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Geospatial Analysis of Elephant Migration from Hwange National Park, Zimbabwe, 2009–2017

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Abstract

Hwange National Park, the largest national park in Zimbabwe, has been recorded as experiencing elephant migrations to neighbouring Botswana for several years due to drought-related dryness of water bodies. The adverse impacts of climate change have led to a rise in Zimbabwe's annual mean surface temperature, rendering the country more susceptible to drought conditions and decreased rainfall. To investigate the directional trend of elephant migration patterns from Hwange National Park to neighbouring Botswana, spatiotemporal analysis was conducted from 2009 to 2017 using ArcGIS Pro software. Secondary data was utilized for analysis, with elephant migration data abstracted from Movebank, an open-source data portal for large collections of animal tracking data. These migration patterns were remotely tracked through GPS sensors. Additionally, annual mean surface temperature data, sourced from the International Monetary Fund's climate data, was considered an allied factor with the fundamental objective of the research. A bar chart was created to represent the temperature data statistically. The results emphasized that annual mean surface temperature fluctuations in Zimbabwe have influenced elephant migration, with high surface temperatures recorded in 2010, 2015, and 2016 accompanied by increased migrations. Consequently, the elephants' tendency to migrate towards Botswana has gradually risen throughout the period, underscoring the adverse impacts of climate change.

Keywords: annual surface temperature, climate change, elephant migration, Hwange National Park, Zimbabwe

1. Introduction

As Zimbabwe's largest national park, Hwange boasts a remarkable population of African elephants, earning its global recognition as an elephant paradise. Elephants are the emblem of the Hwange landscape, with approximately 50,000 elephants inhabiting an area of more than 14,600 km^2. Covering an impressive area, this iconic wildlife reserve provides critical habitats for various flora and fauna, particularly elephants, which roam freely across the vast woodlands and grasslands.

The park extends to the edge of the Kalahari Desert; therefore, this region is consistently characterized by water scarcity and sparse vegetation. The pernicious effects of climate change have influenced extreme drought conditions and the drying up of water bodies in Hwange National Park. According to meteorological observations obtained since the 1990s, Zimbabwe's climate has been changing, with notable changes including an increase in average temperatures, a decrease in annual precipitation, and an increase in the duration of the mid-season dry spell [1]. Erratic rainfall patterns affect the availability of water, which has a significant impact on the survival of ecosystems and wildlife. The opencast and underground mining operations, charcoal production, and veld fires in the park area have contributed to deforestation, which accelerates climate change and has a severe influence on the natural environment [2].

The escalating impact of global warming is poised to exacerbate longer, more recurrent, and harsher drought scenarios, particularly in regions with a historical predisposition to aridity. Southern Africa, flagged as a hotspot by the Intergovernmental Panel on Climate Change, stands on the precipice of heightened vulnerability, confronting the amplified threats of scorching temperatures and dwindling precipitation due to planetary warming. The park's susceptibility to such climatic shifts is pronounced in this broader context. Characterized by scant rainfall between November and March, the landscape is primed by prolonged bouts of dryness, with forecasts indicating the persistence of drought conditions caused by recurring El Niño weather phenomena [3].

Drought conditions exacerbated by El Niño tragically resulted in elephant deaths due to dehydration. Hwange National Park is characterized by semi-arid savanna vegetation and grapples with a chronic water deficit for many years [4]. This scarcity has prompted unprecedented behaviour among elephants. In recent years, many of Hwange's elephant populations have moved to Botswana for sustenance. The primary aim of this investigation was to analyze the directional trend of this migration phenomenon from 2009 to 2017. Understanding the patterns and drivers behind such movements is crucial for conservation efforts and wildlife management in both the Hwange National Park and Botswana ecosystems.

The rainy season, coupled with relatively high temperatures, dominates from October to March, whereas from June to August, the park experiences a dry season with low temperatures. In general, below-average rainfall is normally experienced in the country from October to March when the warm phase of ENSO (El Niño) dominates. In contrast, above-average rainfall normally dominates in the same period if a cool phase (La Niña) occurs. The ITCZ plays an important role in influencing rainfall and its annual fluctuations. Rainfall increased when the ITCZ shifted southward and decreased when it moved northward. Scientific research also found that a positive Indian Ocean Dipole/Zonal Mode (IODZM), popularly known as anomalous positive Indian Ocean SST gradient, is most closely associated with rainfall deficiencies and droughts in the country [5].

During the dry season, parks are prone to fire. These fires pose a threat to the park ecosystem and wildlife. Furthermore, the region has been grappling with the adverse effects of climate change, including increasing temperature and decreasing precipitation. These climatic changes have exacerbated the drought conditions in Hwange, leading to severe water shortages and vegetation scarcity. The impact on wildlife has been devastating, with more than 80 elephants reported dead in 2012 owing to severe droughts, highlighting the vulnerability of the ecosystem to changing environmental conditions. Over the past few years, many elephants have migrated from Botswana in search of water during the dry season [5].

2. Materials and Methods

2.1. Study Area

Hwange National Park, located in western Zimbabwe near the Botswana border at coordinates 19.1241° S, 26.5926° E, is a prime example of a subtropical dry forest biome falling under the BSh category of the Köppen climate classification (Figure 1). The park predominantly experiences hot, arid conditions characterized by low humidity and minimal rainfall. Weather patterns vary significantly throughout the year, ranging from mild to extreme. Temperatures peaked during certain months, accompanied by dramatic shifts in rainfall from one month to the next. Throughout the year, average high temperatures typically range between a comfortable 24.7°C and 35°C, but can escalate during summer, occasionally reaching 38°C. These climatic conditions profoundly influence the park's ecosystem, shaping the distribution of flora and fauna, as well as influencing visitor experiences and park management strategies [6].

The predominant vegetation type in the Hwange landscape is dystrophic wooded savannas interspersed with grassland patches [7]. This unique ecosystem is vital for sustaining the diverse wildlife in this region. Surface water sources within a park, such as pans, springs, and seeps, are crucial for the survival of its inhabitants. However, many of these water sources dry up during the dry season due to climate-driven fluctuations, as discussed in a relevant article. The Hwange National Park is renowned for hosting one of the largest elephant populations in Africa.

The varied terrain, encompassing grasslands, woodlands, and mopane forests, offers ideal habitats for these major creatures. However, during the dry season, water scarcity poses a significant challenge for the park's elephants, prompting them to undertake extensive migration in search of sustenance. In recent years, there has been a notable shift in the migratory pattern of Hwange elephants. Observations reveal unprecedented movements, particularly towards neighbouring Botswana, showcasing the adaptive behavior of these magnificent animals in response to changing environmental conditions.

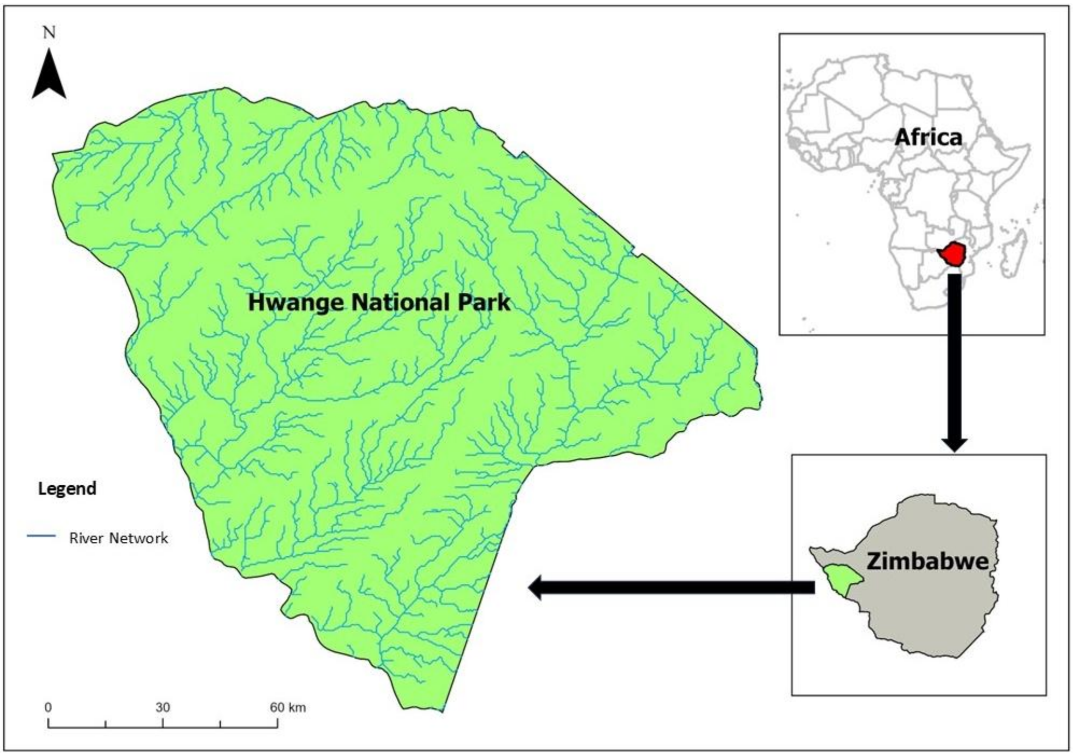

Figure 1. Hwange National Park in Zimbabwe.

2.2. Materials

The utilization of ArcGIS Pro software played a pivotal role in creating comprehensive maps, facilitating the visualization of spatiotemporal patterns in elephant movements. By leveraging the diverse capabilities of the software, researchers can depict intricate geographic data with precision and clarity. The research methodology began with a meticulous definition of the research problem tailored to the specific study area. Conducting a thorough literature review was imperative to identify gaps in the existing research, providing a solid foundation for the study's framework. Subsequently, the collection of appropriate data commenced, with heavy reliance on secondary sources.

One significant source of data was Movebank, an open-access repository hosting extensive animal tracking data including the migratory patterns of elephants captured through GPS sensors. In addition, annual mean surface temperature data were sourced from the International Monetary Fund Climate Data Repository, enriching the analysis with environmental variables. Landsat 8 satellite images sourced from the USGS Earth Explorer website were instrumental in generating land surface temperature maps, offering valuable insights into habitat dynamics.

The processing of data for map creation was largely automated using ArcGIS Pro supplemented by manual oversight to ensure accuracy and reliability. Raw secondary data were subjected to rigorous validation and appraisal to maintain data integrity throughout the analysis. Finally, the processed data were comprehensively analyzed to fulfil the primary objectives of the study, shedding light on the critical aspects of elephant behavior and habitat dynamics. The synergy between advanced GIS technology, comprehensive data sources, and meticulous research methodology has empowered researchers to unravel the complexities of elephant movements and their environmental correlates.

2.3. Methodology

The investigation involved several phases, as shown in Figure 2. First, creating a thematic map illustrating the migration patterns of elephants. This stage involved generating a thematic map illustrating the spatial and temporal patterns of elephant migration from Hwange National Park to Botswana from 2009 to 2017. Second, creating a map of land surface temperature. Using Landsat 8 satellite images, the variance in land surface temperature in the parking area was determined to identify the harshness of the studied environment. Third, generate a bar chart to illustrate yearly surface temperature trends. A bar chart depicting the annual surface temperature from 2009 to 2017 elucidates the relationship between elephant migration patterns and annual temperature variations in Zimbabwe.

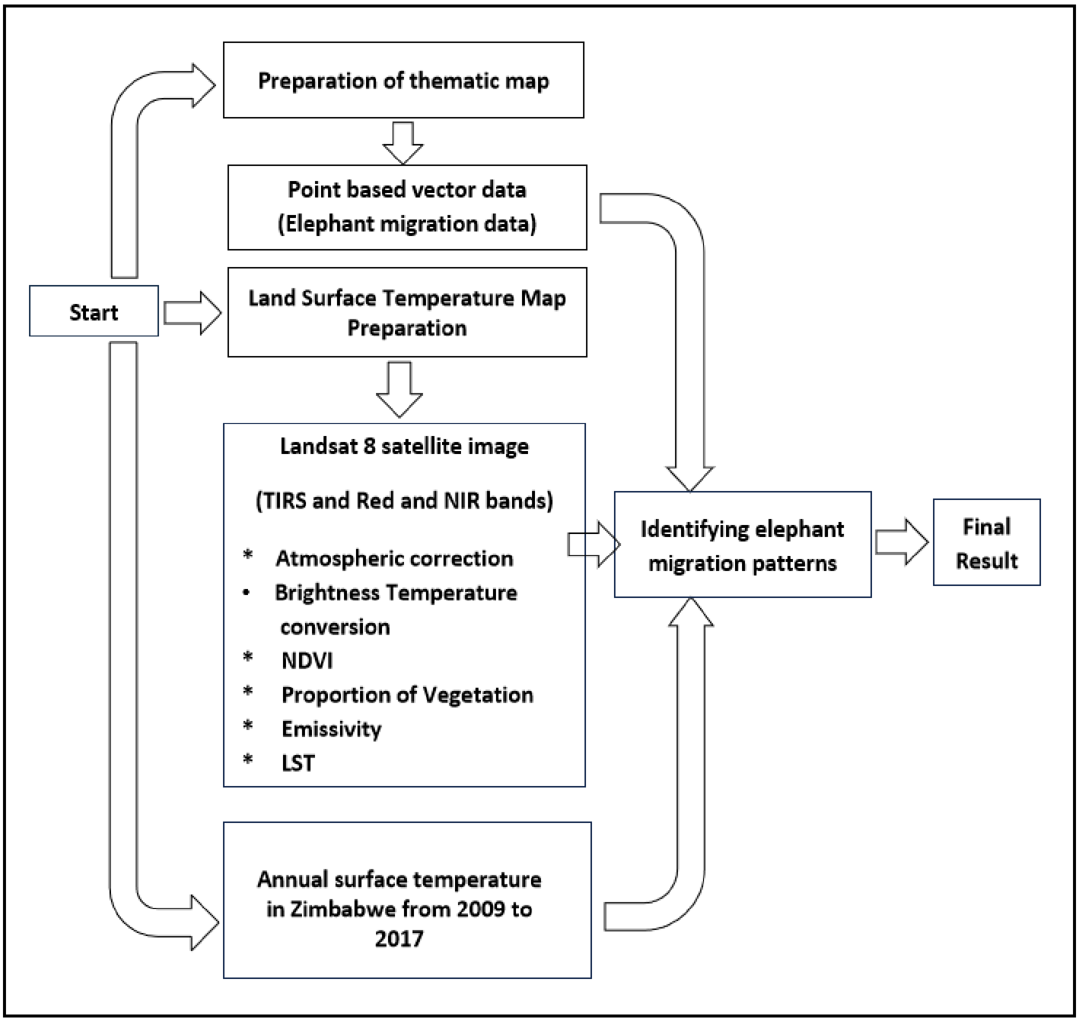

Figure 2. Workflow for the research methodology.

2.3.1. Creating a thematic map illustrating the migration patterns of elephants

The point-based vector data were imported into ArcGIS Pro software, where the necessary formatting was performed to ensure clear visualization. In managing the extensive elephant migration dataset, ArcGIS Arcade functions were utilized to filter data based on relevant years [9]. This comprises a set of statements within the Arcade scripting language developed by ESRI, which facilitates the creation of simple expressions for data visualization. Subsequently, the processed data were enriched by adding map elements.

2.3.2. Creating a map of land surface temperature

Determining land surface temperature relies on analyzing the Normalized Difference Vegetation Index (NDVI) outcomes. Thermal Infrared bands were employed for atmospheric correction and brightness temperature conversion. In contrast, the near-infrared and red bands were utilized to compute the NDVI, Proportion of Vegetation (PV), and emissivity (E). The satellite image utilized for this analysis was obtained on the 6th of November 2017, with 172 paths and 73 rows. Owing to the large size of the study area, a single satellite image was insufficient to cover it entirely. Consequently, three satellite images were used and merged into a mosaic raster.

The determination of land surface temperature was performed using the following steps:

Step 1: Conversion to Top of Atmosphere (TOA) radiance

$$L\lambda = ML * Qcal + AL\text{-}Oi \quad (1)$$

Where Lλ is TOA spectral radiance (Watts/ (m2 * sr * µm)), ML is radiance multiplicative band number, AL is radiance add band (No.), Qcal is quantized and calibrated standard product pixel values (DN), Oi is correction value for band 10 is 0.29.

Step 2: Conversion to Top of Atmosphere (TOA) Brightness Temperature (BT)

$$BT = K2 / \ln (k1 / L\lambda + 1) - 273.15 \quad (2)$$

Where BT is top of atmosphere brightness temperature (°C), Lλ is TOA spectral radiance (Watts/(m^2*sr*µm)) K1 = K1 constant band (No.), K2 = K2 constant band (No.).

Step 3: Normalized Difference Vegetation Index (NDVI)

$$NDVI = (NIR – RED) / (NIR + RED) \quad (3)$$

Where RED is DN values from the RED band and NIR is DN values from Near-Infrared band.

Step 4: Land Surface Emissivity (LSE)

$$PV = ((NDVI – NDVI\ min) / (NDVI\ max – NDVI\ min))^2 \quad (4)$$

Where PV is Proportion of Vegetation, NDVI is DN values from NDVI image, NDVI min is minimum DN values from NDVI Image, and NDVI max is maximum DN values from NDVI Image.

$$E = 0.004 * PV + 0.986 \quad (5)$$

Where E is the land surface emissivity, PV is the proportion of vegetation, and 0.986 corresponds to the corrected value of the equation.

Step 5: Land Surface Temperature (LST)

$$LST = BT/ (1 + (\lambda * BT / c2) * \ln(E)) \quad (6)$$

Where BT is top of atmosphere brightness temperature (°C). λ is wavelength of emitted radiance and the values of λ for Landsat 8: for Band 10 is 10.8, E is land surface emissivity, c2 is 14,388.

2.3.3. Generating a bar chart to illustrate yearly surface temperature trends

Figure 3 illustrates the dynamic fluctuations in annual mean surface temperature in Zimbabwe, emphasizing the trend of increased temperature changes. The data below show the trend of the average surface temperature, with temperature averages taken from to 1951–1980 as a baseline. Data were based on statistics from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) [10]. Positive values signify these fluctuations, indicating a notable rise in temperature experienced by the country. Such temperature shifts can significantly affect various environmental aspects, including wildlife. Between 2010 and 2017, Zimbabwe witnessed a consistent increase in annual mean surface temperature, reaching peaks in 2010, 2015, and 2016. This irregular temperature escalation pattern underscores the adverse effects of climate change.

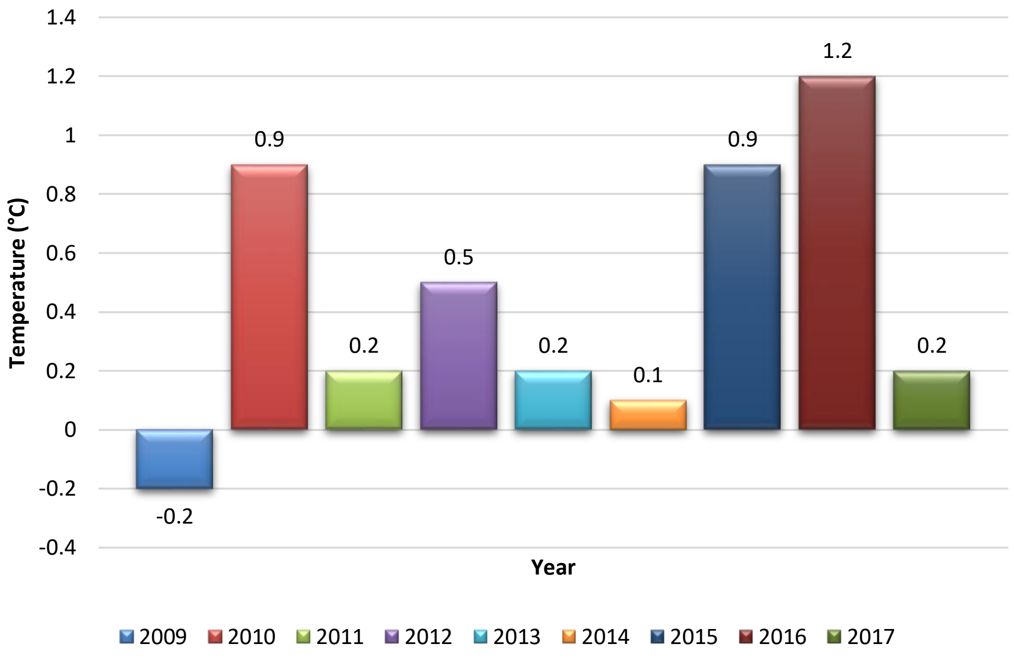

Figure 3. Annual mean surface temperature fluctuation in Zimbabwe from 2009 to 2017.

3. Results

3.1. Elephant Migration Map

Over the specified period, there was a noticeable increase in the migration of elephants from Hwange National Park to Botswana, as shown in Figure 3. Elephants predominantly located in the eastern region of the park tended to migrate towards Botswana. Between 2009 and 2015, a significant proportion of the elephant population crossed the Zimbabwean border. A consistent linear pattern in the direction of elephant migration was discernible, although some elephants diverged from this linear trajectory in 2015 and 2017.

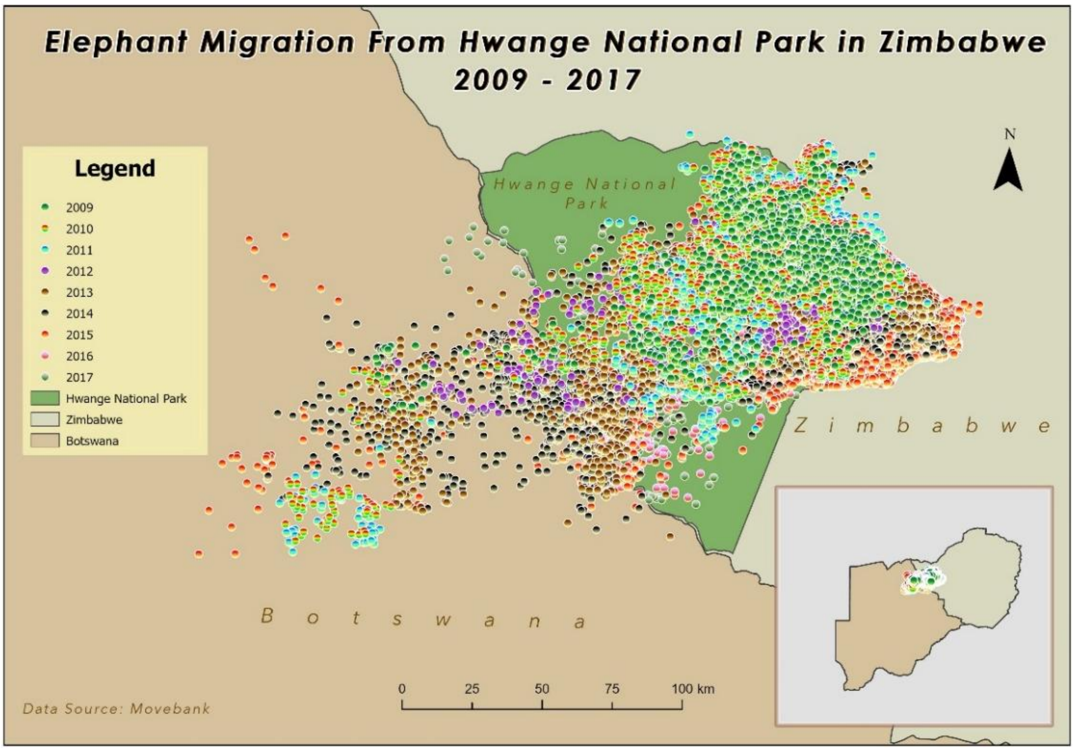

Figure 3. Elephant Migration from Hwange National Park in Zimbabwe from 2009 to 2017.

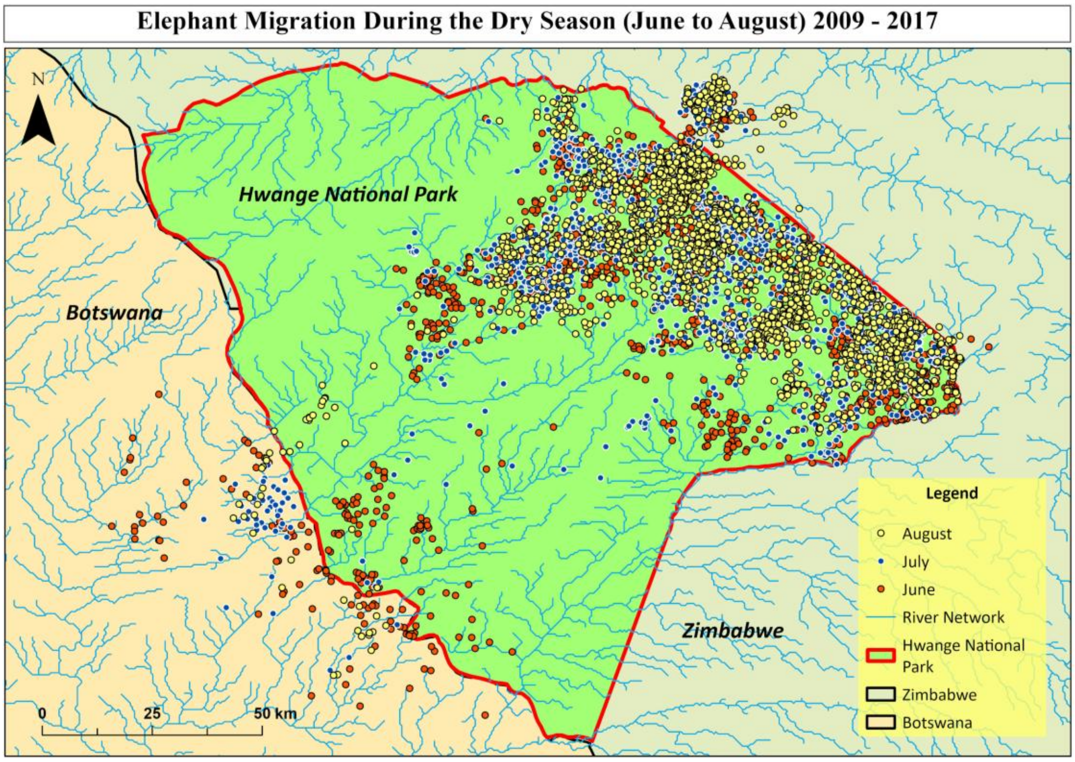

Figure 4. Elephant migration during the dry season (June to August) 2009–2017.

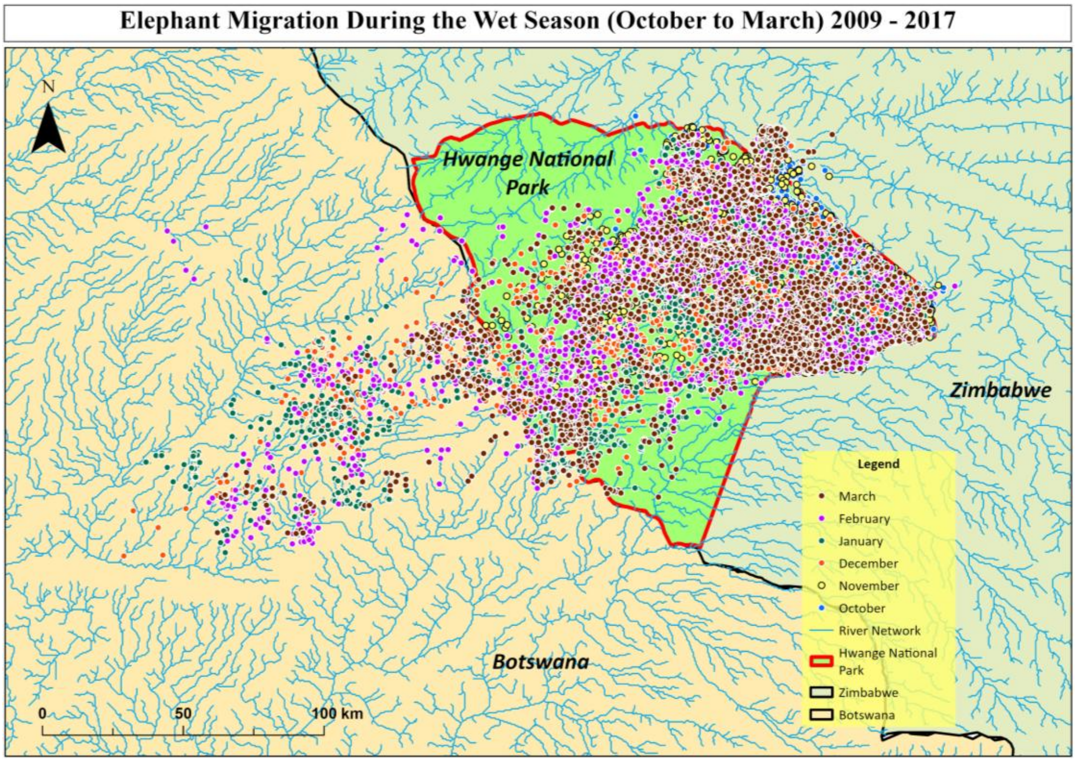

Figure 5. Elephant Migration During the Wet Season (October to March) 2009–2017.

Figures 4 and 5 indicate that more elephants cross the border during the wet season than during the dry season. Most elephants stayed within the park during the dry season, whereas a fraction crossed out. In contrast, elephants developed a distinct linear migratory tendency toward Botswana during the wet seasons of the year. Elephant migration increased during the wet season from October to March. The preceding trend is most likely dictated by the prevailing rain conditions coupled with relatively high temperatures from October to March and below-average rainfall during the warm phase of the ENSO during the same period. Subsequently, the park becomes dry, forcing elephants to migrate. However, on the other hand, the temperatures during the dry period are usually low, which may be the case for the minimal cases of elephant migration in the park. Sometimes, harsh climatic conditions lead to droughts. Overall, there is a linkage between the El Niño phenomenon, fluctuation in the ITCZ, rainfall pattern, and annual variability, yielding marked temperature variations with rainfall amounts that vary considerably in the wet and dry seasons.

3.2. Land Surface Temperature Map

In 2017, the Hwange National Park Area recorded a range of land surface temperatures, with the highest temperatures reaching 38°C and the lowest dropping to 24°C. Notably, the Eastern section had cooler surface temperatures than the western section. The analysis revealed that most of the parkland registered elevated temperatures. Figure 6 illustrates a peak temperature of 38°C recorded in November 2017, highlighting the areas shaded in red as hotspots. This underscores the varied distribution of land surface temperatures across the park, with the prevalent occurrence of high temperatures. Most elephants were found near the river network, indicating dry climatic conditions. The map below shows the LST of the land surface in November, considering the initiation period for elephant migration, as shown in Figure 5.

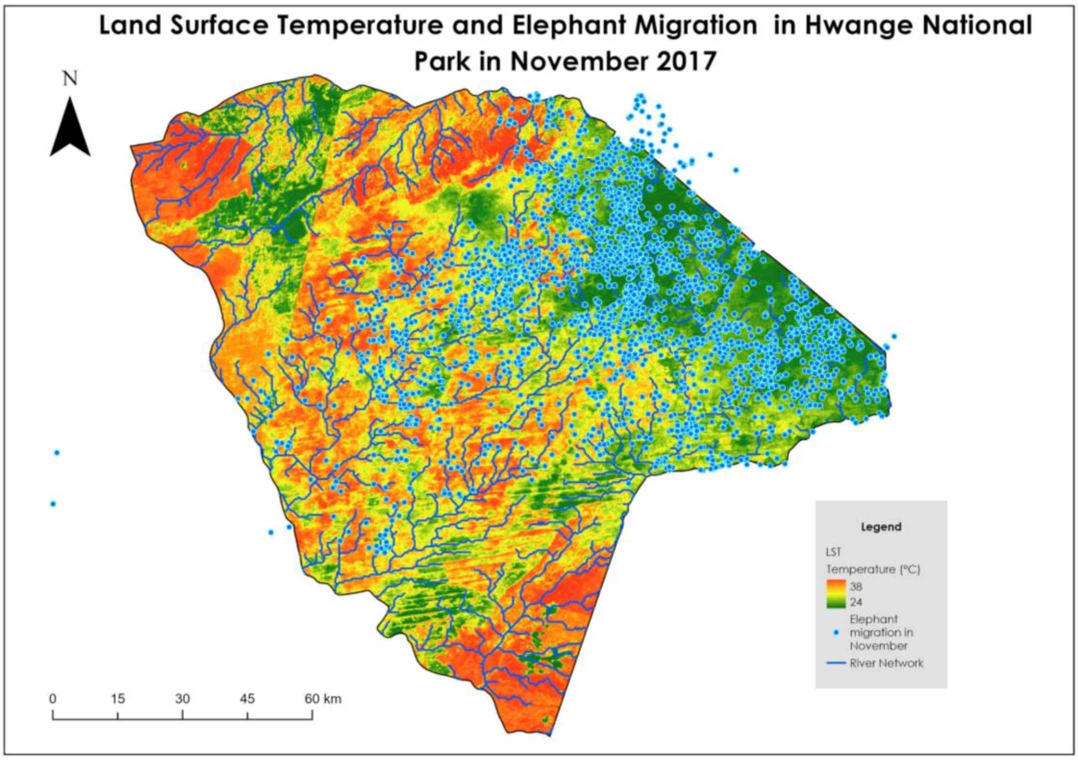

Figure 6. Land Surface Temperature in Hwange National Park for November 2017.

4. Discussion

The eastern section of the region is predominantly inhabited by Hwange elephants, which exhibit a linear migratory pattern towards Botswana. The presence of elephants in the eastern region of the Hwange National Park may be attributed to the provision of artificial water sources in the northeastern section. This intervention has facilitated a substantial increase in the Hwange elephant population, which rose from fewer than 1,000 individuals in the 1930s [10] to an estimated 45,000 individuals during the dry season of 2014, as reported by Chase et al. [11]. As social species, elephants typically prefer to remain within their herds, leading to a tendency for collective migration. Between 2009 and 2015, a significant number of elephants crossed the borders of Botswana. However, from 2015 to

2017, their distribution deviated from the established linear pattern. This shift may suggest the presence of severe drought conditions, which could deplete local waterways, necessitating broader migration to search for water resources.

The migratory patterns of elephants exhibited distinct variations between the wet and dry seasons. While wet seasons generally provide a cooler environment conducive to the availability of fresh resources, this phenomenon is markedly altered in the African context due to climate change influences, such as El Niño and fluctuations in the Intertropical Convergence Zone (ITCZ). Notably, during the wet season, elephant migration occurred more frequently than during the dry season, highlighting the impact of increasingly arid conditions and reduced average precipitation.

The dry season ranges of the monitored elephants were consistently situated in the eastern section of Hwange National Park. In contrast, their wet-season ranges were distributed along a northeast-southwest gradient and extended into Botswana [12]. Our study demonstrated that a subset of the Hwange National Park elephant population engages in large-scale seasonal migration, with the distances between dry- and wet-season ranges falling within the first quartile of migration distances observed in large herbivores [13,14]. This suggests that Zimbabwe is particularly vulnerable to the effects of climate change, which poses significant risks to Hwange elephants and other flora and fauna in the region.

The heterogeneous distribution of land surface temperatures across the park significantly influenced the spatial distribution of elephant clusters, particularly in areas with lower temperature recordings. Elephants tend to select migration paths that allow them to evade regions characterized by elevated temperatures. Furthermore, most elephant locations are closely associated with waterways, suggesting that water scarcity is the primary driver of their migration patterns. This indicated that the availability of water resources is critical in facilitating elephant movement within the park. We cautiously posit that access to surface water is a fundamental driver of large-scale seasonal movements of elephants, both within and outside the park [12].

The bar chart reveals a striking trend in Zimbabwe's average surface temperatures, which was particularly notable in 2010 and 2015. During these periods, the data indicate a significant increase of over 0.5°C compared to previous years. This increase clearly indicates the impact of climate change on this region. Elephants exhibit heightened vulnerability to rising temperatures owing to their substantial water requirements, necessitating up to 200 liters (50 gallons) per day. During the summer months, these animals lose up to 10 percent of their body water daily. Research indicates that the seasonal migration patterns of elephants in Hwange National Park are closely linked to the availability of water resources [15]. Concurrently, anecdotal evidence suggests a relationship between these temperature spikes and the migration of elephants from Botswana to Zimbabwe, traversing considerable distances from their usual habitat. This migration pattern underscores the ecological disruptions caused by shifting climate patterns as animals seek alternative environments in response to changing conditions.

Furthermore, the consistent expansion of annual mean surface temperatures over the years paints a sobering picture of Zimbabwe's vulnerability to drought. Escalating temperatures exacerbate arid conditions, increasing the frequency and severity of drought events. Consequently, Zimbabwe faces growing challenges in water resource management, agricultural productivity, and overall socioeconomic stability due to the destabilizing effects of climate change. The bar chart illustrates the temperature fluctuations. It serves as a visual representation of the urgent need for comprehensive climate action to mitigate adverse effects on Zimbabwe's environment, wildlife, and communities.

In recent years, Zimbabwe has seen growing interest in understanding the impacts of drought through scientific meteorological and remote sensing techniques. However, these efforts have been limited, with only a handful of studies being conducted between 2011 and 2020. Consequently, there is a pressing need for increased investment in drought research that specifically focuses on the utilization of remote sensing techniques. By harnessing the power of remote sensing, researchers can effectively monitor spatiotemporal patterns of drought occurrences across the country. This enhanced monitoring capability is crucial for informing strategic planning and implementing targeted drought risk-reduction initiatives. With a more comprehensive understanding of drought dynamics, policymakers and stakeholders can develop proactive measures to mitigate its impact on agriculture, water resources, and livelihoods, ultimately building resilience in Zimbabwe's vulnerable communities.

5. Conclusions

The migration pattern of elephants from Hwange towards Botswana exhibited a discernible linear trend. The analysis revealed a significant connection between annual mean surface temperatures and elephant migration. High surface temperatures coincided with heightened migration rates in 2010, 2015, and 2016. Fluctuations in Zimbabwe's annual mean surface temperature appear to influence the migratory behavior of elephants, prompting them to seek refuge in Botswana. The observed tendency towards migration to Botswana steadily intensified over the study period. Increasing temperatures underscore the adverse effects of climate change on elephant behavior and habitat utilization. As temperatures rise, elephants seem compelled to seek cooler environments, leading to their migration towards Botswana. This phenomenon highlights the intricate interplay between climate factors and wildlife dynamics, emphasizing the urgent need for conservation efforts and adaptive management strategies to mitigate the impacts of climate change on vulnerable species, such as elephants.

Author Contributions

SP: Methodology, Software, Investigation, Data Curation, Formal analysis, Writing; **AW:** Conceptualization, Supervisor, Methodology, Investigation, Writing - Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

References

1. Ministry of Environment Climate Tourism and Hospitality Industry. Zimbabwe's First Biennial Update Report to the United Nations Framework Convention on Climate Change. 2020. Available online: https://unfccc.int/sites/default/files/resource/Zimbabwe%20Biennial%20Update%20Report%201.pdf (accessed on 20 October 2024).
2. Bulletin, T.C. Hwange: Deforestation Accelerates Climate Change. Available online: https://kubatana.net/2022/02/03/hwange-deforestation-accelerates-climate-change/ (accessed on 7 May 2024).
3. Deines, T. Unusual Elephant Behavior Sparks International Concern: 'We Are Facing a Lot of Water Shortages'. Available online: https://news.yahoo.com/news/unusual-elephant-behavior-sparks-international-110000820.html (accessed on 7 May 2024).
4. Chamaillé-Jammes, S.; Fritz, H.; Murindagomo, F. Climate-Driven Fluctuations in Surface-Water Availability and the Buffering Role of Artificial Pumping in an African Savanna: Potential Implication for Herbivore Dynamics. *Austral Ecol* **2007**, *32*, 740–748, doi:10.1111/j.1442-9993.2007.01761.x.
5. Water Relief for 8,000 Thirsty Elephants Neglected by Zimbabwe. Available online: https://www.thezimbabwean.co/2017/01/water-relief-8000-thirsty-elephants-neglected-zimbabwe/ (accessed on 7 May 2024).
6. The Editors of Encyclopaedia Britannica Hwange National Park, National Park, Zimbabwe. Available online: https://www.britannica.com/place/Zimbabwe/Climate (accessed on 20 October 2024).
7. Rogers, C.M.L. A Woody Vegetation Survey of Hwange National Park; Department of National Parks and Wild Life Management Zimbabwe: Harare, Zimbabwe, 1993.
8. ArcGIS Arcade Function Reference. Available online: https://developers.arcgis.com/arcade/function-reference/ (accessed on 7 May 2024).
9. International Monetary Fund Climate and Weather. Available online: https://climatedata.imf.org/pages/climate-and-weather (accessed on 7 May 2024).

10. Davison, T. Wankie - The Story of A Great Game Reserve, 1st Edition; Books of Africa: Cape Town, South Africa, 1967.
11. Chase, J.M.; Schlossberg, S.; Griffin, R.C.; Bouche, P.J.C.; Djene, W.S.; Elkan, W.P.; Ferreira, S.; Grossman, F.; Mtarima, E.K.; Landen, K.; et al. Continent-Wide Survey Reveals Massive Decline in African Savannah Elephants. *PeerJ* **2016**, 1–24, doi:10.7717/peerj.2354.
12. Tshipa, A.; Valls-Fox, H.; Fritz, H.; Collins, K.; Sebele, L.; Mundy, P.; Chamaillé-Jammes, S. Partial Migration Links Local Surface-Water Management to Large-Scale Elephant Conservation in the World's Largest Transfrontier Conservation Area. *Biol Conserv* **2017**, *215*, 46–50, doi:10.1016/j.biocon.2017.09.003.
13. Teitelbaum, C.S.; Fagan, W.F.; Fleming, C.H.; Dressler, G.; Calabrese, J.M.; Leimgruber, P.; Mueller, T. How Far to Go? Determinants of Migration Distance in Land Mammals. *Ecol Lett* **2015**, *18*, 545–552, doi:10.1111/ele.12435.
14. Berger, J. The Last Mile: How to Sustain Long-Distance Migration in Mammals. *Conservation Biology* **2004**, *18*, 320–331.
15. Marima, T. Drought Is Driving Elephants Closer to People. The Consequences Can Be Deadly Available online: https://www.npr.org/2022/08/15/1117076598/drought-is-driving-elephants-closer-to-people-the-consequences-can-bedeadly#:~:text=Elephants%20are%20especially%20vulnerable%20to,water%20in%20Hwange%20National%20Park. (accessed on 21 October 2024).

