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Spatial Distribution and Modeling of Soil Transmitted Helminthes Infection in Nigeria

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Abstract

Background and Objective: Soil transmitted helminthes (STH) infection affects 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 were assessed from 98 journals and the prevalence of *Ascaris lumbricoides*, *Trichuris trichiura* and hookworms were extracted from them. The spatial distribution of the parasites was performed using DIVA-GIS software. The climatic variables (temperature and precipitation) and elevation variable (altitude) were used in the modeling of the parasites using Maximum Entropy (MaxEnt) modeling tool. **Results:** The average prevalence of *A. lumbricoides*, Hookworms and *T. trichiura* in Nigeria is 25.17%, 16.86% and 9.74% respectively. Delta State (62.08%) had the highest infection of *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 States having the least prevalence of 0.80 and 0.90% respectively. The potential distribution that reveals than southern Nigeria has been at high risk of infections. Precipitations of the wettest month, altitude, precipitation of the warmest quarter are the major environmental variables that affect the distribution of STH. **Conclusion:** Nigeria is characterized by varying prevalence of STHs. All states in Nigeria are endemic for STHs. Southern Nigeria was observed to have higher prevalence of STHs due to the high level of precipitation and low altitude of these regions. “The higher the altitude, the lower the prevalence of STH infections. The higher the temperature and precipitation, the higher the prevalence of STH infections.

Keywords

MaxEnt, Altitude, Temperature, Precipitation, Soil Transmitted Helminths

1. 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.

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 helped policy makers and researchers in the health sector to concentrate in areas of high risks thereby helping to reduce operational cost.

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

Maximum entropy (MaxEnt) modeling is a general-purpose method for making predictions of inferences from incomplete information [11]. Maximum entropy modeling 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 modeling techniques such as MaxEnt that require only presence data are therefore extremely valuable [13]. MaxEnt modeling 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 would help to improve existing distribution maps. This study will help to identify areas of high suitability for soil transmitted helminth infections as well as rank environmental variables according to their relative importance in the determination of 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 modeling tools.

2. Materials and Methods

2.1. Ethics Statement

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

2.2. 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.

2.3. Environmental Data

The climatic variables such as temperature and precipitation influenced global and meso scales and topographic variables such as altitude and aspect that likely affects 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 the climatic and topographic variables in the prediction of distributions of soil transmitted parasites was used 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/ at 1 km spatial resolution *i.e.* Worldclim database version 1.4 and were used in the prediction of soil transmitted helminthes distribution; 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 affect the rate of embryonation of STH parasites. As altitude increases, temperature also decreases, so highlands were colder and lowlands were warmer, which in turn affects the development rate of these parasites.

2.4. 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 file files using DIVA-GIS and were geo-referenced on the map of Nigeria. The prevalence of these parasites were categorized <5, ≥5 to <10, ≥10 to <20, ≥20 to <40 and ≥40.

2.5. 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]: it is present only modeling algorithm (*i.e.* absence data are not required), the performance has been relatively better than other modeling methods and the model has been hardly influenced by small sample sizes and hence prediction will be relatively robust. It has been shown to be among the top performing modeling 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 serve as the presence records to generate background points that was used in finding the maximum entropy distribution [16]. Regularization of the prevalence was performed to control over-fitting. This modeling tool uses five different features to perform its statistics; linear, quadratic, product, threshold and hinge features to produce a geographical distribution of species within a define area. MaxEnt produces a logistic output format used in the production of a continuous map that provides visualization of graded prevalence with an estimated probability of acquiring infection with 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 modeling. 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 calculation on the sets of data obtained 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, 0.5 - 0.7 signifies poor performance, 0.7 - 0.9 signifies reasonable/moderate performance and >0.9 indicates high model performance [18].

Model validation was performed according to Sarma *et al.* [16] as follows; 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 is 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 analyzed 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 color for visual representation of model results ranging from low risk to high risk: 0 - 0.10 (dark green), 0.10 - 0.20 (light green), 0.20 - 0.50 (yellow), 0.50 - 0.70 (orange) and 0.75 - 1 (red).

3. Results

3.1. 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. While *A. lumbricoides* has the highest average prevalence (**Table 1**), these recorded occurrences of STH 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

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

S/No	State	Mean % ± S.E.			Authors
		Ascaris lumbricoides	Hookworms	*Trichuris trichiura*	
1	Abia	18.50 ± 9.19	14.64 ± 3.60	10.39 ± 5.69	Nduka *et al.* [19], Wosu and Onyeabor [20], Kalu and Ihemanma [21], Ihemanma and Oladele [22], Ezeigbo and Ezeigbo [23]
2	Adamawa	9.32 ± 6.60	8.95 ± 4.76	3.70 ± 1.05	Naphtali *et al.* [24] and Enimien *et al.* [25], Houmsou *et al.* [26], Oriakpono *et al.* [27] and Naphtali *et al.* [28]
3	Akwa Ibom	36.07 ± 18.14	55.80 ± 13.44	40.40 ± 29.99	Opara *et al.* [29], Usip and David [30], Usip and Matthew [31]
4	Anambra	19.23 ± 7.68	18.43 ± 6.07	4.73 ± 1.07	Chukwuma *et al.* [32], Ogbuagu *et al.* [33], Ezeagwuna *et al.* [34], Emmy-Egbe [35] and Chioma *et al.* [36]
5	Bauchi	NAD	NAD	NAD	
6	Bayelsa	35.15 ± 0.15	24.53 ± 7.10	7.80 ± 6.10	Agi and Awi-Waadu [37], Bariweni *et al.* [38] and Bariweni *et al.* [39]
7	Benue	NAD	35.40 ± 0.00	3.80 ± 0.00	Tyoalumun *et al.* [40]
8	Borno	2.30 ± 1.30	14.10 ± 4.10	0.90 ± 0.00	Biu *et al.* [41] and Biu *et al.* [42]
9	Cross River	3.00 ± 0.00	5.60 ± 0.00	1.40 ± 0.00	Usip and Ita [43]
10	Delta	62.08 ± 8.60	38.08 ± 10.12	24.05 ± 3.04	Egwunyenga and Ataikiru [44], Nmorsi *et al.* [45], Prosper *et al.* [46] and Ito and Egwunyenga [47]
11	Ebonyi	38.19 ± 6.78	15.96 ± 4.08	9.52 ± 2.54	Uneke *et al.* [48], Ivoke *et al.* [49], Alo *et al.* [50], Dimejesi *et al.* [51], Ivoke *et al.* [52], Okeke and Ubachukwu [53], Nnachi *et al.* [54] and Owaka and Njoku [55]
12	Edo	15.05 ± 4.96	6.47 ± 1.34	2.68 ± 1.26	Wagbatsoma and Aisien [56], Mordi and Paul [57], Oguanya *et al.* [58], Omorodion *et al.* [59], Akinbo *et al.* [60], Nwaneri and Omuemu [61] and Ogbain-Emovon *et al.* [62]
13	Ekiti	NAD	NAD	NAD	
14	Enugu	22.84 ± 12.54	19.54 ± 9.84	11.53 ± 10.73	Emeka [63], Ukwubile *et al.* [64], Aniwada *et al.* [65] and Uzodimma *et al.* [66]
15	FCT	2.50 ± 0.00	4.20 ± 0.00	0.80 ± 0.00	Abayer *et al.* [67]
16	Gombe	NAD	NAD	NAD	
17	Imo	22.76 ± 5.94	11.16 ± 2.29	5.83 ± 1.62	Kamalu *et al.* [68], Kalu *et al.* [69], Ezeigbo *et al.* [70], Udensi *et al.* [71], Kalu *et al.* [72] and Iwunze *et al.* [73]
18	Jigawa	29.50 ± 0.00	24.30 ± 0.00	8.10 ± 0.00	Yahaya *et al.* [74]
19	Kaduna	38.48 ± 7.78	10.38 ± 3.98	4.70 ± 0.20	Auta *et al.* [75], Thomas *et al.* [76] and Auta *et al.* [77]
20	Kano	44.40 ± 0.00	55.80 ± 0.00	NAD	Ahmad *et al.* [78]
21	Katsina	NAD	NAD	NAD	
22	Kebbi	22.00 ± 0.00	10.00 ± 0.00	13.60 ± 0.00	Oluwole *et al.* [79]
23	Kogi	22.00 ± 0.00	17.00 ± 0.00	NAD	Ejima and Ajogun [80]
24	Kwara	19.11 ± 5.57	10.72 ± 4.54	23.37 ± 17.36	Babatunde *et al.* [81], Saka *et al.* [82], Babamale *et al.* [83], Amaechi *et al.* [84] and Bolaji *et al.* [85]
25	Lagos	34.17 ± 18.21	22.85 ± 22.15	24.85 ± 6.45	Adeoye *et al.* [86], Iridapo and Okwa [87] and Ajayi *et al.* [88]

Continued

26	Nassarawa	39.60 ± 0.00	NAD	NAD	Eke *et al.* [89]
27	Niger	10.60 ± 0.00	9.60 ± 0.00	3.90 ± 0.00	Omalu *et al.* [90]
28	Ogun	9.35 ± 3.83	3.65 ± 0.45	3.75 ± 1.95	Okonko *et al.* [91], Sam-Wobo *et al.* [92], Akingbade *et al.* [93] and Banjo *et al.* [94]
29	Ondo	30.03 ± 12.06	16.62 ± 8.45	6.48 ± 2.43	Simon-Oke *et al.* [95], Akinseye *et al.* [96], Dada and Aruwa [97] and Akinseye *et al.* [98]
30	Osun	33.63 ± 5.52	11.00 ± 3.40	4.07 ± 2.17	Kirwan *et al.* [99], Awolaju and Morenikeji [100], Ojurongbe *et al.* [101], Ojurongbe *et al.* [102], Salawu and Ughele [103], Olaniran *et al.* [104] and Fafunwa *et al.* [105]
31	Oyo	55.50 ± 0.00	35.80 ± 0.00	2.90 ± 0.00	Alli *et al.* [106]
32	Plateau	18.35 ± 8.86	10.79 ± 3.13	3.20 ± 1.55	Damen *et al.* [107], Jombo *et al.* [108], Abelau *et al.* [109], Mamman and Reuben [110] and Afolaranmi *et al.* [111]
33	Rivers	9.00 ± 0.00	2.70 ± 0.00	4.00 ± 0.00	Odu *et al.* [112]
34	Sokoto	5.00 ± 0.00	6.60 ± 0.00	3.20 ± 0.00	Mohammed *et al.* [113]
35	Taraba	NAD	NAD	NAD	
36	Yobe	NAD	NAD	NAD	
37	Zamfara	6.50 ± 0.00	3.50 ± 0.00	5.20 ± 0.00	Shehu *et al.* [114]
	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 ≤ 0.05, ns: not significant at p > 0.05.

Kano (44.40%). Meanwhile, it was observed that the prevalence of *A. lumbricoides* was high for 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%.

T. trichiura which 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 States having the least prevalence of 0.80% and 0.90% respectively.

3.2. Predicted Risk of *A. lumbricoides* Infections

The predicted high risk areas of *A. lumbricoides* infections were South-East and South-West region of Nigeria with probability of ≥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 are at risk of infections with probability of ≥0.50. In North-West Nigeria, Kano and Katsina States are the two states that fall 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 ≥0.20 (Figure 1).

3.3. Model Performance and Influencing Factors

The average percent contribution (PC) and permutation importance (PI) of the 20 variables used in the modeling of STH in this study were also assessed. In this study, 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 are among the five top variables in the modeling of STH in Nigeria. The other variables that performed well in the modeling 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 Figure 2. Specificity was calculated. The

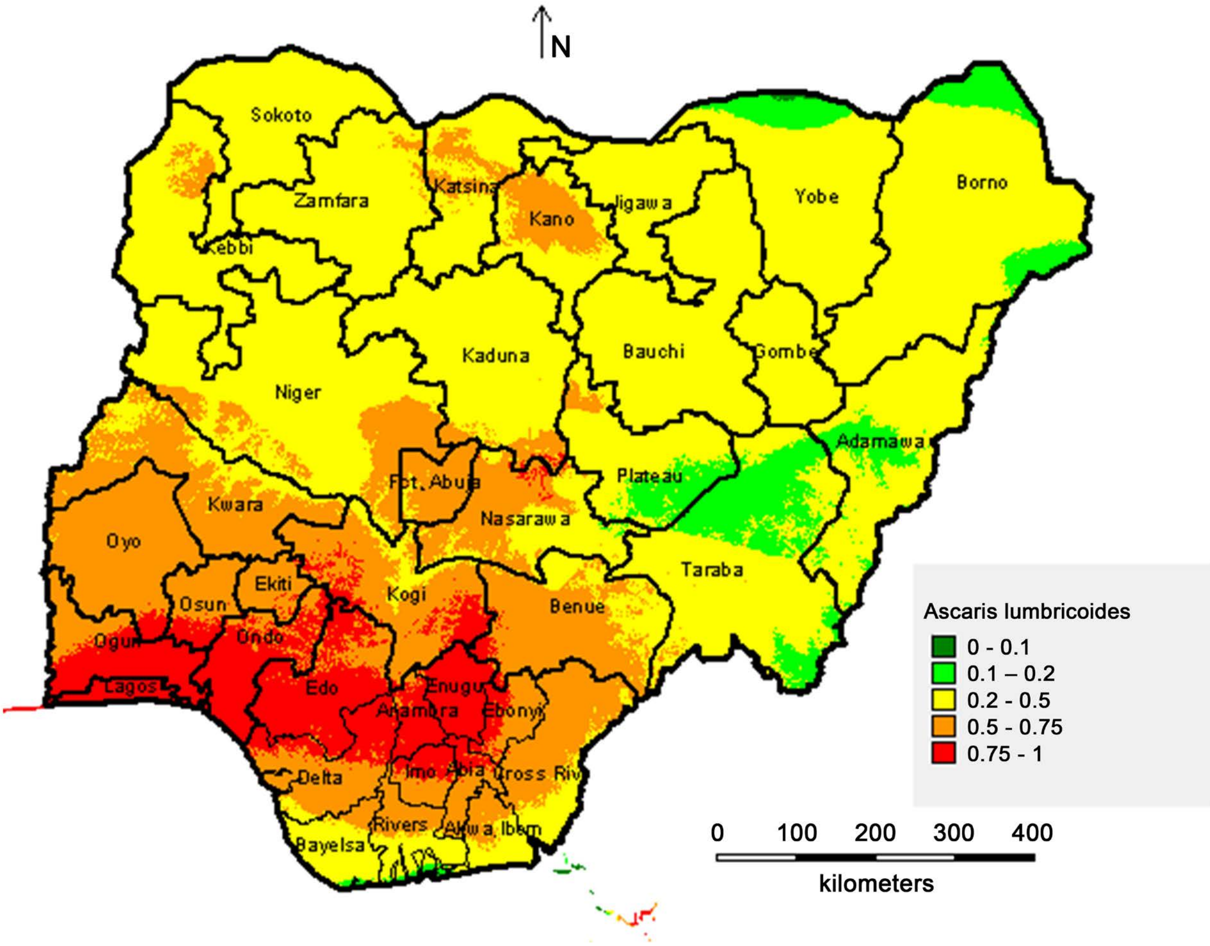


Figure 1. Predicted prevalence of *Ascaris lumbricoides* in Nigeria.

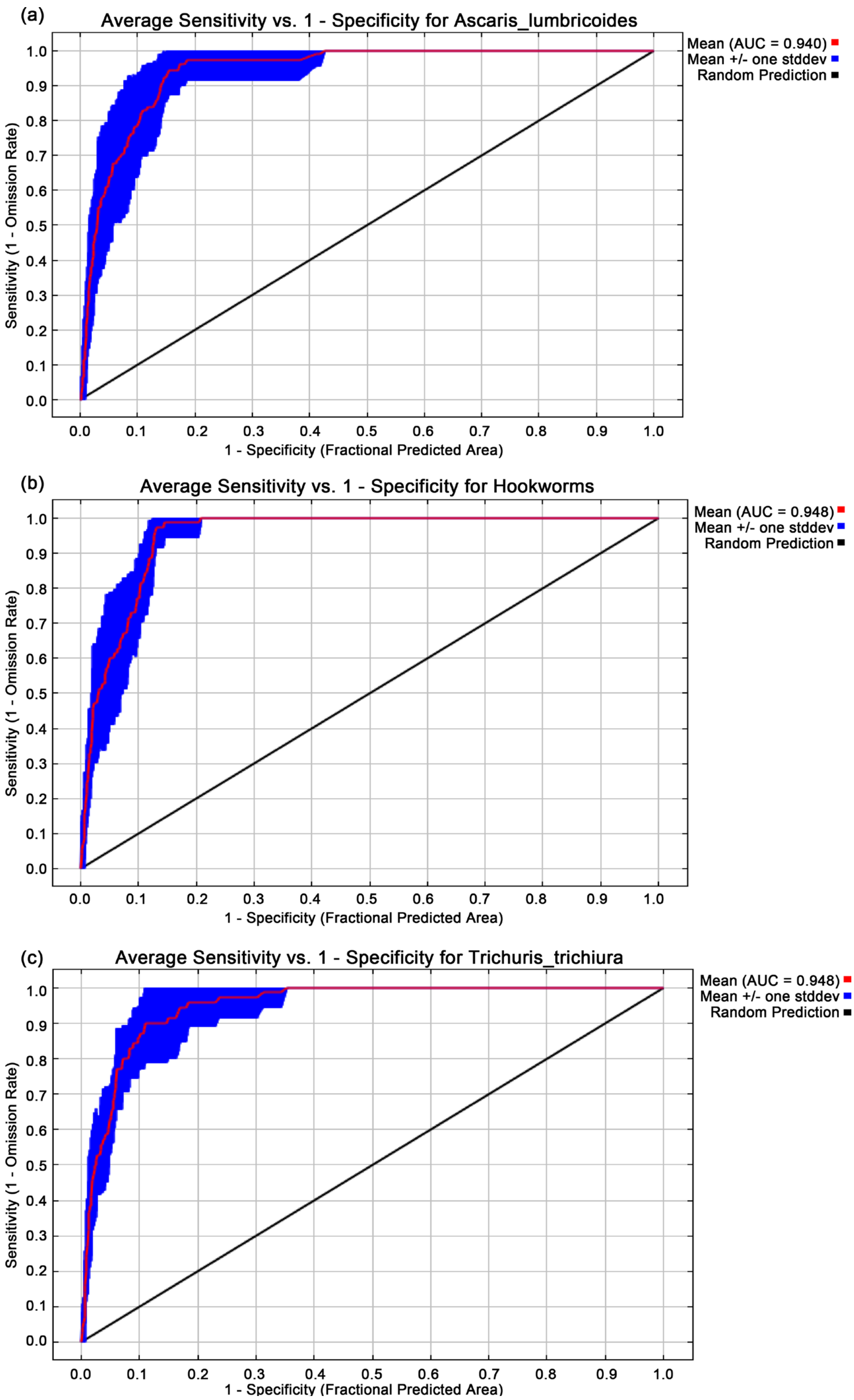
Table 2. Average percent contribution (APC) and average permutation importance (API) of soil transmitted helminthes infection distribution models.

Variable Type	Variables	*Ascaris lumbricoides*		Hookworms		*Trichuris trichiura*		Top five models	
		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.

average and standard deviation of the area under the curve (AUC) for the 10 replicate runs was 0.940 ± 0.028, 0.948 ± 0.017 and 0.948 ± 0.021 for *A. lumbricoides*, Hookworms and *T. trichiura* respectively. These values show an excellent performance of the modeling software as an AUC value of greater than 0.80 shows 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 Figure 3 which gave a total training gain of 1.7 (red bar) and an area under the curve (AUC) value of 0.94 (red bar). The jackknife test indicated that precipitation of wettest month and temperature seasonality are the two variables when used alone will affect the prevalence of *A. lumbricoides* the most. Meanwhile, no variable was observed to significant decrease the gain the most. The jackknife test indicated that precipitation of the wettest month and temperature seasonality are more informative when used in



(a) 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. (b) 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. (c) 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.

Figure 2. Area under the Curve (AUC) (a) *Ascaris lumbricoides* (b) Hookworms (c) *Trichuris trichiura*. Red line indicates the mean value for 10 MaxEnt replicate runs and blue indicates the standard deviation.

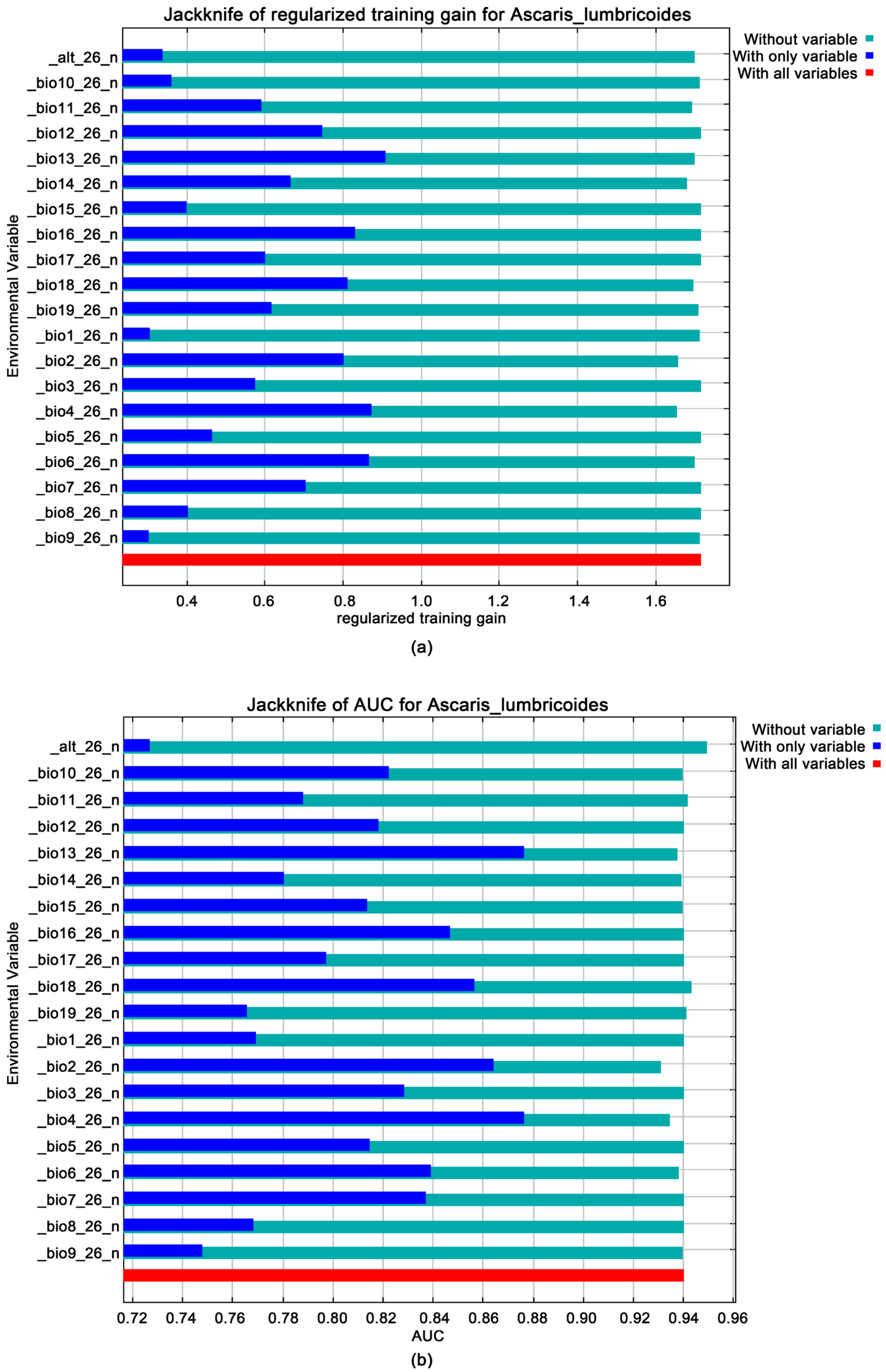


Figure 3. *Ascaris lumbricoides* Jacknife Analysis (a) training gain and (b) AUC. The dark blue, light blue and red bars represent results of the model with each individual variable, all the remaining variables and all variables respectively.

predicting prevalence for this *A. lumbricoides*.

For hookworms, a total training gain of 1.86 and an AUC value of 0.948 (red bars) was observed (**Figure 4**). 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 is therefore considered the most informative in predicting the prevalence of hookworms.

The variable assessment for *T. trichiura* was 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 with training gain of 1.1 both. 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 (**Figure 5**).

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 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.

3.4. Predicted Risk of Hookworms Infections

The five states in South-East Nigeria (Enugu, Imo, Owerri, Ebonyi and Anambra), Edo and Delta States in South-South Nigeria and Lagos and Ogun States in South-West Nigeria are in the high risk areas of hookworm infections with probability of ≥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 part of some states in North-Central (Kogi, Benue, Nasarawa, Niger and FCT) were within areas with risk of probability of ≥0.50. Some states in Northern Nigeria fall within the low risk areas. Part of Kebbi, Sokoto, Plateau, Taraba, Jigawa, Yobe and Borno States with probability of 0.00 to ≤0.10 (**Figure 6**).

3.5. 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 ≥0.50. Kaduna and Katsina states fall within the low risk areas (**Figure 7**).

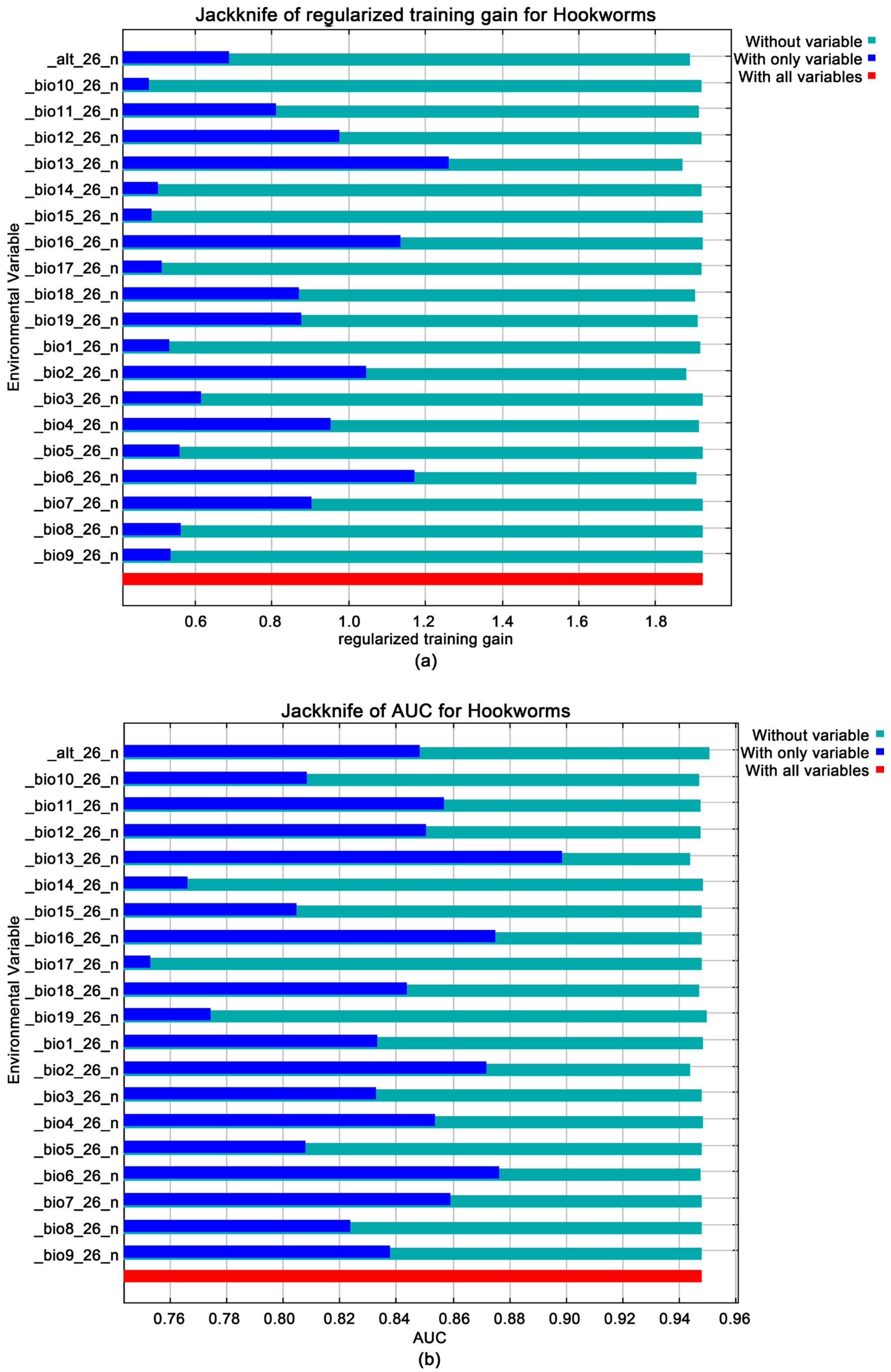
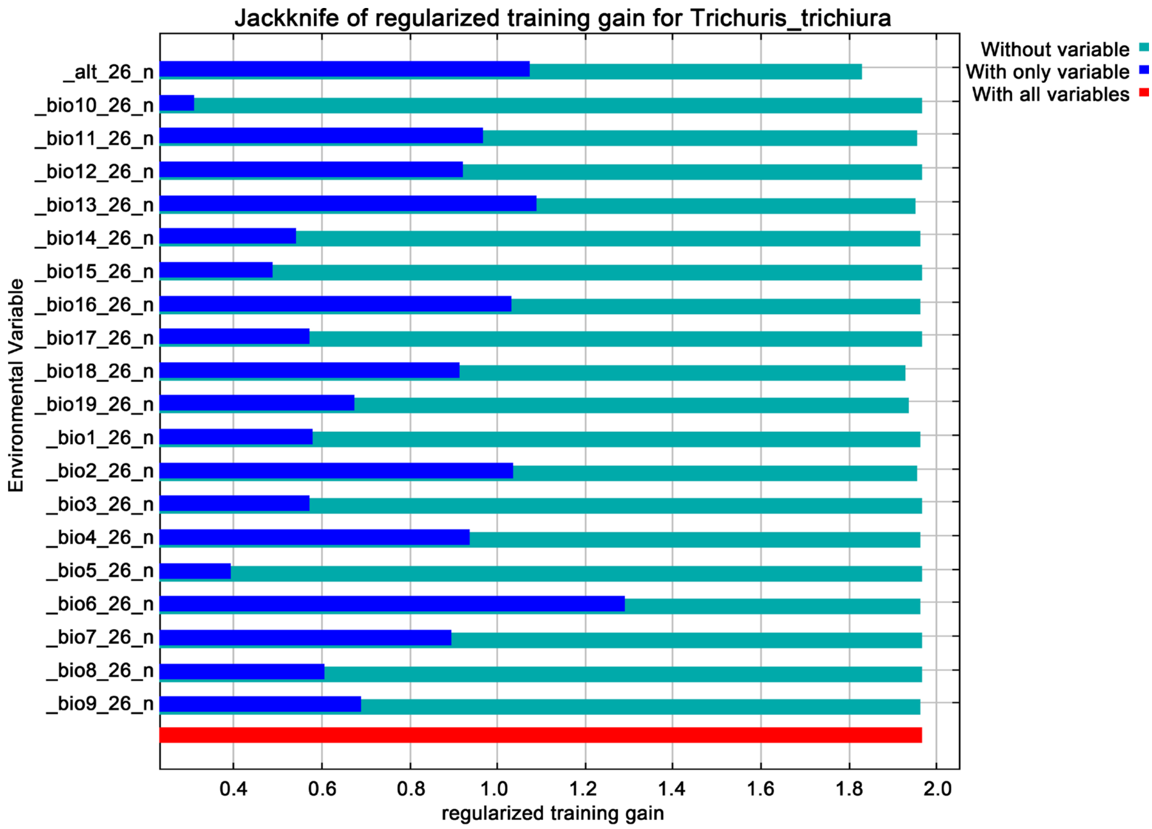
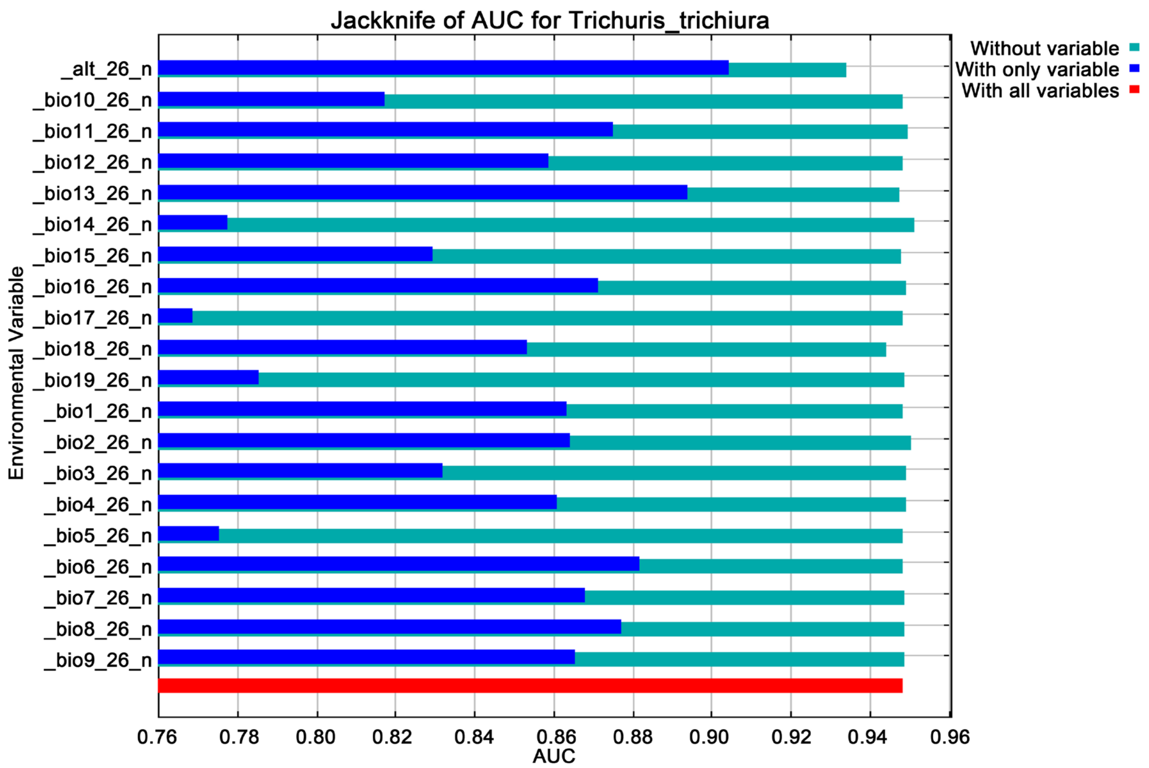


Figure 4. Hookworms Jacknife Analysis (a) training gain and (b) AUC. The dark blue, light blue and red bars represent results of the model with each individual variable, all the remaining variables and all variables respectively.



(a)



(b)

Figure 5. *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.

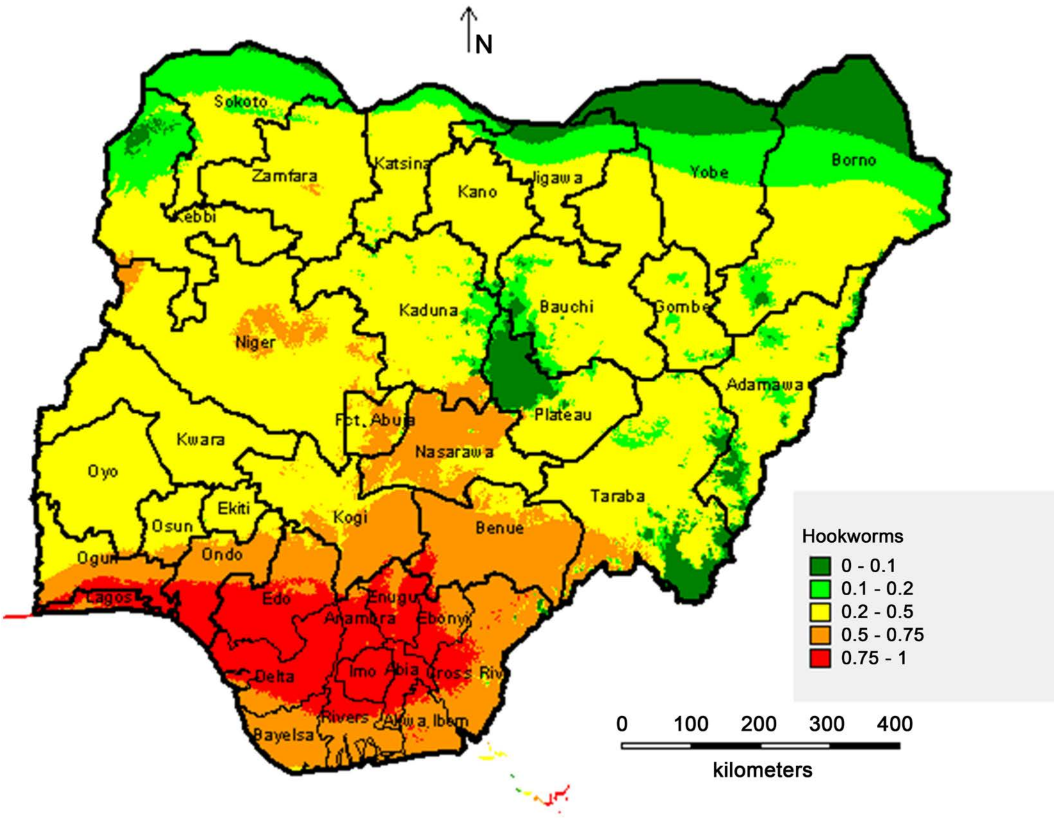


Figure 6. Predicted prevalence of Hookworms in Nigeria.

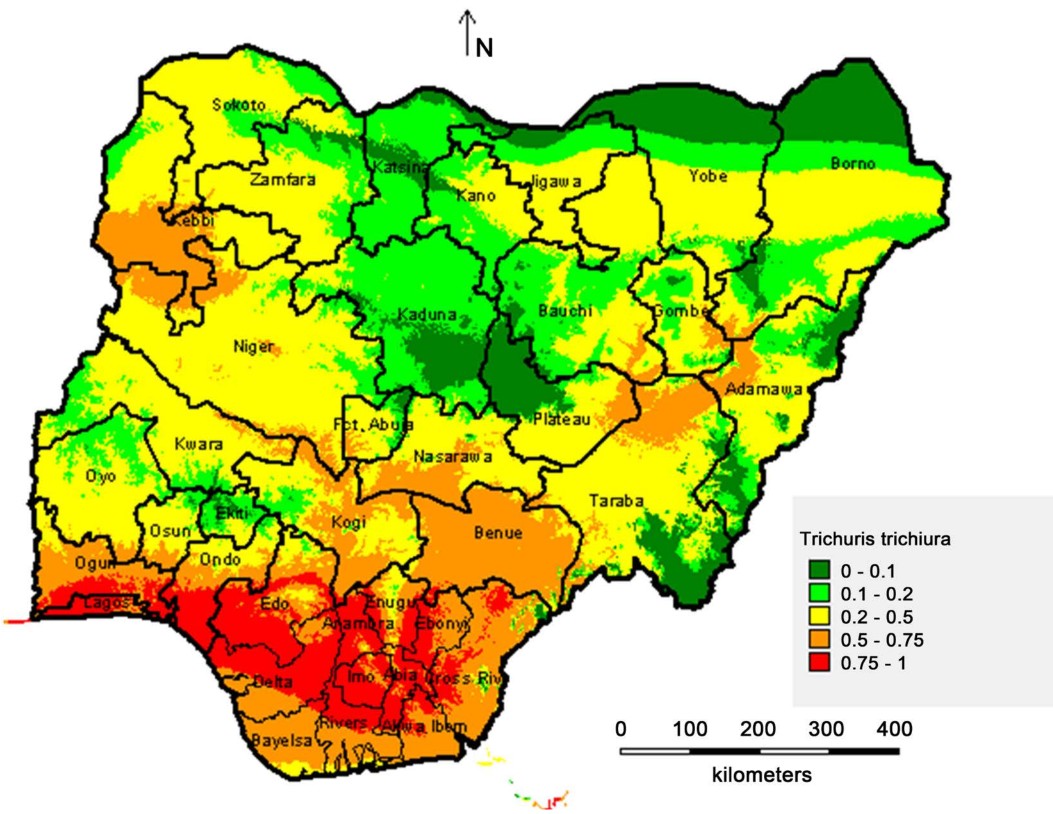


Figure 7. Predicted prevalence of *Trichuris trichiura* in Nigeria.

4. Discussion

Most regions in Nigeria were characterized 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 favorable environmental conditions such as high level of precipitation and the low altitude of these regions [115]. 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 which 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 behavior. Awolaju and Morenikeji [100] and Ojurongbe *et al.* [116] stated that other factors such as socio-economic status, unhygienic practices, ignorance and poverty are among the factors contributing to the high prevalence of STHs in this region. Ugbomoiko *et al.* [117] reported that the use of leaves and paper to clean up after defecation and the act of geophagy are attitudes common in Southern Nigeria and North-Central Nigeria and this might also contribute the high level of infection.

Other factors that are responsible for STHs infection generally in Nigeria are lack of and inadequate toilet facilities leading to open defecation in most communities, poor personal hygiene and improper environmental sanitation, behavior of individuals such as biting of fingernails, walking barefoot [115], 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.* [79] who stated that the overall low infection of 20% could be due to the periodic deworming of school-aged children. Although, the risk prediction shows 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 determine the distribution of these parasites in Nigeria. Similar observation was noted in the studies of Otto [118], Spindler [119] and Oluwole *et al.* [79], they stated that high humidity promotes quick embryonation of *A. lumbricoides* eggs. Studies by Chammartin *et al.* [120] and Lai *et al.* [121] in Bolivia and China respectively also reports the influence of temperature on the distribution of STHs. Oluwole *et al.* [79] states that the low predicted risk in Northern Nigeria could be due to the extreme heat and short wet season. High altitude which was among the top variable in the determinant of infections was observed to significantly contribute to the low risk areas in Northern Nigeria than Southern Nigeria as this region was located on high altitude. Communities located at high altitude also experience low or no influx of parasitic contaminants.

In this present study, *A. lumbricoides* was observed to have the widest spatial and potential distribution in Nigeria with many areas at risk compared to hookworms and *T. trichiura*. This was similar to what was observed by Pullan *et al.* [122] in Kenya, Chammartin *et al.* [120] in Bolivia, Lai *et al.* [121] in China.

5. Conclusion

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 environmental variables that majorly affect the distribution of soil transmitted helminth infections in Nigeria. Southern Nigeria has high prevalence of soil transmitted helminth infections than Northern Nigeria.

Recommendations

The model generated will help to guide individuals in the high risk areas to take preventive and curative measures. The finding also provides us with the scientific understanding of the effect of precipitation, temperature and altitude on the distribution of STHs. Based on this knowledge, planning and control of STHs in Nigeria will yield greater result with the limited funding and human resources available.

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Conflict of Interest

The authors have declared that no competing interest exists.

Authors Contribution

EK conceived the study, CAY extracted data and carried out statistical analysis. EK, CAY and SAL developed the manuscript, read and approved the final manuscript.

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 determine 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 lead to increased prevalence.

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