

# Typhoid Fever in Sudan: Some Geographic and Time Considerations from 2000 through 2008

Samir M. A. Hassan Alredaisy

Department of Geography, Faculty of Education, University of Khartoum, Khartoum,  
P.O.Box 406, Omdurman, Sudan

*Typhoid is used worldwide as an indicator of the level of public health, since it is caused mainly by unhygienic conditions. This article describes geographic and temporal trends of typhoid in northern Sudan as indicative of the level of community hygiene from 2000 to 2008, based on official governmental statistics published in 2009–10. Southern Sudan is excluded for this period because of lack of data. The main findings show that typhoid has a general fluctuating pattern, while three-year prevalence rates depict a steady increase. Regional differences by three-year prevalence rates are remarkable between the central region, including Khartoum and Gezira, and other regions of Sudan; these differences are statistically significant at all significance levels. Geographic proximity is influential in the distribution of typhoid within Sudan's states. The three-year prevalence rates distinguished two major groups of spatial distribution of typhoid by state. The first group shows a continuous increase in typhoid and includes central and western Sudan; the second group consists of two separated pockets of a fluctuating pattern of typhoid in eastern and western Sudan. Proportional change by state before the base year of 2004 shows a lower percentage relative to the period 2005–8, with few exceptions. Rank correlation between percent change in population and percent change in typhoid by state is weak at 0.01. The author proposes the "ESEN-GEO" model to assess and reduce typhoid in Sudan.*

*Key words: typhoid, contamination, immunization, administrative states, education, society, geographic proximity, northern Sudan*

*La fièvre typhoïde est utilisée dans le monde entier comme un indicateur du niveau de santé publique, car elle est principalement causée par*

*de mauvaises conditions hygiéniques. Cet article décrit les tendances spatiales et temporelles de la présence de la typhoïde dans le Soudan septentrional comme une indication du niveau d'hygiène communautaire entre 2000 et 2008, en se basant sur des statistiques officielles publiées en 2009–2010. Le Soudan méridional en est exclu par manque de données. Les principaux résultats montrent que la fréquence de la typhoïde fluctue dans le temps, mais que les taux de prévalence sur trois ans signalent une augmentation régulière. Les différences régionales de ces taux de prévalence sont remarquables si l'on compare la région centrale (qui comprend les régions de Khartoum et de Gezira) aux autres régions du Soudan ; ces différences sont statistiquement significatives à tous les niveaux. La proximité géographique influence la distribution de la typhoïde dans les différentes divisions administratives du pays. Pour les taux de prévalence sur trois ans, on peut distinguer deux groupes principaux de régions en fonction de distribution spatiale de la fièvre : le premier groupe montre une augmentation continue de cette maladie et comprend le Soudan central et occidental ; le second groupe consiste en deux poches de fluctuations séparées : l'une au Soudan occidental et l'autre au Soudan oriental. Les changements proportionnels par région avant la date de référence de 2004 montrent un pourcentage moins élevé pour la période 2005–2008, avec peu d'exceptions. La corrélation entre le pourcentage de la croissance démographique et le pourcentage de l'évolution de la typhoïde par région est faible (0.01). L'auteur introduit le modèle « Esengeo » pour évaluer et ainsi contribuer à réduire la typhoïde au Soudan.*

*Mots-clés : typhoïde, contamination, immunisation, régions administratives, éducation, société, proximité géographique, Soudan septentrional-*

### Introduction

Typhoid enteric fever is a waterborne disease transmitted via the faecal–oral route and is contracted by the consumption of water and foodstuffs contaminated with *Salmonella typhi* or typhoid bacillus or by urine from an infected person or carrier (Royal Tropical Institute 2010). It can live and multiply in the gallbladders of carriers whose health it does not affect; it can survive in water for 7 days, in sewage for 14 days, and in ice cream for 1 month. It is destroyed by temperatures above 50°C (Punjani and Bhatia 1997). The incubation period ranges from 8 to 28 days, depending on whether or not the host has been vaccinated and, if so, on the inoculum size and immune status (i.e., vaccination coverage) of the host. Transmission can also occur directly within a family through contact with a patient or a chronic carrier. Indirectly, improperly washed fruits and vegetables, if consumed raw, can also transmit the bacillus. About 90 % of cases are transmitted indirectly (Lucas and Gilles 2003). Flies act as passive vectors via fluid contacts with their legs when they feed in both latrines and kitchens. Typhoid is recognized by the sudden onset of sustained fever, severe headache, nausea, and severe loss of appetite; it is sometimes accompanied by a hoarse cough and constipation or diarrhea. Because its symptoms resemble those of malaria, typhus, and other enteric diseases, typhoid was not recognized until relatively recently.

Humans are the only known reservoir of infection. Infection may take the form of an overt case of the disease, an ambulatory “missed” case, or an asymptomatic carrier. About 2–4 % of patients treated become chronic carriers of the disease, and in most parts of the world faecal carriers are more common than urinary carriers. The carrier state is more common among persons infected during middle age, especially women (Lucas and Gilles 2003; Bensenson 1975). Carriers are either chronic or convales-

cent. A *chronic carrier* is defined as a person whose stool is continuously positive for *S. typhi* for at least a year following an episode of the disease; a person with positive stool cultures but without any history of the disease can spread infection to others or cause contamination. Chronic carriers are a threat to the community around them (Sonhani et al. 1998). Middle-aged women are common carriers because they care for others, such as household members or young children, who may be infected persons or carriers.

The prevalence of typhoid fever is determined largely by hygienic standards and practices among individuals and communities and has been used as an indicator of the level of community hygiene. Typhoid is an internationally as well as locally notifiable disease because of its epidemic potential (WHO 1997); infection with *S. typhi* causes an estimated 20 million cases of typhoid fever and 200 000 deaths worldwide each year (PhysOrg.com 2009).

Typhoid has been affecting people from time immemorial, without being identified as a separate illness because its symptoms resemble those of malaria, typhus, and dysentery. It is difficult to establish a historical diagnosis prior to the identification of the disease by William Wood Gerhard in 1836, by A. P. Stewart in 1840, and lastly by William Jenner in 1851 (the first to successfully define typhoid fever). However, scholars working on the history of Jamestown, Virginia, believe that a typhoid outbreak was responsible for the deaths of more than 6 000 settlers between 1607 and 1624. During the war against South Africa in the late 19th century, British troops lost 13 000 men to typhoid, as compared to 8 000 deaths in battle (WHO 1997). It appears that the incidence may still be as high today as it was in the past; however, today the fatality rate has dropped dramatically. In January 2010, it was reported that the typhoid outbreak in Gabon had spread to the capital, Libreville, which had been grappling with water shortages for two weeks (IRIN 2010). In many parts of Kenya,

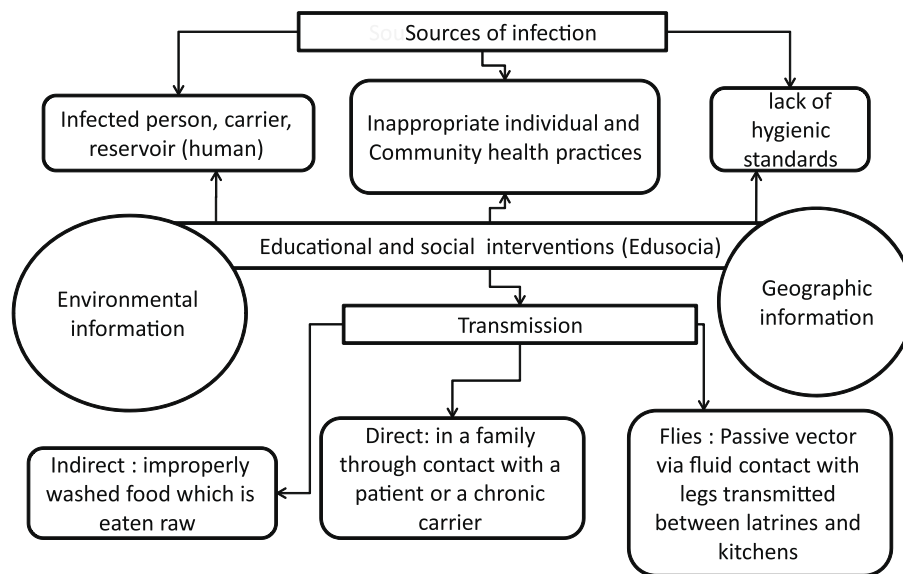


FIGURE 1  
ESENGEO model for typhoid assessment and reduction in Sudan

typhoid fever is prevalent, especially in Nyanza and Eastern provinces, where poverty, congestion, and unhygienic living conditions have worsened the situation. Nyanza, for example, is typhoid-ridden because of a lack of treated water combined with residents' ignoring precautionary and preventive measures (Onyango 2002). In 2002, an outbreak of typhoid struck the Jirgital District in the Rasht Valley of Tajikistan; a latrine-contaminated water source was the suspected source of the outbreak (Médecins sans frontières 2002). In 2003, Crump et al. estimated that the incidence of typhoid fever was 13 per 100 000 persons per year in Bilbeis District, Egypt.

In virtually all areas where typhoid fever is endemic, incidence is highest in children 5–19 years of age. Data mainly from Africa, Asia, and Latin America show that typhoid fever continues to be a public-health problem, with schoolchildren aged between 5 and 15 disproportionately affected. In some endemic areas, children under age five show incidence rates similar to or exceeding those of school-aged children. In Ghana's Ashanti region, the estimated incidence of typhoid is 205 per

100 000 children aged 4–5 years old (Quaicoe-Duho 2009).

In Ochiai et al.'s (2003) study of 5 Asian countries, a total of 21 874 episodes of fever were detected. The annual typhoid incidence (per 100 000 person-years) in the 5–15 age group varied substantially among sites: it was found to be high in India and Pakistan, intermediate in Indonesia, and low in China and Vietnam (Ochiai et al. 2003). Here the relationship between mother and child is important: a child's long-term exposure to its mother, who may be infected or a carrier, transmits typhoid. This is particularly the case when mothers are fully responsible for child-rearing. "These findings highlight the considerable, but geographically heterogeneous, burden of typhoid fever in endemic areas of Asia, and underscore the importance of evidence on disease burden in making policy decisions about interventions to control this disease" (Ochiai et al. 2003, 260).

The Ministry of Health Statistics in Sudan reports that the primary risk factors for typhoid are physical conditions (e.g., climate conducive to insect breeding), population factors (e.g., overcrowding, migration),

TABLE 1

Population, typhoid patients treated, and calculated prevalence rate in northern Sudan, 2000–2008

Year	Population	Patients treated	Prevalence rate
2000	26 046 000	16 035	0.6
2001	26 840 000	18 865	0.7
2002	27 569 000	21 679	0.8
2003	28 363 000	25 166	0.8
2004	29 146 000	38 786	1.1
2005	29 949 000	48 053	1.3
2006	30 767 000	66 436	2.1
2007	31 623 000	77 480	2.0
2008	30 894 000	89 473	2.9
Average	29 021 000	44 663	1.4

Source: Prevalence rates calculated by author from annual health statistics reports for 2000–2008, Ministry of Health, Sudan.

illiteracy, inadequate water supply, and low government expenditure in the health sector. The purpose of this study is to highlight geographic and temporal variations of typhoid in Sudan from 2000 through 2008. The study proposes the “ESEN-GE” (Education, Society, Environment, Geography) model (see Figure 1) to address sources of infection and modes of transmission of typhoid. The ESEN-GE model shows sources of infection of typhoid as including lack of hygienic standards; inappropriate individual and community health practices; and infected persons, carriers, and reservoirs. Similarly, the model depicts direct and indirect modes of typhoid transmission, as well as the role of flies. The main objective of the ESEN-GE model is to assess and reduce infection and transmission of typhoid in a community. The importance of ESEN-GE comes from its simplicity, its potential to deal with the available resources at the grassroots level, and its affordability for use with any infectious disease in any geographic setting. The components of ESEN-GE focus on reducing the incidence of typhoid (arrows in Figure 1) by addressing sources of infection and modes of transmission of typhoid. ESEN-GE works like an open ecosystem, with inputs, processes, and outputs. The inputs are

educational, societal, environmental, and geographical information on typhoid; the processes are the impacts of these inputs on typhoid in a community; and the outputs are the assessment and reduction of typhoid.

Education is important in the assessment and reduction of typhoid. An educated society will, of course, have knowledge about personal hygiene, environmental sanitation, typhoid transmission, and infection. Health education will create awareness of the disease and ways of avoiding infection. Traditional knowledge about infection and curing of diseases is beneficial. In addition, social capacity building through collective work and civil or voluntary organizations can work to assess and combat typhoid. Typhoid is highly linked with the physical environment—temperature, rainfall, and flooding or aridity determine its incidence, morbidity, and seasonality and affect the breeding of insects; the need for such data is substantial for the assessment and prevention of typhoid. Geographical data include information on location, population mobility and density, congestion, and geographic proximity and the role of these factors in typhoid infection and transmission. Typhoid prevalence rates have geographical scales: the global, the continental, the regional, and the national. Determination of such geographic differences



FIGURE 2  
Location and states of Sudan

in prevalence rates provide a spatial database for dealing with typhoid. The application of ESENGEO in Sudan will be further outlined following a review of the results of the present study.

#### Data and Methodology

Sudan is located in north-east Africa; it is bordered by 9 countries and is divided into 16 states (see Figure 2). The population of northern Sudan was recorded 30 894 000 in 2008, with an average population of 29 021 000 and annual change of 2 % for the period 2000–2008 (see Table 1). This population, distributed by region and by state, constitutes the population under study in this paper, as illustrated by typhoid prevalence rates shown in Tables 2 and 3.

Official statistics published by the National Ministry of Health in Sudan were used to analyze typhoid space–time behaviour from 2000 through 2008. The statistics were treated at the national, regional, and state levels; regional agglomeration was carried out by including many administrative states in each of four geographic regions: the northern, central, eastern, and western regions. This regional division follows the general mental map held by Sudanese as to the spatial division of their country.

National and state typhoid prevalence rates were calculated by dividing the number of patients treated by total population and multiplying by 1 000; regional prevalence rates were calculated by summing the prevalence rates for the states within a region and

TABLE 2  
Prevalence of typhoid in Sudan, by region

Year	Northern region	Central region	Eastern region	Western region
2000	0.6	0.1	0.3	0.01
2001	0.02	0.8	0.03	0.01
2002	0.2	0.8	0.01	0.01
2003	0.4	0.9	0.2	0.07
2004	1.4	1.5	0.3	0.08
2005	1.1	2.6	0.1	0.1
2006	0.9	3.0	1.6	0.1
2007	2.3	3.5	0.4	0.3
2008	2.9	2.2	0.9	0.4
Average	1.1	1.7	0.4	0.1
Rank	2	1	3	4

then taking the average. Time trends for typhoid were measured numerically, proportionally, and directionally to depict yearly changes and are presented in graphs. Three-year prevalence rates were also calculated at the spatial scales indicated above. An analysis of variance (ANOVA) compared three-year prevalence rates of typhoid across major regions of Sudan to establish significant differences at the 0.001 level, such that the null hypotheses (that there are no statistically significant differences in three-year typhoid prevalence rates between regions within Sudan) is rejected if the calculated *F*-value is greater than the critical value. Proportional change of typhoid is shown via index numbers by state; actual figures were converted to percentages by taking the year 2004 as the base year to facilitate comparison across all figures. Spearman's rank correlation between percent change in population and percent change in typhoid prevalence rates by state was calculated as follows:

$$r = 6 \sum d^2 / n(n^2 - 1), \text{ where } \sum d^2$$

is the sum of squares of differences between population and prevalence rate for each state and *n* is the number of values.

## Results

### *The General Situation of Typhoid in Sudan*

The number of typhoid patient records in Sudan is successively increasing (see Table 1), with a general annual average of 44 663 patients. The general behaviour of the disease shows a slow increase between 2000 and 2004, a steady increase between 2004 and 2007, and a sharp increased up to 2008. The calculated year-by-year percent change in the number of typhoid patients similarly shows a fluctuating behavioural pattern for the study period. The calculated difference between percent change in average annual typhoid patients (up 21.9 %) and percent change in average annual population (up 2 %) is extremely high at 19.9 %. The prevalence rate of typhoid shows a steady increase from 2000 through 2005, then fluctuates up to 2008 (see Table 1).

The time behaviour of typhoid was depicted by calculating the three-year prevalence rate, which smoothed the curve to depict a steady increase in the prevalence of typhoid in Sudan (see Figure 3). Thus, increasing population is accompanied by increasing typhoid, which reflects educational, societal, environmental, and geographical situations in the country.

TABLE 3

Typhoid prevalence rates (PR) and index numbers (IN) for Sudan by state, 2000–2008

State		Year									Average	Rank
		2000	2001	2002	2003	2004	2005	2006	2007	2008		
Northern	PR	0.04	0.05	0.2	0.6	1.9	1.4	1.0	2.5	1.5	1.02	7
	IN	2.0	2.8	11.1	33.3	100	77.6	55.5	141.2	86.6		–
River Nile	PR	0.6	n/a	0.2	0.2	0.9	0.8	0.9	2.2	4.3	1.3	4
	IN	16.8	0	17.9	23.7	100	85.9	107.9	246.9	530.6		–
Khartoum	PR	0.3	3.4	3.7	3.7	5.2	5.1	6.7	7.9	4.2	4.5	1
	IN	47.1	58.7	66.6	67.9	100	102.5	137.6	170.4	76.1		–
Gizira	PR	0.3	0.5	0.5	0.9	1.2	2.5	2.3	2.7	3.4	1.6	3
	IN	21.6	34.2	41.8	75.1	100	216.3	198.4	237.4	262.4		–
White Nile	PR	n/a	n/a	0.02	0.1	0.2	0.3	0.1	0.5	1.2	0.3	9
	IN	0	0	11.5	39.8	100	206.5	97.3	322.9	821.1		–
Blue Nile	PR	n/a	n/a	n/a	n/a	0.9	5.0	5.1	4.0	0.7	3.1	2
	IN	0	0	0	0	100	524.1	549.6	447.7	787.3		–
Sinnar	PR	n/a	n/a	n/a	n/a	0.08	0.3	0.8	2.6	1.7	1.09	5
	IN	0	0	0	0	100	388.8	1,049	3,373	2,020		–
Red sea	PR	0.6	.005	0.02	0.3	0.6	0.2	0.1	0.1	0.3	0.24	10
	IN	99.3	0.97	4.12	53.4	100	37.6	24.3	19.7	8.7		–
Gedaref	PR	0.2	0.1	n/a	0.1	0.2	0.2	4.7	0.8	2.1	1.05	6
	IN	87.6	46.1	0	62.1	100	75.4	2,379	359.0	861.0		–
Kassala	PR	0.005	0.01	0.01	0.1	0.1	0.01	0.03	0.3	0.2	0.08	14
	IN	3.63	7.3	13.6	18.8	100	8.6	27.7	209.1	195.5		–
S. Darfur	PR	n/a	0.003	n/a	n/a	0.1	0.2	0.3	0.3	0.5	0.23	11
	IN	0	2.4	0	0	100	148.2	252.5	294.8	453.7		–
N. Darfur	PR	n/a	n/a	0.01	0.2	0.2	0.2	0.4	0.9	1.0	0.4	8
	IN	0	0	11.2	98.5	100	112.6	239.4	662.1	791.8		–
W. Darfur	PR	0.04	0.02	0.05	0.07	0.09	0.2	0.05	0.08	0.04	0.07	15
	IN	0	0	23.5	139.5	100	103.7	0	0	0		–
S. Kordofan	PR	.005	0.01	0.02	0.01	0.03	n/a	0.02	0.05	0.6	0.09	13
	IN	11.6	32.6	60.5	32.6	100	0	79.1	230.2	1,802		–
N. Kordofan	PR	0.02	0.03	n/a	0.1	0.05	0.1	0.09	0.2	0.4	0.1	12
	IN	46.2	52.7	0	196.7	100	237.4	254.9	541.7	1,313		–
W. Kordofan	PR	n/a	n/a	0.01	0.09	0.06	0.06	n/a	n/a	n/a	0.05	16
	IN	0	0	23.5	139.5	100	103.7	0	0	0		–

Source: Calculated from annual health statistical yearbooks for 2000–2008, Ministry of Health, Sudan.



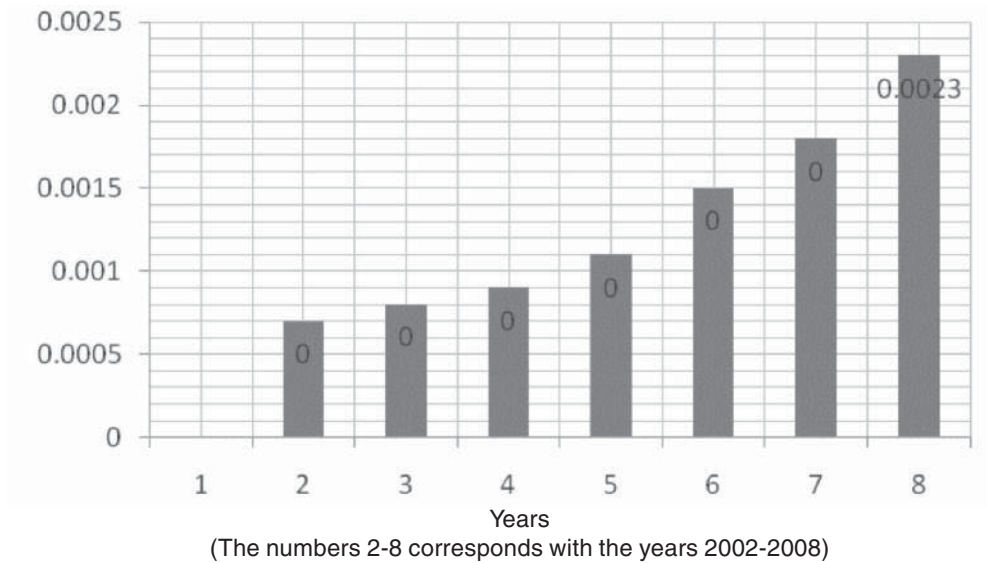


FIGURE 3  
Three-year prevalence rate of typhoid in Sudan, 2000–2008



FIGURE 4  
Geographical regions of Sudan

Sudan has a heterogeneous physical environment, with different climates and habitats extending from near the equator to the Sahara Desert. In this physical environment live different societies with different local cultures, although the majority are Muslim. Education levels vary widely, and in many cases the various communities are separated geographically. These characteristics, of course, substantially influence the space–time behaviour of typhoid in Sudan.

#### *Typhoid Prevalence at the Regional Level*

Regional agglomeration distinguished northern, central, eastern, and western regions within Sudan (see Figure 4). The northern region includes the Northern and River Nile states; the central region includes Khartoum, Sinnar, White Nile, Blue Nile, and Gizira states; the eastern region includes Red Sea, Kassala, and Gedaref states; and the western region includes the north, south, and west Darfur states in addition to the northern, southern, and western Kordofan states. Figure 5 builds on Figure 2 (which depicts typhoid prevalence patterns in



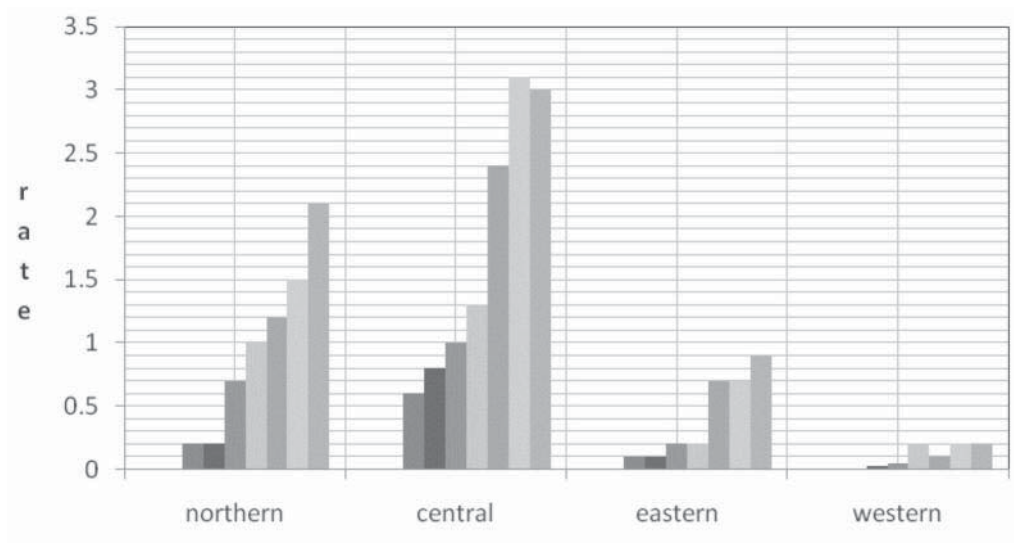


FIGURE 5  
Three-year prevalence of typhoid by region, Sudan, 2000–2008

Sudan's states) to presents typhoid prevalence by geographical region.

Based on data for typhoid prevalence by state and regional agglomerations indicated in "Data and Methodology" above, typhoid prevalence was calculated by region (see Table 2). The northern region shows a fluctuating pattern, while the central region shows an increasing pattern, except for a decrease in 2008. The eastern region is fluctuating, while the western region is stable for three successive years (2000–2002) and then shows steadily increasing prevalence during the remainder of the data period (2003–8). Small differences exist between the eastern and western regions in terms of average prevalence values, while both are remarkably different from the northern and central regions, which showed similar values to each other. Ranking of regional typhoid prevalence puts the central region first, followed by the northern, eastern, and western regions.

Three-year prevalence rates of typhoid were calculated by region (see Figure 5). Regional differences between the central region and other regions of Sudan may relate to population size, the inclusion of many

states in that region (although more are included in the western region), or to data limitations (many states have no records between 2000 and 2003), all of which may have affected the results. In addition, educational, societal, environmental, and geographical differences are also important, as proposed in the ESENCEO model.

These regional differences were statistically tested by analysis of variance (ANOVA), which found statistically significant differences in typhoid prevalence at the 0.001 level both between and within regions of Sudan. Further, the calculated *F*-ratio is greater than all other critical values at all other significance levels, indicating that typhoid is a very serious problem across the country. The fact that the central region ranks first in typhoid prevalence has environmental and socio-economic implications. This region is characterized by remarkable rainfall amounts and clayey soil, and is home to the majority of Sudan's population. The spread of education has made more people aware of diseases and encouraged them to visit doctors and attend hospitals, and this is reflected in the official records of typhoid infection. The presence in

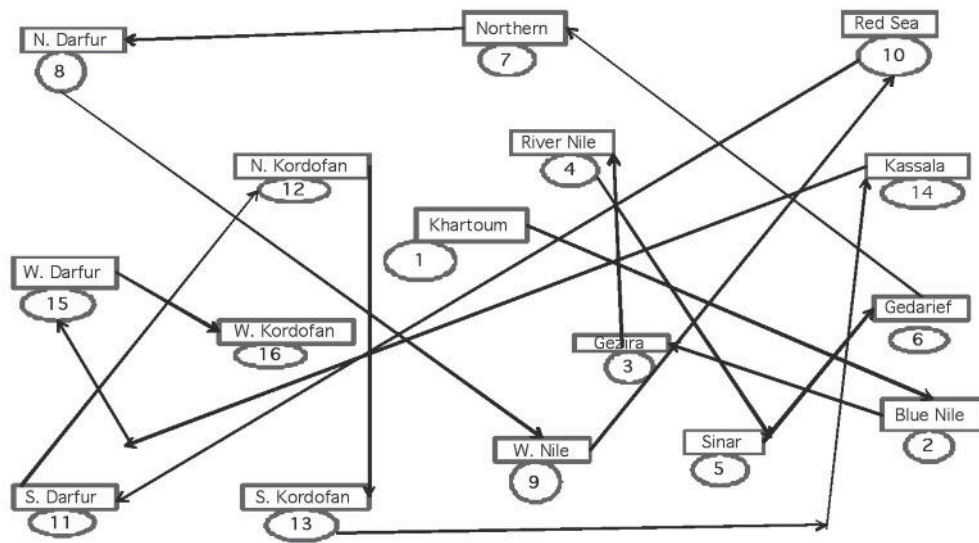


FIGURE 6

Spatial decay of three-year typhoid prevalence rates within ranked points representing states of Sudan (2000–2008)

this region of large urban centres such as Greater Khartoum, Medani, and Kosti creates its own environmental health problems. At the same time, migration from rural areas in peripheral regions may tend to increase the prevalence of typhoid in this region, since migrants tend to be illiterate, poor, and lacking in personal hygiene. The western region occupies the bottom rank, which may relate, in addition to the absence of statistical records, to the spread of illiteracy, political instability, and environmental problems in a mostly arid and semi-arid environment, all of which may lead to under-reporting of typhoid by making people less likely to seek medical care when they are ill.

#### *Typhoid Prevalence at the State Level*

Calculations of the distribution of Sudan's population by states reveal an uneven distribution. Ranking states by percent change in population for the period 2000–2008 distinguishes, first, the arid axis of rapid population change, including the Red Sea area and western Sudan; and, second, the wet axis of slower population change around the Niles,

including the central and northern states. Environmental, socio-economic, and political factors are primarily responsible for these population movements. Table 3 shows prevalence rates and state rankings in addition to index numbers of typhoid prevalence by state.

Ranking states by the general prevalence rate of typhoid (see Table 3) distinguishes some states with rates far exceeding those of Sudan as a whole (see Table 1), including Khartoum and Blue Nile states. Some other states have rates far below the general prevalence rate of typhoid in Sudan (e.g., Kordofan, Darfur, Red Sea, Kassala, and White Nile states). However, Northern, River Nile, Gezira, and Sinnar states show very close rates to the national rate. Calculating the prevalence of typhoid by state also reveals two separate groups in terms of typhoid behaviour over time. The first group shows a fluctuating pattern of behaviour; the second group shows a steady increase in the prevalence rate. The first group includes Red Sea, Gedaref, White Nile, Blue Nile, West Darfur, north Kordofan, west Kordofan, Kassala, and

Sinnar states; the second group includes Gizira, Khartoum, Northern, south Darfur, north Darfur, south Kordofan, and River Nile states.

Proportional change in typhoid by state is shown by index numbers (see Table 3). For example, in Red Sea state, the index number 99.3 for the year 2000 indicates that typhoid prevalence is 0.97 % lower than for the base year, 2004. Generally speaking, before 2004 all states show a lower percentage than in the post-2004 period (2005–8), with a few exceptions in some of the years under study. Ranking correlation by states between percent change in population and percent change in typhoid prevalence gives 0.01, a very weak positive correlation.

Calculation of three-year prevalence rates by state distinguishes two major groups of spatial distribution of typhoid. The first group, which shows a continuous increase in typhoid, is centred around central and western Sudan; it includes 9 states out of 16 (Khartoum, Gizira, Sinnar, White Nile, Blue Nile, South Darfur, North Darfur, North Kordofan, and Northern states). This axis, centred on Khartoum state, goes westward to include north Kordofan, north Darfur, and south Darfur states and also south-eastward to include Gizira, Sinnar, Blue Nile, and White Nile states. Its northward extension includes Northern state but is cut by River Nile state, which belongs to the other group.

The second group includes seven states making up two distinct pockets that show a fluctuating pattern of typhoid prevalence. First is the eastern pocket, including Red Sea, Kassala, and Gedaref states, which shortly goes westward to include River Nile state; second is the western pocket, which includes west and south Kordofan and south Darfur states. It is clear that geographic proximity has influenced the distribution of typhoid within Sudan's states. There is one huge geographical area of typhoid distribution, including the central and western states, in addition to relatively smaller pockets including eastern and western states. It

can be said that Sudan's western states show both types of distribution patterns (continuously increasing and fluctuating). Calculation of three-year typhoid prevalence rates by state reveals differences that are accordingly ranked and plotted (see Figure 6). Figure 6 considers Sudan's states as geographic points linked together by arrows that decay with increasing ranking. The arrow starts at Khartoum state (no. 1) and wanders around Sudan to settle finally in west Kordofan state (no. 16).

### Discussion and Recommendations

The general findings of this study are as follows:

- 1 The prevalence of typhoid fever in Sudan increased steadily from 2000 through 2008.
- 2 Regional differences are remarkable between the central region and other regions of Sudan.
- 3 Geographic proximity influenced the distribution of typhoid within Sudan's states; contiguous states show a typical pattern of typhoid behaviour, either continuously increasing or fluctuating.
- 4 Ranking correlation by states between percent change in population and percent change in typhoid prevalence gives a value of 0.01, indicating a very weak positive correlation.

These findings illustrate geographic and temporal variations in typhoid prevalence by state. The reasons for such variations are socio-economically, environmentally, and geographically related. The states where prevalence of typhoid is high during the data period are those of central Sudan, and particularly Khartoum, Gizira, and Blue Nile states. These states are characterized by major economic investment, and consequently high population concentration and increasing population, as well as relatively good per-capita income. In Khartoum state, where Sudan's capital city is located, the population growth rate was 4.92 % in

1956, increasing to 7.76 % in 1973 and to 8.75 % in 1983, reaching 13.7 % in 1993 (MFEP 1955–93). Mean population density (number of persons per square kilometre) was 55.6 in 1973, 85.5 in 1983, and 169 in 1993. Khartoum state received 39 % of internal migration in 1983 and 45 % in 1993 (MFEP 1955–93). Greater Khartoum's degree of urban primacy has changed: whereas in 1955 Khartoum had 4.7 times the population of Sudan's second-largest urban centre, by 1993 this had increased to 8.9 times (Davies 2001). The central states are also where the large irrigated agricultural schemes are found, such as the Gizira and Rahad schemes, as well as the sugar factories of Kenana and Asalia. Institutions of higher education such as the universities of Khartoum and Gizira are found here, in addition to the central government. Migration and natural population growth are responsible for higher prevalence of typhoid in these states. Studies in Sudan have documented the tight relationship between population mobility, migration, and congestion and the prevalence of diseases such as that of cholera and malaria (Alredaisy and Davies 2003). However, the basic health infrastructure provided does not match the increasing populations of these states, although they score high in their share of hospitals, doctors, and primary health units (Ministry of Health 2008).

The whole of Sudan central's region is characterized by climatic conditions conducive to the spread of typhoid. In Khartoum state, for example, average annual rainfall of nearly 161 mm is confined to the three months of July, August, and September, and during these months the daily temperature ranges from a mean minimum of 25°C to a mean maximum of 38°C, while relative humidity averages 55 %. These climatic conditions, which provide excellent grounds for insect breeding and transmission of typhoid, are further exacerbated by clayey soil conditions and lack of proper systems for disposal of excreta. The

other states with low recorded prevalence of typhoid have, in addition to data limitations, small populations, particularly the western and Red Sea states. Although some parts of western Sudan receive more rain than central Sudan, sandy soil conditions are effective in ensuring water penetration and thus do not provide such excellent niches for insect breeding. Similarly, River Nile and Northern states are characterized by desert conditions and low population density, with the population mostly concentrated along the Nile. In these states, also, per-capita income is expected to be low relative to the central states.

This discussion of typhoid prevalence rates in Sudan's states is commensurate with the statistics of the National Ministry of Health for Sudan as a whole, which relate typhoid to physical conditions, population factors, illiteracy, inadequate water supply, and low governmental expenditure in the health sector. As of 2007, the adult literacy rate (for the population aged 15+ years) was 49.9 % (50.9 % for men and 49.9 % for women). In 2006, 59.2 % of the population had access to safe drinking water; the expected benefit of improved water supply is an 80 % reduction in typhoid rates (Fost 1976). In 2002, adequate facilities for the disposal of excreta were available for only 31.4 % of Sudan's population, and as of 1999, health care was available for only 70 %. These figures must be seen in context: the annual population growth rate was 2.53 % between 2003 and 2007, the natural rate of increase was 41.23 per 1 000 in 2006, and the total fertility rate was 5.9 births per woman in 1999. This population growth was not accompanied by proportional development in the health sector. In 2000, the health sector received 2.08 % of the total budget; in 2004, 1.68 %; and in 2005, 2.20 %, while actual expenditure on the health sector in 2007 was only 0.31 % of the total budget. Between 2000 and 2008, the number of hospitals increased from 309 to 395, an average of only 9 new hospitals per year. Over

the same period, the number of primary health care units (PHCUs) was reduced from 2 558 to 2 005, while the number of health centres (larger facilities offering more complex care) increased from 915 to 1 398. The Ministry of Health (2008) also indicates that the national average is 15.4 doctors per 100 000 population, while Khartoum state has 65.5 doctors per 100 000 population. There are four states that have fewer than 20 doctors per 1 000 000 population, and six states with fewer than 10 doctors per 100 000 population.

This discussion shows that lack of basic infrastructure and human and physical conditions are dramatically influencing typhoid prevalence rates in Sudan. There are gaps in the prevention of typhoid in Sudan that could be bridged by appropriate intervention. Such an intervention could be directed toward the whole of Sudan or toward those states that have high prevalence rates. It is generally assumed that there is a need to educate people about typhoid; in reality, however, people are probably very much aware of the disease but, because of poor water and sanitary infrastructure and because of perhaps population density, it is very difficult to prevent. This study could build a very strong case for prioritizing improved infrastructure in addition to educating people. This could be done by incorporating the ESENGEO model (see Figure 1) in order to assess and reduce typhoid infection and transmission in Sudan.

Building a case for prioritizing improved infrastructure could depend on environmental and geographical information. Environmental information about typhoid in Sudan should include relevant data on the timing of the rainy season and all related climatic characteristics at the state and regional scales, to facilitate appropriate planning for control of insect breeding and the expected incidence of typhoid. Soil information should also be introduced. Geographical information should relate to population growth, increase, mobility,

migration, density, and concentration in order to detect hazardous areas. Access to a map showing foreign and internal capital investment in various regions of Sudan can help to forecast future population-movement trends and their consequences for public health. Geographical and environmental information for the ESENGEO model can also benefit from the available typhoid fever incidence data, which have grown worldwide with efforts to improve disease surveillance and the initiation of population-based typhoid fever incidence studies, in addition to advances in the understanding of the age distribution of typhoid fever, allowing for measurement of incidence rates among narrow age cohorts to be more accurately extrapolated to the general population. The formalization of methods for the assessment of typhoid burden provides a framework for standardized methods (Crump, Luby, and Mintz 2004). Typhoid does not appear as a major disorder in Sudan's burden-of-disease estimates; although national programs addressing child health and survival recognize typhoid fever prevention, reliable epidemiological information is needed on the burden and severity of the disease in populations at risk in order to achieve consensus on case definitions, diagnostic criteria, and the appropriate mix of preventive strategies (including carrier detection and water and sanitation interventions). Including disease management as a tool to increase quality of care, improve patient outcomes, and control costs to reduce provider practice variation is a key aspect of the ESENGEO model. Strategies for administration of vaccines for preventing typhoid should be deployed on a wide scale in ESENGEO, as recommended by WHO (2001), bearing in mind that vaccine can control typhoid fever only to a limited extent (Borgman 1994) and that the eradication of a carrier state can be difficult (Kumar and Clark 1999).

People in Sudan can be educated about typhoid symptoms, treatment, and preven-



tion through school subjects such as geography and biology and also through mosques, churches, adult education, media education, mobile cinema, and distance education. In every state there are local broadcasting and television stations, a university, and distance-education centres. All these facilities can be used to educate people about typhoid. Educational technologies encompass electronic-based delivery methods and innovations in instructional design such as adult education, problem-based learning, and competency-based training. Distance learning includes synchronous methods, which link learners who are separated by geographic distance but allow for simultaneous interaction, and asynchronous methods, which allow for interaction at different times (Muramoto, Campbell, and Salazar 2003). Health education to prevent typhoid includes education about personal hygiene, especially regarding handwashing after toilet use and before food preparation; use of safe drinking water; excluding disease carriers from food handling; and antibiotic treatment.

Social capacity building on typhoid awareness in Sudan can positively be enhanced through religious and cultural norms encouraging personal hygiene and neighbourhood sanitation where God's rewards are endless, ethnoscience concerned with symptoms and treatment of typhoid, conscious use of herbal medicine, and the help of traditional healers and curers capable of transmitting correct information on typhoid to indigenous people. Youth clubs and school vacations can be opportunities for volunteer work in typhoid campaigns and prevention. Charitable donations can be used to provide sanitary materials for poor people and for public bathrooms; posters and other materials to raise awareness about typhoid in public gathering places (markets, central bus stations, mosques, churches, etc.); and funding for local people's committees, administrative localities, and youth clubs to work for environmental sanitation in

their neighbourhoods, including monitoring suspected insect breeding locations.

The application of the ESENGEO model in Sudan can work to assess infection and transmission of typhoid in order to decide on appropriate methods through activation of the inputs, processes, and outputs outlined by the ESENGEO model, with the ultimate result of reducing typhoid in Sudan. However, the ESENGEO model can also be applied for any other similar infectious disease in similar places in Africa, Asia, and Latin America.

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