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Evaluating Human Pressure on Protected Areas in East Africa

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Abstract

Protected areas (PAs) are crucial to achieving effective conservation goals and mitigate the loss of biodiversity. I investigated the following research questions: How does human pressure threaten PAs in East Africa? Is human pressure associated with the factors of country, ecosystem characteristics, size, or governance type of a PA? For this study, I used a combination of a GIS analysis and case studies to evaluate human pressure on PAs in Tanzania and Kenya. For the GIS analysis, I used 589 terrestrial PAs from the World Database on Protected Areas (WDPA). Within each PA, I summarized the landform, landcover, moisture level, governance, size, and human impact. Human impact was measured using two datasets: the Temporal Human Pressure Index (THPI) to evaluate the change in human pressure from 1990 to 2010, and the Global Human Modification (GHM) dataset to evaluate the state of human pressure in 2016. I used summary statistics, scatterplots and boxplots to compare human pressure in PAs to the governance, size, and ecosystem characteristics. For the case study analysis, I focused on four different PAs in Tanzania and Kenya: Randilen Wildlife Management Area, Ngorongoro Conservation Area, Serengeti National Park, and Arabuko Sokoke Forest. I chose these specific areas because I visited them in Spring 2021, and they represent a variety of types and sizes of PAs. The case studies showed human experiences that were not evident from the GIS analysis. Overall, I identified that Kenya had more human pressure in its PAs than Tanzania. I also observed the PAs that had not reported a governance type had the highest increase in human pressure as well as the greatest state of pressure. Furthermore, I found that smaller PAs had more variability in human pressure than larger sized PAs and higher average human pressure. The case studies reinforced the findings of the GIS analysis. Randilen WMA and Arabuko Sokoke Forest, both characterized by small size and "Not Reported" governance type, had the highest increase in human pressure and impact in the current state of the case studies. These case studies offer a perspective on the relationships between managing organizations and the community, which is crucial to maintaining proper protection and reducing human pressure. On the other hand, Serengeti National Park and Ngorongoro Conservation Area both had high increasing pressure over time but a low average human pressure in 2016. These are some of the strictest PAs in Tanzania, and population growth has made it difficult to improve the welfare of the surrounding regions. Based on my results, I suggest that PAs should consider expanding their size, have effective collaboration between all stakeholders to promote the economic benefits of conservation to local communities, include education programs about the ecosystem as well as direct funding effectively to employ more staff to enforce regulations and proper supporting infrastructure within the PA.

Keywords

human pressure, protected areas, Temporal Human Pressure Index, Global Human Modification, Tanzania, Kenya

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Evaluating Human Pressure on Protected Areas in East Africa

by

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I affirm that I have upheld the highest principles of honesty and integrity in my academic work and have not witnessed a violation of the Honor Code. \ Bailey M. Ytterdahl

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ABSTRACT

Protected areas (PAs) are crucial to achieving effective conservation goals and mitigate the loss of biodiversity. I investigated the following research questions: How does human pressure threaten PAs in East Africa? Is human pressure associated with the factors of country, ecosystem characteristics, size, or governance type of a PA? For this study, I used a combination of a GIS analysis and case studies to evaluate human pressure on PAs in Tanzania and Kenya. For the GIS analysis, I used 589 terrestrial PAs from the World Database on Protected Areas (WDPA). Within each PA, I summarized the landform, landcover, moisture level, governance, size, and human impact. Human impact was measured using two datasets: the Temporal Human Pressure Index (THPI) to evaluate the change in human pressure from 1990 to 2010, and the Global Human Modification (GHM) dataset to evaluate the state of human pressure in 2016. I used summary statistics, scatterplots and boxplots to compare human pressure in PAs to the governance, size, and ecosystem characteristics. For the case study analysis, I focused on four different PAs in Tanzania and Kenya: Randilen Wildlife Management Area, Ngorongoro Conservation Area, Serengeti National Park, and Arabuko Sokoke Forest. I chose these specific areas because I visited them in Spring 2021, and they represent a variety of types and sizes of PAs. The case studies showed human experiences that were not evident from the GIS analysis. Overall, I identified that Kenya had more human pressure in its PAs than Tanzania. I also observed the PAs that had not reported a governance type had the highest increase in human pressure as well as the greatest state of pressure. Furthermore, I found that smaller PAs had more variability in human pressure than larger sized PAs and higher average human pressure. The case studies reinforced the findings of the GIS analysis. Randilen WMA and Arabuko Sokoke Forest, both characterized by small size and "Not Reported" governance type, had the highest increase in human pressure and impact in the current state of the case studies. These case studies offer a perspective on the relationships between managing organizations and the community, which is crucial to maintaining proper protection and reducing human pressure. On the other hand, Serengeti National Park and Ngorongoro Conservation Area both had high increasing pressure over time but a low average human pressure in 2016. These are some of the strictest PAs in Tanzania, and population growth has made it difficult to improve the welfare of the surrounding regions. Based on my results, I suggest that PAs should consider expanding their size, have effective collaboration between all stakeholders to promote the economic benefits of conservation to local communities, include education programs about the ecosystem as well as direct funding effectively to employ more staff to enforce regulations and proper supporting infrastructure within the PA.

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INTRODUCTION

Protected areas (PAs) are geographical regions that are recognized, dedicated, and managed through legal, or other efforts, to achieve the long-term goal of conservation of nature with associated ecosystem services and cultural values (IUCN, 2008). At the beginning of the twentieth century, there were few PAs designated for protection (Katz, 2018). However, there are currently more than 200,000 PAs that cover around 15% of the world's surface and 3% of the oceans (Katz, 2018; School of International Training, Lecture in Tanzania, 2021). PAs are crucial for harboring unique biodiversity and represent a commitment for future generations. Not only do they serve an ecological significance, but they can also hold immense economic and sociocultural importance.

In East Africa, which is defined as Tanzania, Kenya, Uganda, Rwanda and Burundi, there are almost 2000 designated PAs that cover around 30% of its lands (Riggio et al, 2019). This region not only has some of the highest concentration of biodiversity on the planet, but it is also characterized by its unique physical geography, such as the Great Rift Valley that creates its vast savannahs, large lakes, and high mountains (Sinclair et al, 2015). In the past, colonial powers established many of these PAs as hunting game reserves but following independence the lands were transformed into National Parks, Nature Reserves, Wildlife Management Areas, or Game Reserves (Riggio et al, 2019). The colonial strategy focuses on species which differs from other regions globally that created PAs due to low agricultural value (Riggio et al, 2019). Although there have been PAs in East Africa that have been downsized, they also continue to be expanded or established throughout the region, especially after the end of the colonial era by the post-independence governments for both economic and ideological reasons (Riggio et al, 2019; Nelson et al, 2007). For instance, in the last twenty years, Tanzania has created two new National

Parks, elevated two game reserves to National Park status as well as expanded the size of five existing parks (Riggio et al, 2019). Across many of these East African countries, PAs have the purpose of biodiversity conservation and to defend the larger, charismatic mammals, such as elephants, big cats, rhinos, and buffalo (Onditi et al, 2021). These animals are crucial to the tourism industry, which is a vital part of these country's economies, especially in Tanzania that earns around $700 million per year and accounts for 5 to 10% of their GDP (Nelson et al, 2007). Biodiversity within these PAs is also undeniably influential to a country's history, political environment, and policy initiatives (Onditi et al, 2021; Nelson et al, 2007). While East Africa has an extremely diverse system of PAs, they are facing unfortunate challenges due to human activities as society continues to develop and further expand in these regions.

One of the primary causes of rapid decline of biological diversity within PAs is the increasing human pressure on natural systems (Geldmann et al, 2014). As populations adjacent to PAs rise, the communities have the need to expand for resources and land, impacting the conservation goals (Walelign et al, 2019). Individuals in the surrounding communities rely on these ecosystems to provide numerous services, such as firewood, timber, medicine, grazing, and meat, which are essential to supporting livelihoods and growth (Riggio et al, 2019; Walelign et al, 2019). Such issues are particularly acute in East Africa, where the population increased by 6.7% from 2013-2017, twice the African average (UNECA, 2018). With the population growth of the region, there are detrimental impacts, such as exacerbating PA management problems, the exploitation of land and resources, and increased human-wildlife conflicts, which can lead to illegal activities, such as poaching (Rija et al 2013; Tranquilli et al 2014). Therefore, it is crucial to examine the human pressure on the PAs in East Africa to safeguard unique wildlife, ecosystem services and other natural resources.

An effective way to evaluate potential impacts of human pressure on PAs is through GIS modeling. There have been several studies on vegetation change of PAs in Kenya and Tanzania using GIS and remote sensing. A study about the Ngorongoro Conservation Area, located in Northern Tanzania, from 1975 to 2000 investigated the impact of the restrictive conservation policies that limited pastoral mobility to only highland areas (Niboye et al, 2010). By using remote sensing, the researchers were able to examine and visualize ecological trends over time due to policy changes since many human induced impacts in PAs can be reversible if addressed early (Niboye et al, 2010). Additionally using a GIS analysis, Riggio et al published a study in 2020 that overlaid and compared four recent global maps of human influences and where this land is located on the Earth. Across the four human pressure indexes, there were overlapping human stressors such as human population, human settlement, electrical power infrastructure, agriculture, and build-up areas, but there were also specific aspects to each dataset in the analysis. The researchers wanted to identify how much of Earth's terrestrial ecosystems were intact. Their findings suggested that half of the terrestrial surfaces have low human impact and provide favorable opportunities for conservation (Riggio et al, 2020).

Not only has GIS been used to evaluate human pressure around the world and vegetation change, but it has also been used to map the effectiveness of PAs. A GIS analysis by Geldmann et al in 2019 investigated the effectiveness of PAs at resisting anthropogenic pressures at a global level. To understand the geographical differences of human impact, the researchers split the world into the six ecoregions, including Afrotropics, Australasia, Indomalaya, the Nearctic, the Neotropics, and the Palearctic. The results found that between 1995 to 2010, there was the second largest increase of human pressure in the Afrotropics, especially higher within the PAs (Geldmann et al, 2019). By assessing PA data from 152 countries, their results have also indicated that there is a correlation between countries with low development scores and increases in human pressure over the 15-year period, leading to poor PA performance through factors such as "corruption, weak law enforcement and reduced engagement from stakeholders" (Geldmann et al, 2019). Similarly, there was a study in Kenya that examined the efficiency of PAs in relation to terrestrial animal ranges and the governance or designation types (Onditi et al, 2021). To effectively manage a PA, there must be significant conservation efforts and outcomes. Therefore, the researchers hypothesized that different governance types overlooking PAs will impact their management efficacies (Onditi et al, 2021). For instance, they assumed that the stricter-managed PAs will have a stronger ecosystem, which would increase the species diversity within them (Onditi et al, 2021). In the end, researchers identified that the stricter PAs in Kenya did not necessarily translate to better ecological conditions, increasing the species richness (Onditi et al, 2021). It is clear this study highlighted that PAs managed by governmental and non-governmental stakeholders contribute similarly to wildlife conservation (Onditi et al, 2021). However, they concluded to maximize the effectiveness of PAs and ensure the protection of terrestrial wildlife, there should be collaboration between organizations of all levels and establish clear guidelines for conservation efforts and outcomes (Onditi et al, 2021).

While previous studies have focused on threats to PAs or their effectiveness, little research has been conducted on the association between human pressure and various factors, such as the type of environment, country, size, or governance class of PAs in East Africa. It is crucial to perform this research to identify areas of high human pressure to create effective policies or enhance management decisions to expand the size of PAs or generate guidelines for their specific environments.

In this study, I considered the following questions: How does human pressure threaten PAs in East Africa? Is human pressure associated with the factors of country, ecosystem characteristics, size, or governance type of PAs? I defined human pressure in my project as the impact that humans have on a protected area with regards to stressors such as human population density, land use, agriculture, development projects and electrical power infrastructure. I examined the threats that endanger terrestrial PAs in East Africa, specifically in Kenya and Tanzania since these countries have some of the highest concentration of PAs. I evaluated the following hypotheses:

1. Kenya has, on average, more human pressure on PAs than Tanzania. I believe this will be the case because many of Kenya's PAs are adjacent to cities, especially near Nairobi.
2. Human pressure is associated with the strictness of governance within a PA. Federal or nationally managed PAs have the least human pressure while local community PAs have the highest. I believe that the federal or national governance will be more effective since they restrict many human activities to preserve the ecosystem within the PA.
3. Human pressure is negatively related to the size of a protected area in Tanzania and Kenya and the smaller PAs will have more stress. With smaller areas, PAs may not have the proper resources to mitigate human pressures.
4. Plains will be the landform most affected by human impact because this ecosystem is accessible and can fulfill human needs.
5. Cropland is the most prevalent landcover associated with the human pressure of PAs. I predict this because croplands are included as a human stressor in the indexes utilized.

6. Although this was questioned in the beginning of the analysis, I believe there will be no substantial relationship between human pressure and moisture levels because there is not much evidence on this characteristic being impacted.

To answer the research questions, I evaluated PAs in Tanzania and Kenya through Geographical Information System (GIS) to estimate the recent change and current state of human pressure working in combination with an analysis of case studies. The case studies included human experiences in four well-known PAs. This assisted to better comprehend or offer an insight to how anthropogenic pressures threaten PAs, discuss what PAs mean to the local communities, and consider additional stressors that may not be present within the human pressure indexes.

METHODS

Identifying and Characterizing PAs

I used the PA boundaries within Tanzania and Kenya found in the World Database on Protected Areas (WDPA). The WDPA compiles information on the marine and terrestrial PAs including the type of protected area, size (in square kilometers) and governance types based on the International Union for Conservation of Nature (IUCN) category and no-take status (World Database on Protected Areas, 2021). The IUCN distinguishes four broad PA governances, each with several sub-types that make a total of 11 types that are reported to the WDPA status (World Database on Protected Areas, 2021). There were originally 1100 PAs, where I then removed the marine or partial terrestrial PAs, redundant entries, as well as remaining NULL data. I took the size of PAs into consideration and eliminated the PAs that were smaller than 10-kilometers squared. In other words, the 10-kilometer squared was the size of a pixel in the Temporal Human Pressure Index (THPI) that helped to evaluate the change in human pressure over two decades. After refining the datasets, I relied on 589 terrestrial PAs in both Kenya and Tanzania (Figure 1). Using zonal statistics, I found the majority landform, landcover, and moisture class of each PA (World Terrestrial Ecosystem Database, Table 1).

Assessing Human Pressure within PAs

The Temporal Human Pressure Index (THPI) and the Global Human Modification (GHM) dataset were both used to evaluate the human pressure in the study area. These two datasets were used because the THPI evaluated the change over time, while the GHM portrays the closest current state of human pressure. The THPI includes spatial and temporal maps of global change in human pressure over two decades between 1990 and 2010 at a resolution of 10 kilometers squared (Geldmann, 2019). Based on the evaluation of 22 spatial datasets, the THPI is a proxy for human pressure based on three files: human population density, land transformation, and electrical power infrastructure (Geldmann et al, 2019). The standardized value within each pixel resulted in a scale of -100 to 100, where positive values indicated increasing human pressure while the negative values infer decreasing human pressure (Geldmann et al, 2019; Table 1).

The GHM was also utilized to evaluate the current state of human pressure in the base year of 2016. The GHM is a cumulative measure of terrestrial territories around the world at a 1-kilometer resolution (Figure 3). These data are continuous with a scale of 0 to 1 (low to high) reflecting 13 primary anthropogenic stressors, in the categories of human settlement, agriculture, transportation, mining, and electrical power infrastructure (Kennedy et al, 2018; Table 1). Using zonal statistics, I found the mean values for the recent change and current state of human impact within each PA.

Statistical Analysis

All statistical analyses were performed in SPSS software. To evaluate the relationship between landform, landcover, management categories and human pressure, boxplots were created (Table 1). For the landcover category, I disregarded settlement because only one PA in Kenya, Ngong Road, had a majority that was settlement. I identified the 5 subtypes of governance, but I omitted joint governance (shared governance) and for-profit organizations (private governances) because there was one PA for each. Additionally, I presented the relationship between the area (in square kilometers) and the human pressure of each PA with a logarithmic-scaled scatterplot.

Case Studies

I then produced a series of case studies on four different PAs, Randilen Wildlife Management Area, Ngorongoro Conservation Area, and Serengeti National Park in Tanzania as well as Arabuko Sokoke Forest in Kenya. I retained the information from notes, lectures, and interviews of my experiences abroad. For these specific examples, I identified their majority ecosystem types, the mean GHM, average change in human pressure as well as the percentiles in Excel to visualize where each case study falls out of all the PAs. The case studies are crucial since they complement the GIS analysis that provide an additional interpretation of the results by having human experiences that may not be included in the indexes. These case studies helped me contextualize the GIS analysis, comprehend how anthropogenic pressure threatens PAs and understand what PAs mean to the local people.

RESULTS

Country vs. Human Impact

Overall, I found that Kenya had higher human pressure on its PAs than Tanzania. The recent change from 1990 to 2010 identified that Kenya also had increasing human pressure (Figure 2). I observed that the current state of human pressure in Kenya also had a high average human pressure (Figure 3). For the mean THPI, there was an average of 5.33 for all PAs in Kenya, and only 2.05 in Tanzania. For the GHM, PAs are measured at 0.33 for Kenya and 0.23 in Tanzania (Table 2). In comparison to the country as a whole, Kenya had an average increase of 1.53 from 1990 to 2010 of human pressure with the change in Tanzania calculated to be 1.05. For the current state as an entire country, I calculated Kenya to have an impact of 0.23 and 0.25 for Tanzania. Therefore, Tanzania had slightly higher human pressure than Kenya in the base year of 2016. I found the most impacted PAs, for recent change and current state, out of all the PAs in the analysis were in Kenya. The top three highest impacted PAs over time were Kerrer Forest, Metkei Forest, and Katimok Forest. In 2016, the PAs with the highest human pressure included Ngong Hills, Ngong Road, and Bunyala (Forest Reserve). On the other hand, the lowest impacted PAs from 1990 to 2010 were Kyanayari Forest Reserve (Tanzania), Nyeri Forest Reserve (Kenya) and Jozani-Chwaka Bay National Park (Tanzania). In 2016, the least impacted PAs were identified as Tsavo East National Park (Kenya), Mt. Kenya National Park (Kenya) and Tsavo West National Park (Kenya).

Governance Type vs. Human Impact

I found that PAs that did not report a governance type experience higher and more variable human pressure than the remaining four governances (Figures 4 and 5). There were similar medians among the PAs managed federally, by Indigenous, local communities and non-profit organizations (Figure 4 and 5) The federal or national managements had many outliers in both the THPI and GHM (Figure 4 and 5). For the 'Not Reported' PAs in the THPI, there was a standard deviation of 12.39, and the GHM had a deviation of 0.16, both having the highest variability out of all governance types. In the THPI for the remaining four governances, the averages are positive, indicating an increasing trend of human pressure. However, they are still low. The GHM also identified higher levels of human pressure in the current state, but also considerably low for the remaining four governances (Table 4 and 5).

Size vs. Human Impact

I found the smaller sized PAs to have more variability of human pressure than the larger sized PAs (Figure 6 and 7). For the relationship between the average THPI of each PA and their size, there is a correlation value of r=0.02. This indicates there is no linear relationship between the two variables (Figure 6). On the other hand, I found that for the average human pressure in the current state, there is a correlation value of r = -0.27 (Figure 7). This suggests that there is a negative association and weak linear relationship between the current state of human pressure and size of a PA.

Landforms vs. Human Impact

The spatial distribution of the landforms included mountains stretching through the central clump of PAs near Nairobi, Kenya going south into PAs of Northern Tanzania (Figure 8). The plains in Kenya were found within smaller PAs along the coast, but in Tanzania the PAs are clumped where many of the plains and hills are located (Figure 8). I found that the recent change in human pressure decreased on tablelands while the mountains had the highest increase (Figure 9). The THPI produced comparable results among the other landforms (Figure 9). However, the current state of human pressure found tablelands to have the highest average out of all the landforms with a large IQR (Figure 10). Plains had the lowest mean of human pressure in the GHM (Figure 10). I found that the change in human pressure calculated tablelands to have the highest SD at 12.76 (Table 5). I identified that that SD in the GHM had similar values ranging from 0.11 to 0.15, indicating high variability among landforms (Table 6).

Landcover vs. Human Impact

I found the spatial distribution of the landcover in western and southern Tanzania to have a substantial number of PAs covered in forests that also stretch along the coast of Kenya. Croplands, shrubland and grasslands covered many the PAs in Northern Tanzania, especially where my case studies were located (Figure 11). For both recent change and current state, cropland had the highest average human pressure with a large IQR and variability (Figure 12 and 13). In the THPI, there was decreasing human pressure for grasslands, and similar averages for the remaining 3 landcovers (Figure 12). The sparsely or non-vegetated areas had the smallest level of human pressure, range and IQR (Figure 13). In the THPI, cropland had a M=3.97 and SD= 12.88 (Table 7). Supporting the THPI, croplands had the highest average human pressure in the current state, with M=0.39 and the SD=0.15 (Table 8).

Moisture vs. Human Impact

The spatial distribution of moisture levels was mostly dry in PAs in both Kenya and Northern Tanzania. The PAs in southern Tanzania were found in my analysis to be moist ecosystems (Figure 14). Overall, there was no major difference between the moisture levels. For the THPI, there was more human pressure in dry ecosystems between 1990 and 2010. The THPI also had many outliers in both moist and dry environments (Figure 15). However, the GHM indicates there were also prominent levels of human pressure in the current state in moist environments. There is a large quantity of upper outliers in the PAs with dry ecosystems (Figure 16). I found that there was an average THPI of 2.24 and a SD=11.42 and the dry environments had an average human pressure of 3.73 and a SD=7.90 (Table 9). The GHM had an average value of 0.29 in a moist ecosystem with a SD=0.13, and a mean of 0.25 for dry ecosystems and a SD =0.14 (Table 10).

CASE STUDIES RESULTS

I visited and researched four primary PAs in Tanzania and Kenya (Figure 1). These PAs are placed in the order in which I visited them while I was abroad in Tanzania and then traveled to Kenya (Table 11).

1. Randilen Wildlife Management Area, Tanzania

The Randilen Wildlife Management Area (RWMA) is in the Monduli district in the Arusha region of northern Tanzania. In the south of the PA, the borders are shared with the well-known National Park, Tarangire, home of the elephants. The WMA was originally established between 2011 and 2012 by 8 villages to create a protected corridor. These villages include Mswakini chini, Mswakini Juu, Naitolia, Lolkisale, Nafco, Oldonyo, Lemooti, and Lengoolwa. The people of these 8 villages are primarily Maasai, who are (Agro) pastoralists that are the dominant tribe in Northern Tanzania and have a history of tolerating wildlife on their lands (Benjaminsen et al, 2013). The livelihood diversification in many Maasai areas has led to an increase in agricultural cultivation and searching for work elsewhere (Benjaminsen et al, 2013). I was able to spend 3 days camping in Randilen WMA from February 18th, 2021, to February 20th, 2021. We were accompanied by two rangers in the park, 2 safari vehicle drivers and our professors. Most of the information of Randilen was learned from the visit to the rural village of Mswakini Juu, located on the northwest border of the WMA, the morning of February 19th, 2021, and had a round table with around 10 of the villagers. There were both men and women with different statuses in the village. Since the villagers spoke Maasai, there were translations that occurred between Maasai to Swahili to English.

Governance and Size

According to the Randilen WMA results, the area in squared kilometers was about 360.9 (Table 11). However, the resource management zone plan (2018) established that the size of Randilen was around 312 kilometers squared or 31,200.68 hectares of land. Similarly, the governance type of Randilen WMA was identified to be 'Not Reported' (Table 11). However, the Randilen Community Based Organization (RCBO) manages the PA and consists of the 8 local villages that make up the borders. By the local villages in Tanzania managing this PA, there is the goal through community management and wildlife conservation to achieve sustainable and tangible economic benefits that directly trickle to the local people through the tourism sector (Randilen Community, 2018).

There are both benefits and drawbacks of becoming a WMA. When we talked with the villagers from Mswakini Juu, many of the women addressed that the children benefited from the economic income. The children in the villages were able to go to school and move on to university. On the other hand, the men stated that through the governance of being a WMA, there were employment opportunities, such as becoming a ranger, developing campsites, stores, or other infrastructure. They also acknowledged that the village government and rangers were more responsive if crop raiding occurred by wildlife. By being in RBCO, the villagers had a voice in the governance process with village councils and through rangers. There were also disagreements among the villagers about some negative aspects of becoming a WMA, in which some stated that rangers or patrols were not enough, and there was an increased cost of living if livestock or crops were destroyed.

Ecosystems

I found that the majority landform covering the protected area was mountains (Table 11). The majority of the landcover was identified as cropland and the moisture was dry (Table 11). These results can be supported by my observations made while we did game drives and were present in Mswakini Juu. RWMA also only gets annually 500 to 800 millimeters of rain, making it a dry ecosystem (Randilen Community, 2018). Since the WMA includes Maasai villages, whose livelihood depends on agricultural cultivation, it is no surprise that the landcover is a majority cropland. Within this ecosystem, there are also a variety of fauna distinct to RWMA. For instance, we were able to find the critically endangered pancake tortoise, who has a soft shell adapted to fitting in small rock crevices. Other faunas include elephants, buffaloes, lions, giraffes and many more.

Human Pressure

According to the THPI dataset, the average human pressure of recent change was in the 67^{th} percentile. However, the average human pressure for the current state was in the 58^{th} percentile (Table 11). In other words, there was notable human pressure in both datasets, one displaying the increasing trend and the other demonstrating the current state. These indexes do not consider the economic well-being of the area or the type of livelihood that the people lead. All 8 of these villages have similar agricultural and pastoralist lifestyles, which becomes difficult when crops get destroyed through human-wildlife conflicts during the year. As we interviewed the villagers, they emphasized that the benefits of becoming a WMA were not seen until years later. Therefore, with the WMA having a population of 18,093 people, it becomes increasingly difficult to balance the population density near PAs, and the needed space for livelihood maintenance (Wilfred, 2010). In other words, it has been found there are some negative tradeoffs between rural communities' self-interests for the necessity of land use and the conservationists’ values in wildlife population (Wilfred, 2010). Some human land-use behaviors have been found to create fragmented habitats, limit wildlife dispersal, and decrease resources due to lack of diversification (Wilfred, 2010). The villagers of Mswakini Juu stated that it is possible to live with wildlife, but sacrifices are made for each village.

2. Serengeti National Park, Tanzania

The Serengeti-Mara Ecosystem in Tanzania spans over 40,000 square kilometers and considered to be one of the largest stretch of PAs on Earth. Specifically, Serengeti National Park (SNP) was founded in 1951, during the British Colonial Era in Tanzania. Originally Serengeti was designated as a “Closed Reserve,” which included the current area of SNP, Ngorongoro Conservation Area, and the Loliendo District (Randall et al, 2015). The closed reserve in the 1930s allowed nominally controlled hunting (Randall et al, 2015). However, the authorities did not enforce a strong policy. In 1937, the colonial government stated there would be a plan to establish a National Park system, which was outlined in the 1940s, but not finalized until the 1950s (Randall et al, 2015). Currently, SNP is one of 22 Parks in Tanzania and one of the most famous PAs in the world. I was able to visit Serengeti National Park from March 3, 2021, to March 6, 2021. We stayed at designated and developed campsites within the park. Throughout the three days, we went on game drives and performed road counts of wildlife to identify if there was a certain habitat in which species were associated. On this excursion, we had our professors as well as two safari drivers.

Governance and Size

According to the World Database on Protected Areas, the size of Serengeti National Park was estimated to be 13,038.70 square kilometers (Table 11). However, current studies estimate

SNP to cover around 14,763 square kilometers (Randall et al, 2015). Similarly, the WDPA identified the governance type to be Federal or National Ministry or Agency (Table 11). Specifically, SNP is managed strictly for conservation purposes and wildlife tourism (Thirgood et al, 2008). In Tanzania, National Parks are the highest level of protection there is for a PA. They preserve areas possessing exceptional values that illustrate the natural or cultural resources of the country (SIT Lecture in Tanzania, February 2021). Therefore, Serengeti National Park does not allow consumptive activities of wildlife or human settlement within the boundaries, unless it includes park staff, tourism staff and researchers (Thirgood et al, 2008). The parastatal organization that overlooks SNP is Tanzania National Parks Authority (TANAPA) which also comes under the jurisdiction of the Ministry of Natural Resources and Tourism (MNRT). During my experiences in SNP, the strictness of the governance was evident. For example, we were unable to leave the safari vehicles unless we were at a designated location, such as visitor centers or campsites.

Ecosystems

The zonal statistics found the majority landform in the PA as hills (Table 11). The majority of the landcover was found to be shrubland and the moisture of the ecosystem was dry (Table 11). The name Serengeti is derived from the Maasai word for *siringet* which translates to the great open space. From the entrance of SNP and to our campsite miles later, there were endless rolling plains and small shrubs. Therefore, the GIS analysis can be supported that majority landcover and landforms in Serengeti are hills and shrublands from surveying the land. Similarly, during our studies in the park, we drove through four distinct environments, observing wildlife in woodlands, grasslands, riverine habitats, and disturbed or impacted lands (such as campsites or areas with dense infrastructure). Many aspects of the Serengeti Ecosystem are shaped by migratory animals, such as the wildebeest, gazelle, and zebra populations (Sinclair et al, 2015). Other well-known fauna of the region includes big cats, such as lions, leopards, and cheetahs, or elephants, warthogs, hippos, buffalo, and hyenas.

Human Pressure

According to the THPI, Serengeti National Park had a slight increase in human pressure, belonging to the 48th percentile, placing this PA directly in the middle of the dataset (Table 11). However, the GHM identified that Serengeti, in the base year of 2016, was in the 8th percentile for human pressure, indicating the limited impact within the boundaries of the PA. In the early 2000s, SNP averaged $5.23 million per annum, and it has only increased over time (Thirgood et al, 2008). Although the tourism of the region brings numerous jobs and income, many people in the surrounding communities may not receive the benefits. I witnessed many settlements, in which I observed there were many agricultural and pastoralist tribes, who are encroaching upon the borders of the PA. Since it is one of the most famous parks in the world, I infer there are hotels, stores, and other attractions in the vicinity. It was found that the fertility rates of the surrounding districts are some of the highest in the country, with rates of 5.6 in the Shinyanga District and 5.9 in the Mara District (Serengeti Watch, 2021). I observed many patrols and rangers through the PA, ensuring that visitors were following the policies to limit human impact on the wildlife and ecosystem. Therefore, rather than witnessing human pressure within the boundaries of the park, there was a concerning level found along the borders.

3. Ngorongoro Conservation Area, Tanzania

Ngorongoro Conservation Area (NCA) is located directly adjacent to Serengeti National Park and 180 kilometers to the West of Arusha City. NCA was originally established in 1959 in accordance with the Ngorongoro Conservation Area Ordinance since the establishment of Serengeti National Park caused some tensions between the Maasai having to evacuate the area (Thirgood et al, 2008). NCA is not only known for the 12-kilometer, volcanic caldera, but also an extensive archaeological site that has evidence of human evolution and human dynamics (SIT Lecture in Tanzania, March 2021). I was able to visit this stunning area from March 6, 2021, to March 8, 2021, with the group of students, my professors and two safari drivers. We camped at a designated location on the mountainside overlooking the crater.

Governance and Size

According to the World Database on Protected Areas, the size of Ngorongoro Conservation Area is 8,257.30 square kilometers. The GIS analysis was fairly accurate relating to the size. Other studies have found NCA to expand 8,285 square kilometers (Thirgood et al, 2008). Similarly, the dataset identifies NCA governance type to be of federal or national ministry or agency. This PA is also a designated UNESCO World Heritage Site. More specifically, NCA is a multiple use area that combines the purpose of conservation of natural resources with authorized development for the Maasai, the primary Indigenous tribe in Northern Tanzania (SIT Lecture in Tanzania, February 2021). When I was driving in NCA, there were many bomas, or Maasai villages, dispersed among the mountain sides and tucked into the forests. I saw many Maasai grazing their livestock on the lands and had straw walls surrounding the village. However, as of April 2021, the new president of Tanzania evicted more than 80,000 Maasai from NCA, leaving their livelihoods and homes behind. Being overlooked by a federal institution, NCA is governed by the parastatal organization called the Ngorongoro Conservation Area Authority (NCAA) also under the authority of the Ministry of Natural Resources and Tourism or MNRT (Thirgood et al, 2008). Like Serengeti, the policy strictness was evident, having visitors not able to get out of their vehicles, unless at a designated site, such as visitor centers, campsites or ‘disturbed habitats.’

Ecosystems

The zonal statistics found the majority landform to be mountains (Table 11). The majority landcover is identified to be forest and a dry environment (Table 11). These results were supported by the various game drives through NCA. While we were driving into NCA, the landcover often changed from hills to dense tropical forests to grasslands. The mountainous landforms were strongly supported in my experiences since NCA is part of the Rift Valley and volcanic caldera. The center of the crater was where I was able to see an immense amount of fauna, such as lions, the critically endangered eastern black rhino (which is a main target of poachers) as well as other wildlife seen in SNP. While the GIS analysis gave an accurate portrayal of most of the ecosystem types, there were other unique highland plains, savannas, woodlands, wetlands, and tropical forests.

Human Pressure

According to the THPI, the human pressure over time was estimated to be in the 55th percentile (Table 11). However, the GHM identifies the level of human pressure in NCA to be in the 13th percentile in the current state (Table 11). NCA has many similar trends to Serengeti National Park since they are directly adjacent to each other. In the early 2000s, NCA averaged a revenue of $5.89 million per annum, which also continued to increase over time (Thirgood et al, 2008). As with SNP, the revenue was derived from tourism, entry, and camping fees (Thirgood et al, 2008). Although there is immense income from tourism, the remaining challenge is to improve the welfare of the surrounding region due to the increasing human population growth, as seen with SNP. Immense poverty can lead to poaching, resistance and more encroachment on the wildlife and ecosystem (Serengeti Watch, 2021). While there were Maasai living within the PA, I learned throughout many interactions with individuals from bomas that there is a strong sense of environmental stewardship in their culture. Maasai have learned the migration patterns and when to graze their animals in certain locations. However, they are being blamed for the degradation of NCA.

4. Arabuko Sokoke Forest, Kenya

Arabuko Sokoke Forest (ASF) is located along the coast of Kenya, about 110 miles north of Mombasa and 18 kilometers south of Malindi. The forest was originally established as a Crown Forest in 1932 and officially gazetted in 1943. However, there were extensions to the forest through the 1960s (Forest Management Plan Team, 2002). I was able to spend the morning at Arabuko Sokoke on March 29, 2021, in which we received a driving tour by a ranger and a short lecture, lasting about an hour, from a representative of the Friends of Arabuko Sokoke Forest (FoASF). FoASF is a nonprofit conservation organization that supports the management agencies and preservation of Arabuko Sokoke. The FoASF representative addressed their role with ASF as well as the various challenges that face the forest.

Governance and Size

According to the World Database on Protected Areas, the size of Arabuko Sokoke was estimated to be 370 kilometers squared (Table 11). However, current management plans measure ASF to be around 41,600 hectares of land, or 416 kilometers squared (Forest Management Plan Team, 2002). Before the 20th century, Arabuko was much larger than it is now, but continues to be one the largest remaining single block of ancient coastal forest in East Africa (Forest Management Plan Team, 2002). Similarly, the WDPA states that the governance had not been reported (Table 11). However, it is overseen by various partnerships, which include the Kenya Forest Service, Kenya Wildlife Service, Kenya Forestry Research Institute, and the National Museums of Kenya. The representative of FoASF addressed the fact that since there are multiple managing organizations, policies can be inconsistent and weak, leading to activities that further increase human pressure. It is also important to acknowledge that even though there are strict federal agencies that overlook the forest, there are zones that hold specific management practices.

Ecosystems

The zonal statistics found that the majority landform covering the PA were hills. The majority of the landcover was forest and the moisture was found to be dry (Table 11). These results were supported with observations made during my morning driving tour in Arabuko Sokoke, with dense forest cover and sand lining the roads. By observing the surrounding communities outside the PA, most of the landcover was agricultural fields. There were many instances where cropland and small infrastructure were directly located adjacent to the electrical fence separating the forest from the community. Within the ecosystems of the forest, there are a high number of endemic as well as rare plants and animal species (Forest Management Plan

Team, 2002). There are 6 globally threatened bird species, with the Clarke's Weaver and the Sokoke Scopes Owl being endemic to the forest and its surroundings (Forest Management Plan Team, 2002). Additionally, three globally threatened mammals are found here which include the Golden Rumped Elephant Shrew, the Sokoke bushy tail mongoose, and Ader's Duiker (Forest Management Plan Team, 2002).

Human Pressure

Although the average THPI indicates an increasing trend of human pressure from 1990 to 2010 in the 93rd percentile, the GHM dataset suggested a low human influence in the current state, belonging to the 37th percentile (Table 11). One aspect that the THPI and GHM do not consider is the economic well-being of the area. This can be a key factor in the analysis since it can have an impact on a region. The representative from FoASF addressed that there are approximately 54 villages that surround the forest, thus competing for the necessary resources. With many of the small rural livelihoods in the region, families were usually found in a state of poverty. Additionally, there are strong protections in place, making access to forest resources limited. Therefore, the unsustainable use of resources is an unfortunate impact from poverty (Forest Management Plan Team, 2002). During my experiences at ASF, we were also able to converse with the patrols of the forest. They stated that most illegal poaching or logging activity did not occur near the main headquarters or guard stations. Lastly, many of these indexes are not able to capture the relationships between the managing organizations and the community, which is crucial to maintaining proper protection and reducing human pressure. FoASF also focused on the relationship that they want to create with the surrounding forest communities. By creating education programs, employing community scouts, and introducing nature-based livelihoods, they can engage with the local communities on a personal level.

DISCUSSION

The purpose of this study aimed to assess whether human pressure is threatening PAs in East Africa, and if pressure was associated with country, ecosystem type, size, or class of governance. My hypotheses were supported when there was more human pressure on Kenya's PAs and cropland as well as identifying no substantial relationship between moisture levels. My hypothesis about the size of a PA was partially supported since there was such high variation between smaller PAs and pressure. In addition, my hypotheses were rejected in terms of governance types, expecting local community PAs to have the highest human pressure, and landforms, predicting that plains were going to have the greatest anthropogenic impact.

Human Pressure in PAs for Tanzania vs. Kenya

I found that the amount of human pressure within PAs, on average, in Kenya were higher than those in Tanzania. My hypothesis stated that Kenya was to have more pressure in PAs than Tanzania, thus supporting it. Both countries have increasing pressure, but it was found to be measurably low in the GIS analysis (Table 2). This result was unexpected since the spatial distribution of the GHM appeared to have increasing trends in the center and southwest of Kenya. There was also a long pattern of high human pressure on Kenya's coast, due to the issue of deforestation on coastal forests as seen with Arabuko Sokoke Forest (Figure 3). However, human pressure for the GHM remained mostly in Northern Tanzania (Figure 3). Between the two countries, Tanzania has the greatest coverage of strict PAs, which in my analysis was identified as federal or nationally governed PAs like Serengeti National Park or Ngorongoro Conservation Area, estimating to cover around 20% of Tanzania's land (Riggio et al, 2019). Therefore, by having a large span of different PAs, there continues to be an increasing trend of conservation efforts in the country (Riggio et al, 2019). By having more PAs, it can help establish what works well for certain ecosystems, sizes and governances. This can produce positive outliers, indicating low human pressure, overall impacting the average of the country. Other studies have found that anthropogenic pressures have been increasing within PAs, especially with the most notable changes in the tropics or areas surrounding the equator, which are primarily distinguished by a low HDI (Geldmann et al, 2019). There have been relationships established where PAs in regions with lower human development scores have not been able to efficiently mitigate threats of human pressure (Geldmann et al, 2019). Collectively, these studies suggest that PAs within each country have their own history, political and socioeconomic factors that can impact the human pressure of the region.

Governance Type and Size

In my analysis, I discovered that the PAs designated as 'Not Reported' have significant human pressure compared to the other governance types. My hypothesis stated that local community managed PAs would have more human pressure, while federal and nationally managed PAs would have the least. This was not necessarily supported in my analysis. It came to my attention that Arabuko Sokoke Forest, which is managed by multiple organizations of various levels in Kenya was considered as to not be reported. It is important to acknowledge that the WDPA relies on each country providing the necessary information for the general governance or IUCN category of PA. The variability within not reported governances may be justified by having smaller PAs that may have fewer resources than others. Many of the other governances were consistent and similar to one another. This was also found in previous research analyzing the effectiveness of PAs in Kenya in terms of terrestrial wildlife and their ranges within PAs (Onditi et al, 2021). Although there was more unique wildlife in state-managed PAs compared to privately governed, the diversity coefficients were comparable. In other words, the researchers identified that governmental and non-governmental stakeholders contribute similarly to conservation in PAs, mirroring many of the results of my GIS analysis (Onditi et al, 2021; Figure 4 and 5). For instance, the federally or nationally managed governances had similar average human pressure as those in local communities, Indigenous people, and non-profits.

It is important to recognize that in my analysis there are 418 PAs or 71% in both countries that are federally or have a national ministry or agency governing them. A study found that many strict PAs, typically managed by federal or national agencies, have experienced little human pressure, or less than 2% overall in East Africa (Riggio et al, 2019). In my analysis, Serengeti National Park, and Ngorongoro Conservation Area, two of the most well-known and strict PAs in Tanzania, had the lowest human pressure for recent change and in the current state. Although the stricter governance tends to be more encouraging for the reduction of human pressure, Geldmann et al. established formal protections can weaken collaboration between stakeholders, causing the overexploitation of previous sustainably used and managed resources (2019). Conservation strategies often incorporate initiatives to ensure the livelihoods of adjacent communities, but strict protection can also lead to the loss of various economic opportunities that result in illegal use of resources from PAs (Geldmann et al, 2019). Therefore, the researchers suggested that where PA management may be ineffective, tenure rights to unprotected lands may offer an alternative to unsustainable activities in the short term (Geldmann et al, 2019). In relation to my analysis, especially in the case study of Arabuko Sokoke Forest, governmental or national organizations attempt to collaborate with local communities to create economic opportunities or promote nature-based livelihoods since resources may have been lost due to PA designation. For instance, PAs can erode the authority and rights of many indigenous and local communities to "deter outsiders and providing opportunities for other people or companies to enter the reserve" (Geldmann et al, 2019, 23212). In response, PAs that follow community-based conservation techniques, such as Randilen WMA, can protect their grazing lands from outsiders and maintain authority over their ancestral lands. Several studies have supported the fact that indigenous and local communities can reduce certain human pressures, such as forest loss, sometimes more effectively than federal PAs (Geldmann et al, 2019). This was supported by my analysis with the lower means and standard deviations with Indigenous and local community governed PAs compared to the other types (Table 3 and 4). However, it should be acknowledged that in the case study of Randilen WMA, a community owned reserve, there was some of the highest human pressure change that belonged to the 67th percentile and the current state in the 58th percentile. To mitigate the amount of human pressure in a PA, the type of government management is vital to consider.

The relationship established between the size of a PA and the human pressure indexes was surprising. My hypothesis stated that human pressure was negatively related to the size of a PA and smaller PAs having more stress. With both the results from the recent change and current state of human pressure, the variability decreased as the size of a PA got larger (Figure 6 and 7). With small PAs, there were values that ranged from a high of over 0.8 in the GHM and almost 40 in the THPI. Similarly, they also reached a low of almost 0 in the GHM and -50 in the THPI. In other words, the smaller area PAs had more inconsistency and unpredictability than the larger area PAs. It came to my attention that Arabuko Sokoke Forest and Randilen Wildlife Management Area were the smallest PAs of the case studies and had not reported their governance types. It was also then found that they both had the highest increase in pressure and in the current state. This made me question if this was due to the corresponding economic resources that were available or lack of them. According to Bertrand Chardonnet, a protected area and wildlife consultant in Africa, it is a necessity to consider the size of a PA and whether it should be increased. Chardonnet stated that by expanding the boundaries of a PA, there is the "maintenance of ecological integrity, enhancement of biodiversity and biological representation, economic viability, minimization of threats, [and] the enhancement of management effectiveness" (Chardonnet, 2019, 11). Increasing the boundaries of a PA, where feasible, can lead to a decrease in the density of human-wildlife conflicts which tend to be more prevalent with the demographic growth of Africa, with East Africa having the highest rate (Chardonnet, 2019). Overall, this variance for the size of the PA and pressure indexes was an incredibly important finding to address.

Ecosystem Types

In terms of the ecosystem characteristics, my hypotheses were both supported and rejected. It can be supported that cropland had the most human pressure and there was not a well-established relationship between moisture levels. However, my hypothesis can be rejected where plains were predicted to have the highest human pressure. It was found that, on average, plains had the lowest human pressure. It was also interesting to address that while the THPI found tablelands to have decreasing human pressure, the GHM found tablelands to have the highest average human pressure in the current state (Figure 9 and 10). This may be explained by a change in lifestyle due to climate, vegetation, or resources available in the region.

Cropland, having the highest level of human pressure, can be supported by both the GIS analysis and various case studies, such as Arabuko Sokoke Forest and Randilen WMA. As of 2015, there is still a certain degree that habitats within a PA are converted for anthropogenic use (Riggio et al, 2019). Surprisingly, this conversion is low, that is estimated to be around 6.8% (Riggio et al, 2019). It is important to acknowledge that this estimate may be low due to the action of degazetting or decreasing the size of the establishment (Riggio et al, 2019). Although my hypothesis regarding plains was rejected, many savannahs in the last 50 years have been converted to human used agriculture across Africa (Geldmann et al, 2019). It is also important to recognize that while cropland had the highest mean and variability, it was used in both the human pressure indexes to calculate the datasets, in the categories of land transformation or agriculture, so it was no surprise that this landcover stood out from the other natural ones.

Lastly, my analysis supported my hypothesis that there was not a significant difference between the two moisture levels. It should be acknowledged that many of the PAs in moist environments were found in regions of proximity to large bodies of water, especially Lake Victoria. A previous study based on a GIS analysis of wilderness areas around the world, established that more temperate biomes did not have concentrated human pressure (Anderson and Mammides, 2020). Conversely, wild areas in more tropical biomes were increasingly impacted by anthropogenic activities (Anderson and Mammides, 2020).

Limitations and Future Research

Although this study provides evidence for human pressure impacting several defining factors of PAs in Tanzania and Kenya, there are many limitations to the datasets used in the analysis. In addition, future research will be beneficial to consider other components not included in this study to create the necessary policy and take proper action.

Although the World Database on Protected Areas is one of the most widespread global databases for PAs, it is neither complete nor perfectly accurate since it depends on country submissions (OECD, 2019). The GIS areas that were measured in squared kilometers given within this dataset were different from the actual sizes of the PAs, especially those found in the case studies. However, it is important to acknowledge that many regions are consistently changing due to management or policy requirements at both a local and national level. Similarly, not all PAs were included in the WDPA since they were smaller or locally owned. Although few were found missing, this occurred with Randilen WMA, which had to be separately added to the analysis.

The human pressure datasets have their limitations as well. While the THPI and GHM offer in-depth analyses of human pressure, they still lack many other dimensions of threats on PAs, such as invasive species, climate change, poaching, fire regimes and other illegal resource use, which may be difficult to track but existent on many occasions (Geldmann et al, 2019). Therefore, the THPI and GHM serve only as fractional measures of assessing pressure within and around PAs (Geldmann et al, 2019). However, this limitation was taken into consideration to an extent with the utilization of case studies to complement the GIS analysis.

Due to the availability of the datasets used in my analysis, this study can be replicated to look at more specific anthropogenic activities that may impact PAs. Although there were relationships found between human pressure and specific factors, it would be valuable to investigate if there is a relationship or correlation between size and governance type of a PA. A potential study that could also be beneficial to the future of PAs is the creation of buffer zones around specific case studies and perform a similar analysis in the surrounding regions. According to Chardonnet (2019), there should be a 3-10-kilometer buffer zone that restricts certain activities that may be harmful to PAs (17). Similarly, it would be interesting to address the economic activity or further the understanding of HDI around a well-known PA and if there is a relationship with encroaching human pressure.

CONCLUSION

My analysis addressed if distinct factors of PAs in Tanzania and Kenya are associated with increasing levels of human pressure using two different indexes that measured the impact over time and one in a single base year. It was found that all PAs in Tanzania and Kenya had human pressure. It is notable that the categories, such as landforms and moisture, had similar trends among human pressure. However, smaller PAs and those that had not reported a governance were found to have high variability. This was observed in my case studies, where Arabuko Sokoke and Randilen WMA had the highest increase and state of human pressure. On the other hand, Serengeti National Park and Ngorongoro Conservation Area were the strictest and largest PAs, which had measurably low human impact.

The results of my analysis can have important policy implications for PAs in both Tanzania and Kenya. To mitigate the levels of human pressure, effective policy is essential to ensuring positive conservation outcomes in the various PAs. This study helps support the idea that different management authorities of PAs should meet regularly to reassess techniques to maintain them and remain on track for their conservation goals. Based on my results and insights from the case studies, it can be beneficial to identify why PAs that have not reported a governance have higher human pressure or more variability, including reasons like underfunding, understaffing, or if there is competition between management authorities and local communities. I also recommend that PAs consider expanding their size where it is feasible. Based on suggestions from case study communities, there should be more direct finances for supporting infrastructure, education programs or more PA staff to enforce regulations. It was also identified that there should be protections that can effectively integrate the collaboration of various stakeholders and local players of a PA.

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TABLES AND FIGURES

Table 1. Data table displaying all the layers utilized in this analysis.

Name	**Who Created**	**Time Valid For**	**Description**
Tanzania and Kenya Boundaries	ESRI Africa	2021	Shapefile of the administrative boundaries of the countries in Africa.
Randilen Wildlife Management Area	Ministry of Natural Resources and Tourism	N/A	Shapefile with the boundaries of Randilen WMA in Tanzania.
World Database on Protected Areas (Tanzania and Kenya)	UN Environment Programme World Conservation Monitoring Center	2021	Shapefile of all the marine and terrestrial protected areas in Kenya and Tanzania, including information about governance (Federal/national, Indigenous people, local communities, non-profit, and not reported), size, and country.
World Terrestrial Ecosystem Database	ESRI	2020	This raster classifies the world into areas of similar climate (dry and moist), landform (mountains, tablelands, plains, hills) and landcover (sparsely or non-vegetated, grassland, shrublands, forest, cropland and settlement)
Temporal Human Pressure Index (THPI)	Jonas Geldmann, Lucas Joppa, and Neill D. Burgess	2019	Spatial and temporal raster of global change in human pressure from 1990 and 2010 at a resolution of 10 kilometers squared.
Global Human Modification	Christina M. Kennedy, James R. Oakleaf, David M. Theobald, Sharon Baruch-Mordo, Joseph Kiesecker	2018	Raster is based on the spatial extent and intensity of human activities and based on 13 stressors.
Regional Cities-East Africa	ArcGIS Online-HiFrank	2020	Points in locations of major cities in East Africa, specifically national and regional capitals.

Table 2. Each country with the average human pressure in each index (THPI and GHM)

Country	***THPI***	***GHM***
Tanzania	2.05	0.23
Kenya	5.33	0.33

Table 3. The THPI and Governance Type of PAs in Tanzania and Kenya

Governance	***Median***	***Mean***	***Standard Deviation***
Federal	2.50	2.18	8.80
Indigenous	2.00	2.76	4.20
Local Community	2.71	2.26	7.34
Non-Profit	2.11	3.18	9.00
Not Reported	8.99	8.14	12.39

Table 4. The GHM and Governance Type of PAs in Tanzania and Kenya

Governance	***Median***	***Mean***	***Standard Deviation***
Federal	0.21	0.23	0.10
Indigenous	0.22	0.20	0.07
Local Community	0.21	0.22	0.08
Non-Profit	0.23	0.26	0.07
Not Reported	0.46	0.46	0.16

Table 5. The THPI and Landform Type of PAs in Tanzania and Kenya

Landform	***Median***	***Mean***	***Standard Deviation***
Mountains	3.84	4.25	9.30
Tablelands	-0.12	-0.67	12.76
Plains	1.68	2.15	9.09
Hills	1.46	1.82	8.81

Table 6. The GHM and Landform Type of PAs in Tanzania and Kenya

Landform	***Median***	***Mean***	***Standard Deviation***
Mountains	0.26	0.29	0.15
Tablelands	0.36	0.33	0.15
Plains	0.18	0.21	0.11
Hills	0.21	0.22	0.12

Table 7. The THPI and Landcover Type of PAs in Tanzania and Kenya

Landcover	***Median***	***Mean***	***Standard Deviation***
Sparsely or Non-Vegetated	0.87	2.92	4.00
Grassland	-0.09	-0.85	6.28
Shrubland	3.85	4.21	6.76
Forest	2.26	2.53	8.32
Cropland	5.11	3.97	12.88

Table 8. The GHM and Landcover Type of PAs in Tanzania and Kenya

Landcover	***Median***	***Mean***	***Standard Deviation***
Sparsely or Non-Vegetated	0.13	0.16	0.09
Grassland	0.17	0.18	0.11
Shrubland	0.20	0.22	0.11
Forest	0.21	0.22	0.10
Cropland	0.36	0.39	0.15

Table 9. The THPI and Moisture of PAs in Tanzania and Kenya

Moisture	***Median***	***Mean***	***Standard Deviation***
Moist	2.11	2.24	11.42
Dry	3.72	3.73	7.90

Table 10. The GHM and Moisture of PAs in Tanzania and Kenya

Moisture	***Median***	***Mean***	***Standard Deviation***
Moist	0.26	0.29	0.13
Dry	0.22	0.25	0.14

Table 11. Comparisons between the case study location for the GIS analysis

Case Study and Country	**Area (Km^2)**	**Governance**	**Landform Majority**	**Landcover Majority**	**Moisture Majority**	**THPI Mean and Percentile**	**Global Human Modification Mean and Percentile**
Randilen Wildlife Management Area (TZA)	360.90	Not Reported	Mountains	Cropland	Dry	6.30 67th Percentile	0.30 58th Percentile
Serengeti National Park (TZA)	13038.70	Federal or national ministry or agency	Hills	Shrubland	Dry	2.80 48th Percentile	0.10 8th Percentile
Ngorongoro Conservation Area (TZA)	8257.30	Federal or national ministry or agency	Mountains	Forest	Dry	3.80 55th Percentile	0.10 13th Percentile
Arabuko Sokoke Forest (KEN)	373.50	Not Reported	Hills	Forest	Dry	16.0 93rd Percentile	0.20 37th Percentile

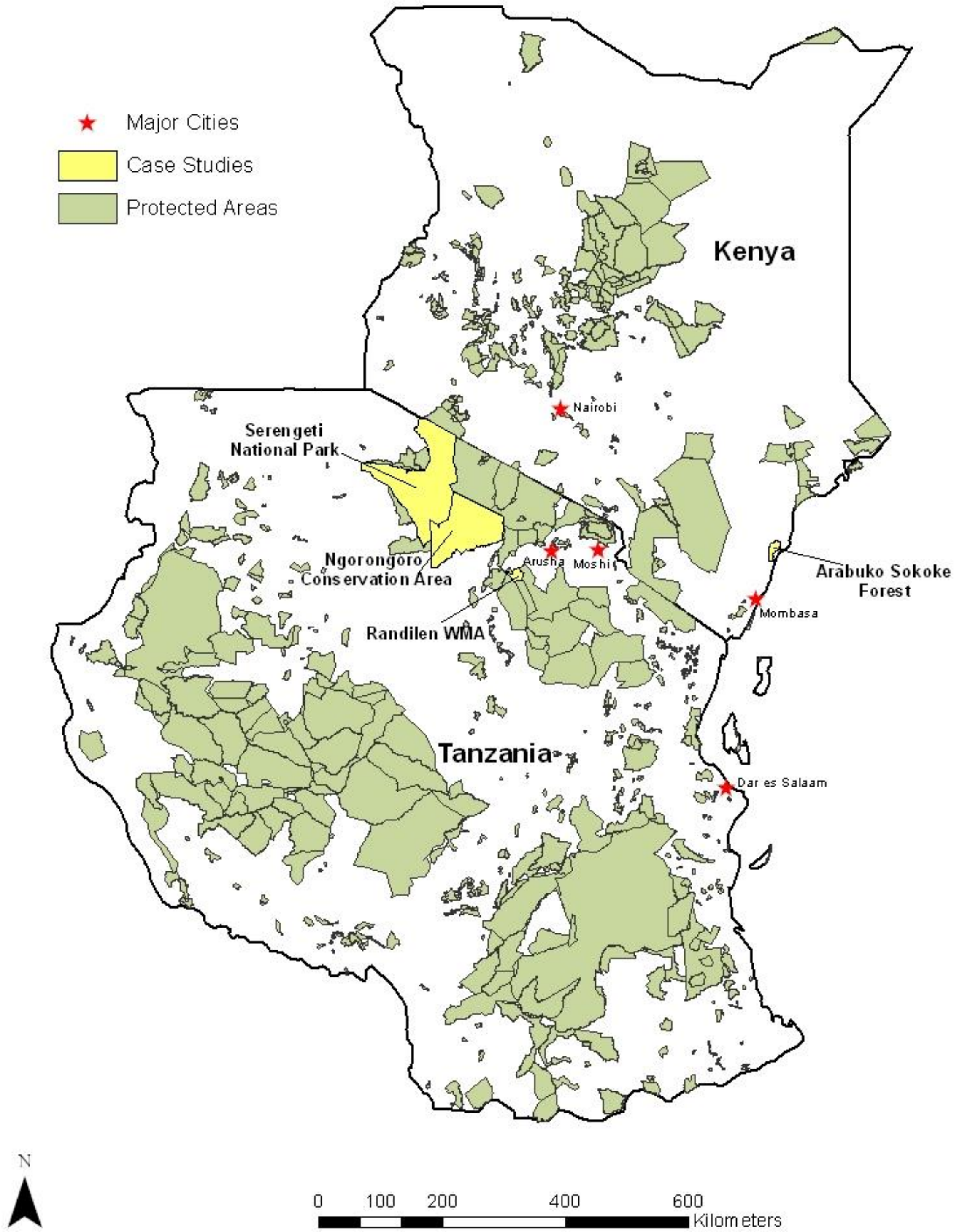

Figure 1. Study Area and Case Studies, highlighted in yellow, of the PAs in Tanzania and Kenya.

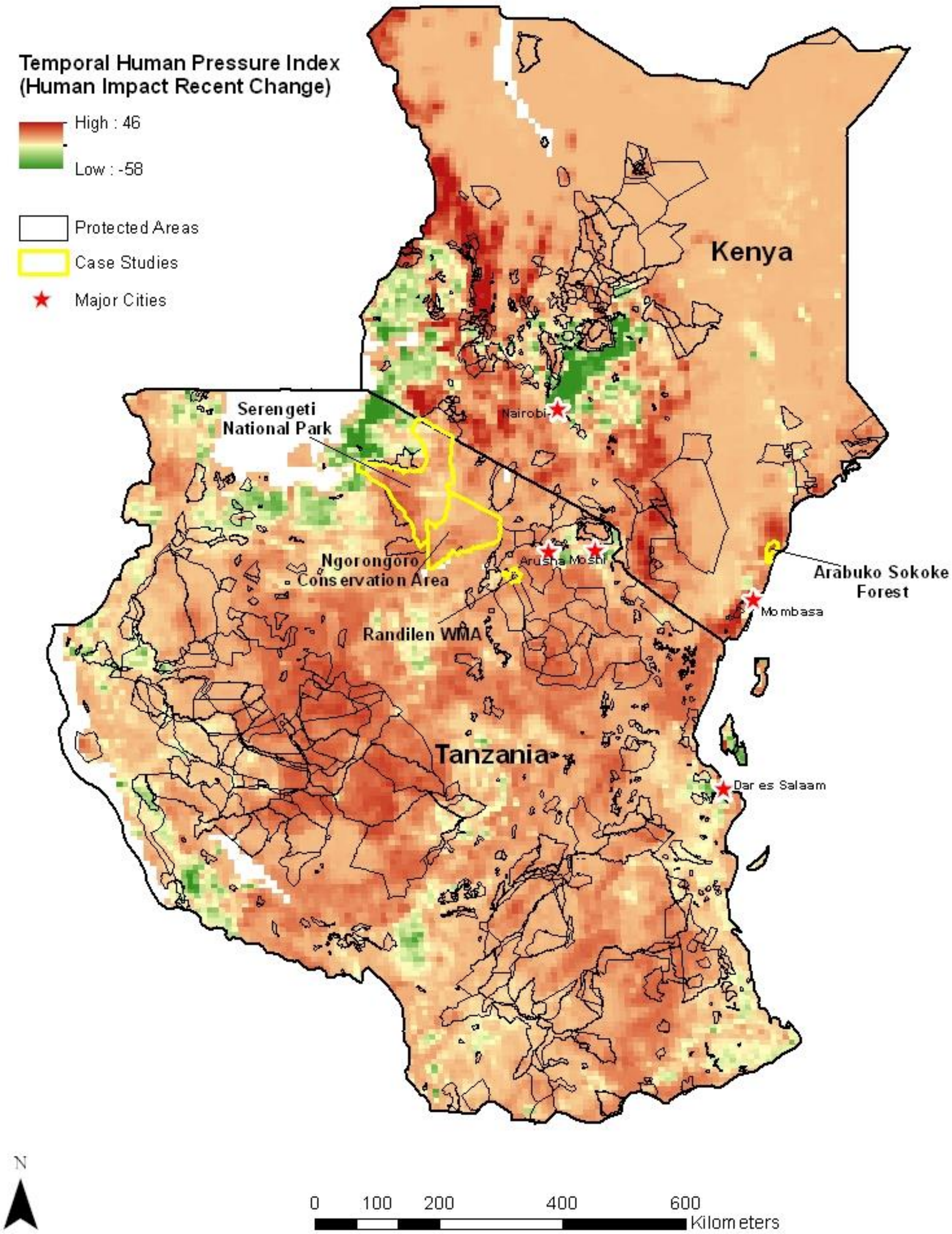

Figure 2. The spatial-temporal distribution of human pressure from 1990 to 2010. There has been increasing human pressure in all the PAs in Tanzania and Kenya over time.

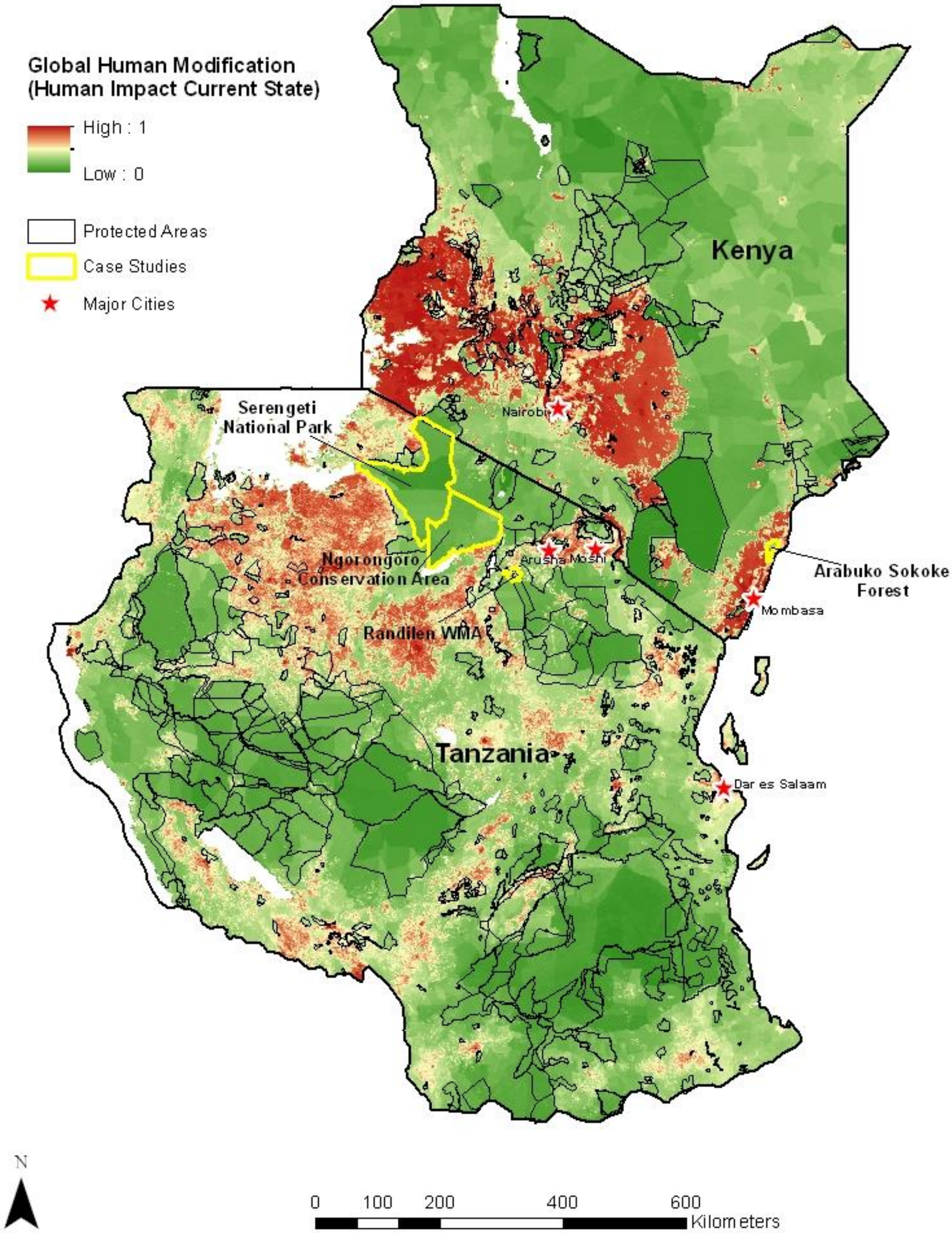

Figure 3. The spatial distribution of the current human pressure state in 2016 in relation to the PAs. There is immense human pressure in Kenyan PAs, especially near Nairobi.

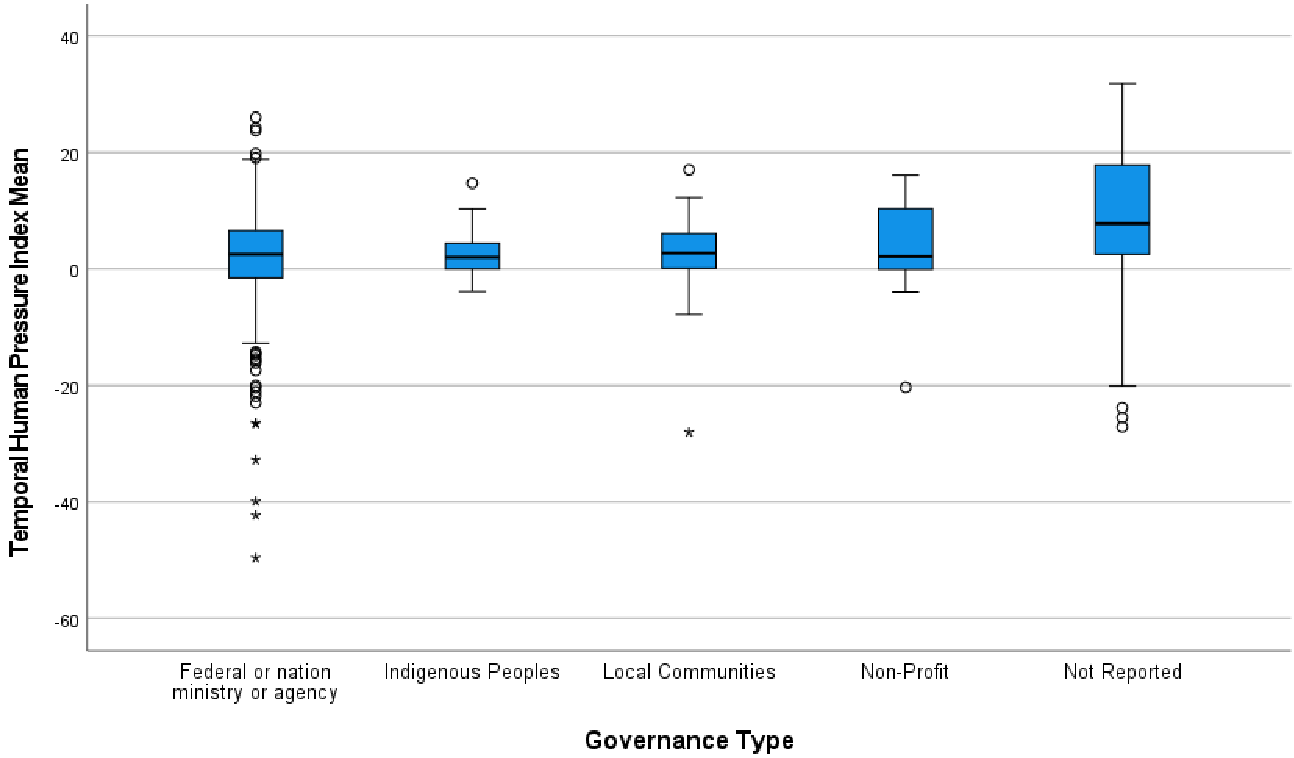

Figure 4. The relationships established between the THPI and Governance Type

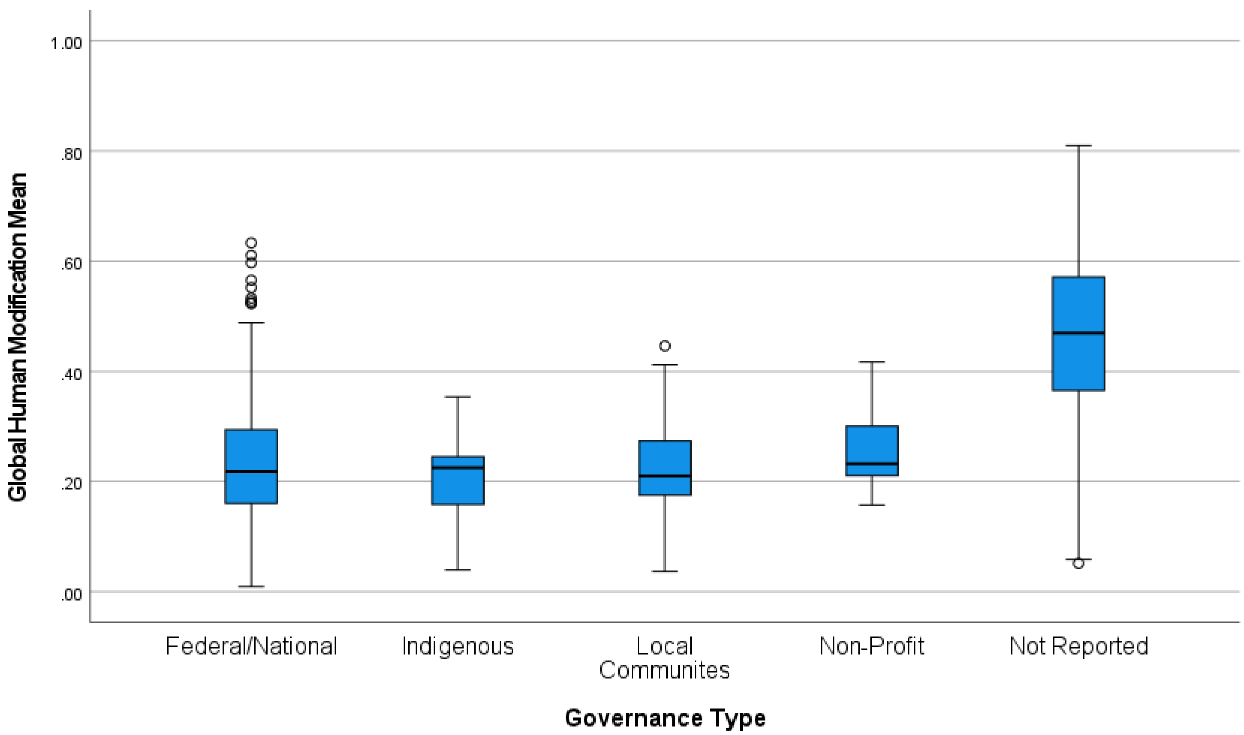

Figure 5. The relationships established between the GHM and Governance Type

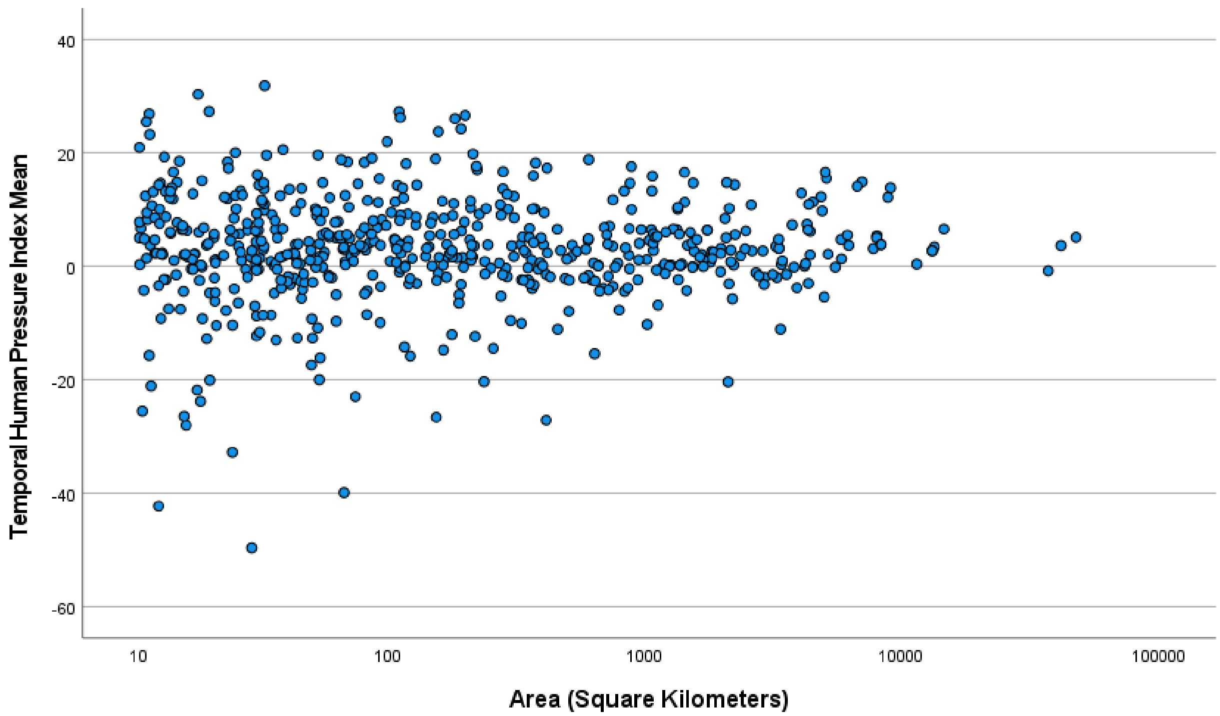

Figure 6.The relationships established between the THPI and the area of each PA

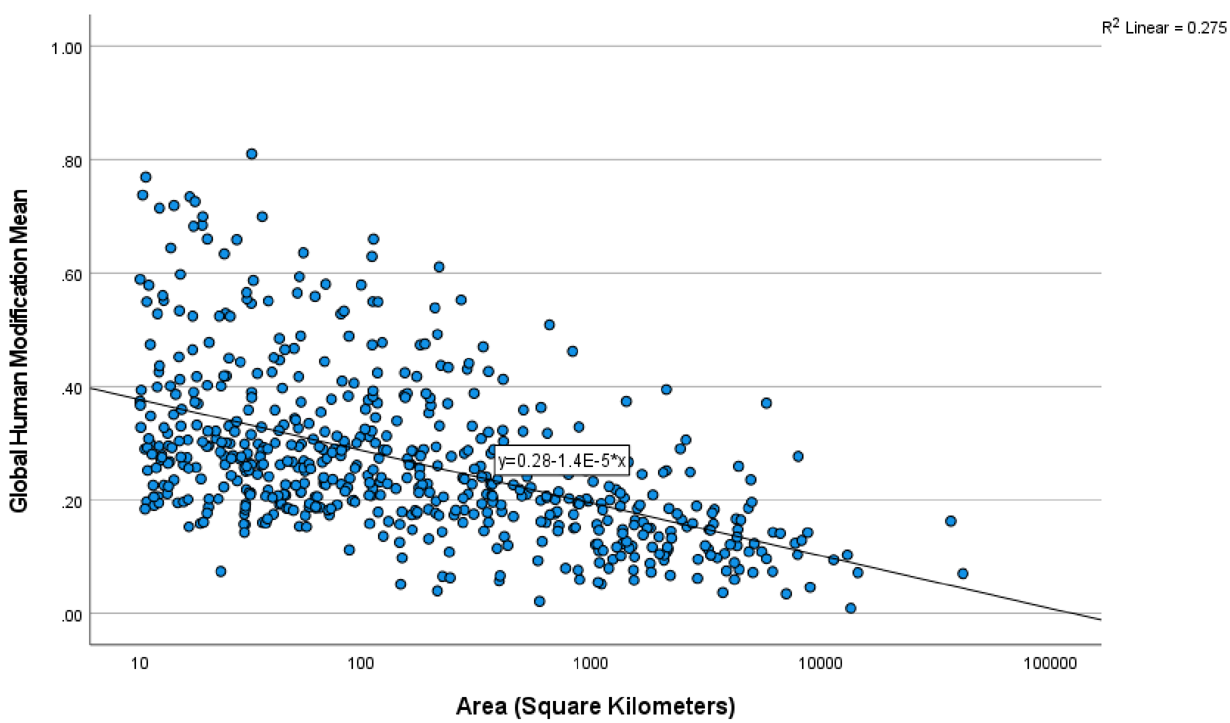

Figure 7. The relationships established between the GHM and the area of each PA

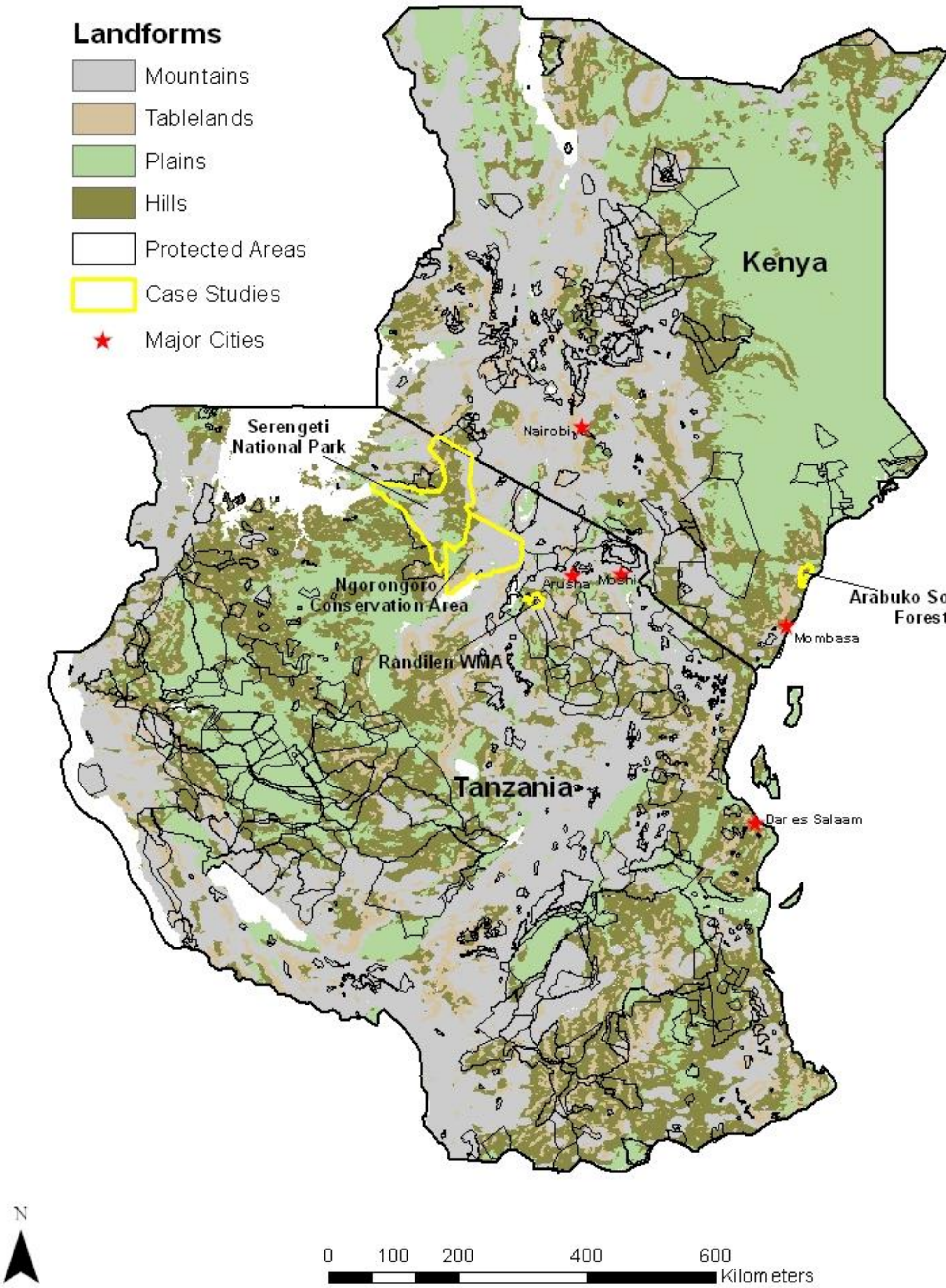

Figure 8. The spatial distribution of the different landform types and PAs in Tanzania and Kenya using the World Terrestrial Ecosystems Database.

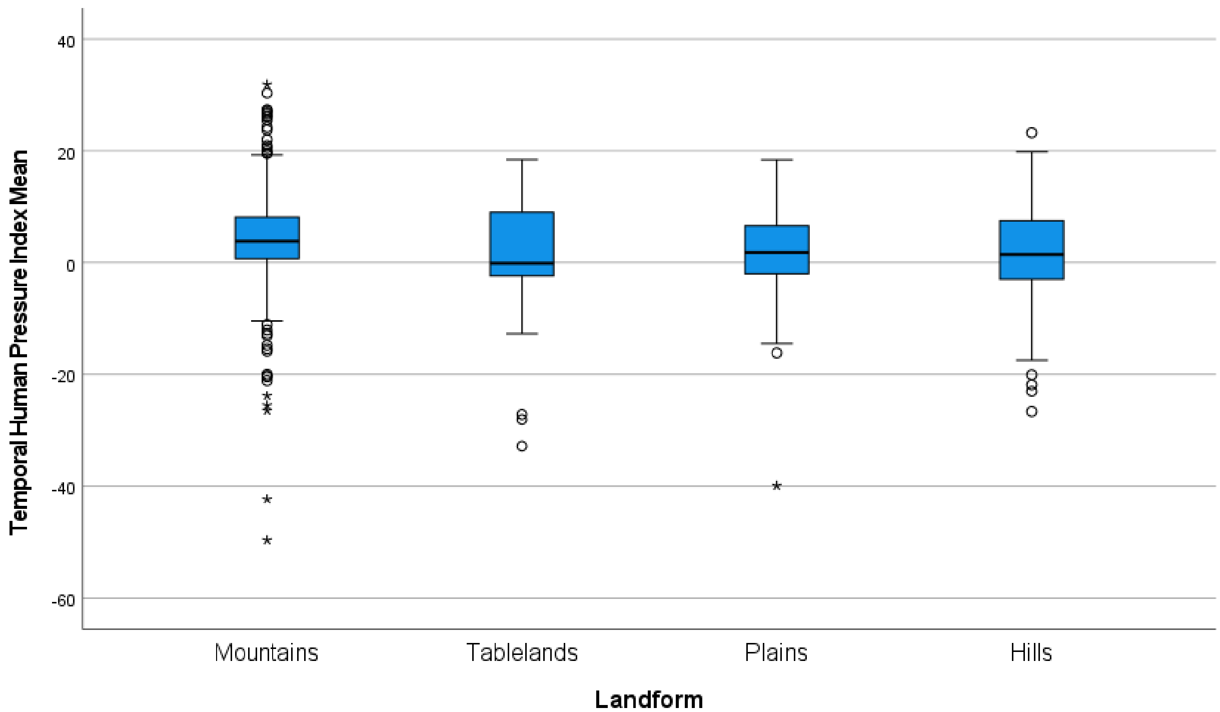

Figure 9. The relationships established between the THPI and Landform type

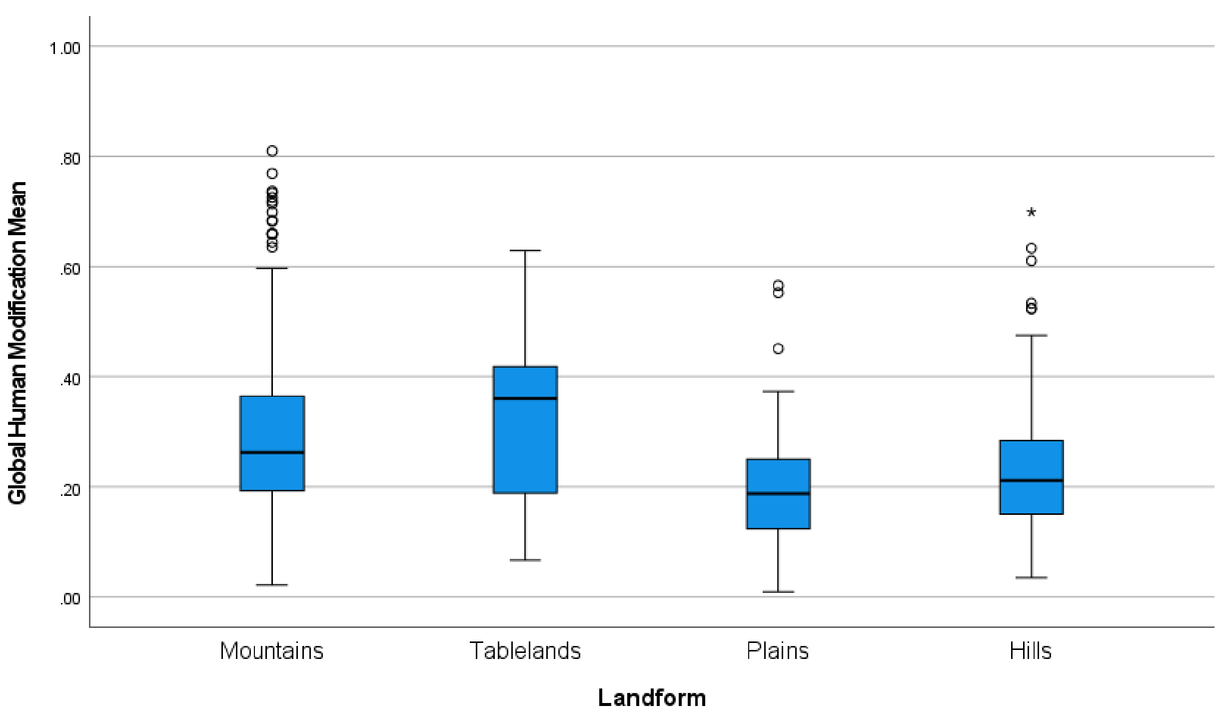

Figure 10. The relationships established between the GHM and Landform Types

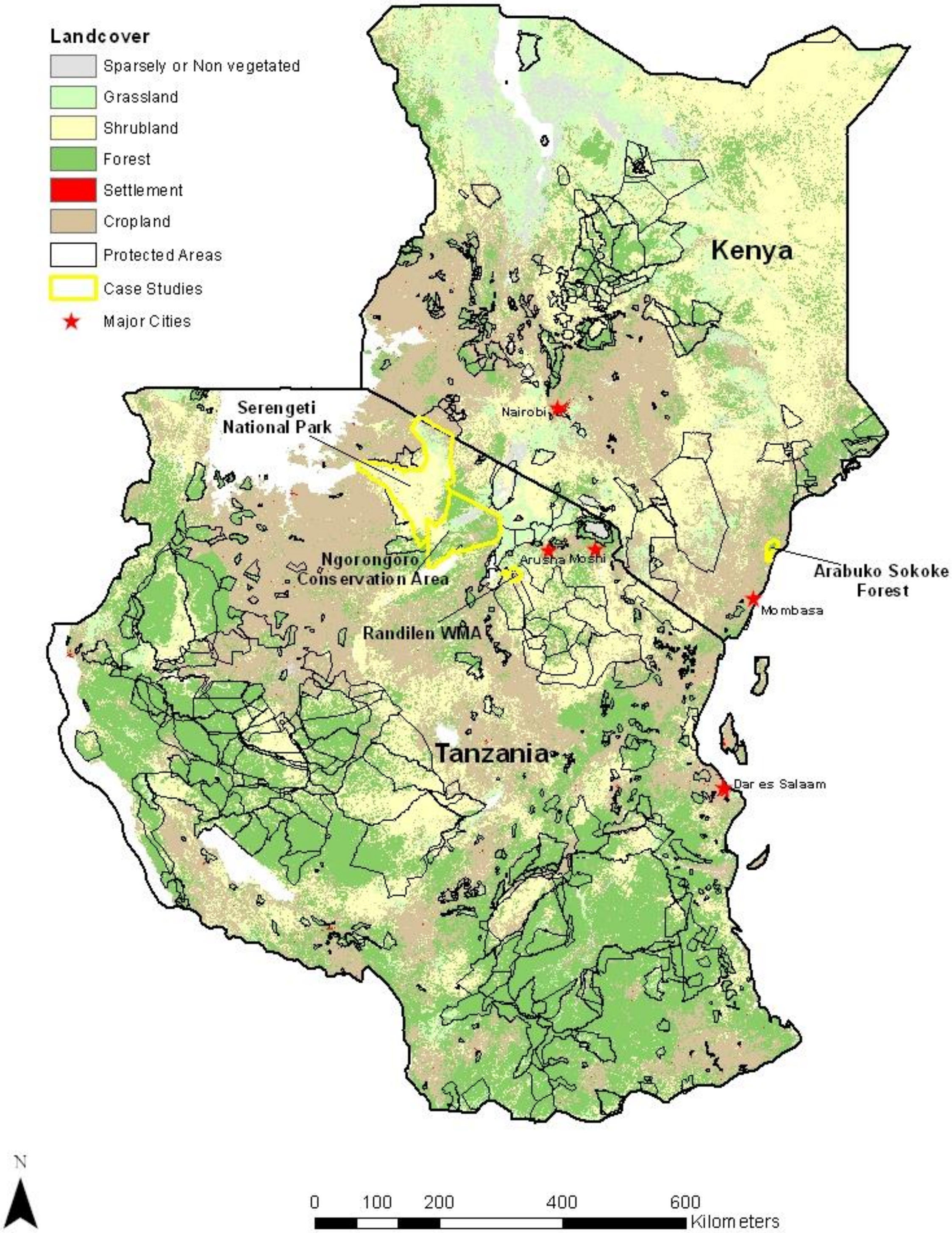

Figure 11. The spatial distribution of landcover types and PAs in Tanzania and Kenya using the World Terrestrial Ecosystems Database.

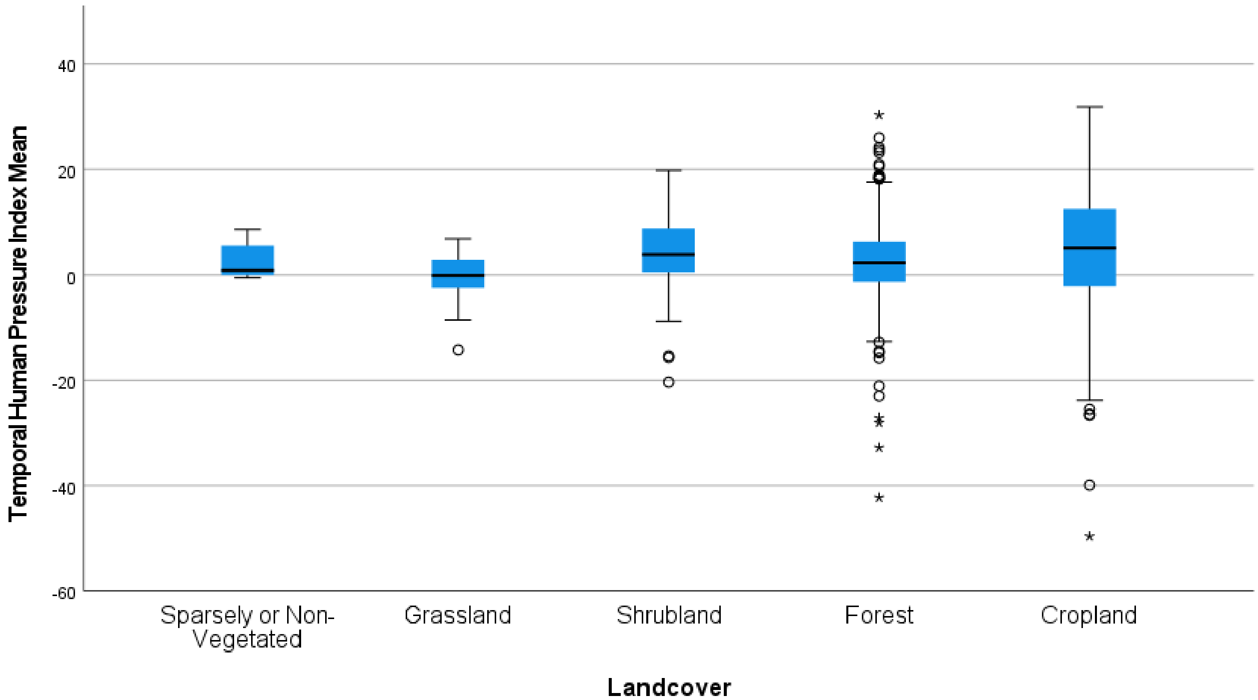

Figure 12. The relationships established between the THPI and Landcover

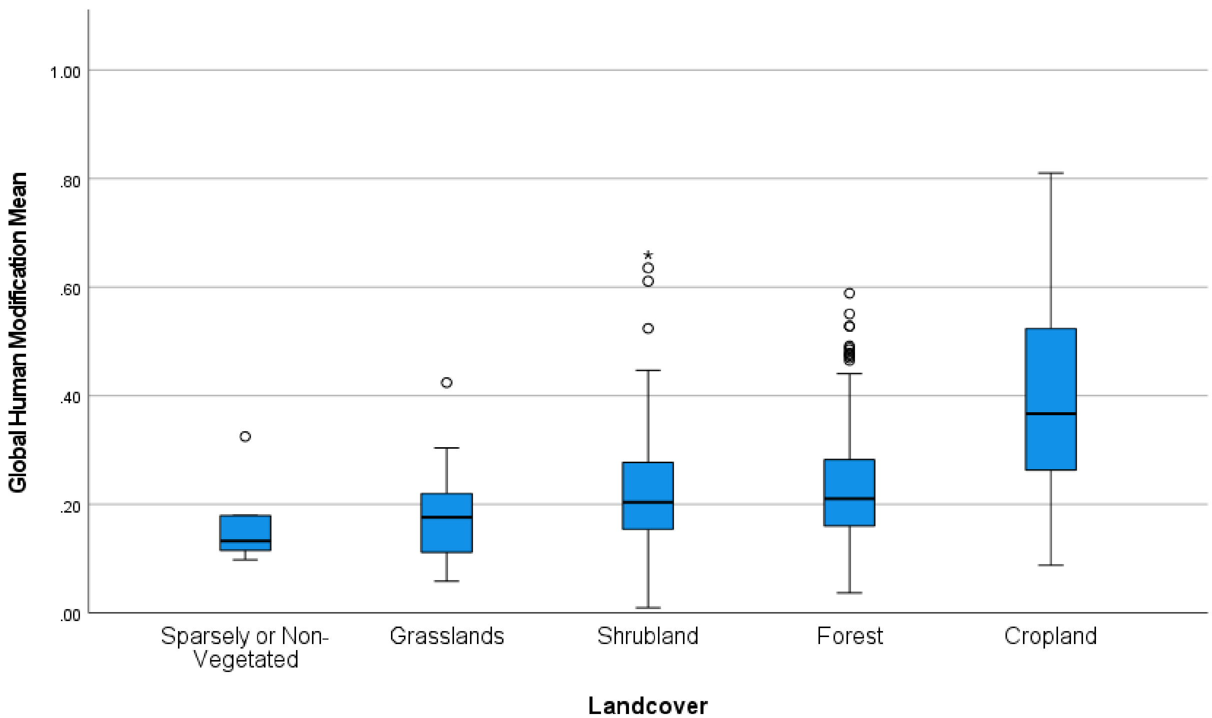

Figure 13. The relationships established between the GHM and Landcover Type

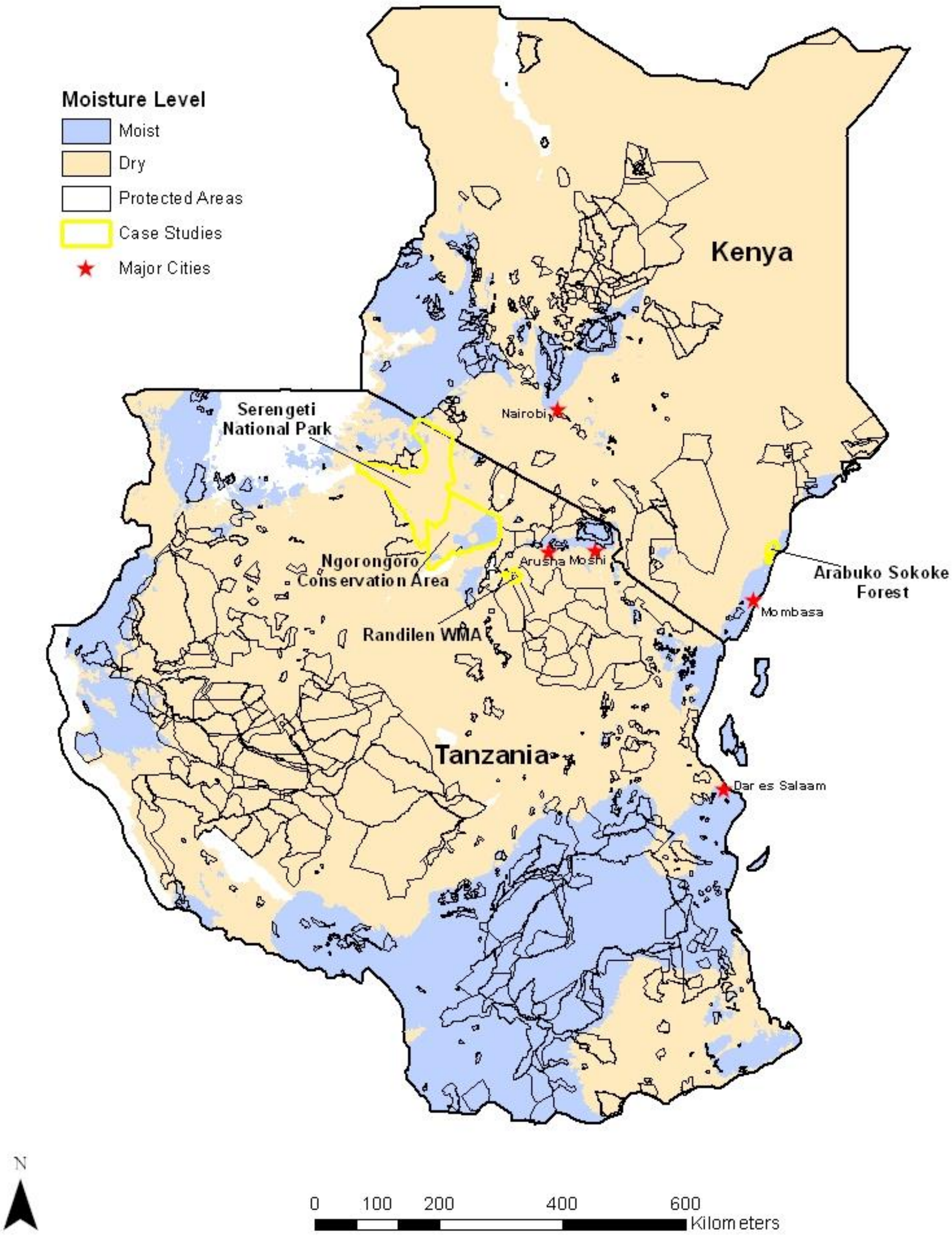

Figure 14. The two types of moisture levels and PAs in Tanzania and Kenya using the World Terrestrial Ecosystems Database.

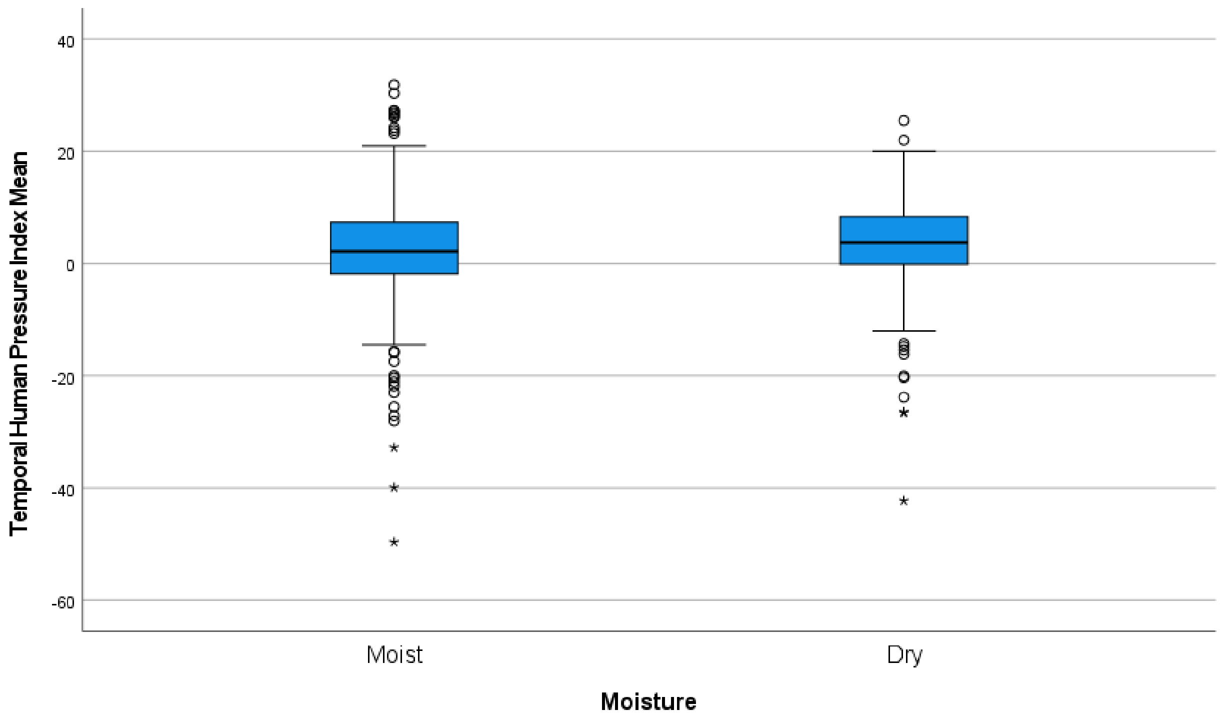

Figure 15. The relationship established between the THPI and Moisture Levels

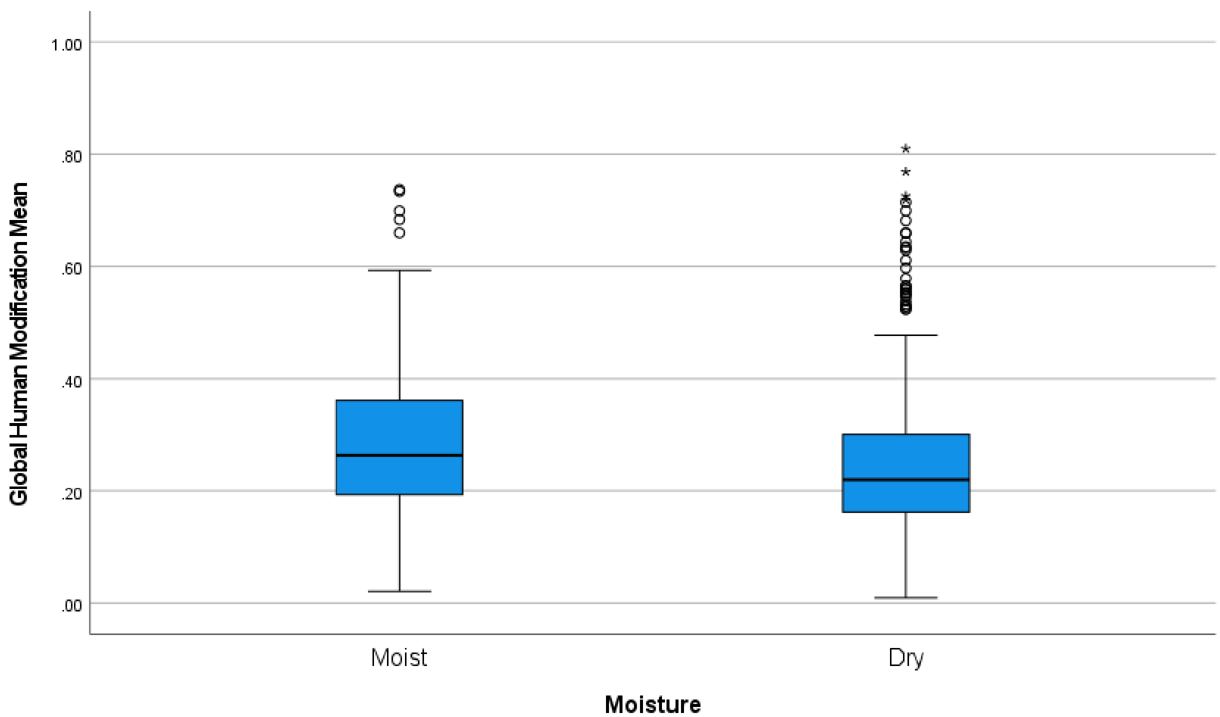

Figure 16. The relationship established between the GHM and Moisture Levels