

GEOSPATIAL FORECAST MODEL FOR TSETSE-TRANSMITTED ANIMAL TRYPANOSOMOSIS IN ETHIOPIA

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ABSTRACT: The aims of this study were to develop a geographic information systems (GIS) forecast and risk assessment model for cyclically transmitted trypanosomosis in Ethiopia by matching features in the environment to available information on the preferences and limits of tolerance of the parasite and its vector, and validate and further develop the GIS model using data from current and historical prevalence survey data and habitat microenvironment studies from trypanosomosis endemic areas. Results indicate that GIS model developed for parasitic diseases based on growing degree day (GDD) concept can be applied to tsetse-transmitted trypanosomosis. GIS for animal trypanosomosis was created using Food and Agriculture Organization - Crop Production System Zones (FAO-CPSZ) database and Normalized Difference Vegetation Index (NDVI) and maximum temperature (Tmax) from the Global Land 1km dataset. The two datasets used to determine the risk of tsetse flies and consequently animal trypanosomosis in Ethiopia indicated the magnitude of the disease and possible expansion of the "fly belt" in the future. The GIS model indicated the distribution and importance of tsetse-transmitted trypanosomosis in Ethiopia. Spatial and statistical analysis verified the use of GDD concept and climate forecast system that was developed to determine the suitability of a given environment for the proliferation of a biotype, in this case tsetse and trypanosomes. Results presented here indicate the importance of GDD and the two climatic variables (NDVI and Tmax) in the development of forecast model for tsetse-transmitted trypanosomosis in Ethiopia.

Key words/phrases: Ethiopia, GIS, NDVI, Tmax, trypanosomosis

INTRODUCTION

Ethiopia, with its great variation in climate and topography, possesses the largest cattle population in Africa. However, livestock productivity remains marginal due to prevalent diseases, malnutrition and management constraints. Tsetse-transmitted trypanosomosis, locally referred as 'Ghendi' caused principally by *Trypanosoma congolense*, *T. vivax* and *T. brucei*, is one of the major cattle health constraints in the country (Zeleeke Dagnachew *et al.*, 1985; Rowlands, *et al.*, 1995; Getachew Abebe and Yilma Jobre, 1996). The early works of Langridge (1976) indicated that tsetse flies infested about 98,000 km² of potentially fertile land in the southwestern part of Ethiopia denying efficient agricultural activity in the region. However, precise information on the distribution and abundance of these vector flies as well as the disease are scanty. The pattern of disease

transmission by tsetse flies, on the other hand, varies markedly from region to region, depending on climate and biogeography, and broad ecological categories have been widely used to describe variations in the observed epidemiological features in an area (Ephraim Mamo, 1993; Getachew Abebe and Yilma Jobre, 1996). Careful definition of environmental factors that govern the vector ecology and disease transmission patterns are essential steps towards the development and institution of a sound trypanosomosis control scheme both at a national and regional level.

Geographic information systems (GIS) provide a way to use computers to create, archive and analyze traditional map data on epidemiology of diseases and to combine these with global environmental data derived from sensors on board earth-observing satellites. A GIS is created by linking standard computer database 'attributes' to map features represented as digital vector

(polygons, points, lines) or 'raster' image. Using a new generation of commercially available digital geographic databases and hand held geographic positioning systems (GPS) precise point location and maps can be created for disease applications.

Crop models are well known that describe the suitability of different environments for cultivation and recommended times for planting, fertilizer and pest control (Van Velthuis *et al.*, 1995). It is proposed that similar methods can be developed, with GIS agroclimatic databases and satellite sensor technology, to describe the distribution range and suitability of different areas for propagation and transmission of disease, and that this information can be used to design control programs and optimize interventions.

Literature reports on GIS medical and veterinary applications include malaria (Beck *et al.*, 1994; 2000; Bergquist, 2001), rift valley fever (Linthicum *et al.*, 1987), filariasis (Thompson *et al.*, 1996), African trypanosomiasis (Rogers and Randolph, 1993; Rogers, 2000; Hendrickx *et al.*, 2001), theileriosis (Lessard *et al.*, 1990), *Onchocerciasis* (Richards, 1993), *Leishmaniasis* (Cross *et al.*, 1996), *Amblyomma variegatum* (Hugh-Jones *et al.*, 1992), lyme disease (Kitron *et al.*, 1992); *Fascioliasis* (Zukowski *et al.*, 1991; Malone *et al.*, 1992; Malone and Zukowski, 1992; Malone *et al.*, 1998; Yilma Jobre and Malone, 1998), and *Schistosomiasis* (Cross and Bailey, 1984; Malone *et al.*, 1997; Malone *et al.*, 2001).

The aims of this study were to develop a GIS forecast and risk assessment model for cyclically transmitted trypanosomiasis in Ethiopia by matching features in the environment to available information on the preferences and limits of tolerance of the parasite and its vector, and validate and further develop the GIS model using data from current and historical prevalence survey data and habitat microenvironment studies from trypanosomiasis endemic areas.

MATERIALS AND METHODS

GIS construction

The GIS databases were developed using ArcView 3.2 GIS (ESRI, Redlands, CA) and ERDAS imagine 8.3.1 (ERDAS, Atlanta, GA) softwares. The Food and Agriculture (FAO) Crop production System Zone

(CPSZ) database was originally developed for predicting a relative ecological suitability of an area for various crops (Van Velthuis *et al.*, 1995). According to agro-climatic environmental classes CPSZ boundary files were defined by classifying administrative units, or sub-units of administrative units if sharp ecological demarcations occur. Selected environmental features for 460 CPSZ in Ethiopia were extracted from CPSZ database and imported into ArcView 3.2 (ESRI, Redlands, Ca) as shape files for comparison to a compilation of animal trypanosomiasis survey data available at the Faculty of Veterinary Medicine, Addis Ababa University from 1985 (Getachew Abebe and Yilma Jobre, 1996), National Tsetse and Trypanosomiasis Investigation and Control Centre (Zelee Dagnachew *et al.*, 1985; NITICC, 2000) and Langridge's study report (Langridge, 1976). Prevalence data for the analysis was limited to 65 sites for which accurate latitude-longitude map coordinates were available. Global 1-km data was downloaded, imported as image file and calibrated to NDVI and Tmax values as described previously in studies on schistosomiasis (Malone *et al.*, 2001). Briefly the Global 1-km format for NDVI is scaled to positive values of 0–200 rather than accepted – 1 to + 1 NDVI range. Tmax data calibration yielded mid-day earth surface temperature values. Regional scale AVHRR data and other data layers included in the GIS were transformed to geographic, latitude-longitude, decimal degree format using the ESRI Digital Chart of the World (DCW) as a base map standard for GIS construction.

Forecast index based on Growing Degree Days (GDD)

The climate based parasite forecast system developed for fasciolosis by Yilma Jobre and Malone (1998) and Malone *et al.* (1998) was adapted to further develop a GIS risk assessment model for tsetse-borne trypanosomiasis for Ethiopia. Using growing degree day (GDD) value requirements for life cycle completion on tsetse fly species (*G. morsitans submorsitans* and *G. tachinoides*) and a water budget analysis using the Penman method for calculating potential evapotranspiration (PET), monthly forecast indices were

calculated for major cyclically transmitted *Trypanosoma* species, in this case *T. congolense*. Annual cumulative index values for specific endemic sites was then stratified and designated as '0' or no risk area ≤ 0 index value; '1' or 'marginal' 1–439 index value; '2' or 'low' 440–1440 index value and '3' 'high risk' ≥ 1441 index value. Annual cumulative index values (risk index for GDD) ranged from 0–2951.2. The base temperature was the temperature measurement (17°C) below which no development of tsetse's puparium stage in the environment (Seifert, 1996). GDD is defined as the number of degrees above 17°C average annual mean temperature from the CPSZ database.

Forecast index based on Global 1-km composite data

Evaluation was done to determine global 1-km NDVI and Tmax values consistent with known trypanosomosis areas using scatter diagrams prepared by plotting global 1-km NDVI and Tmax annual composite values, extracted from 10 km buffer areas centered on prevalence data points, against the infection prevalence survey data for the 65 sites (veterinary clinics). On average veterinary clinics in Ethiopia offer animal health services to a minimum area of 10 km diameter.

Validation of forecast models

Trypanosomosis infection prevalence and tsetse abundance database for 460 CPSZ homogenous agroclimatic map units in Ethiopia (IGADD-FAO, 1995) was developed using data obtained from the Faculty of Veterinary Medicine, Addis Ababa University (Getachew Abebe and Yilma Jobre, 1996), National Tsetse and Trypanosomosis Investigation and Control Centre (Zeleeke Dagnachew *et al.*, 1985; NTTICC, 2000) and Langridge's survey report (Langridge, 1976). Model validation was carried out by computer based statistical computations employing linear regression (Bruning and Kintz, 1977) to assess the relationship of the known disease and fly distribution with selected physical environmental determinates from the CPSZ database matrix. The

latter included climate data (annual rainfall, average annual mean temperature, potential evapotranspiration), altitude and average annual mean normalized difference vegetation index (NDVI).

RESULTS

Forecast based on GDD

Varying degrees of tsetse risk occur in all areas of Ethiopia except the central highlands and the northeast and southeast arid areas of the country. The highest risk areas were localized in the western zones associated with the river valleys of Blue Nile, Didessa, Baro, Akobo, Gojeb, Ghibe and Omo. The risk area extended from the southern part of the Rift valley, around the southwestern corner of the country and along the western lowlands and escarpments to the Blue Nile. The risk area further extends north from the Blue Nile to Tekeze River along the Sudan border. In the east the risk area spreads to the north along with the eastern escarpment and Awash River through the northern part of the Rift Valley of Ethiopia. Foci of risk areas were observed along the Wabi-Shebele and Genale Rivers flowing towards Somalia. Varying degrees of tsetse risk areas were found in five of the nine regional states namely, Amhara, Benshangul, Gambella, Oromiya, Southern Nation, Nationalities and People Region. According to the risk model, the eastern lowlands (Afar and Ogaden) and the central highlands of Ethiopia were free from tsetse-transmitted trypanosomosis.

Forecast based on Global 1-km composite data

To develop optimum criteria ranges for the NDVI and Tmax values for 10 km buffers, data collection sites were extracted from the combined three-year composite map. Query best-fit results were 135–155 for NDVI and 17–27°C for Tmax (Fig. 1a, b and Fig. 2 a, b). Evaluation on global 1-km NDVI and Tmax values revealed that tsetse infested areas were in best fit with *T. congolense* endemic areas as well as "fly belts" of Ethiopia.

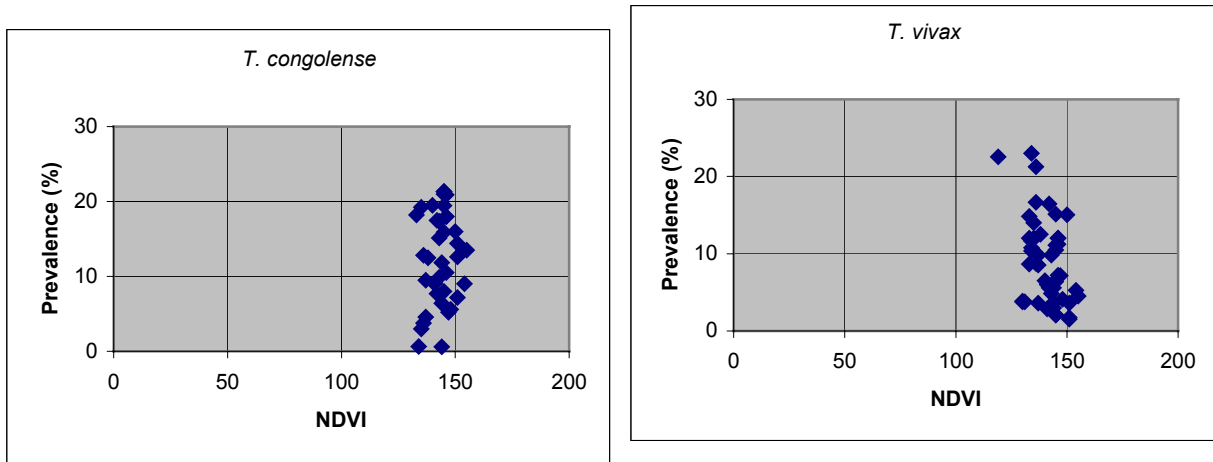


Fig. 1a and b. Scatter diagrams of *T. congolense* (a) and *T. vivax* (b) prevalence rate as compared to the values extracted from 1992–1995 composite NDVI from 10 km diameter areas centered on prevalence survey sites.

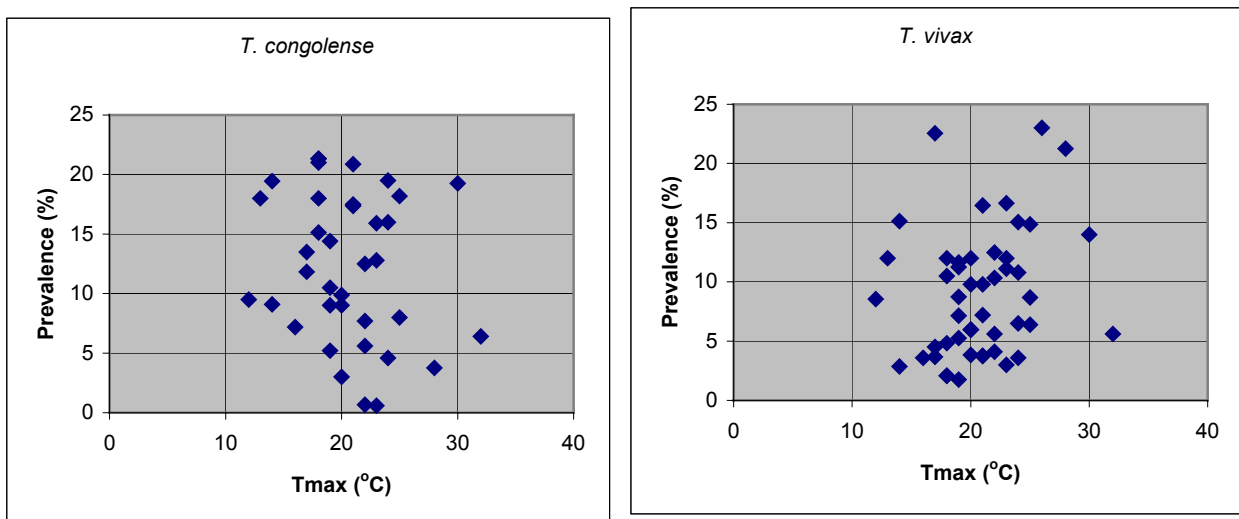


Fig 2a and b. Scatter diagrams of *T. congolense* (a) and *T. vivax* (b) prevalence rate as compared to the values extracted from 1992–1995 composite Tmax from 10 km diameter areas centered on prevalence survey sites.

Comparison of the forecast models with known tsetse infested areas

The two forecast models matched with the most authoritative work of Langridge (1976) who surveyed some 213,000 km² and concluded that some 98,000 km² were infested (Fig. 3a and b). All the areas classified by Langridge as high and low risk were within the risk area model of the work reported here. In addition, the prevalence data on tsetse transmitted trypanosomes indicated that with the exception of few foci in the north and central highlands escarpments, tsetse transmitted trypanosomes in particular *T. congolense* infection

was confined to the known “fly belt” of Ethiopia. Analysis revealed a spatial correlation between *T. congolense* > 5% prevalence and annual forecast index (Fig. 1b and Fig. 4a). Nevertheless, there were a number of *T. congolense* prevalence sites on the highlands, just at the margin of the forecast area. These areas were very close to tsetse-infested area and most of the animals from the close by tsetse infested area travel to the nearest clinic on the highlands. *T. vivax*, one of the most important cattle trypanosomosis next to *T. congolense* was found both in the tsetse infested (Fig. 4b) and tsetse free area.

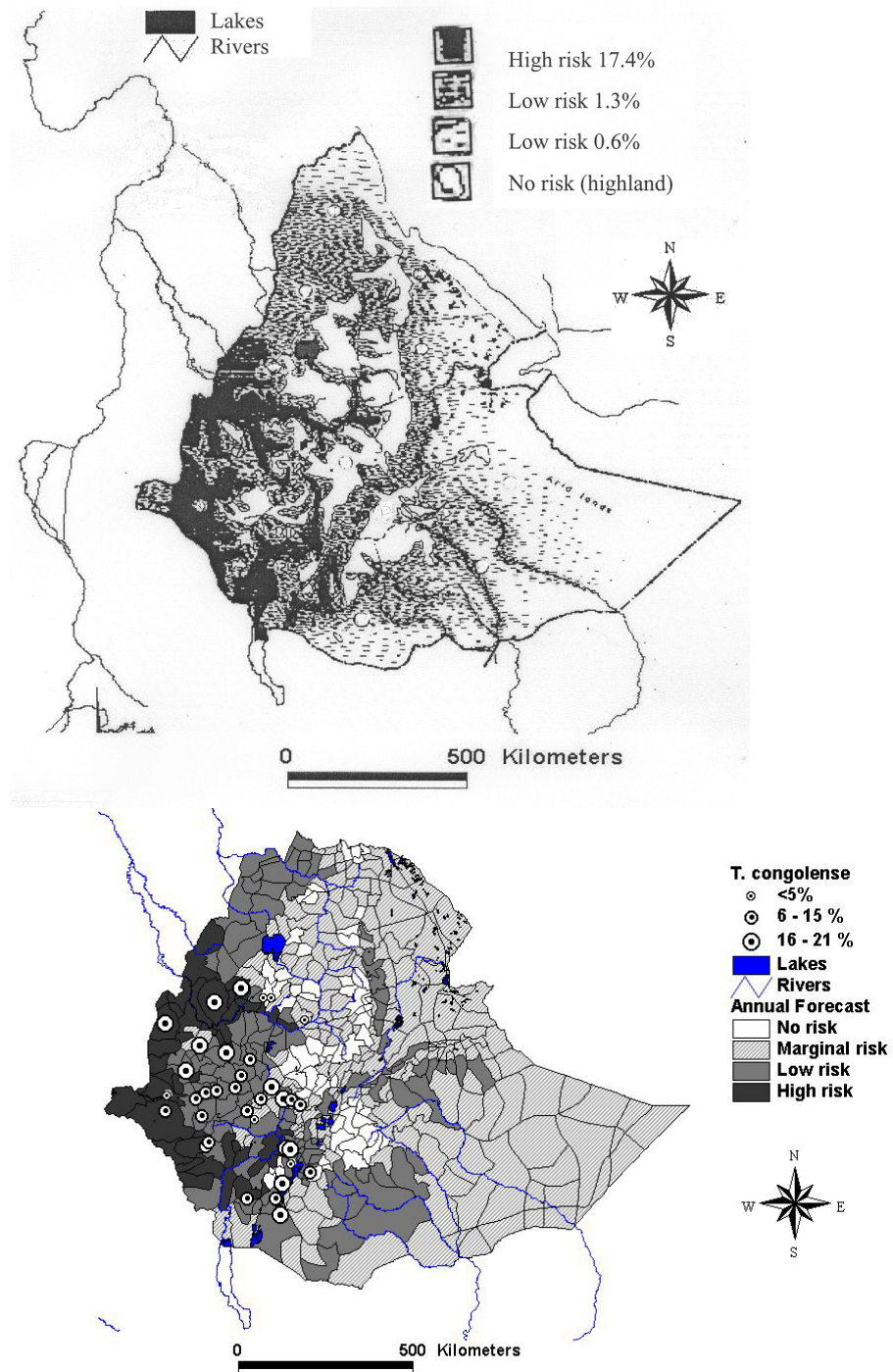


Fig. 3a and b. Langridge's map of tsetse distribution in Ethiopia (a) and GIS map of tsetse and trypanosomosis potential distribution and abundance gradients for Ethiopia with known *T. congolense* prevalence sites (b).

DISCUSSION

Results indicate that GIS model developed for parasitic diseases based on GDD concept can be applied to tsetse-transmitted trypanosomosis (Fig. 3b). GIS for animal trypanosomosis was created using FAO-CPSZ database and NDVI and Tmax from the Global Land 1km dataset. The two datasets used to determine the risk of tsetse flies and

consequently animal trypanosomosis in Ethiopia indicated the magnitude of the disease and possible expansion of the "fly belt" in the future. The GIS model indicated the distribution and importance of tsetse-transmitted trypanosomosis in Ethiopia. Spatial and statistical analysis verified the use of GDD concept and climate forecast system that was developed to determine the suitability of a given environment for the proliferation of a

biotype, in this case tsetse and trypanosomes. Like other insects, tsetse fly requires specific climate and topography environments for the completion of its life cycle as well as survival. As a result tsetse flies are prone to environmental changes (temperature, moisture, vegetation, altitude, *etc*). According to Langridge (1976), the tsetse flies in Ethiopia are confined to the southern and western regions between longitude 33° and 38°E and latitude 5° and 12°N. They infest areas which together amount to 97, 855 square km. Tsetse infested areas lie in the lowlands and also in the river valleys of Blue Nile, Baro, Akobo and Omo. The infested area extends from the southern part of the Rift Valley, around the south-western corner of the country and along the western lowlands and escarpments to the Blue Nile. Restricting a further eastward spread is the cold limit imposed by highlands that rise to the height above which tsetse cannot survive, or the semi-desert condition along the

southern border east of the Rift Valley. Langridge (Fig. 3a) was, however, suspicious of the spread of tsetse flies northwards from the Blue Nile to Tekeze River. This possibility is clearly indicated by the forecast model, reported here. Elsewhere there have been advances of tsetse, including extension of the upper altitude limit of the fly from about 1,600 m to 2,000 m in certain areas, although it is unclear whether flies caught at the highest altitudes are representative of a self-sustaining stable population, that can persist in these areas. Tsetse fronts in many places are unstable and tsetse-animal interface is constantly moving (NTITCC, 2000). Consequently new areas are being invaded and settled communities are being continually evicted by the advancing tsetse. Such hot spots include the areas in Upper Didessa Valley, the northern and northeastern edges of Lake Abaya in the Rift Valley and, the upper reaches of the Omo-Ghibe and its tributaries.

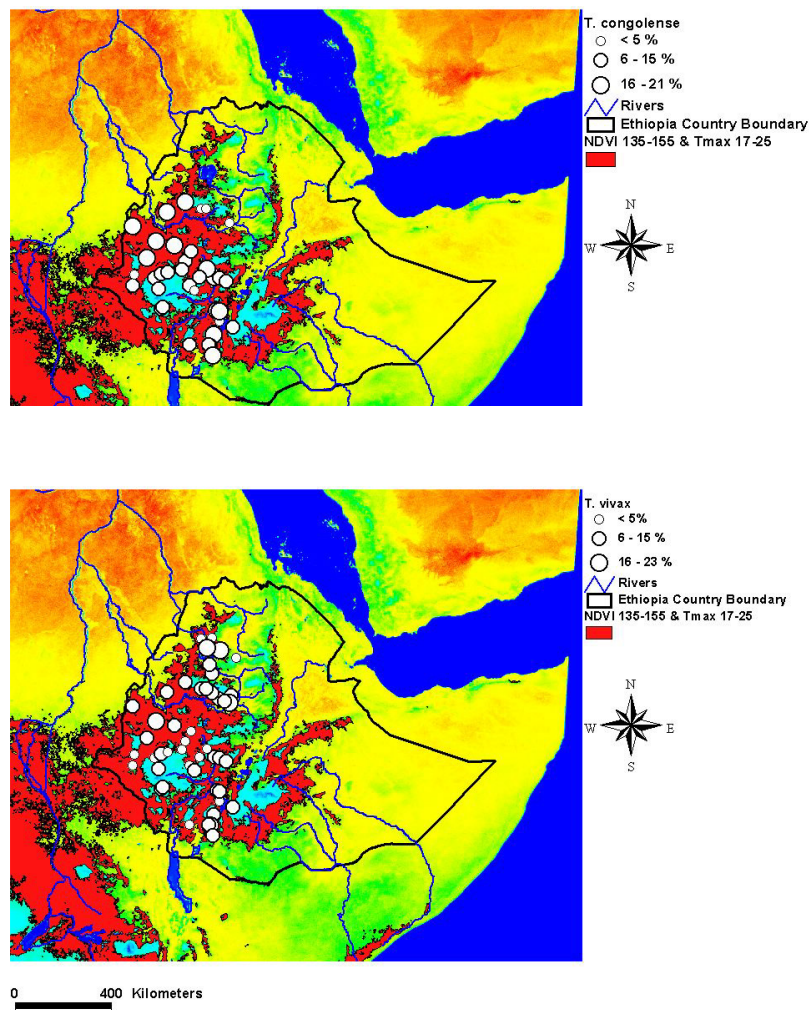


Fig. 4a and b. GIS annual composite model query that met criteria for both NDVI (135–155) and Tmax (17–25) for *T. congolense* (a) and *T. vivax* (b). The area in black represents the best fit for tsetse-transmitted trypanosomes in Ethiopia.

Five species of *Glossina* (*G. morsitans submorsitans*, *G. pallidipes*, *G. tachinoides*, *G. fuscipes fuscipes* and *G. longipennis*) have been recorded from Ethiopia, but only four are widespread and cause significant economic importance. These are *Glossina morsitans submorsitans* and *G. tachinoides*, which have a west to east distribution across Africa south of the Sahara desert, and *G. pallidipes* and *G. fuscipes*, which often occur together in East Africa, although the former extends far to the south where as the latter has an essentially central African distribution (Langridge, 1976; NTIICC, 2000).

T. congolense and *T. vivax* are the most prevalent trypanosomes that infect cattle in the tsetse infested and tsetse free areas of Ethiopia respectively. In the tsetse-infested areas of the country, though, the prevalence of *T. congolense* among trypanosome-infected animals was found to be high (58.5%), a considerable number of animals were also harboring *T. vivax* infection (31.28%) (Getachew Abebe and Yilma Jobre, 1996). Similar findings were reported by Langridge (1976) and Rowlands *et al.* (1995) who respectively indicated 60% *T. congolense* and 31% *T. vivax*; and 84% *T. congolense* and 14% *T. vivax* infections in southwest part of Ethiopia. Higher proportions of *T. congolense* infection were detected in areas such as Gamo Gofa, Illubabor, Sidamo and Ghibe valley. The predominance of *T. congolense* infection in tsetse infested areas of Ethiopia indicate the existence of increased contact of cattle with tsetse vectors. This high ratio of *T. congolense* infection may also suggest that the major cyclical vectors are the savanna tsetse flies (*G. m. submorsitans* and *G. pallidipes*), which are more efficient transmitters of *T. congolense* than *T. vivax* in East Africa (Langridge, 1976). However, in areas such as Wollega and Keffa, the respective ratios between *T. congolense* and *T. vivax* infections were found to be more or less similar. Bourn and Scott (1978) have reported a different situation at Angar Gutin where the chief vector was *G. morsitans*. The study indicated a 94% *T. vivax* infection in recently introduced oxen, but on keeping the oxen on the settlement site for more than two years, the infections with *T. vivax* had dropped to less than 10%. One of the factors that could depress the incidence of *T. vivax* is the use of drugs. In East Africa, except for the haemorrhagic syndrome, *T. vivax* is generally less virulent than *T. congolense* and consequently cattle develop tolerance to *T. vivax* more readily and easily than to *T. congolense* (Getachew Abebe and Yilma Jobre, 1996).

CONCLUSION

The present study suggests that NDVI and Tmax, when applied together, are particularly important in indicating tsetse-transmitted trypanosomosis risk areas. This is in agreement with the work of Rogers (2000) in which he highlighted that NDVI and temperature are the most important climatic variables in predicting tsetse distribution in East Africa. Previous studies on the application of GIS on African trypanosomosis were done using discriminate analysis with remotely sensed and ground-measured variables to successfully predict the presence of *G. morsitans* and *G. pallidipes* in Kenya, Tanzania and Zimbabwe (Rogers and Randolph, 1993). Results presented here indicate the importance of GDD and the two climatic variables (NDVI and Tmax) in the development of forecast model for tsetse-transmitted trypanosomosis in Ethiopia. The finding reported in this study is the first of its kind in using climate based GDD and/or CPSZ database to develop forecast models for tsetse-transmitted trypanosomosis. Furthermore, the model can be potentially used to predict tsetse abundance and trypanosomosis occurrence in other parts of Africa, where these are major concerns for development.

ACKNOWLEDGMENTS

We wish to thank the 2000 J. William Fulbright Research Scholar Exchange Program, Council for International Exchange of Scholars (CIES) and United States Information Agency (USIA), Department of State, Washington DC for financial and administrative supports. The assistance of Mr. Michael Kearny in statistical analysis of results is highly appreciated.

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