Integrated monitoring and evaluation and environmental risk factors for urinary schistosomiasis and active trachoma in Burkina Faso before preventative chemotherapy using sentinel sites: implications for monitoring and evaluation of integrated control programmes

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Abstract

Background: Over 1 billion of the world's poorest inhabitants are afflicted by neglected tropical diseases (NTDs). Since 2006, there have been initiatives to implement integrated control programmes aimed at tackling these debilitating NTDs, mainly using preventative chemotherapy. Monitoring and evaluation (M&E) of these integrated programs presents particular challenges in comparison to single disease vertical programmes. We used baseline data from the National NTD programme in Burkina Faso in order to assess the feasibility of an integrated survey design, in school-aged children, as well as to elucidating the contribution of environmental and weather variables to the risk of infection with either Schistosoma haematobium and ocular Chlamydia trachomatis, or both, in school-aged children by distinguishing between single and mixed infections of these two NTDs. Methods: S. haematobium infection was diagnosed by detecting eggs in urine. A trachoma case was defined by the presence of Trachomatous inflammation-Follicular (TF) and/or Trachomatous inflammation-Intense (TI) in either eye. Baseline infection data collected from 3,324 children aged 7–11 years in 21 sentinel sites across 11 regions of Burkina Faso were analyzed using simple and multivariable hierarchical binomial and multinomial univariate and multivariate logistic regression models fitted by Markov Chain Monte Carlo estimation methods. The probabilities of the risk of belonging to each infection category were estimated as a function of age, gender (individual level), and weather and environmental variables (at sentinel site level, interpolated from national meteorological stations). S. haematobium infection was diagnosed by detecting eggs through microscopic examination of urine after filtration. A trachoma case was defined by the presence of Trachomatous inflammation-Follicular (TF) and/or Trachomatous inflammation-Intense (TI) in either eye. Results: We Through sentinel-site surveillance defined at the school level, this study showed that urinary schistosomiasis and trachoma sentinel-site surveys at the school level, surveys can be implemented simultaneously. Overall prevalence levels from the sentinel sites assessed were 11.79% (95% CI: 10.70–12.89) for S. haematobium infections; 13.30% (95% CI: 12.14–14.45) for trachoma infections, and 0.84% (95% CI: 0.53–1.15) for co-infections. The only significant predictor of S. haematobium infection was altitude. Multivariable analysis indicated only ‘altitude’ as an important predictor of S. haematobium infection to be altitude, precipitation, minimum temperature and air pressure. There were significant negative associations between the prevalence of active trachoma signs and minimum temperature, and air pressure. Conditional upon these predictors, these data are consistent with the two pathogens being independent. Conclusions: According to WHO thresholds urinary schistosomiasis and
trachoma—likely do constitute public health problems in Burkina Faso according to WHO recommended thresholds—constitute serious public health problems in Burkina Faso and their control is strongly recommended. Sentinel site (at school level) surveys for these two NTDs can be implemented simultaneously. However, to support MDA treatment decisions in Burkina Faso, the protocol used in this study would only be applicable to hypoendemic trachoma areas. We also propose that the protocol applied in this study to be used only in hypo-endemic trachoma areas of Burkina Faso if MDA treatment decisions have to be made based on results arising from similar study designs—More research is needed to confirm if these findings can be generalized to West Africa and beyond.
Background

Schistosomiasis and trachoma are among the most prevalent of the so-called "Neglected Tropical Diseases (NTDs)", an umbrella term that encompasses a group of parasitic, bacterial, and viral infections collectively imposing a similar disease burden to that of malaria and HIV [1, 2]. NTDs are widespread in sub-Saharan Africa [3], where they affect more than 500 million people [1]. These NTDs are both the result of, and a major contributor to, the poverty of many rural and some disadvantaged urban populations in tropical regions of the world [4]. However, the fact that some NTDs are treatable with affordable (or donated), safe and effective drugs has encouraged the implementation of ‘preventative’ chemotherapy control programs. Although these drugs do not prevent such infections, they help prevent or minimize the burden of disease that would ensue if left untreated.

According to the World Health Organization (WHO), more than 200--206 million people are infected with parasites of the genus *Schistosoma* (of whom 120 million have symptoms and around 20 million show severe disease sequelae) [5]. Schistosomiasis is an indirectly (snail)-transmitted disease whose distribution is particularly sensitive to environmental changes, including changes of human origin. Transmission of the parasite is highly focal, with heterogeneity reflecting numerous human and snail host as well as environmental ecological factors [6]. Identifying the broad scale patterns of schistosomiasis is crucial because ecologically and climatic changes plus human migration may have led to changes in the prevalence and distribution of the disease in different parts of endemic countries [7]. The current mainstay for schistosomiasis control is to mitigate against the burden of the disease by controlling morbidity through chemotherapy with an oral drug called praziquantel (PZQ). It is recommended that mass drug administration (MDA) with PZQ is recommended to be delivered to total at-risk populations defined where a survey shows prevalence of over 50% in school-aged children and to children aged 6–16 years where survey prevalence is between 10% and 50% in this group (although pre-school-aged children can also be infected), and MDA to children aged 6–16 years where survey prevalence is between 10% and 50% [8]. (Although the indicator group for schistosomiasis comprises school-aged children, pre-school-aged children can also be infected, the implications of which are considered in the Discussion below). Because schistosomiasis exhibits strong spatial heterogeneity at local levels, there is a need to identify and locate high-risk communities or schools that require MDA [7] so that cost-effective management of limited resource funds can be achieved.

Trachoma is the leading infectious cause of blindness worldwide [9]. Around 80 million people have active trachoma, an inflammatory early stage of the disease caused by recent infection with the ocular bacteria *Chlamydia trachomatis*, with the young children bearing the heaviest burden [10]. Repeat infection leads to scarring of the eyelid, which causes the eyelids to turn inwards and subsequently cause the eyelashes to
scratch the cornea, ultimately leading to blindness (WHO estimates that 6 million people globally are blind from trachoma). The WHO endorses a four-pronged approach to eliminate blinding trachoma by the year 2020 known as SAFE: Surgery for trichiasis, Antibiotic against infection, Facial cleanliness, and Environmental sanitation [11]. Currently, Pfizer Inc. donates millions of doses of the antibiotic azithromycin (Zithromax, ZTX) for trachoma control. MDA with ZTX is at present recommended for entire endemic communities to be conducted annually for three years, 

*if wherever* the prevalence of active trachoma in children of ages 1–9 years old at the district level is above 10% [11]. Trachoma is associated with individual and environmental risk factors as well as climatic conditions which may be important determinants of trachoma transmission (which in some cases can occur mechanically through flies) [12-15]. These may vary between settings and hence the need for studies aimed to identify risk factors relevant to specific environments. Indeed, understanding risk factors is essential in designing appropriate interventions for the ‘F’ and ‘E’ components of the SAFE strategy (e.g. water availability for Facial cleanliness and Environmental improvements) [16].

Based on the argument of co-endemicity of NTDs within countries [17], global advocacy for the amelioration or elimination of the disease burden imposed by these conditions has recently increased, with a renewed interest in the scaling-up of integrated NTD interventions in sub-Saharan Africa, mainly using preventative chemotherapy distributed through MDA [18]. More particularly, MDA is a relatively efficacious tool to control the infection and morbidity caused by of NTDs: the helminthiases and trachoma and such an approach offers opportunities for integration. There is also an interest in trying to deliver some of treatments through in the modality of school-based programmes, and again schistosomiasis and trachoma lend themselves to this approach as the burden of infection is mostly concentrated among the young.

For instance, in September 2006, the United States Agency for International Development (USAID) launched the NTD Control Program, the first global effort to support country programs to integrate and scale-up delivery of preventative chemotherapy for five targeted NTDs: schistosomiasis, trachoma, lymphatic filariasis (LF), onchocerciasis and soil-transmitted helminthiases (STHs). Burkina Faso, a landlocked country in West Africa, is endemic for all these five NTDs [19] and thus it was selected as one of the first five country programs for implementation of integrated NTD control. However, despite the current generous support of USAID for the control of these NTDs, if compared to the scale of the actual problem and in monetary terms to amounts spent on malaria, tuberculosis and HIV/AIDS, resources targeted at NTD parasite control are limited. Furthermore, environmental factors that influence disease transmission are unlikely to be uniform over large geographical areas [20]. Consequently, when designing integrated control programs, it is essential
to know the distribution and abundance of the target diseases, to enable optimizing both the targeting of suitable interventions and the use of available resources [21]. In addition, currently, however, there is little evidence on the feasibility of integrated survey designs [22].

An important question in integrated NTD control is related to at what spatial scale should the programs be integrated. This will depend on the geographical distribution and prevalence of both single infections and of co-infections. This will depend on the geographical distribution and prevalence of single infections and of co-infections. Therefore, the aims of the current study were to: a) identify initially whether combined methodologies survey designs based on sentinel sites are useful Monitoring and Evaluation (M&E) tools for the assessment of integrated schistosomiasis and active trachoma control programmes; and b) Another aim of this study was to understand the infection patterns due to of these two NTDs in these selected baseline sentinel sites within Burkina Faso, as well as their associations of the infection patterns of these two NTDs with demographic and environmental and demographic variables associated with the infection patterns of urinary schistosomiasis and active trachoma in Burkina Faso. Such results obtained should can inform the construction of reliable disease maps [23] and mathematical modeling efforts of these two NTDs -as well as the ‘E’ component for the SAFE strategy in the case of trachoma.

To this end, we use baseline data from the National NTD Burkinabé control program, so that questions concerning the integration of mapping, planning of drug delivery for schistosomiasis and trachoma, and Monitoring & Evaluation (M&E) of integrated control programs can be addressed.

Methods

Environmental conditions, control programme, sentinel sites and sampling

Burkina Faso has a tropical climate with two very distinct seasons: the rainy season with between 600 and 900 mm of rainfall, and the dry season during which the Harmattan, a hot dry wind from the Sahara, blows. The rainy season lasts approximately four months, May/June to September, and is shorter in the northern part of the country. Four large agro-climatic regions can be defined, characterized by a strong south–north decreasing gradient of average annual rainfall. The Sahel in the north receives less than 500 mm rainfall a year and exhibits high temperatures [24].
Although initially control programmes for schistosomiasis, trachoma, LF, onchocerciasis and the STHs operated autonomously, the Burkina Faso NTD Control Program has recently taken a phased approach to integrated MDA. For instance, Burkina Faso was under the umbrella of the Onchocerciasis Control Programme in West Africa until 2002 and community-directed treatment with ivermectin (CDTI) is the mainstay of control in areas where the infection was not eliminated. For the case of schistosomiasis and trachoma, in 2007 drugs were distributed for these two infections and STHs as an integrated package in three target districts (Tenkodogo, Koupela and Bogandé) and in 2008 these efforts were scaled up to include the LF and onchocerciasis programmes as a platform for becoming a fully integrated MDA campaign on a national level. Thus it should be noted that at the time these surveys were planned, integrated assessments of schistosomiasis and trachoma as well as their co-infections using sentinel sites were made the main focus of these efforts.

In the current study we used baseline data (collected during November 2007 and February 2008 from 21 sentinel sites across 11 regions of the country) from longitudinal baseline surveys which were performed during November 2007 and February 2008 in 21 sentinel sites across 11 regions of the country and which aimed also to contribute to the assessment of the impacts on schistosomiasis and trachoma disease burden of the integrated NTD control programme in Burkina after MDA (i.e. once the follow-up data would be collected a year later) underpin evaluation of subtle morbidity changes during the control activities of the integrated programme. We will present the analyses of the follow-up studies elsewhere.

Sentinel sites were schools which were chosen based on a list which of villages provided by the onchocerciasis program encompassed villages to be endemic for onchocerciasis under the surveillance of the African Programme for Onchocerciasis Control (APOC). Among these villages, those which were also endemic for with the greatest prevalence of LF and schistosomiasis (based on national historical data at the time) were selected randomly. Then, once at the sentinel site, the method for selecting school children in each of the ages of the 7-11 years old, was random sampling. In addition, these surveys aimed to provide prevalence estimates of schistosomiasis and active trachoma at the sentinel sites in an integrated fashion and used the opportunity to survey for both diseases on the same children at the same time. An M&E meeting between the National Coordinators and Schistosomiasis Control Initiative (SCI) staff preceded these surveys in February 2007 in Ouagadougou in order to decide on the cohort design and sampling.

A fixed cohort was recruited at each sentinel site to allow comparisons to be made across sentinel sites and regions. Required sample sizes were calculated using the EpiSchisto software tool (http://www.schoolsandhealth.org/epidynamics.htm) based on an expected reduction in mean infection
intensity of 40% (for *S. haematobium*) following chemotherapy to achieve 80% statistical power and a significance level of 5%. The value of 40% was chosen as a conservative estimate of the expected reduction over a two-year period (two annual PZQ treatments—see section S1 in the Supplementary Information document for more further information around the technicalities in details about the concerning sample size calculations). An overall dropout rate of 55%, as observed in the SCI Burkinabé longitudinal monitoring data from the National Vertical Schistosomiasis Control Program (NVSCP) during 3 annual surveys over the course of the monitoring period, was incorporated (i.e., 763 children from 15 schools were successfully followed up during 2004-2006 with data mainly on *S. haematobium* infection). EpiSchisto was also used to get predictions within the integration era (i.e., “post-treatment environment”) where as a starting point of the integrated programme, we used the most recent available SCI Burkinabé data at the time (from the 3rd annual survey, i.e., 2006 from the NVSCP). The relationship between prevalence and intensity of *S. haematobium* infection arising from a negative binomial distribution of parasites among hosts was applied in order to estimate using maximum likelihood the inverse overdispersion (\(k\)) parameter that characterizes this distribution and which is necessary to parameterize EpiSchisto for these particular settings. Figures 1A and 1B illustrate these calculations, respectively, for pre-treatment baseline (2004) and 2nd year post-treatment (2006) from the SCI Burkinabé longitudinal monitoring data for the NVSCP. A cluster random sampling design was not considered appropriate here (despite the fact that this is the most reliable survey method for trachoma prevalence estimation [26]) as one of the purposes of this study was to utilize an integrated method.

Detailed statistical aspects have been provided in previous studies [19, 25].

**Figure 1 here**

A cluster random sampling design was not considered appropriate here (despite the fact that this is the most reliable survey method for trachoma prevalence estimation [26]) as one of the purposes of this study was to utilize a novel integrated method, because of uncertainty of expected prevalence estimates, and lack of recent trachoma data in the country at the time these surveys were designed.

All children enrolled in the study were interviewed by appropriately trained personnel at the Ministry of Health, Burkina Faso, after once parental consent was acquired. Administrative, customary, and religious authorities, among others, were all involved in these surveys in order to facilitate the sequence of the latter in the implementation in the field. Ethical clearance was obtained from the Burkina Faso Ministry of Health and Imperial College London.

**Indicators for urinary schistosomiasis**
Experienced technicians from the National Vertical Schistosomiasis Control Programme (NVSCP) collected from the children one urine specimen to determine the prevalence and intensity of *S. haematobium* infection by the filtration method. The intensity of *S. haematobium* infection was expressed as the number of eggs per 10 mL of urine.

**Indicators for active trachoma**

Clinical signs of active trachoma, namely, trachomatous inflammation-follicular (TF) and trachomatous inflammation-intense (TI), were graded for each eye separately by two an experienced ophthalmologists from the National Trachoma Programme, a local ophthalmologist from each sentinel site and an ophthalmic nurse according to the WHO simplified grading system [27]. Standardization of the grading by the examiners and thus reliability tests were not performed during the baseline surveys but they did happen before-at the follow-up studies. In this study, active trachoma was taken to indicate trachoma signs, and was defined as the presence of either of these signs (TF, TI) in either eye. All children with evidence of active trachoma were treated according to national Burkinabé guidelines and advice was then given on face washing. The nurse cleaned his/her hands with alcohol and the examiner changed gloves after examining the eyes of each child.

**Interpolation of environmental and weather data, exploratory and statistical analysis**

The National Climatic Data Center (NCDC) is the world's largest active archive of weather data. Environmental and weather information from all nine meteorological stations in Burkina Faso were obtained on a daily basis for 2000 to 2008 for the following variables: altitude (in meters above sea level - MSL), precipitation (in millimeters - mm), minimum, maximum, minimum-and average temperature (in degrees Celsius°C) as well as air pressure (in millibars- mbars) from the National Climatic Data Center (NCDC) NCDC website (http://www7.ncdc.noaa.gov/CDO/cdoselect.cmd?datasetabbv=GSOD&countryabbv=&georegionabbv=). Such variables were selected based on their potential possible biological relevance of to the intermediate hosts of schistosomiasis and the mechanical (fly) vectors of trachoma. The average values over these years for each of these environmental and weather variables at each meteorological weather station were then calculated. Similar data were not available for the twenty one sentinel sites of this study individuallt but their geographical positions was were recorded using Garmin® GPS devices.
Inverse distance weighted (IDW) interpolation was employed to estimate such environmental and weather variables for the sentinel sites, by using a weighted sum of the values of the nine known points for each environmental and weather variable. More precisely, IDW assigned weights to sample points (i.e. sentinel sites), which are inversely proportional to the inverse distance squared distance—that the particular school sentinel site is separated from the point of estimation (i.e. the meteorological weather station). Inverse squared distance was used, meaning that the weight assigned to a particular point diminished by the square of the distance. The equation for the inverse squared distance weighted interpolation used, is as follows:

\[ \hat{u} = \frac{\sum_{i=1}^{9} \frac{1}{d_i^2} u_i}{\sum_{i=1}^{9} \frac{1}{d_i^2}} \]

where \(d_i\) is the distance between the sentinel school site and weather station \(i\). The \(u_i\) terms are the average values of environmental and weather variables as calculated for each meteorological weather station \(i\). This approach makes use of the spatial autocorrelation in the environmental and weather data because only points relatively close to the point of estimation will affect the prediction.

Exploratory analyses were undertaken to explore the structure of the datasets: Firstly, Pearson correlations were calculated for the average values of the environmental and weather variables at each meteorological weather station. Secondly, Pearson correlations between the school-level prevalences of single and dual infections with the interpolated environmental and weather variables were calculated (see section S2 in the Supplementary Information document). Thirdly, scatter plots were produced to examine relationships between school-level prevalences of single and dual infections with the interpolated environmental and weather variables (see section S3 in the Supplementary Information document). Finally, summary statistics were generated for the environmental and weather variables (Table 2).

For the modeling of the relationship between the \(S.\ haematobium\) prevalence and the interpolated environmental and weather variables, binomial logistic regression models were used. Similar models were applied in order to examine the relationship between active trachoma prevalence and the interpolated environmental and weather variables. In these single pathogen binomial logistic regression models no distinction between single and dual infections was considered. Subsequently, in order to differentiate between single and dual infections, multinomial logistic regression models were attempted to be fitted in order to allow for the modeling of the relationship between a polytomous response variable with the 4 categories of type of infection (i.e. 1st category: not infected; 2nd category: only \(S.\ haematobium\); 3rd category: only active trachoma; and 4th category: either infection) and the interpolated environmental and weather variables. In
other words, we first built binomial models for the single pathogens and only when we understood them separately we tried to assess them jointly. Potential confounding effects (age and gender) were adjusted for in all logistic regression models. A problem in developing models using environmental and weather variables is that many such variables are highly inter-correlated making it difficult to separate the effects of the independent variables statistically [28]. To reduce the dimensionality of these collinear variables, firstly we selected those variables likely to have greater biological significance on infection transmission [29]. To take into account the nested structure of our data we fitted hierarchical models with Markov Chain Monte Carlo (MCMC) estimation methods, including children and schools as random effects drawn from some common prior distribution with unknown parameters. Children within each school as well as the results from different schools were treated as ‘exchangeable’ in the sense that their joint probability densities should be invariant to permutations of the indexes each pair of children within a school were equally correlated [30]. We have used the MLwiN v 2.21 default settings which set specify diffuse prior distributions (fixed parameters $p(\beta) \propto 1$ and scalar variances $p\left(\frac{1}{\sigma^2}\right) \sim \Gamma(0.001,0.001)$) and which approximate maximum likelihood estimates. Secondly, the remaining additional variables were added included in to the models following through a backward stepwise elimination method procedure, comparing the deviance information criterion (DIC) at each stage [31], the chi-squared statistic for the likelihood ratio test of nested models to the theoretical $\chi^2$-distribution [31]. We tested as considered as potential explanatory variables the interpolated values of altitude, precipitation, maximum minimum temperature, average temperature, and air pressure at all sentinel sites and we calculated 95% credible intervals (i.e. confidence intervals derived from 2.5% and 97.5% quantiles of the chains of parameter estimates), considered the significance level to be 0.05. PROC LOGISTIC in SAS software was used (version 9.1; SAS Institute Inc., Cary, NC, USA) for the fit of binomial and multinomial logistic regression models. Odds ratios from all these models were reported relating to differences comparable to rounded standard deviations of the interpolated environmental and weather variables (see Table 2) to make the results more readily interpretable.

A likelihood ratio test was used to evaluate whether the multinomial logistic regression model provided a fit to the data that was sufficiently better than did the two single pathogen binomial logistic regression models to justify the additional parameters involved.

Finally, we used the map-making facility available at www.spatalepidemiology.net, which utilizes Google Maps [32], in order to display the NCDC weather stations and sentinel sites visited during the M&E surveys in Burkina Faso. We also used this tool to display the observed S. haematobium and active trachoma prevalence and treatment strategy, as well as the need for intervention with the SAFE strategy, based on WHO-recommended implementation thresholds [33]. It should be noted though, however, that although for trachoma these thresholds were established based on prevalence of clinical signs of disease in children 1-9
years of age, the observation that the prevalence in school-aged children is greater than 10% probably means that this prevalence is even greater in the younger age groups, warranting treatment, and regimens for preventative chemotherapy of these two diseases [33].

Results

A total of 3,324 children aged 7 to 11 years were surveyed from the 21 sentinel sites (Figure 12). Overall observed prevalence values by sentinel site of single and dual S. haematobium and active trachoma infections are illustrated in Table 1. Only 0.84% (28) of the surveyed children was found to be co-infected with urinary schistosomiasis and trachoma.

Figure 23 illustrates MDA recommendations for S. haematobium and active trachoma infections for the 21 sentinel sites from observed data on the prevalence of the two diseases. Our data suggest that in only two sentinel sites would both PZQ and ZTX be required. In addition, Figure 23 shows that to the north (i.e. in the driest areas) of Burkina Faso the prevalence of S. haematobium infection was between 10% and 49% (i.e. medium) but that of trachoma was less than 10% (i.e. low).

Table 2 contains summary statistics for the interpolated and meteorological weather-station-based values of the environmental and weather variables. For instance, for altitude, minimum (min) and maximum (max) values were 259.0 and 440.8 aboveMSL respectively; for precipitation, min and max values were 1.53 and 2.98 mm; for max temperature, min and max values were 34.0 and 37.3 °C; for min temperature, min and max values were 21.8 and 23.3 °C; for average temperature, min and max values were 27.5 and 29.5 °C and finally for air pressure, min and max values were 961.0 and 978.5 mbars. The distributions of the interpolated values appear to be similar to the distributions of the original weather-station-based data.

Table 3 contains the odds ratios (ORs) of the significant environmental and weather variables for the risk of S. haematobium infection — without distinguishing between single and mixed infections — as being estimated from the univariate and multivariate logistic regression models. On univariate analysis the risk of S. haematobium infection was significantly increased in higher temperatures (OR for maximum temperature = 2.287, p<0.001; OR for minimum temperature = 2.774, p<0.001; OR for average temperature = 2.107, p<0.001); higher air pressure (OR = 1.859, p<0.001); lower altitude (OR = 0.383, p<0.001); and lower
precipitation (OR = 0.440, p<0.001). Such associations were also noticeable through scatter plots (see section S2 in the Supplementary Information document). Multivariate analysis was then undertaken (without including maximum and average temperatures due to collinearity with minimum temperature). On multivariate analysis, negative significant associations between the risk of S. haematobium infection and precipitation, minimum temperature as well as air pressure, were indicated. Furthermore, this same multivariate logistic regression model indicated that 50 meters above sea level (MSL) increase in altitude would decrease the odds of S. haematobium infection by 95.2%.

Table 3 contains the odds ratios (ORs) and 95% credible intervals (95% CrI) of the significant environmental variables for the risk of S. haematobium infection as being estimated from the simple and multivariable hierarchical logistic regression models. According to simple hierarchical logistic regression modelling, the risk of S. haematobium infection was significantly increased for higher temperatures (minimum, maximum and average); higher air pressure; lower altitude; and lower precipitation. Such associations were also noticeable in the scatter plots (see section S3 of the Supplementary Information document). A multivariable hierarchical logistic regression model was then fitted (without including maximum and average temperatures due to collinearity with minimum temperature). The risk of S. haematobium infection was indicated to be only negatively and significantly associated with altitude; a 50 MSL increase in altitude would decrease the odds of S. haematobium infection by 99.8%.

Table 4 contains the ORs of the significant environmental and weather variables for the risk of active trachoma infection—without distinguishing between single and mixed infections—as being estimated from the univariate and multivariate logistic regression models. Univariate logistic regression models indicated (perhaps counter-intuitively) increased risk of active trachoma infection at higher altitudes (OR = 1.645, p<0.001) and greater precipitation (OR = 1.744, p<0.001) and decreased risk of active trachoma infection at higher temperatures and air pressure (OR for max temperature = 0.479, p<0.001; OR for minimum temperature = 0.701, p<0.001; OR for average temperature = 0.744, p<0.001; OR for air pressure = 0.607, p<0.001). On inspection of the scatter plots of active trachoma prevalence by the environmental variables, such associations were noticeable (see section S2 in the Supplementary Information document). Similarly as before, maximum and average temperatures were excluded from the multivariate logistic regression model building due to collinearity with minimum temperature. On multivariate analysis the risk of active trachoma infection remained decreased at higher minimum temperature (OR = 0.718, p<0.001) and higher air pressure (OR = 0.060, p<0.001). Altitude and precipitation were finally removed from the final multivariate logistic regression model as they did not meet the 0.05 significance level through the backward elimination method.
Table 4 contains the ORs and 95% CrI of the significant environmental variables for the risk of trachoma signs as being estimated from the simple and multivariable hierarchical logistic regression models. Simple hierarchical logistic regression models indicated (perhaps counter-intuitively) an increased risk of trachoma signs at higher altitudes and greater precipitation, and a decreased risk of trachoma signs at higher temperatures (minimum, maximum, and average), and air pressure. On inspection of the scatter plots of active trachoma prevalence by the environmental variables, such associations were noticeable (see section S3 in the Supplementary Information document). Similarly as before, maximum and average temperatures were excluded from the multivariable hierarchical logistic regression model building due to collinearity with minimum temperature. On multivariable analysis, the risk of trachoma signs remained decreased at higher minimum temperature and higher air pressure. Altitude and precipitation were finally removed from the final multivariable hierarchical logistic regression on the inspection of credible intervals and the DIC, through the backward elimination method.

A scatter plot of the observed school-level prevalence levels of dual infections versus those predicted from the two single pathogens hierarchical logistic regressions assuming that S. haematobium infection and trachoma signs were independent (see section S.4 in the Supplementary Information document on the plot of these values) provided no evidence of interdependence between the two pathogens.

A scatter plot
Discussion

Through sentinel site surveillance defined at the school level, this study showed that urinary schistosomiasis and trachoma surveys can be implemented simultaneously. Results indicated that both of these diseases are prevalent in Burkina Faso and they likely do constitute public health problems according to WHO recommended thresholds [15, 19, 34-36]. Treatment with both PZQ (for urinary schistosomiasis) and ZTX (for trachoma) was only required, however, though for two of the 21 sentinel sites surveyed here.

With regards to the M&E of the impact of integrated control programmes, sentinel site surveillance conducted in schools are ideal in the case of schistosomiasis for the following reasons [37]: (i) schools are accessible and receptive; (ii) the highest prevalence levels of *S. haematobium* infection are found among school-age children; (iii) data collected in this age range may be used to evaluate not only if schistosomiasis threatens the health of school-aged children, but also if there is need for intervention in the community as a whole; (iv) children in intermediate grades (generally between ages 9–12) allow for the accompaniment of treatment impact over one to two years, before they leave school. In the current study, we have chosen to recruit a longitudinal cohort of 7-11 years old at baseline for both logistical reasons (through integrating with the ongoing surveys) and as this would enable us to follow-up these same children during three years and thus we wanted to increase participation by making at the same time these surveys eventually logistically manageable.

Furthermore, our past experience with SCI data [19, 38, 39] has demonstrated that morbidity is also detectable in young school-aged children which suggests that children may become infected early in life [19, 38, 39]. As we were interested ultimately to monitor changes in the infection and to quantify the rate of which infections changes, we feel suspect that changes in morbidity in the younger age groups of school children will be more sensitive to changes in the force of infection (i.e. per capita rate at which a host acquires new infections) by MDA. However, we do recognize that if we had also included data from the even younger age groups (i.e. pre-school children) who did not receive schistosomiasis treatment in the monitoring programme, our understanding of the secular changes in transmission caused by a morbidity control programme could be improved, helping also differentiate between the impact of PZQ on the individual and the community [40].

On the other hand, it should be noted that school-based surveys might underestimate the prevalence of trachoma in the community as a whole and they do not determine the priority for surgical intervention [26]. In addition, a key feature of trachoma epidemiology is that of is the age-profile of infection prevalence, which increases to a peak at very young ages and declines at older ages (particularly in heavily infected
Communities). This feature would not be captured in study designs such as that used in the present study [16, 41-43]. Trachoma interventions using WHO thresholds were established for a different age group than the one analyzed here and thus we are aware that inference on this matter should be treated with some caution. Nevertheless, as in any case, the distribution of infection and disease will vary according to endemicity levels, the protocol applied in this study could be of use to hypoendemic trachoma areas of Burkina Faso if MDA treatment decisions have to be made based on results arising from similar study designs. A peak shift of the maximum infection prevalence in younger ages (slightly greater than 5 years of age) has been observed in hypoendemic areas [41].

Some other general limitations of this integrated sentinel site surveillance system with the school as an operational basis are discussed here. In this school-based approach a significant proportion of the school-aged children may not attend school and so the practicality of this approach may be limited to areas where school attendance is high, not too low. In Burkina Faso the percentage of attendance for the primary schools (children aged 7-13 years old) is approximately 63% and thus we might have missed a significant proportion of S. haematobium infection and trachoma signs. Moreover, observer error might have compromised the sensitivity and specificity of clinical diagnosis, although the magnitude of this effect is likely to be smaller [44].

Environmental effects on the emergence and re-emergence of pathogens are well recognized and thus a secondary aim of this study was to characterize quantitatively the effect of specific environmental factors in addition to demographic factors on the two NTDs of interest here: urinary schistosomiasis and trachoma.

Altitude, precipitation, minimum temperature and air pressure were all important predictors of S. haematobium infection (Tables 3 and 5) by simple hierarchical logistic regression modelling. Temperature and rainfall were important predictors of prevalence of S. haematobium infection also in Tanzania [45] and such statistical relationships are consistent with the known biology of freshwater snails, the intermediate hosts for schistosomes. S. haematobium is transmitted by snails from the genus Bulinus. In Burkina Faso B. truncatus and B. senegalensis occur in all endemic schistosomiasis areas of the country [35, 46] and their dynamics are known to be sensitive to temperature and rainfall [29]. However, multivariable analysis indicated only altitude to be negatively significantly associated with prevalence of S. haematobium infection.

Furthermore, there were significant negative associations of prevalence of active trachoma signs with minimum temperature and air pressure (Table 4 & 5). The significant negative association between minimum temperature as well as air pressure and active trachoma signs in our study, strengthens the argument that
environmental factors, and particularly climatic conditions, may be important determinants of the physiology and behavior of *Musca sorbens*, a mechanical vector of trachoma in some settings [10, 13, 15]. Even if these are speculative, the following mechanisms can also be envisaged [14]: Preferred breeding sites of *M. sorbens* are fresh human faecal materials lying on the ground. High temperature and sunshine may induce rapid dryness of faecal materials, causing them to become inadequate breeding sites. Moreover, the lifespan of *M. sorbens* strongly depends on temperature, decreasing from 35 days at 24°C to less than 12 days at 32°C, yielding less frequent contacts of *M. sorbens* with children's faces, and in turn, lower contamination of *M. sorbens* with *C. trachomatis* [47, 48]. We did not find any significant association between age and trachoma prevalence and we suspect that this is due to the fact that pre-school aged children are not included in the current surveys. *Estimates are not shown.*

Conditional upon these predictors, these data are consistent with the two pathogens being independent.

As mentioned previously, the present study was designed to be as simple as possible in order to increase participation and to make it logistically manageable in settings with few resources. We therefore did not apply the questionnaire to collect observational data, such as water-use behavior, and evidence of latrine use and hygienic habits/states. Perhaps an investigation of the relationship between fly density, markers of socio-economic status, hygienic habits/states and altitude in these sentinel sites could be informative. Such facts may have led us to missing more subtle or complex relationships between risk factors for urinary schistosomiasis and active trachoma [14] in the current study. Environmental effects on the emergence and re-emergence of pathogens are well recognized and thus in this study we aimed to characterize quantitatively the effect of specific environmental and weather factors in addition to demographic factors on two of the most prevalent NTDs in sub-Saharan Africa: urinary schistosomiasis and trachoma. Through sentinel site surveillance defined at the school level, we showed that urinary schistosomiasis and trachoma surveys can be implemented simultaneously. Results indicated that although both these diseases are prevalent in Burkina Faso and constitute serious public health problems as previously discussed [14, 18, 34-36], treatment with both PZQ (for urinary schistosomiasis) and ZTX (for trachoma) was only required two of the 21 sentinel sites surveyed.

Furthermore, there were significant negative associations of prevalence of active trachoma signs with minimum temperature and air pressure (Table 4 & 5). The significant negative association between minimum temperature as well as air pressure and active trachoma signs in our study, strengthens the argument that environmental factors, and particularly climatic conditions, may be important determinants of the physiology and behavior of *Musca sorbens*, a mechanical vector of trachoma in some settings [9, 12, 14]. Even if these
are speculative, the following mechanisms can also be envisaged [13]: Preferred breeding sites of *M. sorbens* are fresh human fecal materials lying on the ground. High temperature and sunshine may induce rapid dryness of fecal materials, causing them to become inadequate breeding sites. Moreover, the lifespan of *M. sorbens* strongly depends on temperature, decreasing from 35 days at 24°C to less than 12 days at 32°C, yielding less frequent contacts of *M. sorbens* with children's faces, and in turn, lower contamination of *M. sorbens* with *C. trachomatis* [47, 48]. We did not find any significant association between age and trachoma prevalence and we suspect that this is due to the fact that pre-school aged children are not included in the current surveys (estimates are not shown).

We believe that despite the potential limitations contained in terms of age groups selected for the assessment of *S. haematobium* infection and active trachoma, the fact that there was found very low prevalence of co-infections in the studied sentinel sites, carries important implications for integrated NTDs surveillance and control strategies. The importance of environmental factors in determining *S. haematobium* or single trachoma infection risks as well as the very low prevalence of co-infections in the studied sentinel sites carries important implications for integrated NTDs surveillance and control strategies. The presence of relatively few co-infections has clear consequences for the concept of integration of mapping, planning of drug delivery, and M&E of integrated control programs for these two NTDs. Results of the current study are in accordance with observations reported in the Plateau and Nasarawa States in Nigeria [17]. We agree with these authors’ recommendation of the authors of that study that current population-based district level surveys for the mapping of trachoma should not be replaced by school-based surveys. Finally, given that NTD interventions require baseline data for targeting treatment and evaluation, the benefits of including more than one disease indicator in overlapping age groups when using an integrated M&E protocol, warrants further study. In particular, different study designs would require further investigation. More research would also be needed to ascertain whether the findings presented here can be generalized to West Africa and beyond. With regards to M&E of the impact of integrated control programmes, sentinel site surveillance conducted in schools have the following advantages in the case of schistosomiasis [37]: (i) schools are accessible and receptive; (ii) the highest prevalence levels of *S. haematobium* infection are found among school-age children; (iii) data collected in this age range may be used to evaluate not only if schistosomiasis threatens the health of school-aged children, but also if there is need for intervention in the community as a whole; (iv) children in intermediate grades (generally between ages 9–12) allow for the accompaniment of treatment impact over one to two years, before they leave school. However, school-based surveys might underestimate the prevalence of trachoma in the community as a whole since children attending school in underserved communities largely come from households with higher socioeconomic status and therefore have a markedly lower risk of disease compared to children not attending school [25]. In addition, a key feature of trachoma epidemiology which is
the age-profile of infection prevalence, which increases to a peak at very young ages and declines at older ages, will not be captured in study designs such as that used in the present study [15, 41-43].

Some limitations of this integrated sentinel site surveillance system with the school as an operational basis are discussed here. In this school-based approach a significant proportion of the school-aged children may not attend school and so the practicality of this approach may be limited to areas where school attendance is high. In Burkina Faso the percentage of attendance for the primary schools (children aged 7-13 years old) is approximately 63% and thus we might have missed a significant proportion of *S. haematobium* and trachoma infections. In addition, the present study was designed to be as simple as possible in order to increase participation and to make it logistically manageable. We therefore did not apply the questionnaire to collect observational data, such as water-use behavior and evidence of latrine use. In addition, an investigation of the relationship between fly density, markers of socio-economic status and altitude in these sentinel sites could be informative. Such facts may have led us to missing more subtle or complex relationships between risk factors for urinary schistosomiasis and active trachoma [13] in the current study. Moreover, observer error might have compromised the sensitivity and specificity of clinical diagnosis, although the magnitude of this effect is likely to be smaller [44]. One might also argue that the present data may not be generalisable to the whole geographic population but the current estimates are clearly useful evaluations within these sentinel sites. Assuming close similarity to a larger geographical region in various respects may make it possible for these trends to be extrapolated to underpin the construction of reliable infection maps and the parameterization of mathematical models for the transmission rates of these two NTDs as well as the ‘E’ component for the SAFE strategy in the case of trachoma. Furthermore, surveillance and control strategies in the medium and long terms should take into consideration the local epidemiological characteristics and the availability of material and human resources particularly in the absence of external funds. For example, in a poor country like Burkina Faso where *S. haematobium* and trachoma infections still represent serious public health problems and local infrastructure conditions hinder the satisfactory implementation of control actions, efforts might have to contemplate encompassing, at least, more vulnerable groups, such as school-aged and school-attending children [49].

Conclusions

Finally, given that NTD interventions require baseline data for targeting treatment and evaluation, the benefits of including more than one disease indicator warrant further study. To our knowledge, only few three previously published studies-three in Nigeria, Southern Sudan and Togo [17, 22, 49] and another more
recent one offering a conceptual framework around these issues [50]-have discussed and tested different survey methodologies for M&E of different NTDs in integrated control programmes. Our study reports on baseline findings from sentinel site surveillance of *S. haematobium* and trachoma infection signs by using an integrated M&E protocol in Burkina Faso. Based on these findings and in general higher chlamydial loads are detected among preschool-aged rather than school-aged children in hyper-endemic trachoma areas, we recommend the protocol applied in this study be used only in hyper-endemic trachoma areas of Burkina Faso if MDA treatment decisions have to be made based on results arising from similar study designs. More research is required to confirm if these findings can be generalized to West Africa and beyond. Although co-morbidity from each of these two NTDs is rare, lack of data in literature for younger ages in the case of schistosomiasis and key features of trachoma epidemiology urge for recommendations that lead us to recommend that current methodology to be modified to assess the younger age groups both for schistosomiasis and trachoma.

To date, different sampling frames are currently used for each NTD. Harmonization and consistency of survey methods will simplify reporting at regional and international levels thus allowing for comparable progress reports to be made. Such work is currently conducted from SCI in collaboration with Vector Control Division in another integrated NTD control program in Uganda.

**Competing interests**
The author(s) declare that they have no competing interests.

**Authors’ contributions**
AF obtained funding and AF & JPW were the principal investigators. AK, ST, CAD, BY, EBO and JPW, participated in the design of data collection. ST, AO, BY, CK and MK participated in data collection. AK drafted the manuscript. AK carried out statistical analysis. All authors contributed to the critical revision of the manuscript for important intellectual content and agreed on submission.

**Acknowledgments**

Obituary: Dr Bernadette Yoda the National Trachoma Coordinator at the Ministry of Health in Burkina Faso has sadly passed away at the age of 50 years old in Ouagadougou on the 10/08/10. In 1989 Dr Yoda obtained her medical degree and in 1994 she acquired her diploma in Epidemiology organized by WHO in Bamako in Mali. In 1998 she obtained the speciality of ophthalmologist and by following several trainings and workshops in West Africa and Europe she always devoted her services to those in need in Burkina Faso. As her collaborators and co-authors on this article we will always remember her as a very devoted, hard working and conscientious person. Her two children have remained by her side through it all.
This sentinel site surveillance was funded by the Bill & Melinda Gates Foundation. Technical Support for the National NTD Control Program in Burkina Faso is provided by the United States Agency for International Development (USAID) NTD Control Program through a grant to the Schistosomiasis Control Initiative (SCI) under a Cooperative Agreement with Research Triangle Institute (RTI) International.

We are grateful to the national Burkinabé field team and school-children for their participation in these surveys and to Drs David Aanensen and Wes R Hinsley from the Department of Infectious Diseases Epidemiology at Imperial College London for help with extracting the environmental data. Additionally we would like to thank Drs Nick Grassly, Manoj Gambhir and Isobel Blake for helpful discussions around the epidemiology of trachoma. A special thanks to Drs Thibaut Jombart and Judith Legrand for help with the inverse distance weighted interpolation method. CAD thanks the MRC for Centre funding. AK is currently supported by an MRC Population Health Scientist Fellowship. Finally, we would like to thank Prof Sir David Cox for general advice with statistical analysis and last but not least our local partner in Burkina Faso-RISEAL.
References


Legends of figures

**Figure 1.** Relationship between prevalence and intensity of *S. haematobium* infection from the Burkinabé Vertical National Schistosomiasis Control Program at baseline and follow-up. *A:* Baseline Burkinabé data 2004; *B:* 2nd follow-up Burkinabé data 2006 after two annual rounds of treatment with PZQ. The fitted relationship arises from assuming a negative binomial distribution of schistosomes among human hosts (see main text).

**Figure 12.** Location of sentinel sites (white markers) and meteorological stations (red markers) in Burkina Faso for the assessment of urinary schistosomiasis and active trachoma in school-based surveys.

**Figure 23.** MDA recommendations for schistosomiasis and trachoma for the 21 sentinel sites from observed data on prevalence of the two diseases; low *S. haematobium* prevalence (<10 %) and low trachoma prevalence (<10 %) (white markers; *no MDA recommended*); low *S. haematobium* prevalence (<10 %) and high trachoma prevalence (>10%) (yellow markers; *MDA for trachoma is recommended*); medium *S. haematobium* prevalence (10-49%) and high trachoma prevalence (>10%) (red markers; *MDA in school-aged children; community MDA for trachoma*).
Table 1. Observed prevalence by type of infection (urinary schistosomiasis and trachoma) and sentinel site in 21 schools of Burkina Faso (n=3,324 children aged 7–11 years).

<table>
<thead>
<tr>
<th>Sentinel site (size)</th>
<th>Only <em>S. haematobium</em> infection</th>
<th>Only trachoma signs</th>
<th>Co-infection with trachoma signs and <em>S. haematobium</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>BADONGO (n=148)</td>
<td>20.95 (14.70 - 28.39)</td>
<td>12.84 (7.91 - 19.32)</td>
<td>0 (0.00 -2.46)</td>
</tr>
<tr>
<td>BAWAN (n=203)</td>
<td>2.96 (1.09 – 6.32)</td>
<td>12.81 (8.54 - 18.20)</td>
<td>0.49 (0.00 – 2.71)</td>
</tr>
<tr>
<td>BAYANDI (n=141)</td>
<td>3.55 (1.16 - 8.08)</td>
<td>7.09 (3.45 - 12.66)</td>
<td>0 (0.00 – 2.58)</td>
</tr>
<tr>
<td>DOUNA (n=219)</td>
<td>17.35 (12.58 -23.03)</td>
<td>4.57 (2.21 – 8.24)</td>
<td>0 (0.00 -1.67)</td>
</tr>
<tr>
<td>GORA (n=211)</td>
<td>0 (0.00 -0.02)</td>
<td>13.27 (9.00 - 18.61)</td>
<td>0 (0.00 -0.02)</td>
</tr>
<tr>
<td>KARI (n=224)</td>
<td>0.45 (0.00 – 2.46)</td>
<td>20.54 (15.44 - 26.42)</td>
<td>0.45 (0.00 – 2.46))</td>
</tr>
<tr>
<td>KOUMBRI (n=156)</td>
<td>19.23 (13.37 - 26.30)</td>
<td>5.77 (2.67 – 10.67)</td>
<td>0.64 (0.00 -3.52)</td>
</tr>
<tr>
<td>LERBOU (n=91)</td>
<td>45.05 (34.60 - 55.84)</td>
<td>0 (0.00 – 3.97)</td>
<td>3.30 (0.00 -9.33)</td>
</tr>
<tr>
<td>LIJOULGOU (n=147)</td>
<td>9.52 (5.31 - 15.46)</td>
<td>10.88 (6.35 - 17.07)</td>
<td>0.68 (0.00 – 3.73)</td>
</tr>
<tr>
<td>MEDIGA (n=150)</td>
<td>27.33 (20.38 - 35.20)</td>
<td>9.33 (5.20 - 15.16)</td>
<td>3.33 (1.09 -7.61)</td>
</tr>
<tr>
<td>MINIMA DOURE (n=99)</td>
<td>14.14 (7.95 - 21.59)</td>
<td>2.02 (0.25 – 7.11)</td>
<td>2.02 (0.25 – 7.11)</td>
</tr>
<tr>
<td>NAGBINGOU (n=146)</td>
<td>20.55 (14.31 - 28.02)</td>
<td>8.22 (4.32 - 13.92)</td>
<td>1.37 (0.17 - 4.86)</td>
</tr>
<tr>
<td>NOUMOUSSO (n=218)</td>
<td>0 (0.00-1.68)</td>
<td>32.57 (26.39 -39.23)</td>
<td>0.46 (0.00 – 2.53)</td>
</tr>
<tr>
<td>PANAMASSO (n=216)</td>
<td>0 (0.00 – 1.69)</td>
<td>35.65 (29.27 -42.43)</td>
<td>0 (0.00 – 1.69)</td>
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<tr>
<td>SAMPIERI (n=121)</td>
<td>5.79 (2.36 – 11.56)</td>
<td>10.74 (5.85 - 17.67)</td>
<td>0 (0.00 – 0.03)</td>
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<tr>
<td>SIDOGO (n=153)</td>
<td>7.84 (4.12 -13.30)</td>
<td>9.80 (5.59 - 15.65)</td>
<td>0.65 (0.00 – 3.59)</td>
</tr>
<tr>
<td>SOALA (n=148)</td>
<td>9.46 (5.27 - 15.36)</td>
<td>12.84 (7.91 - 19.32)</td>
<td>4.05 (1.50 – 8.61)</td>
</tr>
<tr>
<td>TIAO (n=131)</td>
<td>0 (0.00 – 2.78)</td>
<td>6.87 (3.19 - 12.64)</td>
<td>0 (0.00 – 2.78)</td>
</tr>
<tr>
<td>TIKAN (n=147)</td>
<td>10.20 (5.82 - 16.27)</td>
<td>2.72 (0.75 – 6.82)</td>
<td>0.68 (0.00 -3.73)</td>
</tr>
<tr>
<td>TOUGOURI (n=136)</td>
<td>14.71 (9.22 - 21.79)</td>
<td>9.56 (5.19 - 15.72)</td>
<td>0.74 (0.00 – 4.03)</td>
</tr>
<tr>
<td>WINDOU (n=119)</td>
<td>37.82 (29.09 - 47.16)</td>
<td>0.84 (0.00 – 4.59)</td>
<td>1.68 (0.00 - 5.94)</td>
</tr>
</tbody>
</table>
Table 2. Summary statistics of interpolated and meteorological station-based environmental and weather variables

<table>
<thead>
<tr>
<th>Environmental &amp; weather variables</th>
<th>Interpolated (i.e. for sentinel sites; n=21)</th>
<th>At weather stations (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>Altitude*</td>
<td>321.1</td>
<td>304.0</td>
</tr>
<tr>
<td>Precipitation◊</td>
<td>2.37</td>
<td>2.39</td>
</tr>
<tr>
<td>Min temperature‡</td>
<td>22.8</td>
<td>22.9</td>
</tr>
<tr>
<td>Max temperature‡</td>
<td>35.5</td>
<td>35.6</td>
</tr>
<tr>
<td>Av temperature‡</td>
<td>28.7</td>
<td>28.7</td>
</tr>
<tr>
<td>Air pressure▲</td>
<td>973.5</td>
<td>975.1</td>
</tr>
</tbody>
</table>

*MSL: Meters above sea level; ◊mm: millimeters; ‡°C: Celsius; §°C: Celsius; ▲mbars: millibars

Table 3. Odds Ratios and 95% credible intervals for the risk of the prevalence of S. haematobium infection (n=3,324)-adjusted for host age and gender in 21 school sentinel sites in Burkina Faso.

<table>
<thead>
<tr>
<th>Environmental and weather variables</th>
<th>Simple hierarchical logistic regression models</th>
<th>Final multivariable hierarchical logistic regression model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude*</td>
<td>0.168 (0.118 – 0.242)</td>
<td>0.168 (0.118 – 0.242)</td>
</tr>
<tr>
<td>Precipitation◊</td>
<td>0.406 (0.322 – 0.510)</td>
<td>REM</td>
</tr>
<tr>
<td>Min temperature‡</td>
<td>2.856 (2.686 – 3.000)</td>
<td>REM</td>
</tr>
<tr>
<td>Max temperature‡</td>
<td>2.313 (2.198 – 2.385)</td>
<td>NI</td>
</tr>
<tr>
<td>Av temperature‡</td>
<td>1.742 (1.710 – 1.779)</td>
<td>NI</td>
</tr>
<tr>
<td>Air pressure▲</td>
<td>2.151 (2.140 – 2.174)</td>
<td>REM</td>
</tr>
</tbody>
</table>

NI: These variables were not included in the final multivariate binomial logistic regression model building, as DIC Akaike criterion indicated poorer fit than when min temperature was included.
REM: The effects of these variables were removed as DIC indicated by backward elimination.

°per 50 MSL: Meters above sea level; ◊per 0.5 mm: millimeters; ‡per 1 °C: Celsius; §per 0.5 °C: Celsius; ▲per 5 mbars: millibars

Table 4. Odds Ratios and 95% credible intervals for the risk of the prevalence of active trachoma signs (n=3,324)-adjusted for host age and gender in 21 school sentinel sites in Burkina Faso.
Simple hierarchical logistic regression models | Final multivariable hierarchical logistic regression model
---|---
Environmental and weather variables | ORs (95 % Credible Intervals) | ORs (95 % Credible Intervals)
Altitude* | 1.730 (1.189 – 2.433) | REM
Precipitation◊ | 1.690 (1.336 – 2.016) | REM
Min temperature‡ | 0.570 (0.546 – 0.591) | 0.746 (0.717 – 0.768)
Max temperature* | 0.465 (0.436 – 0.484) | NI
Av temperature‡ | 0.580 (0.564 – 0.591) | NI
Air pressure▲ | 0.606 (0.602 – 0.609) | 0.616 (0.608 – 0.622)

NI: These variables were not included in the final multivariate binomial logistic regression model building as DIC Akaike criterion indicated poorer fit than when min temperature was included.
REM: The effects of these variables were removed as DIC indicated by the automated selection (i.e., backward elimination) of a ‘best subset’ of independent variables when PROC LOGISTIC was implemented in SAS software as they did not meet the 0.05 significance level.
*per 50 MSL: Meters above sea level; ◊per 0.5 mm: millimeters; †per 1 °C: Celsius; ‡per 0.5 °C: Celsius; ▲per 5 mbars: millibars

**Table 5.** ORs of prevalence of single and dual infection (n=3,324)-adjusted for age and gender. 95% confidence intervals are given in brackets.

| Environmental and weather variables | Only *S. haematobium* infection | Only active trachoma signs | Co-infection with active trachoma and *S. haematobium*
---|---|---|---
Altitude* | 0.403 (0.346 to 0.470) p<0.001 | 0.044 (0.021 to 0.081) p<0.001 | 1.445 (1.565 to 1.816) p<0.001
Precipitation◊ | 0.467 (0.405 to 0.538) p<0.001 | 0.373 (0.270 to 0.498) p<0.001 | 1.785 (1.198 to 2.128) p<0.001
Max temperature* | 2.143 (1.885 to 2.436) p<0.001 | 0.458 (0.396 to 0.531) p<0.001 | 1.933 (1.272 to 2.937) p<0.001
Min temperature‡ | 2.704 (2.167 to 3.374) p<0.001 | 0.152 (0.089 to 0.265) p<0.001 | 0.725 (0.627 to 0.838) p<0.001
Av temperature‡ | 2.052 (1.770 to 2.380) p<0.001 | 0.762 (0.675 to 0.860) p<0.001 | 0.769 (0.699 to 1.185) p<0.001
Air pressure▲ | 1.700 (1.449 to 2.003) p<0.001 | 0.060 (0.030 to 0.119) p<0.001 | 0.607 (0.555 to 0.663) p<0.001

NI: These variables were not included in the final multivariate model building as Akaike criterion indicated poorer fit than when min temperature was included.

*50 MSL: Meters above sea level; ◊0.5 mm: millimeters; †1 °C: Celsius; ‡0.5 °C: Celsius; ▲5 millibar
Risk factors for urinary schistosomiasis and active trachoma in Burkina Faso before preventative chemotherapy: implications for monitoring and evaluation of integrated control programmes.

Description: This file contains some further statistical analysis that supports the methodology finally used.
Additional files provided with this submission:

Additional file 1: Supplement_for_the_manuscript_01.11.docx, 182K
http://www.biomedcentral.com/imedia/1349715985515387/supp1.docx