Part II: Schistosomiasis: final report

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INTRODUCTION

The tropical, parasitic disease schistosomiasis is second to malaria in contributing to the overall chronic disease burden in the developing world. It has been reported that 120 million people are symptomatic and 20 million people harbour severe infections[1]. Symptoms of the disease have a history, which dates back to the Egyptian Pharaohs who recorded urinary infections. Now in the twentieth century, worldwide prevalence of the disease appears to have increased with 200 million infected people and 500 to 600 million people from 74 developing tropical countries at risk of being infected[2]. Approximately 80% of the infected people are from sub-Saharan Africa[1]. The incidence of schistosomiasis in South Africa is difficult to quantify, as it is not a notifiable disease. In 1986 Pitchford reported that there were between 3 and 4 million people infected with one or more species of schistosome in South Africa[3]. Prevalence ranges were reportedly between 10% in some areas and 80% in the lowveld and east coast[3]. Children between the ages of 5 and 14 years are most at risk. The disease is endemic in KwaZulu-Natal and has been found along the coastal belt of the province, in the Eastern Cape, in parts of Mpumalanga, as well as the North and Northwest provinces[4].

Successful control strategies have been implemented in Brazil, China, and Egypt but the disease has spread to previously low or non-endemic areas[1]. According to the World Health Organisation, 20000 deaths are associated with schistosomiasis[1]. Projections forecast that as a result of population growth in endemic countries, morbidity and mortality due to malaria and schistosomiasis could double by 2010 if there is no intervention[1]. The risk of increasing infections with schistosomiasis may be further exacerbated by changes in the environments that support the growth and development of the parasites and their intermediate snail hosts. Drugs for effective treatment of the disease are available, but these are not always accessible to the people who need them. The lack of these treatments combined with suitable environments for transmission of the parasites contribute to an on-going cycle of disease which impact adversely on the quality of life and increase the burden of disease in developing nations. Even if treatment is provided there is the risk of re-infection if behaviours are not modified.

The link between climate and schistosomiasis transmission may be utilised to allow scientists to establish stable and unstable transmission seasons and to quantify the risk of infection within populations in particular localities. A geographic information system (GIS) provides a valuable tool to map the prevalence of schistosomiasis, and to illustrate the relationship between climatic variables and schistosomiasis [5,6,7,8,9,10].

Using a GIS to link environmental factors, climate, projected climatic change and schistosomiasis contributes to our current understanding of the disease. It facilitates spatial analysis and predictive modelling of the occurrence of schistosomiasis within a region. Advanced GIS tools allow the digital manipulation of both the disease and climate data. Scenarios may be created, taking into consideration the biology of the snail and parasite, as well as current climatic profiles and predicted future profiles.

This study examined the current distribution of schistosomiasis in relation to temperature and rainfall, and found the possible outcome under the provided climate change scenarios, and the implications thereof in terms of the people at risk.

SECTION 1: DERIVING A SCHISTOSOMIASIS DISTRIBUTION MODEL

Schistosomiasis in South Africa

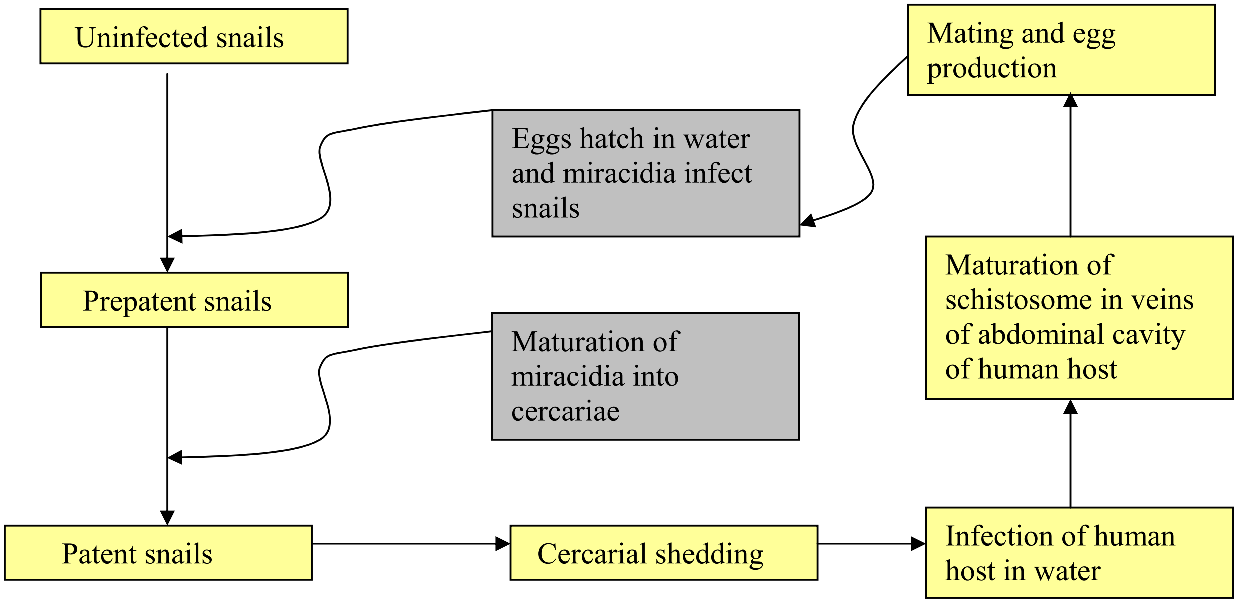

Fig 2.1: Life cycle of parasite

Schistosomiasis may be contracted in water bodies that are suitable for survival of the snail intermediate hosts that are susceptible to infection by cercariae. Upon contact with human hosts, cercariae penetrate the skin and transform into schistosomulum larvae that enter the circulatory system, mature in the liver and migrate to the small intestine or bladder (figure 2.1). After about six weeks the larvae reach sexual maturity and the male and female worms mate and produce eggs. The female worm may produce between 300 and 3000 eggs per day. The adult worm's lifespan ranges between three and eight years while it resides in the human body. However, the lifespan may be lengthened if favourable conditions within the human host persist. When humans defaecate or urinate in or near water bodies, the eggs are released. The eggs then hatch and become ciliated miracidia, which infect suitable snail hosts.

In South Africa, the pulmonate snails *Bulinus africanus, Bulinus globosus* and *Biomphalaria pfeifferi* are intermediate hosts in the transmission cycle. Both snails are aquatic and have been found in permanent fresh water habitats such as stagnant pools, streams, rivers, canals, irrigation schemes and dams[11]. The snails are generally found less than one metre below the surface and are able to survive several months of relatively dry conditions in sand, mud and streambeds. Under normal field conditions both snails can survive for approximately one year.

The snails *Bulinus globosus* and *Bulinus africanus* are the intermediate hosts for *Schistosoma haematobium*, which causes urinary schistosomiasis in man. The South African *Schistosoma haematobium* requires approximately six weeks to six months for complete development from miracidia to ceracaria [12]. This development is dependent on the prevailing temperature. Infection by this parasite may cause haematuria and chronic bladder schistosomiasis, which may be associated with bladder cancer[13]. Further development of the disease sequelae could result in painful haematuria and irreversible damage due to hydronephrosis and hydroureter[13]. Eventually the kidneys may fail.

The intermediate host *Biomphalaria pfeifferi* is necessary for completion of the *Schistosoma mansoni* life cycle which causes intestinal schistosomiasis in humans. Intramolluscan development takes place in a shorter time period (6 to 7 weeks) than that observed for *S.haematobium*[11,12]. Infection with *S.mansoni* may result in chronic illness like cirrhosis as a result of eggs of the parasite being shunted from the liver and then into general circulation in the body[13]. *S.mansoni* infects the hepatic portal system and long-standing infections could cause occult blood loss. If the eggs of either *S.mansoni* or *S.haematobium* become trapped in the liver, a cellular granulomatous reaction may occur, causing fibrosis. Liver portal tract fibrosis causes hepatosplenic disease, which is commonly associated with *S.mansoni* infections. The lungs may also be involved, resulting in cardiopulmonary schistosomiasis caused by infection with *S.mansoni.* Once *S.mansoni* or *S.haematobium* eggs infect a person, the pathology of schistosomiasis is determined by the egg burden. Very heavy infections can lead to death.

Factors affecting transmission

Both abiotic and biotic factors contribute to the schistosomiasis transmission cycle and these determine the spatial distribution of the disease. The presence of suitable water bodies is crucial to the cycle of transmission as people become infected by contact with contaminated water. The disease is associated with polluted water resources and poor or inadequate provision of basic services such as sanitation. In addition to human contributory factors such as swimming in high risk areas, irrigation, building of dams and migration, favourable climatic conditions for survival of the schistosome parasites and their respective snail hosts must also prevail. The abiotic factors affecting transmission include temperature, rainfall, geomorphology and current velocity. The most important of these abiotic factors has been found to be temperature [14] and to a lesser extent, rainfall in the form of habitat stability or habitat permanence. The effect of rainfall on schistosomiasis is indirect as it affects the amount of surface water that is available in suitable water bodies. Thus, rainfall is a proxy indicator of the availability of water, which in turn defines the pattern of schistosomiasis.

The presence of a suitable intermediate host snail is required for transmission of the disease. If the intermediate host's or parasite's life cycle is adversely affected by an external variable, the disease transmission cycle is also affected. Thus, distribution of the disease depends largely on the distribution of suitable snail hosts as the parasite is intermediate-host specific. However, there are areas where the suitable snail hosts do occur, but there is no disease. In such areas, environmental conditions may be unfavourable for development of the parasite and thus the cycle of disease may be interrupted. Alternatively, these factors could act to affect the vigour of an established host or parasite population.

Experimental work on the growth and survival of the parasites and their snail intermediate hosts suggests that both organisms are sensitive to changes in their environment. unsuitable conditions for reproduction of both the parasite and the snail limit the distribution of the disease. Changes in the environment may lead to the spread of the disease to generally low or non-endemic areas. If there is a season during which the snails and parasites are unable to breed then transmission of the disease may be interrupted during that season[15]. Evidence of *S.mansoni* infections in South Africa extend from Messina in the Northern Province down to Port St. Johns and East London in the Eastern Cape. Low prevalences were reported in the Rustenburg area in the NorthWest province, and in Bronkhorstspruit in Gauteng. In Mpumalanga, high infections (> 70%) were reported in Barberton and Nkomazi. Lower prevalences were reported in the Witrivier area (<10%). In KwaZulu-Natal, only Umbumbulu and Mtunzini had prevalences of 51% to 70 % and lower. Lower prevalences (<50 %) presented in the coastal regions of Ubombo, Lower Umfolozi, Lower Tugela, Inanda, Umzinto and Port Shepstone (Fig 2.2b).

The distribution of *S.haematobium* is broader than that observed for *S.mansoni*, but the Northern Cape, Western Cape and Free State are still free of the disease (Fig2.2a). The limits of the disease are from Messina in the Northern Province, into Christiana in the Northwest Province and down to Port Elizabeth and Uitenhage in the Eastern Cape. Highest prevalences (70% to 100%) are observed in the Northern Province, Gauteng, North West Province, Mpumalanga and KwaZulu-Natal[4].

It is relevant at this stage to discuss the climate that may be observed where both *S.mansoni* and *S.haematobium* infections occur. Most of South Africa experiences a mild, temperate climate. The moisture-laden easterly trade winds come in from the Indian Ocean and bring in rain from October to April. The effect of these winds diminishes as one moves westwards. The mean annual precipitation decreases westwards from the escarpment across the plateau, where no schistosomiasis is recorded[4]. Temperature patterns are regional and they vary depending on exposure to prevailing winds, latitude, altitude and rainfall.

Temperature effects on transmission

Temperature affects the ecology, geographical distribution and metabolic processes of both the snail host and the parasite. Michelson[16] identified four stages in the transmission cycle that are susceptible to thermal variation viz., temperature can affect (1) the ability of miracidia to infect suitable snails, (2) the duration and completion of intra-molluscan larval development, (3) cercarial emergence and (4) cercarial infectivity for the final (definitive) host. The intra-molluscan stage of transmission has been identified as the weakest link and most sensitive to the effects of temperature. It has been cited that the optimal temperature for survival of the parasites approximates 15 ^{o}C[22]. Transmission of schistosomiasis depends not only on survival of *S.haematobium* and *S.mansoni*, but also on survival of *Bulinus africanus* or *Bulinus globosus* and *Biomphalaria pfeifferi* respectively. The parasites are more sensitive to low temperatures than they are to high temperatures, while the opposite appears to be true for their snail hosts which do not survival well at high temperatures.

According to Pitchford[3] snail hosts can survive in areas where temperatures drop below freezing in winter, for instance on the highveld of Mpumalanga, Gauteng and Northwest Province. If low autumn and winter temperatures are experienced, intra-molluscan development to the cercarial stage may be prolonged for both *S. haematobium* and *S. mansoni* so that during winter, transmission may be reduced or even stopped, depending on altitude[3]. Thus although the parasite and snail hosts may both survive, transmission of schistosomiasis would be minimal during the cold autumn and winter days in South Africa where average minimum temperatures range from sub-zero to approximately 13^{o}C in July. In late September and early October, almost simultaneous cercarial emergence is observed from snails infected the previous autumn. Thereafter transmission of *S. haematobium* continues throughout summer while that of *S. mansoni* may be reduced in mid-summer, but declines for both species in April and/or May.

de Kock & van Eeden[18] concluded that *Biomphalaria pfeifferi* is adapted to warmer, stable habitats within the country. However, although Joubert et al.[17] demonstrated that

B*iomphalaria pfeifferi* could be found in waters that exceeded 30°C in endemic areas, there is wide acceptance that this species is more sensitive to both cold and warm temperatures than *Bulinus africanus*[19,20]. Thus *B. pfeifferi* is believed [20,21] to have an optimal temperature range of 22-27°C which is narrower than that for *B. africanus*.

Rainfall effects on transmission

Rainfall, as the main source of water for snail habitats, affects the survival of the intermediate hosts and consequently the transmission of schistosomiasis as well in the following ways: (1) it determines current speed which in turn affects the ability of snails to remain in contact with (and feed on) exposed substrata and (2) it determines whether or not habitats dry out and if they do, the length of time the snails are subjected to desiccation and/or aestivation. Rainfall also affects human water contact activities such as swimming, fetching water, washing clothes and fishing – people tend to reduce their contact with waterbodies when it is raining. For example children may not swim in rivers or lakes if it is raining or people may not go to rivers at all to collect water but will instead collect the rainwater itself and use that. Rainfall is also accepted as the most important factor ensuring that faeces containing *S. mansoni* ova are washed into water after being deposited on shady banks.

If there is adequate rainfall within a particular season, snail breeding sites may increase but human water contact with individual habitats may be reduced. High levels of human contact with the limited waterbodies available during the dry season may however result in intense, though focal, transmission.

METHODS

According to the literature it was found that temperature is the most significant variable, but others include rainfall, current velocity, geomorphology and habitat stability. Two models were developed to express the relationship between temperature and/or rainfall and schistosomiasis. The first model is descriptive and uses explicit temperature cut-offs. The second statistical model is based on empirical data from the Atlas of Bilharzia in Southern Africa[4] and makes use of both temperature and rainfall.

Climate data

Spatial rainfall and temperature data as described in part one of this report[23] were used. The climate dataset was based on extrapolations obtained from over sixty years of weather station data. The future climate change scenarios were obtained from the Genesis (GEN) and Climate System models (CSM) which were derived from global climate models (GCMs) through a process of downscaling. For the purposes of the models that were developed in this study, the present and future Hadley with sulphates (HS) and without sulphates (HN) models as well as the University of Natal[24] (Unatal) dataset were used as these contained minimum and maximum temperatures, and monthly rainfall. Lesotho and Swaziland were included in the formulation of the models as the data for these countries were available and also impact upon the epidemiology of the disease in South Africa by virtue of their close proximity to endemic areas within the country. The differences between the Hutchinson's[23] data and the Hadley models are outlined in the malaria section of this report. The differences between the present scenarios and the Hutchinson's[23] data are striking as only small areas within the country are within 2°C of the correct temperatures.

Descriptive Model

The basis for the first (descriptive) model comes from a paper published by Pitchford in 1981[25]. This author classified air temperature regimes according to their suitability for transmission of *S.mansoni* and *S.haematobium*. This work represents early initiatives in establishing the geography of schistosomiasis in relation to temperature and it allowed the definition of minimum and maximum temperature cut-offs for both *S.mansoni* and *S.haematobium*. Pitchford[25] based his results on outdoor field experiments that were expected to approximate the field temperature requirements of the two parasites. His logical statements based on temperature were translated into maps based on spatial climate data. Thus, a spatial model was produced which describes the occurrence of schistosomiasis as proposed by Pitchford[25]. The outcome of this model was tested and the applicability of Pitchford's findings was assessed against the known distribution of *S.mansoni* and *S.haematobium* from the Atlas of Bilharzia[4] (Figs. 2.2a, 2.2b).

Pitchford[25] used three indices of temperature viz., monthly mean of the daily maximum (Mdx), monthly mean of the daily minimum (Mdn) and the monthly range (R). Mask layers were created in Idrisi using Hutchinson's[23] climate data and Pitchford's[25] experimental findings on Mdn and Mdx. The climate images were overlaid for each month and those maximum and/or minimum temperatures that did not satisfy Pitchford's[25] cut-offs were excluded or *masked* out. The mask layers were created using Idrisi's Boolean logic to define areas that were suitable and unsuitable for survival of the parasites. The excluded temperature regimes are shown in table 2.1.

For *S.haematobium* (Table 2.2, Fig 2.3a) the optimal mask was created using the following temperature cut-offs: minimum temperature of 1^0C or less for one month or more, temperature range of 14^0C or more during December and January (mid-season of transmission) and a minimum temperature of 14.5^0C or more for four months or more. Green denotes the areas have suitable temperatures for transmission of *S.haematobium*. White denotes areas that have unsuitable temperatures.

The mask for *S.mansoni* (Table 2.2, Fig 2.3b) was obtained using the following temperature parameters: a minimum temperature of 3^0C or less for one month or more, temperature range of 14^0C or more during December and January (mid-season of transmission) and minimum temperature of 16^0C or more for two months or more.

Table 2.1: Excluded temperature cut-offs as cited by Pitchford[25]

Excluded temperature regimes	**Effect on parasite occurrence**
Minimum temperatures of 5^0C or less for one month or more	Too cold for *S.haematobium* and *S.mansoni.* Too inclusive in the western regions.
Minimum temperatures of 17^0c or more for seven months or more and maximum temperatures of 30^0C for three months or more	Allowed little or no transmission of *S.mansoni*. The minimum temperature covered virtually the whole country with the exception of the eastern border of KwaZulu-Natal. The maximum temperature excluded parts of the western regions of the country. It did not fit well in the Northern Province and eastern part of Mpumalanga.
Maximum temperatures of 27^0C for four months or more	Suitable for *S.haematobium.* Limited the Eastern Cape, but fit relatively well in the Northern Province, Mpumalanga and KwaZulu-Natal. Too inclusive west of the Free State.
Maximum temperatures of 27^0C for three months or more, combined with minimum temperatures of 17^0C for one month or more, maximum temperatures of 27^0C, minimum temperatures of 16^0C and 17^0c for nine months or more respectively	Suitable for *S.mansoni.* The 27^0C for 3 months mask was more inclusive than 27^0C for four months. The nine-month regimes were overly exclusive.

Table 2.2: Included temperature cut-offs as cited by Pitchford[25]

Included temperature regimes	Effect on parasite occurrence
Minimum temperatures of 1^0C or less for one month or more	Unsuitable for *S.haematobium* and *S.mansoni.*
Temperature range of 14.5^0C during the mid-season of transmission of transmission (December and January)	Unsuitable for both *S.haematobium* and *S.mansoni.*
Minimum temperatures of 14.5^0C or more for four months or more	Suitable for *S.haematobium*.
Minimum temperatures of 3^0C or less for one month or more	Unsuitable for *S.mansoni.*
Minimum temperatures of 16^0C or more for two months or more	Suitable for *S.mansoni.*

Empirical model

Disease data

This model was based on schistosomiasis data that were digitised from the Atlas of Bilharzia in Southern Africa [4] and displayed on maps. The database consists of point prevalence data for *S.mansoni* and *S.haematobium* and also occurrence of *Biomphalaria pfeifferi*, *Bulinus africanus* and *Bulinus globosus*. These authors made collections of urine, faecal, blood samples and rectal biopsies from a representative sample of children of school-going age in particular localities. The disease data were obtained by direct positive evidence of the parasites *S.haematobium* and/or *S.mansoni.* The data are available in categories (table 2.3). The Atlas does not provide useful information on the sample size, or the total population that was sampled.

Table 2.3: Prevalence ranges of disease

No.	Category (%)
1	0
2	1-5
3	6-10
4	11-25
5	26-50
6	51-70
7	71-100

Aims

The aims for developing this statistical model were (1) to determine if there was a statistical relationship between the prevalence ranges of disease and underlying climate data, (2) to use the model to predict the prevalence rates for areas where there are no data, (3) to transfer the model to climate scenarios based on changes as a result of global warming and (4) to estimate the number of children between 5 to 14 years who could be affected by schistosomiasis.

The disease data were overlaid on monthly minimum temperatures (Tmin), monthly maximum temperatures (Tmax) and monthly rainfall respectively, derived from Hutchinson's[23] climate data. Idrisi's EXTRACT function was used to compile a database consisting of each disease data point and it's associated Tmin, Tmax and rainfall.
The temperature data were then grouped in quarters as follows:

(1) hottest three months during which time relatively stable, high temperatures are experienced (December to February - Summer),
(2) when rapidly increasing temperatures are experienced (September to November - Spring),
(3) when rapidly falling temperatures are experienced (March to May - Autumn)
(4) the coldest three months when there are relatively stable, low temperatures (June to August - Winter)

The rainfall data were added to give total annual rainfall at each disease data point.

The resulting database for each parasite species was subjected to ordered logistic regression analysis as this was found to be the most appropriate given the nature of the disease data. Ordered logistic regression analysis makes few assumptions regarding the data. Unfortunately the categorised disease data obtained from the Atlas of Bilharzia[4] allows limited spatial and statistical analysis particularly since no useful information on the sample size of the surveys were available. The actual prevalence rates were also unavailable.

The probability of each pixel occurring in each disease category was calculated using the following equations:

1. Category 0%

$P_0 = \quad 1/1 + e^{s - 9.98656}$

2. Category 1-5%

$P_1 = 1/1 + e^{s - 10.80347} - 1/1 + e^{s - 9.98656}$

3. Category 6-10%

$P_2 = 1/1 + e^{s - 11.52915} - 1/1 + e^{s - 10.80347}$

4. Category 11-25%

$P_3 = 1/1 + e^{s - 12.42612} - 1/1 + e^{s - 11.52915}$

5. Category 26-50%

$P_4 = 1/1 + e^{s - 13.804767\ -} 1/1 + e^{s - 12.42612}$

6. Category 51-70%

$P_5 = 1/1 + e^{s - 14.24769} -1/1 ^{+} e^{s - 13.804767}$

7. Category 71-100%

$P_6 = 1/1 + e^{s - 14.24769}$

where S = 0.0033635 x annual rain - 1.27823 x tmax1 + 0.7063469 x tmax2 - 0.7712254 x tmax3 + 1.664342 tmax4 -2.958864 x tmin1 + 3.678978 tmin2 -1.461983 x tmin3 + 1.00727 x tmin4.

tmax1 = maximum temperatures for December, January and February,
tmax2 = maximum temperatures for March, April and May,
tmax3 = maximum temperatures for Jun, July and August,
tmax4 = maximum temperatures September, October and November, and similarly for minimum temperatures (tmin1 to tmin4).

RESULTS

Results of descriptive model

The disease data for each parasite were overlaid on each of the masks to determine the optimal combination of temperature cut-offs that explained the distribution of the disease. Those temperature regimes that were too exclusive of the positive prevalence data were eliminated from further analysis. The results are illustrated in figure 2.3.

Table 2.4: Validation of model for *S.haematobium* based on Pitchford's[25] data

Temperature mask	Survey Results			
	Disease present		**Disease absent**	
Number of disease data points in **suitable zone**	**a**	1530	b	231
Number of disease data points in **unsuitable zone**	**c**	213	d	256
Total	**a + c**	**1743**	**b+d**	**487**

The sensitivity for the *S.haematobium* temperature model was found to be 87.78% using (a/a+c x 100, table 2.4), with a standard error (S.E) of 0.0078 and the 95% confidence interval for the presence of schistosomiasis was 0.86 to 0.89. This indicates that 87.78% of the positive disease data points were correctly identified in the temperature suitable zone. The proportion of true negatives that were correctly identified by the temperature mask was found to be 52.57% using (d/b+d x 100), but the estimate was not very precise (S.E = 0.023, and 95% confidence interval of 0.48 to 0.57). Thus, the descriptive model for *S.haematobium* had a high sensitivity (87.78%) but a relatively low specificity (52.57%).

Table 2.5: Validation of model for *S.mansoni* based on Pitchford's[25] data

Temperature mask	Survey Results			
	Disease present		**Disease absent**	
Number of disease data points in **suitable zone**	**a**	499	a	400
Number of disease data points in **unsuitable zone**	**c**	37	d	322
Total	**a + c**	**536**	**b+d**	**722**

The model for *S.mansoni* had a low specificity as only 44.60% (d/b+d) of the true negative data points were correctly found in the unsuitable temperature zone, (S.E = 0.019 and 95% confidence interval of 0.41 to 0.48, table 2.5). The sensitivity was 93.10% (S.E 0.011, and 95% confidence interval of 0.91 to 0.95). Thus, the *S.mansoni* model was highly sensitive (93.10%) but unspecific (44.60%).

The total positive prevalence for *S.haematobium* lies within the temperature mask area, while a similar picture exists for the negative prevalence (Fig 2.4). The model provided a better fit for *S.haematobium* than for *S.mansoni.* The optimal temperature mask for *S.mansoni* was more inclusive along the East Coast down to the Western Cape (Fig 2.5). *S.mansoni* is more sensitive to fluctuations in temperature and this limits its distribution. It also appears that suitable temperature patterns extend beyond the Eastern Cape and into the Western Cape and yet no disease occurs in that area. Perhaps rainfall may be the limiting factor in this area.

Results of Ordered logistical regression analysis

For *S.haematobium,* it was found that all variables for temperature and rainfall contributed significantly to describing the occurrence of schistosomiasis. An increase in the annual rain, both maximum and minimum autumn temperatures and maximum and minimum spring temperatures predicted an increase in the prevalence of *S.haematobium.* However, an increase in the summer and winter minimum and maximum temperatures predicted a decrease in the probability of *S.haematobium* occurring. The inverse relationship between summer and winter temperatures and the occurrence of schistosomiasis is not generalisable as it has been found that the number of *S.haematobium* cercariae decreased with a sudden drop in the temperature and then increased again as the temperature rose.

On the other hand, for *S.mansoni* it was found that mean monthly rainfall, maximum summer temperatures, maximum spring temperatures, minimum summer temperatures, minimum autumn temperatures and minimum winter temperatures contributed significantly. An increase in maximum and minimum summer temperatures and minimum winter temperatures predicted a decrease in the probability of *S.mansoni* occurring. Increasing the mean monthly rainfall and minimum autumn temperatures and maximum spring temperatures predicted an increase in the probability of *S.mansoni* occurring.

By feeding back the model into the climate data the probability of a pixel in each image belonging to any one of the prevalence categories from 0 to 6 (table 2.3) was determined. More importantly, it allowed the prediction of the prevalence of schistosomiasis where no disease data are available, taking into account the temperature and rainfall parameters used in this study.

It is evident from the model for *S.haematobium* (Fig 2.6 a) that the Western Cape could expect disease prevalences of 11-25% and 26-50% as these two categories were predicted to occur with the highest probability in that area. In fact these categories of disease could be expected for most of the Northeastern and East Coast regions. However, the likelihood that the highest category (71 to 100%) of disease may occur along Messina down to KwaZulu-Natal is high.

For *S.mansoni*, greater proportions of disease (26-50% and 71 to 100%) are predicted. However, the overall image for this species predicts that a vast proportion of the country is unsusceptible to schistosomiasis given the temperature and rainfall patterns presiding at those localities (Fig 2.6b). The *S.mansoni* model predicted zero prevalence in Western Cape, Northern Cape, Free State, Northwest province, and a large area within Gauteng and the Eastern Cape, with a 25% probability.

The results for the statistical model are unexpected since only two or three out of seven categories were predicted. These categories happened to be the ones with the greatest ranges, which explains to some extent why they were predicted so frequently.

It is emphasized that the ordered logistic regression model did not take account of spatial correlation, and hence would have given an over optimistic estimate of significance. This does not invalidate the model for prediction purposes, but caution should always be exercised when involving predictions outside the range of the data that the model was derived from, and hence deserves mentioning.

It is important to note that these models utilise historical disease and climate data and as a result may differ from the present situation for schistosomiasis. The models are conservative in that they take into account only temperature and rainfall. Thus, the results of this study provide a partial explanation for the occurrence of schistosomiasis within the country. Future work could include factors such as the availability of suitable water bodies, other temperatures variates like frost and chill units, normalised differentiation vegetation index (NDVI) and geomorphology.

CONCLUSION

The two models described above attempt to explain the distribution of schistosomiasis in South Africa using temperature and rainfall only. The models developed for the purpose of this study represent a novel approach to studying the epidemiology of schistosomiasis in South Africa. There are only a few studies of note in Egypt[6], the Philippines and Caribbean[9] and China[26]. Such models may be applied over space (the whole country) and time (future scenarios).

The models for *S.mansoni* were not applied with the Hadley climate scenarios, as it was believed that they did not reflect the occurrence of schistosomiasis adequately. Further, schistosomiasis control has always focussed on *S.haematobium*, since the distribution of *S.mansoni* is wholly contained within that of *S.haematobium.* As mentioned earlier, *S.mansoni* is the more sensitive of the two parasites and has more subtle preferences, thus it is more difficult to predict. For these reasons the *S.mansoni* model was excluded from the following climate scenarios.

SECTION II: CLIMATE SCENARIOS

INTRODUCTION

General circulation models predict what will happen to the climate in the future and warn of possible dramatic climate events such as floods. In short, these models are simulations of atmospheric, oceanic and other systems. It is expected that the climate will indeed change unnaturally as a result of greenhouse gas emissions. According to a publication by the South African Department of Environmental Affairs and Tourism[27], in 1990 South Africa contributed over 1 % of the global emissions. The report cites that the mean air temperature over South Africa will increase, but there are differing opinions on the magnitude of the increase with the most likely estimate being around 2 ^{o}C. It is predicted that the average rainfall will also change. From the data that was made available for this study it is evident that different changes are predicted for different localities within the country.

In the context of climate change, one may consider what effects such change may have on schistosomiasis transmission in South Africa. Transmission may be favoured if the temperature remains optimal for survival of both the snail host and the parasite. At high temperatures it is the snail host that limits survival of the parasite. Thus, an increase in maximum temperatures may limit the growth and survival of the snail hosts and consequently limit parasite development. At low temperatures the parasites are more vulnerable to temperature change, and so once temperatures reach a minimum of about 5 ^{o}C, parasite development will cease and the disease cycle will be interrupted.

Assuming some parts of the country become drier, suitable water bodies may dry up, leading to changes within the snail host community. If, on the other hand, there is an increase in the average rain at a local level, transmission sites may flood, leading to a decline in the number of suitable snail hosts within a community.

Human activities such as irrigation, and the building of canals and dams have resulted in their habitation by species of snail intermediate hosts and have shifted the foci of transmission. This serves to illustrate that the snail hosts may occupy different niches if conditions are suitable. A similar anomaly may exist as far as climate change is concerned where snail hosts may change their niches as the environment becomes adverse for their survival.

The effect of climate changes on the two models that were developed to account for the occurrence of schistosomiasis is reported here.

METHODS

Climate scenarios

The models derived from Hutchinson's[23] climate data were re-run on the Unatal[24] data set for comparative purposes, as well on the present and future HN and HS models respectively. The model that was developed using Pitchford's[25] results provided a platform on which to compare the climate data. The more detailed statistical model produced disease prevalence maps.

Estimates of population

An African population model with predictions for 1995 was used to determine estimates of the population occurring within temperature suitable areas[28]. The advantages of using this population model were outlined in the malaria section of this report. The peak in the standard age/prevalence curve for schistosomiasis occurs around the 5 to 9, 10 to 12 and 13 to 14 age groups. Thus, the models that included population estimates for the 5 to 9 and 10 to 14 age groups [28] were used. This was done by extracting the total population for each pixel deemed suitable by the model developed for *S.haematobium*. The model for *S.mansoni* was excluded in estimating the population as it did not compare well with the known occurrence of disease, and for other reasons that were mentioned earlier.

RESULTS

Results of Descriptive model

Comparison of climate data

The Unatal[24] climate data closely approximated the model developed using Hutchinson's[23] data, with the exception of the exclusion of the Northern Cape. The results revealed that the Hadley scenarios did not compare well with the Unatal[24] and Hutchinson's[23] data. Even the present scenarios overestimate the areas that the model delimits as suitable. The future scenarios are relatively more inclusive of areas in the western parts of the country.

The present HN scenario for *S.haematobium* (Fig 2.7) revealed that the borders of the whole country, with some exceptions in KwaZulu-Natal and the Eastern Cape, would be susceptible to schistosomiasis if suitable conditions for the parasites and snail hosts persist. The same increasingly inclusive trend is evident for the future HN scenarios as one moves west along the country (Fig2.8).

For the present HS scenarios (Fig 2.9) it is evident that the regions bordering the outskirts of the country are suitable for transmission of *S.haematobium*. The same trend is observed for the future HS scenario with the model encroaching inland (Fig 2.10). A comparison of the HN and HS results reveals that the former model is more generous in exhibiting suitable schistosomiasis prone areas further inland.

Population estimates

The estimates for the population at risk using the Hadley climate models are tabulated in table 2.6. The future Hadley climate models predict an increase in the population occurring within the confines of the model compared to the results obtained using the Hutchinson[23]data. The present scenarios for the Hadley models closely approximates the estimates using Hutchinson's[23] data. The population almost doubles in the future scenarios for both Hadley models compared with Hutchinson's[23] data.

Table 2.6: Estimates of children between 5 and 14 years at risk in the *S.haematobium*-suitable zone based on descriptive model

	Hutchinson[23]	**HN**	**HS**
Present	4,102,334	4,649,723	4,373,175
Future		9,598,659	8,141,858

Results of Statistical Model

Comparison of climate data

The HN present scenario (Fig 2.11) predicts the maximum likelihood of prevalences of 11-25%, 26-50% and 71-10 % for *S.haematobium.* Interestingly, predictions in the western provinces of the country were zero for this species. The future HN scenarios for *S.haematobium* show that a larger area is prone to prevalences of 26-50% and a proportionally smaller area to 11-25% prevalence (Fig 2.12). However, it is projected that 11-25% and 26-50% prevalences may occur in the Eastern Cape area which the present scenarios exclude.

The HS present scenarios are similar to the HN scenarios in that the same categories for disease are predicted, but the difference exists in the ``geography" of the predictions as they extend inland towards the Free State, Northern Cape and Lesotho (Fig 2.13). This trend continues in the future HS scenarios for *S.haematobium* only (Fig 2.14). Prediction of 11-25% and 26-50% are scattered in the Northern Cape and Western Cape that were excluded on the present scenarios for HN.

The statistical model for *S.mansoni* was applied to the present scenarios using the Hadley model and the result did not resemble the actual distribution at all. Therefore, it is questionable whether this exercise was at all meaningful for this species.

Population estimates

Table 2.7: Estimates of children between 5 and 14 years at risk in the *S.haematobium*-suitable zone based on statistical model

Category (%)	**Hutchinson[23]**	**HS Present**	**HS Future**	**HN Present**	**HN Future**
0	7,193,072	3,707,947	4,104,171	2,246,853	1,472,339
11-25	530,284	395,568	397,482	425,712	347,372
26-50	1,769,105	1,976,972	2,894,356	2,454,639	2,168,552
71-100	1,043,337	4,455,312	3,139,790	5,408,595	6,547,537

The present Hadley scenarios predict that more children occur in the categories above zero, compared with the Hutchinson[23] data (table 2.7). The estimates in the zero prevalence category are larger using the Hutchinson[23] data, but the overall picture is offset by increases in the predictions for the other higher categories (26-50%, 71-100%) using the Hadley models. The future Hadley without sulphates scenario indicates that more children occur in the 71-100% category compared with the other climate models. This increase is marked compared with the Hutchinson[23] data.

IMPLICATIONS

The results of the descriptive model using Pitchford's[25] hypothesis suggest that there will be a broadening of the area that is currently suitable for the transmission of *S.haematobium* in the future. Given this, it is not surprising that the total population at risk of *S. haematobium* infection according to the future predictions is greater than that predicted for the present climate scenarios. The potential for urinary schistosomiasis will exist in areas that are currently free of the disease if the temperature parameters described in this study are considered. This is especially evident in the western regions of the country. However, it becomes necessary here to assess the impact of other variables affecting the epidemiology of the disease in order to explain the possible occurrence or recurrence of the disease where there is currently little or no transmission.

The statistical model considers rainfall and seasonal temperature differences and allows the consideration of the implications of changes in the levels of schistosomiasis transmission in greater detail. This discussion illustrates the need for careful review of the patterns of schistosomiasis presenting at different localities within the country. In addition to an increasing number of people living in schistosomiasis-prone areas, there is also a shift from lower to higher prevalences, which means an increment in the percentage of people infected.

RECOMMENDATIONS

1. The use of spatial analysis to study schistosomiasis in South Africa is new. It is recommended that the models that were developed in this study be refined. Periodic reviews would need to be undertaken to accommodate any changes in the general circulation models in the future. Further, there is a need to evaluate and look more closely at the effects of other environmental parameters that affect the transmission of schistosomiasis.

2. The global circulation models that were used in this study were downscaled to a local level, and major anomalies may exist at a focal level where schistosomiasis occurs. It is suggested that it may be more realistic to use climate models that originated at a more local level or sub-global level. Taking point 3 below into consideration, it is suggested that such disease models be reviewed once the global circulation models become more refined.

3. The disease data that were used in this study were obtained from formerly disadvantaged communities where both sanitation and piped water were inadequate. Pitchford[29,30] showed that there was a reduction in the transmission of schistosomiasis after the introduction of piped water and other "environmental" control measures. During the course of the past four years the government has endeavoured to introduce piped water and better sanitation to these communities. Hence, schistosomiasis transmission is expected to decrease in these areas. It would be advantageous to introduce the likely effect of piped water and improved sanitation into the models that were described here. However, this may require the collection of updated, current disease data. The results of the 1996 census include data on the availability of a main water supply and sanitation to individuals and households. This information may be applied to modelling schistosomiasis. The descriptive model described here estimates that approximately 4,1 million children between 5 and 14 years live in those areas where suitable environmental conditions for schistosomiasis transmission exist. The future Hadley scenarios predict a doubling of this figure. The estimates of the children at risk may change given subsequent improvements in the infra-structure in these schistosomiasis-prone areas.

4. Climate-based spatial disease models are valuable to the health sector as they can predict potential changes in the distribution of the disease. Hence, such models can warn of potential risks under certain climate conditions, and serve to alert health-authorities of those areas where certain environmental conditions affect the probability of suitable conditions for transmission of schistosomiasis.

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