

Impact of Climate Change and Anthropogenic Activities on Hadejia-Jama'are Tsetse Fly (Diptera: Glossinidae) Ecology in Jigawa State, Nigeria

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This review article was done by the author and all reference materials used have been duly cited and listed accordingly.

ABSTRACT

Aim: This study was aimed at identifying factors that influenced the apparent decimation of tsetse fly (Diptera: Glossinidae) population, eliminated human and decreased animal African trypanosomiasis in Jigawa State, within Sahel-Sudano ecological zone of Nigeria.

Study design: On the spot physical inspection, interviews and review of data on climate change, socioeconomic, demographic, and environmental variables were collated.

Result: Among the notable factors identified included human population density that resulted in the widespread agricultural crop farming and logging activities particularly within the forest reserves and available outgrowth of natural tree covers across the state. The *Glossinna morsitans* belt along Hadejia, Jama'are, D. Gaya and Katagun Rivers' natural swath of riparian forest galleries have virtually been depleted. The area lacked thick continuous vegetation cover conducive for tsetse fly breeding. The key informants interviewed were unanimous that aerial wide insecticide spray with dichlorodiphenyl-trichloroethane (DDT) eliminated tsetse flies along with game and aquatic animals. Prevalence of animal trypanosomiasis in cattle in the state could be attributed to nomadic or transhumant animal management system. With reported absence of tsetse fly and no case of human African trypanosomiasis for over two decades in the state corroborated the negative impact of climate change and anthropogenic activities on normalized vegetation index in the extinction of tsetse fly population in the Hadejia-Jama'are primordial sleeping sickness focus.

Conclusion: Extrapolated climate change data analysed over a longer period showed that tsetse suitability index in the area tends to zero due to a combination of high temperature and increased aridity and desertification. These factors in conjunction with past area wide insecticidal control have contributed to absence of tsetse fly and human African human trypanosomiasis or sleeping sickness in a known primordial endemic foci. The documented cases of the disease in livestock have been attributed to the nomadic or transhumant animal management system.

Key words Agriculture, Climatic changes, Desertification, Forest fragmentation, Trypanosomiasis, Tsetse fly.

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1. INTRODUCTION

The phenomenon of climate change has been defined as statistical variations that persist for an extended period, typically decades or longer. It includes shift in the frequency and magnitude of sporadic weather event as well as the slow continuous rise in global mean surface temperature (1, 2). The causes of climate change are both natural and anthropogenic. All the co-confounding factors of climate change have manifested the negative impact of demographic change in population over the years putting pressure on the natural woodland cover culminating in desertification (3). Here, the terms global warming and climate change are used interchangeably (4). The regions that are most vulnerable to the disease-related impact of climate change are the temperate latitudes and the countries in the Indian and Pacific Oceans and sub-Saharan Africa, which will be disproportionately affected by extremes in temperature, and where public health programmes may be unable to cope up with the changes in disease transmission (5). Impact of climate and ecological changes on vector borne tropical diseases like malaria, schistosomiasis, filariasis, dengue fever, leishmaniasis, Chagas disease, African trypanosomiasis, and onchocerciasis are expected to be on the rise (6, 7). According to Franco *et al* (8), the epidemiology of trypanosomiasis is mediated by the interaction of the parasite (trypanosome) with the vectors (tsetse flies), as well as with the human and animal hosts within a particular environment. Related to these interactions, the disease is confined in spatially limited areas called “foci”, which are located in Sub-Saharan Africa, mainly in remote rural areas. The tsetse fly population density and rate of tsetse challenge increases from the semi-arid region to the sub-humid and humid zones. The tsetse fly belt occupy about 75-80% of the Nigerian land mass (928,300 km²) from the coast to latitude 12-13°N with extension along Hadejia and Jama'are river systems (9). The increase in human population over the years has put more pressure for land use on crop agriculture and other developmental needs with consequent impact on the natural difference vegetation index (NDVI). There is an estimated 1.7m herds of cattle. The economy of Jigawa State is largely characterized by informal activities with agriculture as the major economy activity. Over 80% of the population is engaged in subsistence farming and animal husbandry accounts for more than 70% of its gross domestic product (GDP).

2. MATERIALS AND METHODS

2.1 Study Area

Jigawa state is situated in the north-western geopolitical zone of Nigeria. It lies between latitudes 11.00°N to 13.00°N and longitudes 8.00°E to 10.15°E (10) with a Geonames ID: 2565345. It occupies a land area of 24,515.620 sq km and has a projected population of 4,348,649 of which 50.4% are males and 49.6% females (10). About 80% of Jigawa households derive their income from farming and 85% of the population of the state live in rural areas. Population density is estimated to be 178 people per square kilometre (sq km). This is above the average national population density of 139 people per sq km as at 2006 (11). It holds a sizeable numbers of cattle, sheep, goats, camel, donkey, horses. The annual mean temperature for the 2013 was 25°C (with a range between 21-31°C) according to figures provided by (12). The annual rainfall is 600mm in the north and 1000mm in the southern part of the state. The dry season last between 7-8 months (from October –May) and the wet season last for 4-5 months (from June- September). The general relief of this belt is within the range of 300 to 900 metres above sea level (13). The people are mostly Hausa, Fulani, mixed with Kanuri tribe.

2.2. Secondary Thematic Attribute Data on Climate Change Indices

Information on entomology, parasitology, ecology, land occupation and production systems were collected and combined in a geographic information system (GIS) as described by (14). Insect population growth modelling, gridded climate data and geospatial analysis, the potential steady state tsetse population can be calculated using the tsetse suitability index (TSI) as the standardized value (Z-score) of this steady state population described by (15). Inference were drawn by correlating the climatic data over the years with those of reported scientific finding on tsetse optimal ecological requirement and established threshold limits for lethal minimal and maximal temperature, aridity, and humidity. The interplay of these factors on TSI were equally considered.

2.3 Change in Vegetation Land Cover

Woodland cover is very crucial to understanding the interplay of climatic factors and the TSI is the optimum environment needed. Spectral vegetation indices was used to assess ecological responses to environmental

change including the NDVI that measures canopy greenness (16, 17). The changes in vegetation obtained over a time series spanning from 1940 to 2010 for Jigawa State (10) were adapted.

2.3 Climate Change

This study relied on the data analyses of climate change from 1901-2012 (13, 18) provided better platform to investigate the visible impact of long-term temporal climatic changes on TSI in the study area. Most respondents in a study by (2) gave causes of climate change in the study area as deforestation (40%), bush burning (30%), overgrazing (13%), exhaust from motors and industries (11.7%) and others (5%). The calculated decadal mean from 1950-2006 by (19) was ranked to derive the moisture effectiveness zone (MEZ) used in mapping out the spatial-temporal aridity trend.

3. RESULTS

3.1 Socioeconomics and cultural activities

The majority of the population (about 80%) are crop farmers, trading 5%, livestock herders 5%, fishermen 1%, artisans 2%, and others, 7%. At Gumel LGA, we observed the absence of any river or stream and the area has no stretch of vegetation cover. There was bimodal herd migration particularly in search of water and forage during dry season and movement during wet season was mainly to avert clash with crop farmers. It was observed that indigenous herds looked healthier than the nomadic herds. The use of bull for traction, donkey as beast of burden to convey farm products and sand from excavation sites, and also for transportation to pull cart were common practices.

3.1 Thematic Rainfall Climate Change Pattern from 1960-2009

Trend in rainfall fluctuations observed in Dutse Station from 1960-2009 computed by (20) on Figure 1 indicated negative change pattern that started in 1968 were punctuated in 1973 and 1993, and continued up to 1998. Seasonal rainfall prediction (12) for northern Nigeria region have a range of mean annual rainfall between 300mm-1200mm. The relative humidity is very high during rainy season reaching about 65 to 70%. In dry season, the RH falls to average range of 10 to 35rH.

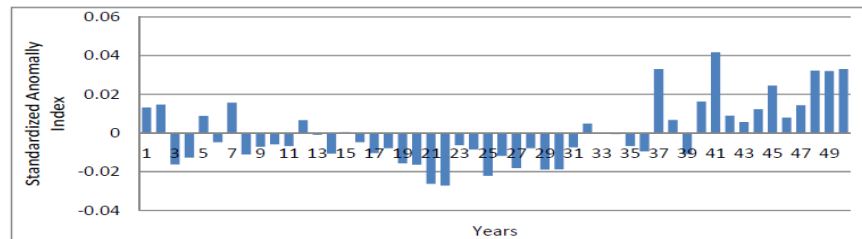


Figure 1: Annual rainfall fluctuations for Dutse (1960-2009). Source: (20) Ifabiye and Ojoye, (2013).

3.3 Influence of Temperatures on Tsetse Fly Survival

The optimal temperature at which different tsetse fly species can survive is 26°C and most savannah species cannot survive for too long above 32°C (21). The development rate of various stages of tsetse fly is directly proportional to the temperature. High temperature will shorten the interval period adult emerge from pupal stage (20 days at 30°C but 100 days at 16°C), and the lifespan of adult (although the correlation with vapour pressure deficits is better) and the period between successive feeds is very important (22).

3.3.1 Temperature anomalies

Climatic trend considered on a climatological year basis confirmed the earlier increasing trend from 1960-2013 base periods (18) showed that the 1960-1989 period was more significant. It was regarded as the driest so far in the zone due to the recurring drought depicted in Fig. 1. According to (12) report in previous years, the extreme north experienced highest daily maximum temperatures of 42.0 - 44.7°C between February and May 2012 and over a period of forty to sixty (non-consecutive) days.

3.3.2 Drought and desertification

The years before 1960s were termed pre-drought years followed by prolonged and persistent drought of the 1970s and 1980s and the wet period of 1990 to 2013 (18). This concurred with earlier observation that there was a spell of drought within the period from 1970-1993 with a strong threat of desertification taking place at an alarming rate (20). Basically, Jigawa State lies within moisture zone in the southern part and the extremely deficient moisture zone in the extreme north that extends to about lat. 12°N and lat. 10°N in the northwest and northeast, respectively (13).

3.4 Impact of Livestock and Human Population on Vegetation Cover

Jigawa State is within the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria, which is acclaimed to house about 25% and 75% of human and cattle populations including goats and sheep, and almost all the donkeys, camels and horses found in the country (23). The huge livestock population has contributed to overgrazing. Drastic changes in NDVI of the area from the period of 1940-2013 showed the southward movement of desert encroachment. Analysed change in land cover types in Jigawa State from 1986, 1999 and 2009 period using Landsat imagery depicted remarkable decrease in wetland, woodland and shrub land covers (10) as shown on Fig. 2. The preponderance increase in areas of scattered cultivation and bare land are shown on the summary of land cover of Jigawa State for the same periods (Table 1). The increase in bare surface more than doubled from 1986 to 1999 by 114%, and an increase of about 25% from 1999 to 2009.

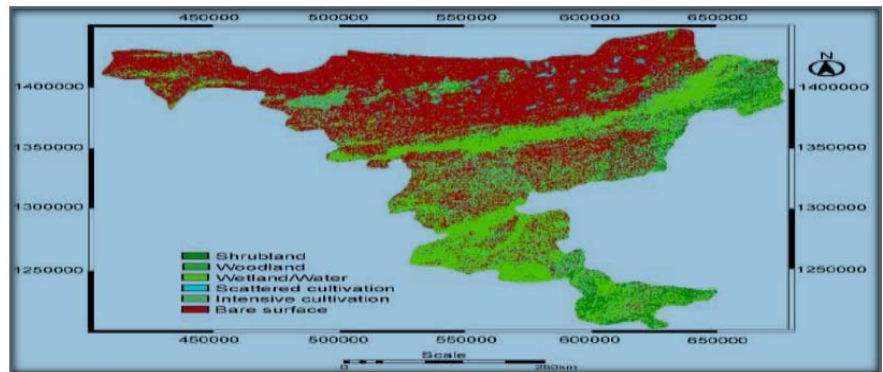


Figure 2: Land cover of Jigawa State in 2009. Source: (10) Jibril *et al.* (2015)

Tsetse flies are known to thrive well at particular range of temperatures (16°C–38°C) and need optimal relative humidity (rH) that ranged between 50%–80% to survive. Therefore, they are linked to the presence of water that increases the local humidity, allowing for the growth of vegetation that protects them from direct sunlight and wind, and attracts the animals to where tsetse feed (5, 22). Temperature has major effects on birth rates, development, and mortality, and especially strong relationships exist between adult mortality and ambient temperature, which in some species are markedly non-linear (24). Critical thermal minimum (CT_{Min}) was defined as the loss of coordinated muscle function, and critical thermal maximum (CT_{Max}) was defined as the onset of muscle spasms (25). Water availability is also known to affect mortality rates; puparial and

teneral adults are most sensitive to dry conditions, whereas mature adults are most sensitive to temperature (15).

Table 1: Summary of land cover for Jigawa State in 1986, 1999 and 2009

Landcover Type	Years			Difference (Percentage)	
	1986	1999	2009	1986/1999	1999/2009
Wetland/Water	2662.13	2181.57	1577.29	-480.56 (-18.05)	-604.27 (-27.70)
Woodland	2112.57	1467.86	953.99	-644.72 (-30.52)	-513.87 (-35.01)
Scattered cultivation	5336.15	4313.17	6825.42	-1022.98 (-19.17)	2512.25 (58.25)
Shrub land	7377.36	6092.68	4358.37	-1284.67 (-17.41)	-1734.31 (-28.470)
Intensive cultivation	3244.99	3190.27	1693.87	-54.72 (-1.69)	-1496.41 (-46.91)
Bare surface	3057.05	6544.7	8381.31	3487.65 (114.09)	1836.61 (28.06)

After a slight modification by including percentage difference. Source: (10) Jibril *et al.* (2015).

3.5 Variables Implicated in Tsetse Fly Physiological Ecology

Extinction probability of pupa and adult flies are dependent on temperature and saturation deficit, respectively. This coupled with the metabolic rate-temperature (MR-T) that is of fundamental importance to physiological ecology. Metabolic cold adaptation (MCA) predicts that populations or species from cooler environments will have either a higher metabolic rate at a common temperature or steeper MR-T relationship, indicating greater sensitivity of respiratory metabolism to temperature (26). An evolutionary adaptation of the MR-T reaction norms to cool climates (<22° C) in tsetse provide support to MCA within an insect species. A practical demonstration of the cause effect of temperature extremes on pupa and saturation deficit on adult fly as depicted by (15) are shown on Fig. 3(a, b). In a study, 32° C was the limit for survival for all strains tested. A relative humidity (RH) ranging from 40 to 76 % had no effect on fecundity at 25–26 °C (27). Pupae can die in many ways - parasites, predators, flooding, dehydration and freezing all appear to be major sources of pupal death, which is correlated with temperature. High temperatures reduce the amount of time that flies can live without a blood meal, and low temperatures have the opposite effect. Only half of emerging teneral adults become adult females. The death rate of adult females is believed to be temperature dependent. During the dry season, the average female life expectancy of *G. tachinoides* is one month; in the rainy season, the life expectancy is three months. The growth of the male population is not temperature-dependent.

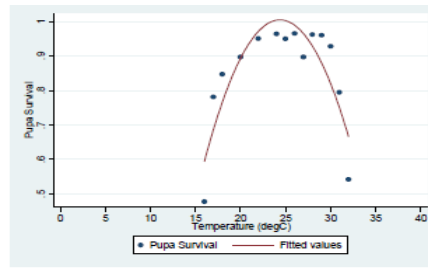


Fig. 3a: Pupa Survival and Temperature. Adopted from (15) Alsan, (2015).

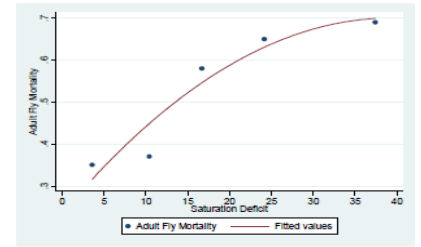


Fig. 3b: Adult fly mortality and saturation deficit.

Pupa and adult tsetse fly react differently to extremes of temperatures with low temperature not critical to fly emergence from pupa, both temperature extremes (low and high) are critical to the survival of adult flies (28). On the other hand, extreme dryness or aridity and extreme humidity or flooding of breeding sites are very critical to pupa fly emergence. The abiotic climatic factors as they affect pupa and adult tsetse fly are listed on Table 2. A strong relationship exist between increasing temperature that caused increased mortality of *G. pallidipes* adults in the field (25). At higher temperatures, survival of flies was very low, i.e. the median survival was four days at 31 °C and 2 days at 35 °C for the two sexes (at 60 % rH). The median survival in wild-caught *G. pallidipes* at 37.9, 36.2 and 35.6 °C (95 % CIs: ± 0.5 °C) were 1, 2 and 3 hours, respectively (29).

Table 2: Summary of climatic extremes that affect pupa and adult tsetse fly survival.

S/No.	Climate index	change	Pupa	Adult fly	Remarks
1.	Extreme temperature	low 10°C	Not critical and is used in SIT to preserve pupa.	Critical to fly survival leading to metabolic rate-temperature	Metabolic cold adjustment could result over a long period.
2.	Extreme temperature	high $\geq 32^\circ\text{C}$	Critical if the rH is low.	More severe and death occur with increasing temperature.	The critical thermal maxima (CT_{Max}) is 38°C .
3.	Extreme low rH	<40	It is very critical when temperature is within normal.	Death within 5 minutes	Is due to increased rate of water loss.
4.	Extreme high rH or		No effect except	No effect but support	Period of wet season with

	precipitation		flooding	of	widespread	dispersal	high precipitation.
			breeding sites.		of adult flies.		
5.	Extreme incident radiation (ISR)	low solar	Non-critical		Non-critical		Low mortality for both pupa and adult stages.
6.	Extreme incidence radiation	high solar	Highly critical.		Highly critical.		High mortality for both pupa and adult stages.
7.	Extreme aridity or dryness/drought		Difficult emergence moisture deficit.	for fly during	Increase in water loss leads to high mortality rate.		High mortality for both pupa and adult stages.

3.6 Incident Solar Radiation

The greatest amount of incident solar radiation ranged between $26.0 - 28.0 \text{ Wm}^{-2} \text{ day}^{-1}$ during the hot season in the country occurred in Katsina, Kano, Jigawa, Bornu, Adamawa Yobe (12). Optimal ISR for tsetse fly is below $24.0 \text{ Wm}^{-2} \text{ day}^{-1}$.

3.7 Demographic changes and anthropogenic activities

Massive clearing of forest for commercial logging with most areas been put under crop farming particularly along the Hadejia Jamaare River Basin helped in destroying the swath of natural riparian vegetation. The abiotic and biotic factors that have influenced tsetse fly ecology in Jigawa State are shown on Tab. 3. This has culminated into the disappearance of the primordial *Glossina morsitans* belt. The encroachment into natural forest reserves in places like Gurmina Forest Reserve in Birnin Kudu LGA (Coordinate P0544348 and H1259215) Government Reserve at Gabta Village (P0637942 and H1380914), Baturia Forest Reserve (P0638282 and H1380623) were observed. Many of those interviewed could recall that the aerial insecticidal spray was done with an insecticide believed to be dichlorodiphenyl-trichloroethane $\text{C}_{14}\text{H}_9\text{Cl}_5$ (DDT) or 1, 1-(2, 2, 2-trichloroethane-1, 1-diyl) bis (4-chlorobenzene). Active ground spray of the rivers were done in 1975 (30). The Adiyani wetland in Guri LGA bordering Yobe State has a nearby Forest Reserve, where monkeys, antelopes, duikers, monitor lizards and snakes were said to be found. At Gumel LGA it was observed that there was no river/stream in the area. The area was said to be free of tsetse but has other biting flies (31). Nomadic herds that migrate to neighbouring states, southern parts of Nigeria and Cameroun in search of both food and water may be at risk of infection. Secondly, bush clearing was used in the past for tsetse fly control.

Table 3: Effects of anthropogenic activities and biotic factors on tsetse fly population ecology in Jigawa State

S/No.	Variable Factors	Anthropogenic activities	Effects on tsetse population
1	Normalised difference vegetation index.	Clearing trees and bush burning for crop farming and logging for firewood have depleted and fragmented the forest cover.	Exposes fly to direct sunlight harmful and not conducive for tsetse fly survival.
2.	Arial and ground spraying with insecticides (DDT)	River forest galleries, forest reserves and wetlands possible tsetse suitable breeding ecosystem.	Death of tsetse fly the target, other non-targeted flies, game and aquatic animals.
3	Increased population density over the year has put serious pressure on land-use.	Over the years, there have been steady increase in population density now at 179 person/ sq. km.	The population density was above national average of 150 person/ sq. km is enough to drive <i>tachinoides</i> and <i>morsitans</i> out of existence.
4	Huge livestock population	Bimodal migration to tsetse infested areas.	The few cases of animal trypanosomoses may stem from nomadic or transhumant system of animal husbandry.
5	Continued presence of haematophagous insects.	Reported cases of Tabanid, Stomoxy, Hyppobosca	Mechanical transmission of <i>T. evansi</i> or <i>T. equiperdum</i> and <i>T. vivax</i> .

4. DISCUSSION

Many factors that interplay in the tsetse fly population and disease endemicity status in Jigawa State have been thematically studied. A cause and effect of the relationships between the vector, host and parasite interaction within the prevailing environment is crucial to determining the public health status of tsetse fly and African trypanosomiasis. High water loss rates are a consequence of high levels of teneral activity in dry air and, it is assumed, in high temperature conditions such will lead to a dehydration of the teneral fly which can be fatal (32). Abdulkadir *et al.* (13) cited (33) Adger, who opined that the escalating variability in rainfall distribution, deforestation and degradation of natural resources in the zone has significant eco-climatic and socio economic impacts. These cumulative effects of rapid depletion of natural resources in the region, through over exploitation and variability in the distribution pattern of rainfall have drastically affected the quality of the biotic and abiotic components in the zones in general and Jigawa State in particular.

Jigawa state lies within the arid prone zone, which is graded as high in the southern fringe, very high at the central area and extremely high at the northern part of the state (19). Impact of incessant deforestation across the state has tremendous negative effect on the climate change, with increasing risk of desert encroachment becoming eminent (13). The lack of effective implementation of existing forest management policy is responsible for the destruction of the forests in the country as observed by (3) who inferred that for 105 years, temperature has increased by 1.1°C and rainfall has decreased by 81 mm. This was caused by high deforestation rate thus leading to increase in desertification (Inyang and Esohe, 2014). Implication of this on tsetse fly distribution is the shrinking of the areas previously within the TSI (Fig. 2). Moreover, according to studies by (11) it was estimated that about 1.6 million hectares (out of the state's 2.4 million hectares of landmass) can be cultivated during the rain-fed season. This is a practical demonstration on the level of anthropogenic pressure on the NDVI. There is no doubt that Nigeria is having the highest deforestation rate of natural forest on the planet according to (33). Impact of human population on tsetse distribution has been classified into three categories (35): (i) low human population density having no effect on tsetse populations; (ii) moderate human population density causing a decline in tsetse populations; and (iii) high human population density eliminating *fusca* and *morsitans* populations. Jigawa State has 179 per square kilometre falls within the third category.

In the first instance, univariate and multivariate analysis of climate and productivity variables showed that temperature variables are much better predictors of *G. pallidipes* presence and absence than NDVI variables (36, 37). There has been a significant change in the climate of Sudano-Sahelian ecological zone of Nigeria as reported by (20, 23) with the fact that rainfall has been increasing in the Sudano Sahelian therefore the region is getting wetter since the mid-1980s respectively (Table 2). Observed drastic fluctuations in the dry season rainfall will have major consequences on biotic lives in the ecological zone. It is obvious that human population, combined with climatic changes (Fig. 1) have contributed to reducing spatial distribution of tsetse flies (38). The abiotic factors which affects tsetse mortality rates include temperature and atmospheric moisture acting on the adult fly (39), extremes of the temperature (both high and low) causing pupae to metabolise all the fat reserves and die before development is completed (40), and seasonal heavy rainfall which floods puparial sites. During seasonal periods of stress, females also produce smaller puparia, giving rise to under-sized adults with a higher mortality rate than normal-sized adults (29, 41, 42) may have impacted negatively on the tsetse population in Jigawa State.

Any prospective plan to tackle desert encroachment should not be oblivious of the consequence and its wider ramification not to regenerate the sleeping sickness focus. Concerted efforts towards reforestation needs a cross-sectoral approach ranging from reforestation to agro-forestry to a drastic reduction in the consumption of firewood (11). The effects of climate change and anthropogenic activities on Hadejia-Jama'are sleeping sickness focus may be similar to observation made by (43) that with combined medical action on HAT probably led to the disappearance of *T. b. gambiense*. Cause effects of these two factors combined have exacerbated the widening dessert encroachment due to the influence of climate change over the years (Fig. 2). Even the wetlands were not exempted from the crunching effect of draught whereby the area was virtually dried up especially in the dry season.

The aerial wide insecticide spray in the past was reported to have destroyed the game animals, fishes and other insect along with tsetse fly that was the main target. These outcome have all contributed in no small measure to the degrading of tsetse fly ecology and breaking the sleeping sickness endemic focus now almost alien to most of the young ones except the very elderly who could recount the scourge of the disease in a distant past. In effect, the area known as tsetse fly free belt must have enlarged under the prevailing circumstance. The absence of tsetse fly may not preclude the continued transmission of the disease in animals particularly cattle because of the bimodal annual migration of herds to and from tsetse infested areas outside the zone. There are proven cases of

mechanical transmission of *T. vivax* and *T. equiperdum* or *T. evansi* infections in cattle and equid in tsetse fly free areas (44, 45). A far reaching consequence of climate change witnessed in the Sudano-Sahelian Ecological Zone of Nigeria from 1960-2013 was the observed negative impact on tsetse fly leading to its elimination from study area. Contrary to reports from elsewhere outside the zone by (46, 47) on the Jos Plateau hitherto known to be tsetse fly free has been confirmed to be infested with both *Glossina* species and other haematophagous biting flies. Attempts have been made to relate malaria resurgence in East African highlands to changes in temperature (48) and climate variability caused by the El Niño-Southern Oscillation (ENSO) (49). The most important anthropogenic factors that exacerbated the already worsened impact of climate changes on tsetse fly ecology is clearing of forest vegetation cover, depletion of game animals, herd migration in search of water and pasture particularly during precarious period of drought (50). Alteration in the environment has made the dynamics of vector-host-parasite relationship to maintain the focus of infection invariably unattainable, thereby leading to its imminent collapse. From Fig 3, the extreme north had experienced highest daily maximum temperatures of 42.0 - 44.7°C over a period of forty to sixty (non-consecutive) days (12), which is capable of destroying both pupa, teneral and adult female flies. This observation is in tandem with (51) that stated that a further rise in temperature in areas that already experience high temperatures increases have the likelihood of reduction in the vector geographical ranges due to desiccation. Study conducted by (52) reported tsetse fly transmitted animal trypanosomiasis in areas of high risk in semi-arid and sub-humid zones in west Africa will generally contract due to both climate change, human population growth and increase in control activities. Similarly, Muriuki *et al.* (53) using time-population trend over five decades observed a three-fold expansion in cultivation in settled areas over a 50 years period with decrease in woody vegetation cover.

The Hadejia-Jama'are sleeping sickness focus is situated within the northern distributional limits of *Glossina tachinoides* and *G. palpalis*. According to (54), the area correspond best with the joint condition that temperature and saturation deficit do not exceed 27°C and 14 mmHg respectively, while the southern, cooler, limit is set by the line of 6/7 mmHg saturation deficit (55). Recent studies in the Maasai Steppe of Tanzania by (56) showed that the relative abundance of *G. m. morsitans* and *G. swynnertoni* was negatively correlated with maximum and minimum temperature, respectively. At the continental scale, a strong correlation between land cover and tsetse habitat is found for both the *fusca* and *palpalis* groups, whereas a weaker correlation found for the *morsitans* group may be indicative of less restrictive ecological requirements (57). Tsetse fly distribution in the study area appears to be driven by ecological factors such as variation in land use. Although targeted control of tsetse flies have played a role in determining distribution, no major control operations have been implemented in the area for 15 years (58) as shown on Tab. 3. This will translate to strong impact of climatic changes on vector-borne diseases (59) including African trypanosomiasis. Thermal data is claimed to be the most useful predictor variables, followed by the NDVI as both interplay in sustaining the low TSI of this primordial focus. It has been observed that as more areas are becoming more suitable for flies, other areas become less suitable, so that the distributional limits shift slowly with time (60). Using the effects of temperatures on vector ecology, vector biology and vector-parasite interactions via a disease transmission model, Moore *et al.* (61) predicted how epidemics can occur when mean temperatures are between 20.7°C and 26.1°C. Although the model did not predict a large-range expansion, but rather a large shift of up to 60 per cent in the geographical extent of the range. The extent of the tsetse free areas of northern Nigeria will continue to expand or contract depending on the changing climatic and environmental indices (62). This in line with epidemiological disease model projections for pathogen-host interaction (63). It is worthy of note that tsetse population may recover as observed in the far north of Sudan where *G. m. submorsitans* from refugia after intervention or re-colonisation of a cleared zone (64). Tsetse fly re-invasion could possibly be from neighbouring Yankari Game Reserve in Bauchi State and the Forest Reserve at Tundun Wada in Kano State, which are known to be tsetse fly infested.

Conclusion:

To conclude this discuss, it is apparent that the old Hadejia-Jamaare sleeping sickness endemic focus may have collapsed due to the vagaries of climate change, high human pressure on land for intensive crop farming that lead to fragmentation of the natural forest or tree covers. Consequences of widespread commercial exploitation of trees for firewood at alarming and uncontrolled manner without regards to existing laws will be difficult to reverse as an estimated 90% of the population is said to live below the poverty line and continued to rely on firewood for cooking. The spatial extent of tsetse free areas in the extreme northern Nigeria will continue its southward spread influenced by desertification that has remained unchecked. Any attempt of reforestation or greening the affected area should consider the environmental impact with respect to tsetse fly re-invasion and recolonization of the focus. It is expedient to use the huge database on climate and NDVI available from geographical information system and remote sensing data to initiate field epidemiological and entomological assessment of the actual

current geospatial coverage of the tsetse free areas in northern part of Nigeria. This will pave way for adequate utilization of the vast land within this ecological zone for meaningful livestock development and allied business.

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COMPETING INTERESTS

The author declares there is no competing interest.

AUTHORS CONTRIBUTION

This work was conceptualized, scripted and reviewed by the author. Sources of data and information from publications available in the open domain that were relied on in this review have been duly cited and listed under the references.

ETHICAL APPROVAL

Ethical approval is not necessary. The interview did not infringe on the privacy of those interviewed. There are no ethical issue involved. Those interviewed freely consented to participate in the study approved by the author's affiliate Institution Research and Development Committee.

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