Research Journal of

Parasitology

ISSN 1816-4943

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS Research Journal of Parasitology

ISSN 1816-4943
DOI: 10.3923/jp.2018.19.35

Research Article

Spatial Distribution and Modelling of Soil Transmitted Helminthes Infection in Nigeria

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Abstract

Background and Objective: Soil transmitted helminthes (STH) infection affect more than two billion people worldwide with Nigeria having the highest burden in Sub-Saharan Africa. This study examined the spatial and potential distribution of STHs in Nigeria. **Materials and Methods:** Secondary data for the prevalence of *Ascaris lumbricoides*, *Trichuris trichiura* and hookworms in Nigeria contained in 98 journal publications were extracted and used in determining the spatial distribution of the parasites using DIVA-GIS software. A total of 19 bio-climatic and topographical variables grouped into 3 main variables namely: temperature, precipitation and altitude were used in the modeling of the potential distribution of the parasites using Maximum Entropy (MaxEnt) modeling tool. **Results:** The average prevalence of *A. lumbricoides*, Hookworms and *T. trichiura* in Nigeria were 25.17, 16.86 and 9.74%, respectively. Delta State (62.08%) had the highest prevalence for *A. lumbricoides* followed by Oyo (55.50%) and Kano (44.40%) while 14 states had prevalence of below 20.0%. Akwa Ibom and Kano States had the highest average prevalence of 55.80% for hookworm infections. Delta, Oyo and Benue States had prevalence of 38.08, 35.80 and 35.40%, respectively while 22 states had prevalence of hookworm below 20.0%. *T. trichiura* had the least average prevalence among the three STHs. Akwa Ibom State had the highest prevalence for this parasite with 40.40% followed by Lagos, Delta and Kwara States with prevalence values of 24.85, 24.05 and 23.37%, respectively. Other states in the Federation had prevalence values of less than 12% with Federal Capital Territory (FCT) Abuja and Borno State having the least prevalence of 0.80 and 0.90%, respectively. The potential distribution reveals that southern Nigeria has been at high risks of infection. Precipitation of the wettest month, altitude and precipitation of the warmest quarter are the major environmental variables that affect the distribution of STH. **Conclusion:** All states in Nigeria are endemic for STHs. Southern Nigeria has higher prevalence of STHs than Northern Nigeria. The prevalence distribution is determined by temperature, precipitation and altitude.

Key words: MaxEnt, Altitude, Temperature, Precipitation, Soil transmitted helminths

Citation: Clement Ameh Yaro, Ezekiel Kogi and Sodangi Abdulkarim Luka, 2018. Spatial distribution and modelling of soil transmitted helminthes infection in Nigeria. Res. J. Parasitol., 13: 19-35.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Soil-transmitted helminths (STHs) (*Ascaris lumbricoides*, hookworm and *Trichuris trichiura*) are responsible for more than 40% of the worldwide morbidity from all tropical infections[1]. STH is ranked first among the seven neglected tropical diseases (NTDs) most prevalent in Nigeria as having the highest burden on the population[2]. Social-ecological systems govern the transmission of STH and thriving in areas with poor sanitation and hygiene[3]. Hotez *et al*.[4] and Oluwole *et al*.[5] reported that Nigeria has the highest infected people with STH in sub-Saharan Africa with children of age 5-14 years at high risk of infection and morbidity. Despite the recognition of the importance of STH infections coupled with the control strategies, the infections from these parasites still remain the major cause of malnutrition, iron-deficiency and anaemia in Nigeria[2] and children co-infected with these parasites have been shown to have hampered cognitive and physical development that leads to inefficiency in learning and school achievements[6,7]. The Federal Ministry of Health, Nigeria in 2012 highlighted the need to scale-up interventions across NTDs programmes in their five year master plan due to the impact of these parasites[2].

The use of geospatial health resource data and improved software analysis to produce low-cost digital health maps and transmission models for tropical diseases was encouraged by Malone[8] as these models help policy makers and researchers in the health sector to concentrate in areas of high risks thereby helping to reduce operational cost.

Predictive modelling of geographic distributions of infections using environmental conditions of sites of known occurrence constitutes an important technique in analytical biology and its applications in epidemiology is enormous[9]. Predictions of infection risk areas where prevalence data are lacking can also be supplied by spatial statistical models[10].

Maximum entropy (MaxEnt) modelling is a general-purpose method for making predictions of inferences from incomplete information[11]. MaxEnt modelling is useful in epidemiology as it allows the use of presence-only datasets[11] making it of merit for research and development in parasitology which usually has presence-only datasets[12]. The uses of modelling techniques such as MaxEnt that require only presence data are therefore extremely valuable[13]. MaxEnt modelling technique also allows the use of both continuous and categorical data that enables interaction between variables[14] producing a better visualization of results on maps.

Although, spatial and potential distribution of STHs was carried out by Oluwole *et al*.[5] using survey data obtained by the Federal Ministry of Health, Nigeria in the year 2011, the need to updated and use other data obtained from different parts of the country to assess the distribution of these parasites will help to improve existing distribution maps. This study will help to identify areas of high suitability for STH infections as well as rank environmental variables according to their relative importance in the determination of these infections.

The purpose of study was to assess the spatial and potential distribution of *Ascaris lumbricoides*, *Trichuris trichiura* and hookworms under present climate change by using DIVA-GIS (an open access Geographic Information System for mapping and visualization) and MaxEnt ecological niche modelling tools.

MATERIALS AND METHODS

Ethics statement: Data used for this study are secondary data. Therefore, no specific ethical approval was required.

STH Infection Data: Literature searches were performed on http://www.google.com.ng to assess the prevalence of soil transmitted helminthes in Nigeria. A total of 98 journal articles published from year 2005 to 2017 were downloaded from the internet and the prevalence of *Ascaris lumbricoides*, *Trichuris trichiura* and Hookworms were extracted from them.

Environmental data: The climatic variables such as temperature and precipitation influenced global and meso scales as well as topographic variables such as altitude and aspects that likely affect species distributions at meso and topo-scales while land-cover variables like percent canopy cover influence distributions at the micro-scale[11]. Hence, the use of climatic and topographic variables in the prediction of distributions of STHs was applied to the prevailing circumstances in Nigeria.

In this study, a total of 19 bioclimatic variables of present climate (1950-2000) for Nigeria were downloaded from http://www.worldclim.org/ (Worldclim database version 1.4) at 1 km spatial resolution and were used in the prediction of STHs' distributions as follows: BIO1-Annual Mean Temperature, BIO2-Mean Diurnal Range, BIO3-Isothermality, BIO4-Temperature Seasonality, BIO5-Maximum Temperature of Warmest Month, BIO6-Minimum Temperature of the Coldest Month., BIO7-Temperature Annual Range, BIO8-Mean

Temperature of Wettest Quarter, BIO9-Mean Temperature of Driest Quarter, BIO10-Mean Temperature of Warmest Quarter, BIO11-Mean Temperature of Coldest Quarter, BIO12-Annual Precipitation, BIO13-Precipitation of Wettest Month, BIO14-Precipitation of Driest Month, BIO15-Precipitation Seasonality, BIO16-Precipitation of Wettest Quarter, BIO17-Precipitation of Driest Quarter, BIO18-Precipitation of Warmest Quarter and BIO19-Precipitation of Coldest Quarter. Elevation data derived from the Shuttle Radar Topography Mission were also downloaded from http://www.worldclim.org/. These bioclimatic variables can be summarized into 3 main variables: altitude, temperature and precipitation. Temperature and precipitation are directly proportional to the rate of embryonation of STHs while altitude is inversely proportional to temperature (as altitude increases, temperature decreases, so highlands were colder and lowlands were warmer), which in turn affects the development rate of these parasites as earlier stated for temperature.

Spatial analysis of soil transmitted helminthes: Spatial distribution of STH in Nigeria was performed using Data-Interpolating Variational Analysis Geographic Information System (DIVA-GIS) software for Windows (version 7.5.0) downloaded from http://www.diva-gis.org/. The mean prevalence of each parasite; *A. lumbricoides*, *T. Trichiura* and Hookworms were computed in Microsoft Excel version 2013 and converted to comma delimited files. These files were converted from text files to shape files using DIVA-GIS and were geo-referenced on the map of Nigeria. The prevalence of these parasites were categorized into <5, $\geq$5 to <10, $\geq$10 to <20, $\geq$20 to <40 and $\geq$40.

Ecological niche modeling: The potential distribution of soil transmitted helminthes parasites were modelled using MaxEnt software version 3.3.3k download from http://www.cs.princeton.edu/~schapire/maxent/. MaxEnt uses environmental data at occurrence and background locations to predict the distribution of a species across a landscape[11,15]. In this study, MaxEnt was used for mapping potential geographic distribution of soil transmitted helminthes in Nigeria. This modeling tool was selected based on the reasons of Sarma *et al.*[16] which is a presence-only modelling algorithm (i.e., absence data are not required). Its performance has been relatively better than other modelling methods and has hardly been influenced by small sample sizes and hence prediction will be relatively robust. It has been shown to be among the top performing modelling tools by Elith *et al.*[17].

Probability of presence of each of the STH was estimated by MaxEnt using the mean prevalence of each of the STH obtained for all the states in Nigeria which served as the presence records for generation of background point used in finding the maximum entropy distribution[16]. Regularization of the prevalence was performed to control over-fitting. This modelling tool uses five different features to perform its statistics namely: Linear, quadratic, product, threshold and hinge features to produce a geographical distribution of species within a define area. MaxEnt produced a logistic output format used in the production of a continuous map that provides a visual graded prevalence with an estimated probability of acquiring infection with each STH species between 0 and 1. This map distinguishes areas of high and low risk for STH infections[16].

The 19 environmental variables and the elevation data obtained were used for the ecological niche modelling. The level of significance of contribution of the altitude and 19 bioclimatic variables was used to calculate jackknife (a method of assessing the variability of data by repeating calculations on the sets of data obtained each time by removing one value from the complete set) and area under the receiver operating characteristics curve (AUC) was used to evaluate the model performance. The AUC values vary from 0.5 to 1.0; an AUC value of 0.5 showed that model predictions were not better than random, values <0.5 were worse than random, values from 0.5-0.7 signified poor performance, values from 0.7-0.9 signifies reasonable/moderate performance and values >0.9 indicated high model performance[18].

Model validation was performed according to Sarma *et al.*[16] using the 'sub-sampling' procedure in MaxEnt. About 75% of the parasites prevalence data were used for model calibration and the remaining 25% for model validation. Ten replicates were run and average AUC values for training and test datasets were calculated. Maximum iterations were set at 5000. Percent contribution (PC), permutation importance (PI) and jackknife procedures in MaxEnt were used to investigate the relative importance of different bioclimatic predictors. Sensitivity and specificity of infections were also measured. Sensitivity, which was also named the true positive rate, can measure the ability to correctly identify areas infected. Its value equals the rate of true positives and the sum value of true positives and false negatives. Specificity, which was also named the true negative rate, can measure the ability to correctly identify areas uninfected. Its value equals the rate of true negatives and the sum value of false positives and true negatives.

Data were analysed using One-way analysis of variance (ANOVA), followed by Turkey's test. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) software (version 21.0 for Windows; SPSS Inc., Chicago, IL). Statistical significance was set at $p<0.05$. Map visualization were performed on DIVA-GIS 7.5.0 using grid file output of MaxEnt with the geographic area restricted Nigeria. Five classes of probabilities were given a specific colour for visual representation of model results ranging from low risk to high risk as follows: 0-0.10 (dark green), 0.10-0.20 (light green), 0.20-0.50 (yellow), 0.50-0.70 (orange) and 0.70-1.0 (red).

RESULTS

Spatial distribution of STH INFECTIONS in Nigeria: The average prevalence of *A. lumbricoides*, Hookworms and *T. trichiura* in Nigeria were 25.17, 16.86 and 9.74%, respectively, with *A. lumbricoides* having the highest average prevalence (Table 1). These recorded occurrences of STH

Table 1: Mean Prevalence of *A. lumbricoides*, *T. trichiura* and Hookworms in Nigeria

	Mean %±SE			
State	*Ascaris lumbricoides*	Hookworms	*Trichuris trichiura*	Authors
Abia	18.50±9.19	14.64±3.60	10.39±5.69	Nduka *et al.*[19], Wosu and Onyeabor[20], Kalu *et al.*[21], Ihemanma and Oladele[22] and Ezeigbo and Agomoh[23]
Adamawa	9.32±6.60	8.95±4.76	3.70±1.05	Ezeagwuna *et al.*[24] and Enimien *et al.*[25], Houmsou *et al.*[26] and Naphtali *et al.*[27]
Akwa Ibom	36.07±18.14	55.80±13.44	40.40±29.99	Opara *et al.*[28], Usip and David[29] and Usip and Matthew[30]
Anambra	19.23±7.68	18.43±6.07	4.73±1.07	Ezeagwuna *et al.*[24],Chukwuma *et al.*[31], Ogbuagu *et al.*[32], Emmy-Egbe[33] and Chioma e*t al.*[34]
Bauchi	NAD	NAD	NAD	
Bayelsa	35.15±0.15	24.53±7.10	7.80±6.10	Agi and Awi-Waadu[35], Bariwemi *et al.*[36] and Bariweni *et al.*[37]
Benue	NAD	35.40±0.00	3.80±0.00	Tyoalumun *et al.*[38]
Borno	2.30±1.30	14.10±4.10	0.90±0.00	Biu *et al.*[39] and Biu *et al.*[40]
Cross river	3.00±0.00	5.60±0.00	1.40±0.00	Esiet and Edet[41]
Delta	62.08±8.60	38.08±10.12	24.05±3.04	Egwunyenga and Ataikiru[42], Nmorsi *et al.*[43], Prosper *et al.*[44] and Ito and Egwunyenga[45]
Ebonyi	38.19±6.78	15.96±4.08	9.52±2.54	Uneke *et al.*[46], Ivoke *et al.*[47], Alo *et al.*[48], Dimejesi *et al.*[49], Ivoke *et al.*[50], Okeke and Ubachukwu[51], Nnachi *et al.*[52] and Owaka *et al.*[53]
Edo	15.05±4.96	6.47±1.34	2.68±1.26	Wagbatsoma and Aisien[54], Mordi and Ngwodo[55], Oguanya *et al.*[56], Omorodion *et al.*[57], Akinbo *et al.*[58], Nwaneri and Omuemu[59] and Ogbain-Emovon *et al.*[60]
Ekiti	NAD	NAD	NAD	
Enugu	22.84±12.54	19.54±9.84	11.53±10.73	Emeka[61], Ukwubile *et al.*[62], Aniwada *et al.*[63] and Uzodimma *et al.*[64]
FCT	2.50±0.00	4.20±0.00	0.80±0.00	Abaver *et al.*[65]
Gombe	NAD	NAD	NAD	
Imo	22.76±5.94	11.16±2.29	5.83±1.62	Kamalu *et al.*[66], Kalu *et al.*[21], Ezeigbo *et al.*[67], Udensi *et al.*[68], Kalu *et al.*[69] and Iwunze *et al.*[70]
Jigawa	29.50±0.00	24.30±0.00	8.10±0.00	Yahaya *et al.*[71]
Kaduna	38.48±7.78	10.38±3.98	4.70±0.20	Auta *et al.*[72], Thomas *et al.*[73] and Timothy *et al.*[74]
Kano	44.40±0.00	55.80±0.00	NAD	Ahmad *et al.*[75]
Katsina	NAD	NAD	NAD	
Kebbi	22.00±0.00	10.00±0.00	13.60±0.00	Oluwole *et al.*[76]
Kogi	22.00±0.00	17.00±0.00	NAD	Ejima and Ajogun[77]
Kwara	19.11±5.57	10.72±4.54	23.37±17.36	Babatunde *et al.*[78], Saka *et al.*[79], Babamale *et al.*[80], Amaechi *et al.*[81] and Bolaji *et al.*[82]
Lagos	34.17±18.21	22.85±22.15	24.85±6.45	Adeoye *et al.*[83], Ibidapo and Okwa[84] and Ajayi *et al.*[85]
Nassarawa	39.60±0.00	NAD	NAD	Eke *et al.*[86]
Niger	10.60±0.00	9.60±0.00	3.90±0.00	Omalu *et al.*[87]
Ogun	9.35±3.83	3.65±0.45	3.75±1.95	Okonko *et al.*[88], Sam-Wobo *et al.*[89], Akingbade *et al.*[90] and Banjo *et al.*[91]
Ondo	30.03±12.06	16.62±8.45	6.48±2.43	Simon-Oke *et al.*[92], Akinseye *et al.*[93], Dada and Aruwa[94] and Akinseye *et al.*[95]
Osun	33.63±5.52	11.00±3.40	4.07±2.17	Kirwan *et al.*[96], Awolaju and Mornikeji[97], Ojurongbe *et al.*[98], Ojurongbe *et al.*[99], Salawu and Ughele[100], Olaniran *et al.*[101] and Fafunwa *et al.*[102]
Oyo	55.50±0.00	35.80±0.00	2.90±0.00	Alli *et al.*[103]
Plateau	18.35±8.86	10.79±3.13	3.20±1.55	Damen *et al.*[104], Jombo *et al.*[105], Abelau *et al.*[106], Mamman and Reuben[107] and Afolaranmi *et al.*[108]
Rivers	9.00±0.00	2.70±0.00	4.00±0.00	Odu *et al.*[109]
Sokoto	5.00±0.00	6.60±0.00	3.20±0.00	Mohammed *et al.*[110]
Taraba	NAD	NAD	NAD	
Yobe	NAD	NAD	NAD	
Zamfara	6.50±0.00	3.50±0.00	5.20±0.00	Shehu *et al.*[111]
Total	25.17±2.24	16.86±1.79	9.74±1.82	
p-value	0.017*	0.001*	0.460ns	

NAD: No available data, *Significant at $p\leq 0.05$, ns: Not significant at $p>0.05$

infections according to the states in Nigeria showed that for *A. lumbricoides*, Delta State (62.08%) had the highest infection followed by Oyo (55.50%) and Kano (44.40%). Meanwhile, it was observed that the prevalence of *A. lumbricoides* was generally high for most states in Southern part of Nigeria. Zamfara, Sokoto, Borno Sates and the Federal Capital Territory (FCT), Abuja had low prevalence values of below 3.0% while 14 states in the country had prevalence of below 20.0%.

For Hookworms, Akwa Ibom and Kano States had the highest average prevalence of 55.80% in the country. Delta, Oyo and Benue States had prevalence values of 38.08, 35.80 and 35.40%, respectively while 22 states in the country had prevalence of hookworm below 20.0% with Rivers State having the least prevalence of 2.70%.

Trichuris trichiura had the least average prevalence among the three STHs. Akwa Ibom State had the highest prevalence for this parasite with 40.40% followed by Lagos, Delta and Kwara States with prevalence values of 24.85, 24.05 and 23.37%, respectively. Other states in the Federation had prevalence values of less than 12% with FCT, Abuja and Borno State having the least prevalence of 0.80 and 0.90%, respectively.

Predicted risk of *A. lumbricoides* infections: The predicted high risk areas of *A. lumbricoides* infections were South-East and South-West regions of Nigeria with probability of $\geq$0.75. Also, all the states in Southern Nigeria, four states in North-Central Nigeria (Kwara, Kogi, Benue and Nassarawa States) with the FCT, Abuja were at risk of infections with a probability of $\geq$0.50. In North-West Nigeria, Kano and Katsina States were the two states that fell within the high risk areas. The prediction reveals that Nigeria was expected to have increased risk of infections with *A. lumbricoides* in comparison with the spatial distribution of infection where most areas fell within probability of $\geq$0.20 (Fig. 1).

Predicted risk of Hookworms infections: Five states in South-East Nigeria (Enugu, Imo, Owerri, Ebonyi and Anambra), two states (Edo and Delta States) in South-South Nigeria and two states (Lagos and Ogun States) in South-West Nigeria were in the high risk areas of hookworm infections with probability of $\geq$0.75. Also, all the states in South-South, South-East, four states in the South-West (Lagos, Ogun, Ondo and part of Osun) and parts of some states in North-Central Nigeria (Kogi, Benue, Nasarawa, Niger and FCT) were within areas with risk probability of $\geq$0.50. Some states in Northern Nigeria fell within the low risk areas. Part of Kebbi, Sokoto, Plateau, Taraba, Jigawa, Yobe and Borno States had risk probability of 0.00 to $\leq$0.10 (Fig. 2).

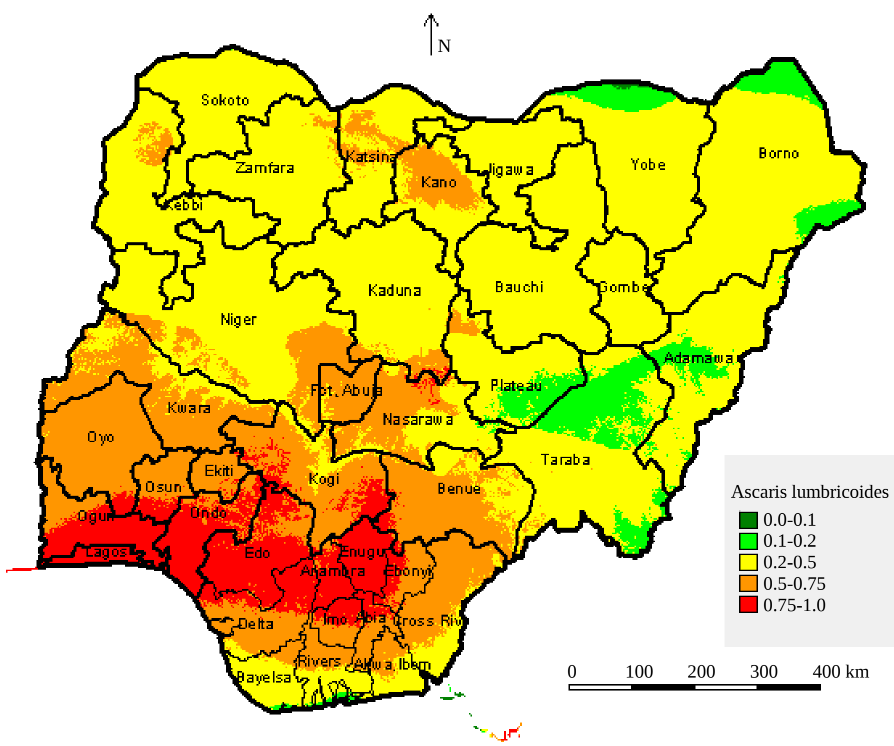

Fig. 1: Predicted prevalence of *Ascaris lumbricoides* in Nigeria

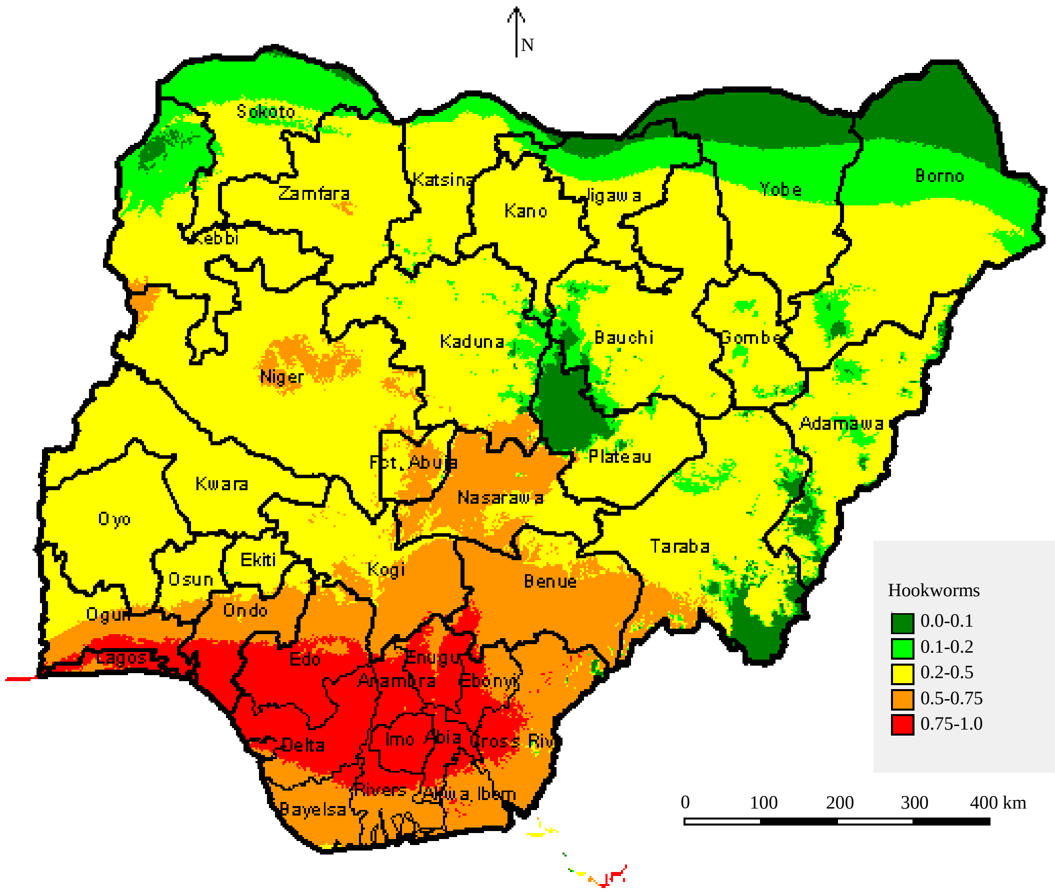

Fig. 2: Predicted prevalence of Hookworms in Nigeria

Predicted risk of *T. trichiura* infections: Risk of infection with *T. trichiura* was lower as compared to *A. lumbricoides* and Hookworms. Although, some states in Nigeria were expected to experience high risk of infections; South-West (Lagos, Ogun, Ondo and part of Osun), all the states in the South-South and South-East Nigeria and parts of Benue, Kogi, Niger, Kebbi, Plateau, Taraba, Adamawa, Gombe, Bauchi and Maiduguri were within risk of $\geq$0.50. Kaduna and Katsina states fell within the low risk areas (Fig. 3).

Model performance and influencing factors: The mean Percent Contribution (PC) and Permutation Importance (PI) of the 20 variables used in the modeling of STH in this study were also assessed. Precipitation of the wettest month had the highest PC and PI of 20.4 and 41, respectively, followed by altitude with PC of 15.2 and PI of 17 and precipitation of warmest quarter with PC of 10.8 and PI of 9.9. Also temperature seasonality was the fourth ranked model with PC of 8.2 and PI of 5.5. These four variables were among the five top variables in the modelling of STH in Nigeria. The other variables that performed well in the modelling were annual precipitation in PC and temperature seasonality in PI (Table 2).

The receiver operating characteristics (ROC) curve obtained as an average of the 10 replications runs is shown in Fig. 4. Specificity was calculated. The average and standard deviation of the Area under the Curve (AUC) for the 10 replicate runs was 0.940$\pm$0.028, 0.948$\pm$0.017 and 0.948$\pm$0.021 for *A. lumbricoides*, Hookworms and *T. trichiura*, respectively. These values showed an excellent performance of the modelling software as an AUC value of greater than 0.80 showed higher sensitivity and specificity for the presence of these parasites.

The relative importance of each variable to the prevalence of *A. lumbricoides* was assessed with the jackknife test in Fig. 5 which gave a total training gain of 1.7 (red bar) and AUC value of 0.94 (red bar). The jackknife test indicated that precipitation of wettest month and temperature seasonality were the two variables, when used alone, affected the prevalence of *A. lumbricoides* the most. Meanwhile, no

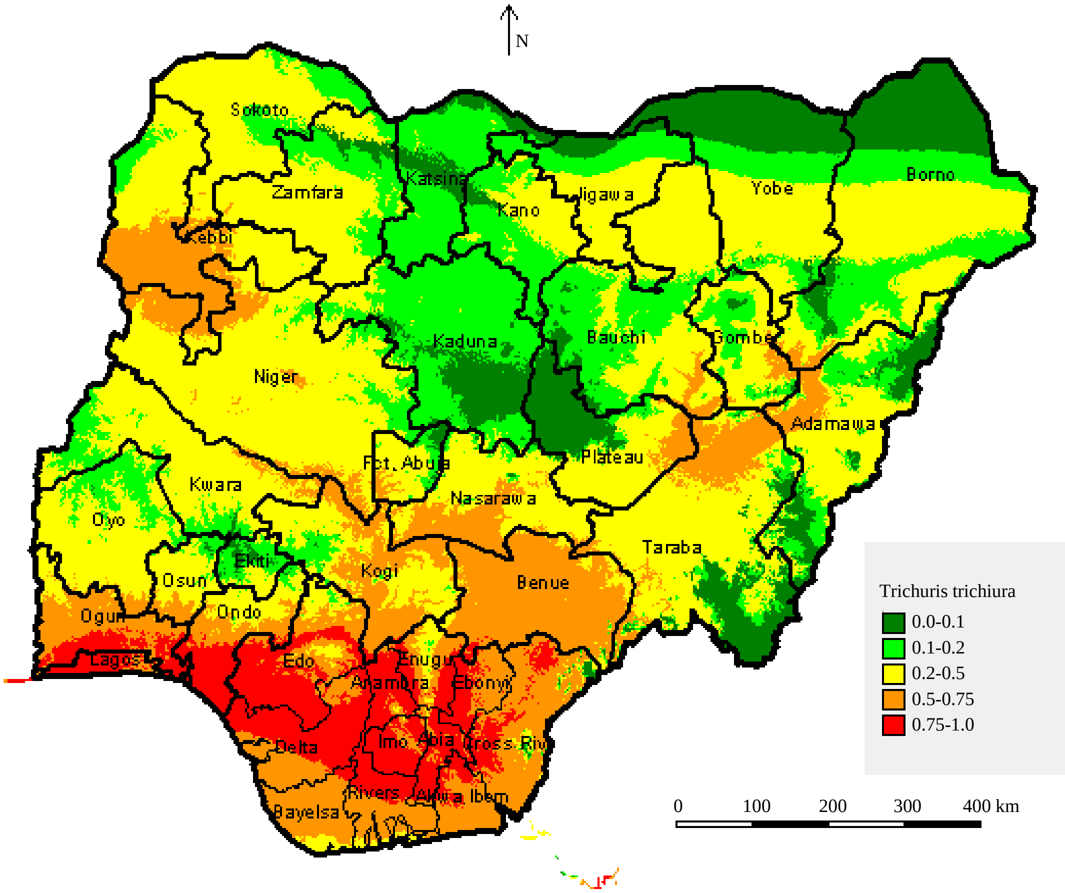

Fig. 3: Predicted prevalence of *Trichuris trichiura* in Nigeria

Table 2: Average percent contribution (APC) and average permutation importance (API) of soil transmitted helminthes infection distribution models

		Ascaris lumbricoides		Hookworms		*Trichuris trichiura*		Top five models	
Variable type	Variables	PC	PI	PC	PI	PC	PI	PC	PI
Elevation	Altitude	2.5	2.6	9.7	7.3	33.3	41.2	15.2	17
Temperature	BIO1	0	0.2	0.6	1.5	0.3	0.7	0.3	0.8
	BIO2	4.8	18.5	3.4	13.8	0.8	3.8	3	12
	BIO3	0	0	0	0	0	0.2	0	0.1
	BIO4	17.6	12.9	5.6	2.9	1.3	0.8	8.2	5.5
	BIO5	0	0	0	0	0	0	0	0
	BIO6	15.3	0.9	19.4	0.2	13.4	0.1	16	0.4
	BIO7	0.2	0	0.1	0	0.3	0	0.2	0
	BIO8	0	0	0	0	0	0.4	0	0.1
	BIO9	0	0.8	0	0.1	0.1	2.2	0	1
	BIO10	0.2	0.6	1.7	2.2	0	0	0.6	0.9
	BIO11	4.1	2	1.4	1.1	3.2	5	2.9	2.7
Precipitation	BIO12	7.2	0.2	19.7	0.1	6.7	0	11.2	0.1
	BIO13	25.8	53.2	31	63.3	4.3	6.6	20.4	41
	BIO13	5.9	5.2	1.1	1.7	3	7.4	3.3	4.8
	BIO15	0	0	0.2	0	0.2	0	0.1	0
	BIO16	11.4	0.5	0.3	0	1.2	3.3	4.3	1.3
	BIO17	0.4	0.6	0.5	0.9	0.3	0	0.4	0.5
	BIO18	0.6	1.4	1.8	3	30	25.3	10.8	9.9
	BIO19	4	0.4	3.5	2	1.6	2.9	3	1.8

PC: Percent contribution, PI: Permutation importance, Bolded: Five top models in terms of PC and PI, Elevation Variable: Altitude, Temperature variables: BIO1, BIO2, BIO3, BIO4, BIO5, BIO6, BIO7, BIO8, BIO9, BIO10 and BIO11, Precipitation Variables: BIO12, BIO13, BIO14, BIO15, BIO16, BIO17, BIO18 and BIO19

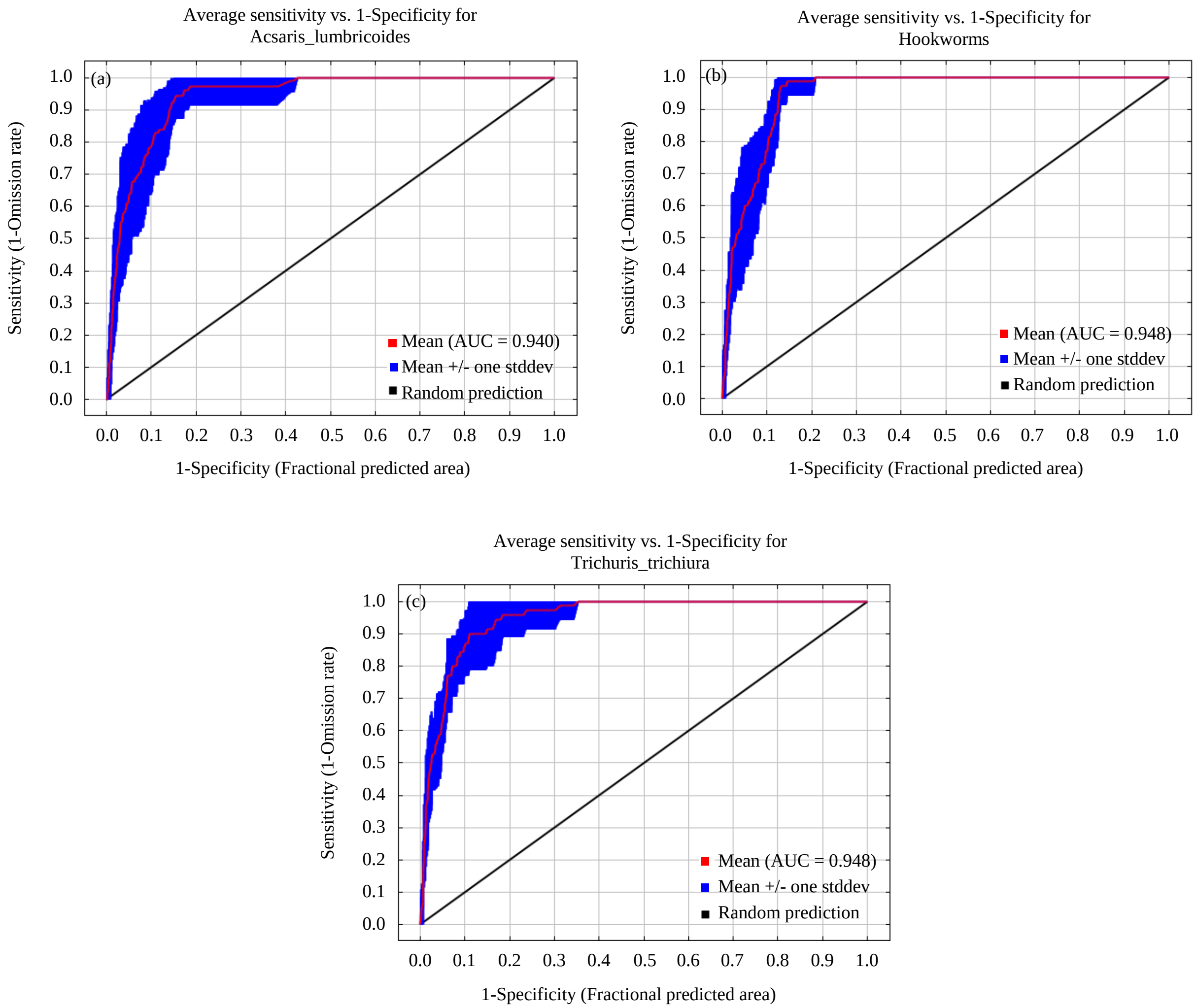

Fig. 4(a-c): Area Under the Curve (AUC) (a) *Ascaris lumbricoides*[1] (b) Hookworms[2] (c) *Trichuris trichiura*[3]

Red line indicates the mean value for 10 MaxEnt replicate runs and blue indicates the standard deviation, [1]Average AUC = (0.964, 0.909, 0.928, 0.967, 0.903, 0.938, 0.965, 0.913, 0.965 and 0.948) divided by 10, [2]Average AUC = (0.969, 0.936, 0.935, 0.918, 0.947, 0.938, 0.968, 0.948, 0.944 and 0.974) divided by 10, [3]Average AUC = (0.928, 0.905, 0.964, 0.930, 0.972, 0.963, 0.938, 0.959, 0.964 and 0.960) divided by 10

variable was observed to significantly decrease the training gain. The jackknife test indicated that precipitation of the wettest month and temperature seasonality were more informative when used in predicting prevalence for *A. lumbricoides*.

For hookworms, a total training gain of 1.86 and an AUC value of 0.948 (red bars) was observed (Fig. 6). Also, precipitation of the wettest month had the highest training gain of 1.26 and an AUC value of 0.889 when used alone. This variable was therefore considered the most informative in predicting the prevalence of hookworms.

The variables assessments for *T. trichiura* were observed to be different from the other parasites. A total training gain of 1.96 and an AUC value of 0.95 were observed with minimum temperature of the coldest month having the highest impact on the prevalence of this parasite when used alone with a training gain of 1.3 followed by precipitation of the wettest month and altitude both having training gain of 1.1. For the AUC values, altitude was highest with 0.906 followed by precipitation of the wettest month and minimum temperature of the coldest month with AUC values of 0.892 and 0.882, respectively (Fig. 7).

The modeling result of STH in Nigeria revealed that most of the areas at high risk of infections were the states in the South-East (Anambra, Enugu, Imo, Abia and Ebonyi), South-South (Edo, Rivers, Delta, Cross-River, Akwa-Ibom and Bayelsa) and some states in the South-West (Lagos, Ogun and Ondo) and North Central (Benue and Kogi) and few states in

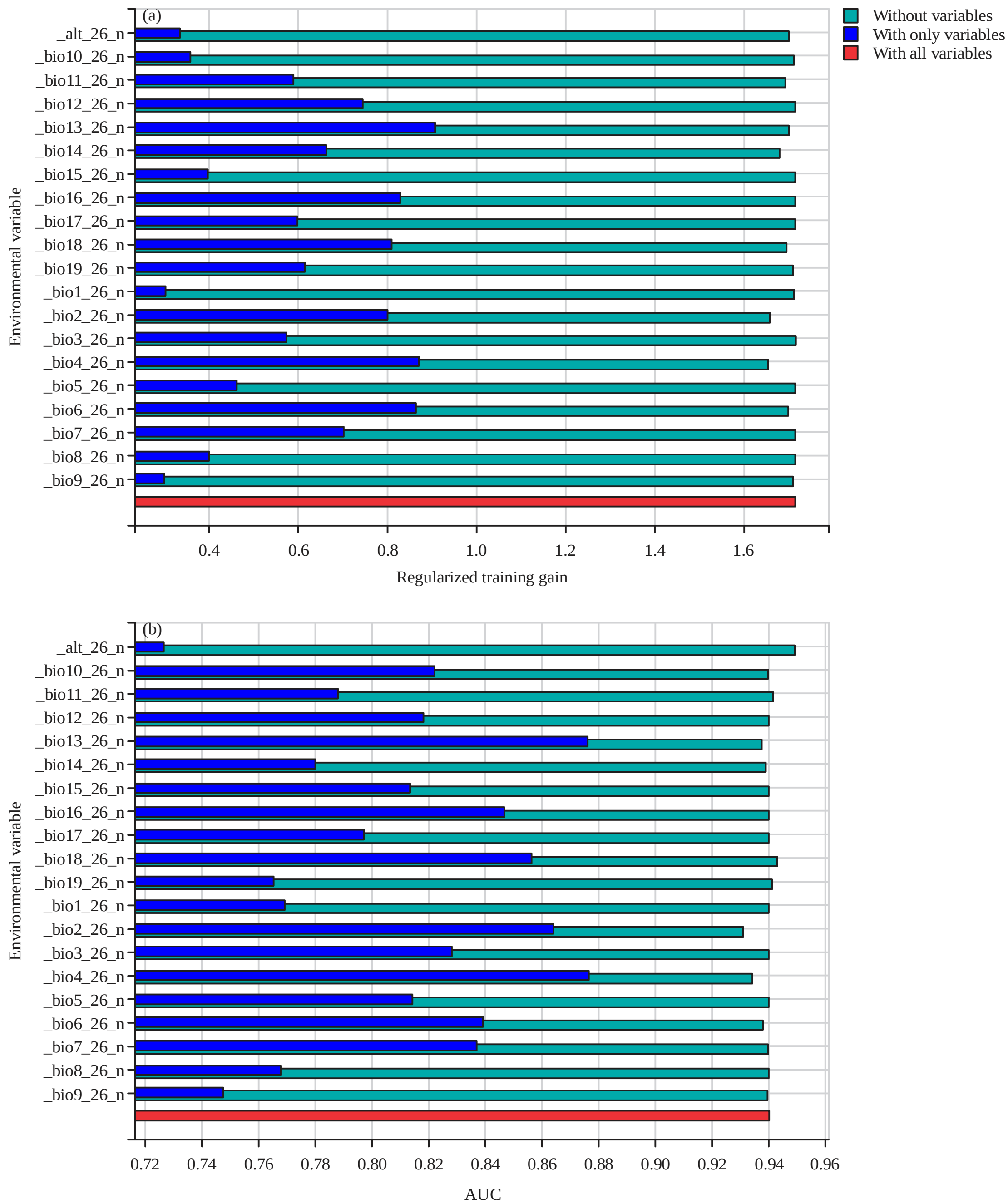

Fig. 5(a-b): *Ascaris lumbricoides* Jacknife Analysis (a) Training gain and (b) AUC
The dark blue, light blue and red bars represent results of the model with each individual variable, all the remaining variables and all variables respectively

the extreme northern part of the country such as Kebbi and Niger and parts of Taraba and Adamawa States. These areas are observed to have high precipitation throughout the year and were mostly in locations of low altitude. Kebbi, Niger and Taraba States fell within the high risk region, despite their low precipitation and high altitude when compared to the southern region.

DISCUSSION

Most regions in Nigeria were characterised by varying prevalence of STHs. This study revealed that all states in Nigeria were endemic for STHs with some regions at higher risk than others. The high prevalence of STHs in Southern Nigeria observed in this study was due to the favourable

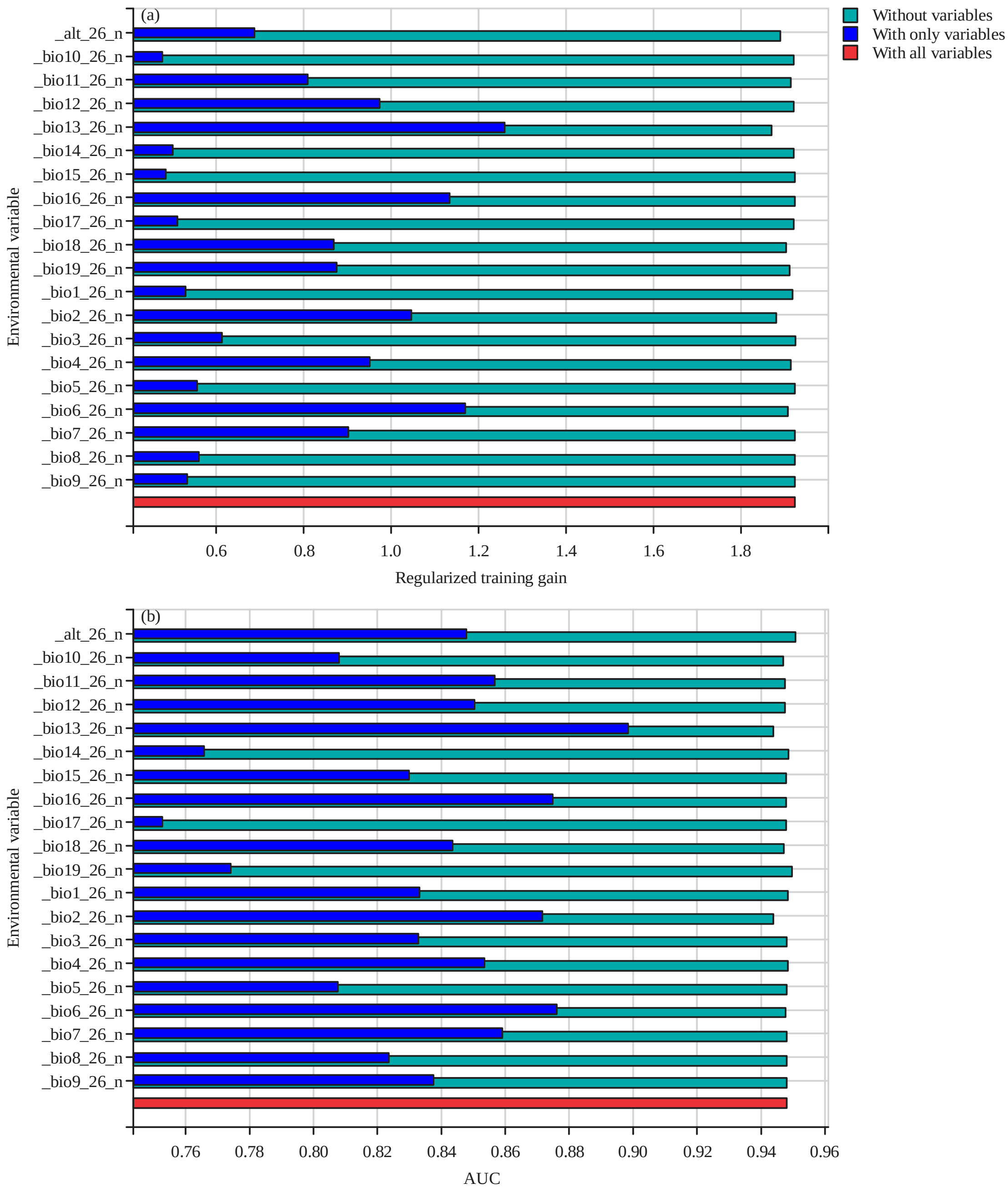

Fig. 6(a-b): Hookworms Jacknife Analysis (a) Training gain and (b) AUC
The dark blue, light blue and red bars represent results of the model with each individual variable, all the remaining variables and all variables respectively

environmental conditions such as high level of precipitation and the low altitude of these regions[112]. Altitude was inversely proportional to the prevalence of STH infections. That is, the lower the altitude, the higher the prevalence of STH infections. On the other hand, temperature and precipitation were directly proportional to the prevalence of STH infections. This explains the high prevalence and risk in the Southern region. The reverse situation observed in Kebbi, Niger and Taraba States with high risk of infection with STHs despite low precipitation and high altitude could be due to the presence of man-made lakes that run through several communities providing the required humidity for STHs transmission. This trend was same in Kano State only in the case of *A. lumbricoides* which may be due to other prevailing factors such as population density and human behaviour. Awolaju and Mornikeji[97] and Ojurongbe *et al.*[98] stated that other

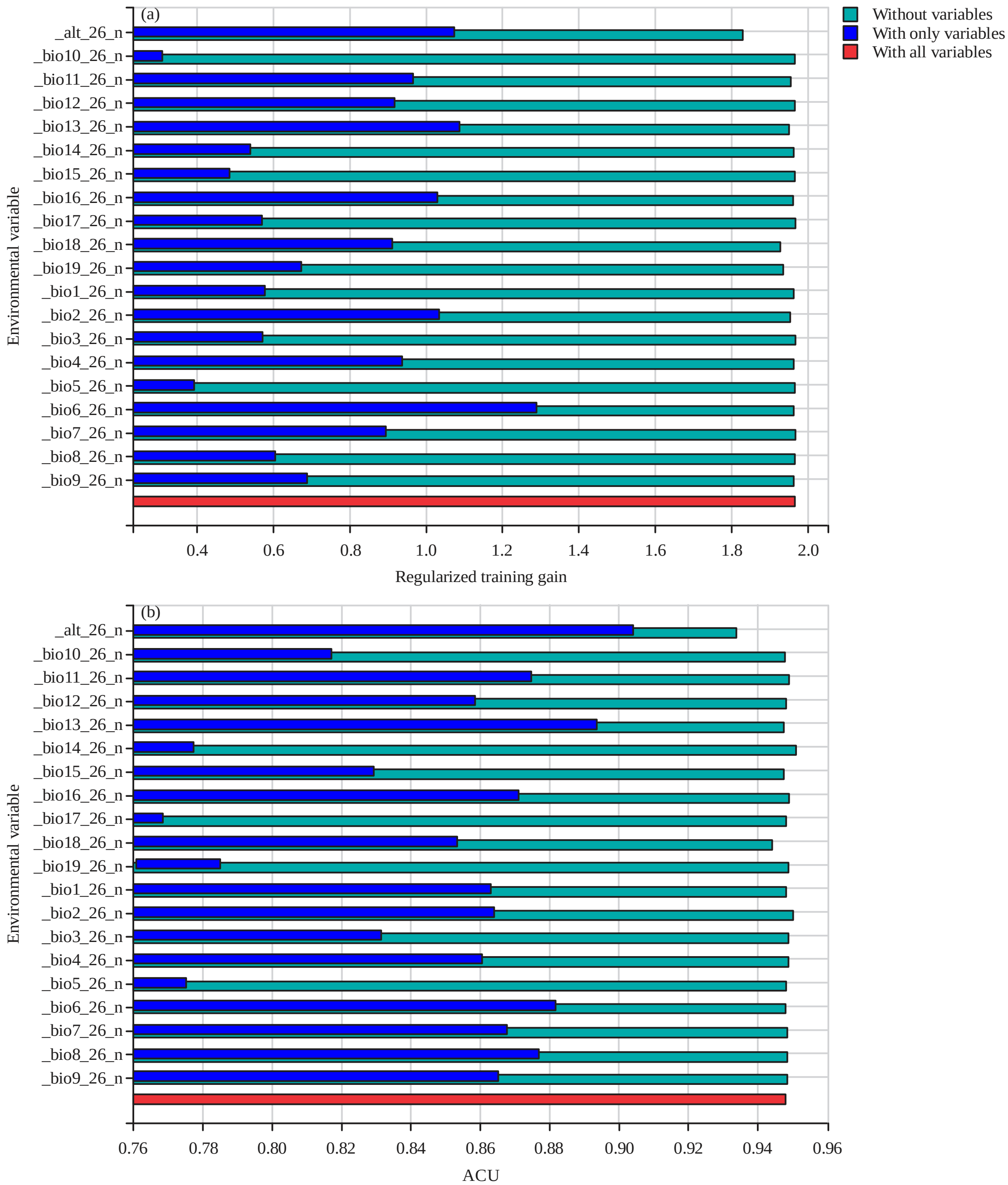

Fig. 7(a-b): *Trichuris trichiura* Jacknife Analysis (a) Training gain and (b) AUC

The dark blue, light blue and red bars represent results of the model with each individual variable, all the remaining variables and all variables respectively

factors such as socio-economic status, unhygienic practices, ignorance and poverty of the people are among the factors contributing to the high prevalence of STHs in these regions. Ugbomoiko *et al.*[113] reported that the use of leaves and paper to clean up after defecation and the act of geophagy are attitudes common among the people in Southern and North-Central Nigeria and this might also contribute to the high level of infection.

Other factors that are responsible for STHs infection generally in Nigeria are lack of or inadequate toilet facilities leading to open field defecation in most communities, poor personal hygiene and improper environmental sanitation conditions, behaviour of individuals such as biting of fingernails, walking barefoot[112], drinking of contaminated water and low socio-economic status of the populace.

From the spatial distribution of STHs, most communities in Nigeria were characterized with prevalence below 20%. Similar observation was reported by Oluwole *et al.*[76] who stated that the overall low infection of 20% could be due to the periodic deworming of school-aged children. However, the risk prediction showed that increase in prevalence of these parasites was expected in areas presently having prevalence of below 20%. The results obtained using 20 environmental variables revealed that precipitation of the wettest month; altitude and minimum temperature of the coldest month were the three major environmental variables that determined the distribution of these parasites in Nigeria. Similar observation was reported in the studies of Otto[114], Spindler[115] and Oluwole *et al.*[76], in which they stated that high humidity promotes quick embryonation of *A. lumbricoides* eggs. Studies by Chammartin *et al.*[116] and Lai *et al.*[117] in Bolivia and China respectively also reported the influence of temperature on the distribution of STHs. Oluwole *et al.*[76] stated that the low predicted risk in Northern Nigeria could be due to the extreme heat and short wet season (low precipitation) characteristic of the region. High altitude which was among the top variables in the determination of infections was observed to significantly contribute to the low risk areas in Northern Nigeria than Southern Nigeria. Communities located at high altitude also experience low or no influx of parasitic contaminants.

In this study, *A. lumbricoides* was observed to have the widest potential spatial distribution in Nigeria with many areas at risk compared to hookworms and *T. trichiura*. This was similar to the observations of Pullan *et al.*[118] in Kenya, Chammartin *et al.*[116] in Bolivia and Lai *et al.*[117] in China.

CONCLUSION AND RECOMMENDATION

Nigeria is endemic for the *A. lumbricoides*, hookworms and *Trichuris trichiura* with an average prevalence of 25.17, 16.86 and 9.74%, respectively.

Precipitation of the wettest month, altitude, precipitation of the warmest quarter, temperature seasonality and annual precipitation are the five top environmental variables that majorly affect the distribution of STH infections in Nigeria.

Southern Nigeria has high prevalence of STH infections than Northern Nigeria.

The information generated by the model can be used as a guide for the planning and control of STHs in Nigeria that will yield greater result within the limited funding and human resources available if targeted at the high risk areas revealed in the maps generated by the model.

SIGNIFICANCE STATEMENT

This study discovers the areas of high risk for soil transmitted helminths infections in Nigeria as well as identifying environmental variables that majorly determines the distribution of these parasites. This study will help researchers, policy makers in the health sector and other relevant authorities to intensify control strategies in areas of high risk of infections. It reveals that increasing altitude leads to decreased prevalence and increasing temperature and precipitation leads to increased prevalence.

ACKNOWLEDGMENTS

The authors appreciate the Center for Information and Communication Technology, Kogi State University, Anyigba, Nigeria for providing an enabling environment for the analysis to be conducted.

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