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# The influence of environmental factors on the historical distribution of *Biomphalaria pfeifferi* in the Tshwane Metropolitan Municipality

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**Abstract**: Schistosomiasis remains the most endemic disease in tropical regions. Transmission rates and prevalence of schistosomiasis in Africa are relatively high compared to other regions. This is mostly associated with the lack of clean water and sanitation as necessities to curbing the spread of the disease. Over 90% of people in sub-Saharan Africa (SSA) are deprived of clean water and sanitation. 60-80% of the children in South African communities are infected. Climate variability plays a role in the distribution of vector-borne diseases by affecting intermediate host reproduction and changing their habitats thereby decreasing or increasing host survival and disease transmission ability. This study aims to determine the influence of environmental factors on the spatial distribution of *Biomphalaria pfeifferi* in the Tshwane Metropolitan Municipality. The use of species distribution models (SDMs) to model the intermediate snail hosts habitats in South Africa is uncommon, compared to other African countries. To our knowledge no modelling study has been done in South Africa particularly in the Tshwane Municipality, and this has therefore, paved a way for this study. A systematic literature review was conducted to identify all the important climatic variables that impact on the distribution of bilharzia-transmitting snails. *Biomphalaria pfeifferi* occurrence data was accessed from the National Freshwater Snails Collection, and the climate data was extracted from the ERA5 website respectively. The principal component analysis was used to reduce the multidimensionality of the dataset, with this framework tool, Pearson's correlations helped identify the variables showing a high correlation with the snail datasets and these were included in the ecological niche model. The following climatic variables: temperature, rainfall, water temperature, and other climate-related phenomena such as droughts and flooding influence the distribution patterns of intermediate snail hosts. The model showed high species presence along the central parts of Tshwane, mostly in the following areas Roodeplaat, Mamelodi, Winterveldt, and Refilwe. However, the south-eastern parts of the municipality did not indicate any species occurrence. The findings confirm that environmental factors impact on the historical distribution of *Biomphalaria pfeifferi* in the Tshwane Metropolitan Municipality. The response curves from the MaxEnt model depict the relationship between habitat suitability and environmental factors.

**Keywords:** Schistosomiasis, Modelling, MaxEnt, *S. mansoni*, *Biomphalaria pfeifferi* (*B. pfeifferi*).

## 1. Introduction

Schistosomiasis, also given the name bilharzia is a water-borne disease. According to WHO, is the most neglected disease in Sub-Saharan Africa (de Necker, 2020). Although this disease has been neglected for some time this is contrary to its existence. Since, it has been depicted in many studies that its existence traces back to 5800 BC (Gomes et al, 2021). Though until recently the amount of research on Neglected Tropical Diseases (NTDs) has sprawled over many regions. Alarmingly, this disease poses an immense burden for many people, most particularly in African countries, as 85% of schistosomiasis cases are reported in Africa (Daniel, 2009). The prevalence of schistosomiasis is mostly associated with the subtropical and tropical regions (Aula et al, 2021). Over 240 million people worldwide, and in South Africa an estimated 5.2 million people, are thought to be affected (Tanser et al, 2018; Bhengu et al, 2020). *Biomphalaria pfeifferi* is one of the most important vectors of *Schistosoma mansoni* and according to many studies these are prevalent in Sub-Saharan Africa (McCreesh et al, 2015). It has been reported that *S. mansoni* infections may increase in parts of eastern Africa as temperatures continue to rise, influencing growth, survival, and distribution of the parasite and its intermediate molluscan hosts (McCreesh et al, 2015). The reproduction of *Schistosoma* parasites occurs in snails and mammals. (Adekiya et al, 2020;

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Nelwan, 2019; Wendt & Collins, 2016). Infections are high among school-going children in poor communities. For example, a study conducted in Rwanda concluded that about 69.5% of the school-going children in this region were infected (Nyandwi et al, 2017). Additionally, between 2007-2008 the country recorded an overall prevalence of 2,4% (Nyandwi et al, 2017). South Africa reports an infection rate of 60-80% amongst school going children mostly in rural communities (Wolmarans et al, 2006). Between 1964 and 1989 the prevalence of schistosomiasis in the Eastern Cape province has been mostly linked or found in boys between the ages of 3 to 16 (Magaisa et al, 2015).

Figure 1 shows how the *Schistosoma* parasite develops into mature stages and how the disease is transmitted from an intermediate snail host to a human host. Schistosoma mansoni eggs have been found to inhabit the intestines (Nelwan, 2019). Subsequently, these eggs are then released into the freshwater environments and hatching occurs which then leads to forming organisms known as miracidia (Adekiya et al, 2020; Nelwan, 2019). This is followed by the second larval stage in which different snail species commonly identified as important vectors of *Schistosoma* such as *Biomphalaria* species are infected with *S. mansoni*. In this stage, the miracidium develops into sporocysts which ultimately multiplies into cercaria as shown in Figure 1 (Nelwan, 2019).

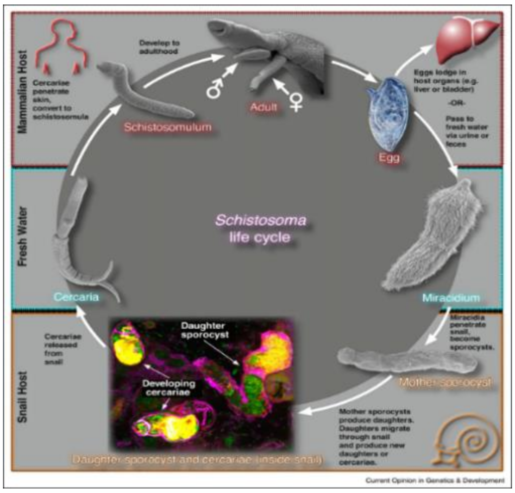


Figure 1. lifecycle of both the intermediate host and the *Schistosoma* parasite source: (Wendt & Collins, 2016)

The life cycle of *Schistosoma* snail species including the reproduction, development, and survival of the infected species is immensely dependent on climate changes. Therefore, climate change can potentially alter the rate at which eggs and miracidia of each parasite occur, simultaneously this can either hamper the survival or aid the reproduction rates of Schistosoma snail species along with parasites (Kalinda et al, 2017). For instance, *B. pfeifferi* has a relatively reduced rate of egg production in temperatures above 27°C (Kalinda et al, 2017). This implies that if there is a consistent increase in temperatures above 27°C species production rate might subside, hence, changing the spatial distribution of the species. According to the IPCC 2023 report, Global average temperatures may increase by 2.2-3.5°C by 2100 (Lee et al, 2023). The IPCC report further notes, global warming above 2°C will inevitably increase distribution and transmissions of vector borne diseases and thus exposing many people to risks. Given these changes there is a need to understand how snail transmission will be affected (Lee et al, 2023; McCreesh & Booth, 2013).

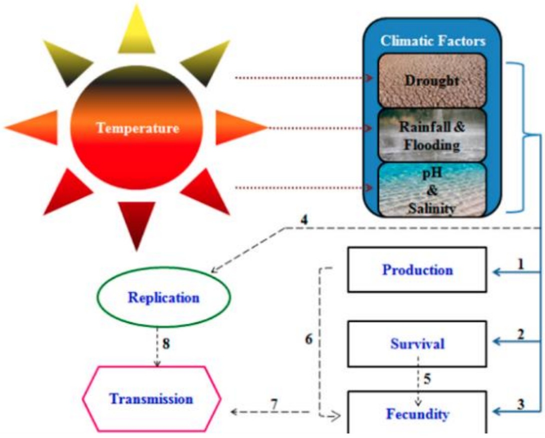


Figure 2. Diagram illustrating climate factors influencing the intermediate snail hosts source: (Adekiya et al, 2020)

Figure 2 depicts the climatic factors that have an influence on the distribution of the intermediate hosts. The fecundity, survival, production, transmission, and replication of these intermediate snail host depends largely on climatic factors (Adekiya et al, 2020). For instance, changes in climate factors including temperature, rainfall, pH, salinity and other extremes, drives the development and the production of the snail host. Additionally, the development of the cercaria and miracidia in the host snails is determined by climate variability. The ability of the intermediate snail to survive is primarily depended on the rate of change in climate factors, more especially since these freshwater snails are highly sensitive to very low and high-water temperatures (Moodley et al, 2003). Similarly, the ability of the freshwater snail host to produce mass populations of miracidia (fecundity) which undergoes replication, relies solely on the rate at which the climate factors fluctuate. An increase in the survival of the snails ultimately enhances the transmission rates. The city of Tshwane has an average maximum temperature of $29^{0}$C (World Weather & Climate Information, 2010-2020). Considering the specific temperature requirements within which *B. pfeifferi* can survive, this will undoubtedly alter the distribution patterns of schistosomiasis. This compliments the observations made by McCreesh et al (2014), where it is derived that schistosomiasis transmissions were spreading in previously non-endemic places. Therefore, it is important to study the influence of climate variability on suitable habitats consisting of a range of environmental variables responsible for the prevalence and the spread of schistosomiasis. These


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regions are characterized by temperatures providing suitable habitats for the intermediate host and the parasite. Over 90% of the people in African countries do not have access to clean water and sanitation (Hailu et al, 2020). It is expected that the human population will continue to multiply with the anticipated increase in the number of people moving into the cities and residing in informal settlements, resulting in many areas characterized by poor sanitation and water services (Johnson & Appleton, 2005). Similarly, the prevalence of schistosomiasis in some regions in South Africa is linked primarily to the persistent rise in the human population and a huge influx of people building slums near potentially infested water bodies due to poorly administered services (Moodley et al, 2003). Several studies have noted the prevalence of schistosomiasis mostly in the following provinces (Limpopo, Mpumalanga, coastal areas of KZN, Upper parts of North West, Gauteng and Eastern Cape) (Bhengu et al 2020; de Necker, 2021, de kock et al, 2004). Figure 3 below shows the distribution of schistosomiasis in South Africa.

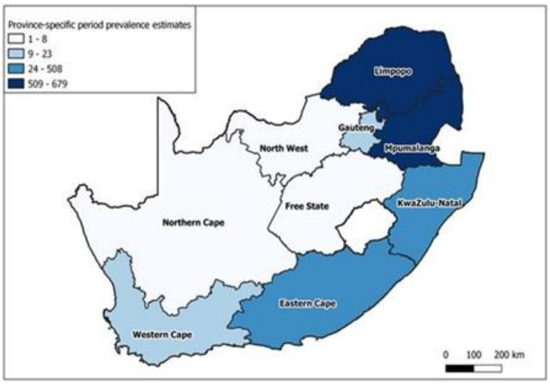


Figure 3. The distribution of schistosomiasis in South Africa Source: (De boni, 2021)

Compared to other African countries, there is a lagged interest on modelling the distribution of schistosomiasis in South Africa using comprehensive species distribution models (SDMs) (Manyangadze et al, 2016). Therefore, Manyangadze argues that maximum entropy is one modelling technique that could enormously improve our understanding of the spatial distribution of schistosomiasis and model habitats of intermediate snail hosts against a range of climate factors to gauge the influence of these factors on the snail distribution patterns. As a result, not many studies have been done in Gauteng, particularly on a local scale. Therefore, the novel feature of this study is to model the historical distribution of schistosomiasis at a relatively small scale. This is important as most infections occur at a local scale especially since the issues of service delivery such as sanitation, water, etc are prevalent In the City of Tshwane (Magidi & Ahmed, 2019). The present study aims to determine the influence of environmental factors on the historical distribution of Schistosoma-transmitting snails in the Tshwane Municipality. This study will carefully identify the important environmental variables and model the effects of climate change on these variables over time. This will help to identify the trends of bilharzia suitable habitats and assist in predicting the possible future distribution and trends of schistosomiasis transmitting snails in the Tshwane Municipality. Most studies conducted in South Africa had much focus on a national level (Manyangadze et al, 2016). This is inadequate as most infections occur at a more localized level (Manyangadze et al, 2016). Therefore, there is a need to shift to a scale that captures the incidences and occurrences of transmissions at a micro-geographical scale. Therefore, this highlights the relevance of our study as it will focus on the City of Tshwane metropolitan municipality.

## 1. Methods

### 1.1 Study Area

Though located in a relatively small province, the City of Tshwane is one of the largest municipalities in the Gauteng province. This municipality has a relatively large size compared to other municipalities and it borders the following provinces Limpopo, Mpumalanga, and Northwest. Apart from that, this municipality comprises of 7 regions, and 105 wards. Spatially, it is found to be located between 250 6’ 34. 60’’ S to 260 4’ 41. 12’’ S and with the longitudes of 270 53’ 24. 26 E to 290 5' 54 31" E (Magidi & Ahmed, 2018). The municipality has an average temperature of 29 ºC and receives an annual rainfall of 622 mm (World Weather & Climate Information, 2010-2020). Additionally, the city has a landmass of 629 618 ha, with an alarming number of 2, 921, 490 people as indicated in a census conducted in 2011 (Magidi & Ahmed, 2018). In 2016, about 3,275,152 people documented in Tshwane (Shikwambana & Tsoeleng, 2020).

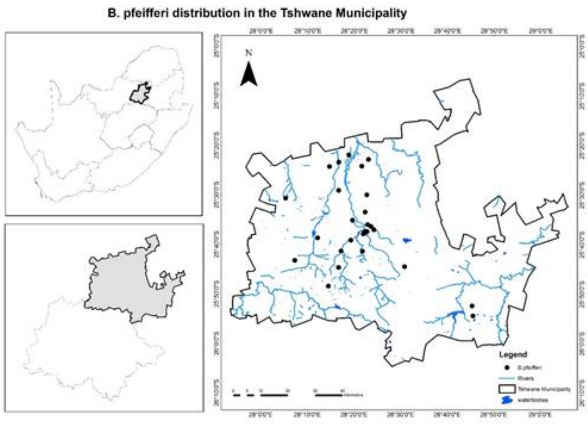


Figure 4. Distribution of *Biomphalaria pfeifferi* in the Tshwane Metropolitan Municipality

### 1.2 Data Collection Methods

The present study used the dataset for *Biomphalaria pfeifferi* extracted from the National Freshwater snail Collection (NFSC) with a temporal resolution of (1950-1980). The occurrence data is widely distributed across South Africa, 524 records of *Biomphalaria pefifferi* species were found in Tshwane after clipping and


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digitising. The snail data was assigned WGS98 as a coordinate system.

### 1.2.1 *Systematic Review to identify climatic variables*

A systematic review of scientific publications was carried out using the following search engines: Google scholar, Wiley, Taylor & Franscis and Elsevier. The search criteria outlined as follows: predictions on the influence of climate factors on schistosomiasis distribution in Africa, *B. pfeifferi* environmental requirements, intermediate snail host specific temperature requirements, distribution of intermediate snail host habitats in South Africa, the influence of climate change on water borne diseases, environmental factors determining the spatial distribution of *B. pfeifferi*. Furthermore, relevant material was extracted from the reference list of the identified articles. The Boolean operators AND/ OR were used to combine the search terms. Only the studies showing the influence of climate change on the distribution patterns of schistosomiasis intermediate snail hosts, effects of climate variability on the distribution patterns of the bilharzia transmitting snail host, factors governing the distribution patterns of the snail habitat suitability and those aimed at modelling the influence of environmental factors on the geographic distribution of bilharzia transmitting snail hosts are included. Studies not showing the relationship between climate factors and the intermediate snail hosts were excluded. Therefore, in ensuring that the first objective of this study is met, a comprehensive literature review was conducted systematically to identify all the important climatic variables that have an impact on the distribution of bilharzia-transmitting snails. More importantly, the papers cited mostly are likely to be selected in this study. The environmental factors, specifically all possible factors contributing to schistosomiasis trends and patterns in most regions have been captured. There is a variety of factors affecting the spatial distribution of bilharzia-transmitting snails as noted in most studies. Among the most common involve temperature, rainfall, water temperature, soil, and water pH. As shown, in a study conducted in the Ndumo area, a species' habitat has specific requirements, which are governed by environmental factors (Manyangadze et al, 2016).

### 1.2.2 *Climate Data Sources*

Climate data was extracted from ERA5 Corpenicus website. This website is representative of Land monthly averaged data from a temporal resolution of 1950-present. The following variables: run off, surface runoff, 2m temperature, bottom lake temp, total lake temp, soil temp level 1, soil temp level 2, total precipitation was downloaded. These climate parameters are simulated to provide a view of the past climate conditions and show how this has evolved over the years. Apart from these properties, ERA5 provides a gridded data type and has a horizontal resolution of 0.1 x0.1 (9km) and is derived from a global coverage. This data is available in a GRIB file format however, this has been converted into CSV format, and all the variables have been converted to units of measures suitable for this analysis.

### 1.2.3 *PCA*

A Principal Component Analysis is a statistical procedure that significantly reduces the dimensionality of large datasets into smaller and more manageable quantities. This procedure is recommended because it does not reduce data quantity only, but it keeps the important information derived from the original dataset. Studies have shown that this procedure is probably the most prominent technique and is widely used in most scientific disciplines (Abdi & Williams, 2010). Similarly, Abdi & Williams (2010) explains a PCA is a statistical tool for analysing data tables observations described by several dependent variables, which are, in general, inter-correlated. Both the PCA and Pearson's correlation was implemented using XLSTAT. Furthermore, studies have found that high correlation and collinearity between the climate variables can result in the overfitting of the model. As a result, this impedes the accuracy of the predictions made by the model (Guimarães et al, 2013). The Pearson's correlation has helped to determine the correlation between the independent variables and dependent variables and helps to identify the highly correlated ones. Most importantly, this statistical procedure is used to reduce the effects of multicollinearity by ensuring that only the variables with deserving values selected.

Table 1. Climate variables included in MaxEnt with a correlation <0.75.

| Climate variables ERA 5 | Variable Name | Spatial Resolution | Temporal Resolution 1950 - Present |
|---|---|---|---|
| Ro | Run off | 0.1 x0.1 | 1950-present |
| Sro | Surface Runoff | 0.1 x0.1 | 1950-present |
| T2m | 2m temperature | 0.1 x0.1 | 1950-present |
| tp | Precipitation | 0.1 x0.1 | 1950-present |
| ltlt | Lake total temperature | 0.1 x0.1 | 1950-present |
| Lai-lv | Leaf area index – low vegetation area | 0.1 x0.1 | 1950-present |

multicollinearity between predictor variables was reduced and only those having a value less than 0.75 were taken into consideration (Deka, 2021). Alternatively, Yang et al (2018) used a Pearson's correlation coefficient to eliminate the variables with an r >0.9. Table 1 shows all the statistically significant variables (t2m, lai-lv, tp, sro, ro, ltlt) selected, as they all had a correlation greater than 0.5 but less than 0.75. The selected variables (t2m, lai-lv, tp, sro, ro, ltlt) were displayed and projected on ArcMap, using Albers equal Area, which preserves an area. These raster files were converted to ASCIIs, after clipping and resampling pixels by a pixel size of 30 x 30. The environmental data can only be added on MaxEnt in the form of ASCII files. The occurrence data was prepared on Excel and sorted as CSV.

1.2.4 *Model Implementation*

An ecological niche model known as MaxEnt was used in the present study. It is highly recommended and widely used compared to other modelling algorithms (Deka, 2022; Manyangadze et al, 2016; Yang et al, 2018; Scholte et al, 2012). It effectively predicts the habitat suitability of species distribution using a range of environmental predictors (Ponpetch et al, 2021). Generally, all species distribution models (SDMs) rely on presence only data. As an example of SDMs, MaxEnt model uses the presence only data (occurrence points) to make inferences about the distributions of snail habitat suitability. Climate and environmental variables with an acceptable correlation (t2m, lai-lv, tp, sro, ro, ltlt) were incorporated into the modelling framework against the NFSC snail occurrence data of *B. pfeifferi* to see how different climate and environmental factors influenced the historical distribution of the species habitats In the Tshwane city. All the variables were introduced into MaxEnt in relation to environmental conditions. A total of 10019 pseudo-absence points were randomly taken from the entire study area, this is the information relating to the environmental conditions in a modelled region. MaxEnt model allowed us to predict the distribution of suitable habitats of bilharzia transmitting snails with respect to the influence of climatic variables, showing how the snail's habitat distribution likely changed over time in the Tshwane municipality.

The Area under the Curve (AUC) was examined to check how well the model has performed. The AUC comprises values ranging from 0- 1. Several studies have shown that the MaxEnt performs better when the AUC values are closer to 1, and consequently values smaller than 0.5 indicate poor predictive ability (Scholte et al, 2012). Comparatively, a study conducted in Ndumo, revealed that the AUC values of >0.75 show high performance of the MaxEnt model (Manyangadze et al, 2016). Similarly, a high performance of the model was obtained in a study conducted by Pedersen et al (2014), modelling the spatial distribution of bilharzia transmitting snails in Zimbabwe. The model's ability to perform better has also been associated with a relatively smaller sample size (Yang et al, 2018). A Jack-knife test was carried out within MaxEnt. It primarily quantifies the explanatory power of each environmental variable (Manyangadze et al, 2016). A Jack- Knife test was used to determine the performance of the model.

## 2. Results

### 2.1 Identified climate variables

One of the objectives of this present study was to identify the climate data influencing on the species distribution. A range of climatic factors that affects the distribution of schistosomiasis are illustrated by Figure 5. Temperature has a significant effect on the freshwater snails, increasing temperatures changes the ecology of the snail host. Similarly, if temperatures are extremely lower than the

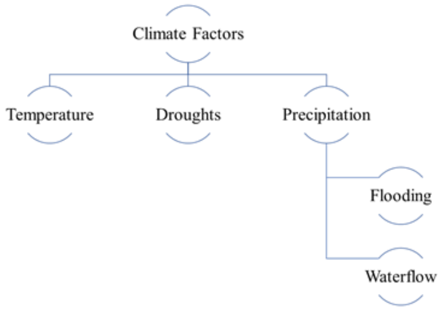
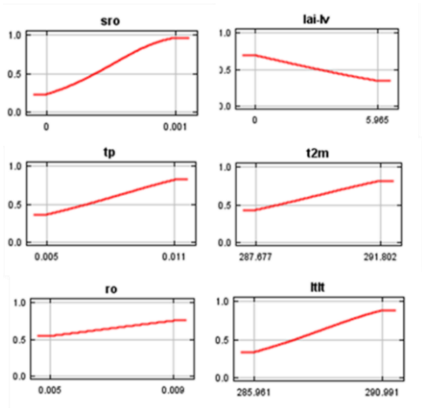



Figure 5. This study identified the following climate factors that influence the distribution of *B. pfeifferi*

climate optimums of an intermediate snail host, that results in the mortality of the snail host thus changing schistosomiasis trends and distribution patterns. Extreme heatwaves result in unprecedented droughts occurrences. The intermediate snail hosts are inherently aquatic, therefore, they spend most of their life cycle in the freshwater environments. The absence of water for prolonged periods has dire consequences for schistosomiasis transmitting snails. This hampers the development, and the reproduction of the schistosome parasite along with the intermediate snail host and ultimately change the geographic ranges in which the species occurs. Precipitation couples with increased water levels, which perpetuate flooding. Freshwater snail inhabits slow moving waters, therefore, an increase in the water flow, enhances the establishment of the intermediate snail hosts in new locations, where the snail species was non- endemic. This in turn increases, the schistosomiasis ranges.

### 2.2 Geographic distribution of the species' habitat




Figures 6. MaxEnt generated response curves for predicted habitat suitability for each climate factor

Figure 6 depicts a set of response curves produced by the MaxEnt model for the present study, for each of these curves, the model has predicted the probability of habitat suitability about a given environmental factor. On each of these response curves, the x-axis represents a respective variable and the y axis, on the other hand, indicates habitat suitability. t2m/2m temperature is directly proportional to the habitat suitability, as a result habitat suitability increases as t2m increases. Similarly, tp/ precipitation is positively correlated with habitat suitability, an increase in precipitation corresponds with an increase in habitat suitability. However, it is clear that habitat suitability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declines with the decrease in lai-lv/ leaf area index low vegetation. The following variables: ltlt, sro, ro also show a positive relationship with the species' habitat suitability. An increase ltlt/lake total temperature, soil run off, and run off increases the probability of habitat suitability.

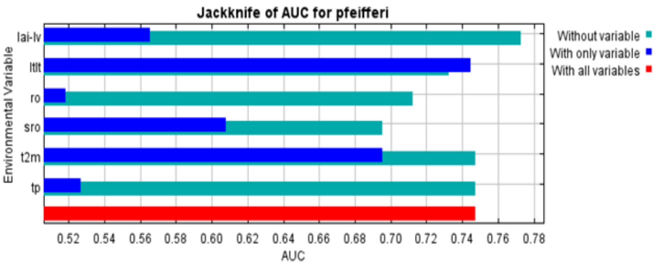


Figure 7. Jack-knife results for the current study showing the contribution of each environmental factor in MaxEnt

The Jack-knife test results of this study indicate a high prediction rate (0,747). The following environmental variables: ltlt and 2m temperature have a reasonably high contribution rate to the model followed by surface runoff, lai-lv when compared to precipitation, and runoff (Figure 7). Precipitation had a relatively low contribution to the model. This implies that the omission of both these variables (ro, tp) will not affect the model results.

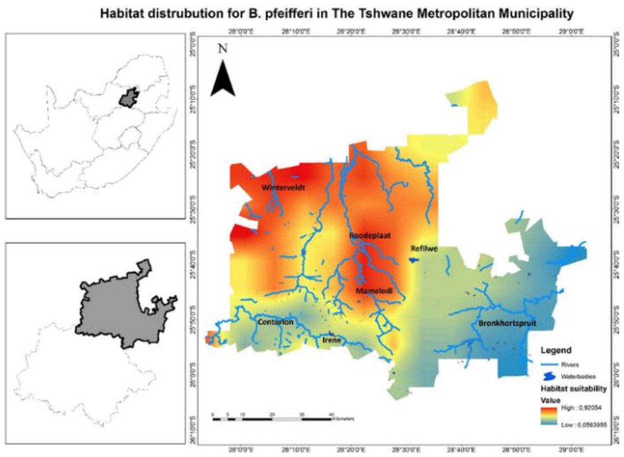


Figure 8. Habitat suitability distribution for *B. pfeifferi* in the Tshwane Metropolitan Municipality. Areas in red show high snail prevalence, whilst the blue parts of Tshwane had no prevalence of the *B. pfeifferi* species.

The predicted habitat distribution of *B. pfeifferi* in the Tshwane Metropolitan Municipality based on the results generated from the ecological niche model is shown in figure 8. The predictions made by the model showed the probabilities of *B. pfeifferi* presence mostly in the central parts of Tshwane. The warmer colours indicate possible areas of the species' occurrence whilst blue parts indicate areas with unsuitable predicted conditions for the occurrence of *B. pfeifferi* species.

## 3. Discussions

The first objective of this study was to identify the climate variables that have an influence on the historical distribution of *B. pfeifferi* in the Tshwane Metropolitan Municipality. Researchers have investigated the relationship between the environmental and climate factors on the species' habitat distribution as illustrated by Figure 5. According to Kalinda et al (2017) temperature is one of the climatic factors impacting on the distribution of *B. pfeifferi* as it has the potential to hamper the species' reproduction rates. An increase in *Schistosoma mansoni* (a parasite for *B. pfeifferi*) infection is linked with temperature within the range of 20°C - 30°C. If temperatures increase above 32°C automatically this hampers the development speed of the snails. This was confirmed in a study by Gordon et al (1984), where it was discovered that the snail production speed deteriorated when temperatures increased from 34°C – 35°C. Similarly, precipitation is another climate factor with an influence on the distribution of *B. pfeifferi* intermediate snail host. According to (Adekiya, 2018; Adenowo et al, 2014), an increase in the geographic distribution of *B. pfeifferi* is linked with an increase in rainfall. Changes in rainfall patterns impact on the environmental factors, for instance, increasing rainfall levels change the species' habitats by increasing the velocity of the stream flow which ultimately endangers this species as it is susceptible to high velocities most of these species prefer a velocity of 0.3 m. $s^{-1}$ (Moodley, 2003). Most snail species cannot thrive in fast flowing water. Therefore, floods can be detrimental to the ecology of the snail host. Other climatic related phenomena such as droughts have an impact on the species distribution as (McCressh & Booth 2013; Rubaba et al, 2016) have specified that these species are sensitive to drought-prone areas, as this affects the prospects of successful aestivation. Only the snails with the ability to aestivate in dry periods survive. Therefore, this can decrease or increase schistosomiasis transmissions in Tshwane Municipality.

The second objective of this study was to map and predict the historical distribution of *B. pfeifferi* in the Tshwane Municipality. Using the ecological niche model, it has been possible to map all the unsuitable and suitable areas for schistosomiasis prevalence. However, it is also important to note that the MaxEnt model approximates the conditions within which the species thrive. The model in this study performed satisfactorily in estimating the possible locations providing environmental conditions that favour the species distribution in the Tshwane Metropolitan Municipality. These predictions were made about a set of climatic and environmental factors, in fulfilling the aim of this study which was to determine how environmental factors affect the distribution patterns of *B. pfeifferi*. Essentially, it is very unlikely to find the *B. pfeifferi* species in areas such as Bronkhortspruit, Irene and Centurion, as *B. pfeifferi* does not favour the environmental conditions in these areas. There is a relatively high species presence in areas such as Winterveldt, Mamelodi, and Roodeplat.


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According to Pedersen et al (2014), MaxEnt Is quite attractive and it is easy to understand when studying species ecology and biology. The results of this study, showed that the model performed well in predicting the probability of the species' presence (AUC>0.75; Mnyangadze et al, 2014). However, it is important to note that in any given study there are limitations. The uncertainty of these models is an impeding factor to the functioning of different models, as a result, the MaxEnt model tends to underestimate the prevalence and the occurrence of species in the focal region while simultaneously overestimating the species occurrence in areas beyond the species prevalence (Gomes et al, 2018). Despite these limitations, we must recognize that the model performed well in predicting the species' habitat suitability in the Tshwane Municipality. The results generated in this study are generalizable to a wider group of researchers within this subject. As indicated in the model, rainfall did not have much contribution to the MaxEnt model and this corresponds with what has been found by Manyangadze et al (2014). Temperature is one of the variables that correlate positively with the distribution of the intermediate snail host. Similarly, Nywandwi et al (2017), found temperature positively correlated with the *Schistosoma mansoni* parasite, a parasite carried by *B. pfeifferi*. Similarly, the response curves showed that temperature, precipitation, run off and surface run off have a positive correlation with the species habitat suitability, except for the leaf index vegetation area. A positive correlation implies that as these variables increase habitat suitability increases simultaneously. Most importantly, this study has helped bring insights into modelling the historical distribution of *B. pfeifferi* in South Africa. Future modelling studies will be necessary to understand the changes in the distribution patterns of this species, especially since it is expected that the climate will continue to change.

## 4. Conclusion

This study aimed to determine the influence of environmental factors and map the historical distribution of *B. pfeifferi* in the Municipality of Tshwane. Suitable conditions for *B. pfeifferi* are mostly visible along Roodplaat, Mamelodi, and up north of Tshwane in Wintervedlt. Temperature had an influence on the distribution of *B. pfeifferi* in the Tshwane Municipality as it has a relatively high contribution to the model, this responds to objective one of this study, and therefore, the temperature is one of the environmental factors that have an influence on the geographic distribution of *B. pfeifferi*. The results of this study will be quite useful in tracking areas that must be prioritized for action in the future. Apart from that, these results will pave a way for future modelling studies in South Africa.

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