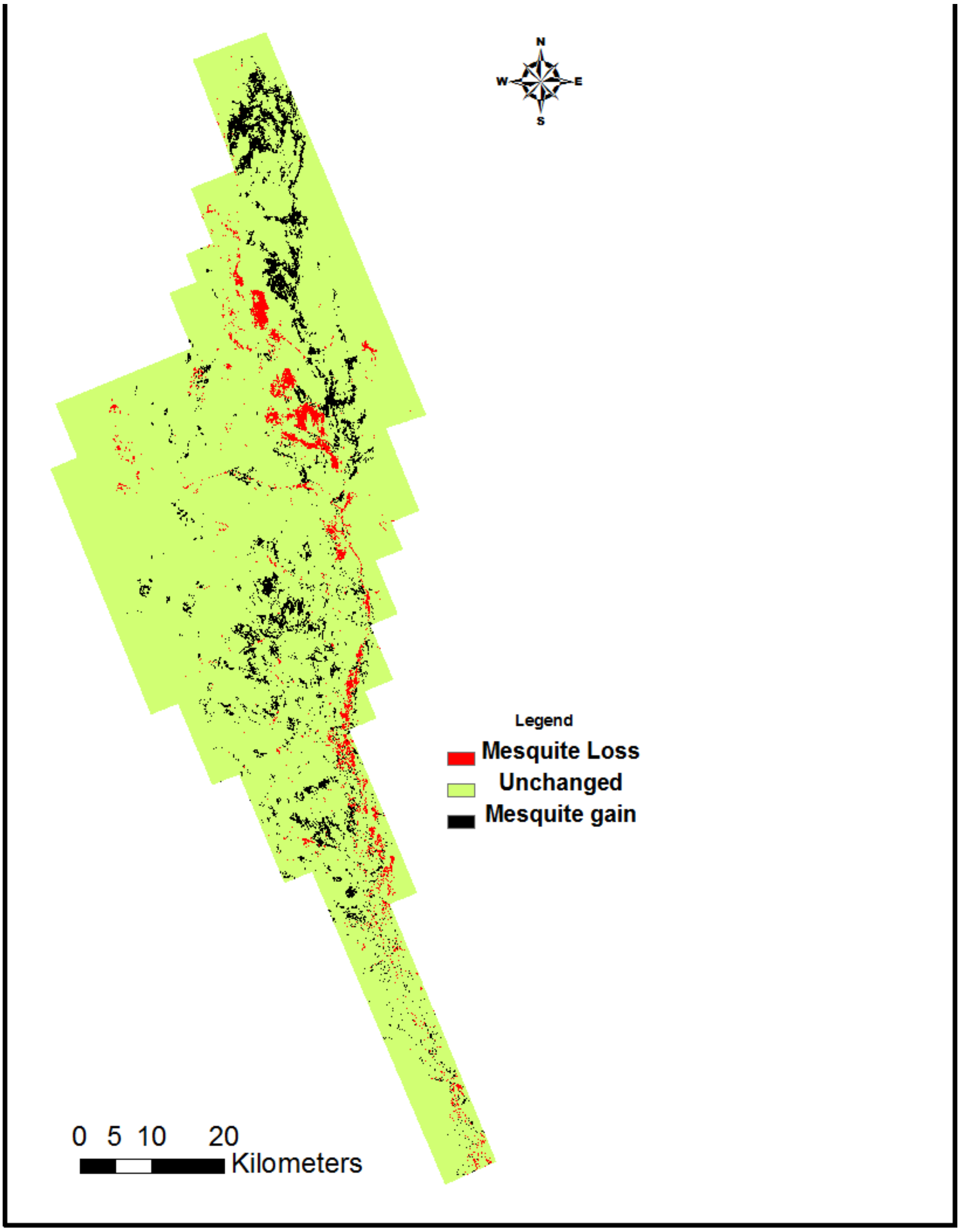

Figure B.3 change detection 1998 vs 1985

Appendix C - Aquacrop Simulations

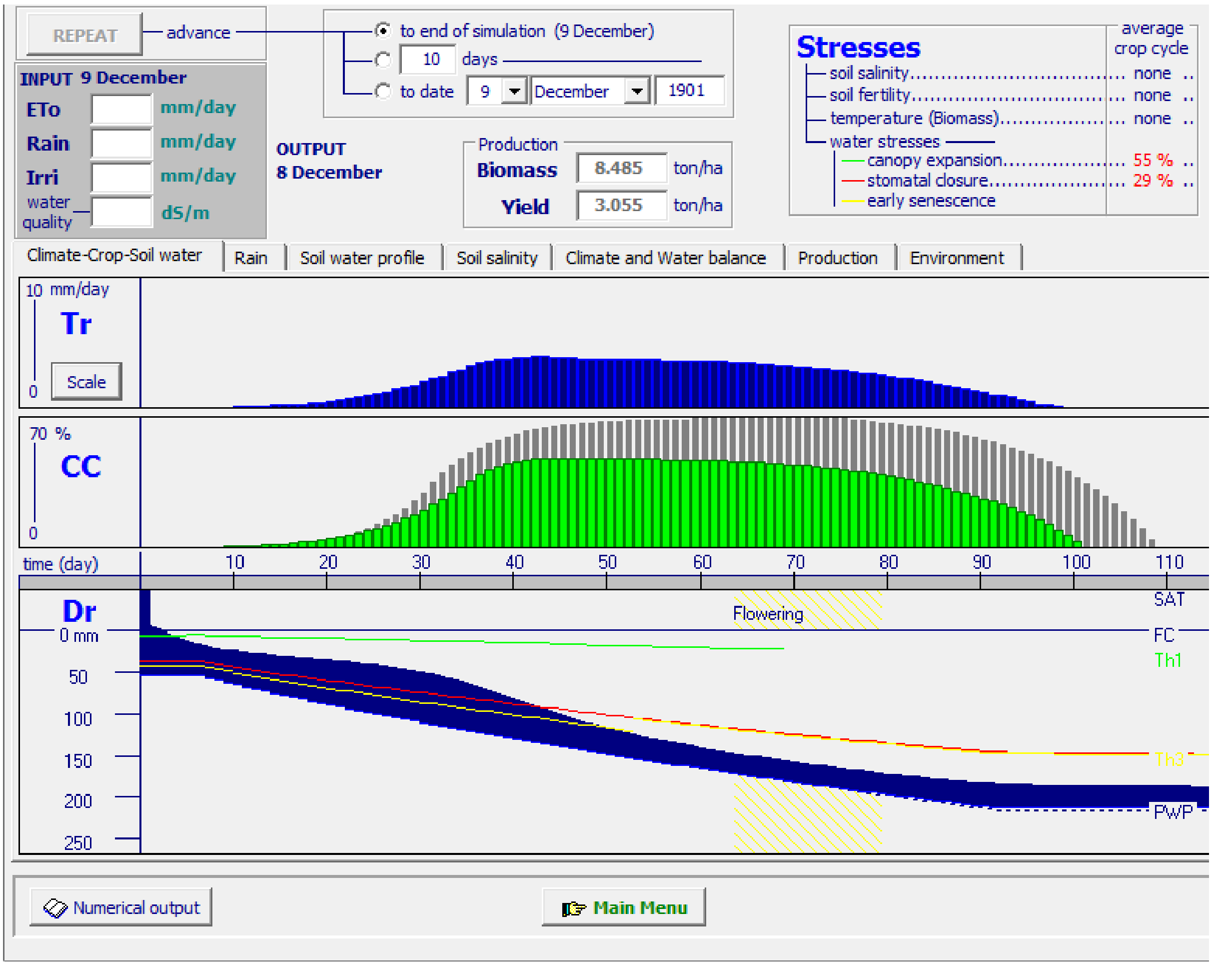

Figure C.1 Simulations under maximum water applications

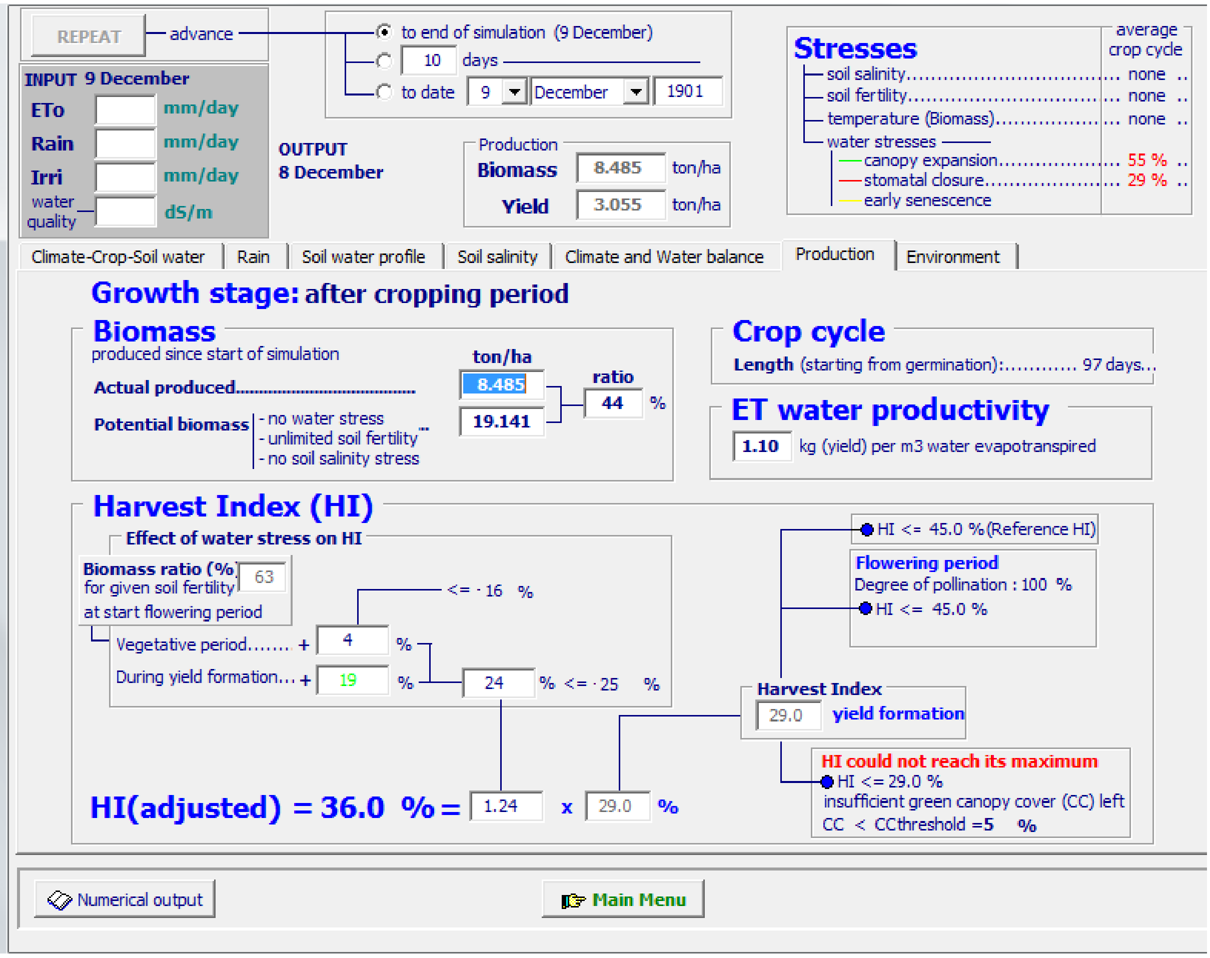

Figure C.2 Simulations which shows the water productivity for 500mm maximum water applications

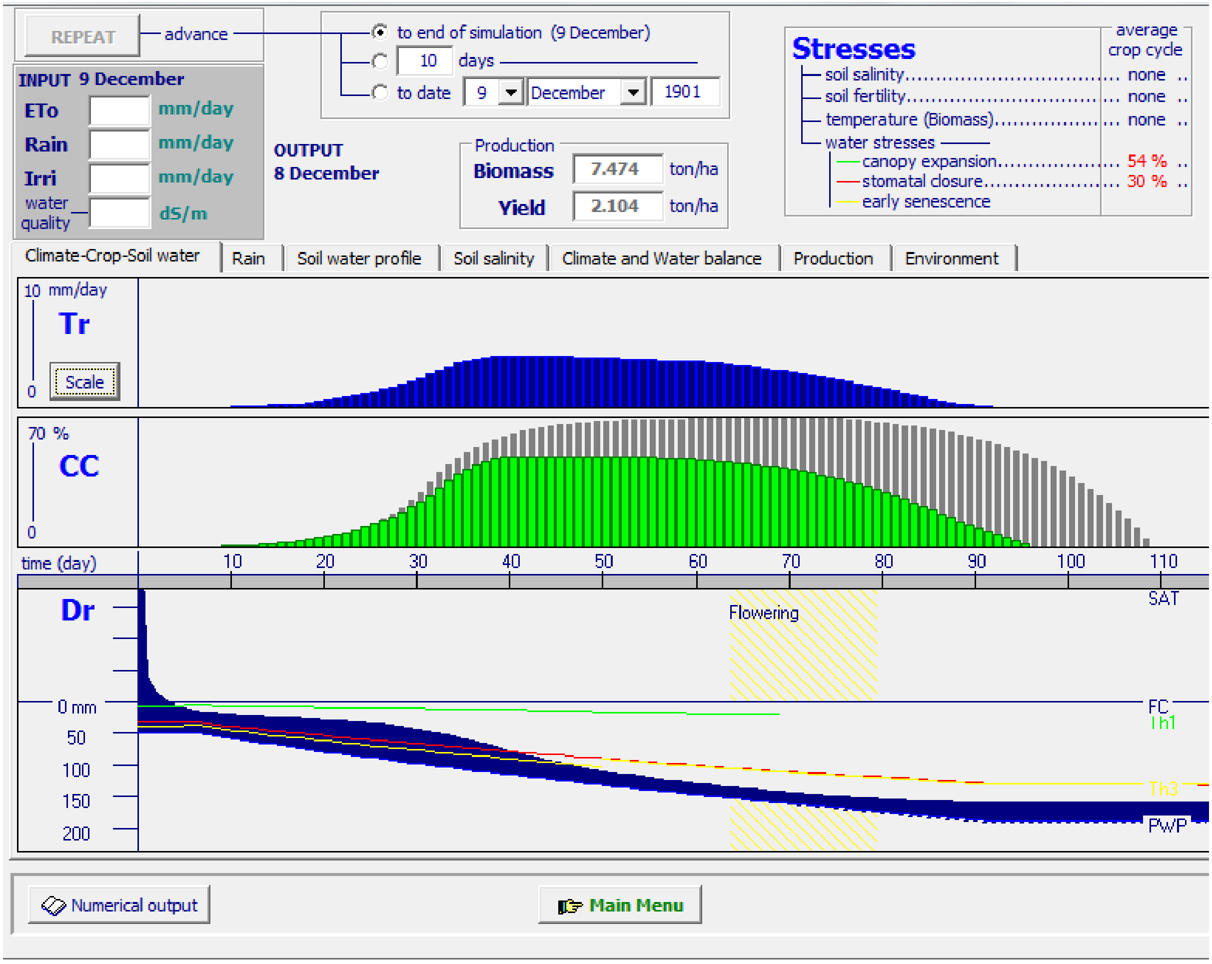

Figure C.3 Simulations after changing the soil type

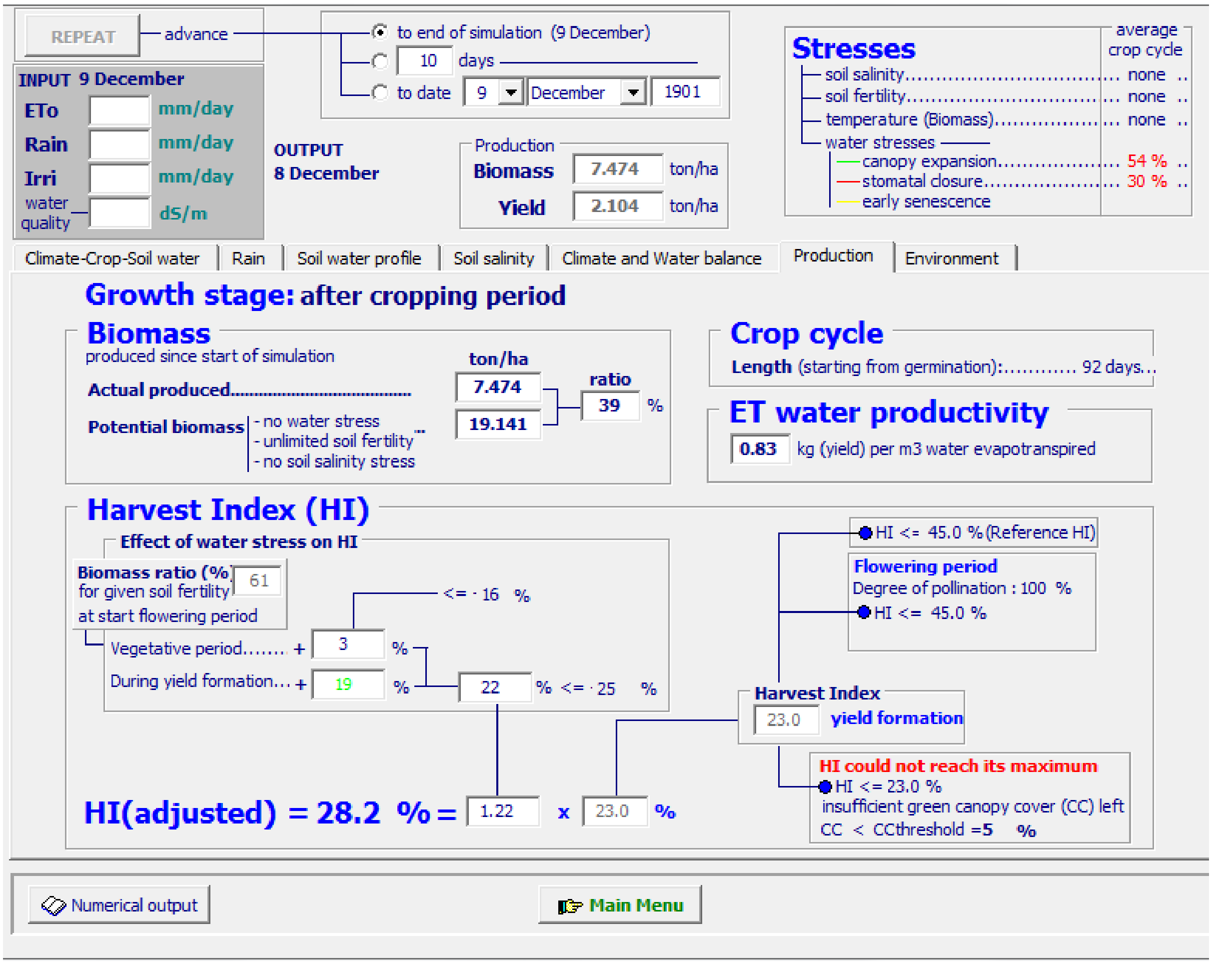

Figure C.4 Crop water productivity for Sorghum at 500mm with changing the soil type.

Appendix D Questionaires

Questionnaire on Mesquite trees (*Prosopis juliflora*) in ……………………….

1. Date…………….
2. Age…………….
3. Sex……………………………
4. Occupation (main income)
    a. Farmer
    b. Agro-pastoralist
    c. Pastoralist
    d. Trader
    e. House wife
    f. Other
5. Do you have crops? If yes, what mainly do you cultivate?(only one answer; be specific)
   No crops……………….
   Yes, I mainly cultivate…………………………..

   No………… yes (specify animals)…………………………..
6. Have you heard about mesquite (*P.juliflora*) (tg:temri musa tr;Sesban arab + hd;temer musa)?
   Yes………………………No…………………….. I don't know…………………………..

(If answer is "no" or "I don't know" please end interview here)

7. Does it grow in the area of your settlement? (Only for people who have settled)
   Yes…………………No…………………….

8. Does it grow on your crops? (Only for farmers/agriculturists and agro-pastoralists)
   Yes………………………No…………………….. I don't know…………………………..

9. Does it grow on your grazing land? (Only for pastoralists and agro-pastoralists)
   Yes………………………No…………………….. I don't know…………………………..

10. When did it occur in your area?
    Year …………………….. I don't know…………………………..

11. Before Prosopis came to your area, did you already hear/know that it grew in other areas?
    Yes………………………No…………………….. I don't know…………………………..

13. Do you know how it came into your area? (Multiple answers are possible)
    a. By livestock
    b. by local people
    c. I don't know
    d. By wild animals
    e. Planted by freedom fighters
    f. It just grew by itself (by wind)
    g. Planted by authorities/government.

14. Which disadvantage/negative effects does it have for your crops? (Multiple answers are possible)
(Only for farmers/agriculturists and agro-pastoralists
    a. It takes water away

b. It take sun light away
c. It takes nutrients away
d. Nothing else grows next to it
e. It decreases the harvest
f. I don't know
g. Other…………………………………..…

15. Which disadvantage/negative effects does it have for the grassland? (Multiple answers possible)(Only for pastoralists/agro-pastoralists)

a. It takes water away
b. It take sun light away
c. It takes nutrients away
d. Nothing else grows next to it
e. Grass does not grow
f. I don't know
g. Other (please specify)……………………………………………

16. Which disadvantage/negative effects does it have for livestock? (Multiple answers are possible)

a. Animals get injured (e.g. by thorns)
b. It's poisoning/toxic for animals
c. Animals die from eating
d. Animals get diarrhea
e. Animals get paralyzed
f. Others (I don't know please specify)………………………….

17. If you have seen/heard animals dying by eating it, which part of the plant do you think caused the death? (Multiple answers are possible)

a. Leafs
b. Seeds
c. I don't know
d. Thorns
e. Plant juice
f. Fruits
g. Other (please specify)………………………………………

18. Have you lost animals yourself because they ate Prosopis/died of injuries by thorns etc.?
Yes…………………….No………………….I don't know…………………….

(NEXT TWO QUESTIONS ONLY IF LAST ANSWER WAS "YES")

{18.a) How many have you lost?
Number…………….. I don't know…………………..18. b) Which kind of your animals died? (Multiple answers possible), Specify…………………………………………………………}

19. Do you think/experienced that some animals get affected more easily by eating it while other does not/are immune? (Quote which animals?)…………………………
Get effected easily ……………..
Do not get effected…………………………..
I don't know………………………………………..

(QUESTION 20 is for farmers/agriculturists and agro-pastoralists only)

20. Do you think Prosopis influences the outcome of crop harvest negatively?
Yes………….. No………………I don't know……………………….

21. What are in your opinion the advantages (positive effects) of Prosopis for the nature you and or the animals?
…………………………………………………………………………………………
No advantages…………………….I don't know…………………..

22. What do you use it for? (Multiple answers possible)

a) Fence/shelterbelts
b) Windbreak
c) Livestock fodder
d) Bricks
e) I do not use it
f) fuel wood
g) building construction
h) charcoal production
i) shade
j) Others…………………….

23. Have you ever used Prosopis for fuel wood/charcoal production?
Yes………….. No………………I don't know……………………….

24. Do you think it has a good quality for the use of charcoal?
Yes………….. No………………I don't know……………………….

25. Does the local government to your knowledge allow cutting of Prosopis or do they say it needs to be protected?
Can be cut……………It is forbidden to cut………….Don't know………………..

26. Do you think Prosopis improves the soil in your area or does it degrade it?
Improves soil…………..Degrades soil…………………I don't know……………………….

27. Did you ever tried to eradicate (Killing) Prosopis from your crops/grassland?
Yes………….. No………………I don't know……………………….

28. If yes, what problems did you face?
Specify………………………………………………………………

29. If not, why not?
Specify………………………………………………………………

30. Would you wish the local government would try to eradicate it?
Yes……………….no……………… do/did try……………I don't know……………..

31. Keeping everything in mind what you know/experienced with Prosopis: Would you consider it to be a pest/weed, a very useful tree or neither?
Pest/weed……………..Useful tree…………… Neither…….. I don't know…………….

32. If you were taught how you can make use of Prosopis so it would benefit you and your family, would you like to learn/know about it?
Yes………….. No………………I don't know……………………….

33. Do you have anything to add that is important to you?
No……………Yes……………..Specify………………………………………………………………
……………………………………………………………………………………………………….

34. What is the local name of *Prosopis juliflora*?

35. Where is this species found within the area that you live?
   a. On own land
   b. On community land
   c. On government land
36. Name four places with highest density of *Prosopis* in descending order.

37. How did it come to be there? Was it planted? By whom? When? Why? Were you involved?

38. Please describe the habitat in which much of this species is found, and why you think this is so?

39. Has the density/cover of the species increased or decreased in the past 5-10 years? Give an estimate of the extent of increase or decrease.

40. Has the density/cover of the ground cover around *Prosopis juliflora* i.e. grasses and forbs increased or decreased in the past 5-10 years?

41. What are the most important products you harvest from this species?
   a. What aspect of your needs does it supply?
   b. When do you harvest?
   c. How much?

42. What constraints do you face in the harvest of products from this species?

43. What constraints do you face in the sale of products from this species?

44. Are there other ways that people might generate a livelihood through *Prosopis*?

45. Have you tried other ways of using this species?

46. What constraints have you faced in adopting these alternative uses?

47. Would you be interested in learning new or different ways in using *Prosopis*?

48. What are the most serious problems you are facing with this species today? Please quantify any losses.

49. What were the most serious problems you faced with this species 10 years ago? Please quantify any losses.

50. Did you report this problem to anyone? If yes, who did you report to? When and how did they help you?

51. Have you undertaken any management, control or regeneration activities with respect to this species?
52. What are your main sources of income? How has the increase/decrease in *P. juliflora* affected your income? Please quantify.

53. Has the incidence of *P. juliflora* affected the availability of other resources that you have been using and how?

54. Has the proliferation/decline of *P. juliflora* caused any conflicts between you and others in the use of the above resources? Please explain.

55. Please describe the ways you traditionally control access to natural resources for example, access to water, to pasture and to tree products. Who has access, when and where? Does this include other communities? Who controls access?

56. Can we apply these methods to the use and management of *P. Juliflora*? If yes, how? If no, why not? What would be the main challenges?

57. Where do your livestock graze at different times of the year? Wet season or dry season, Name the places and for how long.

58. Please provide us with the numbers and types of livestock that you have. Are they all here or are some away? How many are away? Where and with whom?

59. What would you like to be done with regard to the *Prosopis* problem?

60. Who do you think should do it and why?

Thank you for your time