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Impacts of *Vachelia reficiens* and *Prosopis juliflora* on the Environment of Samburu East Sub-County, Kenya

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Abstract: Negative impacts of invasive plant species are a major challenge globally in the 21st Century. They have enormous environmental and economic costs. In spite of this, little is known of their impacts and management interventions. In Kenya, Samburu East Sub-County has experienced a spread of *Vachelia reficiens* and *Prosopis juliflora.* The resident community and the government are concerned on the extent of the spread and establishment of the species in the area. To address these concerns, the study aimed at analyzing their impacts on; socio-economic activities; the environment; spatio-temporal variations of impacts-, and evaluation of effectiveness of on-going interventions. To obtain quantitative and qualitative data, sequential explanatory mixed-method study design was used. Five-point perception count on a Likert scale was used to rate the magnitude of the impacts. To achieve this objectives, multistage clustered random sampling at each stage of the administrative units was used to obtain sampling design frame. Probability and non-probability sampling methods were employed to obtain data using structured research instruments. Questionnaire validity and reliability were confirmed before data collection. Inferential and descriptive statistics were used to analyze data. The result showed that impact of *Vachelia reficiens* were higher in magnitude than of *Prosopis juliflora* and the effective method of interventions was cutting. The results were statistically significant based on the chi square test analysis at $p < 5\%$. Therefore, the two plant species have statistically significant negative impacts on the socio-economic and environmental systems and impacts differ over space and time. The study recommends management and policy measures for urgent attention in order to safeguard biodiversity and community livelihoods. Implementation of the recommendations by state and non-state actors will enhance environmental sustainability in the sub-county.

Keywords: Household, Environmental Impacts, *Vachelia reficiens*, *Prosopis juliflora*, Invasive Plants, Ecosystem, Environmental Sustainability

1. Introduction

Invasive plant species have been described as either being indigenous or exotic and refer to species that are introduced with or without intentions into new areas and end up causing degradation of the environment they invade through their heavy colonization attribute [1-4]. According to Mashhadi and Radosevich, invasive plant species unlike agricultural weeds, have the ability to successfully establish and spread to new habitats without support from humans. They invade areas of native vegetation, displacing many species. They threaten and change the biodiversity, structure and functioning of many of the world's ecosystems [5].

Characteristics exhibited by invasive plant species include ability of a plant to; become widespread as opposed to normal distribution, dominate other vegetation and form impenetrable thickets, become a health risk to humans and animals, impact negatively on grazing systems and exhibit prolific seeding, high dispersal rates and propagating in various forms-seeds and vegetatively [6].

1.1. Background of the Study

Invasion by invasive plant species have added to challenges faced in the world currently by mankind. To safeguard biodiversity, nations in the world have entered into environmental agreements to avert this challenge. According to Noba et al., the invasion is among the key environmental challenges of the 21st Century as they cause erosion of global biodiversity [7]. Further, invasions from native plants are adding to the challenge. Some of the reported native invasions are of global concern. The invasions have claimed grasslands in affected countries since the era preceding industrial revolution and require sufficient attention to mitigate their impacts. The invasions span Africa, Australia, Asia, North America and South America. In North America alone, native invasions now account for 10%-20% of the invasions [6].

Invasive species negatively affects the three pillars of sustainable development as they cause enormous ecological or loss of biodiversity, economic and social impacts which have negative implications on environmental sustainability [8, 9, 10]. According to Essl et al., substantial efforts are required to counter negative impacts of invasive species in order to meet Vision 2050 on biodiversity values [11].

Invasive species invasion majorly drives ecological change leading to negative changes in ecosystem structure and functions, economic and social systems in the world [10]. The species directly affects nature and have caused 60% of species extinctions. Additionally, Climate change, habitat fragmentation and global trade noted to increase their abundance and severity of the impacts [13]. Further to this, climate change triggers the introduction, establishment and spread of invasive species even to higher altitudes not previously infested, therefore disrupting native ecosystems.

Economically, the impacts of invasive species can be massive and disastrous yet little policy commitments exists to reverse their impacts [14]. According to Zenni et al., the global economic cost of invasive species has been $ 1.288 trillion over the past 50 years and was on the upward trend [15]. Loss of biodiversity and water scarcity due to invasive species in South Africa had compounded impacts of drought and climate change [16]. Despite of the deplorable impacts of native and non-native invasive plants elsewhere, no policy commitment exists to avert their adverse impacts in Kenya. There socio-economic and environmental costs are yet to be established in the study area and in Kenya.

Invasions by Invasive species is a man-made disaster which had been underreported particularly on social impacts of invasive plants compared with economic impacts and have evaded the attention of the media and disaster managers. Recommended, was the need for information on invasive species to be availed to media, policy and decision makers for considerable attention before they turn disastrous [17]. However, the ecological, social and economic impacts of Invasive Alien Plant Species have been acknowledged by scientists, natural resource managers and policy makers worldwide [18]. Despite of this, little information exists in Kenya on these invasive plants and their impacts as to influence policy formulation or decision making.

The arising attention on invasive alien species made conservation and trade authorities to develop Agreements to foster the cooperation between environment, trade and agricultural authorities on mitigation of the species adverse impacts [19]. Establishment and implementation of legal frameworks was a key way forward for the Agreements to function. In Kenya, the Phytosanitary and legal frameworks are in place though poorly enforced and policy on invasive species is still lacking.

Due to changes the invasive species pose on the environment, responses to mitigate their impacts have been attempted. This include prediction model to counter the invasions developed [20]. Further, quantification tools for impact assessment and classifications to determine impact magnitude of the species have been developed [21, 22]. In Kenya, only the distribution of *Vachelia reficiens* has been modelled [23]. However, assessment of the extent and magnitude of the impacts have rarely been done in developing nations including Kenya and in particular Samburu East Sub-County.

Kenya's Arid and semi-arid lands are at risk of invasion from invasive plants which are claiming areas of high water table causing serious conflicts with human activities [24]. *Vachelia reficiens* has not yet been studied widely as to know its origin and impacts though considered as an invasive species in some parts of Kenya. Invasive plant species are threatening Kenya's biodiversity as they distort food chains by lowering grass production thus reducing available food to grazers [2, 23].

Concerns on spread of native and non-native invasions in the rangelands of the sub-county have been raised by the resident community. These rangelands supports livestock production which is the economic mainstay of the local populace and are biodiversity hotspots of international importance yet little is known of the magnitude of impacts and extent of the plants' invasions (CGS CIDP, 2018; KFSSG, 2021). In particular, concerns on the spread and establishment of *Vachelia reficiens,* a native plant and *Prosopis juliflora*, an exotic plant, on pasture land depended by Pastoralists in Samburu, Isiolo and Marsabit Counties in Kenya exists. The concerns have informally singled out soil erosion and loss of biodiversity though unquantified in terms of magnitude as being compounded by *Vachelia reficiens* (Nebosa; 2018, unpublished). Despite of these concerns, quantifications of their socio-economic and environmental impacts have not been done in the sub-county to date.

Therefore, these concerns on the two woody species across the Sub-County, prompted the study. The study, purposed to identify key impacts and the magnitude of the impacts of the two species in the study area and evaluate on-going management interventions. The findings are expected to broaden understanding, information and knowledge base of the invasive species to influence policy and decision making on them for environmental sustainability.

1.2. Statement of the Problem

Invasive plant species can have significant impacts on native ecosystems which may include competition with native species for growth resources like water, sunlight, nutrients, and space. In most cases, invasive plants displace native species and alter the structure and functions of ecosystems. The spread of invasive plant species like *Vachelia reficiens* and *Prosopis juliflora* if not controlled, can have significant and irreversible socio-economic and ecological impacts. Therefore, it is paramount to take steps to prevent their introduction and further spread. In recent years, there has been growing concern about the introduction and spread of invasive plant species in various parts of the world. Kenya as a signatory to the Convention on Biological Diversity (UN, 1992) and International Plant Protection Convention (IPPC, 1997), has recognized the importance of managing invasive species to safeguard biodiversity and livelihoods in the country. However, Kenya currently lacks a policy on invasive species, which has curtailed efforts to stop introduction, management and control of the invasive plants. Furthermore, there is a dearth of information and tools to support the identification, quantification and management of invasive plant species in the country, particularly in the study area. In this context, this research aims to investigate the extent and impact of invasive plant species in the study area and propose management strategies that could be adopted to minimize their negative impacts on socio-economic activities and biodiversity. Additionally, information and research on diversity and impacts of invasive species and management interventions is scanty in Kenya and lacking in Samburu East Sub-County which is mainly an Arid Semi-Arid Land. In spite of this state of lack, it is necessary that in those places with arid and semi-arid conditions, a plant cover be maintained that would not only improve the environmental quality but also offer socio-economic benefits for the mostly pastoralist communities such as those of Samburu East Sub-County where this study was undertaken. Indeed, concerns on the establishment and spread of *Vachelia reficiens* and *Prosopis juliflora* across the Sub-County already exists and are worrying. Their impacts are yet to be identified, demystified and evaluated formally as this study purposes to do. Given the difficulty of reversing or managing the impacts of established woody invasive species in the environment, this study goes further by not only identifying their specific impacts to the study area but more significantly determining how this impacts have affected the ecological status and socio-economic wellbeing of the local pastoralist community of the Sub-County. The study also investigated the options that have been put in place to mitigate the adverse impacts of their invasive character to both the ecology and the economy of the residents and therefore improve the community's general wellbeing.

1.3. Broad Objective

To Identify and determine the magnitude of impacts of *Vachelia reficiens* and *Prosopis juliflora* on the environment of Samburu East Sub County.

1.4. Hypotheses

H_{O1}: There are no significant environmental Impacts of *Vachelia reficiens* and *Prosopis juliflora* on the environment of Samburu East Sub County.

2. Literature Review

2.1. Invasive Plant Species

Richardson and Rejmánek (2011), reported the existent of 622 types of invasive plant species in the world. The species are heavy seeders which are able to spread over several life cycles, displacing indigenous plants and colonizing Sites. However, in Kenya the reported number of major invasive plant species including *Prosopis juliflora* differ, for instance; [25], identified 8; [17], documented 9; [26], reported 9. The plants were introduced for their social, economic and environmental benefits but turned invasive. Conspicuously, *Vachelia reficiens* (*Acacia reficiens*) though a native plant, is not in the list despite of concerns on its spread and extent of expansion in several counties in Kenya including Samburu County. Despite of these concerns, no attention has been specifically directed to document and demystify the arising impacts of *Vachelia reficiens.*

Ouko et al., while adopting the work of Witt (2017), describes *Vachelia reficiens* (Wawra & Peyr.) Kyal. & Boatwr, as an aggressive shrub or tree which grows to a height of 3-4 metres high. It is native to Ethiopia, Somalia, Kenya, Namibia, Sudan, Uganda, and Angola [23]. Kaigongi (2020), *Acacia reficiens* has been renamed *Vachelia reficiens* following the decision of the International Code of Botanical Nomenclature and ratified at XVIII IBC, Melbourne in 2011.

Prosopis juliflora (Swartz D. C) is a world renowned invasive plant which is evergreen with fast growth and belongs to the legume family. It is indigenous to Mexico, South America and the Caribbean. It grows to a height of 12 metres and has spines. It forms impenetrable thickets, and at maturity the trunk diameter is 1.2 metres. Currently the plant has become a problematic weed in pastoral and agro-pastoral communities of Ethiopia, Kenya and generally in the Eastern Part of Africa [27]. According to Shiferaw and Demissew, the plant threatens biodiversity and overtakes other land uses thus reducing their ecosystem goods and services [1]. In Ethiopia, *Prosopis juliflora* has caused great ecological and economic damage [28].

Prosopis juliflora (Swartz D. C) is an alien plant species intentionally introduced to Kenya in 1980's to solve degradation of Arid and Semi-Arid Lands (ASALs) by stopping the spread of desertification in these areas [29]. It was objectively introduced from South America in the 1970s to rehabilitate ASALs of Kenya [30]. This was due to its resilience, fast growth rate and its various uses for fodder, socio-economic goods and environmental Services.

Impacts of invasive species in Sub Saharan Africa have been described as; loss of livelihoods, food insecurity, and loss of biodiversity. This has threatened the economic stability and advancement in the affected countries and

regions. Environmental impacts of invasive species include; declined biodiversity, a decrease in availability and quality of key natural resources, frequent water shortages, increased flooding, pollution on use of chemicals and wildfires [31]. However, impacts of the two species under focus have not been confirmed in the sub-county thus the object of the study.

2.2. Environmental Impacts of Invasive Plant Species

Invasion of northern Kenya's rangelands and grasslands by *Vachelia reficiens* has undermined the conservation of endangered wildlife species by lowering their capacities to support grass and forage available to wildlife [32]. The study was restricted to the impacts of the plant on endangered wildlife other than wildlife in general probably due to conservation interests. The study further excluded *Prosopis juliflora*, an invader plant of similar impacts to wildlife and grasslands elsewhere. This study has broadened the impact of the specie to a wide range of environmental components for a holistic assessment of its many other environmental impacts and included *Prosopis juliflora* in the assessment.

In South Africa *Terminalia sericea* Burch. Ex D.C and *Vachelia karoo* Hayne, have encroached to biomes claiming tens of millions of hectares thus affecting their structure and composition. Invasions by native woody species such as *Juniperus virgiana* L. (Juniper), *Prosopis glandulosa* Torr, (Mesquite) and *Larrea tridentata* (D.C) Cov. (Creosote bush) have claimed approximately 330 million hectares of non-forest lands in the USA. Further, *Quercus garryana* Dougl., and *Pseudotsuga menziesii* (Mirb.) in the Northwest of USA have converted prairies to woodlands thus changing their structure and composition. The altered competitive dominance of trees and grass negatively affects the Earth-atmosphere ecological interactions of savannas iconic biodiversity, wildlife populations and livestock grazers [6]. This has changed the composition of savannas constraining their global significance as they occupy a fifth of the earth's land surface.

Invasive plants introduced to East Africa have escaped cultivation and invaded protected areas, forest and mountain ecosystems reducing biodiversity leading to serious changes to the structure and composition of these ecosystems thus claiming livelihoods of millions of people dependent on these ecosystems for goods and services [2].

In Africa's arid and semi-arid rangelands, increases in undesirable or invasive are responsible for reductions of indigenous vegetation cover [23]. Invasive plants in Africa have claimed pasture land and in cultivated lands, some have persisted as weeds hindering agricultural productivity [32]. Their spread and establishment have greatly contributed to the reduction in grass productivity and species richness. This further has resulted on a decrease of forage availability and quality. Due to this, they are detrimental to wildlife dependent on savanna. However, the study has not expounded on the type of species affected by the invasive species.

Invasive species have chiefly threatened biodiversity in Mali, by suppressing indigenous and endemic plants from flourishing. They have been reported to overtake certain ecosystems leading to extinction of other species such as *Eichhornia crassipes* Mart., [33]. In Egypt, Amer et al. (2021), reported 10 plant species and 5 animal species as the worst invasive species which have had great negative impacts to ecosystems. Plants' genus in the list and found in Kenya include; *Biden pilosa* L., *Ipomoea carnea* Jacq., *Prosopis juliflora Swartz D.C* and *Solanum elaeagnifolium* Cav. but little information is available on these species in Kenya except for the *Prosopis juliflora*.

According to Obiri, a disaster looms in the entire dry forests and rangelands of East Africa as a result of the loss of biodiversity occasioned by invasive species. The disaster, has not been adequately reported despite of the decline and loss of the biodiversity. The invasion had ultimately led to societal disasters like emigrations from infested areas [1]. This justifies the need to free invasive species from environment to foster environmental sustainability and socio-economic development. Due to this, the study is justified on the objects of invasive species in the study area as concerns on frequent migrations have also been informally linked to the invasion of invasive species.

Though Kenya is endowed with diverse geographic regions, it is enormously impacted negatively by climate change. The resultant habitat diversity supports diverse number of plants and animals. Invasive species however, threatens this biodiversity [23]. The invasive plants lower grass production by eroding the capacity of grasslands to support grass thus decreasing food availability to grazers [2]. The study had not quantified the decline of grass production and the invasive species responsible for the decline.

In Kenya, invasive plants are a threat to wildlife more than poaching as they destroy ecosystems and harm wildlife. In particular, Parthenium weed distorts food chain and taints milk and flesh of grazers. In addition to this, Lantana specie causes mouth blisters among grazers yet it is unpalatable [2]. According to Muller et al., invasive species compete with indigenous species for light, nutrients, water and space. Their competition has led to the alteration of the ecosystem structure and disrupts ecosystem functions like energy, water, minerals and organics. This has changed the biotic interactions and ecological networks, distorting ecosystem services causing environmental degradation [33].

Prosopis juliflora aggravates drought and soil erosion by loosening the soil structure through its deep roots. The loosened soil structure becomes unable to sustain water. The plant has prolific growth, and forms thickets which encourages the breeding of mosquitoes that transmit malaria [17]. According to Maundu et al., *Prosopis juliflora* encroaches human-built infrastructure such as paths, dwellings, irrigation schemes, crop farms and pasture land. This has a significant impact on biological biodiversity and rural livelihoods. This was confirmed in three sites assessed which showed a significant plants diversity outside *Prosopis juliflora* thicket than within it. Further, it was evident that, in areas where *Prosopis juliflora* was well established, it was beyond the community's ability to control its expansion [24]. This is an ecological disaster and that no attempts have been

made to assess the impacts of *Prosopis juliflora* and *Vachelia reficiens* in the sub-county.

According to Linders et al., *Prosopis juliflora* has far reaching impacts when its cover is 40%. The tree cover directly causes losses in indigenous species richness [34]. This was supported by Mwangi and Swallows, who reported that in areas where *Prosopis juliflora* had established its population, no other plant could grow. This attribute had made it encroach on native vegetation [30]. According to Linders et al., while adopting the work of Cardinale et al. (2012), experiments have shown that diverse communities generally exhibits higher ecosystem functioning than less diverse ones. This suggests that, a loss of biodiversity will reduce ecosystem productivity and functioning as little biomass is produced [34].

Prosopis juliflora vibrantly invades areas of indigenous vegetation and manifests negative impacts on rural landscape as well as on human and livestock health. The invasion colonizes and degrades important grazing land, farmlands, and rangelands. It further blocks installed infrastructures and wildlife habitats. On overfeeding, it causes death of livestock. *Prosopis juliflora* is reported to have invaded critical wetlands in Kenya such as River Tana, Lorian swamp, and Lengurruahanga. Attempts to eradicate the plant in affected regions have been described as near impossible thus spelling an ecological disaster (MEWNR, 2013).

Modeled prediction of distribution of *Vachelia reficiens* and Opuntia species have shown the population of the two species to likely increase under future climatic patterns. Current extents are expected to triple by the year 2070. Opuntia specie has spread very fast and became a naturalized invasives in ASAL areas of northern Kenya. Its invasion has constrained rural livelihoods and ecosystem functioning. Their future rates of expansion is projected to reduce suitable habitats within conservancies over different climatic scenarios. Their seeds are dispersed by animals mainly elephants and water thus explaining the common distribution of their population mostly along the streams and river banks where the water table is high [23].

According to Kimiti et al., Vachelia *reficiens* in Samburu County has been acknowledged to suppress natural regeneration of vegetation including grass believed by Samburu pastoralist community as of high value to livestock production and livelihoods. Further, areas encroached by *Vachelia reficiens* have been reported to generally lack herbaceous understory and bare grounds are prevalent. In addition to this, the spread of *Vachelia reficiens* in the ecosystem was found to reduce both habitat for endangered wildlife species like the Grevy's zebra as well as available forage for pastoral communities [32]. The study restricted the impacts of *Vachelia reficiens* to one endangered wildlife species rather than wildlife in general and other endangered wildlife.

Nesoba (2018, unpublished), noted that *Vachelia reficiens* is a specie that is indigenous to South Africa and has colonized former grasslands in parts of northern Kenya causing widespread destructions to pastoralists. The species is spreading fast suppressing other plants as it releases a chemical that displaces other species. This had compounded land degradation in the rangelands. The degradation had greatly disrupted ecosystems by changing their structure and composition in northern Kenya.

In northern Kenya, assessed sites cleared of *Vachelia reficiens* (*Acacia reficiens*) and reseeded with *Cenchrus ciliaris* showed increases of more than 25% in overall ground cover, 34% in perennial grass cover, and 60% in standing herbaceous biomass [32]. This implied the negative impacts of the species in colonized sites on plant species richness. However, the study did not put efforts in identifying the specific plant species and the experiment targeted two conservancies as opposed to the entire sub- county which is the focus of this study. Further, the study excluded *Prosopis juliflora* which has been considered a vibrant invader of the northern rangelands.

2.3. Theoretical Framework of Biological Invasions

A number of explanations have been advanced to explicate invasion success of species in particular ecosystems at the global scale [25]. The study has borrowed from the following hypotheses or models fronted as to why species become invasive in the ecosystems around the world are;

2.3.1. Energy Release Hypothesis (ERH)

Introduced Plant species in an alien environment encounters a decrease of natural enemies which results to an increase of their population and distribution [25, 35]. The study has attempted to establish the presence of the plants' natural enemies in the study area through direct observation, open-and-close ended questions posed to Respondents in an explanation to the spread of the two plant species in the sub-county.

2.3.2. Novel Phytochemistry

The hypothesis relies on invasive plants possessing novel biochemical for their defense. Concerns raised on undergrowth suppression by the two species have been explored through the study to explain the spread and establishments of the two species as perceived by the Respondents.

2.3.3. Increased Resource Availability

The hypothesis suggests that availability of plants' resources for growth increases the invasions [25]. The study has employed open-and-closed-ended questions on sites mainly colonized by the two species to explicate the possibility of the species colonizing specific sites on availability of soil moisture and nutrients in explanation of the relevance of the theory on species prevalence and spread.

2.3.4. The Role of Disturbance

Gichua et al., while adopting the work of (Hobbs and Huenneke 1992; Davis et al*.,* 2002) qualifies intensity of disturbance to change plant community vulnerability to invasions [25]. The species are reported to colonize overgrazed areas and accelerate soil erosion. The study has attempted to link the role of disturbance and the spread of the

species through closed -and-open ended questions in the sub-county.

2.4. Conceptual Flow Chart of Biological Invasions of Invasive Species

Biological invasions processes are unique and comprises; introductions of invasive species, their establishments and naturalization, subsequent dispersal to the damage they cause.

Stressors are non-native species which once they find a pathway in the absence of prevention gets transported outside their natural range, upon transportation their populations are established if not detected early during their transportation to control and slow the spread, further spread through dispersal in the absence of control measures to slow the spread exposes them to the new environment, then the receptors of the negative impacts are native species, human beings and the environment. Their negative socio-economic and environmental consequences of the invasions will trigger responses in terms of human adaptation or restoration measures to mitigate or avoid the negative impacts of invasive species.

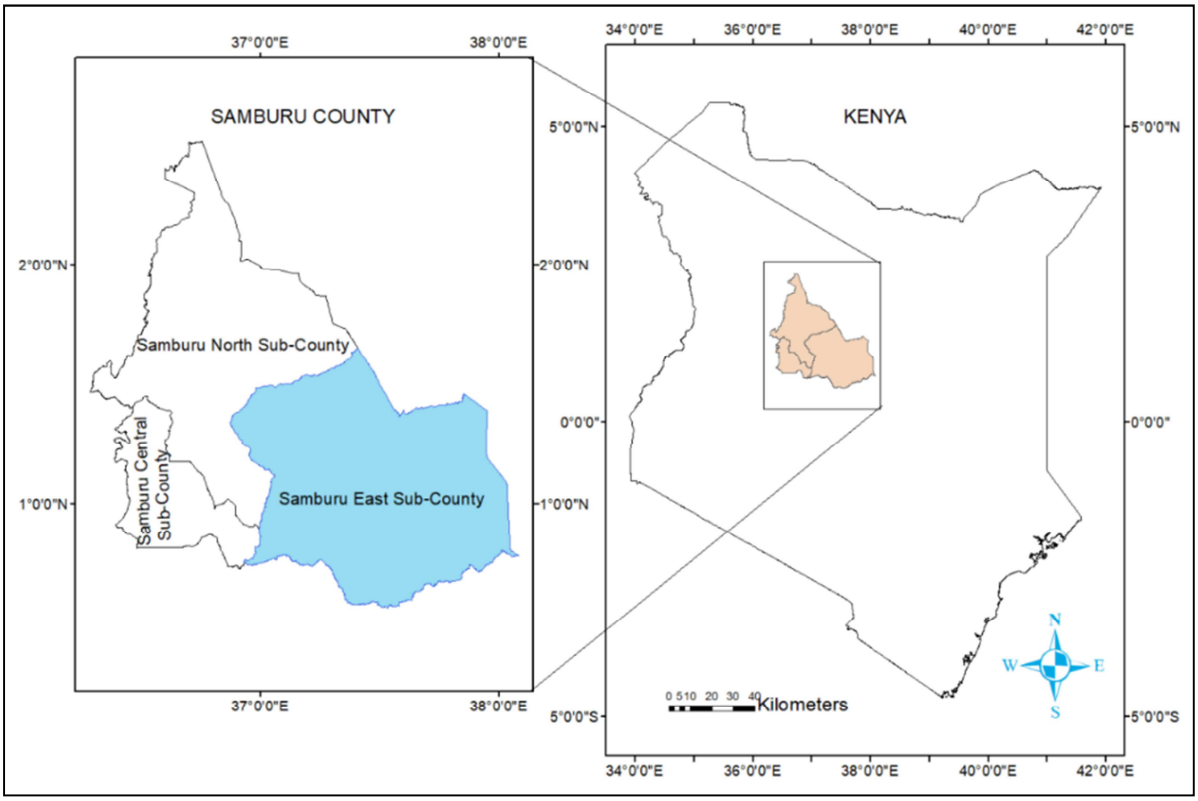
2.5. The Conceptual Framework of the Study

The stronger the independent variable (population of invasive) because of the absence, weak or non-effective intervention measure (intervening variable) the more the impacts of invasive species and the greater the severity or magnitude of their impacts (dependent variable) hence reduced environmental quality and unsustainable livelihoods. This impacts will further depend on effectiveness of a method of intervention (Independent variable) and exposure time (Independent variable) on invasive species on reduction of their population. Presence, effective and timely interventions of the invasive species to weaken their strength will reverse the population of the invasive species and therefore, reduce their impacts and their severity over space and time. This will lead to increased flow of ecosystem goods and services due to improved environmental quality. This on the other hand will benefit the resident community dependent on the environment leading to improved livelihoods.

3. Materials and Methods

3.1. Study Area

The study was conducted in the administrative units of Samburu East Sub-County. It is located in the eastern parts of Samburu County and is among the three Sub Counties in Samburu County (Figure 1). It has 3 Divisions, 12 Locations, 29 Sub Locations, 181 Villages and 17,307 House Holds. The Sub-County is entirely a rangeland and covers an approximate area of 10,049.7 Km^2 with a population of 77,994 people and an average density of Eight (8) persons per km^2. It is dominantly inhabited by the Samburu nomadic pastoral community and the main economic mainstay is livestock production (KPHC, 2019).



Source: County Government of Samburu CIDP (2018)

Figure 1. *Map showing location of Samburu East Sub County.*

It lies between Latitudes 00^0 33' N and 01^0 38'N and Longitudes 36^0 55' E and 38^0 03' E. Generally, the average elevation of the Sub-County is 900 to 2500 m.a.s.l, with few hills, one forest ecosystem, one national game reserve and a number of community wildlife conservancies. The Sub-County is characterized by arid and semi-arid climate with mean rainfall of 354mm. The days are extremely hot while the nights are cool with mean temperatures ranging between 18°C and 30°C (County Government of Samburu CIDP, 2018).

The sub-county lies in ecological zone V-VI. With the exception of forest, hills and riparian ecosystems, the soil moisture availability is low to very low. The soils are weakly developed, mostly sandy and low in organic matter and are saline and sodic in some parts of the sub county. The vegetation is tropical Savanna with varying proportions of open grassland and perennial herbaceous and woody vegetation (Samburu DEAP, 2012).

The sub-county hosts a number of wildlife species of global conservation concern and critically endangered species under CITES. Main environmental issues in the Sub-County are human-wildlife conflicts, land degradation mainly soil erosion, habitat loss, invasive plant species, drought and water scarcity. Generally, the Sub-County is under immense land degradation and is vulnerable to climate change and invasion by invasive species (Samburu DEAP, 2012).

3.2. Study Design

Sequential explanatory mixed-method study design was used in conducting this study. This involved collection of quantitative and qualitative data from household heads within the Ultimate Sampling Units, Key Informants and Focus Group Discussions using structured research instruments. Probability and non-probability sampling methods were employed to capture data from the three categories of respondents within the sampling frame of the sub-county.

3.2.1. Research Instruments

The data collection instruments were developed and structured from extensive literature reviews on adequate background information and information from Key Informants. This was subjected to experts' opinion on their alignment to the study design, sampling design and suitability to capture data accurately and precisely for the study variables.

Household questionnaires and Key Informants Guides were designed and structured to capture preliminary information of the administrative units respondents lived in, their contacts and dates of the interviews, respondents' bio data, socio-economic characteristics of households, environmental characteristics of the sub-locations, knowledge of invasive species, socio-economic impacts of the two species, on-going interventions and recommendations on their management. Questionnaires contained closed-and-open ended, dichotomous yes-and-no questions some with Likert scale ordinal scaled questions with confirmatory or explanatory questions to precisely obtain quality data for the study. Interview guide for the Key Informants was structured to capture similar information as that of household head questionnaires but Likert scale questions were not to be rated but prioritized from a checklist.

Focus Group Discussions guides were structured to have open-ended-essay type questions for discussions on socio-economic activities of residents and environmental characteristics of the sub-location, Discussants knowledge of and interactions with invasive species, impacts of the two species of focus, history of management interventions and recommendations in the sub-location.

3.2.2. Pre-testing of Questionnaires

Three questionnaires were piloted and pre-tested outside the study area before they were subjected to validity and reliability measurements. To ensure quality of the data to be collected, Matters and Errors arising during pre-testing of questionnaires were identified and rectified appropriately and factored in questionnaires before subjecting to validity and reliability measures.

3.2.3. Validity of Questionnaires

The study used the Kaiser-Meyer-Olkin Measure of Sampling Adequacy computed from SPSS version 26 to assess whether the questionnaire had validity or not. The factor loading was computed as 0.847 which was seen to be above the threshold of 0.4, hence the questionnaires were considered valid for use in data collection.

3.2.4. Reliability of the Questionnaires

The Cronbach alpha reliability for measuring internal consistency was computed using SPSS version 26. In this study all the three questionnaires for the pilot were coded into the SPSS and using the internal consistency option the reliability for the entire questionnaire statements was computed. The results showed a reliability coefficient of 0.891 for the 33 items indicating that the questionnaire was reliable and hence appropriate for collecting the required data.

3.3. Target Population

The study captured information from 138 household heads sampled from Samburu East Sub-County total number of households heads (17,703) for the households interview, 3 purposefully Selected Focus Group Discussions (FGD), one each representing a division and 10 Key Informants (KI). Household Heads, FGD and KI were targeted because they were considered to have interacted with the species and are decision makers in the society.

3.4. Sampling Method and Procedure

Sampling size for the household heads was determined using Kalton (2009) formula and multistage clustered random sampling was used to obtain Ultimate Sampling Units. Systematic sampling was then used to get to the

desired household heads at a fixed rate. Purposive sampling was used to get qualitative data from the Key Informants and Focus Group Discussants using structured guides.

3.4.1. Determination of Sampling Size and Sample Description

Formula by Kalton (2009) was used to determine the study sample size with a confidence interval of 95%. *Vachelia reficiens* and *Prosopis juliflora* have existed in the Sub-County for a minimum of 43 years and 33 years respectively. Due to their spread and establishment in the Sub-County, concerns of the spread has been a community concern and some efforts have been locally directed to mitigate their impacts. Due to this long existent, concerns and efforts in place to control, the study assumed that all the respondents were aware and knowledgeable on the species invasiveness. Further the resident community predominantly practices nomadic pastoralism and is dominantly of Samburu ethnicity. Due to these community's substantial interactions with the plant and homogeneity aspects, the study assumed a minimum variability of 10% as suggested by (Kalton, 2009). Therefore, using the above formula the sample size was;

$$ME = z\sqrt{\frac{p(1-p)}{n}}$$

$$n = \frac{p(1-p)z^2}{ME^2}$$

Where:

ME is the desired margin of error (95%) CI, α = 0.05, z is the desired z-score (1.96 for a 95% CI) yielding the desired degree of confidence, p is an estimate of the population proportion and n is the sample size.

$$n = \frac{0.1(1-0.1)1.96^2}{0.025} = 138.29 = 138$$

3.4.2. Sampling Design, Procedure and Frame

The sample size determination was based on probability proportional to estimated size (PPES) of the target population of the household heads. The Sub-County is vast and the population where the samples were obtained is geographically spread thus Multistage sampling technique was employed to divide the population into smaller groups to simplify data collection exercise. This allowed the study to secure probability sample without complete sampling frame. Multistage clustered random sampling was used to determine the sample design frame at each stage of sampling, by clustering the locations and sub-locations and randomly selecting 50% of the administrative units at each stage. Households' Heads in each of the Ultimate Sampling Units interviewed to get data for the study as per sample allocated per Ultimate Sampling Units, were systematically selected at a fixed rate, whereby every 11th Household Head was included.

Three Focus Group Discussions using structured discussant guide were done after interviewing the selected households by randomly selecting three sub-locations, one each from the locational Ultimate Sampling Units for the discussions. This was to ensure that each of the administrative divisions are represented in the Focus Group Discussions.

10 Key Informants were drawn from relevant government agencies, NGOs, CBOs and senior citizens who are members of County Environment Committee dealing with environmental management in the Sub-County and having various special information, experience or vast knowledge on the management of invasive species were purposefully selected and interviewed one month before the household heads interviews. Snowballing sampling was used to capture information from Respondents made reference to, by a Key Informant for special information about the invasive plant species.

3.4.3. Reconnaissance Survey

Adequate reconnaissance surveys and site inspections prior to data collection exercise with the assistance of sub locations' administrative officers and village elders additionally preceded data collection exercise. This was in order to get acquainted with the residents, geography of the area and settlement patterns of the resident community. This further aided the identification and training of Research Assistants and Enumerators for the study and securing cooperation with the sub locations' leadership and populace. This opportunity was also used to identify and assess settlement patterns of the households for listing and alignment with the sampling design of the study.

3.4.4. Data Collection Methods

An interview schedule was developed before data collection commenced. This was important to make sure that data collection was consistent and covered target population for the study. Face-to-face method of interview was employed to capture data from the three categories of respondents. Capturing of responses entailed pencil-and-paper recording.

3.5. Data Processing, Presentation and Analysis

Descriptive and inferential statistics was used to present and analyze the collected data respectively. Data from the respondents was coded, entered in excel sheets and piloted to ensure that coding was appropriate. The data on the excel sheet was fed into SPSS version 26 and validated using logical checks. Qualitative data from the interviews was coded and indexed through intensive content analysis in order to identify major themes and dominant narratives. Quantitative data was analyzed using frequencies and percentages. Summary statistics were exported to excel worksheets to produce graphical figures and tables for interpretation. Inferential analysis were computed to test whether the impacts were statistically significant or not, this was tested using the 5% significant level. Cross tabulations was done to test the Pearson's Chi Square test which assisted to determine whether there was an association between the variables; socio-economic and environmental impacts and spatio-temporal variations of impacts.

3.6. Research Output, Dissemination and Utilization of Findings

The outcome of the study will be disseminated as published information in referred journals and publications for utilization to; Maasai Mara University, the sponsoring entity, government agencies, scholars, policy makers, researchers, rangelands actors, natural resource managers and County Government of Samburu for consideration in sustainable management of invasive plant species in the Sub-County and by extension the county.

4. Results and Discussions

Data was obtained from all the 138 households and subjected to descriptive and inferential analysis. The response rate was 100% and was suitable for data analysis.

4.1. Socio-Economic Characteristics of the Respondents

On gender, 54% of the respondents were male adults and 46% were female adults, with 80% aged more than 30 years. 69% of the respondents had not attained formal education. The marital status of the respondents were that, 85% were married and 15% were either single, widowed or divorced. The various hierarchies of the households were; 56% were household heads while 44% were representatives of the household heads who were not present during the interview time. The main economic mainstay of households was livestock production at 98.6%. This was attributed to the pastoral nature of the people and nature of the climatic patterns in the area.

4.1.1. Years lived in the Area

80% of the respondents had lived in their respective sub-locations for more than 20 years and the remainder 20% lived for 10 to 20 years. This implied that majority of the respondents have been in the area for more than 20 years and hence they were considered to understand and better interpret the environmental characteristics and changes and their effect on the various aspects of the populace in the area.

4.1.2. Major Threats Affecting the Households

The main threats affecting the economic activities of the households in Samburu East Sub-County according to the respondents were drought, livestock diseases and invasive plants. Environmental threats were erosion, invasive plant species and drought. This was also confirmed by Key Informants and Focus Group discussions.

4.1.3. Nature of the Invasive Plants in the Sub-County and Years of Invasiveness

Responses from household heads, Key Informants and Focus Group discussions identified a total of 19 invasive plants in addition to *Vachelia reficiens* and *Prosopis juliflora.* Key of these were exotic species-*Opuntia exaltata* and *Opuntia ficus indica* and three were, *Sansevieria intermedia*, *Cissus rotundifolia* and *Justicia striata* which are indigenous. They were reported to negatively impact on the environment of the sub-county. Though *Vachelia reficiens* was an indigenous species, the respondent indicated the plant is a problematic invader and its origin was Isiolo County. On the other hand *Prosopis juliflora* was confirmed as an exotic plant whose impacts were perceived to have grown in magnitude despite of its recent introduction dating back to 1980s compared with *Vachelia reficiens* whose existence history dates back to 1960s. The respondents singled out the proliferation of the reported invasive plant to have begun in 1997 during *El Nino* time. On presence of invasive plants in Kenya, their perception agreed with the findings [17, 25-26]. On climate change aiding the spread of invasive plant species, their perceptions agreed with the findings [13].

4.2. Impacts of Vachelia reficiens and Prosopis juliflora on Selected Environmental Components

To determine the impacts of *Vachelia reficiens* and *Prosopis juliflora* on selected components of the environment in Samburu East Sub-County, the study considered five environmental components to which the respondents in each sub-location were required to respond to by rating their perceived impacts on a five-point Likert scale of 0-5, where 0 indicate no impact and 5 indicate severe impacts. The data was summarized using Microsoft excel. The mean values were computed by taking the sum of the product of the actual response on each value of the scale and dividing by the number of respondents. Frequencies of the responses per impacts magnitude were converted into percentages and mean impact values obtained for analysis.

4.2.1. Environmental Impacts of Vachelia Reficiens

The results indicated that the impact of *Vachelia reficiens* on environmental components was major in general but severe on natural regeneration. Comparison of the means indicated that *Vachelia reficiens* has had severe impacts on natural regeneration, major impacts on grasslands and moderate impacts on water availability, wildlife and land productivity. On average *Vachelia reficiens* had major impacts on environmental components in Samburu East Sub-County.

On environmental components 100% of the respondents indicated that it had impacts on all components of the environment focused by the study. Mean impacts for the components were at 3.72 which corresponded with major impacts in the Likert scale. This did agree with the findings that the species is harmful to the environment as reported by the research [1, 12].

The study further sought to establish knowledge of the households on the plants that have been impacted by the species. The results showed that the plants that had been displaced to near or local extinction within the expansion range of *Vachelia reficiens* were; 9 grass species especially *Chrysopogon plumulosus* and *Digitaria velutina*, 15 species of shrubs and trees mainly *Vachelia tortilis* and *Senegalia melifera*. Other shrubs affected were in the genera Cordia and Grewia. This shows that the invasive plant has had a great impact on the trees, shrubs and grasses thus biodiversity loss

which have been considered to be near extinction within its expansion rate in the sub-county. This had a direct impact on ecosystem structure and functions thus reduced flow of goods and services from the displaced plants. The views on invasive species leading to ecological change in areas they infest by causing species extinction, coordinates with the findings [2, 10, 12, 16, 23, 32].

On wild life that have been displaced in the sub-county by the invasive plants. the results showed that the most affected animal species were the zebra, Thompson gazelles and Buffaloes among others. This were mainly herbivores. This showed that the invasive plants have had an impact on the animal species too as they have affected the food chain by displacing grass and forage plants which are their main food. The invasive plants thickets have also interfered with free movement of wildlife making it easier for the predators to capture them. This has led to wildlife imbalance as predators were more than herbivores. Impacts of invasive species on food chain and ecosystem structure and functions echoed the works [32, 34].

4.2.2. Environmental Impacts of Prosopis juliflora

The impacts of *Prosopis juliflora* on the environmental components in the sub-locations was also determined. The results indicated that the impacts of *Prosopis juliflora* on environmental components was moderate in general and affected mostly natural regeneration. On comparison of the means, *Prosopis juliflora* had moderate impacts on natural regeneration and water availability while minor impacts on wildlife, land productivity and grasslands. On average it scored moderate impacts on environmental components.

On environmental components only, 85% of the respondents indicated that it had impacts on all components of the environment investigated by the study. Mean impacts for the components were at 2.5 which corresponded with moderate impacts in the Likert scale.

The study further sought to establish knowledge of the households on the plants that have been impacted by the species. The results showed that the plants that had been displaced to near or local extinction within the expansion range of *Prosopis juliflora* were; 5 trees and shrubs mainly *Vachelia tortilis, Salvadora persica, Cordia sinensis* and *Senegalia melifera* being riparian vegetation, 5 grasses species mainly *Chrysopogon plumulosus* and Kaleis species and forage plant *Commelina Africana*. This shows that the invasive plant had a great impact on the trees, shrubs, forage plants and grasses mainly in riparian environments which have been considered to be near or extinct locally in the sub-county. Views on impacts of Prosopis juliflora causing loss of biodiversity thus leading to ecological change, agreed with the works [1, 28, 30].

On wild life that have been displaced in the sub-county in areas of its expansion range by the invasive plants, the results showed that the most affected animal species were waterbucks, warthogs and impala among others. Most of the affected wildlife are dependent on riparian resources. This is because the plant has displaced dry season grazing wetlands and saltlicks hence the impact on wildlife dependent on these resources. This shows that the invasive plants have had an impact on the animal species too as they have affected the food chain and displaced the plants which are their main food. This findings further agreed with the findings [32, 34]. The invasive plants thickets have also interfered with free movement of wildlife making it easier for the predators to capture them.

4.3. Paired t Test of Species Impacts on Environmental Components

Mean difference between the impacts of *Vachelia reficiens* and *Prosopis juliflora* on various environmental components in the study area were analyzed to determine their significance level. Further analysis was done using the paired *t* test where the mean, standard deviation, *t* - statistic and the *p* value were used to test whether the difference was significant or not. The results are presented in Table 1.

Table 1. *Paired t Tests of Species Impact on Environmental Components.*

		Paired Means	Paired Differences			t	df	Sig. (2-tailed)
			Mean	Std. Deviation	Std. Error Mean			
Pair 1	Impacts of *Vachelia reficiens* & *Prosopis juliflora* on water availability	3.12 2.58	.541	1.247	.113	4.790	121	.000
Pair 2	Impacts of *Vachelia reficiens* & *Prosopis juliflora* on wildlife	3.43 2.29	1.139	1.249	.113	10.079	121	.000
Pair 3	Impacts of *Vachelia reficiens* & *Prosopis juliflora* on land productivity	3.43 2.40	1.033	1.414	.128	8.069	121	.000
Pair 4	Impacts of *Vachelia reficiens* & *Prosopis juliflora* on grasslands	4.16 2.20	1.959	1.534	.139	14.104	121	.000
Pair 5	Impacts of *Vachelia reficiens* & *Prosopis juliflora* natural regeneration	4.47 2.92	1.549	1.337	.121	12.801	121	.000

The results in Table 1, shows that the mean difference between the impacts of *Vachelia reficiens* and that of *Prosopis juliflora* were statistically significant in all the environmental components. The results showed that the impact is statistically significant as all the environmental components have shown a *p* value less than 0.05. Further, the t-statistics on each component showed that the impacts were statistically significant in all the environmental components as shown by the *p* value of less than 0.05.

The results indicated that *Vachelia reficiens* had a higher impact on environmental components than *Prosopis juliflora* with both species negatively affecting natural regeneration

mainly compared to other components. This was more evident given that natural recruitments of affected species was absent-seedlings, saplings. A similar view was held by the participants in the focus group and the key informants who indicated that the nature and density of invasive plants dictated how they impacted on the environment. *Vachelia reficiens was* wide spread in all the three divisions and because of the duration it has been in existence for a much longer time than *Prosopis juliflora* thus the impacts.

4.4. Qualitative Analysis of the Species Impact on the Environment

Focus Group Discussions were conducted with 3 different groups and 10 Key Informants interviews. The respondents were in agreement with household heads views on the impact of the two species on the environmental components of the Sub-County. The respondents were required to respond to various questions by giving their perception on the impact of the two species on the various environmental components.

On water availability and quality in the area, the respondents indicated that the species do cause drying of water points contributing to water shortages. The plants were perceived to take up the little available water through their deep and fibrous rooting systems hence depleting water available in the area. *Prosopis juliflora* species which grows mainly along the roads and the rivers and any other water point has the characteristic of using up all the available water and leaving the place very dry. In terms of water quality, the respondents indicated that there has been an increase in the level of siltation of dams and water pans due to massive erosion as they deplete the area of vegetation cover and induce formation of gully erosion. Deep and fibrous root of the invasive plants tends to deplete underground water due to deep rooting system. This also makes it very difficult to eradicate these plants because of their deep rooting system. The leave litter of these plants are acidic hence interferes with the water quality. Respondents' views on water scarcity caused by the plants agrees with the findings [16].

The respondents also indicated that the proliferation of these plant species in the area had led to wildlife imbalance as a result of distorted food chain. This implies that the plants have made it difficult for the ecosystem components to effectively interact and function. There is no balance in the ecosystem as some of the animals have had to migrate leaving the area with a distorted food chain. The distortion of the ecosystem has increased the level of human-wildlife conflicts. This has resulted from the encroachment of the species which have reduced wildlife balance causing presence of more predators and migration of herbivores. At the same time the species have affected the grass land by rendering the range-lands unproductive of the most palatable fodder and grass for the herbivores. This indicated distorted food chain. The species do not offer any food solution to the wildlife, in fact most of the respondents said that the plants cause more harm to the animals as they act as hiding places for the predators, they harbour pests and insects which transmit diseases to the animals. This findings on species impacting negatively on wildlife and their habitats agrees with the observation [32].

In regard to the local displacement/extinctions of flora and fauna, the summary made from the respondents indicated that the species have a tendency to displace useful grass, forage, shrubs and trees important in the food chain in provision of ecosystem services and goods. This had led to total emigration of wildlife hence local extinction. According to the respondents the species in question have a major impact on the ecosystem and there is need to really find a solution on the problem. The fear of many is that as the species tend to thrive in the dry areas and they displace the fodder and other grassland plants that are suitable for animal consumption, there is a likelihood of the species taking over the entire area and this will mean the livelihood of most household will be at stake and may lead to total emigration of people to other areas. This will also lead to more livestock predation. On loss of biodiversity their views are in tandem with those authors [10, 12, 16]. On species constraining economic activities, respondents' perception agrees with the findings [31].

One of the respondents indicated that areas infested by V*achelia reficiens* are generally warmer than non-infested areas. This makes the areas with larger cover of the species warmer than the rest of the areas. The reason behind this could be attributed to the poor ground cover as the plant suppresses other plants which makes the soil bare as to absorb the heat thus making the place warmer. The bare ground also increases the chances of having an erosion and this leads to the large gullies and also the soil surface is hardened suppressing the undergrowth of the other vegetation. This explains the reasons why areas with large cover of *Vachelia reficiens* have bare ground and have massive gullying due to soil erosion. This coordinates with the findings on *Prosopis juliflora* making soils vulnerable to erosion [17].

Prosopis juliflora species which has been found to mainly grow along the roads and around water catchment areas has led to increased loss of wetland ecosystems by blocking and choking glades. This led to displacement of key species like kaleis species. The species' deep and fibrous roots increases water uptake therefore depleting water in the area. This is similar to the works in South Africa [16]. The respondents indicated that the introduction of the species has made their livelihood more difficult as the species have made the areas more bare, water scarce, increased human wildlife conflicts. Their thickets have increased predation by harbouring predators. Affected households have lost the entire herds of camels and donkey rendering them poor as a result of livestock predation by lions mainly. By so doing the species cause poverty as reported [17]. It also causes economic stability as reported [31].

4.5. Chi Square Test of Association (χ^2) for Environmental Components

The chi square test statistic between environmental components and the prevalence of the invasive species was computed. The results presented in the Table 2, shows that

there is a strong statistical association between the impacts of *Vachelia reficiens* and *Prosopis juliflora* on the environmental components in the study area as shown by (χ^2 = 402.566) and (a p value < 0.05). The results shows that the null hypothesis; HO_1: *there are no significant impacts of Vachelia reficiens and Prosopis juliflora on the environmental of Samburu East Sub-County* is rejected and the alternative hypothesis accepted that there is a significant impact between the two species on the environmental components in the study area.

Table 2. *Chi-Square Test of Association for Species Impacts on Environmental Components.*

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	402.566[a]	273	.000
Likelihood Ratio	216.846	273	.995
Linear-by-Linear Association	10.057	1	.002
N of Valid Cases	122		

5. Conclusion and Recommendations

5.1. Conclusion

Based on the findings of the study it is concluded that *Vachelia reficiens and Prosopis juliflora* have significant negative impacts on environmental components in the study area. Respondents were categorical on *Vachelia reficiens* and *Prosopis juliflora* and portends that the plants are disastrous and offer no meaningful benefits so far to the environment and socio-economic wellbeing of the resident community. This is true as the population of the species continue to increase and expand to new areas coupled with the presence of 19 more invasive species in the Sub-County. However, *Vachelia reficiens* an indigenous plant negatively impacted more than *Prosopis juliflora* which is an introduced plant.

Environment is the basis of socio-economic development and it is one of the pillars of sustainable development, the two species therefore constrains the attainment of sustainable development and the attainment of vision 2050 on biodiversity values as advanced by the authors [10, 11]. This calls for a comprehensive management intervention process to try and bring their spread into control in order to safeguard biodiversity, livelihoods and guarantee environmental sustainability.

5.2. Recommendations

The respondents advanced the following recommendations as possible solutions to mitigate the impacts of the two species and other invasive plants in the sub-county;

1) The Government of Kenya should consider and declare *Vachelia reficiens* as a harmful native invasive plant and enroll the plant in the inventory and register of invasive plants in Kenya for incorporation in the Global Invasive Species Programme;
2) Capacity building of communities by County Government of Samburu and development partners currently engaged on voluntary eradication and management of invasive plants including *Vachelia reficiens* and *Prosopis juliflora* to fasten the control of invasive species and prevent their further spread and establishment. This will further enhance the uptake by communities of a government-community led eradication programmes once formulated and operationalized by the County Government;
3) Deliberate attempts for instance formation of bylaws or enforcement of resolutions should be made by County Government of Samburu to encourage the utilization of *Vachelia reficiens* and *Prosopis juliflora* to reduce their population and the accompanying negative impacts on environmental systems;
4) County Government of Samburu should spearhead the formulation and operationalization of a government-community led sustainable eradication Programme for *Vachelia reficiens* and *Prosopis juliflora* in the county to begin with;
5) County Government of Samburu should formulate a stand-alone policy on invasive plant species to mitigate climate change and enhance environmental sustainability as the impacts of invasive plants have been reported to worsen with climate variability.

5.3. Areas for Further Study

Research on factors responsible for the expansion of the two species is recommended to rest their spread and establishment.

Research on cost-effective method of progressive and sustainable eradication of *Vachelia reficiens* and *Prosopis juliflora* and rehabilitation of areas freed of invasive plants to spur environmental sustainability.

Impact of climate change and variability on proliferation and distribution of invasive plants including *Vachelia reficiens* and *Prosopis juliflora* species in the county.

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