Climate variations, urban solid waste management and possible implications for *Anopheles m*osquito breeding in selected cities of coastal Ghana

Mattah, P. A. D.[1,2*], Futagbi, G.[3], Amekudzi, L. K.[4] and Mattah, M. M.[5]
[1] *Centre for Coastal Management, University of Cape Coast, Cape Coast*
[2] *Africa Centre of Excellence in Coastal Resilience (ACECoR), University of Cape Coast, Cape Coast*
[3] *Department of Animal Biology and Conservation Science, University of Ghana, Legon*
[4] *Department of Physics, Kwame Nkrumah University of Science and Technology, Kumasi*
[5] *Department of Environment and Development Studies, Central University, Miotso*
*Corresponding author: *pmattah@ucc.edu.gh*

Abstract

Climate-induced environmental changes are known to support prevalence of disease vectors and pathogens. Temperature, rainfall, humidity and other environmental variables are considered potential drivers of population dynamics of many vectors and pathogens of health importance, especially in the tropics. This study was conducted to understand the variability and trends in atmospheric temperature and rainfall, as well as how these factors may affect the breeding of *Anopheles* mosquitoes in the urban areas in the future. Accra and Sekondi-Takoradi Metropolitan Areas (AMA and STMA) of coastal Ghana were the selected study sites. *Anopheles* larvae were sampled from pre-identified breeding sites in the two cities. Atmospheric temperature and rainfall as measured by synoptic weather stations were collected for the two cities. Again, thirty years climate data on daily minimum and maximum temperature and rainfall for both cities from Ghana Meteorological Agency (Gmet) were employed in the study. Using a statistical downscaling approach, the average of the ENSEMBLE GCM outputs AR4-BCM2 and AR4-CNCM3 scenario A1B were downscaled to match with rainfall and temperature observations of AMA and STMA. Results showed that improper solid waste management in the cities promote the breeding of *Anopheles* mosquitoes. Climate data analysis showed that past rainfall in the cities were below average; in the future, however, up to year 2050, the cities may experience high rainfalls and temperatures above the average. Notably, significant increases may be observed in the total monthly rainfalls as well as a slight shift of rainfall pattern in the minor season. This implies that *Anopheles* mosquito breeding may no longer be seasonal in the cities but perennial and malaria transmission may also follow the same trend. Poor urban dwellers who find it difficult to adopt preventative measures will be prone to persistent malaria transmission. This will increase malaria transmission among vulnerable populations in urban areas. This study recommends that city authorities must intentionally work at lowering the surface temperatures in the cities through the growing of trees and also to regularly desilt drains in order to reduce the breeding of *Anopheles* mosquitoes.

Introduction

Daily weather and climate affect human health in many ways (IPCC, 2014). Climatic variables such as atmospheric temperature, rainfall humidity among others support or promote the prevalence of disease pathogens and vectors (Wu et al., 2016). For example, the development and survival of *Anopheles* mosquitoes, the only known vectors of malaria, have been confirmed to be highly dependent on temperature and rainfall (Beck-Johnson et al., 2013). Although *Anopheles* mosquitoes are known to prefer breeding in clean water bodies (Kudom, 2015; Mattah et al 2017), several studies have also reported their breeding in polluted water bodies just as found in many urban areas of the developing world (Awolola et al., 2007; Castro et al. 2010; Amekudzi et al. 2014a; Kudom, 2015). Rapid urbanization, poor solid waste management and its associated choked drains in sub-Saharan African cities have not only promoted the absence of aesthetic values of the urban environment but also created flooding in cities, as well as support breeding grounds for disease vectors like mosquitoes (Sam, 2009; Thompson, 2010). The presence of choked or clogged drains with stagnant water bodies in urban areas of developing countries therefore, pose serious environmental challenges and public health concerns. Stagnant water in the drains are mainly polluted and known to provide most suitable sites for *Culex* and *Aedes* mosquito species but have in recent times been utilized by *Anopheles* species for breeding (Kudom et al., 2012; Kudom, 2015). Drains, whether paved or unpaved, have increasingly become very important in providing transitory aquatic habitats for breeding of different types of mosquitoes in urban areas (Castro et al., 2010). While there is some paucity in knowledge regarding the specific role and the extent to which certain abiotic factors affect the breeding of vector species like *Anopheles* mosquitoes in urban areas, this study explores the future role of such abiotic factors in *Anopheles* breeding in selected urban areas. The relevance of this study is to show how current weather conditions shown by surface temperature and rainfall, poor waste management and waste accumulation as well as future climate conditions may affect *Anopheles* mosquito proliferation breeding in coastal urban areas in Ghana. This is important in view of the rapid urbanization and concomitant waste management issues occurring in developing countries of sub-Saharan Africa.

In the specific case of *Anopheles* mosquitoes, studies show an increasing exploitation of drains as breeding habitats in various cities of sub-Saharan Africa. Castro et al (2010) found that 6% of 5,400 drains surveyed in Dar es Salam had exclusively *Anopheles* mosquito larvae and while 4% of the drains surveyed had combined *Culex* and *Anopheles* larval presence. In Cape Coast of Ghana, Kudom (2015) discovered that at least 25% of *Anopheles* breeding sites found were choked drains and the proportion of *Anopheles* mosquitoes breeding in choked drains during the dry season increased remarkably. Most *Anopheles* mosquito breeding sites in urban areas are of man-made origin, including the choked drains (Kudom et al., 2012; Kudom, 2015). Also, while climate variations may cause changes in temperature and rainfall, *Anopheles* mosquitoes are reportedly adapting to polluted environments such as in drains of urban areas (IPCC, 2014; Kudom et al., 2012), it is important to explore how various future climate scenarios may affect *Anopheles* breeding in urban areas in the light of current waste and urban drain management practices. Urbanization in itself was touted as being able to influence the epidemiological characteristics of diseases through the provision of good breeding environments for vectors of infectious diseases (Rakotomanana et al., 2010).

This study was conducted in the two most urbanized coastal communities of Accra and Sekondi-Takoradi in southern Ghana with the aim of understanding the variability and trends in atmospheric temperature and rainfall, as well as how these factors are currently affecting and may be affecting the breeding of *Anopheles* mosquitoes in the urban areas in the future. It also explored the contribution of choked drains to the breeding of *Anopheles* mosquitoes in the cities. All these are to provide empirical evidence to confirm or otherwise the increasing belief that urbanization is gradually transforming malaria from being a rural disease into an urban disease (Wilson et al., 2015; Mathanga et al., 2016).

Materials and Methods

Study Areas

This analysis is part of a composite dataset that was collected in the period of twelve months between 2013 and 2014 to study the effects of environment and climate variability on mosquito species. The data presented here dwells on the weather data collected during the main field work as well as historical data for over 30 years from 1980 to 2012 on atmospheric temperature and rainfall taken from the Ghana Meteorological Authority (GMet).

Accra (AMA) and Sekondi-Takoradi Metropolitan (STMA) Areas (Figure 1) are the two most urbanized cities in the coast of Ghana. The two are experiencing rapid urbanization as a result of being: (i) the capital of Ghana, in the case of AMA and (ii) a major harbor and oil city of the country, in the case of STMA. AMA by its status is the national administrative centre where the headquarters of all state and private organizations are located and the twin city of Sekondi-Takoradi is undergoing a rapid expansion to accommodate the fledgling oil business in the country.

While detail descriptions of AMA and STMA have been provided in Mattah et al. (2018), it is worth mentioning that AMA has an estimated population of 2,087,668, while Sekondi-Takoradi has an estimated population of 726,905 in 2019 (Ghana Statistical Service, 2019). The two cities are in the same ecological zone- coastal savanna zone (Dickson and Benneh, 1988), except that STMA is at the very edge of the zone, receives more rains than AMA and shows more characteristics of the rainforest belt. AMA receives on the average annual rainfall of 730 mm while STMA receives an average annual rainfall of about 1,400 mm (Aryee et. al., 2018). AMA's vegetation is thus more of coastal savanna grassland while STMA is of semi-deciduous forest type.

Methods

This study employed an explanatory research design with techniques to explain the effects of environmental variables such as surface temperature and rainfall on the population of *Anopheles* mosquito larvae. The causal

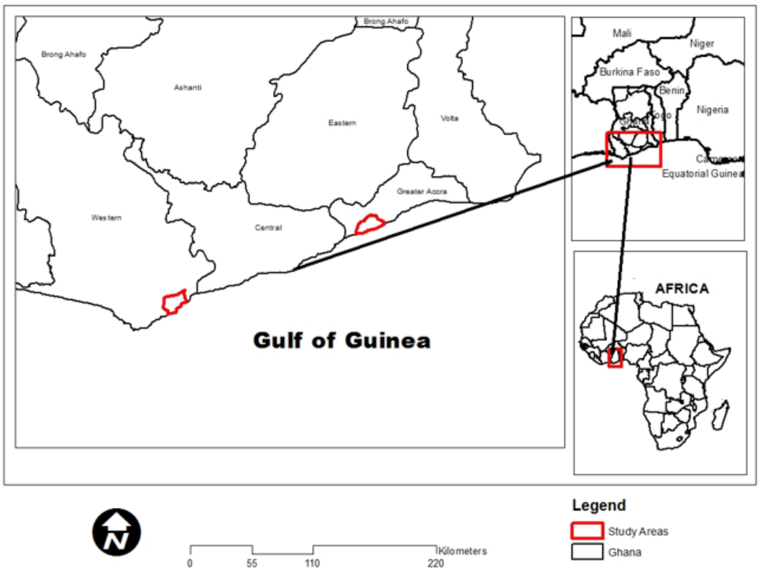

Figure 1: Map of the study areas

relationship between the dependent variable, which is the *Anopheles* mosquito populations, and the independent variables mainly of temperature and rainfall were explored using general linear models.

Sampling and identification of Anopheles mosquitoes

Larval survey was undertaken in twenty-one (21) communities or suburbs of the two cities- nine (9) in AMA and twelve (12) in STMA. These communities were randomly selected from a list of communities using the random sample of cases in SPSS version 16 software. The larval survey was conducted once every month for eleven months between March 2013 and February 2014 minus September 2013. *Anopheles* larval samples were taken using the standard method of larval sampling after (Service, 1993). Larvae were sampled using the dipping method with a 350 ml scoop and 175 ml size ladles. All available water bodies in these communities were considered as potential breeding sites and thoroughly searched for the presence of *Anopheles* mosquito larvae. The presence of *Anopheles* larvae was determined after 15-20 dips. Sampled larvae were transported to the laboratory of the Noguchi Memorial Institute of Medical Research (NMIMR) in the University of Ghana and reared to maturity for morphological identification of the *Anopheles* mosquitoes. Breeding habitats were described with respect to their origin, nature, stability and human activities around where they were sighted. These include puddles, swamps, drains (paved and unpaved), ditches/dugouts, construction sites, urban farm sites, streams/river edges, ponds/lagoons, lorry tyres and containers.

Climate data

Surface temperature and rainfall as measured by synoptic weather stations were collected from the Ghana Meteorological Authority (GMet) for the two cities and for all the months of sampling. Also, climate data on daily minimum and maximum temperature and rainfall for both cities from GMet was acquired for thirty-two years from 1980 to 2012.

Data Analysis

Determination of the relationship between temperature, rainfall and larval density

Temperature and rainfall are two key variables used in this study to project the impact of climate on future of populations of *Anopheles* mosquito larvae. Using Minitab software (Minitab Inc, State College, Pennsylvania) the relationships between the independent variables, that is, temperatures, rainfall and water temperature (which could be used as proxy to surface temperature), and the dependent variable (larval density) were determined using correlation analysis. The predictive abilities of these variables on population densities of *Anopheles* mosquitoes were initially determined using multiple regressions.

Projection of future climate variability

Trends derived from the GMet data was used as a baseline with which projections for the future climate variability was compared. Statistical downscaling approach described in Gutierrez et al. (2011) was used for the projection of future climate variability. Using the method of Gutierrez et al (2011), the average of ENSEMBLE GCM outputs AR4-BCM2 and AR4-CNCM3 scenario

A1B were downscaled and this matched with observations of rainfall and temperature from AMA and STMA. A downscaling portal (https:\\www.meteo.unican.es\downscaling\predictor) which belongs to the Santander Meteorological Group (CSIC-UC) of the Universidad de Cantabria, Spain was used. This downscaling portal provides access to various ENSEMBLE GCMs that are useful for both seasonal predictions and climate change projections. The portal allows for interpolation to the location of interest (in this case AMA and STMA). Even though the downscale portal is able to access GCM output from 2001 to 2100, this study used AR4-BCM2 and AR4-CNCM3 outputs from 2013-2050. GNUPLOT software was used in developing various charts for both the baseline and predicted climate variability for the two cities. Key assumptions for statistical downscaling models according to Wilby et al. (2004) include the fact that the host climate model should be able to adequately reproduce predictors that are relevant to the local predict and at spatial scales used to condition the downscaled response. Again, predictor sets should adequately include the future climate change signal. The last assumption state that the predictors used the future determination of local climate should be within the range of climatology used for the calibration of the statistical downscaling model.

Results

Anopheles mosquito larvae in drains

On the monthly visits to the 21 communities of AMA and STMA for the eleven months, a total of 195 potential mosquito breeding sites were encountered. Out of the 195 potential breeding sites, 48(24.6%) were either paved or unpaved drains. Also of the 48 drains that were potential breeding sites, 22(45.8%) had *Anopheles* mosquito larvae in them. While 20(41.7%) of the 48 drains were found in AMA, 28(58%) were found in STMA. Of the twenty drains found in AMA, 65% of them had *Anopheles* mosquito larvae while 9(32%) of those drains found in STMA had *Anopheles* larvae.

Rainfall and Temperature patterns of the two cities during sampling

Figures 2 shows the distribution pattern of total monthly rainfall and mean monthly

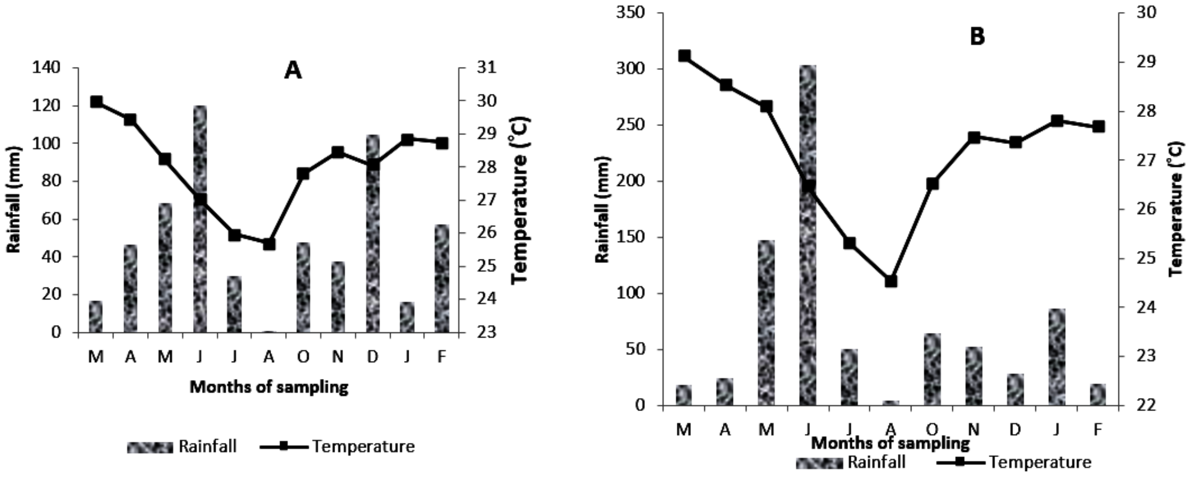

Figure 2: Monthly total rainfall and mean temperature of (A) AMA and (B) STMA

surface temperature for the two cities during the larval survey. In AMA, total monthly rainfall increased gradually from March 2013 to a peak of 120 mm in June and the minimum of 0.2 mm in August 2013 (Figure 2A). Much variability was observed when the minor rainy season extended from September to December. From September (Not shown in the graph) an amount of 66.3 mm of rainfall was received and this decreased in October (47.8 mm) and November (37.3 mm) but increased again in December (104.8 mm). Months of November, December, January and February which hitherto were usually dry, received rainfall of 37.3 mm, 104.8 mm, 16.3 mm and 56.9 mm respectively during the period of larval survey. In STMA, much of the rainfall was concentrated in May and June with the highest total monthly rainfall of 303 mm recorded in June. Like AMA, August remained cold and dry with minimum total monthly rainfall of 4.5 mm (Figure 2B). Also, just like AMA, the minor rainy season of STMA extended from September (not shown on the graph) to December, recording values of 94.3 mm and 28.1 mm respectively.

Weather and larval patterns observed during larval survey

Figures 3 and 4 show how the weather patterns during the sampling period related to the proportion of *Anopheles* larvae sampled in the study areas. In AMA, the proportion of *Anopheles* larvae sampled followed the rainfall distribution pattern where higher proportions of larvae sampled coincided with the major and the minor rainy seasons (Figure 3A). In Figure 3B, the relationship observed between mean monthly temperature and the proportion of *Anopheles* larvae for AMA is shown. In STMA, the onset of the rains in March brought high proportion of *Anopheles* larvae. October and November, which were the minor season also coincided with a slight increase in population of the *Anopheles* larvae (Figure 4A). Figure 4B also shows the relationship between monthly mean temperature and the proportions of *Anopheles* larvae during the sampling period in STMA.

Relationship between temperature, rainfall and larval density

The data from the two coastal cities put together showed a negative but statistically significant correlation between surface temperature and total monthly rainfall (r= -0. 196; p= 0.006;

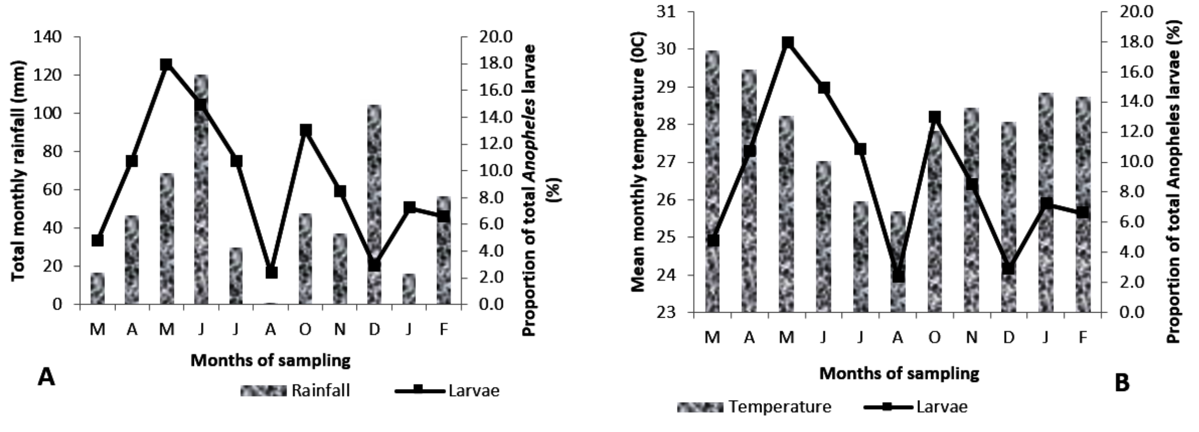

Figure 3: Rainfall and Temperature distribution of AMA: (A) Total monthly rainfall and proportion of *Anopheles* larvae in AMA; (B) Mean monthly temperature and proportion of *Anopheles* larvae in AMA

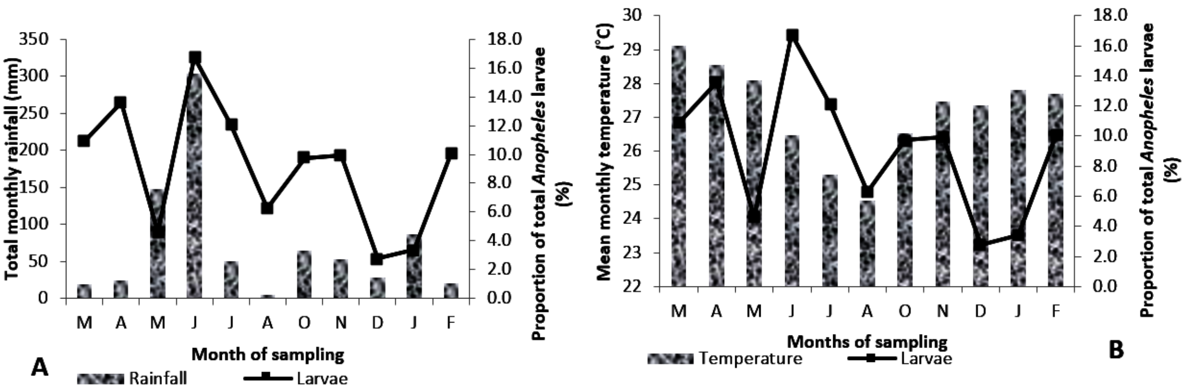

Figure 4: Rainfall and Temperature distribution of STMA: (A) Total monthly rainfall and proportion of *Anopheles* larvae in STMA; (B) Mean monthly temperature and proportion of *Anopheles* larvae in STMA

95%). There was also a significant positive correlation between atmospheric temperature and water temperature (r= 0.240; p= 0.0010; 95%). Again, data from the two cities showed a positive and statistically significant correlation between surface temperature and *Anopheles* mosquito larval density (r= 0.221; p= 0.002; 95%). Also, there was a very weak negative correlation between total monthly rainfall and larval density of the data from the two cities combined though not statistically significant (r= -0.059; p= 0.409; 95%). Likewise, analysis of each city's data revealed weak positive correlations between surface temperature and larval density or rainfall, but none was statistically significant [temperature: AMA, (r= 0.154; p= 0.202; 95%); STMA, (r= 0.055; p= 0.539; 95%) and rainfall: AMA, (r= 0.006; p= 0.958; 95%); STMA, (r= 0.036; p= 0.691; 95%)].

A linear regression analysis of atmospheric temperature and larval density on data from both cities was statistically significant (p= 0.002; 95%).

On the contrary, regression analysis of water temperature and larval density was not statistically significant (p= 0.732; 95%). Additionally, regression analyses of total monthly rainfall and larval density was not statistically significant (p=0.400; 95%). Although regression analyses were done for data exclusively from AMA and STMA, none of the outputs were statistically significant.

Historical and future climate variability over coastal urban Ghana

Anomaly plots for rainfall and temperature over the two cities in coastal Ghana are shown in Figures 5 and 6. The reference values for the anomaly are the averages of both rainfall and temperature of the period 1980-2012. The Anomaly measures the extent to which each year's average rainfall or surface temperature varies or deviates positively or negatively from the reference average of the period 1980-2012. Here, the green portions of the figures depict the data for the reference year and the red portions show the projections for the period 2013 to 2050. From Figures 5A and 5B, it is observed that AMA generally experienced dry and hot weather in much of the period between 1980 and 2012. Rainfall in most of the period was far below the average except for 9 out of the 32 years (Figure 5A). In Figure 5B, except for the period 2007 -2011, the entire period of 1980 to 2012 experienced temperatures which were far below the average. Future projections as depicted in the red portions of the Figures 5A and 5B, however, show that much of the period between 2013 and 2050 would be wet and hotter than the baseline years of 1980 to 2012. From Figures 6A and 6B, just like AMA, STMA experienced dry and hot climate in the period between 1980 and 2012, but the projections show that the future (2013 to 2050) will be wetter and hotter in the study area. Thirteen of the 32 years however had surface temperatures, which were above the average as seen in Figure 6B.

Figures 7 and 8 show the seasonality of rainfall and temperatures for the baseline (1980- 2012) and the projected period (2013- 2050) in the two cities. Seasonality of rainfall in AMA had peaks in June and October for the baseline data (1980-2012) as shown by the green line in Figure 7A. The projected seasonality, which is depicted in red for 2013 to 2050, may have peaks in May and September (Figure 7A). With the onset of the rains in February, the baseline data for AMA shows a major rainy season which spans from March to July and a minor season between September and November. In-between the two peaks is a dip in August, which together with January and February receive the lowest total monthly rainfall. The projected rainfall shows that rainfall may decrease from a peak of 175 mm in June (in the baseline) to a peak of 135 mm in May (in the projected) for the major rainy season. There may also be an increasing rainfall in the minor rainy season from a peak of 65 mm in October (in the baseline) to a peak of 135 mm in September (in the projected) for AMA. The duration of the minor rainy reason may widen starting from August instead of September to December instead of November. It also shows significant shifts in the onset of the rain from February to March as well as the peaks for both major (from June to May) and minor (from October to September) seasons (Figure 7A). Regarding surface temperature, data as depicted in Figure 7B shows the seasonality of the mean monthly temperature for AMA. The baseline data (1980- 2012) reveals a mean temperature trend that ranges between 24°C and 29°C with a peak approximately 29°C in February and a low surface mean temperature in the months of July and August. When projected into the future (2013- 2050) as shown in the redline, significant increase in mean temperature trends is expected (ranging from 29°C to 32°C). A peak of approximately 32°C is expected in February and a dip of 29°C is expected in August. From the projected data, AMA's surface temperature may decrease gradually from January to August and then increase from August to December.

Similar to AMA, STMA has a baseline (1980-2012) which shows seasonality in rainfall with peaks in June (250 mm) and October (110 mm) (Figure 8A). When projected into the future (2013- 2050), total monthly rainfall is predicted to be higher than what was observed in the baseline for all the months, except for May and June as shown in the red line. The projected rainfall in STMA may be generally higher and well distributed throughout the months than observed in the baseline. Significant increases may be observed in the total monthly rainfalls to be seen in the months of July (from 90 mm to 140 mm), August (from 60 mm to 140 mm), September (from 70 mm to 160 mm) and October (120 mm to 170 mm). Just as in AMA, the minor season, is expected to start in August instead of September and last until November.

In Figure 8B, the baseline data (depicted in green) shows the mean monthly temperature for STMA that ranges between 28.4°C and 31.2°C with the peak of 31.2°C in April and a lower mean monthly temperature of 28.4°C for August. Projection for the mean monthly temperature from 2013- 2050 (depicted in red) shows a decreasing trend from March to August and an increasing trend from August to December. In the projections, August may be a little colder, on the average, a difference of 0.25°C while January, February, September, October, November and December may be warmer than experienced in the baseline, on the average, a difference of 1.0°C.

From Figures 7B and 8B, the mean surface

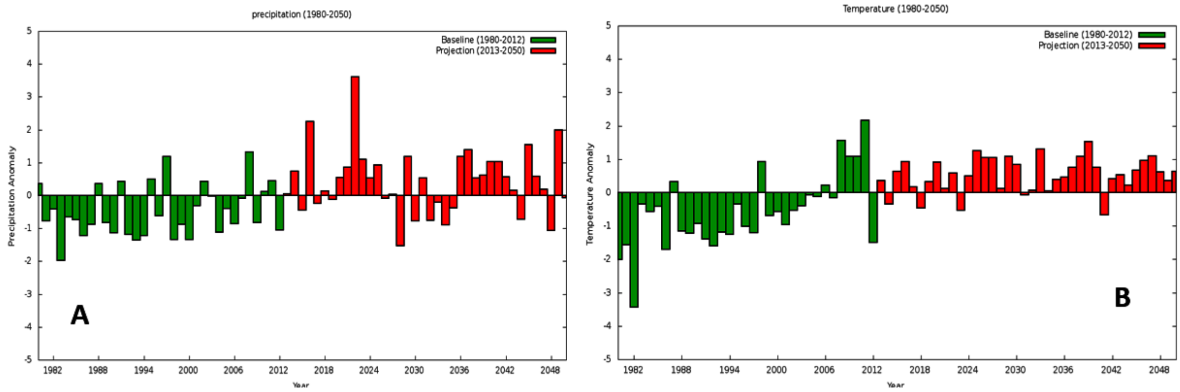

Figure 5: Anomaly plots of (A) rainfall and (B) temperature in AMA

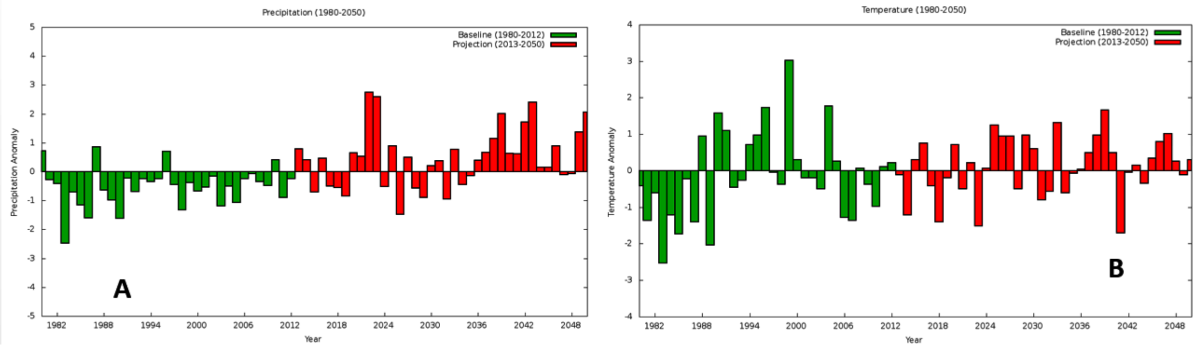

Figure 6: Anomaly plots of (A) rainfall and (B) temperature in STMA

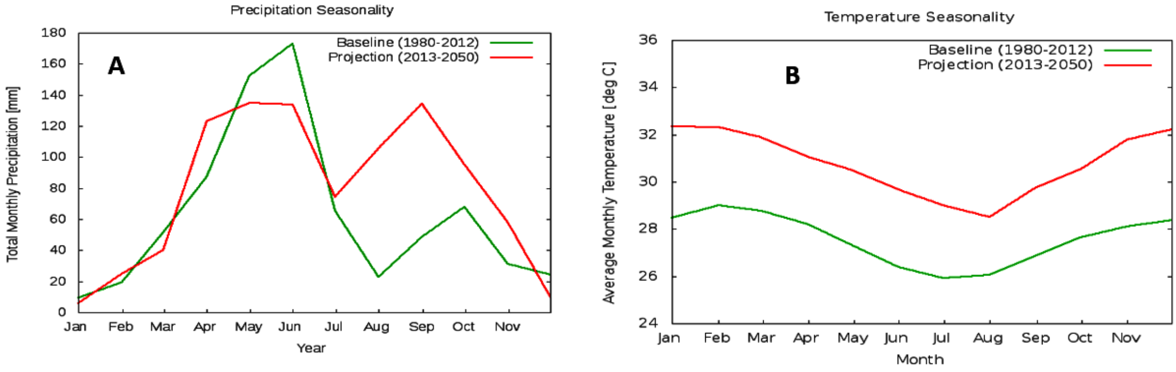

Figure 7: Trends and projections of (A) rainfall and (B) temperature of AMA

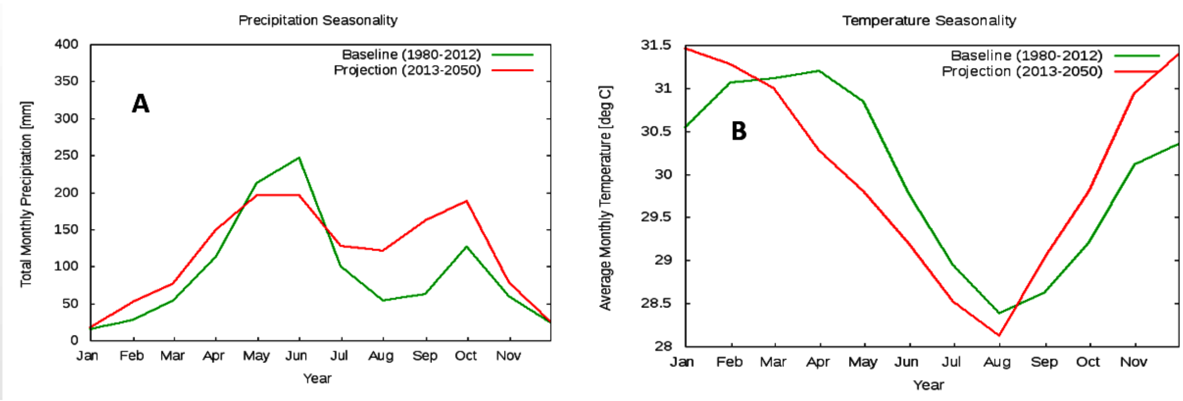

Figure 8: Trends and projections of (A) rainfall and (B) temperature of STMA

temperature experienced in the months of the baseline years of 1980-2012 was 28.9°C and that which is likely to be observed in the projected years of 2013-2050 in the two cities is in the range of 1.5 – 2.0°C more.

Future effects of temperature on Anopheles larval densities under climate variability in coastal urban areas of Ghana

Using the regression analysis which involved the surface temperature (since it is the only independent variable with statistical significant equation), larval densities for the two cities combined were predicted. This was done using the mean surface temperatures for the baseline (28.9°C) and projected (30.6°C) as observed in section of future climate scenarios above.

Substituting the baseline mean surface temperature of 28.9°C and the projected mean surface temperature of 30.6°C into equation 1, the effect of surface temperature on larval density was predicted as increasing from 5.89 to 7.61 for the two cities by 2050. This implies that larval density could go up by a margin of 1.72 at the projected mean surface temperature of 30.6°C in 2050.

More so, the difference between the projected temperature (30.6°C) and that of the baseline (28.9°C) is 1.7°C. This gives a climate projection scenario where atmospheric temperature in the two urban areas of southern Ghana could increase by 1.7°C. The minimum and maximum atmospheric temperatures obtained during this particular study were 24.3°C and 30.4°C respectively. Adding the 1.7°C to the minimum atmospheric temperature of 24.3°C gave a projected minimum temperature of 26°C and that of maximum atmospheric temperature of 30.7°C yielded a projected maximum surface temperature of 31.4°C.

Similarly, should minimum surface temperature in future be 26°C and the maximum temperature be 31.4°C, the projected minimum and maximum larval density will be 2.96 and 8.41, respectively.

In all these cases, the regression equation predicted that larval density would be increasing with corresponding margins of increase in surface temperature in the future.

Discussion

Climate variations in coastal urban areas of Ghana

The data presented in this study provide ample evidence to support the fact that climate variation is occurring, not only at the global level but also at the micro level such as community levels. Climatic variables such as rainfall and temperature at the local levels are showing evidence of change as has been confirmed Foque and Reeder (2019). In Ghana for example, Asante and Amuakwa-Mensah (2015) intimated that surface temperature may increase, while rainfall may also decrease and the cumulative effect of all these changes in the coastal areas could be decreasing fishery resources and shifting vector-borne disease. The data in this particular study showed an extended minor rainy season during the sampling period covering four months (September to December) instead of the usual two months of September and October. This extended rainy season connotes the extension of the breeding of *Anopheles* mosquitoes since the breeding of *Anopheles* species have been associated with rainfall distribution patterns (Getachew et al., 2020). This is contrary to Drake and Beier (2014) postulation that the future potential distribution of *Anopheles* arabiensis species in Africa may likely be smaller than the contemporary distribution by almost half because of climate change. Proportions of *Anopheles* larvae were observed to be increasing with rainfall in the two cities. Various studies conducted in Ghana had also indicated some correlation between *Anopheles* mosquitoes and rainfall pattern (Chinery, 1984; Dery et al., 2010; Kasasa et al., 2013; Klutse et al., 2014; Amekudzi et al., 2014a).

Past climate figures (1980- 2012) for the two cities showed a climate which was generally dry and hot with annual rainfall and mean annual temperatures well below the average for most part of the 33 years' period. Projections from the anomaly revealed that by 2050, much of the annual rainfall and mean annual temperature for the two cities could be above average. This implies that the climate of the two cities will be wet and warm. The findings imply that while the climate was dry and hot during the period 1980 to 2012, yet urban areas received increasing breeding of *Anopheles* mosquitoes (Mattah et al 2017; Osse et al., 2019), with wet and warm climate in the projection years of 2013 to 2050, the rate of increase in *Anopheles* breeding may further increase.

Monthly projections for AMA for the period 2013-2050 showed that the onset of the rains for each year will delay, starting from March instead of February and continue till July which will see a slight dip but then begins the minor season which lasts till December. AMA will therefore receive extended rainy period from March to July and from July to December. Observations in STMA are that the major and the minor rainy seasons are coalescing into one (Figure 8A), which will also lead to an extended rainfall season. Even though in AMA, the start of the rain delay for one month, breeding of *Anopheles* may be all year round for the two cities since the two rainy seasons were seen to be coalescing into one and rainfall well distributed throughout the months of the year. In STMA, the onset of the rains in second decad of March was also identified by Amekudzi et al (2015) and they noted that onset of the rain brought high proportion of *Anopheles* larvae.

Seasonality and Anopheles mosquito larval abundance

Studies using malaria data from health facilities revealed that though malaria cases prevailed all year round, there were peak malaria seasons which coincided with rainy seasons (Amekudzi et al., 2014b) just as *Anopheles* larval presence coincided with rainy seasons in this study. Having rainfall above average as in the projection (red bars) in Figures 5A and 6A may lead to increase in occurrence of water bodies that may serve as breeding places of *Anopheles* mosquito, however whether that will translate into high population of *Anopheles* mosquitoes will depend on other environmental factors. Also, increasing surface temperature may result in higher water temperatures which may or may not be congenial to *Anopheles* mosquitoes depending upon the margin of increase. Amekudzi et al. (2014b) projected that surface temperature along coastal Ghana may rise above 35°C between 2020 and 2030, which they claimed could negatively affect the breeding of *Anopheles* mosquitoes. Contrary to their finding, this particular study showed that increase in surface temperature could lead to increase in larval density in the two cities. Also, the finding that surface temperature could increase by 1.7°C agrees with the fact that scenarios A1B of the ENSEMBLE GCM outputs AR4-BCM2 and AR4-CNCM3 which usually give temperature increase within the range of 1 to 4°C (Gutierrez et al., 2011).

Urban waste management and Anopheles breeding

Most *Anopheles* mosquito breeding sites especially in the dynamic urban environments of sub-Saharan Africa are often ephemeral. However, Mattah et al (2017) observed a growing number of permanent *Anopheles* breeding sites. This was attributed mainly to the lack of care for the urban environment among urban dwellers. This lack of environmental care promotes poor solid waste disposal, unregulated building and construction activities, as well as, the growing number of choked drains in the cities. With the attitude of urban dwellers creating numerous water bodies in the urban environment and with the adaptation of *Anopheles* mosquitoes to all types of water bodies, *Anopheles* mosquito breeding will continue. However, other environmental variables such as temperature and rainfall may play important roles in regulating the population dynamics of the vectors in the water bodies.

Conclusion

In conclusion, the study predicted that increasing surface temperature may lead to increase in larval density of *Anopheles* mosquitoes. Increase in larval density will most likely bring about an increase in the population of the malaria vectors and possibly an increase in malaria cases in the two cities. The predicted extended rainy period in the cities may also make urban malaria transmission a perennial problem rather than the current seasonal occurrence.

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