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Potential Impacts of Climate Change on Wildlife Protected Areas; A Case Study of Maasai Mara National Game Reserve, Kenya

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Abstract

Unpredictable temperature and precipitation patterns brought on by climate change are becoming more widely acknowledged as one of the major variables influencing wildlife populations in protected areas like parks and reserves. The wildlife populations that sustain the thriving tourism business may decline as a result of these temperature and rainfall variations brought on by extreme flooding and drought occurrences. Protected areas form the bedrock of the tourism industry in Kenya, keeping in mind the tourism industry is characterized as heavily 'nature-based in Kenya'. Based on chaos-complexity theory, this study investigated the effects of rainfall and temperature variations on wildlife population dynamics in Maasai Mara National Game Reserve (MMNGR). MMNGR is a top premier wildlife park in Kenya, recording major visits. The study adopted an explanatory research design. Rainfall and temperature data was obtained from 15 rain gauges located in MMNGR operated by World Wide Fund (WWF) and Friends for Conservation. Wildlife population data was collected from the Directorate of Resource Surveys and Remote Sensing (DRSRS). Changes in vegetation cover were determined from satellite imagery using the normalized difference vegetation index (NDVI) method. This method was used to measure changes in vegetation cover that are likely to have been influenced by rainfall and temperature trends. The NDVI images from the years 1975 to 2018 were processed to obtain specific NDVI values per land cover category. NDVI values detected any changes in vegetation cover. The mean monthly rainfall and air temperature in Maasai National Game Reserve for the last 54 years were analyzed. Time series was applied to analyze rainfall and temperature data. Findings indicate that rainfall and temperature variations positively contribute to influencing the decline in wildlife populations, as there could be other factors too. The study findings suggest that high amounts of vegetation cover, as indicated by NDVI maps, prompt high survival rates for wildlife and increased populations and vice versa. This study therefore proposes that extremely high and low rainfall totals and temperature trends are likely to increase *wildlife mortality, hence reducing wildlife survival rates and consequently population. The implications will have a direct influence on the tourism industry as visitors are highly likely to shift their visits to other tourism destinations with abundant wildlife populations.*

Keywords: Reserves, Wildlife Tourism, Vegetation, Climate Change

INTRODUCTION

Trends in Temperature and Precipitation in Kenya's Maasai Mara National Game Reserve (MMNGR)

Climate change continues to exacerbate environmental instability in Kenya, leading to an increase in extreme weather events such as frequent storms, heavy rainfall, floods, and extended droughts. Coastal regions, in particular, are increasingly degraded, contributing to biodiversity loss and reduced habitat availability for both terrestrial and marine species (UNEP, 2023). The impacts of climate change on Kenya’s ecosystems are also evident in the destabilization of key habitats, particularly in coastal and arid areas, where the shifting climate undermines both natural and socio-economic systems (Ogallo *et al.,* 2022).

Moreover, climate-induced droughts are becoming longer and more severe, which affects agricultural productivity and water availability, leading to food security concerns and displacement of vulnerable populations, including wildlife populations (IPCC, 2023). Recent projections suggest that by 2050, Kenya’s biodiversity could face substantial losses as ecosystems transition from forested landscapes to savanna or drylands (KWS, 2023). The Intergovernmental Panel on Climate Change (IPCC) has consistently affirmed that climate system change is unequivocal, and this is now evident from global measurements of rising surface air and ocean temperatures. The latest IPCC reports (2021, 2023) underscore that global temperatures have increased at an unprecedented rate over the past few decades, with the past five years being the hottest on record (IPCC, 2023). These temperature increases are not only observable in surface air but also extend to oceanic heat content, contributing significantly to rising sea levels and extreme weather events globally (IPCC, 2023). Tourism activities would certainly be affected by these weather changes.

Furthermore, according to climate models, if current emission trajectories continue, the Earth will probably surpass the 1.5°C warming threshold by the early 2030s (IPCC, 2023), increasing the frequency and severity of climate impacts such as more frequent heatwaves, wildfires, intense storms, and ecosystem disruptions (IPCC, 2021). Recent data also shows that ocean warming is particularly severe, with significant implications for marine biodiversity, fisheries, and coastal communities (IPCC, 2022).

According to the most recent IPCC reports global temperatures have risen at an unprecedented rate over the past few decades, with the last five years being the hottest on record (IPCC, 2023). The ongoing climate crisis is not only causing temperature increases, but it is also increasing the frequency and intensity of extreme events, such as flooding, droughts, and cyclones, which disproportionately affect vulnerable populations worldwide (IPCC, 2023). These temperature increases are not only observable in surface air but also extend to oceanic heat content, which is a major contributor to rising sea levels and extreme weather events worldwide (IPCC, 2023), which is likely to disrupt tourism.

Furthermore, if current emission trajectories continue, climate models predict that the Earth will likely surpass the 1.5°C warming threshold by the early 2030s (IPCC, 2023), which will increase the frequency and severity of climate impacts, such as more frequent heatwaves, wildfires, intense storms, and ecosystem disruptions (IPCC, 2021). The tourism industry must prepare mitigation strategies and emergency preparedness for such extreme weather events. The ongoing climate crisis is not only driving temperature increases but also increasing the frequency and intensity of extreme events, such as flooding, droughts, and cyclones, which disproportionately affect vulnerable populations around the world (IPCC, 2023).

Studies conducted between 2020 and 2025 have confirmed that despite predictions of wetter conditions due to climate change, many parts of East Africa are experiencing decreasing rainfall and increasing frequency of droughts (Conway *et al.,* 2021; Asefi-Najafabady *et al.,* 2023). Average annual temperatures in Kenya have continued to rise, with an increase of approximately 1.0°C between 1960 and 2003. Recent data shows that this warming trend has accelerated in the past two decades. Between 2000 and 2025, temperatures have increased further, contributing to heightened vulnerabilities across the country (Nyong et al., 2023).

Kenya has experienced both severe droughts and heavy floods each year, with the intensity and frequency of these extreme events rising steadily (Kiptum *et al.,* 2022). The frequency and severity of droughts in the region have been exacerbated by broader climate change patterns, with studies indicating a noticeable shift in rainfall variability in East Africa, including MMNGR, which is contributing to ecosystem stress and loss of biodiversity (Ogutu *et al.,* 2021). Moreover, the loss of habitat due to prolonged droughts has led to the displacement of wildlife, impacting the balance of local ecosystems and the tourism industry, which relies heavily on the region's biodiversity (Mungai *et al.,* 2023; Chepchumba *et al.*, 2024).

Kenya's Declining Wildlife Population and Implications for the Tourism Sector

With tourism, conservation, and associated sectors playing a significant role in Kenya's economy, the wildlife sector now accounts for around 12% of Kenya's GDP (Kenya Wildlife Service, 2023). The country's rich biodiversity, national parks, and game reserves generate economic value that is increasingly recognized as a major driver of sustainable development (World Bank, 2024). However, in recent years rising temperatures, shifting rainfall patterns, and more frequent extreme weather events have started to significantly affect the timing and duration of animal migrations, as well as their breeding cycles (Ogutu *et al.,* 2023). Aduma *et al.* (2018) previously suggested that global land surface warming would drive more drastic shifts in vegetation patterns, altering migration and reproductive behaviors of major herbivores. Recent studies continue to support the prediction that significant weather anomalies will become more frequent in the coming decades, with severe implications for ecosystems and wildlife.

These weather anomalies are made worse by the ongoing effects of climate change, which have disrupted the availability of food and water for herbivores like zebras, elephants, and wildebeests, especially in protected areas in East Africa (Mungai *et al.,* 2024). Additionally, vegetation shifts brought on by changing climate conditions are affecting the distribution of important species, changing migration routes, and increasing competition for resources (Juma *et al.,* 2023). Recent studies conducted between 2020 and 2025 have highlighted the continent's continuous biodiversity problem, with climate change playing a major role in these decreases (Ogutu *et al.,* 2023).

Ogutu *et al.* (2023) state that many species, especially in Africa and Asia, are experiencing continuous population declines that result in localized extinctions and changes in species distribution due to habitat loss, poaching, and changing climatic conditions; these declines are especially concerning in areas such as East Africa, where wildlife populations like elephants, rhinos, and various herbivores are experiencing significant reductions in both numbers and range; a combination of increased human-wildlife conflict, changing ecosystems due to shifting rainfall patterns, and severe droughts has created population imbalances that are hard to reverse (Mungai *et al.,* 2024); and the growing frequency of extreme weather events, such as heatwaves, floods, and droughts, has increased the pressures on wildlife populations, making them more susceptible to extinction (IPCC, 2023).

The loss of key species in MMNGR is also associated with disturbances in migration patterns, which are becoming more unpredictable due to the shifts in rainfall timing and intensity and a reduction in available food and water resources during dry seasons (Ogutu *et al.,* 2023). Mungai *et al.* (2024) reports that populations of iconic species, including wildebeest, zebras, and elephants, have experienced notable reductions in both numbers and distribution due to increasingly frequent droughts, changes in rainfall patterns, and changes in land use brought on by agricultural expansion and tourism pressures.

Research by Ogutu *et al.* (2023) highlights that populations of key species in MMNGR, including buffalo and giraffe, have continued to decline. Buffalo populations have decreased by an additional 12% since 2000, while giraffes have seen a 15% further decline over the same period. The decline in populations of warthogs, topis, and gazelles has also persisted, largely due to more frequent droughts, shifting rainfall patterns, and increasing land use pressures (Mungai *et al.,* 2024). The altered climatic conditions, including prolonged dry periods and irregular rainfall, have disrupted the availability of food and water for many species, exacerbating existing pressures on wildlife (UNEP, 2023). In comparison, according to Ogutu *et al.* (2023), resident wildebeest populations in Maasai Mara have continued to decrease, with a further 10% reduction recorded between 2000 and 2020. Climate change, habitat loss, and human-wildlife conflict have been identified as major contributors to this decline.

The availability of forage and water, which are essential for wildebeest survival, especially during their calving season, has been disrupted by the increasing frequency of droughts, changes in rainfall patterns, and longer dry seasons (Mungai *et al.,* 2024). Ogutu *et al.* (2023) notes that the rate of species decline in the Maasai Mara has not significantly improved between 2010 and 2025, with some species facing growing threats from habitat fragmentation, poaching, climate change, and human-wildlife conflict.

Changes in rainfall patterns, extended droughts, and the encroachment of agricultural land surrounding the reserve have caused significant declines in populations of several key species, including large herbivores like giraffes, buffaloes, and wildebeest (Mungai *et al.,* 2024). Climate change has made these threats worse by altering vegetation patterns and resource availability, which further disrupts the habitats and migration routes of species (Juma *et al.,* 2023).

Temperature and Precipitation Effects on the Dynamics of Vegetation and Wildlife Populations

Temperature and precipitation-induced stress have contributed to increased tree mortality rates due to the increased frequency of extreme weather events, including heatwaves, severe storms, and extended droughts (Juma *et al.,* 2023). These events are further exacerbated by late-growing season frosts and strong winds, which further degrade vegetation, reducing herbivore food sources and changing habitats, and temperature changes have been shown to disrupt migration patterns and breeding cycles for a number of wildlife species (IPCC, 2023).

The combined effects of temperature increases and water availability fluctuations are influencing the reproduction cycles and overall health of aquatic plants, reducing their capacity to sustain local wildlife populations (Mungai *et al.,* 2024). In turn, these changes can lead to cascading effects across ecosystems, threatening biodiversity and the resilience of ecosystems to climate change. In East Africa, changes in rainfall patterns are altering the timing of the annual plant bloom, which in turn affects the availability of food for migrating herbivores such as wildebeest and zebras. As a result, these animals are adjusting their migration schedules, but not always in ways that align with the availability of other key resources such as water (Mungai *et al.,* 2024). These disruptions can lead to lower reproductive success, reduced survival rates, and increased competition among wildlife species, ultimately affecting the broader ecosystem (IPCC, 2023). Ideally, the nature and functionality of natural resource systems, especially biodiversity and vegetation, are strongly influenced by rainfall trends, as water availability is very necessary for wildlife and plant populations to thrive.

Rainfall regulates vegetation, which provides food for wildlife, a high availability of vegetation implies a high population of wildlife, and vice versa, climate change impacts plant population trends and distribution, including wildlife distribution and abundance, through temperature fluctuations and rainfall. Recent research (Ogutu *et al.,* 2023) confirms that climate-induced shifts in the timing of plant reproduction have resulted in a mismatch between the timing of plant availability and the life-cycle events of herbivores, which has implications for migration patterns as animals must adjust to new food sources that may not align with their usual migration routes.

High and recurrent drought and flooding conditions are a possible contributor to the decline in wildlife populations. Ogutu *et al.* (2023) reports that between 2000 and 2025, wildlife populations in Tsavo East and Tsavo West have declined by an additional 15% to 25%, primarily due to factors such as poaching, habitat fragmentation, and the effects of climate change, including prolonged droughts and unpredictable rainfall patterns. Similar declines have been observed in Meru National Park, where a further 20% reduction in wildlife populations has been recorded due to increased human-wildlife conflict, loss of key migratory corridors, and changing vegetation patterns driven by climate change (Mungai et al., 2024).

The prolonged droughts and irregular rainfall patterns observed from 2010 to 2025 have further stressed buffalo populations and other herbivores in the region, leading to a 10% decrease in buffalo numbers between 2015 and 2020. This decline is linked to not only water scarcity but also increased competition for grazing resources, as vegetation is heavily impacted by both prolonged dry periods and erratic rainfall (Mungai *et al.,* 2024). According to Ogutu *et al.* (2023), the wildebeest population in Serengeti dropped by 40% during the 1993 drought, and the recovery has been slow. The combination of higher temperatures, erratic rainfall, and extended dry seasons, all exacerbated by climate change, has contributed to recurring droughts and further stress on the park's ecosystems. The ongoing vulnerability of wildebeest and other herbivores to such extreme weather events is heightened by their dependence on predictable food and water availability.

The region's ecosystems continue to face challenges as the Serengeti struggles with both short-term climate extremes and long-term climate shifts that have disrupted the reproductive cycles and migration patterns of many species (Juma *et al.,* 2023). More recent evidence from 2020–2025 indicates that similar drought events have caused further fluctuations in wildebeest numbers, with population decreases of 10-15% recorded in the past decade (Mungai *et al.,* 2024).

Weather-induced changes in vegetation growth and availability can affect mating timing because zebras depend on the seasonal availability of fresh grass for nutrition (Mungai *et al.,* 2023). Temperature increases, droughts, and altered rainfall patterns have caused mismatches between the availability of optimal grazing conditions and the timing of zebra reproduction, resulting in delayed or early births, which can affect the survival and health of newborn zebras as well as the population's overall success (Juma *et al.,* 2023).

These weather-driven variations in birth timing are increasingly being observed as a result of climate change, highlighting the wider ecological impacts of climate variability on zebra populations and their reproductive cycles. For example, extreme drought conditions can result in a shortage of food resources, which can delay conception or birth; similarly, more favorable wet conditions can result in earlier births as the availability of resources supports faster gestation and earlier onset of reproductive activity (Ogutu *et al.,* 2024).

Ogutu *et al.* (2023) argues that extended droughts in the Mara region have resulted in decreased forage availability during critical periods, which has affected herbivore health and reproduction. These fluctuations in food availability, when combined with rising temperatures and changing rainfall patterns brought on by climate change, can result in poor body condition and lower reproductive rates for species like wildebeest, zebras, and antelopes. The absence of nutrient-dense forage also weakens wildlife resilience to other stressors, such as disease and predation, further lowering survival rates (Mungai et al., 2024).

According to a 2023 study by Ogutu *et al.,* species such as the African elephant, rhino, and some antelope species are especially vulnerable to these changing conditions because they depend on particular habitats and food sources that are changing due to climate change, which disrupts their migration and breeding cycles, causing their populations to decline even more quickly and making recovery more challenging (Juma *et al.,* 2023). Additionally, the increased frequency of extreme weather events like droughts and floods, which affect vegetation and water sources, further jeopardizes the survival of these species. Conservation scientists have also warned that many species may go extinct if immediate mitigation and adaptation measures are not put in place due to the combined effects of climate change and current pressures on wildlife (IPCC, 2023).

Recent studies (Ogutu *et al.,* 2023) indicate that the frequency of droughts in East Africa, including areas like the Maasai Mara and Serengeti, is expected to increase, leading to more prolonged dry periods that disrupt forage availability, water sources, and animal migration patterns. Similarly, increased rainfall intensity and more frequent flooding events are expected to affect wildlife habitats, causing habitat destruction and displacement for many species (Mungai *et al.,* 2024; Chemoiwa & Kipsumbai, 2024). Studies by Ogutu *et al.* (2023) show that species that rely on seasonal wetlands, forested areas, or grasslands are facing heightened risks as these ecosystems become increasingly stressed by climate change. For example, species that rely on seasonal flooding for reproduction, such as certain amphibians and aquatic birds, are at risk if these floodplain ecosystems are disrupted by shifting rainfall patterns and increased drought events. Similarly, herbivores in savanna ecosystems, like the giraffe and zebra, are threatened by the reduced availability of forage due to more frequent droughts and unpredictable rainfall patterns (Mungai *et al.,* 2024). Therefore, based on the research findings, climatic shifts caused by dramatic changes in weather trends in the MMNGR due to floods and drought events are likely to reduce the level of biodiversity and consequently negatively influence tourist visitation.

MATERIALS AND METHODS

The study was conducted in the MMNGR, which is widely and internationally recognized as one of the Seven Wonders of the World (MMNR Management Plan, 2009-2019). The MMNGR is a 1,530 km² protected land area that spans the southern portion of the Greater Mara Ecosystem (GME) to the Tanzanian border; it has been designated as a world heritage site, and its main goal is to conserve the region's biodiversity. The Mara River is a significant geographical feature that not only divides the MMNGR but also plays a vital role in supporting the region's biodiversity, providing water resources for both resident and migratory species, and its seasonal flooding is essential to preserving the ecosystem's equilibrium (Ogutu *et al.,* 2023).

MMNGR is home to a wide variety of habitats that support a wide range of wildlife species. The habitat types within the reserve vary greatly, from large grasslands and shrublands to wooded grasslands and riverine ecosystems. The central plains, which are home to large populations of wild herbivores, are made up of low-lying grasslands and large areas of wooded grasslands with a preponderance of trees like Balanites aegyptiaca and grasses like Themeda triandra (red oat grass), especially in the Mara Triangle, which is located in the western part of the reserve.

The Loita Hills and the southern regions of the Koyaki Ranch, which are outside the core protected area but part of the Greater Mara Ecosystem, are also critical. These areas are dominated by shrubby grasslands, which support important wildlife populations, particularly during migration periods when herbivores move between different grazing areas in response to seasonal changes. These ecosystems play an essential role in the seasonal movement and survival of species, including zebras, wildebeests, and antelopes, which rely on the availability of fresh forage and water sources (Ogutu *et al.,* 2023). Rainfall data from 15 rain gauges in the Maasai Mara region, collected between 1989 and 2003, have provided valuable insights into the climate trends and variations affecting the area. These data, as illustrated in the corresponding map, show significant fluctuations in rainfall amounts, which are critical for understanding the impacts of climate change on the region's ecosystems and wildlife populations. Rainfall and temperature data was analysed using time series method and the results are presented from Fig. 6-14.

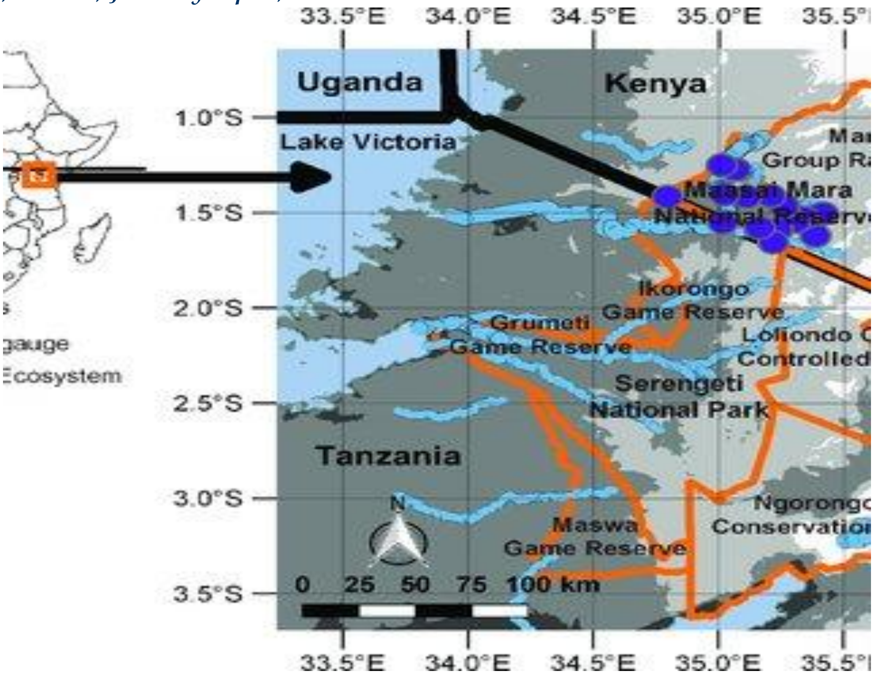

Figure 1: Map Showing 15 raing gauges in MMNGR.
Source: Adopted from (Ogutu et al., 2016)

Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation index (NDVI) is a crucial parameter for plant recognition, which has an apparent connection with vegetation cover. The NDVI is a basic numerical metric that can be used to evaluate the measurements of remote sensing from a remote platform and to determine whether or not the subject or entity being examined includes live green vegetation (Ogutu *et al.,* 2023). The normalized difference vegetation index (NDVI) is derived based on variations in the absorption properties of pigments in the electromagnetic spectrum's red and near-infrared areas. NDVI values vary from −1.0 to 1.0; increasing optimistic NDVI values suggest growing volumes of green vegetation. NDVI values close to zero and rising negative values indicate non-vegetated characteristics such as desert soils, bare fields, and rivers. NDVI calculations were done in order to assess if vegetation trends were likely affected by changing rainfall and temperature data and more importantly whether high vegetation corresponds to high wildlife population and vice versa (Ogutu *et al.,* 2023).

It can be used to track changes in local or global vegetation, which may indicate changes in the ecosystem caused by natural factors like climate change and anthropogenic activities by establishing a relationship between climatic factors and NDVI. Its advantages include flexibility, the ability to distinguish vegetated areas broadly from other surface forms, and greater sensitivity to detecting green vegetation than using a single unit. In order to balance out the effects of irregular lighting, such as cloud shadows or hills, the NDVI takes the difference (NIR-red) and standardizes it. The NDVI is calculated as NDVI = (Near Infrared - Red) / (Near Infrared + Red). The NDVI is inspired by the vegetation of measurement, which is the disparity between the NIR and the red band; with greater chlorophyll intensity, this would be larger.

The Normalized Vegetation Difference Index (NDVI), also known as the "greenness tracker," is a red and infrared channel ratio that compares the two signals and efficiently expresses the degree of pixel greenness (Ogutu *et al.,* 2023). It is frequently used to track green vegetation across large regions and provides a key growth indicator (Mungai *et al.*, 2024).

Ogutu *et al.* (2023) contend that chaos theory proposes several theoretical concepts, including "butterfly effect," "lock-in effect," "edge of chaos," "bifurcation," "self-organization," and "strange attractors," to explain the turbulent relationships and changes in the tourism system during crises. This study adopts the butterfly effect principle, which explains "how seemingly similar destination areas can evolve in completely different manners and explains the unpredictable nature of tourism development, where even slight changes in initial conditions can lead to profoundly different outcomes" (Gossling and Hall, 2020). This is because drought and flooding scenarios have the potential to disrupt the quality and quantity of biodiversity, consequently leading to declining wildlife populations in protected areas like MMNGR rendering these parks unsuitable for tourism activities that thrive with abundant wildlife popultions.

Data Analysis

In order to determine the mean annual NDVI for a particular land category, the NDVI images from 1975 to 2018 were processed to produce specific NDVI values for each land cover category, the random points on each image were generated for specific land use categories, and the multi-values were extracted using a geostatistical technique, and the points were then averaged to obtain specific NDVI values for a given year. The generated points were then extracted through a process of geostatistical technique by a multi-value regression function. The Mann-Kendall trend test was used to analyze rainfall and temperature data.

RESULTS AND DISCUSSIONS

Mean Monthly Rainfall of MMNGR from 1960 to 2012

Fig. 2 summarizes the mean monthly rainfall of MMNGR over the last 54 years. The findings show that the mean annual rainfall in MMNGR between 1960 and 2014 was 1134.8 mm, with the highest mean annual rainfall of 1482.1 mm in 1961 and the lowest, 823.8 mm, in 2005. The years with the highest mean rainfall sums were 1961 (1482 mm), 1977 (1437 mm), 1963 (1427 mm), 1978 (1410 mm), 1968 (1358 mm), 1962 (1343 mm), and 1970 (1314 mm), 2005 (824 mm), 1984 (844 mm), 2000 (928 mm), 1969 (943 mm), 1993 (945 mm), 2009 (960 mm), 2008 (972 mm), 1976 (985 mm), and 1991 (992 mm) had the least amount of rainfall. The standard deviation of the mean annual rainfall is 152.67 mm, which indicates a deviation from the mean between 1960 and 2014. These findings are in agreement with, but also contradict, earlier research showing that East Africa experienced frequent episodes of both excessive and insufficient rainfall.

In fact, Ogutu *et al.* (2024) contend that droughts can cause substantial herbivore mortality and often regulate population size. These results are consistent with a study by Ogutu *et al.* (2023) that found that extreme drought occurred in the years 1993, 1997, 1999, and 2000 and moderate droughts occurred in 1991 and 1994. The current study found the least amount of rainfall received during these periods, for example, in the years 2000 (928 mm), 1993 (945 mm), 1976 (985 mm), 1990 (992 mm), and 1991 (992 mm).

According to Ogutu *et al.* (2014), seasonal rainfall fluctuations primarily cause seasonal changes in plant quantity and consistency; as a result, rainfall controls vegetation fertility, biomass, and efficiency in savannas and is likely to influence wildlife reproductive seasonality (Fynn *et al.,* 2023). Given the increasing number of reports of significant wildlife losses around the world, this research suggests that variations in rainfall may contribute to inadequate habitat with low nutrient concentrations and, consequently, wildlife mortality.

Variability of weather elements attributed to climate change is likely to negatively impact wildlife species in parks and reserves. Additionally, Fynn *et al.* (2024) found that rainfall trends in the Amboseli environment had an effect on the elephant population, and Ogutu *et al.* (2024) on MMNGR demonstrated the impact of annual rainfall variability on the reproductive health of ungulates, influencing the availability of maternal milk and, consequently, survival rates. Fig. 2 shows MMNGR average annual rainfall.

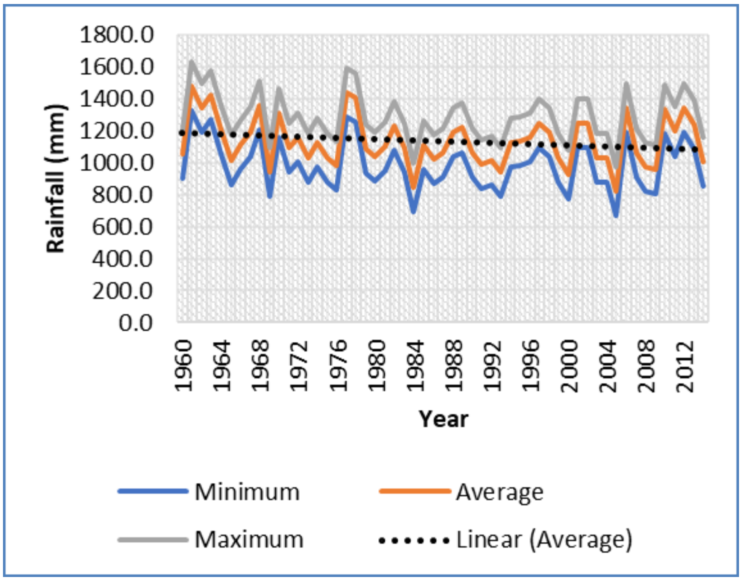

Figure 2: Maasai Mara Annual Average Minimum and Maximum Rainfall
Source: Author (2019)

Rainfall is the primary driver of savannah herbivore population dynamics (Fynn *et al.,* 2023) because it controls the production of plant biomass (Abdulhakim *et al.,* 2022). Rainfall also affects the nature of the animal community by regulating the supply and consistency of food and surface water for herbivores in African terrestrial habitats (Bartzke, 2016). On the one hand, variations in rainfall due to heavy rain led to flooding, and extremely low rainfall creates drought conditions that impact the wildlife population; on the other hand, in addition to causing the previously mentioned mortality of wildlife due to vegetation dieback, drought and flooding conditions also encourage parasite infestations; and on the other hand, excessive rainfall can negatively impact small herbivores (Mungai *et al.,* 2024). Consequently, climate change would exacerbate these conditions for animals, increasing the likelihood of predation, environmental loss and degradation, and ultimately population decline. Consequently, tourism destination areas experiencing these changes are likely rendered unattractive and likely to register reduced tourist visits as well as activities.

Monthly Average Temperature from 1960 to 2014

According to the analysis of the mean monthly temperature of Maasai Game Reserve over the previous 54 years, the highest temperature was recorded in February at 26.90°C, while the lowest temperatures were recorded in July and September at 9.50°C and August at 9.70°C. The results are summarized in Fig. 3.

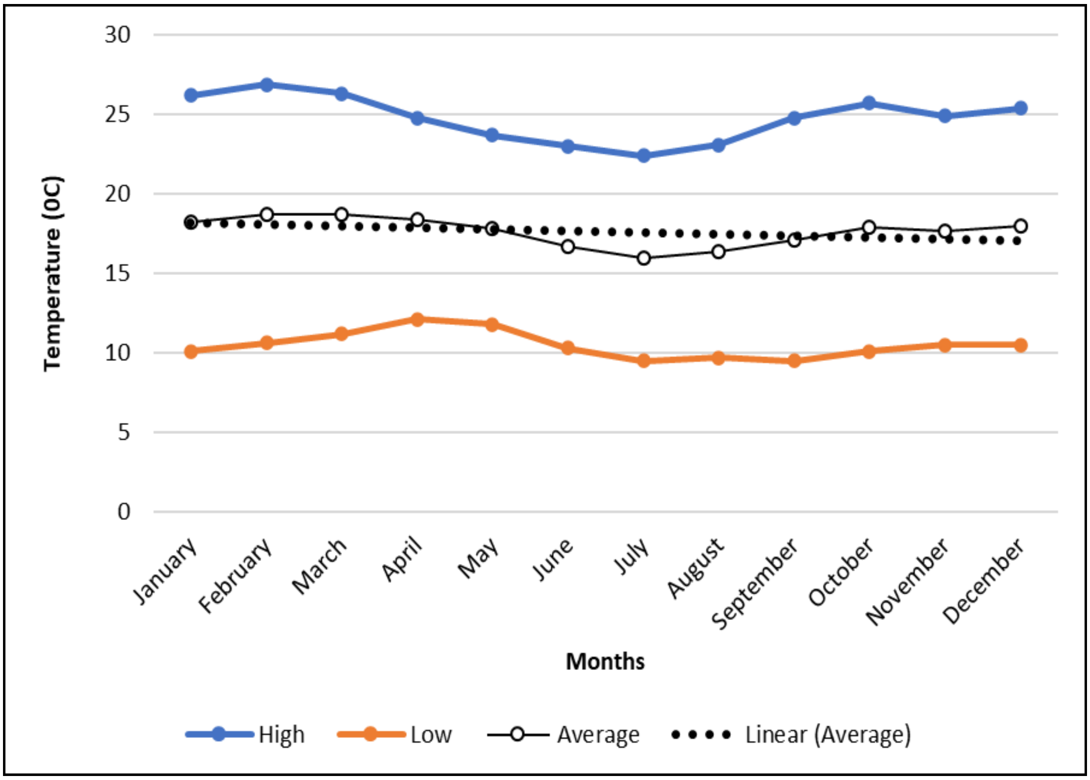

Figure 3: Mean monthly temperature for the period 1960-2014
Source: Author (2019)

According to the study's findings, the average annual temperature in Maasai Mara Game Reserve is 18°C. Fig. 3 shows temperature variations from the mean. These findings are in line with Feynn *et al.* (2023), who suggest that temperature values are likely to fluctuate throughout the year and will likely rise erratically. In fact, according to the IPCC (2024), the earth's surface temperature increased by 0.6 ± 0.2°C over the 20th century and is predicted to rise in the 21st century from 1.1°C to 6.4°C (17). Niang *et al.* (2014) state that temperatures in Africa are predicted to rise more quickly than the rest of the planet, which contrasts with the well-known fact that Antarctica has the highest rate of warming, which could reach 2°C by the middle of the 21st century and 4°C by the end of the century.

A decline in precipitation is predicted for the East African region (IPCC, 2023), and many wildlife species, particularly the large herbivores, are influenced by seasonal trends and variability in rainfall and temperatures (Ougutu *et al.*, 2023). Africa is a continent with significant biodiversity. According to Ogutu *et al.* (2016), the length of the long (March-May) and short (November-December) rainy seasons has generally decreased, spatial and temporal rainfall variation has increased, and the frequency of drought events in East Africa has decreased in recent years; however, Ogutu *et al.* (2023) asserts that climate impacts can result in a decline in wildlife populations, since rainfall trends indicate that MMNGR experienced severe droughts in 1984, 1986, and 1993.

Droughts are linked to extremely high temperatures and flooding that reduces wildlife vegetation, including water availability. Additionally, as a result of climate change, most wildlife species are likely to be exposed to climatic conditions that exceed their physiological tolerance, which leads to physiological stress, decreased fitness, or the possibility of extinction (Ogutu *et al.,* 2023). These findings are consistent with a study by Ogutu *et al.* (2021) that identifies climate change as a cause of declining wildlife populations due to a decrease in rainfall and an increase in temperatures. Based on these findings, this study suggests that both extremely high and low temperatures are likely to have an impact on wildlife dynamics in terms of population and survival rates, and, ultimately, the tourism industry.

Trends in Wildlife Populations (1977-2016)

Data on wildlife populations was obtained from the Directorate of Resource Surveys & Remote Sensing (DRSRS), which regularly carries out aerial surveys and has been doing so since 1977. Data on elephants, buffalo, and wildebeests are shown in Table 1, Fig. 3, 4, 5, 6, 7, 8, 9, and 10 below.

Table 1: Elephant, Buffalo and Elephant population (1977-2016)

Years Wildlife	**1977-1981**	**1982-1986**	**1987-1991**	**1992-1996**	**1997-2001**	**2002-2006**	**2007-2011**	**2012-2016**
Wildebeest	19421	4711.167	13090.8	22529.2	12284	6263.5	9476.8	17777
Bufallo	1385	867.83	916.8	1063.4	400.3333	656.5	336.2	964.5
Elephant	80.33	87.83	105.8	228.8	223.67	135.75	83	157.5

Source: DRSRS (2018)

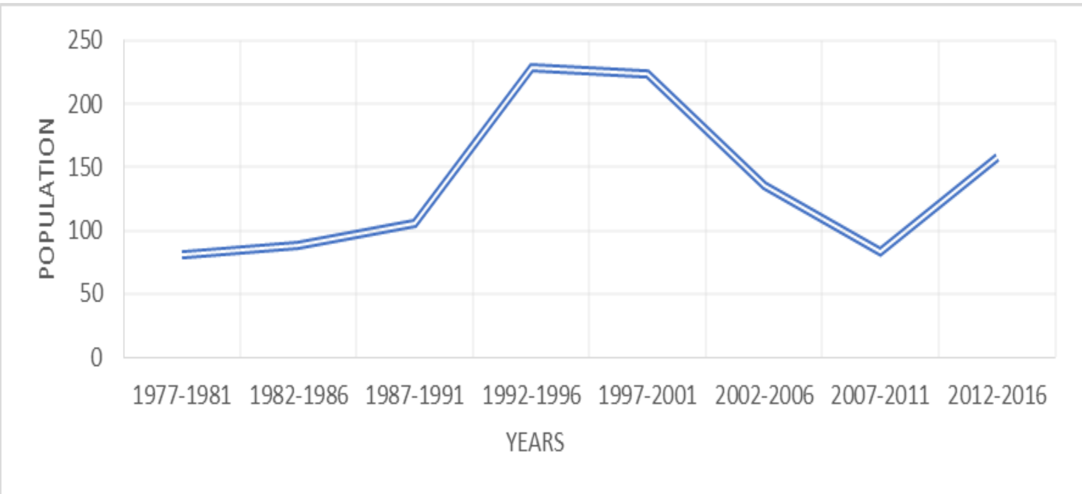

Figure 4: Elephant population (1977-2016)
Source: DRSRS (2018)

The results indicated in Fig. 4 that the elephant population from the year 1977-1991 had been on a moderate rise, reaching 100, until the period 1991-1996 when there was a steady increase in population from 110 to 240. During the period from 1996 to 2011, there was a drastic decline in the elephant population from 200 to 80 elephants. This could be a result of drought during the years 1997, 1999, and 2000. These outcomes correspond with the rainfall analysis that indicated 2005 had the lowest mean annual rainfall (824 mm), followed by 2000 (928 mm), 2009 (960 mm), and 2008 (972 mm), during which a decline in wildlife population was observed, as presented in Fig. 2. Thus, due to low rainfall during the identified period, it is highly likely that it contributed to a decline in elephant population, holding other factors constant. Finally, the period from 2011 to 2016 saw a steady increase in the elephant population from a population of 80 to 160. It is possible that the rise in the elephant population could be attributed to favorable climate conditions.

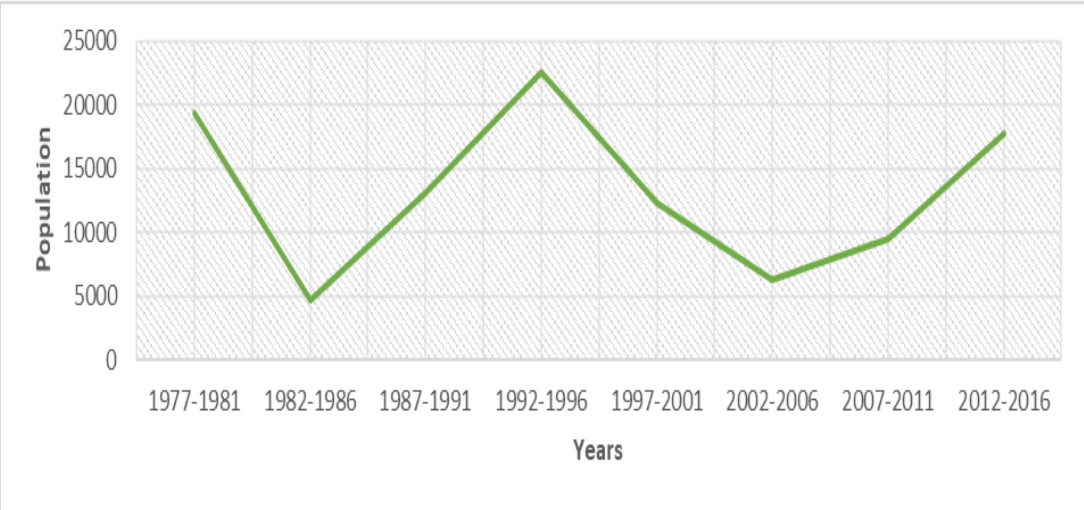

Figure 5: Buffalo population (1977-2016)
Source: DRSRS (2018)

Buffalo population data shows rapid population variation, with a steady decline from 1400 to 900 during 1977-1982. These results are consistent with the study's rainfall data, which shows an intermittent period of very high and low rainfall, such as in 1982 when the rainfall was high at 1437 mm and two years later in 1984 when it dropped to 844 mm, as shown in Fig. 3 above. Therefore, variations in rainfall have the potential to cause a decline in wildlife population. Between 1982 and 1994, the population increased moderately from 900 to 1050, possibly due to stable rainfall during the period.

Data on the wildebeest population show a range of low and high numbers: between 1977 and 1982, the population fell sharply from 2,000 to 5,000; between 1983 and 1996, it steadily increased from 5,000 to 22,500; from 1996 to 2004, it fell sharply from 22,500 to just 6,000, which may have been caused by the droughts of 1997, 1999, and 2000; and finally, between 2004 and 2016, the population increased slowly and steadily from 6,000 to 18,000 wildebeest, which may have been caused by relatively stable rainfall trends.

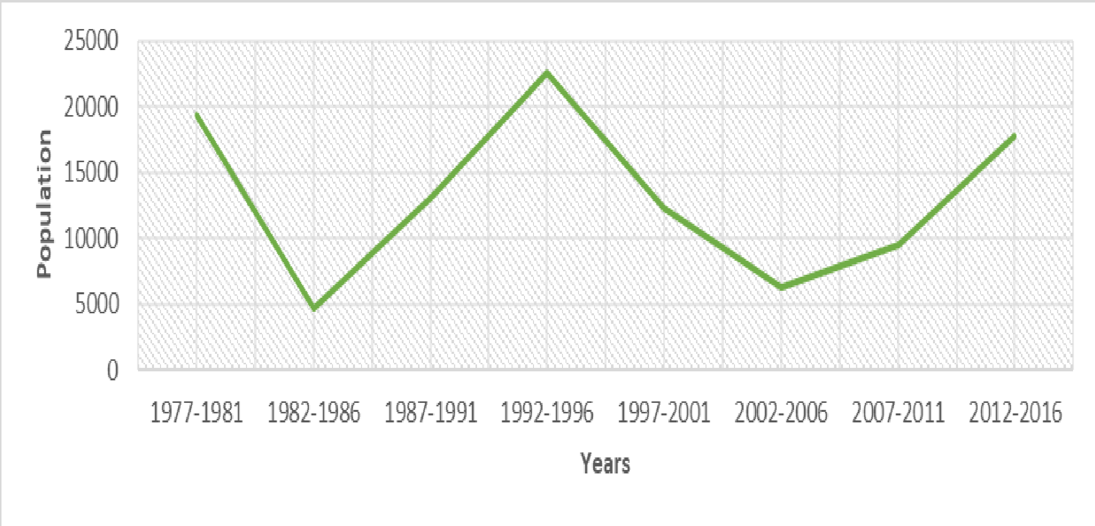

Figure 5. Wildebeast population (1977-2016)
Source: DRSRS (2018)

The wild beast population steadily decreased from 1050 to 400 between 1996 and 1999 due to low rainfall (for example, the calculated average annual rainfall in 1993 was 945 mm). The buffalo population increased from 400 to 650 between 1999 and 2004 and then decreased from 650 to 350 between 2004 and 2008. The buffalo population steadily increased from 350 to 950 between 2011 and 2016 due to rainfall variations that were characterized by high rainfall to declining rainfall, stable rainfall, and again high rainfall trends.

Normalized Difference Vegetation Index (NDVI)

In order to estimate the Normalized Vegetation Difference Index (NDVI), which indicates measurements of vegetation cover, the satellite images were taken from the Landsat Satellite (from 1975 to 2018 with 5-year intervals) and the accompanying estimates show changes in vegetation around the research region from 1975 to 2018.

The Year 1975's NDVI

Vegetation abundance and distribution in MMNGR during the year 1975 (Fig. 6) In accordance with the estimated mean annual rainfall of 1351.68 mm in 1975, which was relatively strong, supporting the large volume of vegetation NDVI=0.8 vegetation, the ramp in color indicates the vegetation level for each spot, with green denoting large amounts of plant cover, yellow denoting small concentrations, and red denoting few to no plants in it.

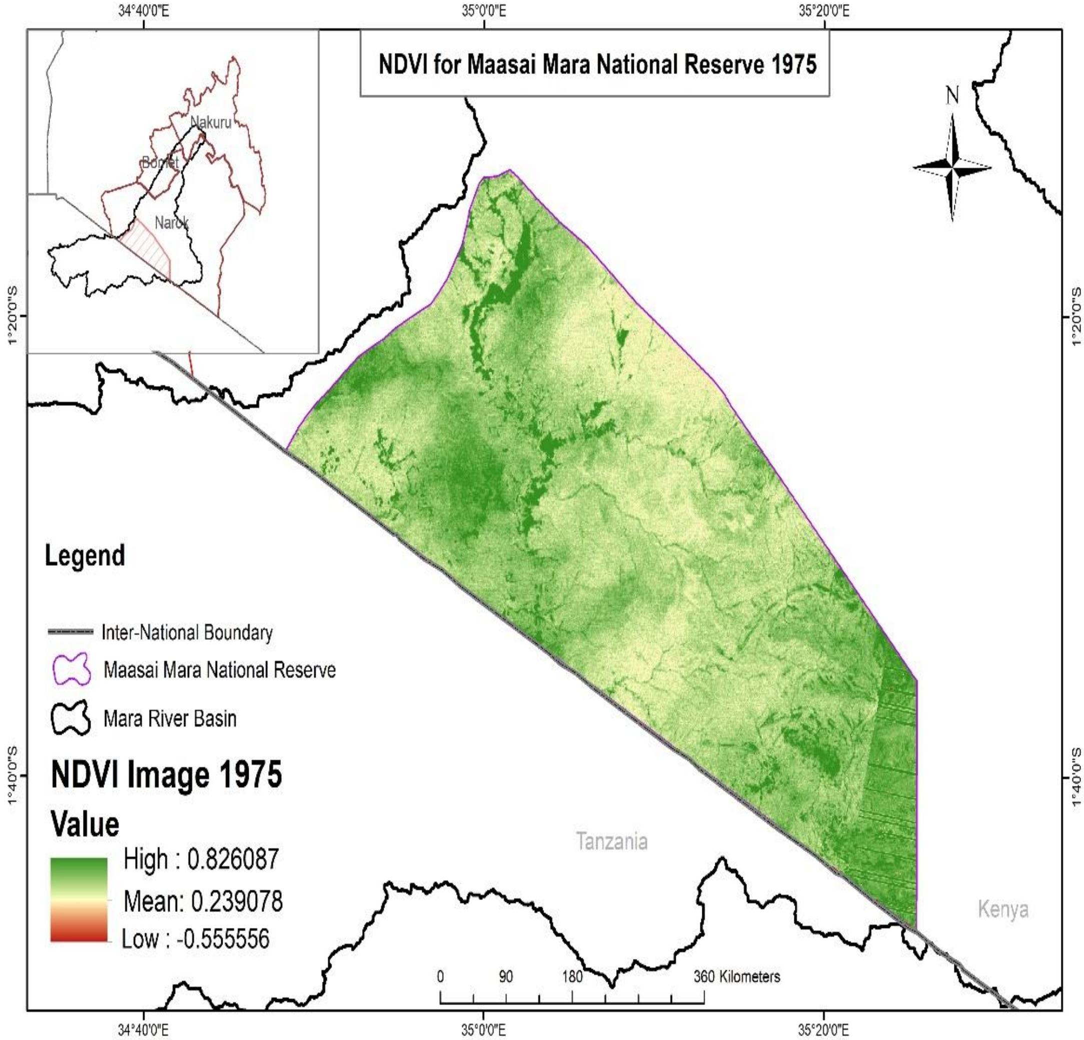

Figure 6: NDVI Map for the year 1975

NDVI for the Year 1980

Five years later, the vegetation in the game reserve has significantly improved. Fig. 7 shows the distribution of the NDVI in the game reserve. The year 1980 had less vegetation than the year before, as indicated by the red color in the figure. The annual rainfall was high in most park areas, with a value of 1040 mm, so greenness indicates abundant vegetation, implying a thriving wildlife population. Additionally, the proximity of the Mara River, which gives rise to river vegetation, is clearly high vegetation along the border of Narok County.

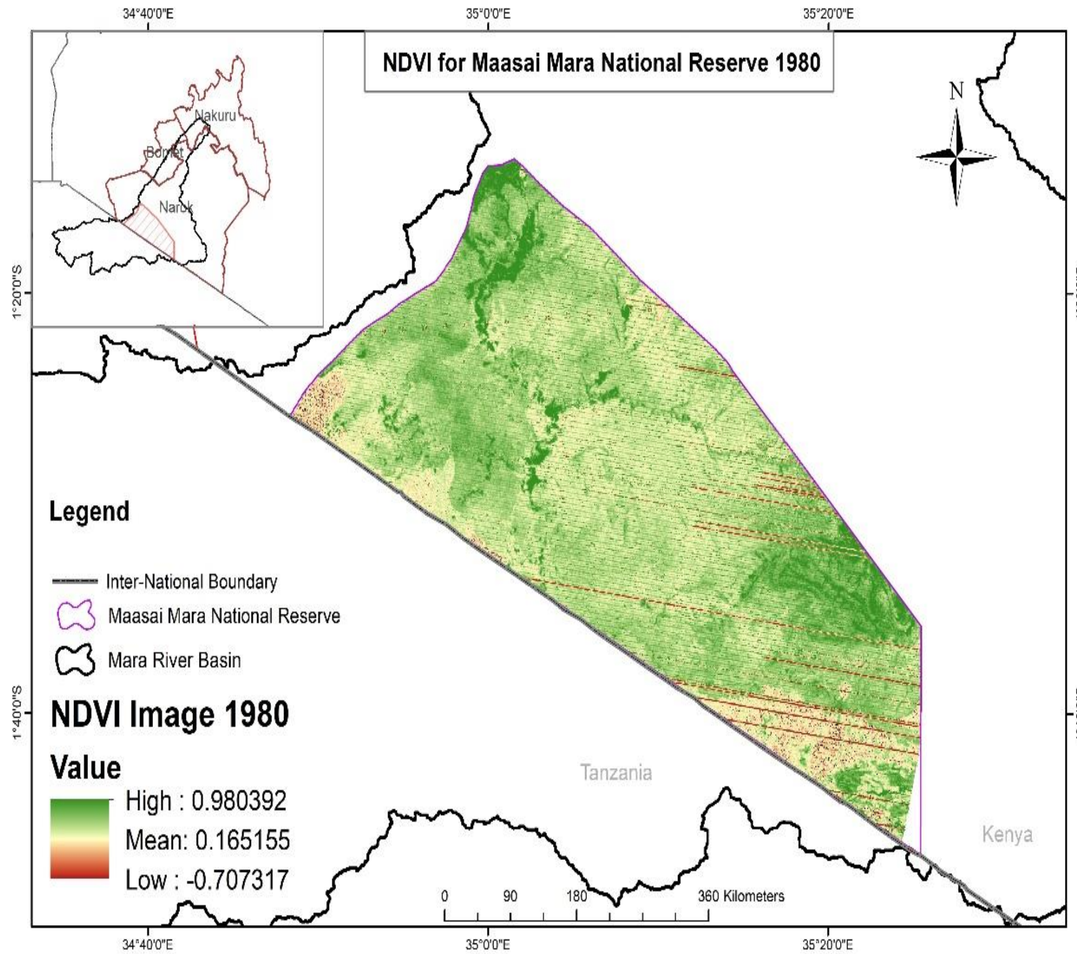

Figure 7: NDVI Map for the year 1980

NDVI for the year 1985

There appears to be a decrease in vegetation cover in the following years. In 1985, vegetation was moderately widely distributed in the park, which may have been caused by abrupt changes in rainfall patterns, as the estimated average annual rainfall was 1113 mm, less than the year before. This decrease in rainfall may have an impact on wildlife populations. Fig. 8 displays the distribution of vegetation with an NDVI of 0.6.

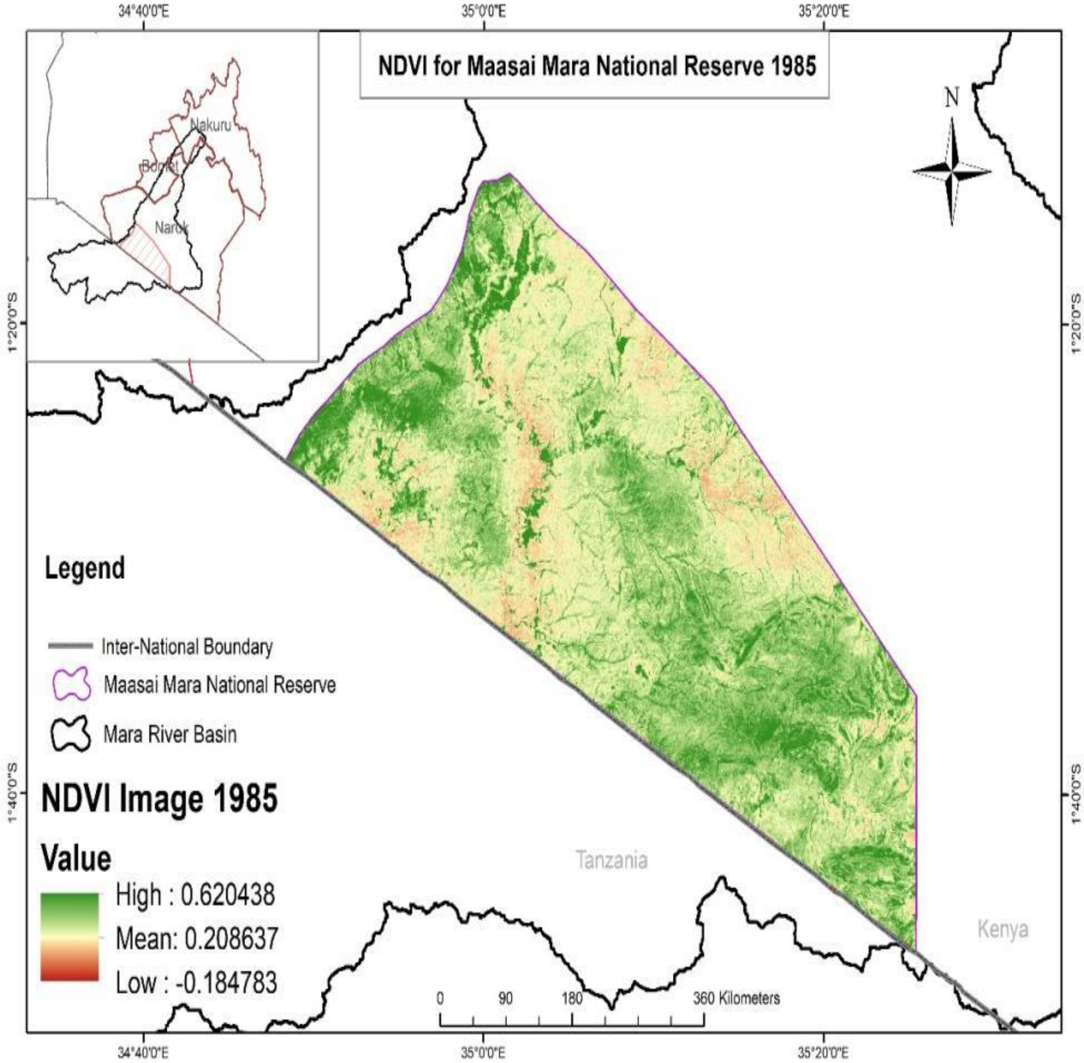

Figure 8: NDVI Map for 1985

NDVI for the year 1989

Drought and famine were severe in 1989; in fact, rainfall decreased significantly between 1985 (average of 1113 mm) and 1987 (1061 mm), with a slight increase in rainfall in 1988 and 1989 (average of 1189 mm and 1219 mm). Consequently, the extended decrease in rainfall led to a decrease in vegetation cover, which in turn caused a decrease in vegetation, which may have contributed to the decline in wildlife population (Fig. 9).

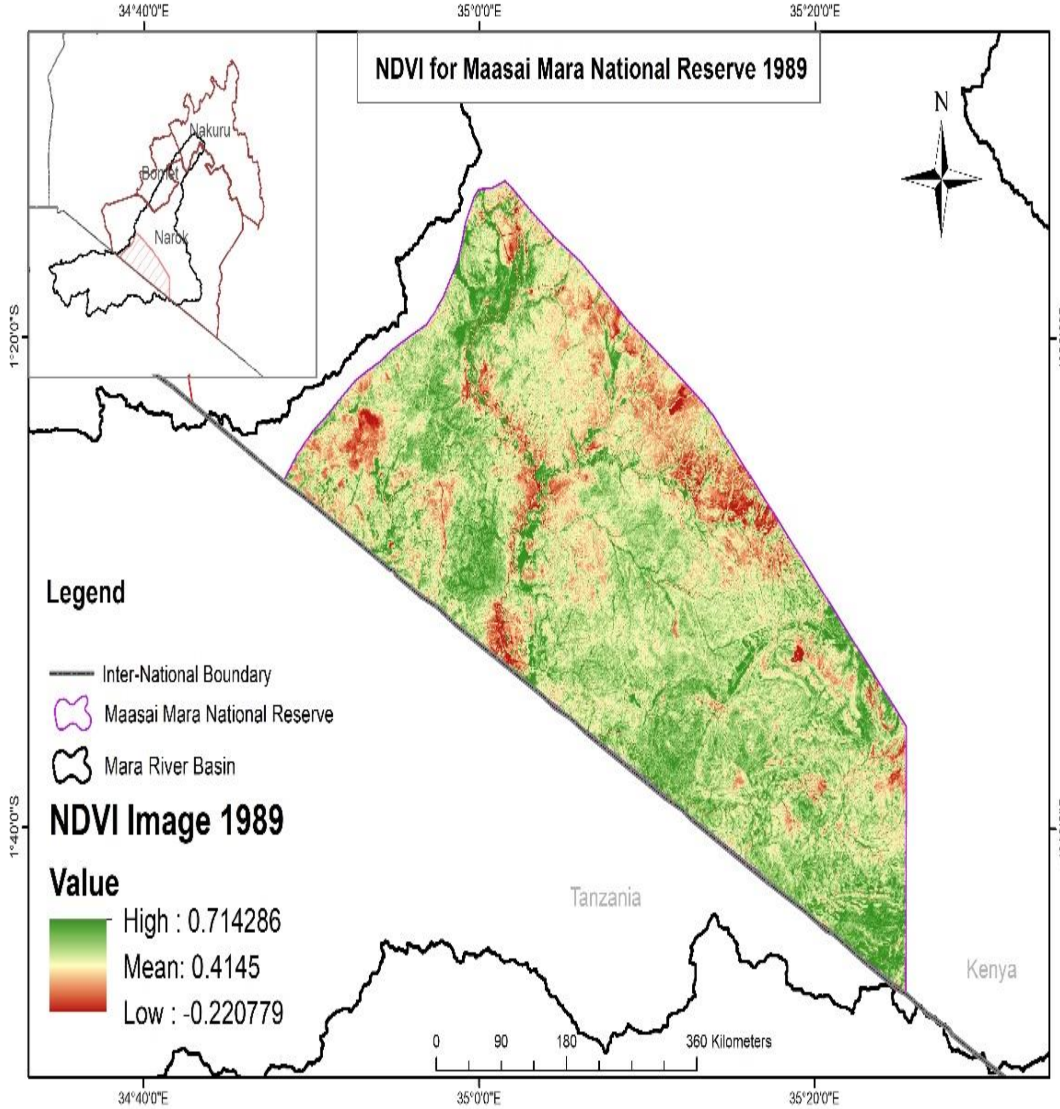

Figure 9: NDVI in 1989

NDVI for the year 1995

There is a concentration growth of vegetation cover at the center of the reserve, while the northwestern part of the park exhibits a high amount of vegetation. The year 1995 shows a general reduction in vegetation cover, as shown in Fig. 10, possibly due to rapid changes in temperature and rainfall. The rainfall trend sharply declined in 1991 with an average of 992 mm and 1993 with an average of 944 mm. Despite the rise of rainfall in 1995 of 1134 mm, the vegetation did not improve that much because of the decline of rainfall in the preceding years.

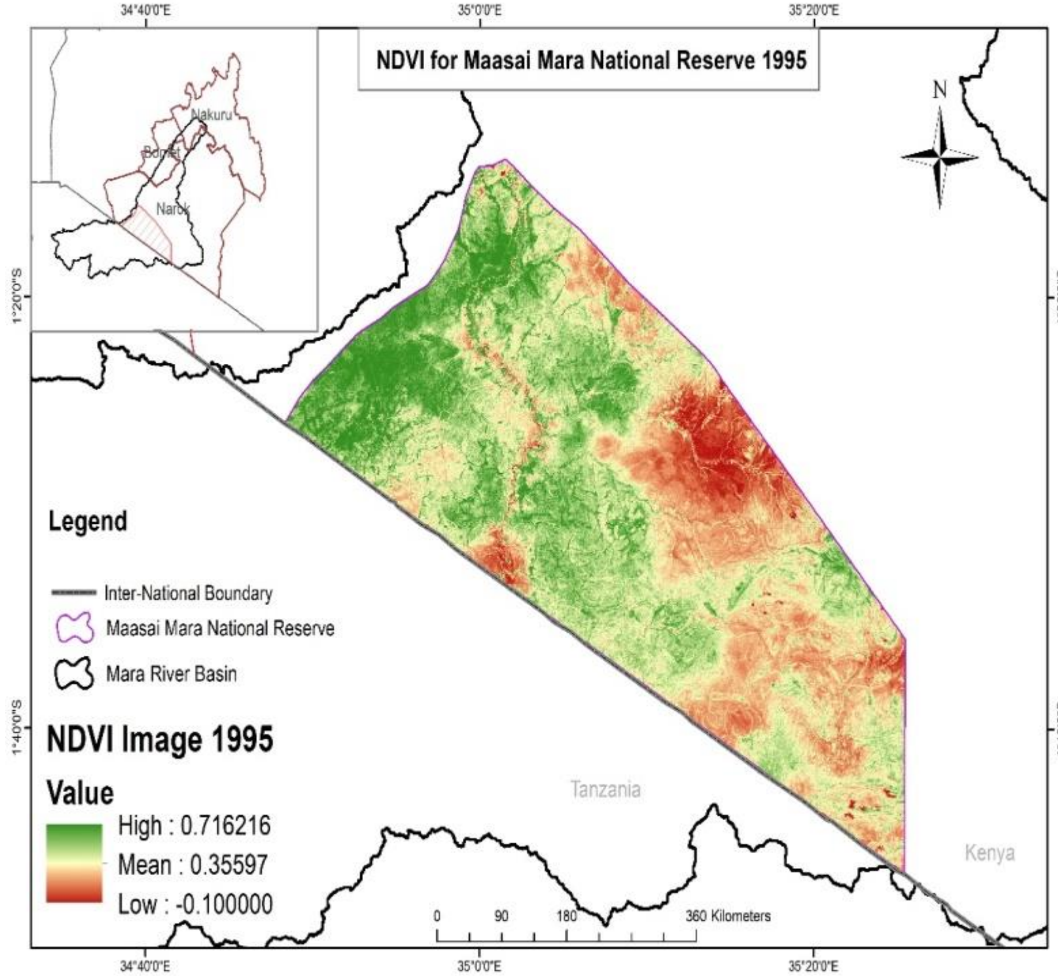

Figure 10: NDVI value for the year 1995

NDVI for the year 2000

The park's worst year was 2000, when there was very little vegetation distribution (NDVI value of 0.3) due to the lowest rainfall ever recorded (annual calculated mean of 928 mm). Most of the park's areas are red, meaning there is no vegetation at all, which suggests a high probability of a decline in wildlife population. The exception is the area around the River Mara, which shows vegetation (Fig. 11).

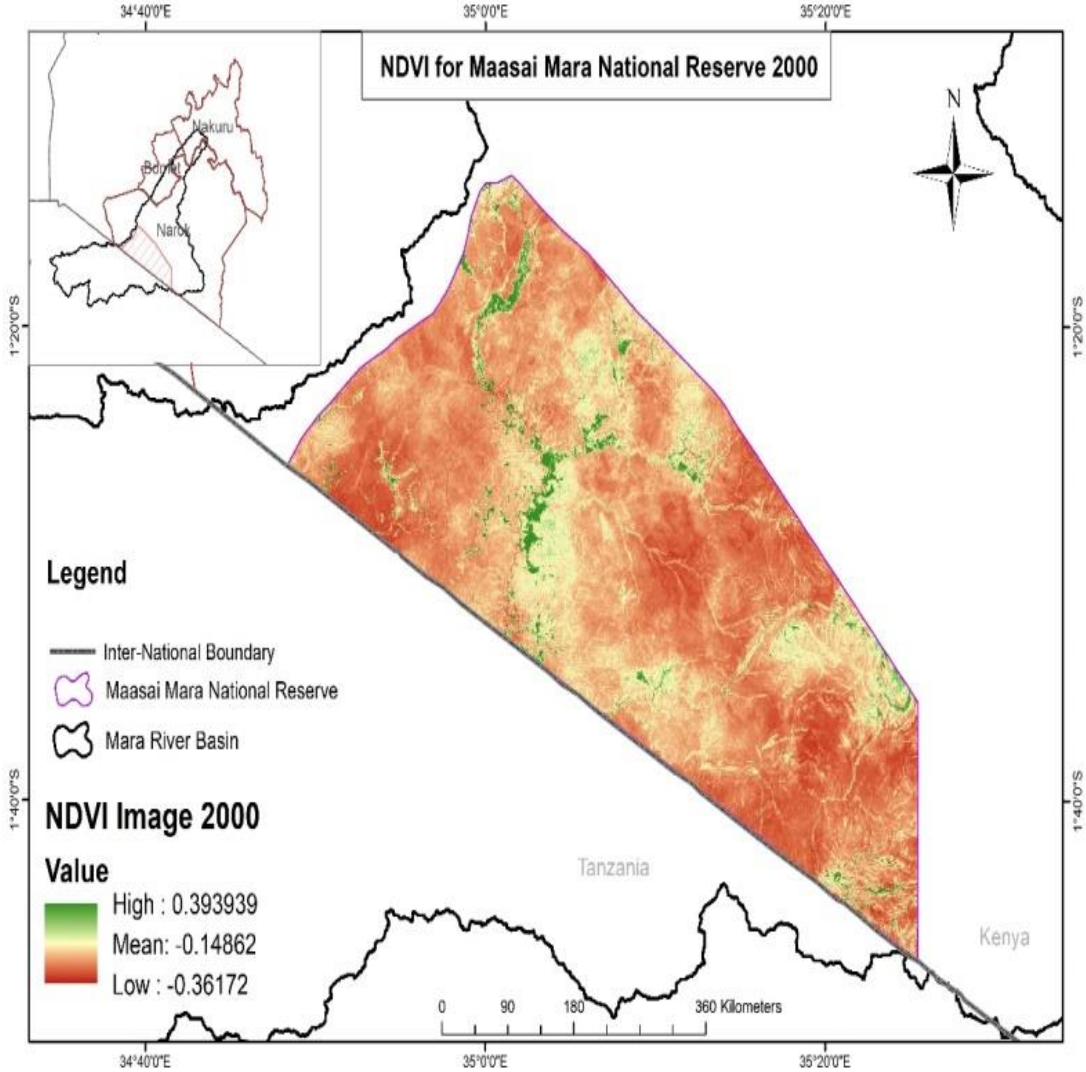

Figure 11: NDVI value for the year 2000

NDVI for the year 2005

With an NDVI value of 0.7, the year 2005 shows a notable improvement in vegetation over the previous year, despite an average low rainfall of 823 mm. This is likely due to the high rainfall in the previous year, which included 1029 mm in 2004, 1030 mm in 2003, and 1250 mm in 2002. It is also likely that rainfall and temperature remained stable during this time, which led to improved vegetation cover. As illustrated in Fig. 12, the vegetation is also fairly evenly distributed throughout the park, which improves wildlife survival rates.

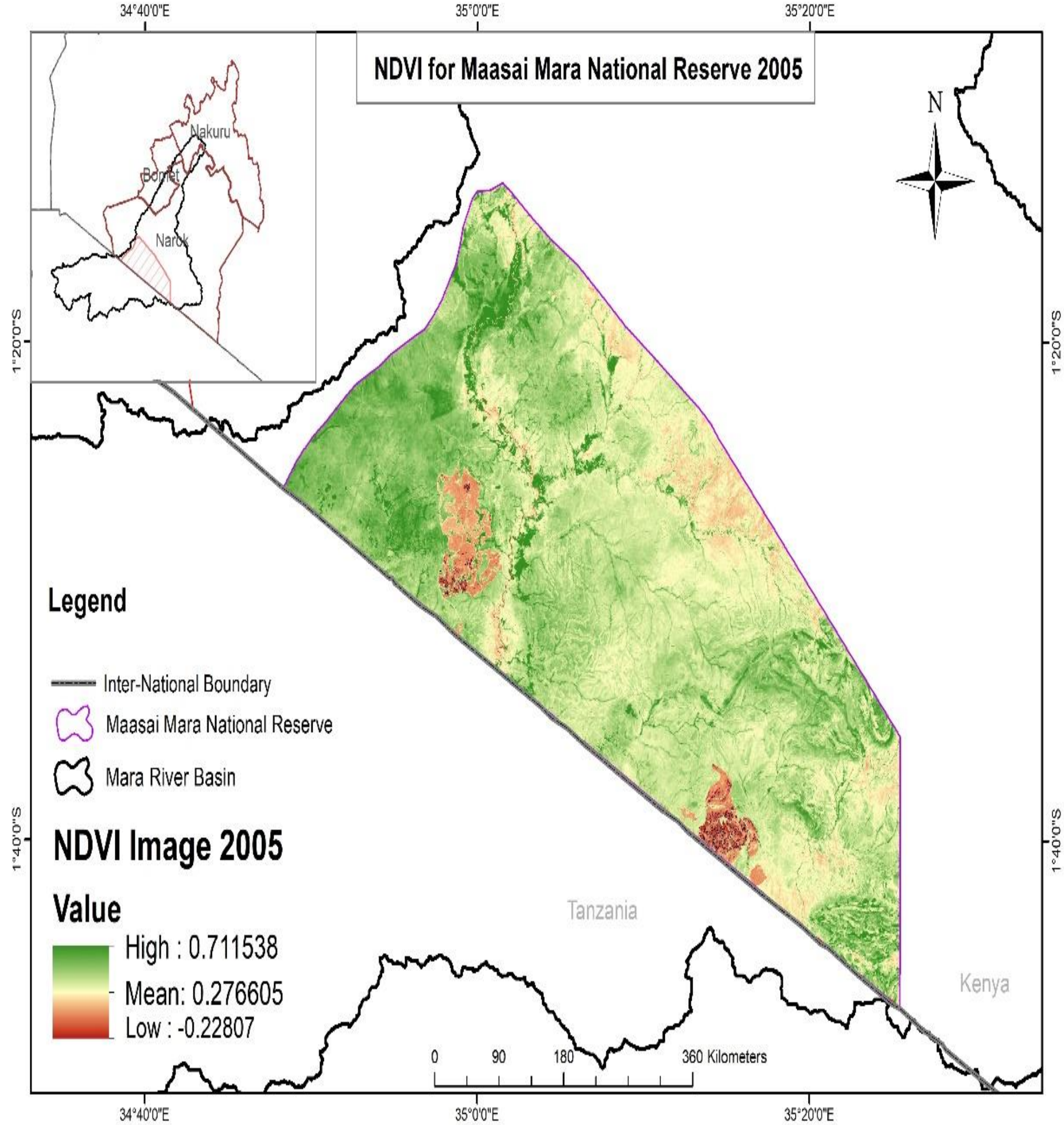

Figure 12: NDVI map the year 2005

NDVI for the year 2010

The NDVI value decreased from 0.7 in 2005 to 0.6 in 2010, indicating a significant decrease in vegetation cover and vegetation abundance in comparison to the previous year. This is undoubtedly due to a sharp decrease in rainfall in the two years prior, 2009 (959 mm) and 2008 (972 mm), which may have a negative impact on wildlife populations (Fig. 13).

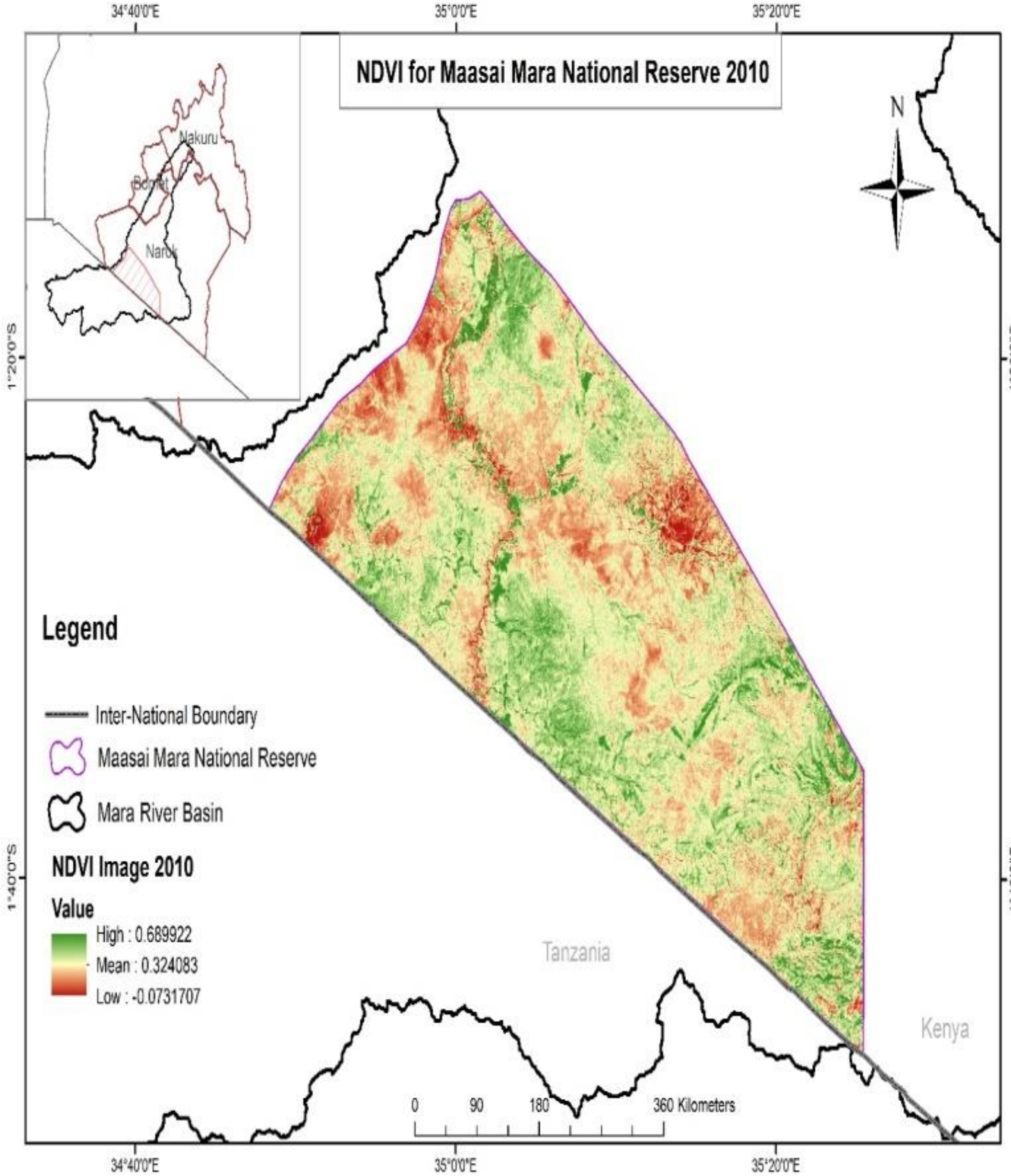

Figure 13: NDVI map for the year 2010

NDVI for the year 2015.

2015 shows a decrease in vegetation cover with NDVI values of 0.6 and 0.4, respectively, compared to 2010; this decline is ascribed to temperature and rainfall variations (Fig. 15).

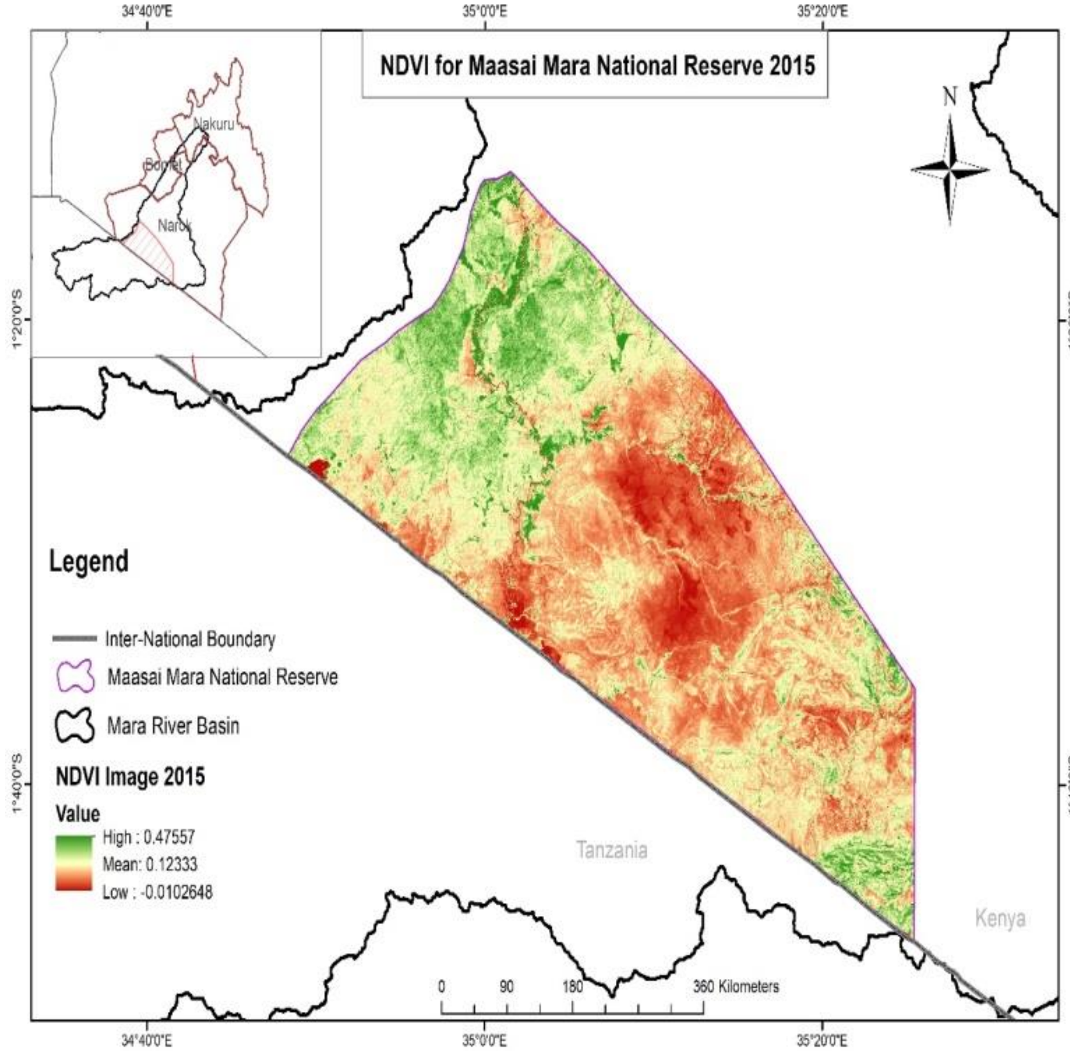

Figure 15: NDVI map for the year 2015

NDVI for the year 2018

The vegetation cover in 2018 was significantly better than in 2015, with high NDVI values of 0.5 and 0.4, respectively, with a lot of vegetation in the northwest portion of the reserve and a generally fair distribution of vegetation with an NDVI value of 0.5. This improvement in vegetation cover is ascribed to better rainfall and temperature conditions than in 2015, as illustrated in Fig. 16.

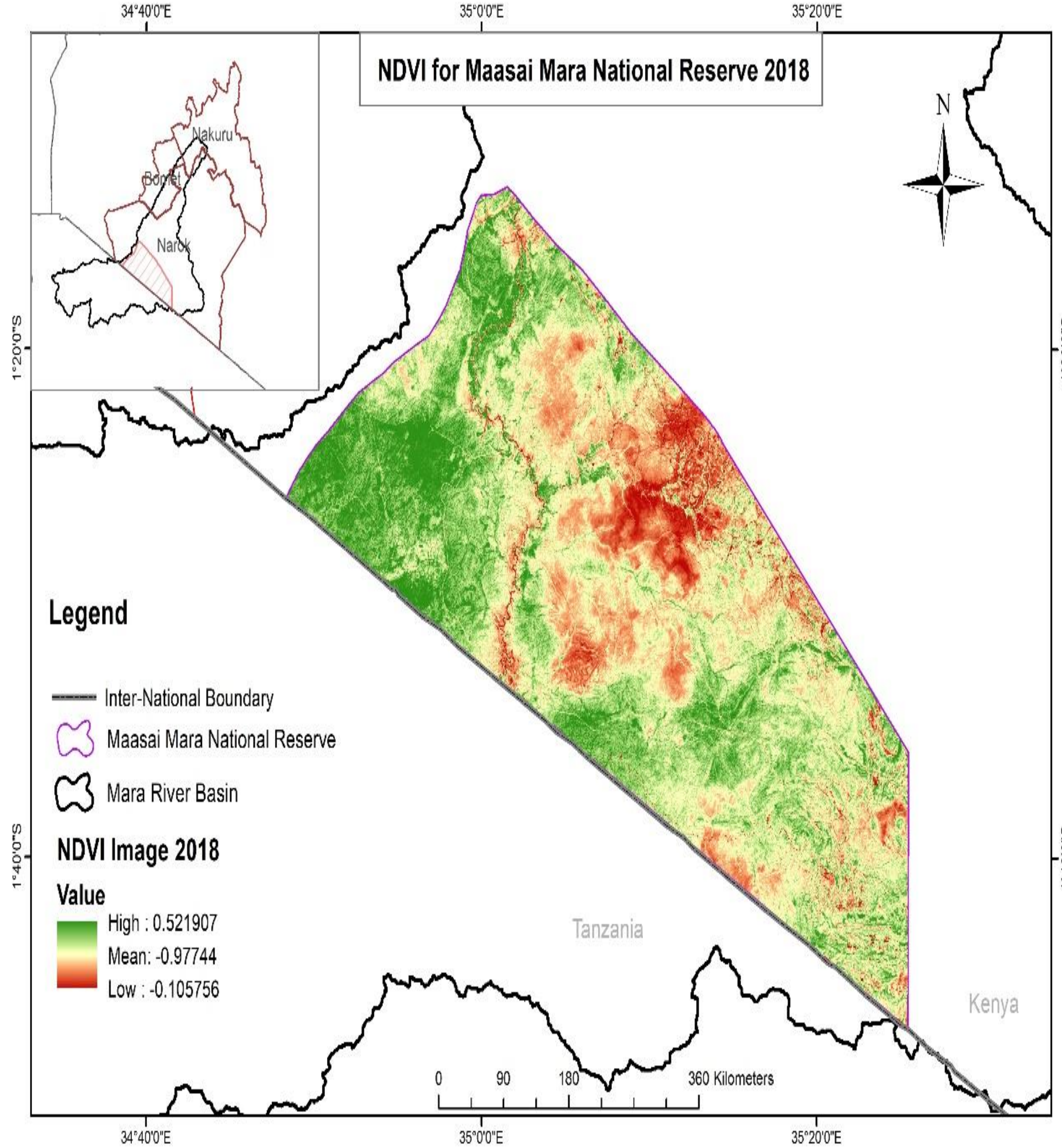

Figure 16: NDVI map for the year 2018

The NDVI analysis from 1975 to 2018 provides strong evidence that the MMNR has seen significant climatic changes over the past three decades. The analysis shows significant changes in NDVI values, which peaked in 1975 and then decreased by relatively small amounts until 1995. The years 1989–2000 was the worst affected, recording the lowest values of all the years, with nearly the entire area having less vegetation. This phenomenon may have been caused by high temperatures and little rainfall in 2000.

There was a significant change in the uniform distribution of greenness throughout the entire region between 2005 and 2010, which was bolstered by high rainfall and low temperatures during the same periods. The NDVI began to rise relatively in 2005 and continued to do so until 2010, although it was observed that NDVI values on the riparian areas along the Mara River do not change because of the year-round presence of water, which facilitates and maintains the steady healthiness of the surrounding vegetation.

According to the study area maps, there is a strong correlation between rainfall and the NDVI; if the rainfall is very strong, it reflects high plant material, thus high NDVI values, which improves the wildlife population while maintaining other factors. The NDVI values of 2015 and 2018 decreased significantly by greater margins, which can be attributed to a drastic change in both temperatures and rainfall. In conclusion, MMNGR has experienced climatic shifts for over 35 years that have resulted in NDVI reduction.

CONCLUSIONS AND RECOMMENDATIONS

Rainfall and temperature are important factors for wildlife survival in wilderness areas like parks and reserves because they determine the availability of forage. In general, drought and flooding conditions are indicators of climate change that hinder the growth of vegetation that wildlife depends on for survival. While other factors, like poaching, also contribute to the decline of wildlife populations, rainfall and temperature have a greater potential to affect wildlife populations because they are primarily responsible for the availability and abundance of forage. Park and game reserve managers must take climate change implications on wildlife population dynamics into account in their management operations and organizational policies so as to ensure tourism activities as well as visitor numbers are not significantly affected by these changes.

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