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Assessment and Management of Human African Trypanosomiasis Propagation using Geospatial Techniques

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Abstract

Human African Trypanosomiasis (HAT) is a chronic and acute vector-borne disease. The propagation of the disease has been linked to environmental factors, and understanding the vector's habitat is vital to its control. The available medications for HAT are dated, lethal and expensive, but biological control of the vector has been successful in some endemic foci. Nevertheless, recently the disease has re-emerged and spread and its management remains demanding. To manage and control the disease effectively, precise, up-to-date and comprehensive knowledge of its spatial characteristics is essential. This study is based in HAT endemic foci of Delta State, Nigeria. The study applied a geospatially developed HAT vector habitat classification scheme to assess the vulnerability level of settlements affected by HAT. In addition, factors influencing HAT propagation and land cover suitability for HAT Vector within HAT vector Habitat Zones were investigated and assessed in a geographic information system environment. The aim was to present HAT endemic countries with strategy for mapping and deriving precise, timely and life saving data/information from HAT vector habitat. The study emphasizes the importance of geospatial techniques where there are dearths of epidemiological data, for improving perceptive of HAT. The study findings suggested propagation of HAT resulted from suitability of water bodies, shrub and less-dense forest for the HAT vector, and continued exposure of human populations to these land cover classes. Overlapping of HAT vector habitat zones within built-up areas was also a cause. This novel approach can also be used in other part of Nigeria as well as adapted to investigate other diseases.

Keywords: Trypanosomiasis, Geospatial, Propagation, Epidemiological, HAT

1.0 Introduction

Human African Trypanosomiasis (HAT) is a chronic and acute vector-borne disease. A disease thought to have been conquered during the 1960s in Nigeria through the use of biological control of the tsetse fly (BICOT), is re-emerging with areas becoming re-infested (Dede & Mamman 2011) and a shift from the north to the southern part of the country. The closure of most Nigerian Institute for Trypanosomiasis Research (NITR) epidemiological out-stations in 1985 led to a drastic decline in active surveillance for HAT, making it difficult to assess the true numbers of infected individuals in Nigeria. However, the number of HAT reported cases rose from 619 in 2002 to 7,104 in 2004 and although declining slightly to 5,548 in 2005, rose again to 6,419 in 2006. The numbers of reported cases of death from HAT from 2002 to 2007 are not available (National Bureau of Statistics 2007).

The recurrence of HAT in both old and new foci prompted WHO at the 50th World Health Assembly to adopt a resolution to increase the disease awareness and, Nigeria was reported as one of the highest ranked endemic countries for HAT (WHO 1997; 2007).

Finding a lasting cure for the disease will aid its eradication, however, other approaches are also important as a cure alone will not prevent disease spread. Assessments of factors that make an environment conducive for HAT are essential for sustainable disease management and to understand HAT propagation. These factors may vary significantly within indigenous clustered settlements, and it is important to characterise these variations and detect hazardous areas. The significance of these factors were emphasized in previous studies (Cecchi et al. 2008; DeVisser & Messina 2009; Sutherst 2004; Berrang-Ford 2007; Courtin et al. 2005) and it has been pointed out that epidemiology of HAT cannot be analysed in the absence of precise environmental data Reid et al. (2012).

1.1 GIS and Remote Sensing Integration in Disease Management

RS data provides reliable, timely, accurate and periodic data, while GIS provide various methods of integrating tools to create different planning scenarios for decision making. Thus the adoption of these technologies in assessing and managing HAT propagation in the study area is appropriate. RS and GIS tools could be regarded as the catalyst needed to dissolve the regional-systematic and human-physical dichotomies that have long plagued disciplines connected with spatial information (Akiode 2008). When investigating a phenomenon with an aim of progressing to efficient management, (e.g. disease control and prevention), some connection is vital to understanding and managing activities and resources that are often missing. With RS and GIS, it is possible to make connections between activities based on geographical proximity.

Currently, GIS and RS are crucial in many fields and has assisted in decision making process (Ageep et al. 2009; Kelly-Hope & Mckenzie 2009; Noor et al. 2008; Ekpo et al. 2008). It was opined in ILWIS 2.1 that, most decisions are influenced to some extent by geography. What is at a location? Where are the most suitable sites? Where, when and which changes took place? ILWIS 2.1 further stated that, in order to be able to make the right decisions, access to different sorts of information is required. Data should be maintained and updated and should be used in the analysis to obtain useful information.

The principle behind the association of RS and the study of disease origin and propagation is the development of a logical chain that connects emitted energy from a remote sensing sensor to disease measures and the disease transmitting organism (Kalluri et al. 2007). For instance, RS sensors at different wavelengths records energy emitted by phenomena on the earth surface or within vector-bone diseased endemic areas. The emitted energy is then pre-processed to generate different land cover classes and/or. The land cover classes can be re-classified into vector habitat; the survival of disease vector and its propagation is associated to the vector habitat. Thus, RS data can give insights into the factors influencing disease propagation using habitat information. Emitted energy recorded of phenomena on the earth's surface could also be pre-processed to obtain ancillary datasets such as normalised difference vegetation index (NDVI), land surface temperature, etc. All of these could be analysed singly or combination with other datasets/information to examined and manage the disease in a given environment.

The landscape is central to the study of disease origin and propagation; and in-depth knowledge of the landscape and factors that affect disease propagation retrieved using RS is, therefore, a function of the spatio-temporal interaction between the land cover classes.

1.2 The Study Area

This study is based in Ethiope-east and Ukwuani Local Government Areas in Delta State, Nigeria. The two HAT foci is located between latitudes 5o30'N and longitude 6o00'E (Figure 1).

Delta State is one of the states that make up the Niger Delta Region of Nigeria. Though the Niger Delta Region is rich in natural resources, basic amenities are lacking and a large portion of the region is inaccessible to the health service workers due to geography and frequent civil unrest (Niger Delta Regional Development Master-plan (NDRDMP) 2006). The predominant occupations include farming, fishing and hunting (NDRDMP 2006; Niger Delta Environmental Survey 1997). Water-related diseases are a critical health problem for these people, representing around 80% of all reported illnesses in the region (NDRDMP 2006). Communities also suffer from weak infrastructure including water supply and sewerage. Only 5.4% households in Delta State have access to treated pipe-borne water, with the majority dependent on sources such as rivers and wells (National Bureau of Statistics (National Bureau of Statistics 2008a). Only 11.2% of households have toilets with septic tanks (NDRDMP 2006), with most utilising bush latrines (National Bureau of Statistics 2008b). These socio-economic characteristics show the importance of the physical environment to the livelihood of the human population, as well as its contribution to exposure to vector-borne HAT.

This study intends to assess HAT propagation in all the settlements and land cover types within the study area. That is, the research is intended for community level intervention that can be adapted for other diseases at national level.

Figure 1: **A Landsat 7 ETM+ true colour image of Delta Statewith local government areas (**inset Niger Delta region in red**)**

2.0 Material and Method

All the data used were projected to the World Geodetic System (WGS) 84 datum Universal Transverse Mercator (UTM) Zone 32N. Anonymised hospital record of HAT cases between 1994 and 2006 acquired from Eku Baptist hospital, Delta State Nigeria was exported into ArcMap 10.1 as shapefile. The settlements in the study area were georeferenced using Timble GPS to acquired ground control points (GCPs) and merged with the hospital record and a base map for further analysis.

The analysis carried out in this study applied a geospatially developed HAT vector habitat classification scheme by Akiode & Oduyemi (2014). Using Geospatial-fuzzy multicriteria analysis, Akiode & Oduyemi 2014 integrated land cover classes and environmental/climatic variables derived from RS image to classify the study area landscape into three HAT vector habitat zones, namely ‘breed’, ‘feed’ and ‘rest’.

Each HAT vector habitat zone was logically queried in ArcMap 10.1 to categorise the degree of hazard in the zones based on three values of fuzzy membership. The hazard map and fuzzified Euclidean distance map of land cover classes used in the development of the HAT vector habitat classification scheme were merged to compute and categorised vulnerable areas within 400m of each HAT vector habitat zone into four vulnerability categories. HAT mean centre was also calculated using hospital record.

2.1 The Mean Centre

To track changes in the distribution of HAT for the years 1994 -2006, and to identify the possible origin for HAT disease in the study area, the ArcMap spatial statistics tool was used to create a point map that illustrates the mean centre for each year of HAT case occurrence. The tool calculates the average geographical coordinates for HAT cases for specified years. Figure 2 shows the average mean centre calculated over this period.

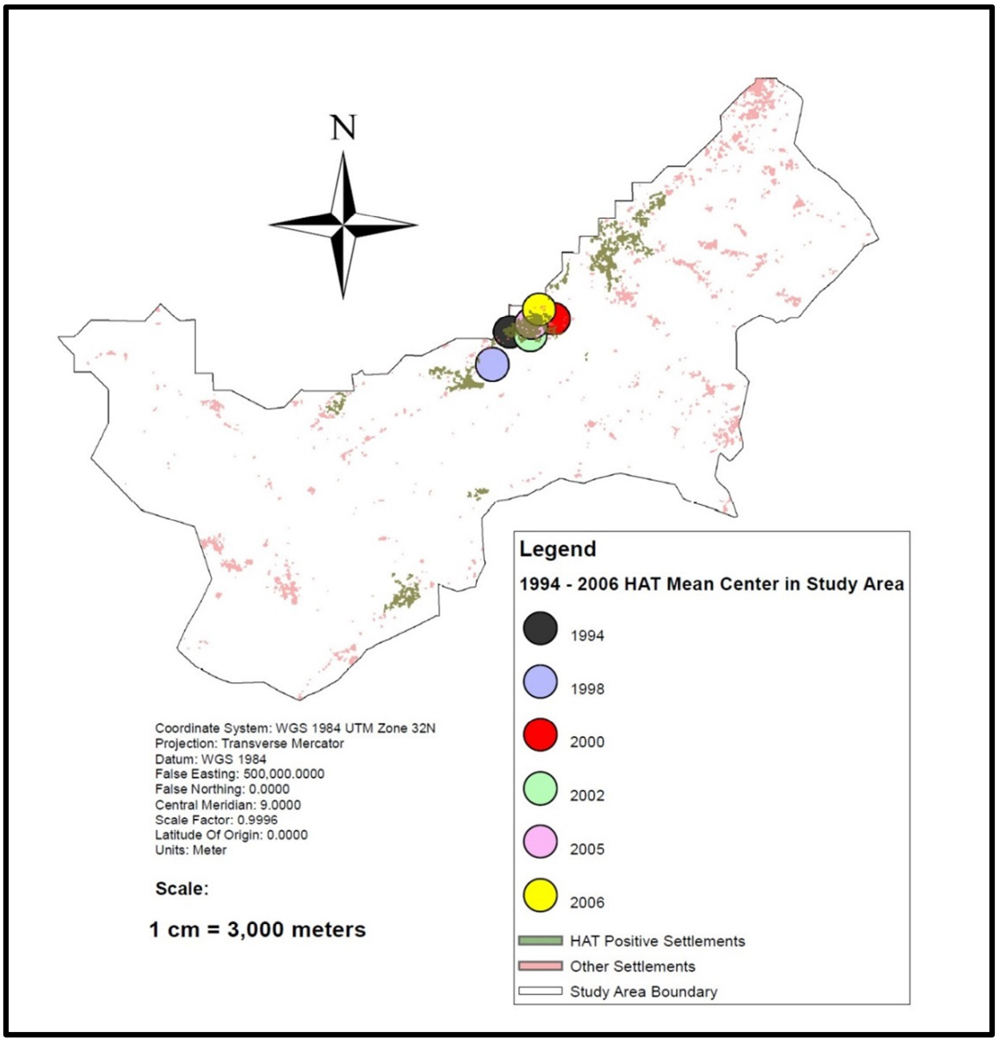

Figure 2: Average mean centre of HAT distribution within the case positive settlements in the study area (source: HAT record of cases acquired from HAT sentinel centre, Eku Baptist Hospital, Nigeria).

2.2 Assessing Vulnerability of HAT Positive Settlements

The vulnerability of settlements that recorded one or more cases of HAT between 1994 and 2006 in the study area was assessed by adapting Cecchi et al. 2008 tsetse fly (HAT vector) suitability threshold. After calculating the average of the percentage of HAT vulnerability categories within each settlement, the outcome was categorised as Table 1.

Table 1: Proposed threshold for determining vulnerability of settlements within HAT vector habitat zones (source: proposed by researcher, adapted from Cecchi et al. 2008)

Predicted area of presence within settlement (%)	Vulnerability category for HAT vector zone	Vulnerability index	Description
> 50	High	3	**Potential highest vulnerable locations**
> 25 and ≤ 50	Moderate	2	**Potential fairly high vulnerable locations**
> 5 and ≤ 25	Low	1	**Potential low vulnerable locations**
≤ 5	**Non**	**0**	**Vulnerability free locations**

2.3 Investigating Factors Responsible for HAT Propagation in the Study Area

There is the need to investigate factors responsible for HAT propagation in the study area. A spatial analysis called zonal histogram was used to investigate the frequency distribution of values of land cover classes present within the vulnerable areas of each HAT vector habitat zone in the study areas. The zones were earlier categorised as "Very High", "High", "Moderate" and "Low" (Akiode & Oduyemi, 2014).

2.4 Land Cover Suitability Assessment for HAT Vector within Habitat Zones

In order to establish the suitability of the land cover classes for the HAT vector, the classes grouped within the very high and high vulnerability categories in each vector habitat zone, were investigated. Cecchi et al. (2008) tsetse fly suitability index was adapted for the analysis. Cecchi et al. (2008), determined land cover suitability for tsetse flies based on the percentage of the entire surface affected by the fly within a land cover class. In the context of this study, the land cover suitability for the HAT vector was determined based on the percentage of each HAT vector habitat zones (breed, feed and rest), within a specified land cover class.

3 Results

3.1 Assessing Vulnerability of HAT Positive Settlements

All the HAT positive settlements were contained within each zone and the three HAT vector zones overlapped within each settlement.

The result of vulnerability assessment conducted for all the settlements with one or more cases of HAT between 1994 and 2006, revealed, as shown in Figure 3, that two out of the nine settlements were highly vulnerable to the breed zone, while the others are moderately vulnerable.

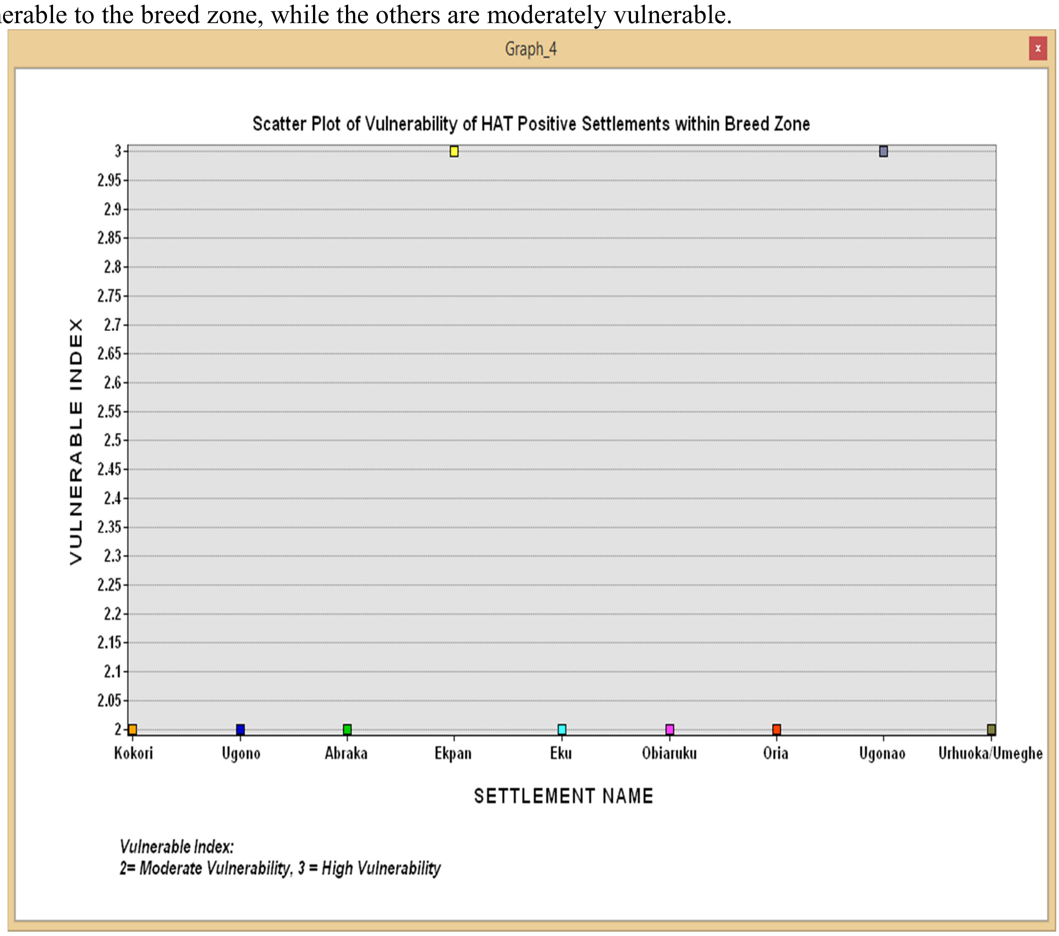

Figure 3: Scatter plot of vulnerability of HAT positive settlements within HAT vector breed zone in the study area.

Figure 4 showed that only one settlement is highly vulnerable to the feed zone and one settlement has low vulnerability, while others are moderately vulnerable. For the rest zone (Figure 5), two of the settlements have low vulnerability. High vulnerability was recorded for one settlement while others are moderately vulnerable to rest zone.

One important observation was the settlement Abraka, which has low vulnerability to both the feed and rest zones and is moderately vulnerable to the breed zone. The analysis carried out in section 2.1 revealed Abraka as the mean centre (Figure 2) for all the HAT case years except for 1998. Another settlement that caught the attention of the researcher is Ugonao, which has the highest vulnerability to all the zones. When the three habitat zones were overlaid on the settlement map, the three habitat zones overlapped and completely covered the settlement; this could be responsible for its high vulnerability status.

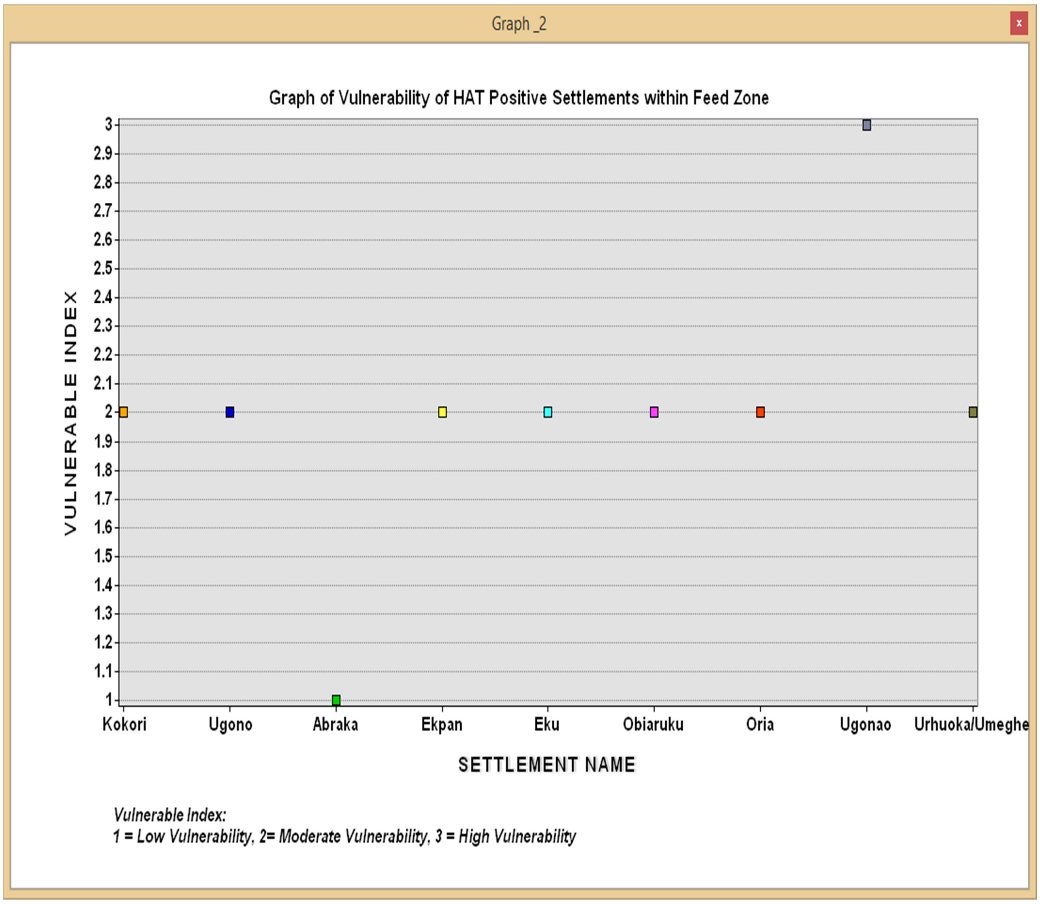

Figure 4: Scatter plot of vulnerability of HAT positive settlements within HAT vector feed zone in the study area

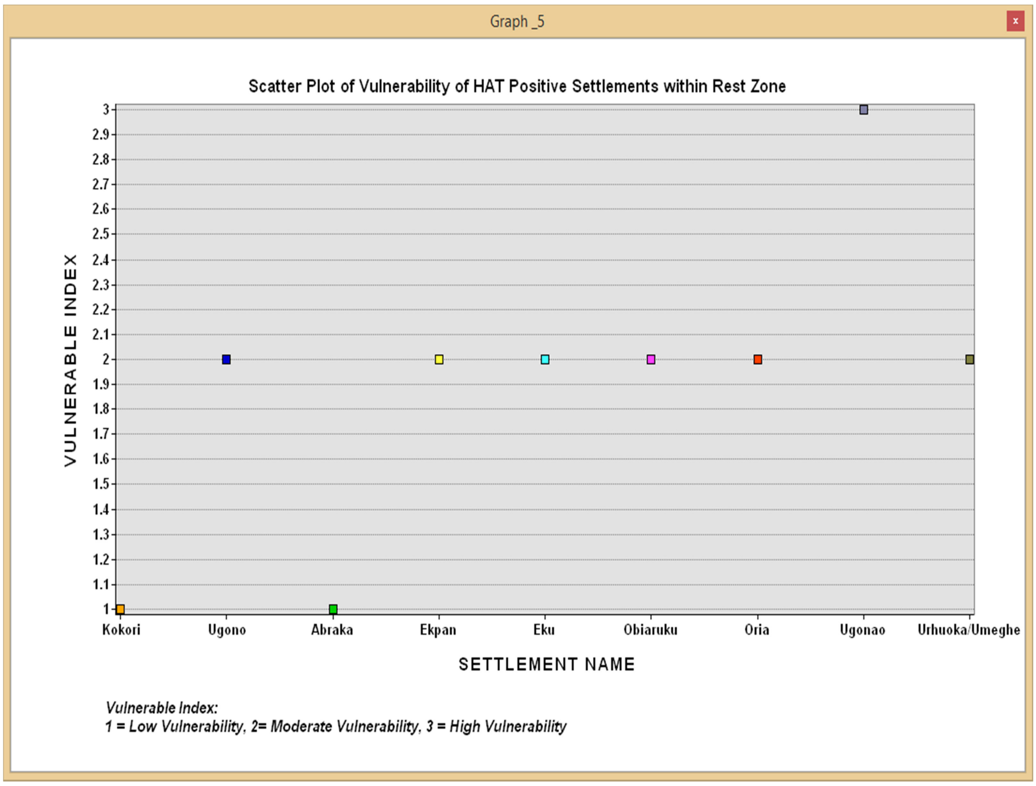

Figure 5: Scatter plot of vulnerability of HAT positive settlements within HAT vector rest zone in the study area.

3.2 Investigating Factors Responsible for HAT Propagation in the Study Area

The histogram analysis (Figures 6 - 8), revealed the land cover types that contributed or are contributing most to HAT propagation in the areas. However, it was observed that the histogram analysis did not reveal true information, it was noticed that the area coverage of the vulnerability category within specified locations influenced the result. Therefore, high frequency distribution of a land cover in a location may not necessarily mean high suitability.

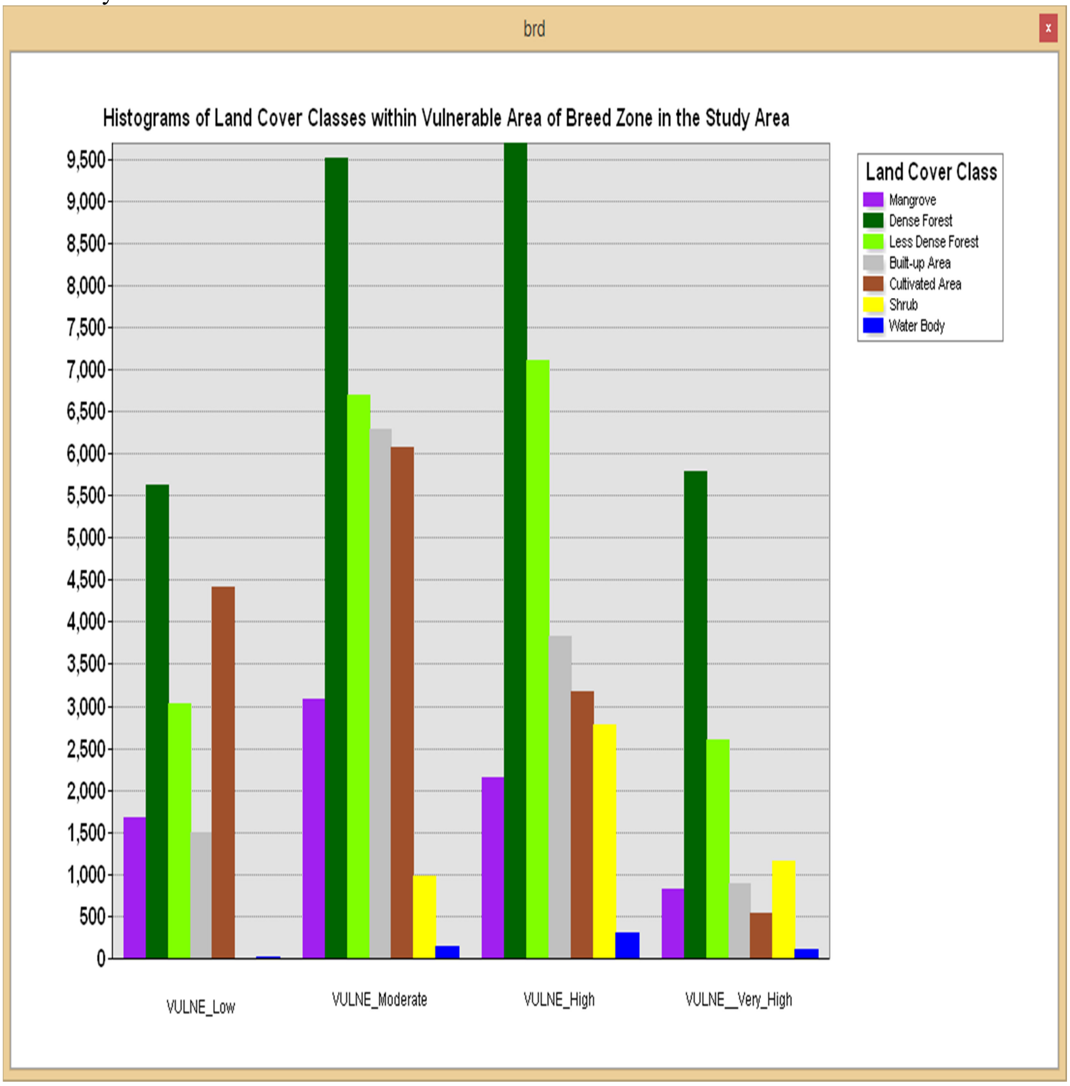

Figure 6: Frequency distributions of land cover classes within HAT vector breed zone in study area (VULNE_Low = low vulnerability category; VULNE_ Moderate = moderate vulnerability category; VULNE_ High = high vulnerability category and VULNE_Very_High = very high vulnerability category).

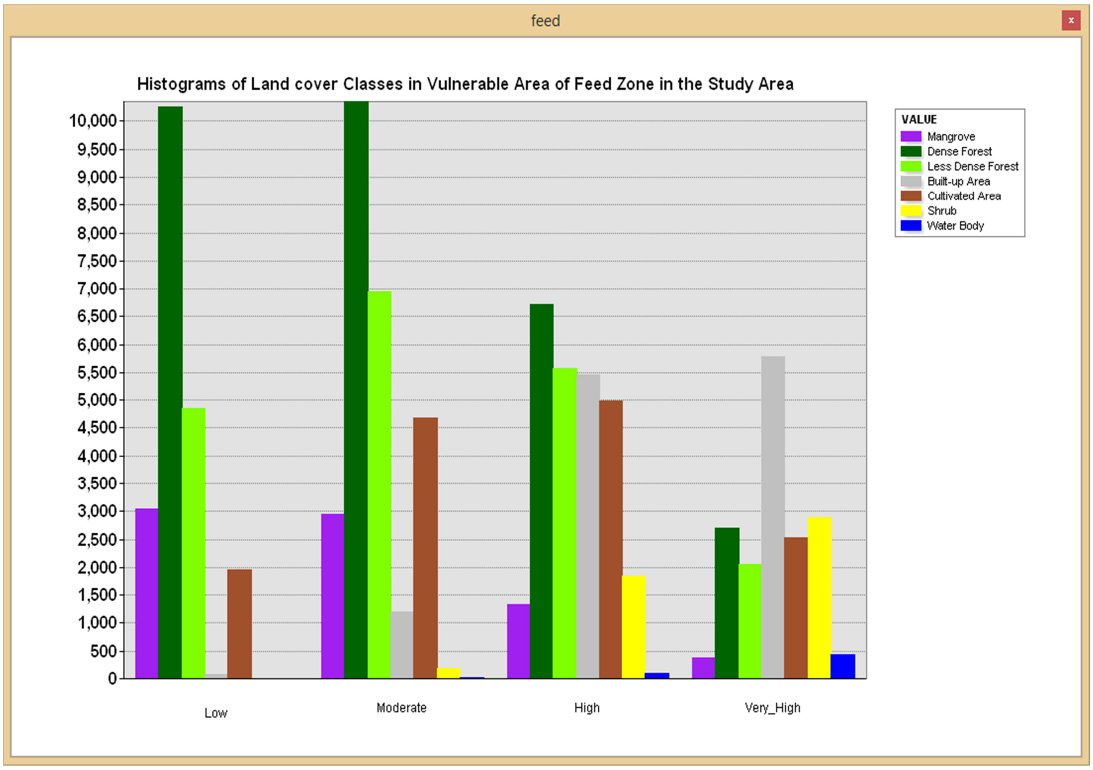

Figure 7: Frequency distributions of land cover classes within HAT vector feed zone in study area

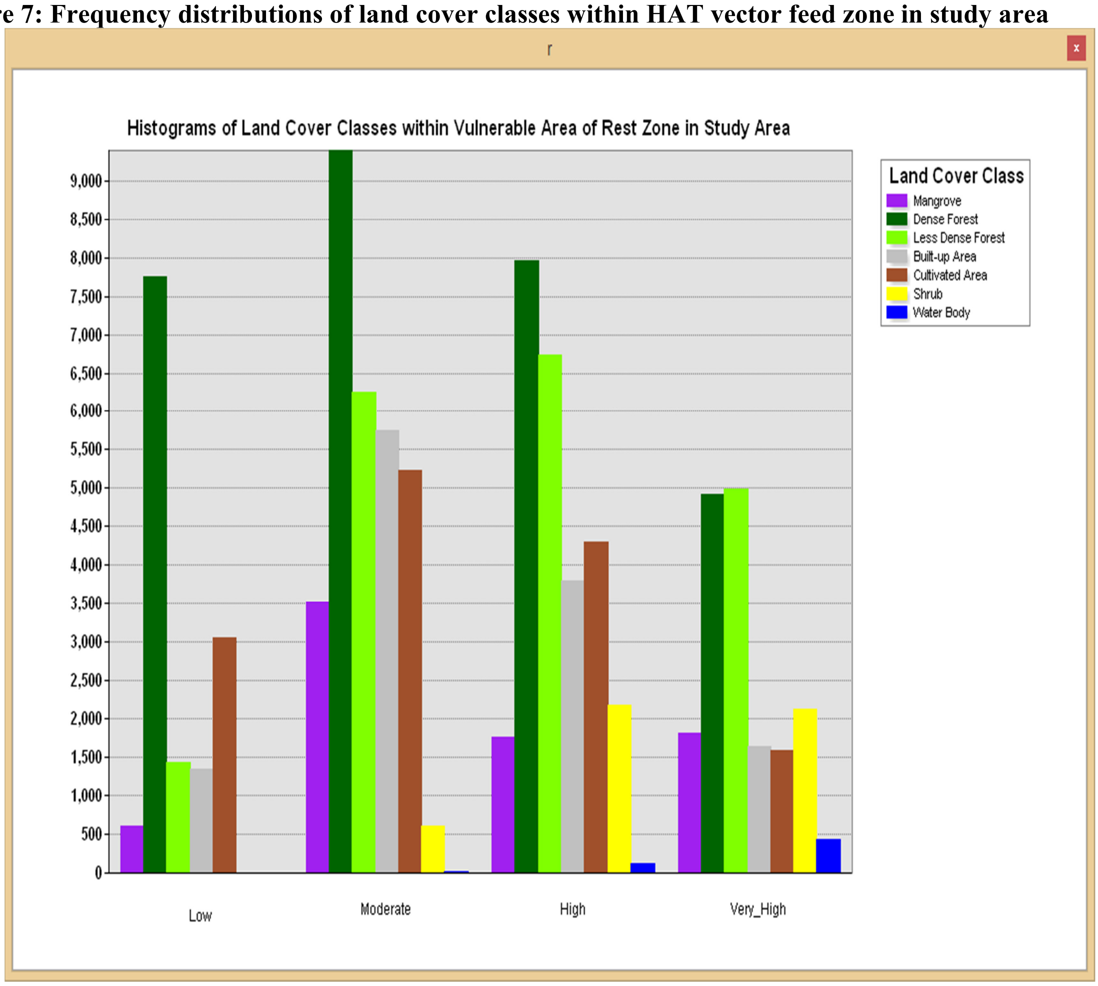

Figure 8: Frequency distributions of land cover classes within HAT vector rest Zone in the study area

3.3 Land Cover Suitability Assessment for HAT Vector within Habitat Zones

As a result of the observation in section 3.2, a land cover suitability assessment was performed.

The results, shown in Tables 2 - 4, revealed water bodies and shrub as potentially the highest contributing factors to HAT propagation in the study area. Another factor highlighted was less-dense forest, which can be categorised as a moderate potential contributing factor based on the analysis. The researchers' deduction was based on the fact that these land covers were prominent in all the three HAT vector habitat zones.

Table 2: Suitability of land cover classes for HAT vector within HAT vector breed zone in the study area

Land cover class	Area of land cover within Study area (m2)	Area of breed zone within land cover class (m2)	% of breed zone within land cover	Suitability category for tsetse	Suitability Index	Description
Mangrove	65528100	6634167.5	10.1	Low	1	**Potential low hazard locations**
Dense Forest	260262900	248478954.5	95	High	3	**Potential highest hazard locations**
Less-dense Forest	165814200	147229124.5	89	High	3	**Potential highest hazard locations**
Built-up Area	105891300	15269656.4	14	Low	1	**Potential low hazard locations**
Cultivated Area	121106700	15763599.6	13	Low	1	**Potential low hazard locations**
Shrub	42045300	34414211.7	82	High	3	**Potential highest hazard locations**
Water Body	4968900	3687541.1	74	High	3	**Potential highest hazard locations**

Table 3: Suitability of land cover classes for HAT vector within HAT vector feed zone in the study area

Land cover class	Area of land cover within Study area (m2)	Area of feed zone within land cover (m2)	% of feed zone within land cover	Suitability category for tsetse	Suitability Index	Description
Mangrove	65528100	289552.9	0.4	Non	0	**Potential Hazard free locations**
Dense Forest	260262900	7017399.3	3	Non	0	**Potential Hazard free locations**
Less-dense Forest	165814200	20140957.9	12	Low	1	**Potential low hazard locations**
Built-up Area	105891300	98303203.6	92.8	High	3	**Potential highest hazard locations**
Cultivated Area	121106700	105048082.5	86.7	High	3	**Potential highest hazard locations**
Shrub	42045300	37488582.0	89	High	3	**Potential highest hazard locations**
Water Body	4968900	4309228.2	86.7	High	3	**Potential highest hazard locations**

Table 4: Suitability of land cover classes for HAT vector within HAT vector rest zone in the study area

Land cover class	Area of land cover within Study area (m2)	Area of rest zone within land cover (m2)	% of rest zone within land cover	Suitability category for tsetse	Suitability Index	Description
Mangrove	65528100	58549296.1	89.3	High	3	**Potential highest hazard locations**
Dense Forest	260262900	28333601.2	11	Low	1	**Potential low hazard locations**
Less- Dense Forest	165814200	128135666.8	49	Moderate	2	**Potential fairly high hazard locations**
Built-up Area	105891300	10756038	10.2	Low	1	**Potential low hazard locations**
Cultivated Area	121106700	14383965.3	12	Low	1	**Potential low hazard locations**
Shrub	42045300	32710959.5	78	High	3	**Potential highest hazard locations**
Water Body	4968900	3755671.2	76	High	3	**Potential highest hazard locations**

4. Discussion and Summary

The aim of this study was to present HAT endemic countries with strategy for mapping and deriving precise, timely and life saving data/information from HAT vector habitat. The study applied a geospatially developed HAT vector classification scheme to identify the landscape factors influencing propagation of HAT as well as assessing the suitability of these factors for the HAT vector within each HAT vector habitat zone. The landscape suitability assessment carried out using an adapted tsetse fly suitability-threshold, revealed water body, shrub and less dense forest as the landscape features that contribute most to the propagation of HAT in the study area. The risk of HAT propagation is not, however, completely linked to land cover, but depends also on other factors not considered in this research. Human population in the study area are exposed to these land cover classes daily, for example, washing of cloths or fetching of water from the stream. Also, some of the local markets are surrounded by shrubs and less dense forest. The propagation of HAT in the study area is, therefore, likely to be due to the favourable landscape and probably the continuous exposure of the human population to water bodies, shrubs and less dense forest.

Another important contributing factor to HAT propagation in the study area is the overlapping of the HAT vector habitat zones (Breed, Feed and Rest) within the built-up areas. The implication of this for the study area or other places with similar characteristics is continuous human-vector contact at all times, day or night. This may have serious consequences. Apart from shrub, the identification of water bodies and less dense forest as the largest contributing factors to HAT propagation in the study area supports previous studies in other parts of sub-Sahara Africa, which have associated the HAT vector with these land cover classes (Courtin et al. 2005; Batchelor 2010; DeVisser & Messina 2009 ; Zoller et al. 2008). Previous, studies generally highlight water bodies, and vegetation as contributing factors. However, the method applied in this study and the level of detail has revealed shrub as one of the most important contributing factors. The implication of this for the study area is that the majority of human populations may be vulnerable to HAT, because most places of residence are surrounded by shrub, and irrespective of the people's occupation, age or gender, could be infected provided the shrub that is closest is suitable for the HAT vector.

Based on past surveillance exercises, previous studies, for example, Osue et al. (2008), have suggested a particular settlement as the most vulnerable to HAT in the study area. The identification of the settlement (Abraka) as the mean centre (section 2.1) of HAT in the study area, which from the result of further analysis (section 3.1) turned out to have low vulnerability to HAT, illustrated underlying factors contributing to the high frequency of HAT in the settlement, yet, this research has not considered all other potential factors. The incorporation of socio-economic/cultural characteristic data of the settlement and/or other settlements in the study area may provide further knowledge of some of the underlying factors influencing HAT propagation in the settlement, and the study area.

The land cover suitability analysis carried out in this research (section 3.3) has not been validated; the suitability analysis was based on the area coverage of land cover class within the HAT vector habitat zones. Sensitivity analysis using different thresholds or integration of other criteria such as HAT vector abundance with this analysis may have influenced the outcome considerably; the abundance of the HAT vector could be combined with environ-climatic datasets for delineating the vector habitat into zones in future, and also incorporated into the suitability analysis.

Finding a lasting cure to HAT is one of the mechanisms for eradicating the disease. However, there are other ways of approaching the problem that should be considered, as a cure will not prevent the disease from spreading. Preventing the propagation of HAT in the study area will involve limited or no contact between the HAT vector and humans.

The results of the application of the HAT vector habitat classification scheme revealed water bodies, shrub and less dense forest as the largest contributing factors influencing HAT propagation in the study area. This suggests that strategies that will limit the exposure of human populations to these land cover should be a high priority for the Federal Government of Nigeria. Limiting the exposure of the human population to these land covers is a challenge, more so that another potential factor influencing the propagation of HAT in the study area is overlapping of the three HAT vector habitat zones within the built-up areas. The Federal Government, State Government and most especially the Local Government, should embark on a public awareness programme, educating the people in the study area about the dangers of exposure to the HAT vector and suggest some precautionary measures. The government could ensure provision of basic amenities, such as constant pipe-borne water at an individual household level and provide affordable gas or electricity for cooking to reduce constant exposure to water bodies and less dense forest. Also, provision of public toilets and encouraging/enforcing construction of toilet facilities in households to limit exposure to shrub/water body should be government priority.

The overlapping of the HAT vector habitat zones within built-up areas is a threat to human population in the study area. Thus, control programmes targeting individual vector habitat zones should also be a priority for the Governments. The use of insecticide to control the vector is one option, but this may not be healthy to the environment, thus, environmental friendly control measures such as biological control could be used. However, this may be difficult to achieve due to constraints such as, the heterogeneous nature of the landscape, inadequate funding, low capacity buildings for health workers and little or no technical know-how. The continuous exposure of the human population to the HAT vector, most especially within the feed zone, may ensure continuous propagation of the HAT in the study area.

Due to the overlapping of the HAT vector habitat zones within human settlements, future studies focusing on the development of effective environmental friendly measures that will reduce the vulnerability of human population to HAT, as well as ensure sustainable environment, is essential.

The existing surveillance system, rural health care institutions and facilities cannot adequately inform the extent of the disease. The researchers, therefore, finally recommends the application of the geospatially developed HAT vector classification scheme on a nationwide scale, to ascertain the magnitude of not only HAT, but other vector borne diseases.

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