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Effects of Land Surface Temperature, Soil Water Content and Land Use/Cover on the Spatial Distribution of Urinary Schistosomiasis in the FCT, Nigeria Using GIS and Remote Sensing

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Abstract

This study was designed and conducted to determine the effect of some environmental factors - Land Surface Temperature (LST), Land Use/Cover (LUC) and Soil Water Content (SWC) on the distribution of urinary schistosomiasis in the FCT using the Geographic Information System and Remote Sensing. The prevalence data of 14.8% was obtained from a study among 83 primary school pupils in various communities in the FCT between 2011 and 2013, using blood-in-urine as diagnostic indicator of infection. Remotely-sensed environmental data for land surface temperature, land use/cover and soil water content were downloaded from the United States Geological Survey website hosting the Moderate Resolution Imaging Spectro-Radiometer (MODIS) data specific to the geo-location of prevalence data. These were processed and analysed in GIS using spatial intepolation and displayed as maps. Soil water content was the only significant environmental variable among the listed ones in the determination of the pattern of prevalence of urinary schistosomiasis in the FCT. These were tested using Logistic Binary Regression Analysis (Forward Stepwise – Likelihood Ratio method) and the resulting model correctly predicted the pattern of infection to the tune of 80% using the equation P = 1/1 + e^{-z} where P is the probability of finding infection in the FCT and z = -6.40 + (0.04 x soil water content). The highest number of schools harbouring infected pupils was in the area with high soil water content. This may be due to the fact that the bulinid intermediate snail vectors require high soil water for their survival and transmission, particularly in the FCT where there are late rains which are also not sustained for many months. This also brings the farming community into contact with the intermediate host to enhance sustained transmission of the infection. The result of this study shows that among the three variables investigated, soil with high water content was the major determining factor in the prevalence of urinary schistosomiasis in the FCT and this information is relevant in the delineation of at-risk communities for treatment and control purposes.

Keywords: Geographic Information System, Remote Sensing, Schistosomiasis, MODIS.

1. Introduction

Schistosomiasis is a parasitic disease caused by several species of Digenetic Trematodes of the Genus *Schistosoma which are* transmitted by Bulinid snails. These are aquatic snails of the Genera *Biomphalaria* and *Bulinus* which transmit *S. mansoni* and *S. haematobium*

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respectively. The disease is endemic in 35 out of 36 states in Nigeria and the Federal Capital Territory (Ekpo *et al*., 2013). Even the more urbanized Abuja Municipal Area Council was not exempted from the disease (Bassey and Aisien, 2018). *Schistosoma haematobium* is the more predominant species in the country as well as in the FCT (Ekpo *et al*., 2013; Bassey and Aisien, 2018). It is one of the re-emerging Neglected Tropical Diseases (NTDs) which is a source of great concern to African nations where it is endemic as well as to the World Health Organization (WHO, 2015; WHO, 1995). This is particularly so as studies have shown that about 11.3million children require treatment annually in Nigeria (Ekpo *et al*., 2013).

In recent times, automated mappings of epidemiological data as well as sophisticated analysis of satellite imagery which display vector/environment relationships are done using the Geographic Information System (GIS) (Malone, 2005). This is important because environmental factors are known to play a major role in the transmission of schistosomiasis; hence spatial epidemiology is employed in the determination of the complex interplay of these environmental factors in patterning infection. This gave rise to the Bayesian spatial models which are a major tool in the design of control measures especially when funding is limited (Clements *et al*., 2009). Studies using digitized maps of regional features have shown that population density and duration of annual dry season are the most important determinants of the prevalence of urinary schistosomiasis in Bahia, northern Brazil (Bavia *et al*., 1999). Climate and topography were also implicated in the determination of the spatial distribution of the disease (Berquist, 2001).

Mean temperature, annual precipitation and soil acidity were found to affect the spatial distribution of the disease in Nigeria (Ekpo *et al*., 2013). Studies in the Federal Capital Territory observed plinthosol soil type to be a significant variable in the spatial distribution of the disease and this was confirmed by the regression model which correctly predicted soil type as the significant variable to the tune of 80% (Bassey and Ekpo, 2018).

Studies on a larger scale in Africa revealed the interplay of some environmental factors in the distribution of schistosomiasis. In areas where total annual rainfall was <850mm or altitude was >1400m, there were no infections; hence there was no need for control measures (Brooker, 2007). The use of geographic information system and remote sensing alongside climatic data, infection prevalence and vector data base also revealed that the construction of the three Gorges dam projects in China caused changes in the distribution and abundance of the intermediate host *S. japonicum* (Zhou *et al*., 2001). In Tanzania, land surface temperature, land use/cover, soil water content, soil type and normalized difference vegetation index were shown to positively affect the distribution of urinary schistosomiasis. On the other hand, altitude showed a negative effect on the probability of schools having a prevalence of >50% whereas land surface temperature and normalized difference vegetation index both had a positive effect (Brooker *et al*., 2001). The Rapid Epidemiological Mapping of Onchocerciasis (REMO) Infection in Nigeria was made possible by the use of these tools (Gemade *et al*., 1998). In Nigeria, predictive maps of the probability of occurrence of urinary schistosomiasis have been produced and the risk of infection quantified in FCT, Ogun, Kano, Ondo, Cross River States and other parts of the country (Bassey and Ekpo, 2018; Ekpo *et al*., 2008; Abdullahi, 2009; Ajakaye *et al*., 2016; Adie *et al*., 2013; Ifeanyi *et al*., 2010). Pellic vertisol soil type was found to be significant in the determination of high and low risk areas in Ogun State. The purpose of this present study was to find out if land surface temperature, land use/cover and soil water content has any effect on the distribution of urinary schistosomiasis in the FCT.

2. Materials and Methods

2.1 Study area

The Federal Capital Territory (FCT) is located approximately in the centre of Nigeria; with the capital at Abuja. It lies between longitude 6.45 and 7.39 East of the Greenwich Meridian and latitude 8.25 and 9.20 North of the equator. In the dry season, daytime temperatures can be as high as 49^{o}C and can drop to 12^{o}C at night while the rainy season temperatures reach about 28-30^{o}C and 22-23^{o}C at night. The annual total rainfall is in the range of 1,100mm-1,600mm. The FCT is made up of 6 (six) Area Councils namely: Abuja Municipal Area Council, Abaji, Gwagwalada, Kuje, Bwari and Kwali Area Councils.

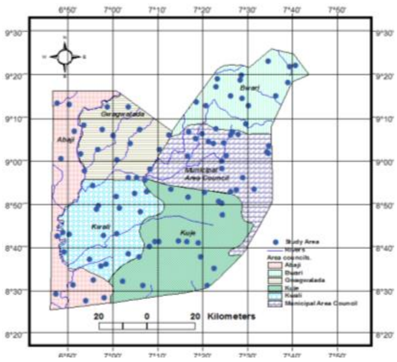

Fig. 1: Map of the FCT with grid lines showing the study area.

2.2 School survey and infection data

In order to get a uniform number of schools in communities representing the entire FCT, a map of the FCT was put under horizontal grids and the three schools closest to the center were selected from each grid to give a total of twenty percent of all Local Education Authority Primary schools in the six Area Councils. The total number of schools was 105 schools selected by str*atified random sampling*. 2,853 pupils were taken from 15 schools in Gwagwalada Area Council; 1,227 from 12 schools in Abaji; 2,681 from 20 schools in AMAC; 2,279 from 16 schools in Bwari; 1,831 from 17 schools in Kwali and 2,716 pupils from 19 schools in Kuje Area Council. The sex ratio was 1:1, with 7,153 males and 6,434 females making up the total 13,587 pupils involved in the study.

2.3 Prevalence data

The infection data was obtained from an earlier survey by (Bassey and Ekpo, 2018) for prevalence of urinary schistosomiasis using 'blood-in-urine' (haematuria) as the diagnostic indicator in 83 schools across the five Area Councils of the FCT.

2.3 Geographic Mapping of School Locations: Measurement of Longitude, Latitude and Altitude

The geographic coordinates of the affected schools were determined using the Gazette of Place name in Nigeria, topography maps of States and Local Governments (transcription from 1.150,000 scales) which were already geo-referenced with digital base maps of the FCT. Longitude, latitude and altitude were measured using a hand held Global Positioning System

(GPS) (Garmin 12XL, Garmin Corp, USA) which was put inside each of the school compounds and the average of three readings was used to determine the pixel for each school. This was done in order to reduce errors caused by atmospheric conditions and receiver noise. With these data, the schools/communities were located on the map.

2.5 Remotely-Sensed Environmental Data collection

Land/Use Cover and Soil Water Content

Land Use/Cover and Soil Water Content data were obtained courtesy of the Geographic Information System (GIS) unit of the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria, and these were already geo-referenced in geographic plain projections. To obtain the values which correspond to the study area, cross tabulation was done using the ArcView GIS spatial analyst extension tool to generate point specific values for each school in the study area (Ekpo *et al.*, 2008).

2.6 Annual Land Surface Temperature

The annual minimum, maximum and mean land surface temperatures for the study area were obtained from the Atmospheric Very High Resonance Radiometer (AVHRR) on board the National Oceanic and Atmosphere Administration's polar orbiting meteorological satellite, using reviewed standard procedures (Hay, 2000). The LST was then calculated using the formular:

LST = (Channel 4- Channel 5)/(Channel 4 + Channel 5), where channel 4 is the thermal infrared value emitted at 10.5-11.5µm and Channel 5 is 11.5-12.5 µm. (Price, 1984). These were calculated for each pixel which corresponds to a school location and then prevalence data were layered unto the digital maps for the environmental variables in ArcView GIS. Using the ArcView Spatial Analyst Extension tool, cross tabulation was done on the data to generate point specific values for each school in the study area for use in subsequent analysis (Ekpo *et al.*, 2008).

2.7 GIS software

The analysis of the data was done using ArcView GIS software with spatial analyzer (version 3.2a) and unique school identifiers were used for locating each school which was linked to the parasitological data for the display of both spatial prevalence and environmental data. Separate layers were also created for school locations, infection data and environmental data and ArcView GIS 3.2a spatial analysis extension was then used to perform spatial analysis (Bassey and Ekpo, 2018).

2.8 Statistical analysis

The Microsoft Excel and SPSS software packages were used in entering the data for analysis and the results were displayed as tables, figures and maps using the Earth Resources Data Analysis System (ERDAS) Image 8.4TM (Leica Geo-systems, ERDAS Inc. Atlanta, Georgia, USA) as image processing software. Values for the environmental variables were calculated for each pixel that corresponded to school locations. Prevalence maps of the infection were layered unto digital maps in ArcView GIS to obtain point specific values for each school in the study area (EROS Data Centre, 1996).

2.9 Analysis of digital maps

Prevalence data were double entered and verified using Epi-info software (version 6.04; CDC, Atlanta, GA). Descriptive Statistics, including 95% Confidence Intervals, Standard Deviation (SD) and Standard Error (SE) were calculated for disease prevalence in each Area Council of the FCT.

2.10 Logistic Binary Regression Analysis - Calculations and production of predictive maps for the FCT (spatial analysis)

The Logistic Binary Regression Analysis in SPSS (Ekpo *et al.*, 2008) was used to display the spatial heterogeneity associated with urinary schistosomiasis and its relationship to ecological factors. In predicting the probability of presence of infection in the FCT, calculated values for the environmental variables were fed into the regression equation all at once and the regression analysis was conducted. Final variable remaining in the analysis was used to determine the line of best fit and this was the one that was significant in the determination of the presence of urinary schistosomiasis in the FCT. The odds ratio, (including 95% Confidence Intervals), likelihood ratios and P-values were calculated. The line of best fit generated from the logistic binary regression model was fed into the map calculator module of the GIS spatial analyst to generate the predictive model maps of urinary schistosomiasis in the FCT. The relationships were modelled thus:

Probability of presence of urinary schistosomiasis in the schools/communities

In this study, the probability of finding infection in the FCT was achieved by the Forward Stepwise Likelihood method using the equation P=1/1+e-z where P is probability of finding infection in the FCT and Z= -6.40 + (0.04 x soil water content) where -6.40 is the regression coefficient constant and 0.04 is the regression coefficient of soil water content. The spatial distribution was achieved by entering the line of best fit from the logistic regression models into the map calculator module of the GIS Spatial Analyst.

3. Results and Discussion

3.1 Prevalence of Urinary Schistosomiasis: Relationship between Prevalence of Infection and some Environmental Variables in the FCT.

Land Cover/Use

There was no particular pattern in the spread of Land Cover/Use in the FCT when viewed alongside the prevalence of the infection. However, it was observed that high prevalence was often seen in areas where rain-fed and irrigation agriculture was practiced. Out of the 83 schools with infected pupils, 53 (63.86%) of them were located in these areas (Table 1), while 36 (43.22%) were in areas where only rain-fed agriculture was practised (fig 2). However, and use/cover was on its own not a significant variable.

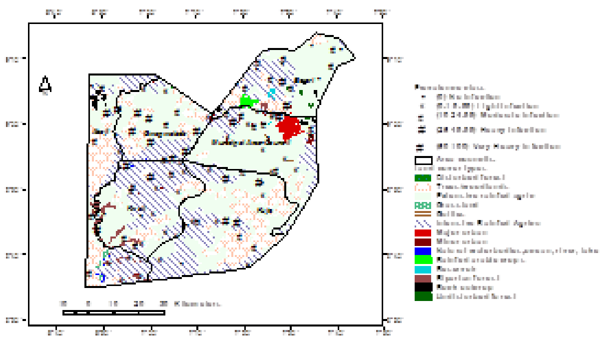

Fig. 2: Distribution of urinary schistosomiasis in relation to land use/ cover.

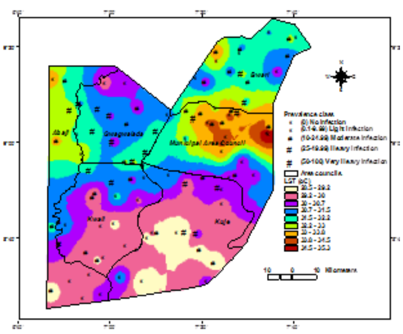

Fig. 3: Distribution of urinary schistosomiasis in relation to Land Surface Temperature in the FCT.

Table 1: Distribution of reported 'blood in urine' in relation to land cover/use in the FCT.

S/N	Area Councils	No of positive schools	No of schools with Intensive rain-fed/irrigation agriculture	No of schools with extensive rain-fed agriculture
1	Abaji	10	7	1
2	AMAC	18	5	12
3	Bwari	10	9	5
4	Gwagwalada	14	7	8
5	Kuje	16	13	5
6	Kwali	15	12	5
	Total	83	53 (63.86%)	36 (43.32%)

Land surface temperature

The highest numbers of schools 41 (49.4%) harbouring infected pupils were located in areas within the temperature range of 30.5-32.4^{0}C. Thirty-six (43.37%) were located within the range of 28.5-30.4^{0}C while the range of 32.5-35.3^{0}C had 21 (25.3%) schools with infected pupils. Number of schools with infected pupils reduced as the temperature increased above 32.5^{0}C. However, temperature on its own followed no particular pattern and so was not a significant variable in the determination of the prevalence of urinary schistosomiasis in the FCT.

Table 2: Distribution of reported 'blood in urine' in relation to mean land surface temperature in the FCT.

S/N	Area Councils	No of positive schools	No of schools with mean temperature of 28.4-30.4^0	No of schools with mean temperature of 30.5-32.4^0	No of schools with mean temperature of 32.5 – 35.3^0
1	Abaji	10	0	3	4
2	AMAC	18	7	3	15
3	Bwari	10	2	11	2
4	Gwagwalada	14	2	13	0
5	Kuje	16	15	4	0
6	Kwali	15	10	7	0
	Total	83	36 (43.37%)	41 (49.4%)	21 (25.3%)

Soil water content

Water content of the soil in the FCT ranged between 86.5mm-136.5mm. The areas covering AMAC, Northern and Central Kuje, Kwali, Gwagwalada and north to central Abaji had high soil water content of between 114.3-135mm. Bwari, central to lower Kwali and Kuje had low soil water content of between 86-114mm. There was a distinct pattern of urinary schistosomiasis across AMAC, Northern Kuje, upper Kwali, Gwagwalada to North to Central Abaji with high soil water content. This corresponded to the areas of wide spread infection. Soil water content was found to be significant in the determination of the prevalence of urinary schistosomiasis in the FCT with a direct correlation. Hence, infection increased as soil water contents increased particularly between 126-136.5mm, which contains 82 (98.8%) schools with infected pupils (Table 3). The disease was seen to be widespread in areas of high soil water content (Fig 4). The result shows that out of the three ecological variables investigated;

soil water content was the only significant variable in the determination of the presence of urinary schistosomiasis in the FCT.

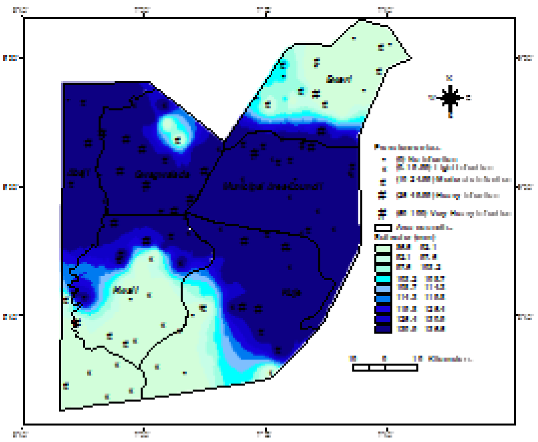

Fig. 4: Distribution of urinary schistosomiasis in the FCT in relation to soil water content.

TABLE 3: Distribution of reported 'blood in urine' in relation to mean soil water content in the FCT.

S/N	Area Councils	No of positive schools	No of schools with mean soil water content of 86.5-100	No of schools with soil water content of 101-125	No of schools with soil water content of 126-136.5
1	Abaji	10	0	14	7
2	AMAC	18	0	0	21
3	Bwari	10	5	12	3
4	Gwagwalada	14	0	2	21
5	Kuje	16	1	5	15
6	Kwali	15	0	13	15
	Total	83	6 (7.2%)	46 (55.4%)	82(98.8%)

3.2 Logistic Binary Regression Analysis.

Probability of finding urinary schistosomiasis infection in the FCT

The probability of finding schools harbouring pupils with urinary schistosomiasis in the FCT was positively correlated with soil water content. The logistic binary regression model confirmed that soil water content was a significant variable in determining the presence of urinary schistosomiasis in the FCT. The other variables in the equation which were land use/cover and LST were not significant environmental factors and so were dropped during the regression analysis leaving only soil water content.

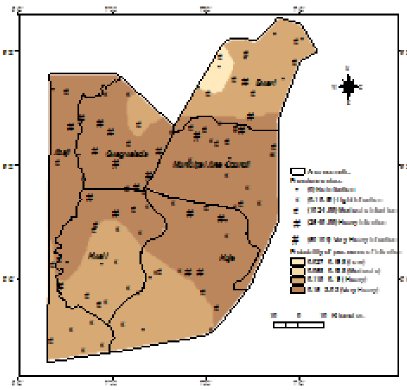

Fig.5: Probability of presence of urinary schistosomiasis in the FCT as observed and predicted through the Logistic Binary Regression Model.

The model correctly predicted infection to the tune of 80.0% in the communities. This showed that the probability of finding schistosomiasis in the FCT was highest in the areas with high soil water content as shown by the regression analysis and this corresponds to southern Bwari, AMAC, northern Kwali, north to central Kuje and north to central Abaji Area Councils of the FCT, where a clear urinary schistosomiasis belt was observed (fig. 5).

3.3 Discussion

This study revealed that soil water content was significant in influencing the probability of finding infection with urinary schistosomiasis in the FCT. This agrees with works done on S. haematobium in the Federal Capital Territory (Bassey and Ekpo, 2018), S. haematobium in Tanzania (Clements *et al*., 2006), S. mansoni in Ethiopia (Malone, *et al*., 2001), and S. mansoni on land surface temperature in South Africa (Moodley, et al., 2003). Land surface temperature and soil type were the factors that were found to affect the distribution and prevalence of urinary schistosomiasis in Ogun State, whereas normalized difference vegetation index (NDVI) showed no relationship with prevalence of infection in the State

(Ekpo *et al*., 2008). This may be because the temperature of the soil needs to reach a required high level before the life cycle of the bulinid intermediate host can be completed for transmission to take place.

On the other hand, a significant relationship was observed between NDVI and prevalence of schistosomiasis in Tanzania (p=0.188; p<0.00, P<0.0003) (Clements *et al*., 2006). Similar studies in Cross River state showed a negative correlation as the prevalence of infection increased with decrease in NDVI (Adie *et al*., 2013). However, a negative association between NDVI and the risk of infection with S. japonicum was reported in China (Seto *et al*., 2002; Xiao-Nong *et al*., 2008). About 98.8% of schools harbouring infected pupils were located in areas with high soil water content while only 6% were located in areas with low soil water content. This is not surprising because the intermediate host that transmits the infection requires water to be able to complete its life cycle and survive all year round. Hence, the aquatic snail can survive for a long time, enhancing transmission of the disease in these areas. This is particularly advantageous because the FCT has a typical hot climate with late rains. Soil with high water content is therefore a necessity for snail survival as it aids snail egg coating. Therefore, water-logged soils enable the snail intermediate host to survive in the hot, dry season.

The presence of water all year round also causes farming communities to be brought into close contact with the infected water, thus enhancing transmission. When subjected to logistic regression analysis, land surface temperature and land use/cover were thrown out before the end of the analysis, while soil water content remained and was found to correlate positively with the high prevalence of schistosomiasis in the FCT. This may be due to the fact that the snail intermediate host as well as the infective stage larvae prefer water laden areas and so where the soil water content was high, the snails were abundant and transmission increased. Hence, across the middle belt areas of the FCT (except for upper to middle Bwari, middle to lower Kwali, Kuje and Abaji as well as a small part of north eastern part of Gwagwalada with low soil water), transmission and prevalence were high. A clear 'urinary schistosomiasis belt' was seen to cut across the areas with high soil water content in the FCT. This urinary Schistosomiasis belt was also clear in an earlier study (Bassey and Ekpo, 2018) where plinthosol soil type was found to be significant in determining the spatial distribution of urinary schistosomiasis. This may be due to a combination of factors - the high water content of this soil, which makes it water logged, an ability that enhances its water holding capacity for many months of the year, and the high silt containing nature of the plinthosol soil type which enables the completion of the life cycle of the snail intermediate host, hence, continuous transmission of the infection from season to season.

This observation is in line with results obtained in Cross River State where reports have it that the deep lateritic soils found in some parts of the State were water-logged and so supported farming activities which brought farming populations in contact with infected water sources, hence enhancing transmission (Adie *et al*., 2013). Also the swampy hydromorphic soils found in some parts of the state also supported a rich abundance of snail vectors and brought rice farmers in contact with infected water bodies. The Southern Senatorial District of Cross River State had no infection mainly because of the influence of the Atlantic Ocean which berthed the shoreline and changed it from freshwater to brackish water which had been shown not to support these species of snail populations because of the high salinity. More schools with infected pupils were found in areas where the LSTs were between 28-32.4ºC and dropped as the temperature increased. This shows that the snail intermediate host would prefer these optimum temperatures for their life cycle development However, despite this, temperature in itself was not significant in the determination of the prevalence of the disease in the FCT. The LU/C also showed no significance but areas with schools harbouring infected pupils lay across areas where irrigation and rain-fed agriculture were practised, showing a need for man-water contact for the infection transmission to be effected.

4. Conclusion

This study shows that high soil water containing soils may influence the spatial distribution and prevalence of urinary schistosomiasis in the FCT, due to its water-retaining ability and silty nature which enables the sustenance of the eggs and larvae without being washed away by fast flowing waters or dried up by lack of water, enabling the survival of the Bulinus snail intermediate host, leading to continued transmission of the disease even in the dry season. This is important information for the purpose of planning control measures in the FCT as the schistosomiasis belt has been demarcated for the concentration of efforts to stem the disease.

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