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RESEARCH ARTICLE

The risk and associated control problems of Human African Trypanosomosis (HAT) in the endemic foci of Greater Equatoria Region, South Sudan

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ABSTRACT

This study aims to analyze, map, and identify the prevalence of, service provision for, and risk distribution and control for Human African Trypanosomosis (HAT), or sleeping sickness, in the endemic areas of Greater Equatoria Region (GER), including Eastern, Central, and Western Equatoria States of South Sudan. Passive and active screening data, detection data, and existing facilities and centers for sleeping sickness were used to assess the prevalence, screening coverage, and overall risk in the region for the 2016–2018 period. In addition, historical literature and surveillance information were used. The results show that 0.43% (*N* = 14,552) of the total at-risk population (*N* = 3,399,400) of GER were subjected to passive or active screening for Gambian HAT (gHAT), which showed an infection rate of 0.30%. Out of the total area of 196,211 km^2, 58.77% of the region (115,311 km^2) was found to be endemic to HAT. The population remains at high or very high risk for the disease in Western Equatoria State due to a number of active historic gHAT foci. With relative peace currently prevailing in the region, there is need to reinforce the leadership of South Sudan's health ministry with sufficient internal and external resources to support its activities.

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Introduction

Human African Trypanosomosis (HAT), also known as sleeping sickness, is a lethal parasitic disease transmitted by tsetse flies. Ancient and medieval histories show that people in parts of sub-Saharan Africa (SSA) may have been living with the disease for a long time (Steverding, 2008). It was first reported in Southern Sudan, however, only in the early 1900s, and over 3,000 cases were documented there between 1920 and 1925 (Ruiz-Postigo et al., 2012). It was most likely introduced into Southern Sudan during the colonial era. Colonial soldiers, laborers, and traders are thought to have carried sleeping sickness from its ancient endemic foci in West Africa into the Belgian Congo and then into the Lado Enclave, part of Southern Sudan, and into Uganda in the late 1880s (Palmer & Kingsley, 2016). With inconsistent funding from international organizations like the World Health Organization (WHO) and Médecins Sans Frontières (MSF) and a lack of commitment from

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colonial governments including British and Belgian and the governments of the Sudan and its regional government of Southern Sudan, the control of sleeping sickness in the region has been mixed at best.

With international and some local efforts, the spread of the disease was considerably reduced in the late 1960s and early 1970s (Moore et al., 1999; Palmer & Kingsley, 2016). However, devastating civil wars, population displacements, poor health facilities, insecurity, and lack of investment in HAT control have resulted in a reemergence of the disease over the past few decades (Gao et al., 2020; Moore et al., 1999), especially in the Greater Equatoria Region (GER) of South Sudan, which boarders the Democratic Republic of Congo (DRC), Uganda, and Central Africa Republic (CAR; Lukou & Ochi, 2020). HAT remains one of the deadly neglected tropical diseases (NTDs) in South Sudan (Gao et al., 2020; Mohammed et al., 2008; World Health Organization, 2020) due to the presence of *Trypanosoma brucei (T. b. gambiense*, the parasite that causes Gambian HAT (gHAT)) in the region (Ford, 2007). South Sudan was a signatory to international treaties and conventions for the control and elimination of targeted NTDs by the year 2020 (World Health Organization, 2018). In line with these treaties, South Sudan developed its Master Plan (2016–2020) for eliminating NTDs including sleeping sickness (South Sudan Ministry of Health, 2016). However, South Sudan's optimistic goal of doing so by 2020 was unrealizable for two main reasons. First, the country did not invest financially (South Sudan Ministry of Finance, 2019) in the recognition of its set goals. Second, persistent civil strife, a weak health system, and inadequate control and surveillance activities made it difficult to achieve strategic objectives (Franco et al., 2020). For instance, South Sudan has one of the poorest health infrastructures in SSA, but the government reduced its spending to only 2% of its total 2018–2019 budget toward health care (South Sudan Ministry of Finance, 2019) in the hope that international non-governmental organizations (INGOs) would address the gap. This study helps to assess how the country might best attain its goal of eradicating sleeping sickness (Courtin et al., 2019; Franco et al., 2020). Emerging from one of the longest and bloodiest civil conflicts and decades of political and social unrests in the world, South Sudan's capacity for health care and disease control continues to be extremely limited, leaving international agencies free to act with unfettered mandates (Palmer & Kingsley, 2016). South Sudan's lack of clear focus and priorities has encouraged international actors to focus on their own tools over domestic systems (Palmer & Kingsley, 2016), something that contributes to the erosion of the authority of weak states (Tvedt, 1998). This study helps us to better understand how the political situation in the country affects the spatial management and control of HAT in GER. With the outbreak of COVID-19 and sharply fluctuating global oil prices, South Sudan's financial state might further deteriorate in coming years. The spread of coronavirus might exacerbate simmering tensions in the country, putting extra strain on fragile political settlements between the government and rebels groups (Carboni, 2020) and on HAT control activities in the region. Urgent actions are, therefore, required to address the threats of sleeping sickness in the region.

Trypanosoma is a unicellular parasitic protozoan that causes infectious diseases in humans including Chagas, limited to Latin America, and Human African Trypanosomosis, limited to Africa (Kirchhoff, 1994). Chagas is caused by *Trypanosoma cruzi* (*T. cruzi*), while HAT exists in two distinguishable forms (Samdi et al., 2009): Gambian HAT (gHAT), caused by *Trypanosoma brucei gambiense (T. b. gambiense)* usually found in western and central Africa; and Rhodesian HAT (rHAT), caused by *T. b. rhodesiense*, which is endemic in eastern and southern Africa. Both gHAT and rHAT invariably lead to death if appropriate treatment is not provided (Lumbala et al., 2015). *T. b. gambiense* causes a chronic form of the disease that can infect an individual for months or even years without the patient showing major symptoms. *T. b. Rhodesiense* causes a more acute form of the disease, in which the first signs are observed a few weeks after infection (Selby et al., 2019; World Health Organization, 2020). The geographical distribution of HAT is usually confined to a spatially limited tsetse fly belt referred to as the endemic 'foci' of the disease, predominantly found between latitude 14°N and 29°S in Africa (Dumas & Boa, 1988; Simarro et al., 2010).

Sleeping sickness presents in two phases. The first stage is known as the hemolymphatic phase in which the trypanosomes are restricted to the blood and lymphatic system (World Health Organization, 2020). The patient experiences fever, headaches, joint pains, itching, malaise, weakness, fatigue, and arthralgia (Centers for Disease Control and Prevention, (CDC), 2020; World Health Organization, 2020). The second or late stage is known as the neurological phase in which the parasite moves into the cerebrospinal fluid (World Health Organization, 2020). This stage is generally characterized by confusion, disturbed sleep patterns, sensory disturbances (e.g., paresthesia, hyperesthesia, anesthesia, pruritus, and visual problems), and neurologic symptoms including abnormal reflexes, seizures, and coma, just to mention a few (Centers for Disease Control and Prevention, (CDC), 2020; World Health Organization, 2020). Currently, gHAT, known as an anthroponosis, causes roughly 98% of reported cases of sleeping sickness in Africa, and the other 2% are caused by rHAT, known as a zoonosis (World Health Organization, 2020). Gambian HAT is found in 24 countries in west and central Africa, while rHAT is found largely in 13 eastern and southern African countries (Wamboga et al., 2017; World Health Organization, 2020). Gambian HAT remains a public health problem in many countries of central Africa where humans are assumed to be the main reservoir of the parasite (Palmer et al., 2014). Due to its chronic nature, high levels of *T. b. gambiense* endemicity often go undocumented in the early period of transmission due to mild and unrecognizable symptoms. However, *T. b. rhodesiense* produces an acute epidemic disease when transmitted close to human populations, especially by a riverine species of the tsetse fly (Smith et al., 1998).

Sleeping sickness is mediated by the interaction of trypanosomes with the vectors (tsetse flies) that transfer the disease to human and animal hosts within a particular environment (Alibu et al., 2015). Hence, the risk of HAT infection depends on tsetse flies infected with *T. b. gambiense* (Smith et al., 1998) or *T. b. rhodesiense* (Selby et al., 2019). The people most at risk are those who work outdoors for long periods and are therefore most exposed to the bites of tsetse flies (Lehane et al., 2016). The last decade of the twentieth century was one of the worst periods in history for HAT, with a peak of 50,000 new cases reported in a year. These alarming levels necessitated surveillance and control efforts at the beginning of the twenty-first century to decrease occurrences of the disease. Efforts from the global community, including by MSF, the WHO, the Belgian Development Cooperation (BDC), and the Drugs for Neglected Diseases Initiative (DNDi), just to mention a few, led to the initiation of the WHO NTD roadmap, which included the ambitious goal of eliminating HAT by 2020 (Franco et al., 2020; Gao et al., 2020; World Health Organization, 2018). Achieving this goal required that all HAT endemic countries have less than 2000 annual reported cases by 2020 and show a 90% reduction in areas reporting more than one case per 10,000 people per year calculated over a 5-year period compared to the 2000–2004 baseline (Castaño et al., 2020; Franco et al., 2017, 2020). However, the WHO has realized the limitations of such ambitious targets and has now moved the goalpost to 2030 (Courtin et al., 2019). This study helps us to assess whether South Sudan is meeting its responsibilities in the global and sub-continental efforts to reduce HAT.

Sleeping sickness due to *T. b. gambiense* in South Sudan is predominantly confined to the GER including Eastern, Central, and Western Equatoria States (Lukou & Ochi, 2020). This is partly due to the presence of the tsetse fly vector G*lossina fuscipes fuscipes*, which is an effective transmitter of the parasite (Mohammed et al., 2008). Due to protracted civil wars and unrests, and lack of sustained funding and strategic planning to control the disease in this region, South Sudan has experienced periodic large-scale outbreaks of sleeping sickness, along with some successful large-scale control efforts. However, these initiatives have either been scaled down or collapsed due to limited funding and insecurity, which has resulted in the resurgence of the disease. For example, in the 1970s, the Belgian Sudanese trypanosomiasis treatment and control initiatives successfully reduced the number of sleeping sickness in the region, but political instability and insecurity brought the program to a halt (Moore & Richer, 2001; Moore et al., 1999). Consequently, by late 1990s, in the midst of the second Sudanese civil war (1983–2005), the prevalence of HAT rose by 19% among residents in southwestern communities bordering the DRC (currently Western

Equatoria State), which remains one of the endemic foci in the country (Ford, 2007; Moore et al., 1999). In 2007, the International Medical Corps (IMC) took over HAT activities from MSF Switzerland in Kajo Keji County hospital but halted operations there just a year later. Since the IMC's closure, HAT cases from Kajo Keji have been diagnosed in Magwi county (Nimule hospital), and Yei, and sometimes in bordering HAT centers in Uganda (e.g., Moyo hospital; Ruiz-Postigo et al., 2012). No screening for HAT has been performed in Kajo Keji since 2008. Understanding the variations in the disease control patterns is crucial for its elimination (Simarro et al., 2010). Moreover, disease maps are required for planning, managing, and monitoring purposes across the whole spectrum of neglected tropical diseases. Disease distribution maps are also required to better estimate the at-risk population and needed interventions (Simarro et al., 2012).

Therefore, this study aims to analyze, identify, and map the prevalence, service provision, and risk distribution and control for gHAT in all endemic areas of GER, South Sudan, where cases have been reported. The paper explores and discusses some of the risk factors underlying distributions, variations, and control of sleeping sickness within and between the counties and states in GER. The study elucidates the risk factors involved and their implications in the gHAT elimination process as an important heath problem in South Sudan. Knowledge of gHAT risk classification is important for informing policies that prioritize sleeping sickness control with limited resources in environments of civil unrest and war. This paper helps the reader to understand how civil unrests and wars in South Sudan have weakened gHAT control activities and exacerbated its persistence in its ancient foci, while most other gHAT endemic countries are achieving some milestones in reducing sleeping sickness (Courtin et al., 2019; Franco et al., 2017, 2020).

Methods

Study site description

South Sudan is a nascent country in the eastern region of Africa. It is landlocked with an estimated area of 645,920 km^2 and a population density of about 13 persons per km^2. The country lies within the Central African Region and the Sahel Belt with 90% of its area within the Nile Basin and a vast swamp called the Sudd region. South Sudan is bordered by the Republic of the Sudan to the north, Ethiopia to the east, Kenya to the southeast, Uganda to the south, the Democratic Republic of the Congo to the southwest, and the Central African Republic to the west (Figure 1). The country has 10 states divided into counties, which are further subdivided into payams (sub-counties). Payams are constituted of several bomas (villages), which are the smallest administrative units in the country. Although South Sudan has vast reserves of wealth including raw materials and fresh water, its economy has heavily depended on oil.

Climatic and environmental conditions make South Sudan vulnerable to food shortages, epidemics, and tropical diseases, including a wide range of neglected tropical diseases such as sleeping sickness. This study was conducted in the Greater Equatoria Region (GER), which has an estimated area of 196,211 km^2 and a population of 3,399,400 people (National Bureau of Statistics, 2015). The last census of the region was done in 2008 before it seceded from Sudan. Since then the Government of South Sudan has relied on population estimates made by its census bureau and international NGOs (National Bureau of Statistics, 2015; South Sudan Ministry of Finance, 2019; United Nations Population Fund, 2021; United States of America Central Intelligence Agency, 2021; World Health Organization, 2020). In 2021, a population survey was conducted in preparation for a 2022–2023 census. We selected the GER for this study partly because it is located within the tsetse fly belt surrounded by countries, including Kenya, Uganda, and the Democratic Republic of Congo, that have or continue to experience HAT outbreaks due to the presence of the efficient tsetse vector G*lossina fuscipes fuscipes* (Mohammed et al., 2008). In addition, the region is a HAT endemic part of South Sudan (Mohammed et al., 2008). Sleeping sickness endemic regions refer to areas with persistent presence of the disease.

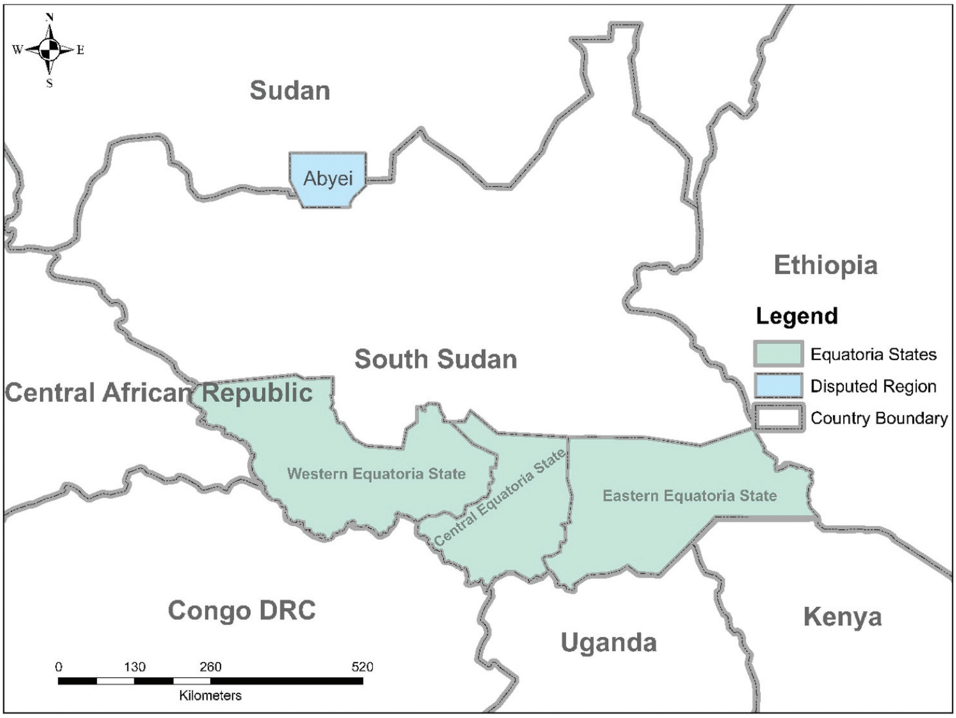

Figure 1. Study area.

The country has some of the worst health indicators in the world. Accurate statistics are hard to get, but estimates suggest that about one-third of the population has no access to health services, and nearly two-thirds of rural health facilities are nonfunctional or are in a state of disrepair. Rural health facilities are further affected by lack of qualified staff and insecurity due to wars and civil unrests (AbuAgla et al., 2013; Bunny, 2017). Medical malpractice is also widespread, especially in rural communities, largely due to the practice of deploying untrained and/or uncertified health workers in the face of acute shortages of health personnel. Qualified health practitioners are more likely to be employed by NGOs in non-medical fields and/or to work in urban areas. The result is a highly uneven geographic distribution of health workers in favor of urban areas, which widens the sharp inequities in health-care access in a country where more than 80% of the population still lives in rural areas (National Bureau of Statistics, 2015; United Nations Population Fund, 2021; United States of America Central Intelligence Agency, 2021). General estimates show that South Sudan has a life expectancy of about 59 years and a death rate of 9.84 persons per 1000 for 2021. Because of population collapse owing to conflict and population displacement, nearly 42% of the population of South Sudan is below the age of 15 (National Bureau of Statistics, 2015; United Nations Population Fund, 2021; United States of America Central Intelligence Agency, 2021).

Data collection

The study used gHAT data collected for the counties in the three states of the GER. Sleeping sickness screening and detection data on the county levels for 2016–2018 were obtained from the South Sudan National Ministry of Health (South Sudan Ministry of Health, 2016), while the spatial data were obtained from the South Sudan National Bureau of Statistics (NBS; National Bureau of Statistics, 2015). Population estimates were collaborated between data collected from the NBS, United Nations Population Fund, and the United States of America Central Intelligence Agency

Table 1. Thresholds for the definition of sleeping sickness risk categories.

Category of risk	Threshold level	HAT cases per annum
Very high	$\geq 10^{-2}$	≥1 per 10^2 People
High	$10^{-3} \leq R < 10^{-2}$	≥1 per 10^3 people AND, <1 per 10^2 people
Moderate	$10^{-4} \leq R < 10^{-3}$	≥1 per 10^4 people AND, <1 per 10^3 people
Low	$10^{-5} \leq R < 10^{-4}$	≥1 per 10^5 people AND, <1 per 10^4 people
Very low	$10^{-6} \leq R < 10^{-5}$	≥1 per 10^6 people AND, <1 per 10^5 people

Source: Simarro et al. (2012).

(National Bureau of Statistics, 2015; United Nations Population Fund, 2021; United States of America Central Intelligence Agency, 2021). In addition, extensive literature on the number of HAT cases and the mean population in South Sudan endemic counties from 2013 to 2018 was obtained from a 2020 WHO Report (National Bureau of Statistics, 2015; South Sudan Ministry of Finance, 2019; World Health Organization, 2020). Based on the report, gHAT surveillance in the region was done passively – people go to health facilities to be screened – and actively – at-risk communities were massively screened for sleeping sickness. The South Sudan Ministry of Health (MoH) was able to provide us with only three years (2016–2018) of gHAT data (Stanton et al., 2018; Wamboga et al., 2017). No additional data were available from the MoH.

Data analysis

The estimated coverage was obtained by dividing the total passively and actively screened sleeping sickness cases by the total population at risk for each state and year. Available HAT facilities and centers in the region were mapped based on the county where they are located and the type(s) of services they offer (World Health Organization, 2020). HAT risk indices and endemism (prevalence) were calculated based on the sum of all passively and actively screened cases per annum (p.a.) divided by the estimated exposed total population for each county. The calculated indices were then generated based on the HAT risk classes (Table 1) established by Simarro et al. (Simarro et al., 2012). The total at-risk area was calculated by dividing the total endemic area of the state with screened gHAT cases by the total land mass of the state and the GER, respectively. All analyses were done using ArcGIS 10.7.

Ethics statement

No ethics approval was needed for the study because no physical contacts were established with human participants and no one was interviewed. The study relied exclusively on data obtained from the South Sudan Ministry of Health, NBS, and WHO Reports, which contain fully anonymous information.

Results

HAT screening and outreach

Table 2 presents the results of gHAT passive and active screening in the Greater Equatoria Region (GER) for 2016–2018. The results show a total of 760 people passively monitored for HAT infections in 2016: 243 in Western Equatoria State, 393 in Central Equatoria State, and 124 in Eastern Equatoria State. There were no active cases screened for the same year in the three states. In 2017, a total of 1,128 people were passively screened in GER: 104 in Western Equatoria State, 1,023 in Central Equatoria State, and only 1 in Eastern Equatoria State. In the same year, a total of 2,223 people were actively screened for gHAT infection in Magwi County, Eastern Equatoria State. In 2018, a total of 921 and 9,520 people were passively and actively screened, respectively, in the whole of Greater Equatoria Region with no active screening in Western Equatoria that year.

Table 2. Total number of people passively or actively screened for Gambian HAT in the period 2016–2018.

	Year	2016		2017		2018	
State	Location	Passive	Active	Passive	Active	Passive	Active
Central Equatoria	Yei	0	0	817	0	537	4,694
	Kajo Keji	0	0	1	0	0	0
	Lainya	0	0	45	0	0	0
	Morobo	0	0	0	0	0	0
	Juba	124	0	160	0	125	0
	Sub-total	**124**	**0**	**1,023**	**0**	**662**	**4,694**
Eastern Equatoria	Magwi	393	0	1	2,223	38	4,826
	Sub-total	**393**	**0**	**1**	**2,223**	**38**	**4,826**
Western Equatoria	Tambura	2	0	47	0	26	0
	Maridi	0	0	0	0	23	0
	Mundri-Lui	241	0	57	0	172	0
	Yambio	0	0	0	0	0	0
	Ibba	0	0	0	0	0	0
	Nzara	0	0	0	0	0	0
	Sub-total	**243**	**0**	**104**	**0**	**221**	**0**
Grand Total		**760**	**0**	**1,128**	**2,223**	**921**	**9,520**

Data Source: South Sudan National Ministry of Health.

HAT infections were passively detected in 17 people (7 in Magwi, 2 in Tambura, and 8 in Munduri-Lui) of the 760 people screened in 2016, while 12 (1 in Kajo Keji, 5 in Juba, 1 in Magwi, 2 in Tambura, and 3 in Munduri- Lui) and 15 (10 in Juba, 2 in Tambura, and 3 in Munduri-Lui) infections were found among the 1,128 and 921 people passively screened in 2017 and 2018, respectively (not shown in Table 2). The gHAT cases found in 2016 were across the two disease stages (Centers for Disease Control and Prevention, (CDC), 2020; World Health Organization, 2020). All detected cases in 2017 were in stage I of the disease. Out of the 15 confirmed gHAT cases found in 2018, 14 were in stage II and 1 was in stage I of the disease. A total of 0, 2,223, and 9,520 people were actively screened for gHAT in 2016, 2017, and 2018, respectively. A cumulative total of 14,552 people were passively and actively screened for sleeping sickness over the three years in the three states of GER (Table 2), which is equivalent to 0.43% of the overall estimated at-risk population (N = 3,399,400) of the region. With a total of 44 confirmed cases, the infection rate was 0.30% among passively and actively screened patients (N = 14,552) in the three years of review.

Figure 2 shows the percentage of people screened for gHAT from 2016 to 2018 in GER. The results indicate that none of the three states met the required sleeping sickness outreach target of 75% (Courtin et al., 2015; Tirados et al., 2015) over the three-year time period. Central Equatoria (CE) and Western Equatoria (WE) states did not reach 1% coverage. In

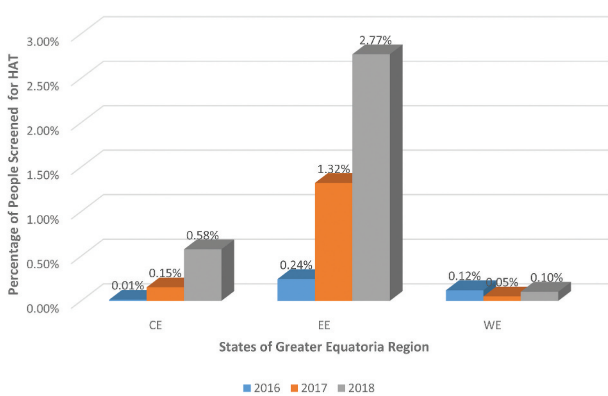

Figure 2. HAT's screening outreach in Greater Equatoria Region. Data Source: National Ministry of Health.

Eastern Equatoria (EE), monitoring increased 12-fold from 0.24% in 2016 to 2.77% in 2018 but was still below the required outreach threshold for screening gHAT infections among residents in the region. Overall, South Sudan screened less than a quarter of the at-risk population from 2016 to 2018.

HAT service centers

Figure 3 shows gHAT service facilities, including diagnostic, confirmation, and treatment centers, in the study area. The diagnostic facilities are used only for diagnostics purposes, while the confirmation and treatment facilities confirm and treat sleeping sickness, respectively. Active screening at diagnostic centers is done using the Card-Agglutination Trypanosomiasis Test (CATT), while passive screening uses clinical symptomatology or the Rapid Diagnostic Test (RDT). Positive cases are further confirmed using a parasitological test with real time or loop-mediated isothermal amplification (LAMP) and polymerase chain reaction (PCR). Some counties are equipped with diagnostic, confirmatory, and/or treatment facilities for HAT, but some do not have any. For example, in Western Equatoria State, only Maridi County has a gHAT confirmatory facility, Tambura and Mundri East counties have treatment facilities, but Ibba County has both diagnostic and confirmatory facilities. In Central Equatorial State, the counties of Lainya, Kajo Keji, and Morobo have diagnostic facilities, but Yei has diagnostic, confirmatory, and treatment service centers, and Juba has only treatment facilities. Magwi is the only county in Eastern Equatoria State with both diagnostics and treatment service centers (Figure 3). Although counties with no data might have other basic health facilities, they did not have services to handle sleeping sickness cases during the period of review. In general, GER has very dispersed health centers located in the urban parts of the counties to provide gHAT services. ‘Urban’ does not necessarily mean the county has all the services to qualify as an urban area, but it has a comparatively large population and some basic government services. Hence, when confirmatory results are needed, the patients’ blood samples can be taken to the relevant service centers.

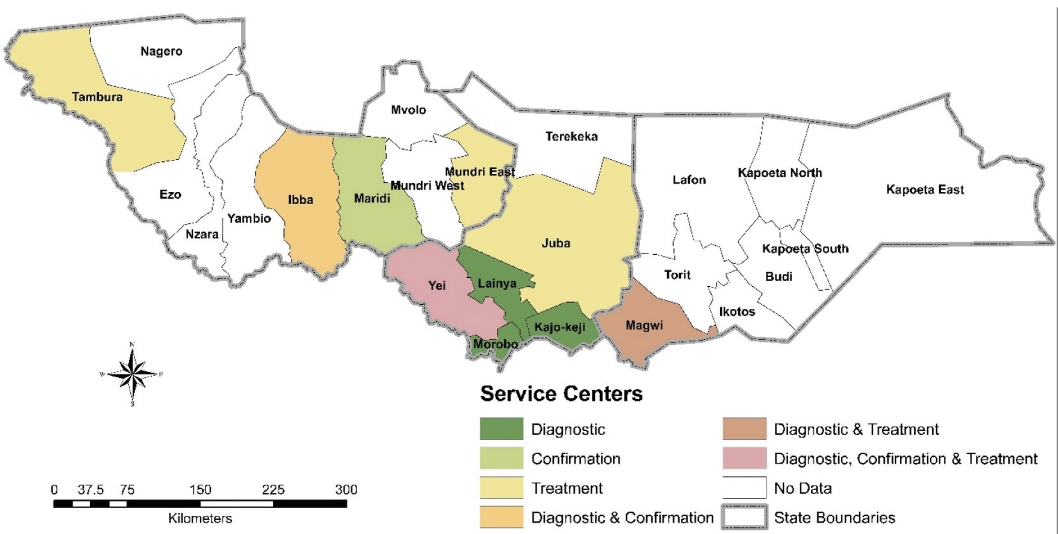

Figure 3. Distribution of Gambian HAT centers in the counties of Greater Equatoria Region. Data Source: South Sudan National Ministry of Health.

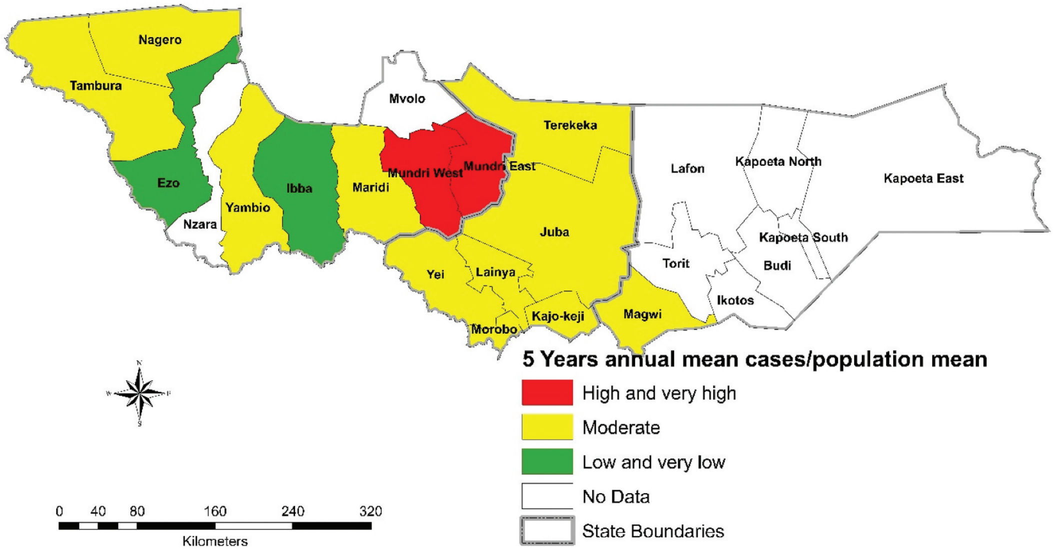

Figure 4. Gambian HAT risk distribution in the counties of Greater Equatoria Region for the period 2013–2018. Data Source: WHO report (World Health Organization, 2020).

Table 3. Total endemic areas for Gambian HAT in Greater Equatoria Region.

State	Total area (km^2)	Total endemic area (km^2)	% Total endemic per state	% Total endemic per GER
Western Equatoria	73,976	66,787	90,28%	34.04%
Central Equatoria	43,284	43,284	100%	22.06%
Eastern Equatoria	78,951	5,240	6.64%	2.67%
Total	196,211	115,311	58.77%	58.77%

HAT risk and endemism

Figure 4 illustrates the distribution of the 5-year average gHAT risk in the various counties of GER. The results show three classes of HAT risk: high and very high, moderate, and low and very low. Mundri East and West counties exhibited high and very high risk of gHAT in Western Equatoria and the whole GER. Tambura, Nagero, Yambio, and Maridi counties showed moderate risk, while Ezo and Ibba counties exhibited low and very low risk for gHAT in Western Equatoria State. All counties in Central Equatoria State showed moderate risk for the disease. Overall, Western Equatoria State showed all three risk categories compared to Central Equatoria State, whose counties all showed moderate risk. Only one county, Magwi, in Eastern Equatoria State showed moderate risk with the rest having no data.

Table 3 indicates the endemic areas within and among the three states of the Greater Equatoria Region. Out of a total area of 196,211 km^2, 58.77% (115,311 km^2) was endemic to gHAT. Within the three states, 90.28%, 100%, and 6.64% of Western, Central, and Eastern Equatoria States, respectively, were endemic to HAT. The results show that 34.04% (66,787 km^2) and 22% (43,284 km^2) of Western and Central Equatoria States, respectively, accounted for the regional total HAT endemism in GER. Eastern Equatoria State represented only about 3% (5,240 km^2) of the total endemic foci of sleeping sickness in the study area.

The study shows that gHAT endemic areas in GER (115,311 km^2) constitute about 18.0% of the total area of South Sudan (644,329 km^2). Overall, 1.7% (10,983 km^2), 13.5% (86,646 km^2), and 2.7% (17,681 km^2) of the area in South Sudan falls within the high and very high, moderate, and low and very low risk indices for gHAT, respectively.

Limitations

This study has some limitations worth noting. The South Sudan Ministry of Health (MoH) was only able to provide us with three years' worth of gHAT data for passive and active screening and detection (2016–2018) in Greater Equatoria Region (GER). Hence, the study depended heavily on secondary data obtained from government and WHO reports. The limited dataset hindered our ability to do a more comprehensive spatiotemporal HAT variation analysis and draw wider conclusions about the gHAT situation in the GER. With poor health-care infrastructures and many unqualified health practitioners at work, it was hard to assess the quality of screening and detection services provided in the available health facilities and better understand the gHAT cases in the dataset. Wars and civil unrests might have aggravated the situation of the disease and compromised many control efforts. The MoH has limited access, possession, and control over data collected in its own territory by many INGOs.

Based on the perception that South Sudan lacks a tradition of disease control, data management skills, and health infrastructure, many INGOs collect data but do not share them with relevant state ministries (Palmer & Kingsley, 2016). Ongoing conflicts, and the long-term presence of international actors, might be contributing to the erosion of local authorities not only in South Sudan but also in similar countries in sub-Saharan Africa (SSA) that have weak institutional structures (Tvedt, 1998). Rather than contribute to bettering its health-care systems, the South Sudan government reduced its health-care budget for the 2018–2019 fiscal year in the hope that INGOs would fill the gap. Knowingly or unknowingly, the delegation of the country's essential services to INGOs with unfettered mandates has had monumental consequences, not only in South Sudan but in similarly weak states in SSA. Some of these effects include a lack of control over data collected in their own territories and reliance on secondhand information from international reports rather than data from their own repositories and relevant ministries. It is important that conflict-prone countries in SSA recognize the realities of outside domination in terms of aid or international assistance and start building needed institutions in order to avoid the intentional or unintentional 'crowding out' of their legitimacy by international actors (Tvedt, 1998). We should note that this statement is not meant to oppose international assistance but to caution in-conflict countries in SSA at risk of becoming 'blank slates' for international actors (Palmer & Kingsley, 2016) when they transfer their states' responsibilities to global players.

Discussion

The main objective of this study was to analyze and map the prevalence of, service provision for, and risk distribution and control for gHAT (sleeping sickness) in Greater Equatoria Region (GER), South Sudan. Literature shows that medical treatments, including diagnostics through routine passive and active screening and detection (Stanton et al., 2018; Wamboga et al., 2017), are essential for controlling sleeping sickness (Welburn & Maudlin, 2012). However, screening must reach at least 75% of the at-risk population for the program to be effective (Robays et al., 2004). This study showed outreach ominously lower (just 0.43%) than the target coverage required for the effective mitigation of the spread of sleeping sickness (Courtin et al., 2015; Tirados et al., 2015). With such limited coverage, South Sudan cannot claim it is moving toward eradicating the disease in its own territory and thus meet its regional and global commitments. In general, the control threshold of at-risk population monitoring has not been met in South Sudan and the gHAT endemic foci of GER. This failure is due to several factors.

First, the Government of South Sudan has not made the necessary financial commitment toward combating gHAT in its territory. The country has relegated most of its essential health services to INGOs with no monitoring strategies (Franco et al., 2020; South Sudan Ministry of Finance, 2019).

Second, GER has a huge land mass and low population density, and the poor state of communication networks presents insurmountable challenges for universal health service coverage and delivery in the region. HAT facilities are mainly located in predominantly 'urban' areas, but they serve the neighboring rural villages where they are less likely to offer complimentary types of services. For example, only two of the counties, Yei in Central Equatoria and Magwi in Eastern Equatoria, have health facilities that can provide both diagnostic and treatment services for sleeping sickness. In addition, all diagnosed patients are subjected to confirmatory examination and treatment at the closest HAT facility. The different health facilities are linked and send patient samples to other health centers where services are available. However, the dispersed nature of these facilities and continuous civil unrests and wars in the region present a barrier to reaching other centers. Unfortunately, patients can die while awaiting diagnosis, confirmation, and/or treatment. Moreover, samples may be lost in transit to another health facility. In many parts of South Sudan, people need to travel about 20 km on average to reach a primary health-care unit (PHCU). Over 80% of the at-risk population live within a 5-h walk of a fixed health facility offering diagnosis and/or treatment for gHAT (Simarro et al., 2014), but the estimated distance and time to the health facilities do not necessarily mean accessibility for many people due to poor roads, insecurities, and communal tensions (Carboni, 2020). Consequently, the broad dispersion of overstretched health facilities and resources, at least in the medium term, challenges equitable access to basic health services (South Sudan Ministry of Health, 2016) and could contribute to the persistence of sleeping sickness in the GER.

Third, continuing political instability makes it difficult for those in need to access the few available health facilities that provide gHAT-related services. As mentioned above, only two years after its independence, another civil war broke out in the country in 2013. A peace accord was signed in 2015 but was violated in 2016. During and after the civil wars, GER faced continuing unrests. Currently, tensions are high in many parts of the country, especially GER, due to escalating intercommunal violence (Carboni, 2020). The ongoing intra- and intercommunal violence may lead to the collapse of the shaky 2018 peace agreement, further weakening already poor gHAT surveillance and treatment in the region.

Fourth, the region lacks sufficient human and medical resources to handle complex gHAT diagnostics and treatment. The lack of skilled staff is complicated by a high turnover rate due to unfavorable working conditions (AbuAgla et al., 2013; Bunny, 2017). These challenges are further complicated by the remoteness of the treatment and diagnostic centers and political instability, all of which present significant hurdles to effectively diagnose and treat cases of gHAT and lower the prevalence of the disease (Tong et al., 2011). Hence, there is an urgent need for gHAT service centers with diagnostic, confirmatory, and treatment facilities that are adequately and appropriately staffed with qualified medical personnel to better control sleeping sickness in GER.

We found that although the study area predominantly shows moderate to low and very low risk for sleeping sickness, some of the counties have a high risk for one or more cases of the disease per 10,000 people per year. When interpreting these risk estimates, it is important to recognize the uncertainty that surrounds the number of at-risk people and the positive cases of sleeping sickness detected in the study area (Simarro et al., 2012). During the study period, there were pockets of civil unrests in the region that could have prevented at-risk populations from being tested for gHAT due to displacements. In addition, we were not able to attain primary data from the responsible ministry in the Government of South Sudan. HAT caused by *Trypanosoma brucei gambiense* is a particularly problematic disease that surges during conflict in endemic areas. Given the resulting disruption of gHAT control activities, and its chronic nature of transmission, incidence can peak several years after infections (Tong et al., 2011), which may contribute to its risk distribution and persistence. South Sudan is a country where civil wars persisted for decades and continue in many parts of the region. In the GER, these wars create political instabilities and insecurities, which, combined with population displacement and poor health facilities, have culminated in the resurgences of sleeping sickness (Moore et al., 1999). The situation may have also resulted in the persistence of gHAT in its endemic foci in GER.

It should be acknowledged, however, that gHAT medical intervention (screening, detection, and treatment of cases) is only successful in reducing infection levels, controlling outbreaks, and preventing people who are already infected from dying – it fails to protect people from being infected in the first place. Hence, there is also a need for vector control programs (Tirados et al., 2015). Currently recommended HAT control practices include a combination of medical intervention (screening, detection, and treatment of cases) and vector controls that target the human reservoir. Vector control is an effective and cost-efficient way to disrupt the transmission of gHAT (Grébaut et al., 2004) by breaking the fly–human cycle and reducing the disease vector (*Glossina sp.)* population. Vector control has been used in several SSA countries, including Cameroon, Equatorial Guinea, and Chad, with considerable success (Grébaut et al., 2004; Mahamat et al., 2017; Simarro et al., 2006). Targeting the human reservoir using systematic and periodic case finding surveys coupled with appropriate screening and detection methodologies, broad coverage, and treatment of all HAT cases can rapidly reduce the prevalence and transmission of the disease (Simarro et al., 2006). However, we found no evidence that South Sudan has tried to eradicate the gHAT vector in GER. Consequently, poor gHAT screening coverage and the lack of vector control activities are contributing factors in sustaining transmission in known HAT foci with historically endemic cases.

Compared to other SSA countries, 6% of South Sudan's total area is at risk for gHAT, while the Democratic Republic of Congo (DRC) leads with 65% of its total area at risk for the disease (Franco et al., 2020), followed by Angola at 8.5% and Central African Republic (CAR) at 6%. Compiled cases of gHAT for the period 2009–2018 show DRC with a total of 39,090 cases, followed by CAR with 2,596 cases, Chad with 1,666 cases, and South Sudan with a total of 1,432 cases of sleeping sickness (Franco et al., 2020). Out of the 15 SSA countries where gHAT is endemic, South Sudan ranked fourth in number of cases recorded between 2009 and 2018 (Franco et al., 2020). At the country level, an estimated 15,754 cases of sleeping sickness were reported between 2000 and 2009 (Simarro et al., 2010) in the gHAT endemic region of Southern Sudan, which is now the separate nation of South Sudan after secession from Sudan in 2011. As of 2012, the total number of gHAT cases in South Sudan dropped to an estimated 1,270 (Simarro et al., 2012). Our study shows that about 18.0% of the South Sudan region was endemic to gHAT between 2013 and 2018. This endemic area is slightly larger than what earlier researchers found between 2000 and 2009 (15.8%; Simarro et al., 2012). The differences in endemic areas could partly be due to changing number of people and the environments due to displacements and wars in the region. The difference could also be because of the different study periods used and the changing boundaries of South Sudan owing to disputed regions. Due to inter- and intra-tribal tensions, the country has not asserted clear internal state and external country boundaries with neighboring countries (Carboni, 2020; Justin & De Vries, 2019). Nonetheless, the endemic regions in South Sudan represent 7.4% of the total endemic countries to gHAT in Africa (Simarro et al., 2012).

With an infection rate of only 0.30% among screened cases between 2016 and 2018, authorities in South Sudan should not take comfort but rather exert more effort to make sure monitoring in the region improves to cover more at-risk populations. South Sudan officials could not provide evidence for the low number of reported positive gHAT cases they claimed in the country based on epidemiological evidence, control, and surveillance activities in 2017 (World Health Organization, 2020). With further monitoring, it is more likely that more gHAT cases would be found in the region. Hence, the low number of cases in South Sudan must be interpreted with caution as capacities for screening and detection have continued to deteriorate and gHAT endemic areas are highly insecure (World Health Organization, 2020). Although outreach, screening, and detection for sleeping sickness, the distribution and availability of gHAT service facilities, and the percentage of endemicity of gHAT in the GER were explored, the study was not able to fully assess all gHAT risk factors in the region due to limited available data.

Nevertheless, HAT is known to be confined to endemic foci areas, and it is in these areas that the disease tends to persist over time as long as the factors responsible for its transmission continue to exist. However, many factors, including interactions between the environment, the host, the vector, and the parasite, might influence distribution patterns of HAT (Franco et al., 2014). Therefore, complex interactions between the environment, the host, and the parasite seem to offer plausible explanations for gHAT distribution and probability in or around the endemic foci. These relationships, however, are not well understood (Franco et al., 2014) in the study area. Hence, poor gHAT screening coverage and lack of vector control in the region, plus inherent problems of insecurity and lack of human and financial resources, could all be contributing to the country's limited ability to effectively reduce the risk to sleeping sickness in the region. An integrated approach that includes vector control and medical treatment seems to effectively reduce *T. b. gambiense* transmission and cases (Courtin et al., 2015; Grébaut et al., 2004; Mahamat et al., 2017; Simarro et al., 2006). The combination of vector control and medical interventions could reduce sleeping sickness duration and the number of new infections in many SSA countries (Grébaut et al., 2004; Mahamat et al., 2017; Simarro et al., 2006). Vector control that targets areas of human–tsetse fly interaction will reduce the level of human exposure to gHAT, specifically where it is high (Courtin et al., 2015). Therefore, a comprehensive approach to gHAT control may produce needed results and consequently lead to elimination of sleeping sickness not only in South Sudan but also in HAT-affected countries throughout SSA.

Such comprehensive control programs require a coordinated approach: treatment of infected individuals; passive or active case finding by global and regular screening and/or detection in the population; health education; and vector control measures (usually by trapping at sites of human–fly contact). These measures are difficult to achieve and have so far defeated the capacities of INGOs on a country-wide scale (Smith et al., 1998). Financial resources are required for control programs, while financial constraints are important barriers that negatively impact HAT monitoring and control programs and prevent wider use of existing facilities (Franco et al., 2017). With limited and dwindling global support, aid-dependent countries in SSA like South Sudan should start prioritizing their limited resources to enhance their health situation.

Conclusion

Gambian HAT risk seems spatially and temporally persistent in already known HAT foci in the three states of the Greater Equatoria Region (GER). However, due to the data limitations explained above, these results need to be interpreted with caution. The South Sudan government should demand more access to data collected in its territory by INGOs to help local or international researchers independently analyze and interpret the HAT status in the country. Access to macro- and microdata will assist researchers and governments in evaluating, revaluating, and suggesting local HAT control programs and management strategies in South Sudan rather than depending solely on INGO reports. The situation could change if South Sudan commits more of its financial resources to improving its health systems. This study shows that the risk of gHAT varies in proportion within and between counties and states in the GER. Currently, South Sudan is not meeting its global and regional target of having not more than one case of HAT per 10,000 people per year. This failure seems to be due to a number of interrelated factors, some of which are explained above. High and very high risk distribution is mainly confined to the Western Equatoria State, which has a number of historic gHAT endemic foci.

Despite the data limitations outlined above, there is a clear need to increase passive and active HAT screening and detection coverage, in addition to vector control activities, in order to improve the quality of gHAT health-related services in GER. With relative peace currently prevailing in the region, the leadership of the South Sudan Ministry of Health needs to be reinforced with sufficient internal and external resources to support its activities. These conditions would help to bring the risk of sleeping sickness under effective control, leading to elimination in the GER, South Sudan.

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References

AbuAgla, A., Yousif, N., & Badr, E. (2013). *Understanding the labour market of human resources for health in Sudan*. Sudan Ministry of Health.

Alibu, V. P., John, C. K., Matovu, E., Malele, I. I., Chisi, J. E., Mbongo, N., Intisar, E. R., Mohammed, Y., Mubarak M. A., Erneo B. O., Lukaw, Y. S. (2015). Molecular xenomonitoring of trypanosomes in tsetse flies. *Journal of Parasitology and Vector Biology*, *7*(6), 108–114. https://doi.org/10.5897/JPVB2015.0188

Bunny, A. (2017). *Retaining skilled workers in a conflict setting: A study of human resource management approaches in international non-governmental development organizations in South Sudan*. RMIT University.

Carboni, A. (2020). *CDT spotlight: Growing pressure in South Sudan*. Armed Conflict Location & Event Data Project (ACLED).

Castaño, M. S., Aliee, M., Mwamba Miaka, E., Keeling, M. J., Chitnis, N., & Rock, K. S. (2020). Screening strategies for a sustainable endpoint for Gambiense sleeping sickness. *Journal of Infectious Diseases*, *221*(Suppl. 5), S539–S545. https://doi.org/10.1093/infdis/jiz588

Centers for Disease Control and Prevention, (CDC). (2020). *Parasites – African Trypanosomiasis (also known as sleeping sickness)*. Accessed June 24th, 2021, from https://www.cdc.gov/parasites/sleepingsickness/disease.html

Courtin, F., Camara, O., Camara, M., Kagbadouno, M., Bucheton, B., Solano, P., & Jamonneau, V. (2019). Sleeping sickness in the historical focus of forested Guinea: Update using a geographically based method. *Parasite* Paris, *26*, 61. https://doi.org/10.1051/parasite/2019061

Courtin, F., Camara, M., Rayaisse, J., Kagbadouno, M., Dama, E., Camara, O., Traoré, I. S., Rouamba, J., Peylhard, M., Somda, M. B., Leno, M., Lehane, M. J., Torr, S. J., Solano, P., Jamonneau, V., & Bucheton, B. (2015). Reducing human-tsetse contact significantly enhances the efficacy of sleeping sickness active screening campaigns: A promising result in the context of elimination. *PLoS Neglected Tropical Diseases*, *9*(8), e0003727. https://doi.org/10.1371/journal.pntd.0003727

Dumas, M., & Boa, F. Y. (1988). Human African Trypanosomiasis. In A. A. Harris (Ed.), *Handbook of clinical neurology* (pp. 339–344). Elsevier Science Publishers.

Ford, B. (2007). Civil conflict and sleeping sickness in Africa in general and Uganda in particular. *Conflict and Health*, *1*(1), 6. https://doi.org/10.1186/1752-1505-1-6

Franco, J. R., Cecchi, G., Priotto, G., Paone, M., Diarra, A., Grout, L., Mattioli, R. C., & Argaw, D. (2017). Monitoring the elimination of human African trypanosomiasis: Update to 2014. *PLoS Neglected Tropical Diseases*, *11*(5), e0005585. https://doi.org/10.1371/journal.pntd.0005585

Franco, J. R., Cecchi, G., Priotto, G., Paone, M., Diarra, A., Grout, L., Simarro, P. P., Zhao, W., & Argaw, D. (2020). Monitoring the elimination of human African trypanosomiasis at continental and country level: Update to 2018. *PLoS Neglected Tropical Diseases*, *14*(5), e0008261. https://doi.org/10.1371/journal.pntd.0008261

Franco, J. R., Simarro, P. P., Diarra, A., Ruiz-Postigo, J. A., & Jannin, J. G. (2014). The journey towards elimination of gambiense human African trypanosomiasis: Not far, nor easy. *Parasitology*, *141*(6), 748–760. https://doi.org/10.1017/S0031182013002102

Gao, J., Qian, Z., Hide, G., Lai, D., Lun, Z., & Wu, Z. (2020). Human African trypanosomiasis: The current situation in endemic regions and the risks for non-endemic regions from imported cases. *Parasitology*, *147*(9), 922–931. https://doi.org/10.1017/S0031182020000645

Grébaut, P., Mbida, J. A. M., Kondjio, C. A., Njiokou, F., Penchenier, L., & Laveissiére, C. (2004). Spatial and temporal patterns of human African trypanosomosis (HAT) transmission risk in Bipindi focus, in forest zone of southern Cameroon. *Vector Borne and Zoonotic Diseases*, *4*(3), 230–238. https://doi.org/10.1089/vbz.2004.4.230

Justin, P. H., & De Vries, L. (2019). Governing unclear lines: Local boundaries as a (re)source of conflict in South Sudan. *Journal of Borderlands Studies*, *34*(1), 31–46. https://doi.org/10.1080/08865655.2017.1294497

Kirchhoff, L. (1994). American trypanosomiasis (Chagas' disease) and African trypanosomiasis (sleeping sickness). *Current Opinion in Infectious Diseases*, *7*(5), 542–546. https://doi.org/10.1097/00001432-199410000-00004

Lehane, M., Alfaroukh, I., Bucheton, B., Camara, M., Harris, A., Kaba, D., Lumbala, C., Peka, M., Rayaisse, J.-B., Waiswa, C., Solano, P., & Torr, S. (2016). Tsetse control and the elimination of Gambian sleeping sickness. *PLoS Neglected Tropical Diseases*, *10*(4), e0004437. https://doi.org/10.1371/journal.pntd.0004437

Lukou, Y. S., & Ochi, E. B. (2020). Historic and current trends of human African trypanosomiasis in South Sudan. *Journal of Parasitology and Vector Biology*, *12*(2), 29–34. https://doi.org/10.5897/JPVB2020.0387

Lumbala, C., Simarro, P. P., Cecchi, G., Paone, M., Franco, J. R., Betu Ku Mesu, K., Makabuza, Victor, J., Diarra, A., Chansy, S., Priotto, G., Mattioli, R. C., & Jannin, J. G. (2015). Human African trypanosomiasis in the Democratic Republic of the Congo: Disease distribution and risk. *International Journal of Health Geographics*, *14*(1), 20. https://doi.org/10.1186/s12942-015-0013-9

Mahamat, M. H., Peka, M., Rayaisse, J., Rock, K. S., Toko, M. A., Darnas, J., Brahim, G. M., Alkatib, A. B., Yoni, W., Tirados, I., Courtin, F., Brand, S. P. C., Nersy, C., Alfaroukh, I. O., Torr, S. J., Lehane, M. J., & Solano, P. (2017). Adding tsetse control to medical activities contributes to decreasing transmission of sleeping sickness in the Mandoul focus (Chad). *PLoS Neglected Tropical Diseases*, *11*(7), e0005792. https://doi.org/10.1371/journal.pntd.0005792

Mohammed, Y. O., Mohammed-Ahmed, M. M., El Malik, K. H., & El Rayah, I. E. (2008). Distribution pattern of Glossina fuscipes fuscipes (Diptera: Glossinidae) in Bahr el Jebel State, Southern Sudan. *International Journal of Tropical Insect Science*, *27*(3–4), 210–215. https://doi.org/10.1017/S1742758407872390

Moore, A., & Richer, M. (2001). Re-emergence of epidemic sleeping sickness in southern Sudan. *Tropical Medicine & International Health*, *6*(5), 342–347. https://doi.org/10.1046/j.1365-3156.2001.00714.x

Moore, A., Richer, M., Enrile, M., Losio, E., Roberts, J., & Levy, D. (1999). Resurgence of sleeping sickness in Tambura County, Sudan. *American Journal of Tropical Medicine and Hygiene*, *61*(2), 315–318. https://doi.org/10.4269/ajtmh.1999.61.315

National Bureau of Statistics. (2015). *Population Projections by County: 2015–2020. The Republic of South*. Retrieved May 5, 2021, from https://www.ssnbss.org/home/document/census/population-projections-for-south-sudan-by-county-from-2015-to-2020/

Palmer, J., & Kingsley, P. (2016). *Controlling sleeping sickness amidst conflict and calm: Remembering, forgetting and the politics of humanitarian knowledge in Southern Sudan, 1956–2005*. Overseas Development Institute pp. 31–48. Retrieved March 3, 2022,from https://researchonline.lshtm.ac.uk/id/eprint/4650323/1/PALMER%202016%20-%20History%20of%20HAT%20humanitarianism%20SSudan%20-%20ODI-HPG.pdf

Palmer, J. J., Surur, E. I., Checchi, F., Ahmad, F., Ackom, F. K., Whitty, C. J. M., & Matovu, E. (2014). A mixed methods study of a health worker training intervention to increase syndromic referral for gambiense human African trypanosomiasis in South Sudan. *PLoS Neglected Tropical Diseases*, *8*(3), e2742. https://doi.org/10.1371/journal.pntd.0002742

Robays, J., Bilengue, M. M. C., Stuyft, P., & Boelaert, M. (2004). The effectiveness of active population screening and treatment for sleeping sickness control in the Democratic Republic of Congo. *Tropical Medicine & International Health*, *9*(5), 542–550. https://doi.org/10.1111/j.1365-3156.2004.01240.x

Ruiz-Postigo, J. A., Franco, J. R., Lado, M., & Simarro, P. P. (2012). Human African Trypanosomiasis in South Sudan: How can we prevent a new epidemic? *PLoS Neglected Tropical Diseases*, *6*(5), e1541. https://doi.org/10.1371/journal.pntd.0001541

Samdi, S., Abenga, J. N., Fajinmi, A., Kalgo, A., Idowu, T., & Lawani, F. (2009). Seasonal variation in trypanosomosis rates in small ruminants at the Kaduna Abattoir, Nigeria. *African Journal of Biomedical Research*, *11*(2), 229–232. https://www.ajol.info/index.php/ajbr/article/view/50717/39409#:~:text=The%20over%20all%20trypanosome%20infection,the%20ruminants%20followed%20by%20T

Selby, R., Wamboga, C., Erphas, O., Mugenyi, A., Jamonneau, V., Waiswa, C., Torr, S. J., & Lehane, M. (2019). Gambian human African trypanosomiasis in North West Uganda. Are we on course for the 2020 target? *PLoS Neglected Tropical Diseases*, *13* (8), e0007550. https://doi.org/10.1371/journal.pntd.0007550 *PLoS neglected tropical diseases*.

Simarro, P. P., Cecchi, G., Franco, J. R., Paone, M., Diarra, A., Ruiz-Postigo, J. A., Fèvre, E. M., Mattioli, R. C., & Jannin, J. G. (2012). Estimating and mapping the population at risk of sleeping sickness. *PLoS Neglected Tropical Diseases*, *6*(10), e1859. https://doi.org/10.1371/journal.pntd.0001859

Simarro, P. P., Cecchi, G., Franco, J. R., Paone, M., Diarra, A., Ruiz-Postigo, J. A., Mattioli, R. C., & Jannin, J. G. (2014). Mapping the capacities of fixed health facilities to cover people at risk of gambiense human African trypanosomiasis. *International Journal of Health Geographics*, *13*(1), 4. https://doi.org/10.1186/1476-072X-13-4

Simarro, P. P., Cecchi, G., Paone, M., Franco, J. R., Diarra, A., Ruiz, J. A., Fèvre, E. M., Courtin, F., Mattioli, R. C., & Jannin, J. G. (2010). The atlas of human African trypanosomiasis: A contribution to global mapping of neglected tropical diseases. *International Journal of Health Geographics*, *9*(1), 57. https://doi.org/10.1186/1476-072X-9-57

Simarro, P. P., Franco, J. R., Ndongo, P., Nguema, E., Louis, F. J., & Jannin, J. (2006). The elimination of Trypanosoma brucei gambiense sleeping sickness in the focus of Luba, Bioko Island, Equatorial Guinea. *Tropical Medicine & International Health*, *11*(5), 636–646. https://doi.org/10.1111/j.1365-3156.2006.01624.x

Smith, D. H., Pepin, J., & Stich, A. H. (1998). Human African trypanosomiasis: An emerging public health crisis. *British Medical Bulletin*, *54*(2), 341–355. https://doi.org/10.1093/oxfordjournals.bmb.a011692

South Sudan Ministry of Finance. (2019). *South Sudan National budget brief – 2019. Ministry of Finance and Planning, Government of the Republic of South Sudan*. Retrieved March 6th, 2022, from http://www.mofep-grss.org/wp-content/uploads/2019/09/UNICEF-South-Sudan-National-Budget-Brief-2019.pdf

South Sudan Ministry of Health. (2016). *South Sudan National Master Plan for Neglected Tropical Diseases: 2016–2020*. Retrieved March 6th, 2022, from https://espen.afro.who.int/system/files/content/resources/SOUTH_SUDAN_NTD_Master_Plan_2016_2020.pdf

Stanton, M. C., Esterhuizen, J., Tirados, I., Betts, H., & Torr, S. J. (2018). The development of high resolution maps of tsetse abundance to guide interventions against human African trypanosomiasis in northern Uganda. *Parasites & Vectors*, *11*(1), 340. https://doi.org/10.1186/s13071-018-2922-5

Steverding, D. (2008). The history of African trypanosomiasis. *Parasites & Vectors*, *12*(1), 3. https://doi.org/10.1186/1756-3305-1-3

Tirados, I., Esterhuizen, J., Kovacic, V., Mangwiro, T. N. C., Vale, G. A., Hastings, I., Solano, P., Lehane, M. J., & Torr, S. J. (2015). Tsetse control and Gambian sleeping sickness: Implications for control strategy. *PLoS Neglected Tropical Diseases*, *9*(8), e0003822. https://doi.org/10.1371/journal.pntd.0003822

Tong, J., Valverde, O., Mahoudeau, C., Yun, O., & Chappuis, F. (2011). Challenges of controlling sleeping sickness in areas of violent conflict: Experience in the Democratic Republic of Congo. *Conflict and Health*, *5*(1), 7. https://doi.org/10.1186/1752-1505-5-7

Tvedt, T. (1998). *Angels of mercy or development diplomats? NGOs & foreign aid*. James Currey Ltd. & Africa World Press, Inc.

United Nations Population Fund. (2021). *World population dashboard: South Sudan*. Retrieved May 2, 2021, from https://www.unfpa.org/data/world-population/SS

United States of America Central Intelligence Agency. (2021). *World factbook: South Sudan*. Retrieved May 5th, 2021, from https://www.cia.gov/the-world-factbook/countries/south-sudan/

Wamboga, C., Matovu, E., Bessell, P. R., Picado, A., Biéler, S., Ndung'u, J. M., & Arez, A. P. (2017). Enhanced passive screening and diagnosis for gambiense human African trypanosomiasis in north-western Uganda – Moving towards elimination. *PloS one*, *12*(10), e0186429. https://doi.org/10.1371/journal.pone.0186429

Welburn, S. C., & Maudlin, I. (2012). *Priorities for the elimination of sleeping sickness. Advances in parasitology*. Elsevier Science & Technology.

World Health Organization. (2018, April 18-20). *Report of the third WHO stakeholders meeting on gambiense human African trypanosomiasis elimination*.

World Health Organization. (2020). *Trypanosomiasis, human African (sleeping sickness): Key facts*. Retrieved October 7, 2020, from https://www.who.int/en/news-room/fact-sheets/detail/trypanosomiasis-human-african-sleeping-sickness