UNIVERSITY OF NAIROBI

ASSESSING THE POTENTIAL IMPACT OF CLIMATE VARIABILITY AND ANTHROPOLOGICAL ACTIVITIES ON HONEY BEE FODDER PLANTS IN SAGALLA, TAITA TAVETA COUNTY, KENYA

BY

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DECLARATION

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DEDICATION

This research project is dedicated to the Sagalla community at large, the Elephants and Bees Project and my family. Their support and encouragement were my motivation to continue with my forward surge in the quest for knowledge and success in life

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ABSTRACT

Honeybees are globally recognized for products such as honey and wax, and as valuable pollinators of both natural ecosystems and agricultural crops. However, studies have shown that climate variability and human - driven environmental changes are affecting the population dynamics of the bees and their preferred fodder plants and subsequently, the socio-economic benefits of the honey bees. Although the decline in the honey bee and their associated plants may be attributed to all these factors combined, which rarely acts in isolation, previous studies in honey bee pollinator and pollination interactions have rarely considered they together decline. This study therefore aimed to investigate the effects of the combined and interactive factors of climate and anthropogenic environmental change on the bee forage diversity, plant-honey bee pollinators' interactions and bee keeping activity. The project interviewed 25 respondents of smallholder farmer/beekeeper households using a semi-structured questionnaire. The beekeepers and other key informants in the study site were asked to report on important constrains and opportunities for beekeeping. Transect walks were conducted during the wet and dry season to determine the diversity of bee forage plants in twelve (12) randomly selected farms lined while bee population was determined by observing the beehive fences. Rainfall data collected in the same period were subsequently built into a statistical model to predict relationship between diversity of bee forage plants and bee population using precipitation data. Descriptive statistics were used to analyze quantitative data and percentages for the qualitative data. The major findings of the study indicated that there was a positive relationship between the warmer and drier weather conditions experienced during dry season and the lower diversity of bee forage plants [Bee forage plants (F_P) (at confidence range) = 12.425 + 0.8757M, p-value; R^2 = 0.8]. Similarly, there was also a positive correlation between the honey bee (B) population size and the availability of bee forage plants [(F_B) = 17.116 + 0.6365 P, R^2 = 0.55]. The findings indicated that warmer and drier conditions in dry season were accompanied with about 57% decline in the diversity of the honey bee fodder (floral resources) and about 36% decline in honeybee population. The most important plant families observed to be used by honey bee as fodder included Acanthaceae, Labiatae, Rubiaceae and Compositae. Among the plant species in the understory community, *Tridax procumbens*, *Digera muricata* and *Justicia flava* were found to be among the most important to honey bees. Hence, this study show clear evidence of a link between climate variability, diversity of honey bee fodder plants and honey bee population. The findings of this study recommends that beekeeping farmers in the study site should give consideration to the season long fodder resources needed by bees in dry season and ensure connectivity of natural habitats in farming areas, so that bees' can more easily disperse and easily collect floral resources essential in response to changing climates.

Keywords:

Environment, Climate variability, Climate change, Honey bee, fodder plants

Pollination, Beehive fence

ACRONYMS

ASAL-Arid and Semi-Arid Lands

HEC-Human Elephant Conflict

IPCC-Intergovernmental Panel on Climate Change

WMO-World Meteorological Organization

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1.0 CHAPTER ONE: INTRODUCTION

1.1 Background Information

Pollination in plants is animal mediated for about 70- 90% of angiosperm species (Fontaine *et al.,* 2006). It is a service conducted by approximately 20,000 different species of insects and animals' (e.g. bees, butterflies, mongooses etc.) making animal pollination an indispensable ecosystem service.

At least 90% of wild flowering plants and 76% of the food crops rely on insect mediated pollination (IPBES, 2016). Worldwide, the honey bees (*Apis mellifera* L.) are among the major pollinators of nearly 74% of the world's cultivated food crops, estimated at $153 billion annually and form an important source of livelihood(Reddy *et al*., 2013). Even as bees provide pollination and all other socio-economic and ecosystem services, plants remain a core source of their nutrition (pollen and nectar). The ability of the bees to acquire and mobilize sufficient and variable nutrients around their habitat affects all aspects of their physiology. Plants are therefore an important fuel for bee population growth, survival and socio-economic services in our societies (Di Pasquale *et al.*, 2013).

The global distribution and niche occupation of bee species in the wild has been influenced by their geography and feeding behaviour. Over time, both the plants and honey bee have evolved into numerous subspecies in order to overcome various climatic and environmental changes relating to productivity, vigor and climate conditions (Van Engelsdorp & Meixner, 2010). The honey bee which is a generalist feeder, developed to become the most widely distributed of bee species. Human utilization of the bees for different purposes has largely contributed to their global distribution.

Like in most places in the world, the honey bees are a notable source of livelihood to the Sagalla community of Taita Taveta County, Kenya. Here, smallholder farmers place about 10-15 hives around their small farms of about 1¼ acres to act as natural deterrents against the crop raiding elephants from the neighboring Tsavo East National Park. This technique has resulted in a three-fold advantage: increased crop yield production due to reduced damages to the crop by elephants, not to mention fewer life-threatening human-elephant conflicts; better crop yields due to increased pollination of crops in farms by the honey bee; and lastly a new income stream from the sale of honey and other hive products such as wax (King *et al.*,. 2017).

Flowering plants and bees have a mutual relationship, with the plants relying on bees for pollination while the bees get rewarded for this service by extracting pollen and nectar from the flowers that serve as their main source of nutrients. Studies have demonstrated that a decline in the diversity of bee forage plants also lowers the populations of the associated bee pollinators (Scaven & Rafferty, 2013). There has been mounting global concern in the last decade about the increasing decline of bee forage plants, which is consequently depressing honey the bee population. This has resulted in lower ecosystem services and socio-economic benefits associated to beekeeping (Bartomeus *et al*., 2011). This is also of concern in the Sagalla area where the declining bee population is leaving behind a pollination vacuum that is subsequently affecting the livelihoods of both the farmers and beekeepers in the community.

The changes in diversity of bee forage plants may be attributed to five major global change pressures. These are climate variability and change (normally depicted by severe and prolonged droughts), intensification of agricultural practices, alteration of landscape, introduction of non-native plant and animal species and attacks by predators and pathogens (McLaughlin *et al.*, 2002). Some of the above named scenarios occur in the Sagalla area of Taita Taveta County, one such example being the recently experienced severe dry season (drought) in the year 2017.

These pressures differ in their biotic or abiotic nature and their space and time scales and may interact in non-additive ways (antagonistically or synergistically). Research has shown that climate change and climate variability has the potential to alter the relationship and phenological synchrony between plants and bee pollinators (Giannini *et al.*, 2012). Although predictions of the impacts of climate variability on plant and pollinators population decline are supported by shifts in geographic range that correspond to climatic variability and climate warming, few plant and bee pollinators extinctions have been linked mechanistically to this climate variability (Steffan-Dewenter & Westphal, 2008). It is clear however, that the phenomena of many biological processes is modulated by climate parameters such as rainfall and temperature, making them potentially sensitive to impacts of climate variability (Zacepins & Karasha, 2013). In addition, mutualistic interactions between honey bee and plants may be more vulnerable especially in ASAL areas such as Sagalla because of the potential for phenological mismatching if the species involved do not respond in tandem to changes in climate conditions.

Even after studies have indicated that pollinators decline as a consequence of the five major global pressures, rarely are these factors considered together in studies of plant-pollinators interaction and decline (González-Varo *et al*., 2013). Since these different environmental drivers rarely act in isolation, actions aimed at buffering the impacts of a particular pressure could thereby prove ineffective if another pressure still exists and not addressed. This study therefore highlights the combined and interactive effects of anthropogenic climate variability and environmental change on the plant-honey bee pollination interactions.

The study area of Sagalla is unique due to its various cryptic habitats which are areas hidden from normal investigative view of researchers and scientists, but which consist of a large reservoir of the earth's biota that are not readily discoverable with the state of the art research techniques and their hidden location (Popic *et al*., 2013). In these cases, continuous habitat degradation due to human activities can or may have occurred before researchers could intercept important ecological data substantiating the observed loss since many of these are microhabitats where vast numbers of plant and pollinator species that inhabit very small enclosed and virtually hidden spaces. Pollinator community and their interactions with plants are highly variable in time and space. Interactions that are extremely important one season or one year might not exist the next season/year. This study therefore aimed at documenting the diversity of honey bee forage plants and their interaction with honey bee pollinators in the study area. The expected outcomes of this study will facilitate and enable future comparison of records across time and space. The report of those observed changes enables us to understand the dynamic relationship between plants and honey bee pollinators. The findings of this study will also enable scientists to understand and predict how current relationship may be affected by climate variability and other anthropogenic factors (Ricketts *et al.*, 2008). This study will also report on important environmental and socio-economic constraints and opportunities for beekeeping in Sagalla and other areas applicable.

1.2 Statement of the problem

Existence of a wide range of fodder plants is ideal for sustaining the honey bee population levels needed for optimum agricultural production in crops and hive products. However, climate variability and various anthropological factors such as land use changes have resulted in decreased honey bee forage plants in Sagalla by more than 46% from one season to another (Beyene & Verschuur, 2014). This decrease has in turn led to the decline of honey bee populations with a resultant diminishing of their ecological services. These services include in part, the diminished pollination of crop plants and protection from attacks by elephants.

The livelihoods and food security of Sagalla community are therefore in jeopardy due to low income from hive products, low crop production, increased food prices and attacks from elephants (King *et al.*, 2017). This study therefore investigated the effects of combined factors of climate variability and land use changes on diversity of honey bee fodder plants and its effects on honey bee pollinators in Sagalla and important constraints and mitigation options for beekeeping activities.

1.3 Objectives of the study

1.3.1 Broad objective

To assess potential impact of climate variability and anthropological activities on honey bee fodder plants, honey bee populations and mitigations for beekeeping in Sagalla, Taita Taveta County, Kenya.

1.3.2 Specific Objectives

1. To document the diversity of honey bee fodder plants in Sagalla.
2. To determine the impact climate variability and anthropogenic activities on the diversity of bee fodder plants and honey bee populations.
3. To explore the environmental and socio-economic opportunities and constraints for beekeeping (apiculture) in Sagalla and possible mitigation strategies against climate variability threats/constrains.

1.4 Justification

The deficiency in the knowledge and awareness needed to restore capability of the honey bee pollinator represents a major liability in livelihoods and ecosystem rehabilitation and restoration programs. When compounded with the likely negative impacts of climate variability and climate change on pollination services, the necessity to understand and manage bee pollinator services in restoration plans and programmes becomes paramount. By taking a comprehensive approach in this study, it may be possible to build in resilience in number of bees, plants and our farming systems.

This remarkable insect pollinator is the main source of honey, income, beeswax, preservative, food and a number of other nutritional and health products for many where only one hive with just a single super box can produce hive products amounting between 3,000-4000 Kenya shillings per harvest. As important as these hive products are to us, their value pales in comparison to the value and diversity of plants and optimum climate conditions round them. Thus, increased hive products and large bee populations are in everyone's best interest and anyone who uses or grows plants and utilize hive products is a stakeholder in plant and bee conservation.

The study will therefore document the relationship between climate variability and human activities on the diversity of honey bee fodder plants and their interaction with honey bee pollinators in the study site. The data accrued in this study will allow for future comparison of records across time and space to be able to observe change and to be able to well understand and clarify the relationship between plants and honey bee pollinators. This will help us to identify broader options for bee keeping, honey production, crop production and pollination services through the deliberate management of bees’ number and their habitat.

1.6 Significance of the Study

The documentation of the relationship between climate variability, bee population and diversity of bee fodder will sensitizing the community to conserve and sustainably use the plant resources to assist in managing and maintaining pollinator-plant synchrony and their socio-economic benefits at the community level. The findings of these study will also add scientific and research knowledge by giving new interpretation of old material, combining old with new interpretations, identifying research and knowledge gaps existing in apiculture sector and point the way in fulfilling a need for additional research. The findings will inform beekeepers and policy makers on the extent to which beekeeping is and can contribute and enhance ecosystems and livelihood change of farmer's household in a rural agrarian setting.

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 Honey bee classification and significance in the environment

The best-known honey bees are the European or Western honey bee (*Apis mellifera)* and African honey bees *(Apis mellifera scutellata)* of genus *Apis* mainly domesticated for the crop pollination and production of hive products. Some other bees that produce and store honey include stingless bees but only members of the genus *Apis*, are true honey bees. African honey *bees (Apis mellifera scutellata)* are distinguished from other bee species by their honey production, storage and the construction of colonial nests and perennial from wax. According to VanEngelsdrop and Meixner (2010), only seven (7) species of honey bee were recognized in the early 21st century, with a total of 46 sub-species. African honey bees *(Apis mellifera scutellata)* of family *Apidae* represent only a small fraction of about 20,000 known bee species.

Beekeeping has traditionally been practiced in Kenya for many years. However, only a small percentage of the country's honey production potential has been tapped. The two species of honey bee, *Apis mellifera* (which include European and African honey bee) and *A. cerana indica* (Eastern Asian honey bee*)*, are often maintained, fed, and transported by beekeepers. The African honey bee *(Apis mellifera* subsp. *scutellata)* which is a subspecies of European honey bees, occurs naturally in Kenya and most sub-Saharan countries (Amdam *et al*., 2005).

About 80% of Kenya consists ASAL's, which have high potential in beekeeping and production of hive products. Apicultural activity is a major occupation in these areas due to the abundance of bee flora (King *et al.*, 2011). ASAL regions in Kenya include areas such as Baringo, West Pokot, and Taita Taveta, which is the study area, practice beekeeping. Modern bee-keeping in Sagalla started in the year 2009 and has since become an key enterprise and important source of livelihood to the Sagalla community (King *et al*., 2011).

2.2 Honey bee health and nutrition

Nutritional requirements of the honey bees are obtained from nectar and pollen of a diverse combination of flowering plants. Pollen provides the only natural protein for the honeybees' with the adult worker bees requiring 3.5 - 4.4 mg of pollen in a day to be able to meet daily dry matter requirement of 64-76% protein. One larva of honey bee requires 123-186.8 mg pollen or 26-37.9 mg protein for proper development (Brodschneider & Crailsheim, 2010). Adult honey bee workers require about 3-5 mg of utilizable sugars in a day and honey bee larvae requires about 58.6 mg of carbohydrates to develop properly making nectar an important source of nutrition for the honey bees (Brodschneider & Crailsheim, 2010). Dietary proteins are broken down into amino acids, ten of which are essential to honey bee development. Nevertheless, those required in the highest concentrations are isoleucine, leucine and valine while increased concentrations of lysine and arginine are needed for brood rearing (Di Pasquale *et al.*, 2013). Therefore, lack of sufficient pollen leads to inability to rear the brood well and this eventually affects the colony size and strength.

Foraging worker bees collect nectar, which is the source sucrose (carbohydrates) and water. The monosaccharides dominating the honey bee diets are glucose and fructose but the most common sugar in bees hemolymph is trehalose, which is a disaccharide consisting of two molecules of glucose. Water collected by the Honey bees is required to maintain osmotic homeostasis, prepare liquid brood food and to cool the hive through evaporation (Zacepins & Karasha, 2013). The water needs of a colony are generally met by foraging for nectar. Occasionally, foragers will collect water from streams or ponds on dry days to meet the needs of the hive.

2.3 Importance of beekeeping to Sagalla community

Modern hives have enabled beekeepers to manage bees, and transport bees, moving from field to field, allowing the beekeeper to charge and manipulate pollination services they provide, revising the historical role of the self-employed beekeeper, and favoring large-scale commercial beekeeping operations in our societies.

Worldwide bee farming is a rewarding and enjoyable occupation with many benefits and for the Sagalla community it has a number of advantages over other farm enterprises. First, it requires little land (15 to 20 colonies require a ¼ acre) which does not have to be fertile. Honey is a source of non-perishable food, with low capital needed compared to other farm enterprises and labour required is minimal. Many hive products can be obtained which are great source of income i.e. honey, beeswax, , propolis, bee colonies bee venom, pollen royal jelly, package bees, bee brood, queen bees, and. The honey bee encourages biodiversity conservation since they are good pollinators of plants, crops, fruits, trees, thus playing a big role in bio-diversity and improvement of crop yields. The medicinal value of most honey and other hive products provide remedy for a number of human ailments (Schweitzer, Nombré, & Boussim, 2013). And recently the community has develop a technique to use bees as natural deterrent against crop raiding elephants through the construction of beehive fence around small scale farms (King *et al*., 2017)

2.3.1 The Beehive Fence Concept

Vollrath and Douglas-Hamilton (2002) of Save the Elephants (STE) realized that elephants avoided trees with beehives living in them. This observation led to the development of a novel technique to prevent elephants from raiding crops by lining cropland with fences of beehives suspended from the wires (King *et al.,* 2009). These beehive fences were simple, cheap and made using only locally sourced materials. The hives, or dummy hives, were hung every ten meters and were linked together in a specific formation such that if an elephant touched one of the hives, or the interconnecting wire, the beehives along the whole fence line would swing and released the bees (King *et al.,* 2009, 2011, 2017).

The tests done on the beehive fence design in three rural farming communities in Kenya to be over 80% successful in deterring elephants and significantly reducing human elephant conflict in these areas. The most commonly used hives by the Sagalla community are Langstroth hives which are considered the most efficient hive in honey production. A langstroth hive is any vertically modular beehive whose key features are having vertically hanged frames for brood and honey, an inner cover and a top cap to provide weather protection. Not only do they swing efficiently in the beehive fence and hence prevent elephant invasions that cause trauma and injury to family members, they also provide optimum honey yields. The bees also help increased yield production through both reduced damage and, potentially, increased bee pollination of crops. The farmers therefore benefit from the additional income through the sale of honey and hive products and less life-threatening HEC situations. It has been noted that the higher the number of beehives occupied in a farm, the more effective the beehive fences are in deterring elephants and the more the socio-economic benefits to the farmers (King *et al.*, 2017).

2.4 Effect of climate variability on honey bee pollination Services

Climate variability may threaten pollination services in our ecosystem (González-Varo *et al.*, 2013; McLaughlin *et al.*, 2002). However, empirical studies explicitly focusing on the effects of climate variability on wild plant-pollinator interactions as well as those on crop pollination are scarce. The fourth assessment report developed by the IPCC lists many observed global changes, most notably, global temperatures increase, change in rainfall patterns, frequency and intensity of precipitation (Baede *et al.*, 2007). Effects of these changes have been observed in the study area and they include the severity and timing of seasonal events that have strongly affected terrestrial ecosystem structure, distributional ranges of plant and bee species. These consequences of climate variability have negatively affected the livelihoods of the Sagalla community. In a recent review, Scaven & Rafferty, (2013) found that the timing of both flower bloom and pollinator activity seemed to be changed by temperature increases creating space and time mismatches with severe demographic consequences for the species involved. These mismatches may affect the plants by reduced pollen deposition and bee visitation, while the bee pollinators experience shortage in the availability of food. Creation of time and space mismatches between wild plants and their pollinators was reported by Steffan-Dewenter & Westphal, (2008) who investigated the nature of responses of both bee pollinators and plants to increasing temperatures and found that disparities in the slopes of the responses and season in a year indicated a potential mismatch between plants and bee pollinators.

Sagalla location is located in ASAL of Kenya and is vulnerable to impacts of Climate variability and climate change. Colwell *et al.*, (2008) extrapolated that any future temperature increases in the tropics, even relatively small in magnitude, was likely to have consequences that are more deleterious in ASAL areas than changes at higher latitudes. He attributed this to the fact that tropical insects are relatively sensitive to temperature changes (with a narrow span of suitable temperature) and that they were currently living in environments very close to their optimal temperature. Sunday *et al.,* (2011) pointed out that in contrast, insect species found at higher latitudes where the temperature increase was expected to have broader thermal tolerance and higher chance of survival since they are living in climates cooler than their physiological optima. The authors noted that warming would actually enhance the performance of insects living at these latitudes. It is therefore likely that tropical agro ecosystems such as Sagalla will suffer from greater extinction of native pollinators and population decrease than agro ecosystems at higher latitudes.

2.5 Interactions between the honey bee and the fodder plants (floral resources).

Plants are a core source of nectar to bees and the availability and abundance of plants resources and varieties in our ecosystem will mean there is lots of nectar for the bees, reproduction success, more bees, increase in bees' activity and eventually more benefits such as honey and wax, obtained from the bee's activity. On the other hand, plants depend heavily on bees as main pollinators and therefore having more bees in our ecosystem (such as through beehive fences) will mean more plants resources and varieties for human and animal survival. Therefore there is a strong positive correlation between bees and plants, where change in numbers of either plants or bees could influence the availability of the other and the benefits associated with it.

Both bees and flowering plants have different climate and environment requirements for their existence and survival in our ecosystems. In a recent review, Amdam *et al*., (2005) discussed the impacts of increased temperature on plant-pollinator interactions. The researchers found that the timing of both plant flowering and pollinator activity seemed to be strongly affected by rainfall and temperature. The dry season experienced the highest temperatures and low rainfall leading to severe condition and scarce honey bee forage. Plants and honey bee pollinators are known to respond differently to changed climatic, temperatures, and human practices thus creating temporal and spatial mismatches in type and distribution of bees and bee fodder in an area (Hladik *et al.*, 2016). These mismatches within an area may reduce chances of honey bee visitation and pollen deposition, while honey bee pollinators experience scarce/reduced food availability leading to low quantity and quality honey. Recently, there has been growing interest in planting bee fodder plants and crops that provide pollen and nectar during dry season and prior blooming season of most flowering plants (Hladik *et al,*. 2016), a practice adopted in the study area of Sagalla to improve efficiency in their both crop and wild plant productivity. This has come out successful but with a cost of bees not having access to plant floral diversity and clean, natural forage that is pesticide free within the farming environment/ agro ecosystems. Bees need abundant and diverse pesticide free forage to sustain strong, healthy populations and high quality honey. Good, clean and abundant forage and nutrition defines the bees strength and their susceptibility to many stressors that weaken the hive to succumb to disease, pests, attacks and even pesticide poisoning (Pettis *et al.*, 2012).

2.6 Effect of climate variability on the biology of the honey bee

Nutrition is the fundamental link between organisms and their environment. The honey bees' ability to mobilize and acquire enough and a variety nutrients affects all aspects of their physiology (Brodschneider & Crailsheim, 2010). Nutrition is the fuel to population growth and survival. Survival and growth of the honey bees colonies is defined by availability of flowering plants.

These food resources allow them to meet all their nutritional requirements as they age and as they engage in different colony tasks.

Research has shown that reproductive success of the honey bee is highly dependent on floral diversity and optimum conditions around them (Di Pasquale *et al.*, 2013). Studies have shown that in a good season with optimum environment condition and sufficient fodder, bees can produce up to 2000 eggs a day which may sum up to colonies of up to 60,000 individuals per hive (Hatch *et al.*, 1999). Successful reproduction translates to large colonies with increased scale of bee activity and eventually huge return in honey production and pollination services. The queen bee regulates her reproductive activities according to environmental conditions and the availability of food (pollen and nectar) which depend on the abundance and variety of flowers around them. Thus, during the dry season, the queen's reproduction behaviuor diminishes as the food amounts and frequency diminish due to low number and variety of flowering plants available. The worker bees have to travel long distances under unfavorable conditions to visit flowers thus affecting colony's activity and ecosystem services (Di Pasquale *et al.*, 2013).

Worldwide, honey bees are important pollinators and like other insects, they are ectothermic, requiring elevated body temperatures for flying (Zacepins & Karasha, 2013). The thermal properties of their environments regulate the range of their activity. The high surface-to-volume ratio of their bodies makes them to rapidly absorb heat at high ambient temperatures and rapidly cool at low ambient temperatures. Studies by Sunday (2013) showed that tropical plants and insects such as bees are relatively sensitive to changes in average global temperature with a narrow span of optimum temperature and that they are presently living in an environment very close to their optimal temperature, a case in point being Sagalla during dry season. The Intergovernmental Panel on Climate Change (IPCC) further predicts a temperature increase ranging from 1.2-6.5°C by the end of this century (Baede *et al.*, 2007). With respect to the potential effects of future global warming, honey bee pollinators' behavioural responses during dry season to avoid extreme temperatures have the potential to significantly, reduce pollination services and their benefits.

2.6.1 Impacts of climate variability on agro-ecosystems

Studies indicates that heterogeneous agro ecosystems, which are characterized by a high diversity of crops and semi-natural habitats, tend to have pollinators that are more likely to survive on other fodder crops, herbs and wild plants while waiting for their main food crop to flower (Ricketts *et* *al.*, 2008). Intensified farm management has expanded at the cost of non-crop and semi-natural habitats. Semi-natural that consists of wild crops and wild plants habitats provide important food resources for honey bee pollinators such as alternative sources of pollen and nectar, and breeding and nesting sites. Many of these intensively cultivated agricultural areas are completely dependent on imported colonies bee pollinators facing threats from climate variability and climate change (Kjøhl *et al,*. 2011). The crucial stage in the reproduction of most flowering plants is pollination, and pollinating bees are essential for transferring genes within and among populations of crops and wild plant species. Although the scientific research has mainly focused on pollination limitations in wild plants (Steffan-Dewenter & Westphal, 2008), in recent years there has been increasing appreciation of the significance of honey bee pollination in crop pollination and food production.

Climate variability and change is expected to affect various types of ecosystems and distribution of pests in different ways (Gregory *et al.*, 2009). Studies have shown that rise in temperature may bring in new, and even speed up growth rates of pathogens. Global warming may also favour the growth of weeds/herbs in comparison to food crops and escalation in the, growth rate, abundance and geographic range of many insect and pests attacking crops (Baede *et al.*, 2007). This may lead to more use of pesticides by farmers to control pests, in order to maintain expected crop production, and sometimes without farmers' knowledge on their possible impact and threat on bees and their forage. Research has shown that beehives with access to good and diverse forage tend to be more robust, healthy and are more likely to survive extreme conditions and movement to and from different pollinating jobs (Brodschneider & Crailsheim, 2010). This study highlighted some basic farm level trends and practices among farmers on that increased presence of risky honey bee pests, predators, and use of pesticides on crops to inform us on the trends and their threats and identify possible solution and mitigation options to these threats. This will be important in developing plans and strategies to prevent catastrophic losses of bees from these threats.

2.7 Relationship between honey bee and fodder plants in Sagalla

In order to sustain plant and animal communities in Sagalla and maintain decent, sufficient, and balanced ecosystem services in the study area, the honey bee must meet the pollination demands of the growing plant population in an increasingly degraded environment and uncertainties resulting from climate change and human activities. Several studies have shown that the timing of plant flowering and pollinator activity is strongly determined and affected by climate parameters (McLaughlin *et al.*, 2002). In addition, good pollination produces higher honey yields, larger and faster ripening fruits and better tasting fruits (Steffan-Dewenter *et al.*, 2005). The Intergovernmental Panel on Climate Change (IPCC) predicts an approximate temperature increase between 1.1-6.4°C by the end of this century (Baede *et al.*, 2007; Solomon *et al.*, 2008). This could result in numerous adverse socioeconomic consequences to the Sagalla people associated with climate variability and climate change impacts on their ecosystems, pollinator activities.

Sagalla location has huge potential for beekeeping and honey production to the farmers. There are a lot of resources to support beekeeping and honey production, these resources include both honey bee fodder, and honey bee colonies (Figure 1). However, during severe drought, such potential resources remain minimal in many aspects or diminish with time due to anthropogenic activities such as environment degradation and land use change which negatively affect the livelihoods of the beekeepers in Sagalla. This study therefore assessed the potential impact of climate variability and anthropogenic activities on honey bee fodder plants and beekeeping practice in Sagalla, Taita Taveta County, Kenya. The findings of this study provides information and recommendations for beekeepers, experts and policy makers to be included in current and future monitoring programs for the development of beekeeping and the beehive fence concept and management of honey bees, their habitats and services in ecosystems and our societies.

(a)  **(b)** 

Figure 1*: (*a) uncultivated land and (b) cultivated land: Photos of beehive fence in Sagalla Source: http://elephantsandbees.com/kenya/

3.0 CHAPTER THREE: DATA AND METHODS

3.1 Description of the study area

Sagalla is one of administrative zones of the Taita-Taveta County, located approximately 330km Southeast of Nairobi at the Latitude: 03 24S, Longitude: 038 34E and has an elevation of 600 meters above sea level (Figure 2). The area may be categorized as flat to gently sloping and in some places with steep hills. A large portion of the area is an agro-ecological zone. Temperature in the study area is generally high all the year round, with an average of 26-28^{0}C during wet/rainy season and 32-33^{0}C during dry season. Sagalla receives a mean annual rainfall of about 600 mm (generally considered to be low, unreliable and with an unevenly distributed) with two seasons; short rains between April and May and long rains, when most of the crop planting occurs, between October and December. The Sagalla community consists of pastoral herders and farmers. A recent inclusion are beekeepers since the construction of beehive fences to act as a natural deterrent against crop raiding elephants (Figure 3) (King *et al.*, 2017).

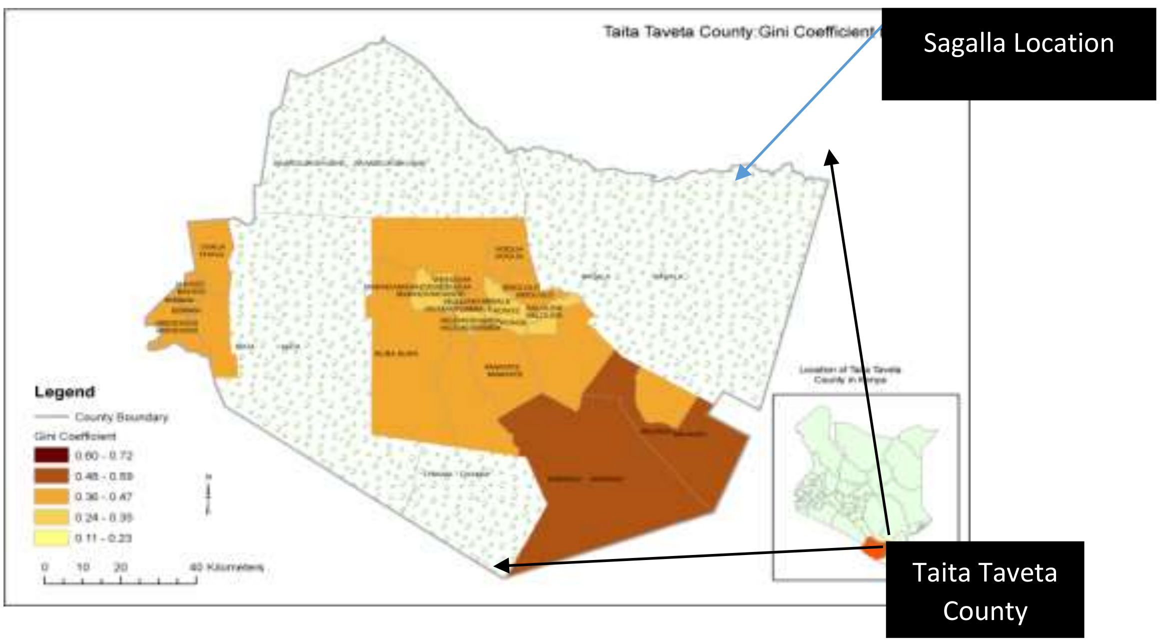


Figure 2: Map showing position of Taita Taveta County in Kenya map and Sagalla Location in Taita Taveta County. Source: maps.google.com

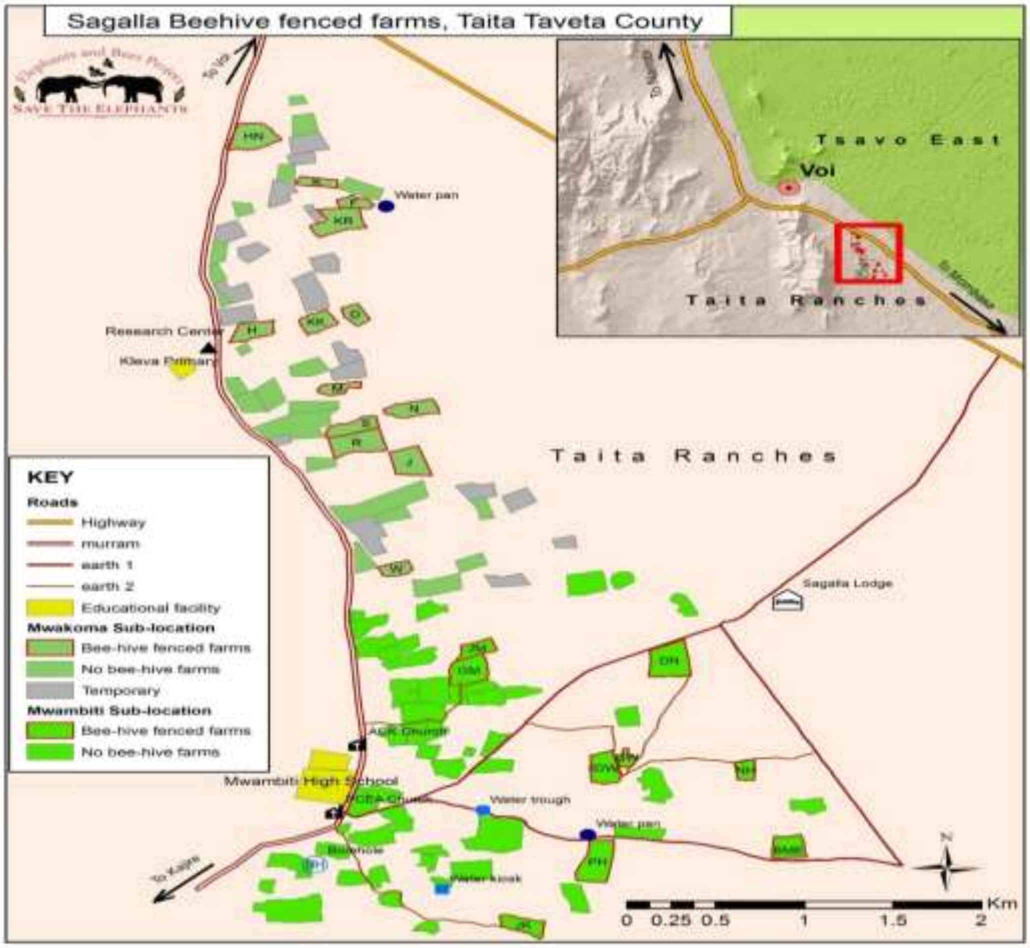


Figure 3. Sagalla beehive fence farms in Taita Taveta County. Source: Elephants and Bees Research Center (King et al., 2017)

3.2 Data collection technique

Transect walks, although labourious were selected as suitable for recording diversity of bee fodder plants and noting important floral resources (pollen or/and nectar) collected by the honey bees (Kadlec *et al*., 2012).

Focused group discussions and household interviews were conducted with farmers and beekeepers by use of semi-structured questionnaires to report on important environmental and socio-economic constrains and opportunities for beekeeping in the study area. Selection criteria for the transects and the respondents are outlined in the next subsection.

3.2.1 Data collection method for objective one

Twelve beehive fence farms selected randomly in the study area were sampled for diversity of bee fodder plants. Transect walks were conducted in each farm twice every month for six months from January to July 2017 and the flowering plants visited by the honey bees were recorded (Figure 4). A list of the plants collected was prepared which indicated the family, scientific and local names of the plant species, products collected by the bees and locations/coordinates of the data collections area. A photograph of each plant collected was taken to assist with the identification. The data was then entered into Microsoft Excel sheet, and classified as dry (Jan-March) and wet season (April-June) bee fodder plants, and then coded for analysis.

Section A (Inside Beehive Fence/Cultivated land)-This is a section inside the beehive fence and is converted land for agricultural use. This section is mainly dominated by crops and herbs also important bee fodder (Figure. 4)

Section B (Outside Beehive Fence/ Uncultivated land)-This is a section outside the beehive fence and is unconverted land .This section is mainly dominated by important wild honey bee plants (Trees, shrubs etc.) (Figure. 4)

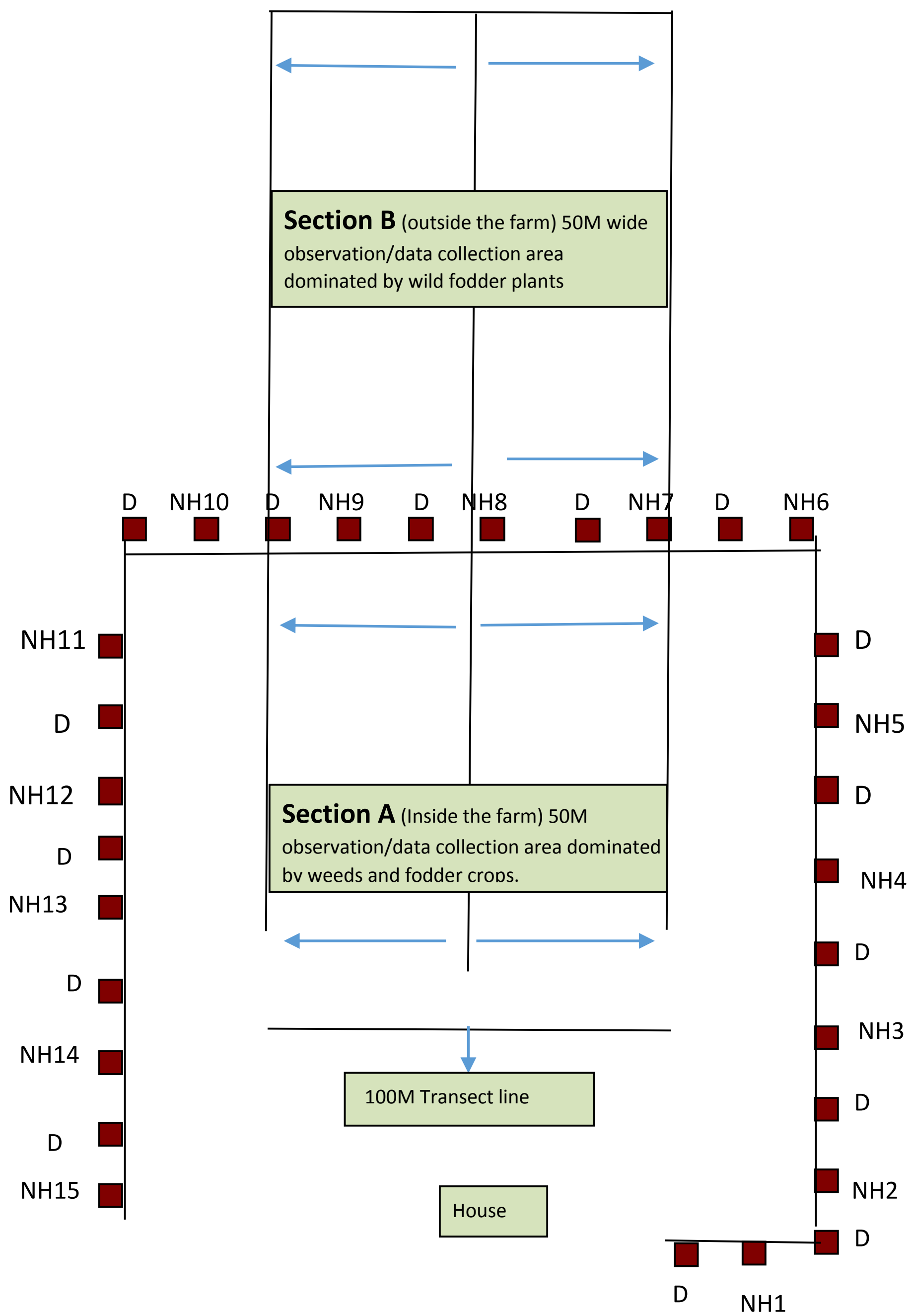


Figure 4. Image of survey walk conducted in each selected farm

3.2.2 Data collection method for objective two

Data on rainfall, diversity of bee fodder plant and bee population (number of hives occupied out of total 342 hives) in the same period were collected prior to implementing any statistical model. The collected data on rainfall, diversity of bee fodder and honey bee population was entered into MS Excel sheet and standardized into monthly and seasonal data.

To investigate impacts of anthropogenic activity on diversity of bee fodder plants, the plants were sampled both inside and outside farms with beehives fences of the selected farms. The sections inside the beehive fence was mainly dominated by herbs and crops planted by farmers While the area outside the beehive fences consisted of natural habitat and unconverted land and was mainly dominated by indigenous plants such as give specific names trees, shrubs etc. (Figure. 4).

3.3.3 Data collection method for objective three

Focused Group Discussions (FDG) and household interviews were used to achieve objective three, which was to investigate the environmental and socio-economic constraints and opportunities for beekeeping in the area. Thirty (30) respondents who included 25 beekeepers and other 5 key informants within the beehive fence project in Sagalla were interviewed. .

3.3 Data analysis and presentation

3.3.1 Data analysis and presentation of objectives one

The diversity of bee fodder plants sampled were summarized in a table outlining their local names, the season the plant was collected, resources collected from these plants (flowers) by bees (whether pollen or nectar), and their classification i.e. trees, shrubs, crops, herbs, climbers etc.

The diversity of bee fodder plants sampled was summarized in a table indicating where the plants were collected (whether inside cultivated land (A) or on uncultivated section (B)). This information was thereafter coded for analysis.

Data were entered into MS Excel sheets in a way that both qualitative as well as quantitative variables could be analyzed. The data on diversity of bee fodder were documented in tables. Descriptive statistics and percentages were used for quantitative and qualitative data respectively.

3.3.2 Data analysis and presentation of objective two

Data on rainfall, diversity of bee fodder and honey bee population were collected during the same period and entered into MS Excel sheet and standardized into monthly and seasonal data and the relevance of their relationships was tested using linear correlation (Popic *et al.*, 2013).

Data showing the relationships between climate variables, honey bee fodder plants species diversity and insect activity (honey bee) were subsequently built into a statistical model using simple linear regression model to predict relationship between diversity of bee fodder plants and bee population using precipitation data as predictor. The process to establish rainfall predictor relationship and relevance to diversity of bee fodder plants and bee population was illustrated using scatter points graph corresponding to observed influence of rainfall on diversity of bee fodder and scatter points corresponding to the observed influence of diversity of bee fodder (floral resources) on bee population. R-square analysis was used to interpret goodness-of-fit for the linear regression model used.

3.3.3 Data analysis and presentation of objective three

The data collected through interviews and questionnaires were documented in excel to provide both qualitative as well as quantitative variables. The data collected by using semi structured questionnaire was entered in to MS-excel and also coded for analysis (IBM, 2012). Descriptive statistics were used to describe quantitative factors. Standard error of mean ± (SE) to describe means while percentage used for describing qualitative characteristics. The results was expressed in percentage and mean ± SD of the results from the questionnaire (Lawless & Heymann, 2010).

4.0 CHAPTER FOUR: RESULTS AND DISCUSSIONS FROM OBJECTIVE ONE- To document wet and dry season diversity of honey bee fodder plants in Sagalla.

Sixty-six (66) honey bee fodder plant species were identified during the transect sampling conducted between January to June 2017. The diversity of the plants in both wet and dry seasons were summarized in Tables 1 - 3. Other information documented in the tables included the plant scientific and local names, the season the plant was collected and also resources collected from these plants (flowers) by bees (whether pollen or nectar or both). Thirty eight (38) species, representing 58% of the total number of plant species collected were flowering during the long rainy season (April, May, June) while 18 species representing 27% of the plants were blooming during dry season (January to March). Only 15% of the collected bee fodder plants were blooming during both wet and dry seasons. The most important plant families used by honey bee as fodder included Acanthaceae, Labiatae, Rubiaceae and Compositae (Table 2). Among the plant species in the understory community, *Tridax procumbens* and *Justicia flava* were found to be among the most important to honey bees.

Comparing the plant diversity of the cultivated areas (section inside beehive fence) to non-cultivated areas (section outside beehive fence), revealed that the cultivated section had a higher diversity of bee fodder plants (crops and herbs) than the uncultivated land which was dominated by wild trees and shrubs (Table 2). Generally, there were more plants flowering during the rainy season and hence provided sufficient fodder to sustain large bee population.

Table 1: Diversity of honey bee fodder (flowering) plants in Sagalla in the different seasons

Category of Bee Fodder Plants	Dry Season Plant Diversity (Number of species)	Wet Season Plant Diversity (Number of species)	Wet &Dry Plant Season Diversity (Number of species)	Totals Biodiversity
Herbs	9	12	3	24
Shrubs	3	5	1	9
Trees	3	10	4	17
Crops	2	4	0	6
Creeping and Climbing	1	4	2	7
Grass	0	3	0	3
Totals	**18**	**38**	**10**	**66**

Table 2: Diversity, distribution and blooming season of the honey bee fodder plants in Sagalla.

	Section of farm collected Inside (A) Outside (B)	*Species scientific name*	Family name	Local Name (language) Sagalla=Taita	Season of flower blooming	Classification	Resources collected by bees
1	AB	*Acacia nilotica*	Mimosaceae		Wet	Tree	Pollen
2	B	*Acacia Senegal*	Mimosaceae		Dry	Tree	Pollen
3	B	*Adansonia digitata*	Malvaceae		Wet	Herb	Pollen/ Nectar
4	B	*Azadirachta indica*	Meliaceae		Wet	Tree	Pollen
5	AB	*Baleria taitansis*	Acanthaceae		Dry	Herb	Pollen
6	AB	*Barleria eranthemoides*	Acanthaceae		Dry	Herb	Nectar
7	A	*Baugainvillea spectabilits*	Nyctaginaceae		Dry	Tree	Pollen
8	B	*Blepharis madaraspatensis*	Acanthaceae		Wet	Herb	Nectar
9	A	*Boerhavia diffusa*	Nyctaginaceae		Dry	Herb	Pollen
10	A	*Boscia coriacea*	Capparaceae		Wet	Tree	Pollen/Nectar
11	AB	*Boscia coriacea*	Capparaceae		Wet	Tree	Pollen
12	A	*Cayratia ibuensis*	Vitaceae		Wet	Climbing	Pollen
13	B	*Cayratia ibuensis*	Vitaceae		Wet	Climber	Nectar

14	A	*Chloris roxburghiana*	Gramineae		Dry	Shrub	Nectar
15	B	*Cissus rotindufolia*	Vitaceae		Dry	Climbing	Pollen
16	A	*Citrullus lanatus*	Cucurbitaceae	Mtangina (Sagalla) Watermelon (English)	Dry/Wet	Crop	Nectar
17	A	*Cleome hirta*	Capparaceae	Mgagani (Sagalla)	Dry/Wet	Crop	Pollen
18	A	*Commelina benghalensis*	Commelinaceae	Lukoka (Sagalla)	Dry	Herb	Pollen
19	B	*Commiphora Africana*	Burseraceae		Dry/Wet	Tree	Pollen
20	B	*Commiphora edulis*	Burseraceae		Wet	Shrub	Pollen
21	B	*Commiphora holtziana*	Burseraceae		Wet	Tree	Nectar
22	A	*Cucumis dispsaceus*	Cucurbitaceae	Kigumbo (Sagalla)	Dry/Wet	Creeping	Nectar
23	B	*Cusonia hostile*	Araliaceae		Wet	Tree	Pollen
24	B	*Cynanchum gerrardii*	Apocynaceae		Wet	Climbing	Pollen
25	B	*Delonix elata*	Caesalpiniaceae		Dry/Wet	Tree	Pollen/Nectar
26	A	*Digera muricata*	Amaranthaceae	Mbalu (Sagalla/Taita)	Wet	Herb	Pollen
27	B	*Drimia altissima*	Hyacinthaceae		Wet	Herb	Pollen
28	A	*Ecbolium revolution*	Acanthaceae		Dry	Herb	Pollen
29	A	*Eragrostis superba*	Gramineae		Wet	Grass	Pollen

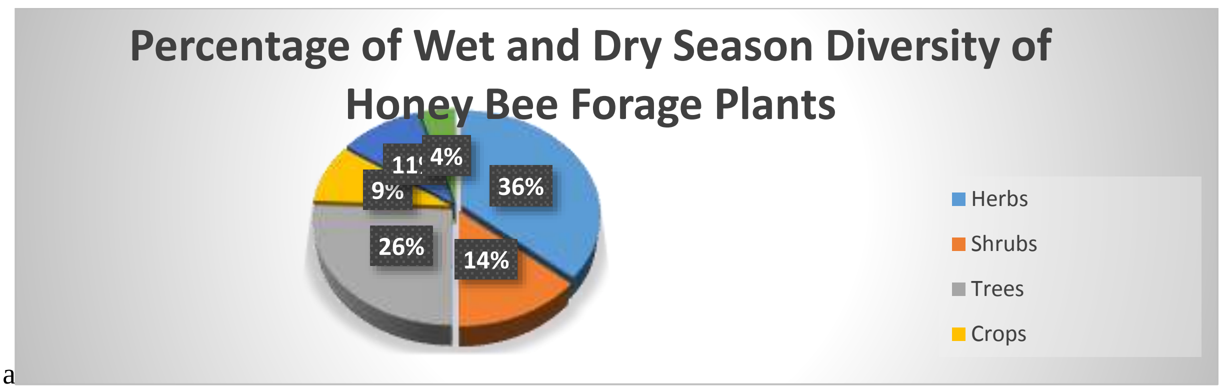
30	B	*Euphobia tenuispinosa*	Euphobiaceae		Wet	Tree	Pollen
31	B	*Euphorbia bussei*	Euphorbiaceae		Dry	Tree	Nectar
32	B	*Euphorbia scheffleri*	Euphorbiaceae		Dry	Shrub	Pollen/ Nectar
33	A	*Euphorbia tirucalli*	Euphorbiaceae		Wet	Tree	Nectar
34	B	*Grewia hostii*	Tiliaciae		Wet	Shrub	Pollen
35	B	*Gutenbergia cordifolia*	Asteraceae		Dry	Shrub	Pollen
36	A	*Helianthus annuus*	Asteraceae	Sunflower (English)	Wet	Crop	Nectar
37	AB	*Helioptropium steudneri*	Boraginaceae		Dry/Wet	Herb	Pollen
38	A	*Ipomoea mombasana*	Convolvulaceae	Nangu (Sagalla)	Wet	Creeping	Pollen
39	A	*Ipomoea* sp. *(red)*	Convolvulaceae	Mwaigacho (Sagalla)	Wet	Climbing	Pollen
40	AB	*Justicia diclipteroides*	Acanthaceae		Dry	Herb	Nectar
41	AB	*Justicia flava*	Acanthaceae		Dry/wet	Herb	Pollen
42	B	*Kleinia squarrosa*	Compositae		Dry	Shrub	Pollen
43	AB	*Launea cornuta*	Compositae	Mchunga(Sagalla)	Wet	Herb	Pollen
44	B	*Leucas glabrata*	Labiatae	Mdomoko (Sagalla)	Dry	Herb	Pollen
45	B	*Lopidogathus glandulosa*	Acanthaceae		Dry	Herb	Pollen
46	AB	*Maerua decumbens*	Capparaceae		Wet	Tree	Pollen

47	A	*Moringa oleifera*	Meliaceae	Mkimbo (Sagalla)	Wet	Crop	Pollen/Nectar
48	AB	*Ocimum gratissimum*	Labiatae		Wet	Herb	Pollen
49	A	*Ocimum kilimandscharicum*	Lamiaceae		Wet	Climbing	Pollen
50	A	*Ocimum spectabile*	Lamiaceae		Wet	Herb	Pollen
51	A	*Oxygonum sinuatum*	Polygonaceae		Dry	Herb	Pollen
52	A	*Panicum maximum*	Gramineae		Wet	Grass	Pollen
53	B	*Parkinsonia aculeate*	Caesalpinioideae		Dry/Wet	Tree	Pollen/ Nectar
54	AB	*Pavonia gallaensis*	Malvaceae		Wet	Herb	Pollen
55	A	*Portulaca oleracea*	Portulacaceae		Wet	Herb	Pollen
56	B	*Ruttya fruticosa*	Acanthaceae		Wet	Shrub	Pollen
57	AB	*Sericocomopsis hildabrandtii*	Amaranthaceae		Dry/Wet	Herb	Pollen
58	AB	*Solanum incanum*	Solanaceae		Dry/Wet	Shrub	Nectar
59	B	*Sterculia Africana*	Sterculiaceae		Wet	Tree	Pollen
60	A	*Tephrosia villosa*	Fabaceae		Wet	Herb	Pollen
61	B	*Thevetia peruviana*	Apocynaceae		Dry/Wet	Tree	Nectar
62	A	*Tribulus cystoides*	Zygophallaceae		Wet	Herb	Pollen
63	A	*Tridax procumbens*	Compositae		Wet	Herb	Pollen
64	A	*Vigna unguiculata*	Fabaceae	Msoko (Taita/Sagalla)	Wet	Crop	Pollen/ Nectar

65	A	*Waltheria indica*	Malvaceae		Dry	Herb	Pollen
66	A	*Ziziphus mauritiana*	Rhamnaceae	Mkunazi (Sagalla)	Wet	Tree	Pollen

4.1 Diversity of honey bee fodder plants in Sagalla

Herbs were the largest proportion (i.e. 36%) of 66 species of honey bee fodder plants collected during wet and dry season. About 26% of all honey bee fodder plants sampled were trees while shrubs represented 14%. Creeping and climbing plants represented 11% of the bee fodder plants collected while crops and grass were the least diverse bee fodder in both season representing 9% and 4% respectively (Table 1, Table 2 and Figure 5a).



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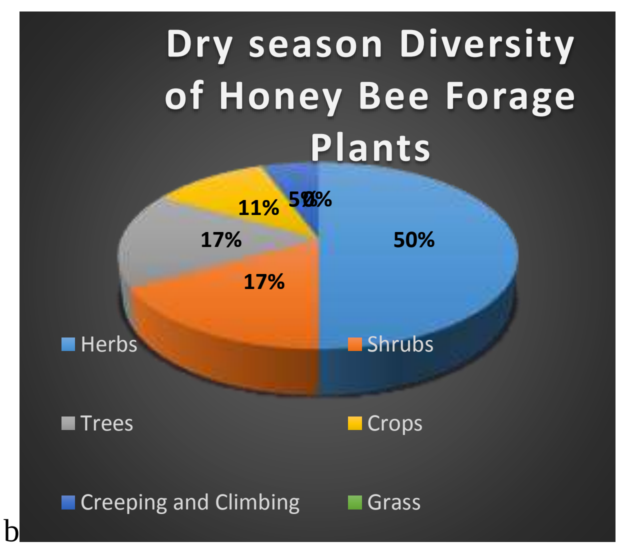

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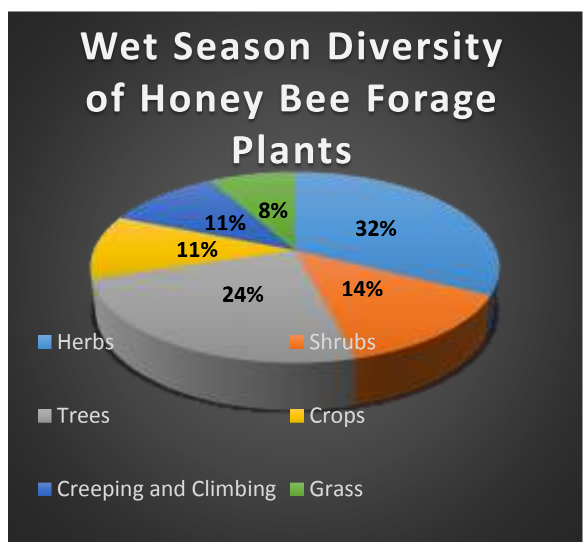


c

Figure 5. Percentage diversity of honey bee fodder plants in Sagalla in the different seasons (legend for a, b and c)

The dry season had the least diversity of honey bee floral resources with only 18 species of plants used during this season. Half of all the plants collected during the dry season were herbs (50%) followed by shrubs 17%, trees 20%, crops represented 11% of dry season bee fodder plants 11% sampled, while the creeping and climbing plants recorded as the least diverse representing 2% of dry season bee fodder plants (Figure 5b). *Digera muricata* of family Amaranthaceae locally called Mbalu and *Boerhavia diffusa* of family Nyctaginaceae were among the frequently collected herbs (Table 2, Figure 6).

Figure 6. Digera muricata (left) and Boerhavia* diffusa *(right)

Some honey bee fodder plants flowered only in particular seasons with the highest number (38 species) observed to be blooming during the rainy season. Diversity of the honey bee fodder was highest during the rainy season, in excess of 20 more plant species. Herbs were still the most dominant fodder representing 32% of 38 wet season bee fodder, followed by trees and shrubs representing 14% and 11% respectively. Grasses were the least diverse bee fodder representing 8% (3 species) while both creepers represented 11% of wet season bee fodder plants (Figure 5b).
Six (6) species of crops were identified as bee fodder during sampling exercise. These crops included Moringa, cowpeas, green grams, sunflower, watermelon and pigeon peas (Table 2). Two crop species (sunflower and Moringa), - blooming in both the wet and dry season, were observed to provide the honey bee with nectar and pollen during both dry season and wet season. The other four (cowpeas, green grams, watermelon and pigeon peas) were observed to be blooming during

the wet season only (Table 1 and 2). They are among the farmers' favorite crops especially during the season when the rainfall is lower, or of short duration (Table 2).

The practice of enhancing agricultural biodiversity was originally not valued as an alternative for improving the pollinator-plant relationship (Hladik *et al*., 2016). However, today, the practice has been recognized and adopted by researchers and scientists as significant in improving bee-plant relationship and as an important element linking conservation practice, improvement of livelihood (beekeepers) and economic development through improved crop pollination and production (Ricketts *et al*., 2008). This concept appears not to be adopted in the Sagalla ranch where findings indicated that the practice of intensive agriculture was replacing the natural wild plants around our ecosystems, and are hence crops are becoming an important source of fodder for bees. Wild plants important for bees fodder are continuously being replaced by the practice of monoculture or few crops varieties that can only sustain a small colony population of the honey bee. This practice of monoculture agriculture is leading to increased stress by exuberating the dry season honey bee fodder scarcity and hence causing a huge challenge to the honey bee fodder availability in Sagalla. For instance, most farmers plant grains and crops such as corn, which are planted every year across the study area, but which firstly, do not provide for the favorite or sufficient nectar and/or pollen needs of the honey bee species and secondly are only available during the wet season

On the other hand, it was noted that the small areas of natural habitat in farmland and the sections outside farms that included wild herbs, shrubs, grass and trees were able to sustain bee species survival. This observation is supported by other studies that have shown that at the farm level, honey bees benefited by preserving or growing alternative fodder before and after blooming of the main crop (Hladik *et al.*, 2016). This study indicated that maintaining diverse flower-rich field margins, set asides, permanent hedgerows or grassy borders were effective ways of doing this. Intercropping with different varieties of drought resistant crops such as cowpeas and moringa could serve as a "reservoir" of bee fodder when wild flowers are not blooming flowers. The findings of this study also indicates that annual communities of plants otherwise regarded as weedy herbs representing 34% and grass (4%) among the collected 66 bee fodder plants sampled in the study played a significant role in supporting healthy honey bee pollinator communities during dry season when other plants are not flowering (Figure 2a).

4.2 Climate variability potential impacts on nectar and pollen production

By observing the resources honey bees collect from flowers, this study observed that pollen was, the most sought after commodity, which was provided by 70% (42 species). Twenty percent (18 Spp.) of all the plant species provided nectar while a paltry 10% (6 Spp.) Provided a combination of both pollen and nectar (Table 3 and Figure 4a).

Since bees feed on flower pollen and nectar, they need a stable supply of flowers in both space and time. Managed honey bees are sometimes given sugar as supplementary feed by beekeepers to boost their feed, but they still need flowers to collect pollen and nectar, their main food and source of protein (Di Pasquale *et al.*, 2013). When there are not enough blooming flowers during the dry season or as a result of anthropogenic activities, for example the practice of monocultures that produces only one type of flower during a peak time, bees are not able to sufficiently feed themselves and their progeny. Bees can therefore go hungry due to these diverse factors, mostly related to climate variability and anthropogenic activities.

Table 3: Resources collected from flowering plants by honey bees

Resources Collected from Plants	Dry Season Plants	Wet Season Plants	Dry & Wet Season Plants	Totals No of Plants
Pollen	11	26	5	**42**
Nectar	5	10	3	**18**
Both Pollen & Nectar	2	3	1	**6**
Totals	**18**	**38**	**10**	**66**

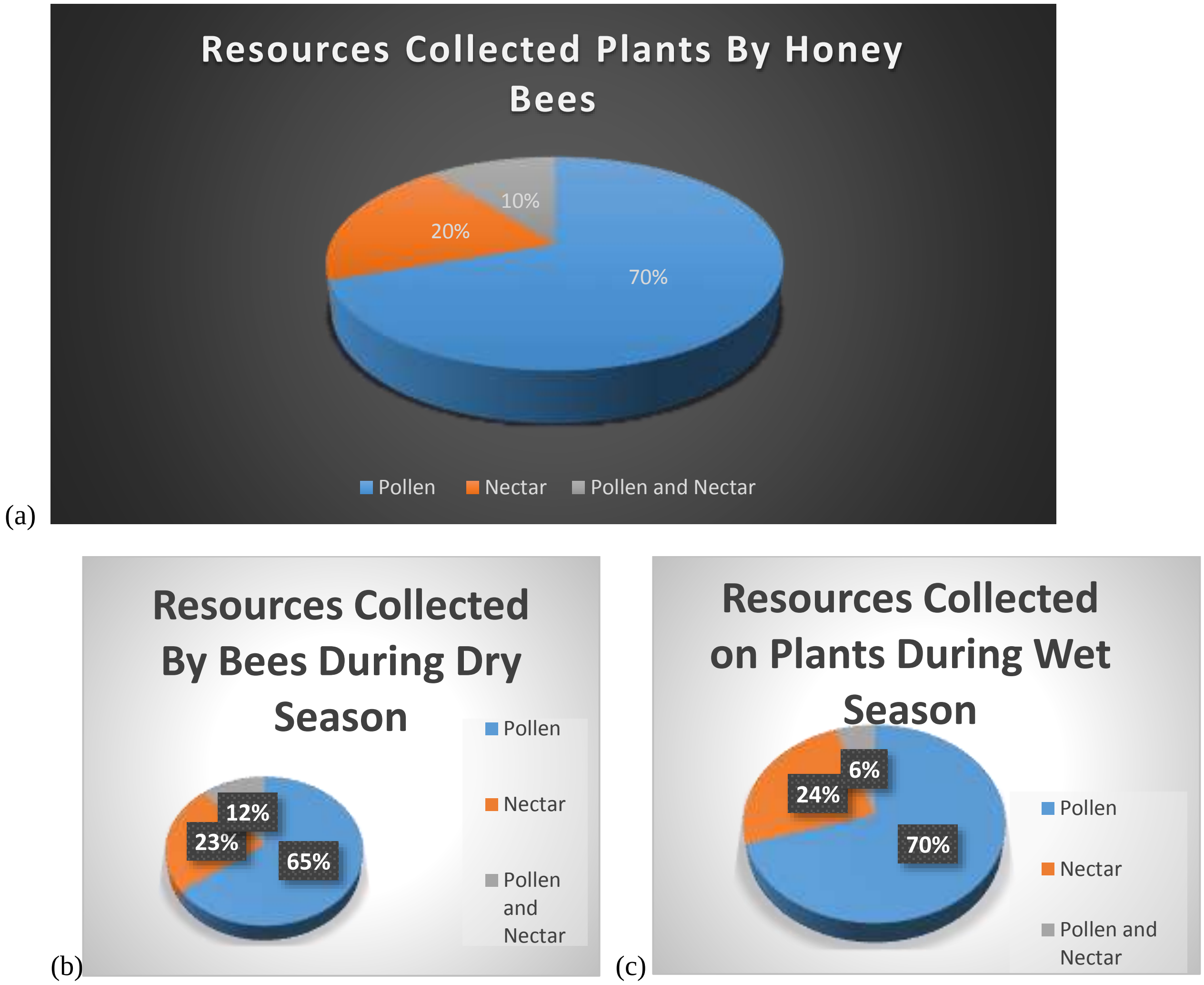


Figure 7. Percentage rating of resources collected from plants by honey bees (legend for a, b and c)

During the dry season, only five (5) species of plants provided nectar and 11 species offered pollen for the bees (Table 2 and 3) .The case was different in wet season where 10 plants produced nectar and 26 giving pollen. During wet season five (5) species of plants provided a combination of nectar and pollen for the bees unlike during dry season where there were only two (2) plant species (Table 3 and Figure 7). The findings of this study pointed out that nectar and pollen production were depressed in many plant species during dry season. It was therefore conclusive that the production or availability of nectar and pollen is determined by availability of rainfall. The observations of this studies are comparable to those of other researchers who have shown that modifications in floral rewards as a result of climate variability affected the likelihood of bees visiting certain flowers hence lowering ecosystem and socio-economic benefits (Memmott *et al*,. 2007). Findings of this study also indicated that altered floral rewards (pollen and nectar) because of climate variability reduced availability of the attractants of flowers, particularly for bees that rely on long-distance signs to detect and locate floral resources. Certainly, altered nectar and pollen composition and production between wet and dry season as we have seen could have both immediate impacts on pollinator energetics and activity and longer-term consequences for pollinator fitness, perhaps especially for those insects, such as honey bees that primarily depend on nectar for sugars as well as for amino acids (Brodschneider & Crailsheim, 2010). Similarly, this study observed that decreased and diminishing pollen and nectar production during severe drought affected the reproductive success of honey bees, their colony size and strength. An explanation for this is that because bees need to travel longer distances under unfavorable climate condition in order to collect sufficient nectar and pollen from available plants to successfully rear their offspring, and sustain their colony. While there had not been much conclusive research on whether less viable pollen and nectar is less appealing to pollinators, observations in this project have shown that that the honey bees favored sunflower crops with attractive and large flower with viable nectar and pollen as opposed to those with shrunken pollen and nectar such as those of *Justicia flava.*

5.0 CHAPTER FIVE: RESULTS AND DISCUSSIONS FROM OBJECTIVE TWO-To determine the impact climate variability and anthropogenic activities on the diversity of bee fodder plants and honey bee populations.

The findings indicated positive correlation between the amount of rainfall and diversity of bee fodder plants (flowering) (0.821754978) or 82.17%, which means that the variables have a moderate positive correlation. There was also positive correlation between the honey bee fodder plants flowering and bee population (0.743311984 or 74.3%) (Table 4).

Table 4: Recorded data on rainfall, hive occupation in percentage and diversity of honey bee fodder

Month	Total Amount rainfall(mm)	Biodiversity of bee fodder in Numbers (n)	Bee Population/Hive occupation status (%)
January	21.3	36	38.5
February	8.9	29	18.1
March	4.2	21	12.3
April	21.9	33	33.7
May	33.7	48	36.3
June	10.2	39	23.4

Correlation coefficient between rainfall and diversity of bee fodder (r) = 0.821754978 (Table 4, Figure 9)

Correlation coefficient between diversity of bee fodder and honey bee population(r) = 0.743311984 (Table 5, Figure 10)

The data collected was subsequently built into a linear regression model to show a relationship between rainfall and the diversity of bee fodder plants using precipitation data as predictor (Figure 8 and 9). The relationship between the diversity of bee fodder and honey bee population was also examined using the diversity of bee fodder (floral resources) as predictor. The findings indicated that the warmer and drier weather conditions experienced during dry seasons were accompanied by loss of both honey bee fodder plants and honey bee population such that, the total diversity of bee fodder plants (P) equals to 0.8757 times the amount of rainfall (M) plus 12.425 where R^2 = 0.6753 (y(P)= 0.689x(M) + 22.897) (Figure 9). Similarly, honey bee species population (B) was found to be strongly influenced by the diversity of bee fodder plants (P) such that, the total honey bee population (B) equals to 0.6365 times the diversity of bee fodder plants in numbers plus 12.425 where R^2 = 0.55, (y(B)= 0.6365x (P)+17.116) (Figure 10). (R^2 = Coefficient of determination, M=Amount of rainfall (mm), P = Diversity of Honey bee fodder plants in Numbers (n) B= Percentage of hives occupied (Bee population))

There appears to be a proportional relationship between rainfall, the diversity of bee fodder resources and bee population levels (Figures 8 -10). The diversity of bee fodder resources were shown to fluctuate with the rainfall amounts with the highest and lowest amounts of bee food sources was recorded in wet (May) and dry (March) seasons respectively (Figures 8). The bee populations were also observed to be dependent on the bee fodder diversity (Figure 8 and 10).

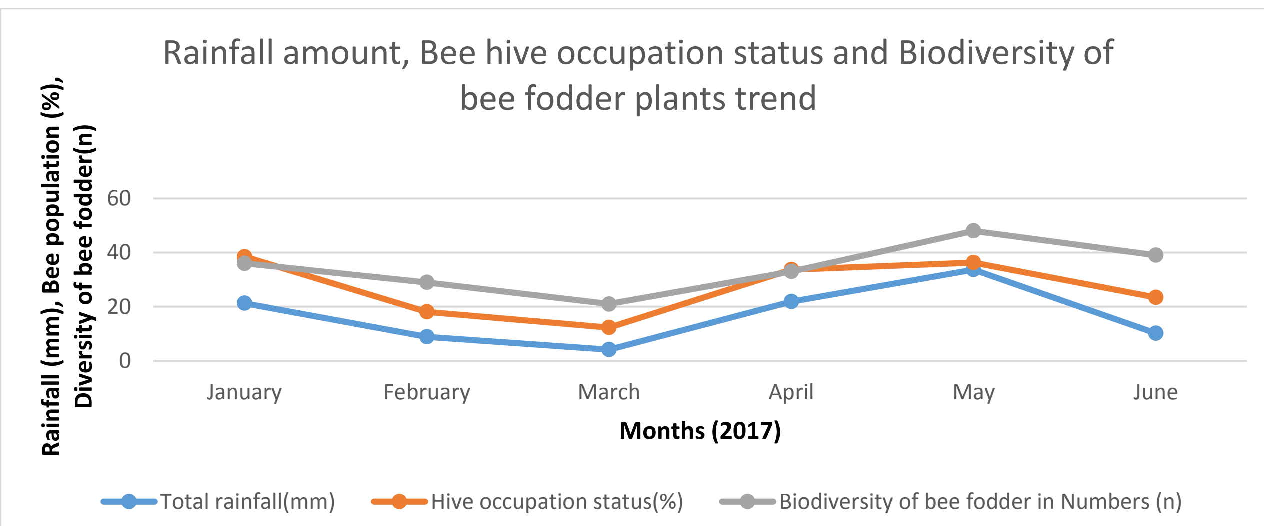


Figure 8. Rainfall, population and bee fodder biodiversity trend from January to June 2017

5.2 Relationship between rainfall and honey bee fodder plants

The finding of this study indicated that the amount of rainfall and diversity of bee plants were significantly correlated (0.821754978 or 82.17%) (Figure 9). The diversity of bee fodder plants exhibited response with respect to weather and climate variability, indicated by the significant interaction between bee fodder and amount of rainfall received, whereas bee fodder were more than two times less diverse in dry season than wet season. The highest variation in bee fodder was recorded at the extreme ends of the gradient, that is, in wet and dry seasons. The amount of rainfall(R) was also found to influence diversity of bee fodder plants (P) where y (P) = 0.689x (M) + 22.897) (Figure 9).

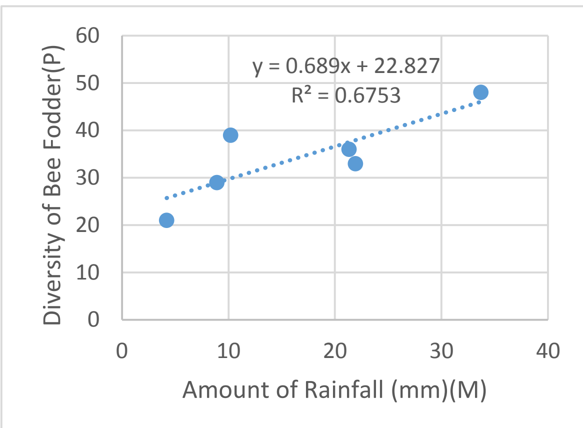


Figure 9. Scatterplot of amount of rainfall (M) verses diversity of honey bees floral resources (P)

The mixed effects of severe drought on the decline in production of flowers is a clear suggestion that certain species are stressed by scarce rainfall or water and high temperatures during dry season while others are not (Zacepins & Karasha, 2013). Reduced rainfall coupled with elevated temperatures brought on by the severe drought were found to have a number of effects on production of flowers such as production of fewer flowers or less likelihood to flower. Examples of plant species that appeared to be affected by low rainfall in the study site included *Grewia hostii*, *Ipomeae mombasana*, and *Boscia coriacea* among others while species observed to withstand drought and high-temperature included *Euphorbia heraldiana*, *E. bussei*, *Delonix elata*, *Parkinsonia aculeata* among others. In addition, the diversity of floral resources and the intensity at which they flowered clearly affected the floral resource availability for honey bee, as well as the degree to which honey bees were attracted to those flowers for nutrients. Reductions in flower abundance and diversity under low rainfall in dry season certainly meant scarce or reduced food availability for the bees, which could translates into population decline, reduced reproductive output, and a reduction in socioeconomic benefits of the Sagalla community (Figure 5, 7 and Table 2, 3).

Studies have shown that the dimensions of the flowers influence the kind of pollinators that are physically adapted and capable of accessing floral rewards. This is as documented by morphological relationships between the length of the bee proboscides and nectar spurs (Scaven & Rafferty, 2013). The observation during this study indicates that even if rewards to these floral resources remain accessible, changes in the abundance and dimensions of flower could impact foraging efficiency of the pollinators, as the size of flower can, in part, determine how costly it is energetically obtain those rewards. Likewise, the occurrence of earlier daytime anthesis as a result of warmer morning temperatures is advantageous to honey bees that are active earlier since they can benefit from access to those rewards before the temperatures rise. However later in the day, the high day temperatures may influence floral resource availability for the pollinators. Another factor that influences access to the floral resources is the floral size. It was observed that honey bees were attracted to larger flowers e.g. sunflower and *Delonix elata,* than small flowers e.g. *Oxygonum sinuatum.*

5.3 Population and foraging activity of honey bee in relation to diversity of bee fodder plants

The findings of this study indicate that the abundance and diversity of both the fodder plants and honey bee population are determined by climate-related factors such that rainfall influences food availability for the honey bees (Figure 10). There was a positive correlation between the honey bee fodder plants flowering and bee population (0.743311984 or 74.3%) (Table 4) .Seventy-four percent (74.17 %,) means that the variables have a moderate positive correlation. Scatter points graph in figure 10 illustrates corresponding observed influence of diversity of honey bee on honey bee population. The honey bee population (hive occupation) shifted between the different seasons whereas in the dry season there was a low population levels and then there is an increase in the honey bee populations towards the rainy season when conditions were optimum for the honey bee population growth (Figure 10).

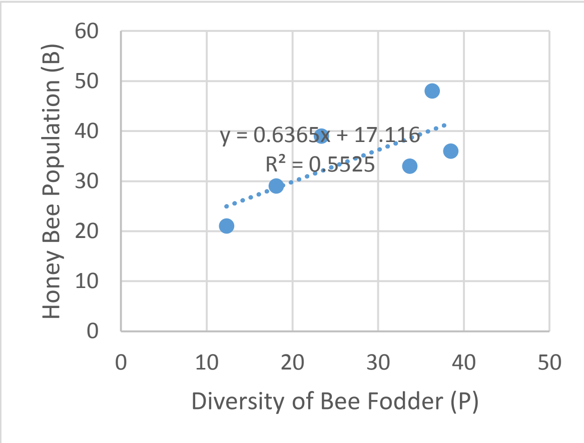


Figure 10. Scatter plot of diversity of bee fodder plants (P) verses honey bee population (B).

We invested the relationship between the diversity of bee fodder plants and bee population and find significant positively correlation. The honey bee population (B) was found to be strongly influenced by the availability of bee fodder plants (P) (y (B) =0.6365x (P) +17.116 (Figure 10). The effects of climate variability on both the flowering plants and honey bee pollinators shaped their pairwise interactions, and their networks interaction (Colinvaux *et al*., 1996). It is clear from findings of this study that climate extremes such as severe drought can alter plant-bee interaction and result to the formation of new interactions networks over time could be weakened as a result of plant and pollinator species loss and phonological mismatches.

Physiological responses to climate variability may alter significantly plant-pollinator networks even without changes in phonological overlap or species composition (Sunday *et al.*, 2011). The more delicate changes in strength of their interaction could result from altered or changed floral reward quantity and quality to the pollinators, loss of colony number/size or reduced life span of honey bee pollinators (Kjøhl *et al.*, 2011). For example, the observation during this study was that when drought became severe and prolonged it led to significant changes in the honey bee-plants network dynamics and structure (Figure 7, 8 and 10). Additionally, though we have discussed separately in figures 9 and 10, the responses of the honeybee and plant physiology to climatic extremities (drought and elevated temperatures) leads to loss of honey bee colony (sometimes losing more than 50% of the colonies during severe drought). This eventually reduces pollination services and pollinator reproductive success resulting to reduced plant and crop pollination and honey production success affecting livelihoods of the beekeepers. If, on the other hand, the responses of honey bee pollinators and plants are complementary, such that both pollinators' body size and flower size are smaller or both foraging and anthesis happen earlier in the day, then there could be little net effect on bee-plant interactions. Even if responses of pollinator and plant species are more variable and less directional, over time new interactions could be formed which could buffer the overall interaction network in the end (Memmott *et al*., 2007). However, the findings of this study indicated that physiological responses to climate extremes significantly impacted pollination networks in many of the same ways that more obvious phonological shifts might, with some flowers or plants visited by fewer honey bee pollinator eventually reducing diet breadths for the honey bee pollinators and their colony size (population).

4.5 Land use and distribution of honey bee fodder plants in Sagalla

Nearly 44% of the honey bee plants were collected inside the farm that is converted land for agriculture/farming, 34% of the plant species were collected outside the beehive fence, which was unconverted land still dominated by wild plants while a final 22% of the species occurred on either side of the beehive fences (Table 2 and Figure 11). Majority of bee fodder plants found outside beehive fence (uncultivated land) were mostly trees and shrubs unlike those found inside the beehive fence (cultivated land) that were dominated by herbaceous crops and wild herbs (Figure 5 and Table 2).

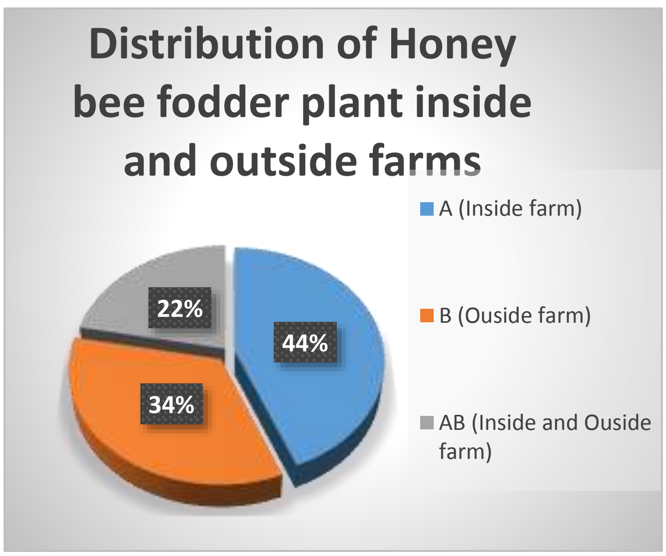


Figure 11. Percentage rating of distribution of honey bee fodder plants inside the farm (dominated by crops) and outside the beehive fence (dominated by wild plants

Researchers have noted that many practices that increase plant diversity, at different scales, can also improve the flower resources available to pollinators, both in space and time (Hladik *et al*., 2016). For example, at the scale of individual sites, crops such as sunflowers, watermelon or Moringa tree, which represented only 9% of all the bee fodder sampled, provided large flushes of pollen and nectar that enhanced conditions for pollinators in the short term (Table 2).

Intensive agricultural landscapes are often effective deserts for honey bees (Ricketts *et al.*, 2008). However, this is contradicted by the observation during this study, where during the dry season, most of the farms sampled where monoculture agriculture dominated, there was an overall low bee floral diversity unlike during wet season when there was an increase in biodiversity (Table 2). The finding also indicated that on a wider or local scale, integrating natural and semi-natural areas into managed farming areas tended to increase the abundance and diversity of bee fodder during drought, leading to higher pollination services from the honey bee and other wild pollinators. Abundance of honeybee around farms was attributed to the existence of nearby semi-natural or natural areas. This in turn increased the production of vegetables and crops though increased pollination. The project has therefore concluded that increasing the overall diversity of plant diversity had the effect of increasing the pollinator populations and subsequently was the key to improved pollination success.

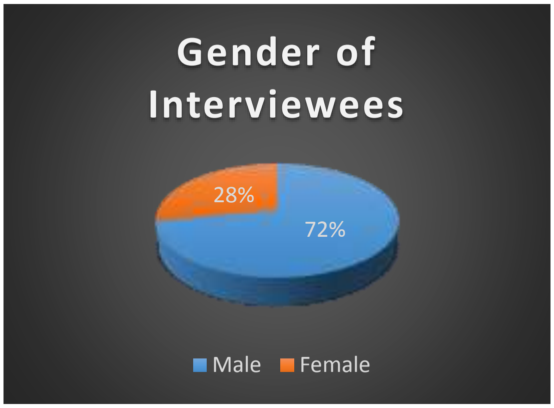
6.0 CHAPTER SIX: RESULTS AND DISCUSSIONS FROM OBJECTIVE THREE-To report on important environmental and socio-economic opportunities and constraints for beekeeping (apiculture) in Sagalla and other areas applicable.

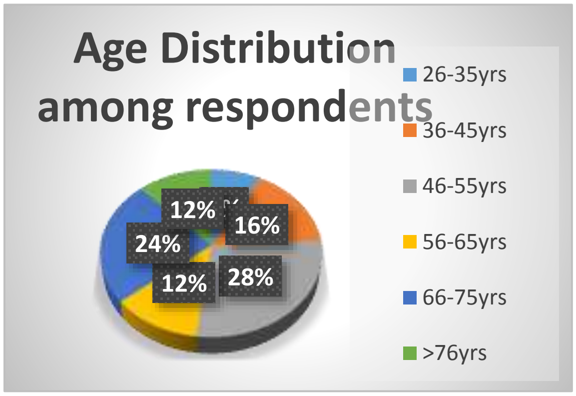
6.1 Status of the informants

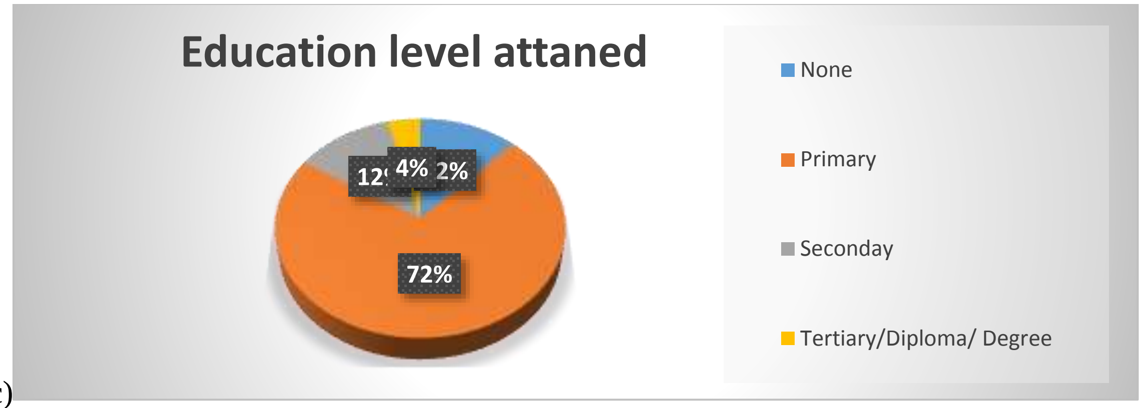
A total of thirty (30) people were interviewed consisting of 78% males and 22% females. Nearly 40% of all interviewed were middle aged i.e. 46 – 65 years old. Those above 65 years of age, (24%) viewed beekeeping as an important source of livelihood that was easy to manage due to their age.

A majority of the respondents (72%) had up to primary school education, 12% had reached secondary school level and 4% have attended diploma/Tertiary college education. Only two percent of the respondents had no formal education (Figure 12c)

A majority of the respondents (72%) did not have formal employment and depended on beekeeping and farming as their only sources of livelihood. The remaining respondents had additional sources of income as follows; 11% had owned small businesses, another 11% engaged in small labor jobs around the village e.g. masonry, carpentry, working in farms while a paltry 6% were in the formal sector working with the public or private sector (NGOs) (Figure. 12d).

a) 

b) 



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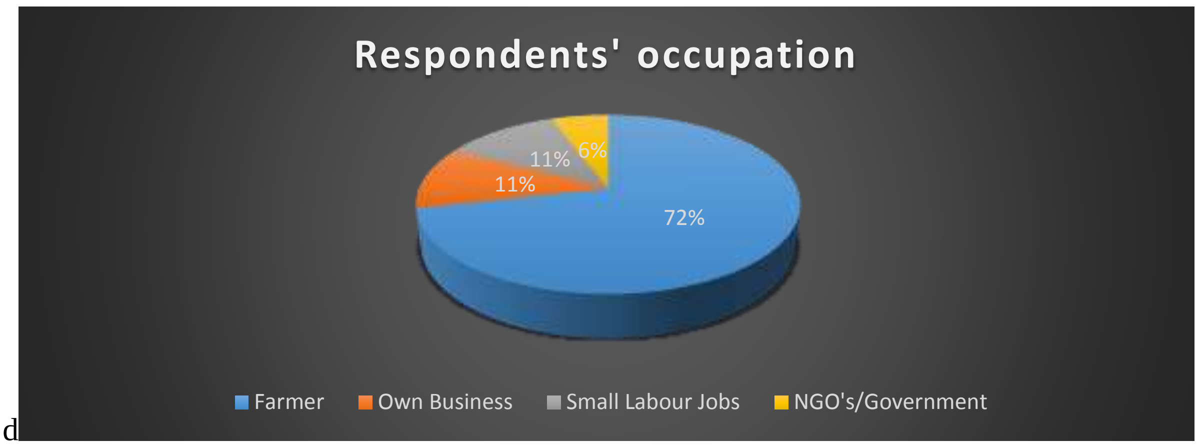


d

Figure 12. Demographic profile of the respondents from Sagalla area showing a) age distribution, b) gender, c) level of education and d) occupation.

The results showed a clear indication of low level of transition especially from primary to secondary, which made it hard for the farmers to get formal reliable jobs and income. This meant that a majority of the Sagalla community rely on farming and beekeeping as the main source of livelihood.

6.2 Area occupancy and household profiles of the respondents

A majority (44%) of the respondents had lived in the area for more than 20 years, 40% have lived in the area for 11-20 years, while 16% had a duration of stay of 5-10 years in the area. Most of the respondents are aware the history of the area and the changes that has been happening over years (Figure 13. a).

A majority of the respondents (44%) owned between 6-11 acres of land, 40% owned between 1-5 acres of land, while 16% own between 11-20 Acres (Figure 13d).

Thirty two (32)% of the respondents interviewed had a household size of 7-12 people which was a relatively high number considering 72% depended on only farming and beekeeping as the only source of livelihood while 68% had household size of 1-6 people (Figure 12 b).

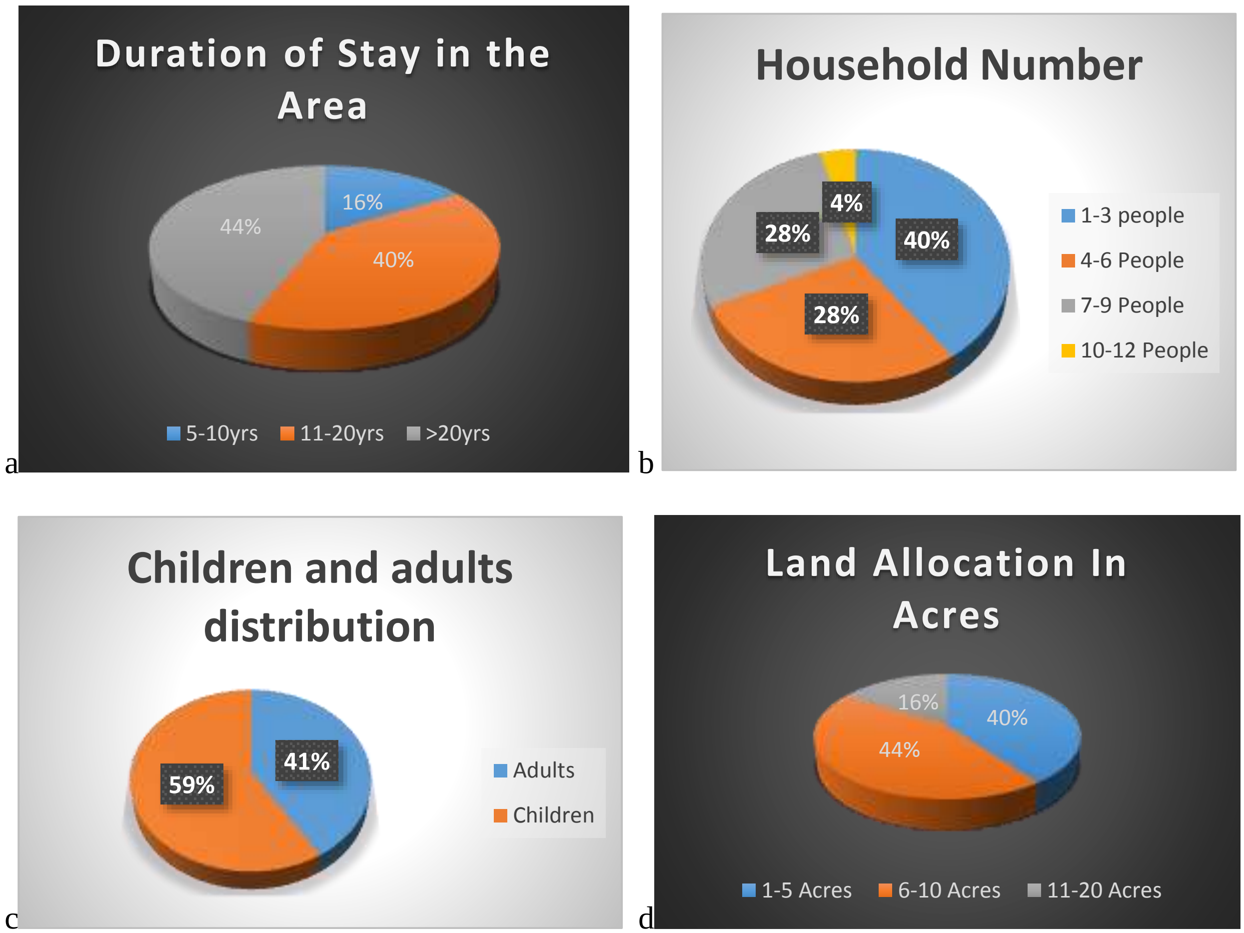


Figure 13. Percentage rating of demographic profile of the respondents from Sagalla area showing duration of stay in the area, household size and land allocation in acres

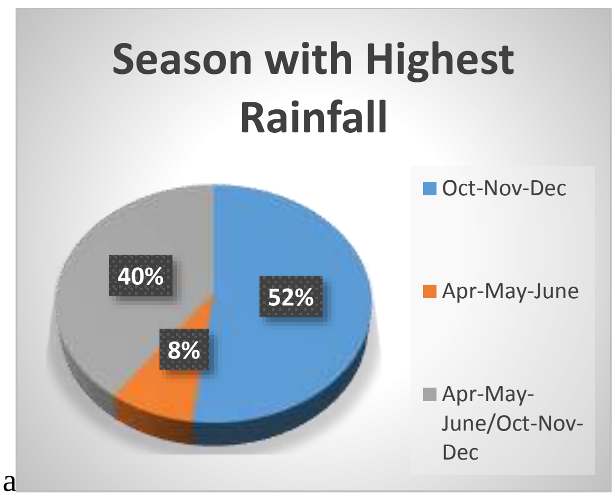
6.3 Respondents perception on climate variability, the seasonal diversity of bee fodder and bee population

There was disparity of opinion among the respondents as to the season that received the highest amount of rainfall. The majority of the respondents (52%) considered October to December as the period with the highest rainfall and hence was the reliable planting season and when most of their beehives got occupied. About 40% of the respondents selected both April to June and October to

December as the seasons that received highest amount of rainfall with the remaining (8%) indicating April-June as the season with highest rainfall (Figure 14a).

At least 44% of respondents indicated April-June and October-December as the seasons with most abundant bee forage (flowers) around their farms followed by 36% who thought October- Dec had the most abundant foliage and finally 12% mentioned April to June. Eight (8%) were not sure.

In response to the question on when the honeybee fodder was available, about 44% of the respondents stated July-Sept as the season with least bee forage due to poor rainfall. Thirty two percent (32%) indicated January-March and July-September as seasons with least bee forage (flowers) also due to poor rainfall (drought). The rest thought either Jan to March or April to June had the least bee fodder (Figure 14c).



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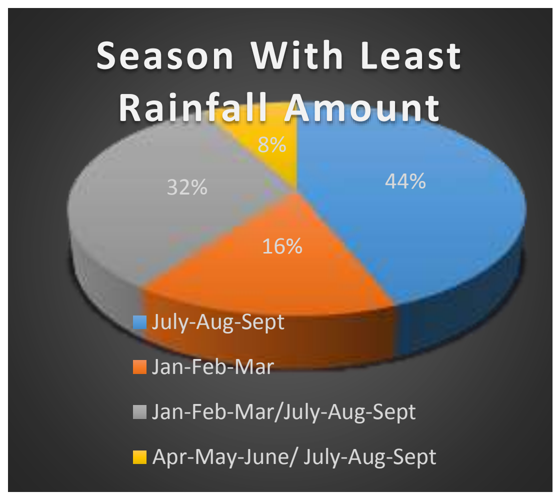

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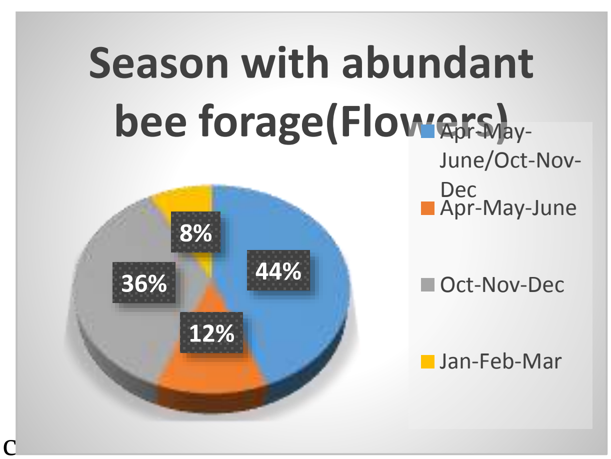

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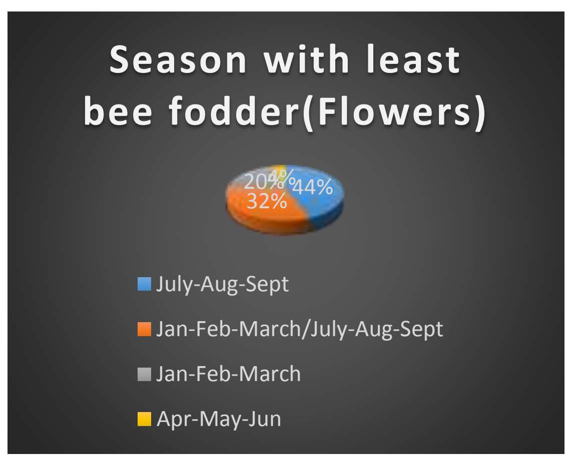

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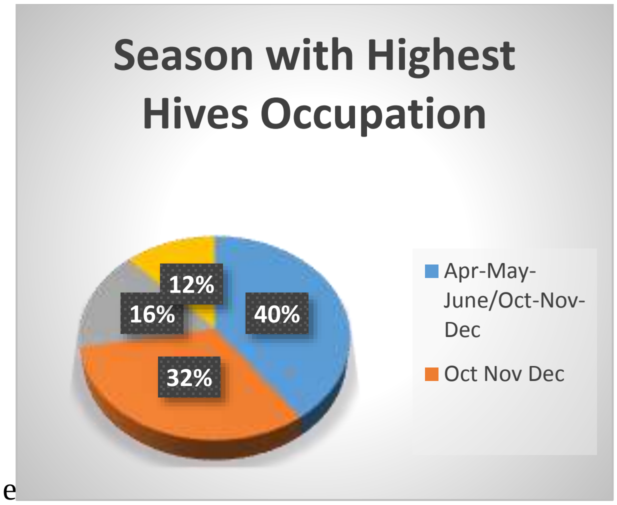
e 

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Figure 14. Perception profile of the rainfall occurrence showing the months with highest and lowest rainfall, seasons with most and least abundance bee forage diversity(flowers)), and seasons with highest and lowest hive occupation (legend of a, b, c, d, e and f).

Majority (40%) of the beekeeping farmers noted that April-June and October-December as seasons they get most of their hives occupied (Figure 14e). These times coincided with the period of highest rainfall and the most number of flowers used by bees (figures 14a, c). About 32% of the respondents specified that October-December as their season of highest hive occupation, while 16% of the respondents understood April-June as the season of their highest hive occupation.

A majority 60% of the respondents indicated July-Sept as the season they lose significant number of bee colony, 16% noted January-March and July-September as season they lose most of their bee colony. A small percentage (12%) of the respondents mentioned January- March as season they lose most of their colony due to extreme drought while 12% of the respondents could not really figure out (Figure. 14). – indicate how this is related to the seasons- wet and dry as well as human interactions. Use data from other experiments to compare with what you found.

Most farmers noted positive correlation between the amount of rainfall and diversity of bee fodder. When the dry season kicks off and rains disappears, average daily temperatures went up while floral diversity declined and there was a decrease in the number of hives occupied. Comparable results were reported by Ricketts *et al.*, (2008); and Scaven & Rafferty, (2013). The Sagalla area has been losing vegetation cover and bee population as a result of climate variability and anthropogenic activities as we have seen. The implication is that the area is losing important bee fodder that contributes to large bee population and honey production. The findings also indicated that some beekeepers were not aware that the loss of bee foraging areas and loss of diversity of bee fodder plants was possibly linked to increasing human activities such as land use change in the area. There is therefore suggests need to increase awareness among the community members on the importance of protecting and conserving the environment to benefit plant-pollinator interactions.

6.4 Respondents' perception on impacts of drought on their beekeeping activity and livelihood

Nearly 56% of the respondents noted July-September as the season they experienced severe and prolonged drought, 28% indicated January-March and July-September as the seasons they experience severe drought while 16% mentioned January-March as a severed drought season. 92% of the respondents admitted that drought to be a significant problem to their livelihoods and beekeeping activity while 8% of the respondents confirmed drought to be a moderate problem (Figure. 15 a). The main dry season challenges mentioned by the respondents included scarcity of water, bee fodder and where they experienced loss of bee colonies due to unfavorable climate conditions. Loss of bee colony meant low honey production and income from honey sales for the beekeepers. In addition, farmers noted that during this period they had increased household expenditure in purchasing food and water and sugar supplements for the bees and domestic use.

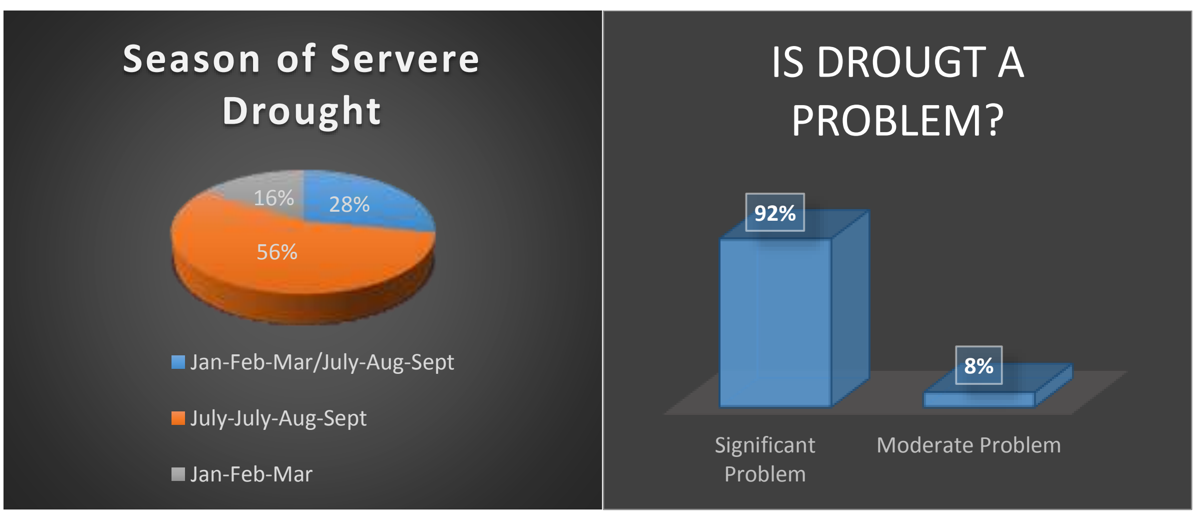

Figure 15. Percentage rating of the respondents' perception impacts of severe drought on their livelihoods

Severe droughts also negatively affects pastoralism and leads to invading of ticks in the area. Prolonged and severe drought also affects income of those who provide casual labor in agricultural fields. Other challenges related to beekeeping-included lack of sufficient grass for making shades to protect the bees and hive against extreme temperatures and drying of regrow posts, which consumes more of their time in hive maintenance.

Zacepins & Karasha, (2013) that reported climate variability and climate change is projected to drive species into extinct by hindering member chances of reproduction and survival as well as decreasing the amount and availability of suitable habitat and resources for survival. The findings of this study showed that drought had a significant impact on the diversity of bee fodder, bee population and consequently honey production and the overall livelihood of the Sagalla community. Activities such as bees' visitation for foraging water. Pollen and nectar were affected by drought.

6.5 Perception profile of changes in the climate of the area and planting seasons

All the respondents (100%) noted that the amount of rainfall had changed in the past 10-15 years with 78% of the respondents mentioning they had observed there was a decline in amount of rainfall and that the rainy seasons had become inadequate and unpredictable. According to most respondents, droughts were currently more frequent, prolonged and severe. All the respondents used to plant twice a year (Apr-May-June and Oct-Nov-Dec), but in the past 3 years, only 52% of them had been succeeded in planting twice a year. The rest of the farmers planting only managed to plant during the Oct-Nov-Dec season, as inadequate and unreliable rainfall made it impossible to sow during the first planting season of Apr-May-June (Figure. 16d).

Flint & Flint, (2012) evaluated the environmental impacts of climate variability and climate change on biological components water resources and noted impacts of climate variability and climate change on hydrologic cycle and ecological processes. The unreliable and unpredictable rainfall in Sagalla clearly indicates the occurrence of climate variability. This change has had an impact on the ecosystem, farming schedules and eventually livelihoods in Sagalla.it has forced the farmers to change their crops they normally plant when the rainy season fails or are shorter than planned and hence include cowpeas, green grams, watermelon, sunflower, black beans and pigeon peas (Table 2). Majority of these crops are important bee fodder for the and hence assist in maintaining crop/plant-bee synchrony when other wild plants are not blooming.

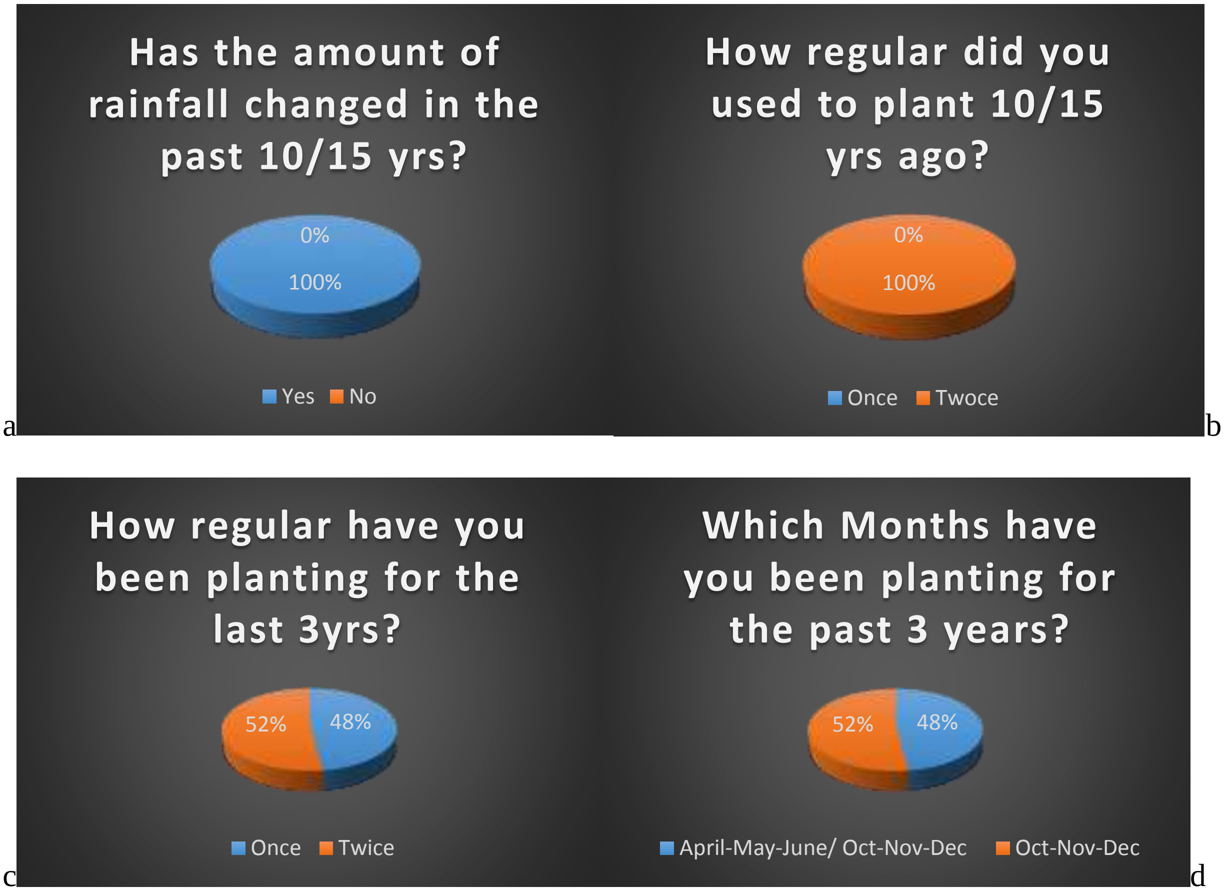

Figure 16. Perception profile of changes in the climate of the area and planting seasons (legend for a, b, c and d)

6.6 Respondents' access to water

A majority (72%) of the respondents depended on private water vendors for water .This meant that majority of the farmers had to buy water for their bees and other domestic uses. Only 40% of all the respondents had some means of water harvesting and water storage tanks while less than 20% had access to tap and borehole water and those who have access, had to walk long distances to get there (Figure 17.a).

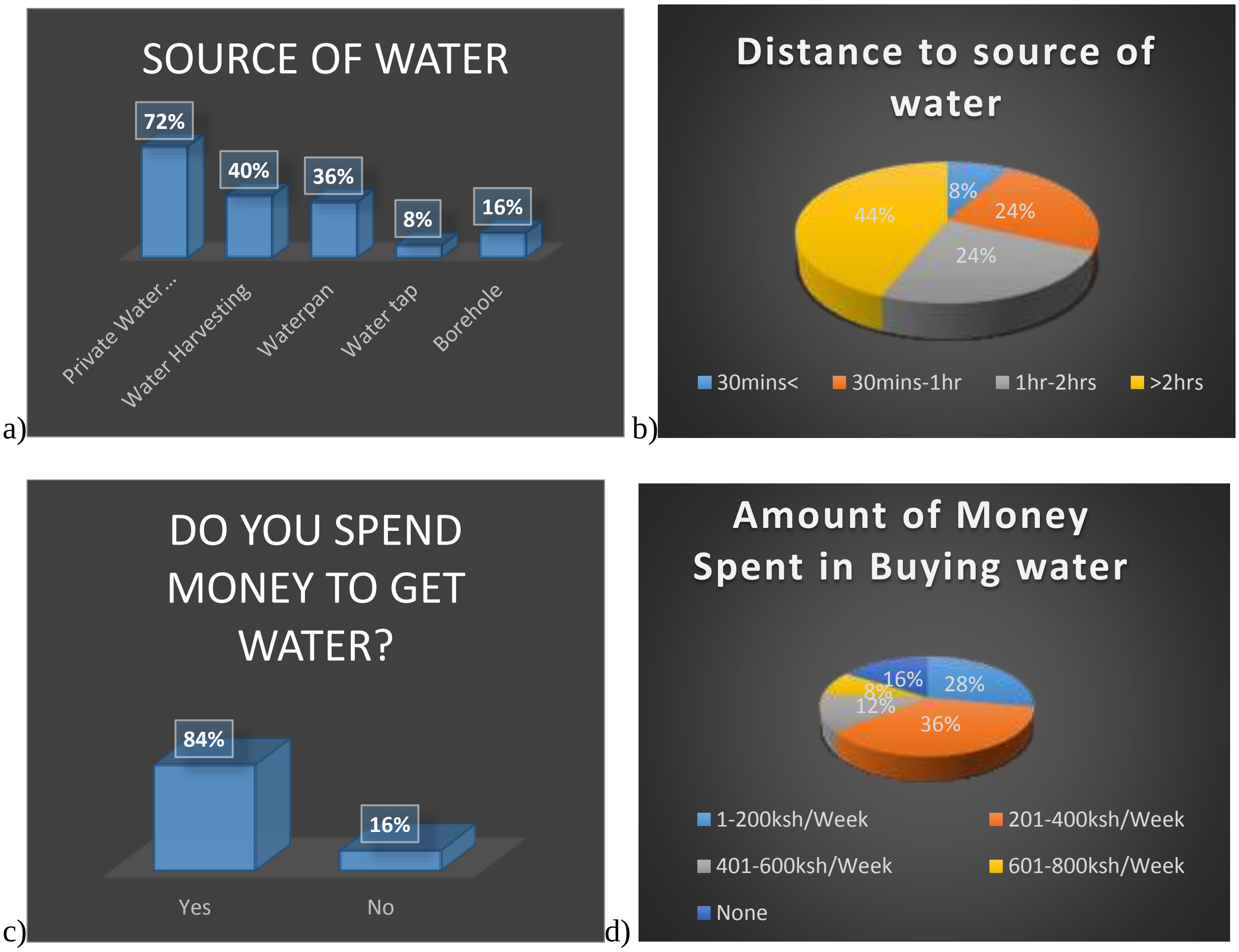

Figure 17. Access to water for bees and other domestic use (legend for a, b, c, d)

Water pans were also an important source of water for bees and animals, but due to their seasonal nature, were unreliable, and also not suitable for domestic use. At least 44% of the respondents spent more than 2 hours to get to their water source, another 48% of the respondents spend between 30 minutes to an hour with only 8% of the respondents spending less than 30 minutes to access the water source (Figure 17.b).

It was noted that 36% of the respondents spent between 201-400 ksh per week to buy water even Twenty eight percent (28%) of the respondents would spend between 1-200 ksh per week on buying water while 12% of the respondents spent between 401-600 ksh/Week on water. Only a small fraction (8%) of the population interviewed spend between 601-800 ksh per week to purchase water. Sixteen (16%) of the respondents do not spend money in buying water, they however have to walk long distance to their source of water, which is time and energy consuming (Figure. 17).

Low and unreliable rainfall in Sagalla meant that the rainfall received was unable to restock the available water sources. Similar results were reported by Hahn *et al.*, (2009), who found that shortage or decrease in the amount of rainfall particularly in the ASAL highly impacts ecosystems and natural resources such as water availability hence affecting communities access to water. Drying of water sources in the study area had impact on the socioeconomic activities including beekeeping because honey bees require water to make brood food, process stores, and hatch eggs. Indeed, bees forage for water at almost any source near their colonies. Proper environmental conservation will enable the protection and preservation of critical water source. Honey bee colony requires sufficient water for the various activities conducted. These include the cooling off the nests or hives on hot dry day, maintaining insect body fluid essential for their metabolism and to production secretions that dilute honey for feeding the young brood (Brodschneider & Crailsheim, 2010). The availability of water to the bees located near their nesting sites enables them to satisfy not only their current colony needs but also to protect the colony against future extreme water stress by storing water in their combs.

6.7 Community change of livelihood as a result of drought.

During severe dry season, 92% of the respondents have had to resort to charcoal burning and other labor activity to bring in some income to support the family (Fig. 18). Specifically 60% of respondents have engaged in the charcoal burning, which contributed to higher carbon emission and deforestation, which were primarily known to be responsible for the carbon emission responsible for climate change. Another 32% of the respondents engaged in felling and sale of firewood in the area, which leads to diminishing of trees and important bee fodder plants.

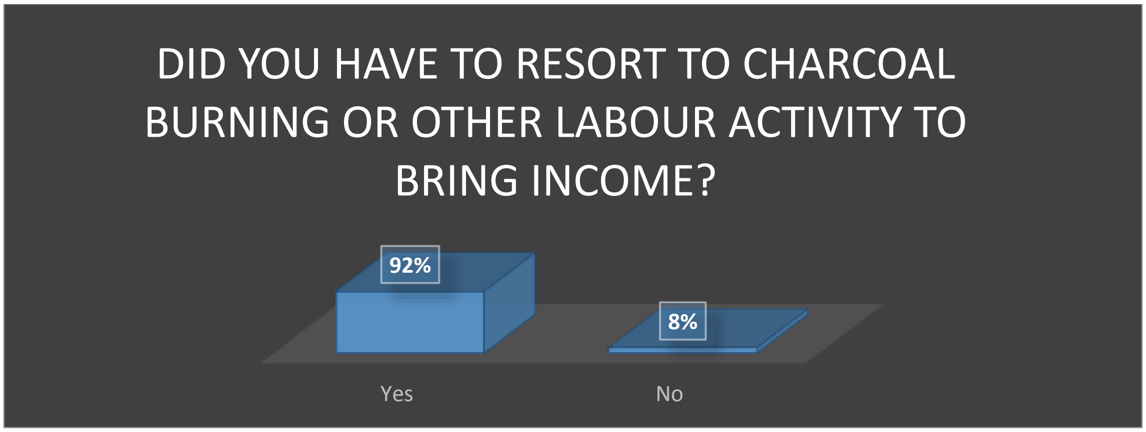

Figure 18. Dry season change of community livelihood

The impact of climate variability and change tended to be severe where people rely on natural rain to sustain their livelihood. In areas such as Sagalla, that has limited livelihood options, the adaptive capacity to impacts of climate variability and change is minimal hence making them vulnerable to these impacts.

6.8 Sagalla community's access to weather and climate information and services

A large percentage (64%) of the respondents had heard and were aware of the term climate change, while 36% are not aware. The main sources of climate and weather information were radio (50% of the respondents), Barraza meetings or workshops organized locally (13%), television (4 %) while 33% of the respondents had no access (Figure. 19).

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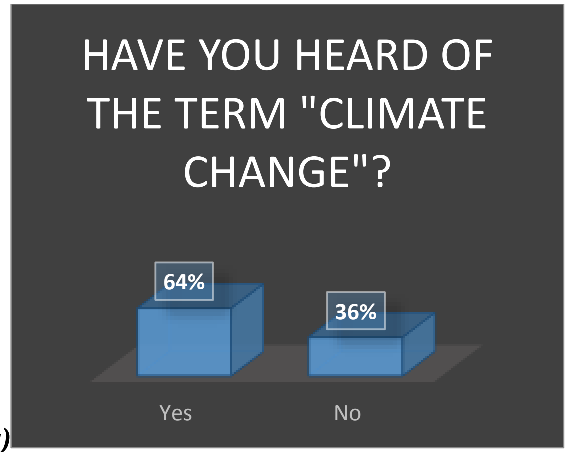

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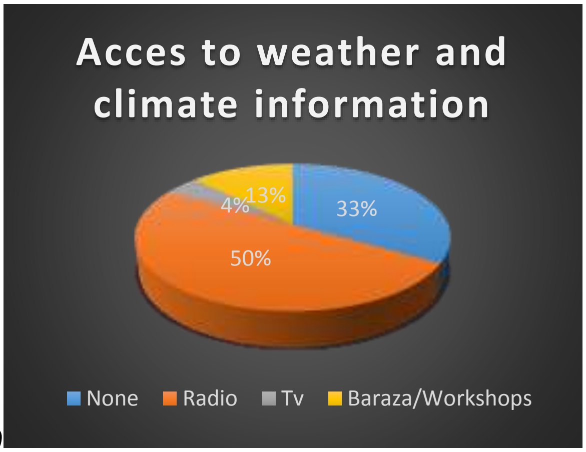
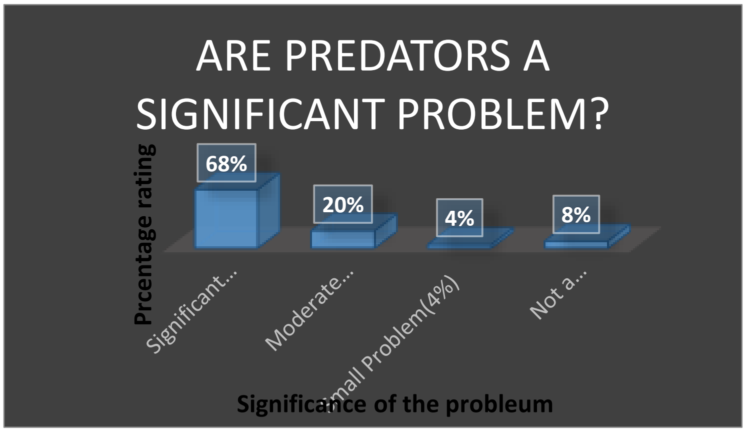


Figure 19. Perception on climate change and community sources of weather and climate information (legend for a and b)

Lack of sufficient and reliable climate information and means of communication puts the respondents and the community at large in a position of making uninformed decision in terms of planning their beekeeping and farming practices and day-to-day activities.

6.9 Respondents perception on impacts of pest and predators on beekeeping activity



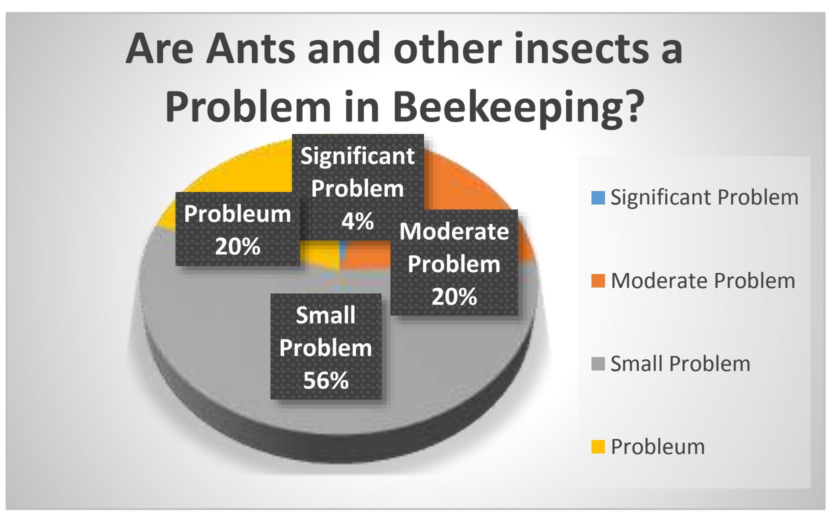
About 68% of the respondents indicated predators, (which was mainly the honey badger) as a significant problem contributing to loss and damage of their beehives and consequently to their hive products. The rest did not consider predators as a major problem (Figure. 20).

Figure 20. Respondents' perception on impact of the predators on beekeeping activity.

Predators can reduce bee pollination services and chances of survival through successful predation (Gregory *et al.*, 2009). For honey bees, direct attack by predators such as honey badger can expose the colony to stress that can lead to colony migrating to a new peaceful nesting site. Other predators that directly feed on bees can significantly decrease recruitment dancing and therefore magnifying the effects of individual predation attempts at colony level.

Farmers in Sagalla have develop techniques to deter honey badger through construction of efficient honey badger guards around their beehives on the hive posts, raising the hive beyond the reach of honey badger, setting of thorns below the hive. Some farmers mentioned that their domestic dogs played a significant role in preventing and reducing honey badger attacks. Other predators though insignificant included agama, bee pirates and hornets.

Figure 21. Respondents Perception on Impact of the ants and other insects to the beekeeping activity.



A majority (56%) of the farmers noted ants and other insects as a small problem to their beekeeping activity, 20% indicated it as a problem, and

20 % considered ants and other insects as moderate problem. Only 4% considered ants as a significant problem (Figure. 21). The community prevented ants and other insects' attacks by greasing the wires connecting the hive to the supporting posts, through regular inspection (every 2/3 days to weekly) and regular cleaning of hives. The ants and insects of concern included black ants (most common), wasps, and termites (destroy hive posts) and beetles that eat honey and honey combs. According to Gregory *et al.*, (2009) ants can be a nuisance and even destroy honey bee colonies

6.9.1 Importance of bee keeping to the Sagalla community

To the Sagalla community, beekeeping provides them with a resilient source of livelihood. The one keeps the community out of poverty and has access to a wide range of options that enables them acquire food an earn income through sales of hive products. All the respondents (100%) indicated the practice of beekeeping; through the construction of beehive fence around their farm is an important deterrent against crop raiding elephants and has significantly reduced human-elephants conflicts in the area. A majority (92%) of the respondent has stated beekeeping as an important source of income through sales of hive products. Many of the respondents (48%) depend on beekeeping as an important source of food. About 24% of the respondents recognize the importance of bee in improving crop pollination and production around the farms. Others respondents indicated honey as an important medicine (28% of respondents) and an important ingredient in preparation of the local brewery (4%) (Figure 22).

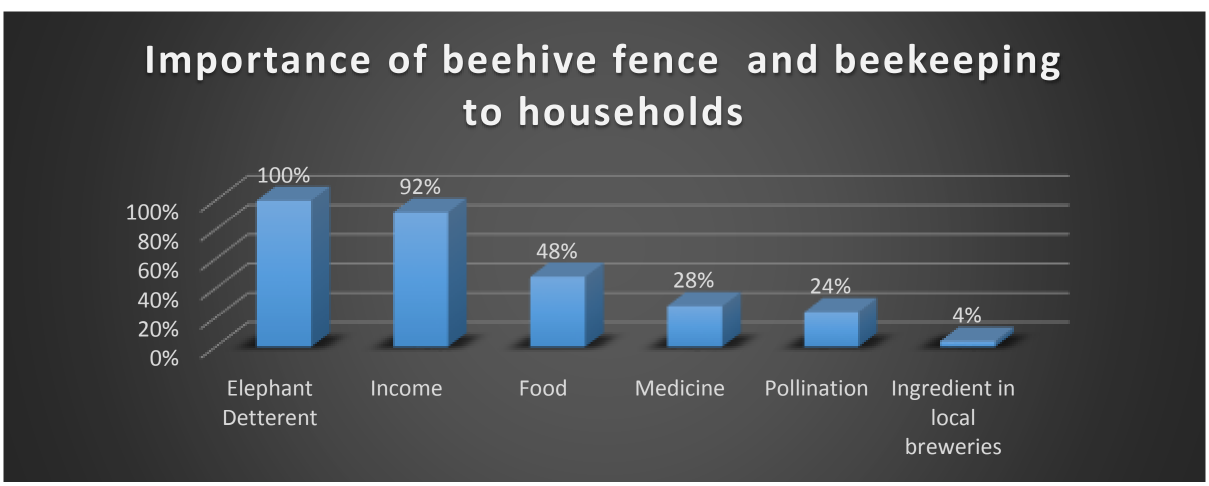


Figure 22. Importance of beekeeping to the community livelihood.

Beekeeping has a very important part to play in the growth and development of the Sagalla community and is a more resilient source of livelihood as compared to other farming practices that enables the community to sustainably utilize the available ecosystem and natural resources. Moreover, for the community a diversified livelihood is a more secure one (Figure 22). The Sagalla area is traditionally a thriving area for beekeeping and honey production (Figure 23).

(a) (b) (c) (d)

Figure 23. Beekeeping activities in Sagalla (a) some of beekeeping farmers beside their beehive, (b) A beekeeper setting a honey badger guard, (c) processing of honey at the Elephants and Bees Project site (d) the author interviewing a beekeeper.

7.0 CHAPTER SEVEN: SYNTHESIS AND DISCUSSION

The decline in the diversity of bee fodder and honey bee colony loss in Sagalla can be attributed to complex interactions between several factors, comprising climate variability, predators, pests, parasites, hive management, and habitat, loss. In our case, we focused on influence of weather and climatic variability on honey bee fodder plants and their population the findings of this study supports the idea that several synergistically acting drivers are responsible for the decline of the honey bee population and their food resources.

The results showed that severe and prolonged drought have a direct negative influence on abundance and diversity and floral resources essential for the survival of the honey bees and altering colony, Floral resource availability and bees harvesting capacity of floral resources (nectar and pollen) can influence the development cycle of the pollinators, their population and socio-economic benefits. Each species of bees is known to have its own rate of growth and development (Di Pasquale *et al.*, 2013). Any kind of climate pressure or movement of a race of honey bees from one geographical area to an new one is therefore guaranteed to have quantifiable genetic consequences.

7.1 Expected mismatches between climate variability and the honey bee-plants interactions

The dry season was the least diverse in terms of bee fodder plant species, while the long rains was the most diverse with 20 more bee fodder plant species that only appeared during this season (Table 1 and 2). Out of the sixty six species collected, the highest number (38 species representing 58% of the total plant number collected were observed to be flowering during the long rains season (April, May, June) and lowest number (18 species representing 27% of the bee fodder sampled were observed to be blooming during dry season of January to March 2017. A small percentage (15%) of the collected bee fodder plants were observed to be blooming during both wet and dry season. Dry season was therefore least diverse in terms of bee fodder and even the bees had to fly long distance under extreme climate conditions (high temperatures) to access these resources.

These climate impacts and modifications in floral rewards to pollinators could affect the choice on how likely honey bees are to visit certain flowers and the benefits they get from these flowers (Memmott *et al*,. 2007). The findings of this study indicated that the warmer and drier weather conditions experienced during dry seasons were accompanied by loss of both honey bee fodder plants such that, the total diversity of bee fodder plants (P) equals to 0.8757 times the amount of rainfall (M) plus 12.425 where $R^2 = 0.6753$ (y(P)= 0.689x(M) + 22.897) (Figure 6). An explanation may be that when floral resources, content or scent are modified or altered at low rainfall and high temperatures, they may potentially influence the detectability of flowers and particularly for honey bee pollinators that rely on long-distance cues to identify and locate their favorite floral resources (Zacepins & Karasha, 2013). Certainly, when the production and composition of nectar is altered from one season to another as we have seen in figure 7. This has immediate effects on honey bee pollinator energetics and activity and longer-term impacts for bee fitness, especially for insects, such as honey bee, that depend on nectar for sugars as well as amino acids. Similarly, pollen production decrease as a result of drought and can impact the reproductive success of bees, which mainly collect and depend on pollen from variety of plants to successfully rear their offspring and increase colony size and their socio-economic benefits (McLaughlin *et al.*, 2002).

Research has shown that the dimensions of the flowers influence the kind of pollinators that are physically adapted and capable of accessing floral rewards. This is as documented by morphological relationships between the length of the bee proboscides and nectar spurs (Scaven & Rafferty, 2013). They observed that even if rewards to these floral resources remain accessible, changes in the abundance and dimensions of flower could impact foraging efficiency of the pollinators, as the size of flower can, in part, determine how costly it is energetically to obtain those rewards. Likewise, the findings of this study indicated that the blooming of flowers earlier as a result of early or unpredicted rainfall, the honey bees' pollinators may benefit from access to those rewards, however later in the season this could affect resource availability for pollinators and their access to these resources.

7.2 Diversity of bee fodder plants and honey bee nutrition

Only five (5) plants species provided nectar and 11 species provided pollen for the bees during the dry season (Table 2). The case was different in wet season where 10 species produced nectar for the bees and 26 species produced pollen. The observation i.e. there is higher diversity of nectar and pollen producing plants available to the bees during wet season (Table 2) which indicated that climatic variability had an impact on beekeeping.

Rainfall and other climate parameters influences development of flowers, pollen and nectar production, which are directly associated with honey bee colony size and strength, foraging activity and development (Di Pasquale *et al*., 2013). Honey bees normally build up enough food stores (honey) to enable them to survive the drought and extreme weather conditions. A major impact of climate variability and change on honey bees stems from changes in the abundance, diversity and distribution of the fodder plant species on which the bees primarily depend for food. An excessively dry climate (drought/famine) in Sagalla and other ASAL areas, which reduces nectar and pollen production and has been seen to impoverish quality of their nutritional value, which adversely affects bees in these habitats. Sufficient and variety of pollen diet that is available during wet season provide sufficient vital resource for rearing the future bee workers and the survival of the entire colony. The shortage of pollen prompted by drought deprive the bees, wearying their immune system, and making them more susceptible to predator stress, pathogens and reducing their lifespan (Gregory *et al.,* 2009). Tropical climates and especially ASAL areas such as Sagalla may have evolved towards more distinct seasons of longer and more severe droughts. In this case, we should scale up our conservation efforts to be able to assist the honey bees to mitigate future changes, adapt to current situation and quickly step up their honey-harvesting plan to build up adequate food (honey) stores to endure dearth periods. Otherwise, the honey bee pollinators could develop a seasonal migration strategy as observed in the study area where bees migrates between study area and Sagalla hill in response to seasons, blooming patterns or disruption by predators, abandoning their homes (hives) and fly long distance to escape starvation or predators.

The impacts of climate variability on seasonal diversity and distribution of bee fodder and honey bee species have been reported by Reddy *et al.,* (2013), and they need planned measures for conserving and protecting our ecosystems and biodiversity. Restoration and conservation efforts aimed at protecting honey bee and plant diversity should give into consideration the kind of land use and also the socio-economic progress in the area. Therefore, the use of ecosystem-friendly agro ecosystem management plan, beekeeping, and ecotourism in key areas, enriched with the fodder plant used by honey bees and other pollinators to nesting and forage, are suggested to provide additional income to beekeepers while protecting the bee pollinators. By implementing these practices, it may be possible for the beekeeping community to conserve and even restore plants and honey bee species biodiversity and ensure the high ecological services delivered by pollinators, as well as improve the income and welfare of the beekeeping community.

7.3 Climate variability, diversity of bee fodder and honey bee population

The results showed that honey bee species population (B) was strongly influenced by the diversity of bee fodder plants (P) such that, the total honey bee population (B) equals to 0.6365 times the diversity of bee fodder plants in numbers plus 12.425 where R2 = 0.55, (y(B)= 0.6365x (P)+17.116) (Figure 10). The collective effects of climate variability on flowering plants and honey bee pollinators determine their pairwise interactions; also, they will shape their networks interaction (Flint & Flint, 2012). The plant diversity-bee population relationship that is used in our prediction model might be directly causal. The relations that we establish between climate and bee population could also be due to other indirect influences. Additional drivers of colony loss, such as predators and pests also affects bee population.

Physiological responses to climate variability and change may alter significantly plant-pollinator networks even without changes in phonological overlap or species composition (Scaven & Rafferty, 2013). The more delicate changes in strength of their interaction could result from altered or changed floral reward quantity and quality to the pollinators, loss of colony number/size or reduced life span of honey bee pollinators. For example when conditions become severe and prolonged add up to significantly affect honey bee-plants network dynamics and structure. Additionally, though we have discussed them separately, the direct pollinators and plant physiological responses to climate extremes (drought and elevated temperatures) that lead to reduced pollination services and pollinator reproductive success lead to reduced plant and crop pollination and honey production success affecting livelihoods of the beekeepers.

Climate variability imposes new physiological challenges on the activity patterns of the bees and other pollinator insects (Di Pasquale *et al.*, 2013). The field observation during this study indicated that weather and climate variability affected the time of day at which bees chose to be active and visit flowers. This therefore affected pollen flow patterns; the chances and probability of pollen receipt by bees, and ultimately honey production and pollination success. During dry season when climate conditions were extreme, bee pollinators restrict their visits to flowers only during the earlier hours of the day, which thus resulted in flower pollination being limited with resultant reduced seed and fruit. Because the honey bee pollinators may have to reduced their foraging trips to shorter distances to evade over heating during flight on extremely hot days, pollen flow pattern would be affected. As a result of shorter flight distances by the honey bees, pollinator dependent plants and crops received less pollination services, impacting pollination success and fruit formation process, honey production phenomena and livelihoods of the beekeepers. Temperature driven shift was observed to affect the bee foraging behavior by declining the honey bee foraging activity when average day temperatures exceeded 34^{o} C.

7.4 Honey bee pests and predators

Honey bees are vulnerable to several parasites, pathogens and certain specific ants and predators. As we have seen, 68% of the respondents indicated as a significant problem while 56% of the beekeepers noted that ants and other insects as a small problem to their beekeeping activity (Figure 20 and 21). Changing variability scenarios may have intense effects in the spread and virulence of these diseases, ants, insects, and parasites. These pathogens tend to have diverse haplotypes of changing virulence (Gregory, *et al,* 2009). Climate variability and change can boost the transfer of these haplotypes to honey bee colony. As climate variability induce migration and movements of honey bees of different races and species from one geographical location to another, this expose them, and brings them into interaction with predators, pests and pathogens with which they have never co-evolved. Bees ability to resist diseases and stress by parasites and predators is determined by a number of factors, mainly their nutritional status and their contact or exposure to toxic chemicals (Brodschneider & Crailsheim, 2010). Therefore, the availability of clean and sufficient nutrients affects their strength and ability to succumb to infection and attacks.

Pathogens and pests may find new possible hosts (Gregory *et al.*, 2009). It is therefore important to conserve the genetic diversity within and among key pollinator species (including varieties and races) to decrease disease-mediated mortality and reduce susceptibility to predators and other stressors. Managed honey bee pollinators may require veterinary assistance and suitable control approaches to avert catastrophic losses. It is also important to conduct frequent inspection of hives and ensure connectivity of natural and semi-natural habitats in our agricultural areas, so that bees can more easily disperse and make needed range shifts in response to food resources and changing climates conditions. Providing more crop varieties and non-crop flowering resources in fields, such as, strip crops (sunflower), cover crops among others can also assist in enhancing their diet breaths.

7.5 Enhancing the plant- honey bee pollinator interactions within-agro ecosystems and in semi-natural habitats

Six (6) species of crops (9% of total sampled bee fodder) were identified as bee fodder during this study. Two of these crops (moringa and sunflower) provided bee with fodder during dry season and the other four were observed to be blooming during the wet season. This crops are farmers favorite crops and crops that most farmers fall for when the rainfall is less or shorter than expected. These crops include moringa (*Moringa oleifera*), cowpeas (*Vigna inguiculata*), green grams (*Vigna radiata*), sunflower (*Helianthus annus),* watermelon (*Citrullus lanatus*) and pigeon peas (*Cajanus cajan*) (Table 2).

Effective crop pollination is greatly reliant on biological timing, of both the pollinators and crops (Kjøhl *et al.*, 2011). Crops such as cowpeas, pigeon peas, green grams in the study area have periods of mass blooming mainly influenced by rainfall and farmers plan to planting season. Over relatively short periods when they are blooming, thus crops require a tremendous peak in honey bee pollinators and provide sufficient fodder for the bees. Climate variability and change may have profound impacts on the timing of these events affecting pollinators-crops interaction.

As average global temperatures rise, crops will be grown in warmer environments and increase in average global temperature above 1-2°C may have a negative consequences on growth of crops and agricultural yield at low latitudes (Colinvaux *et al.,* 1996). About 48% of the respondents have lost their first planting season (Apr-May-Jun) for the past 3 years, and a slight positive impact at higher latitudes of Sagalla. Extreme temperatures and prolonged, severe drought are events that affects crops and particularly during anthesis. While it is clear that water stress and drought will negatively influence crop growth and crop yields, this will also impact on honey bee pollination functions and pollinator-dependent crops. Flowers with fewer attractants are less attractive to pollinators will experience reductions in pollination levels, with decreased seed/food quality and quantity. Reduction in crop yield under drought may also result from a decline in viability of pollen along with an escalation in seed abortion rates, which have been known as the most important factors affecting seed (Ricketts *et al*., 2008).

The outcomes of this study follows the trends observed where the practice of intensive agriculture continues to replace the natural wild plants around our ecosystems (Hladik *et al.,* 2016). Wild plants around the ecosystem are important fodder for bees and as they are continuously replaced by the practice of monoculture or few crops varieties, this can only sustain a small colony or population of the honey bee. In this study the, practice of monoculture combined together with dry season honey bee fodder scarcity was seen as a huge challenge to the honey bee fodder availability. For instance most farmers plant grains and crops such as corn, which are planted every year across the study area, do not provide for the favorite or sufficient nectar or pollen needs of the honey bee species. On the other hand, it appears that small areas of natural habitat in farmland and outside farms that includes herbs, shrubs, grass and trees may permit bee species to persist. At the farm level, honey bee pollinators in the study site benefited from increasing or conserving alternative fodder before and after blooming of the main crop. These results indicate that maintaining flower-rich field margins, set asides, grassy borders or permanent hedgerows are effective ways of doing this. This study compliments the findings of Kjøhl *et al.*, (2011) who noted that intercropping different varieties of drought resistant crops such as cowpeas (*Vigna unguiculata*) and *Moringa oleifera* could serve as a "reservoir" of bee fodder when wild flowers are not blooming . The results of this study also indicates that annual communities of plants otherwise regarded as Herbs representing 34% of 69 bee fodder collected and grass (4%) play a significant role in supporting healthy honey bee pollinator communities during dry season.

7.6 Beekeeping in Sagalla

Climate variability and other anthropogenic activities such as land use changes among other factors (pests and predators) in Sagalla, have negative impacts to the diversity of honey bee fodder and productivity of honey bees. Increasing water stress particularly in situations of drought has shown to reduce pollen and nectar availability, altering plant flowering time, causing physical colony starvation, limiting movement, affecting bee communications, and hindering bee forage activities (Zacepins & Karasha, 2013). Mitigation strategies recommended from the findings of this study against the impacts of climate variability and water stress for beekeepers include the planting of drought resistant crops such as moringa, shifting to pollen rich areas, providing food (sugar supplements and water for the bees just next to the hives). Other options being adopted by the beekeepers include changing types of hives, changing location of hives, placing hives under tree shadows or under grass shades to protect bees against extreme temperatures, setting honey badger guards to prevent predators' attacks and changing harvesting time and methods. Nonetheless, beekeeping farmers in Sagalla still face constraints and support and interventions are needed to strengthen the capacity of beekeepers to mitigate and adapt to these impacts through integrating climate services with available indigenous knowledge and local practices.

Although there is unmet demand for honey in both local, national and international markets, beekeepers in Sagalla face a number of problems as we have seen that prevent them from taking advantage of existing opportunities. Despite the challenges, beekeeping has greatly reduced human elephant conflict in Sagalla through the construction of beehive fence, improved food security, poverty reduction, employment creation and income generation for the Sagalla community (King *et al.,* 2017). The community in its strategy with assistance of the Elephants and Bees Project has identified beekeeping and honey production as one of the means by which can secure their crops from elephant crop raid and earn reliable income through sales of hive products. This strategy makes the Sagalla communities more resilient and better adapt to impacts of climate variability and climate change without damaging the environment they depend on to survive.

The main factor leading the Sagalla community to take up beekeeping was deterring crop raiding elephants and the income generated from honey sales, mainly for those who acquired it after the age of 35 years. Generally, it was seen as a way of supplementing income and complimenting other farming practices through pollination rather than as the main or only source of livelihood. It was a key approach to supplement income from commercial and subsistence farming practices when no other alternatives were available. In addition, a majority of the beekeepers noted the importance and benefits of beekeeping for the surrounding ecosystem and natural environment such as conservation of forest and crop pollination. It is not likely that these aspects were direct motivations to start apiculture. However, as these features were encouraged and promoted during workshops and trainings, these would possibly have had a positive inspiration on the awareness and perception of beekeeping in the area and in eventually adoption of beekeeping among other community members.

The main factors mitigating for or against the adoption of beekeeping practice that came out in this study, are that men in the area are more likely to take up beekeeping. This is since women face a number of barriers' including the lack of time available to keep bees and socio-cultural restrictions in addition to their other activities (e.g. and household chores). However, several key stakeholders said that women have been receiving increasing support to access and attend formal training. On the other hand, this study showed that traditional attitudes do change and women are attracted by this activity as it enables them to generate an income and take more control over their lives. Women's access to beekeeping is likely to improve in the coming decades, especially through training and capacity building.

Beekeeping was not for young people. First, majority of young people favor non-manual and salaried employment jobs, which they find it more secure. This study therefore confirmed Muriuki's (2010) assumption that young people are hesitant to take up beekeeping because negative of attitudes. It was also noted that one likely reason for the deterioration in new entrants to beekeeping practice in Sagalla and most areas in Kenya and around the world is the rising importance of education, which makes beekeeping less popular among young people. In other words, there is a negative relationship between level of education and involvement in beekeeping, as it is the case with other forms of agriculture in Africa (Asciutti *et al.*, 2016). On the other hand, education does not certainly mean that people and communities cannot keep bees. In fact, access to information, awareness and knowledge on beekeeping benefits were found to support beekeeping adoption in the area, even among educated members of the community.

With the help and support from the Elephant and Bees Project and other relevant stakeholders, the communities will be more active in protecting and preserving their natural environment, as they know their beekeeping practice is dependent on local flora as their primary source of nutrition. Other benefits of beekeeping to the Sagalla community are that bees do not compete with livestock for food and women and men of any age can carry out beekeeping. Beekeeping requires little space and compliments other farm activities. In addition, beekeeping does not need good soil bees help the pollination of flowers, plants and crops and most importantly bees produce honey, beeswax and propolis (used in medicines) and other products such as bee venom, royal jelly and bee brood. To them beekeeping is the way to go and honey is always in demand and has a high market value.

8.0 CHAPTER EIGHT: CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSIONS

8.1.1 Impacts of climate variability and anthropogenic activities on honey bee fodder and honey bee population

Honey bee fodder plants, honey bee populations and pollination of both wild and cultivated plant species are under threat as a result of multiple climate and environmental pressures acting in concert. Climate variability, predators such as insects,, agricultural intensification, land-use changes leading to habitat fragmentation all impacted negatively towards plant-pollinator interactions. The negative impact is increased during extreme drought according to the findings of this study. Like we have discussed earlier, these factors do not act independently, and therefore it is often difficult to disentangle their impacts. Nevertheless, this study has shown how climate factors and anthropogenic activities among other factors have an impact on the diversity of the fodder plants and influence their blooming. This in turn affects the bee population levels and eventual honey yield phenomena. The findings shows that climatic variability and change may have a negative or positive action on diversity of honey bee fodder, honey bee population as well as honey production depending on changes in the daily average temperature and amount of rainfall. This is mainly through nutrients availability (pollen and nectar), its quantity and quality that are essential for survival and optimum functioning of the bee ‘colony.

8.1.2 Climate variability and beekeeping in Sagalla

Climate change and climate variability as well as various anthropogenic factors are a threat to the livelihood and survival of the Sagalla community. Tenets of honey bee keeping can play a crucial role in cushioning the Sagalla community against the vagaries of climate variability and change. Through increased pollination services, the community can have increased production of crops and wild plant products , decreased elephants destruction of their lands and hence the diversification and improved livelihoods of the Sagalla community. Many agricultural practices that increase bee fodder plant diversity in Sagalla at different scales should be adopted that increase the floral resources available for the honey bee pollinators, both in space and time. Adoption of organic agriculture may be used to diversify bee fodder, together with the growth of the application of techniques that reduce and/or eliminate chemical pesticides (i.e. integrated pest management). Farming that increases diversity and abundance of bee fodder without using pesticides is entirely feasible, environmentally safe, and economically profitable.

The honey bees have shown great adaptive capacity, as it is found almost everywhere in the world and in highly diverse climates. The findings of this study indicated that maintenance of plant-bee pollinator interactions in the face of climate variability and change is a complex but important conservation goal for the coming decades. Though researchers have made strides in recording the physiological impacts of climate variability on diversity of honey bee fodder plants and honey bee pollinator species, clearly there is much room for expansion in this field of research. As studies and research on the impacts of climate change for plant and pollinator physiology moves forward, studies that more realistically integrate the impacts of climate change should yield valuable insights. In addition, research and studies that integrate behavioural, physiological responses and contemplate connections and interactions among multiple drivers will surely advance our knowledge and understanding of the overall impacts of climate variability and climate change on plant-pollinator interactions and the associated socio-economic benefits. If bees disappear from the surface of the earth as a result of climate change, man will have no more than four years to live. No more bees, no more pollination, no more men. Bees work for man, and yet they never bruise their master’s flower, but leave it having done, as fair as ever and as fit to use. Therefore, both plants and flowers doth stay, and the honey run.

8.2 RECOMMENDATIONS

The following recommendations are proposed for the lessons learnt from the project research:

1. Beekeepers in the study site should give consideration to the season long resources such us drought resistant trees, crops and sugar supplements needed by bees in dry season, both before and after plants and crop flowering.

2. Beekeeping farmers should also ensure connectivity of natural habitats in farming areas, so that bees' can more easily disperse and easily collect floral resources essential for their survival in response to changing climates.

3. Beekeepers can also provide more non-crop flowering resources in fields, such as cover crops, s trip crops or hedgerows that provide alternatives floral resources.

4. Although none of the farmers interviewed use pesticides, the beekeepers in the study site should be informed on the use of bee-harming pesticides, starting with awareness about the top-ranked most dangerous pesticides-

5. Relevant government bodies and Sagalla communities adopt the finding of this research and set policies that create awareness of the need for protecting designated wildlife sites that are important to bees.

6. Additional research on plants and bees should be conducted integrate behavioural, physiological and phonological responses to advance our understanding on bee pollinator and plant interactions

REFERENCES

Amdam, G. V., Norberg, K., Omholt, S. W., Kryger, P., Lourenço, A. P., Bitondi, M. M. G., & Simões, Z. L. P. (2005). Higher vitellogenin concentrations in honey bee workers may be an adaptation to life in temperate climates. *Insectes Sociaux*, *52*(4), 316–319. http://doi.org/10.1007/s00040-005-0812-2

Baede, A., van der Linden, P., & Verbruggen, A. (2007). Annex to IPCC Fourth Assessment Report. *IPCC Fourth Assessment Report*, 75–104. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_appendix.pdf

Bartomeus, I., Ascher, J. S., Wagner, D., Danforth, B. N., Colla, S., Kornbluth, S., & Winfree, R. (2011). Climate-associated phenological advances in bee pollinators and bee-pollinated plants. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(51), 20645–9. http://doi.org/10.1073/pnas.1115559108

Beyene, T., & Verschuur, M. (2014). Assessment of constraints and opportunities of honey production in Wonchi district South West Shewa Zone of Oromia , Ethiopia. *American Journal of Research Communication*, *2*(10), 342–353.

Brodschneider, R., & Crailsheim, K. (2010). Nutrition and health in honey bees. *Apidologie*, *41*(3), 278–294. http://doi.org/10.1051/apido/2010012

Colinvaux, P. a., Liu, K.-B., Oliveira, P., Bush, M. B., Miller, M. C., & Kannan, M. S. (1996). Temperature depression in the lowland tropics in glacial times. *Climatic Change*, *32*(1), 19–33. http://doi.org/10.1007/BF00141276

Colwell, R. K., Brehm, G., Cardelus, C. L., Gilman, A. C., & Longino, J. T. (2008). Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science*, *322*(5899), 258–261. http://doi.org/10.1126/science.1162547

Di Pasquale, G., Salignon, M., Le Conte, Y., Belzunces, L. P., Decourtye, A., Kretzschmar, A., … Alaux, C. (2013). Influence of Pollen Nutrition on Honey Bee Health: Do Pollen Quality and Diversity Matter? *PLoS ONE*, *8*(8). http://doi.org/10.1371/journal.pone.0072016

Flint, L. E., & Flint, A. L. (2012). Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis. *Ecological Processes*, *1*(1), 2.

http://doi.org/10.1186/2192-1709-1-2

Giannini, T. C., Acosta, A. L., Gar??falo, C. A., Saraiva, A. M., Alves-dos-Santos, I., & Imperatriz-Fonseca, V. L. (2012). *Pollination services at risk: Bee habitats will decrease owing to climate change in Brazil*. *Ecological Modelling* (Vol. 244). http://doi.org/10.1016/j.ecolmodel.2012.06.035

González-Varo, J. P., Biesmeijer, J. C., Bommarco, R., Potts, S. G., Schweiger, O., Smith, H. G., … Vilà, M. (2013). Combined effects of global change pressures on animal-mediated pollination. *Trends in Ecology and Evolution*. http://doi.org/10.1016/j.tree.2013.05.008

Gregory, P. J., Johnson, S. N., Newton, A. C., & Ingram, J. S. I. (2009). Integrating pests and pathogens into the climate change/food security debate. In *Journal of Experimental Botany* (Vol. 60, pp. 2827–2838). http://doi.org/10.1093/jxb/erp080

Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change*, *19*(1), 74–88. http://doi.org/10.1016/j.gloenvcha.2008.11.002

Hatch, S., Tarpy, D. R., & Fletcher, D. J. C. (1999). Worker regulation of emergency queen rearing in honey bee colonies and the resultant variation in queen quality. *Insectes Sociaux*, *46*(4), 372–377. http://doi.org/10.1007/s000400050159

Hladik, M. L., Vandever, M., & Smalling, K. L. (2016). Exposure of native bees foraging in an agricultural landscape to current-use pesticides. *Science of the Total Environment*, *542*, 469–477. http://doi.org/10.1016/j.scitotenv.2015.10.077

IBM. (2012). IBM SPSS Advanced Statistics 20. *Ibm*, 184. http://doi.org/10.1080/02331889108802322

Kadlec, T., Tropek, R., & Konvicka, M. (2012). Timed surveys and transect walks as comparable methods for monitoring butterflies in small plots. *Journal of Insect Conservation*, *16*(2), 275–280. http://doi.org/10.1007/s10841-011-9414-7

King, L. E., Douglas-Hamilton, I., & Vollrath, F. (2011). Beehive fences as effective deterrents for crop-raiding elephants: Field trials in northern Kenya. *African Journal of Ecology*, *49*(4), 431–439. http://doi.org/10.1111/j.1365-2028.2011.01275.x

Kjøhl, M., Nielsen, A., & Stenseth, N. C. (2011). *Potential effects of climate change on crop pollination*.

Lawless, H. T., & Heymann, H. (2010). *Descriptive Analysis*. *Sensory Evaluation of Food*. http://doi.org/10.1007/978-1-4419-6488-5

McLaughlin, J. F., Hellmann, J. J., Boggs, C. L., & Ehrlich, P. R. (2002). Climate change hastens population extinctions. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(9), 6070–6074. http://doi.org/10.1073/pnas.052131199

Memmott, J., Craze, P. G., Waser, N. M., & Price, M. V. (2007). Global warming and the disruption of plant-pollinator interactions. *Ecology Letters*, *10*(8), 710–717. http://doi.org/10.1111/j.1461-0248.2007.01061.x

Pettis, J. S., Vanengelsdorp, D., Johnson, J., & Dively, G. (2012). Pesticide exposure in honey bees results in increased levels of the gut pathogen Nosema. *Naturwissenschaften*, *99*(2), 153–158. http://doi.org/10.1007/s00114-011-0881-1

Popic, T. J., Davila, Y. C., & Wardle, G. M. (2013). Evaluation of Common Methods for Sampling Invertebrate Pollinator Assemblages: Net Sampling Out-Perform Pan Traps. *PLoS ONE*, *8*(6). http://doi.org/10.1371/journal.pone.0066665

Reddy, P. V. R., Verghese, A., & Rajan, V. V. (2013). Potential impact of climate change on honeybees (Apis spp.) and their pollination services. *Pest Management In Horticultural Ecosystems*, *18*(2), 121–127. Retrieved from http://www.aapmhe.in/index.php/pmhe/article/view/3

Ricketts, T. H., Regetz, J., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., Bogdanski, A., … Viana, B. F. (2008). Landscape effects on crop pollination services: Are there general patterns? *Ecology Letters*, *11*(5), 499–515. http://doi.org/10.1111/j.1461-0248.2008.01157.x

Scaven, V. L., & Rafferty, N. E. (2013). Physiological effects of climate change on flowering plants and insect pollinators and potential consequences for their interactions. *Curr Zool.*, *59*(3), 418–426.

Schweitzer, P., Nombré, I., & Boussim, J. (2013). Honey Production for Assessing the Impact of

Climatic Changes on Vegetation. *Tropicultura*, *31*(2), 98–102. Retrieved from http://www.tropicultura.org/text/v31n2/98.pdf

Solomon, S., Alley, R., Gregory, J., Lemke, P., Manning, M., Oppenheimer, M., … Agrawala, S. (2008). A Closer Look at the IPCC Report. *Science*, *319*(5862), 409c–410c. http://doi.org/10.1126/science.319.5862.409c

Steffan-Dewenter, I., Potts, S. G., Packer, L., & Ghazoul, J. (2005). Pollinator diversity and crop pollination services are at risk [3] (multiple letters). *Trends in Ecology and Evolution*. http://doi.org/10.1016/j.tree.2005.09.004

Steffan-Dewenter, I., & Westphal, C. (2008). The interplay of pollinator diversity, pollination services and landscape change. *Journal of Applied Ecology*. http://doi.org/10.1111/j.1365-2664.2008.01483.x

Sunday, J. M., Bates, A. E., & Dulvy, N. K. (2011). Global analysis of thermal tolerance and latitude in ectotherms. *Proceedings. Biological Sciences / The Royal Society*, *278*(1713), 1823–30. http://doi.org/10.1098/rspb.2010.1295

vanEngelsdorp, D., & Meixner, M. D. (2010). A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *Journal of Invertebrate Pathology*, *103*(SUPPL. 1). http://doi.org/10.1016/j.jip.2009.06.011

Zacepins, A., & Karasha, T. (2013). Application of temperature measurements for bee colony monitoring: A review. In *Engineering for Rural Development* (pp. 126–131).

APPENDICES

Appendix 1

Household questionnaire

(a) Socio-Economic Characteristics of the Households

1. Name of the respondents…………………………………………

   Location/Villages in each settlement

   Mwakoma ☐ Mwambiti ☐

2. Age

   15-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 >66 ☐

3. Sex

   Male ☐ Female ☐

4. Level of education

   None ☐ Primary ☐ Secondary ☐ Diploma/Tertiary ☐

5. Occupation

   Unemployed ☐ Farmer ☐ Own business ☐ Private Sector ☐ Other Small Labor ☐

6. Duration of stay in the area

   < 2 ☐ 2-5 ☐ 5-10 ☐ 10-20 ☐ >20 ☐

7. Household Size/Number

   <2 ☐ 2-5 ☐ 5-10 ☐ >10 ☐

   Adults…….. Children……….

8. Land holding

   Private Community Government

9. Allocation in hectare

   <1 ☐ 1-5 ☐ 5-10 ☐ 10-20 ☐

10. Who is the owner of the beehives?

    ----

11. Credit availability and their sources?

Yes ☐ No ☐

If yes, where……………………..

12. How many beehives do you have?

1-5 ☐ 6-10 ☐ 11-15 ☐ >16 ☐

(b) Perception Profiling

13. When do you have

a) Highest beehives occupation?

December –January – February	March – April-May	June – July-August	September-October – November

b) Lowest beehives occupation

December –January – February	March – April-May	June – July-August	September-October - November

c) Highest honey harvest

December –January – February	March – April-May	June – July-August	September-October - November

d) Lowest honey harvest

December –January – February	March – April-May	June – July-August	September-October - November

14. When do you experience?

a) Highest Rainfall amount?

December –January – February	March – April-May	June – July-August	September-October - November

b) Least/shortage of rainfall?

December –January – February	March – April-May	June – July-August	September-October - November

15. When do you have swarming?

December –January – February	March – April-May	June – July-August	September-October - November

16. When do you experience least/shortage of bee forage (flowers)?

December –January – February	March – April-May	June – July-August	September-October - November

17. When do you experience severe and prolonged droughts/dry season?

December –January – February	March – April-May	June – July-August	September-October - November

18. Is dry season a problem to your bee keeping activity?

It's much of a problem	It's a problem	It's a small problem	Not a problem

19. What do you do to ensure occupation when there is no many flowers for the bees?

a) Supplement feeds____

b) Plant fodder crops____

c) Other____

Do you think the amount of rainfall in the area has changed in the ten years?

Yes____________ No______________

If yes how do you think it has changed?

____

20. Have you ever hear about climate change?

Yes ☐ No ☐

If yes, what do your understanding about it? ___________________________________

21. Are pests and predators a problem attacking your beehives?

It's much of a problem	It's a problem	It's a small problem	Not a problem

If a problem, which type of pest or predator?

22. Do you use pesticides in your farm?

Yes ☐ No ☐

If yes which type?

23. What is your main source of water during dry season?

Tap water ☐ Harvest and Tank water ☐ Water pan ☐ Other……….

How far is from your house?

<30mins 30mins-1hour 1hr-2hrs >2hrs

24. What are other major constraints of beekeeping and maintaining highest beehive occupation?

What do you think should be done about it?

25. How regular do you impact your beehives?

None ☐ Daily ☐ Weekly ☐ Monthly ☐ Seasonally ☐

Any comments about findings during inspection?

26. How is beekeeping important source of livelihood to you?

Elephant deterrent ☐ Income ☐ Food ☐ Preservative ☐ Medicine ☐ Other…….

27. What practice would you like to extend and engage more in the future?

Farming/Agriculture ☐ Beekeeping ☐ Agriculture and Bee keeping ☐ Other………..

Reason? ______________________________

Do you have any questions for me? ______________________________

Appendix 2

Biophysical Data sheet

Name of the Area/Village…………………………………………………….

Name of the Farm (farmer)…………………………………………………………..

Co-ordinates………………………………………………………………………..

Section	Date		Family name	Species name	Local name	Pic No	Resources collected from plant

Other Notes

……………………………………………………………………………………………….

…………………………………………………………………………………………………