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PUBLIC PERCEPTION OF THE USE OF NATURAL VERSUS SYNTHETIC MOSQUITO REPELLENTS IN GHANA

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Abstract

Purpose — This study examined people's knowledge, taste, and preferences on the use of these ingredients in mosquito repellents.
Methods — The study adopted questionnaires to solicit public opinions and 303 respondents were conveniently sampled using an online Google link. Their responses were examined using descriptive analyses and an ordinal regression model.
Findings — The study identified that 57% of respondents preferred to use mosquito repellents that will contain natural ingredients only, whereas 14% preferred mosquito repellents that will have a combination of both natural and artificial ingredients. The educational status of respondents influences their preference for mosquito repellent.
Conclusion & Recommendation — The study concludes that there is a need to educate people on the effects of using synthetic mosquito repellents. Further scientific investigations are required to examine the efficacy of mosquito repellents made from natural ingredients.

Keywords — Malaria, plant-based repellents, health, efficacy, artificial repellents

Introduction

Mosquitoes thrive in tropical and subtropical climate zones where they transmit yellow fever virus, elephantiasis disease-causing zooparasitic nematode (*Wuchereria bancrofti*), and malaria disease-causing *Plasmodium* spp., among others, to humans. Malaria, for instance, is reported to be a major public health issue and about 3.3 billion people across sub-Saharan African countries are at risk (Asadollahi et al., 2019; Yoon et al., 2015). It has been reported that over 50 species of *Anopheles* mosquitoes transmit malaria. Ghana, for instance, piloted the malaria vaccine in May 2019 and WHO recommended its use for only children (Grant et al., 2022). Many people have to still find the means to protect themselves from mosquito bites. Several people apply different mosquito repellents to reduce the risk of infection by *Anopheles* mosquitoes (Grison et al., 2020; Mendoza et al., 2020; Yoon et al., 2015). Natural-based repellents have been applied by many people. Products such as Cinnamomum Catnip (*Nepeta cataria*), Thyme (*Thymus serpyllum*), peppermint, and *Citronella* are found to be effective in repelling species of *Anopheles* mosquitoes (Asadollahi et al., 2019). Knowledge about these plant-based products is important for the development of new products (Asadollahi et al., 2019; Maia & Moore, 2011). Notwithstanding, individuals' tastes and preferences, knowledge, and perception about these products can influence the use of these products. The choice of mosquito repellents could be based on the knowledge people have about the products. Some people may choose their products based on efficacy whilst others may be concerned about the negative health implications of products. The type of mosquito repellent used could have adverse effects on people. Studies have found that different repellents have been used by consumers without knowing the adverse effects of these products on their health and/or environment. For instance, it is estimated that the fine particulate matter released from the use of a single synthetic mosquito coil is equal to about 137 cigarettes whereas continuous use of similar products for 8-10 days could cause respiratory disorder (Islam et al., 2022). It is reported that insect repellents that contain N,N-diethyl-3-methylbenzamide (DEET) have some side effects such as allergic reactions, neurologic and cardiovascular-related ailments, and systemic toxicity in adults (Khater et al., 2019). Others have also reported that N,N-diethyl-3-meta-toluamide (DEET) causes sensory discomfort which affects motor neurone capacity, memory, and learning capabilities among users (Yoon et al., 2015). Yet, N,N-diethyl-3-meta-toluamide (DEET) happens to be used by many since 1957 (Afify et al., 2019).

Other researchers have established that natural-based products have proved to be effective with low negative environmental impacts (Kwon et al., 2019). Mosquito repellents from plants such as essential oils from neem, horticultural, rushed lavender flowers, soybean, thyme, Greek catnip, and lemon eucalyptus oils are proven to be much safer (Islam et al., 2022). Some authors opine that plant-based mosquito repellents can be applied more often in a day since their effects on the skin are short-lived; therefore, the application of natural-based mosquito repellent could change the dynamism in the attitude and behavior of consumers (Sangoro et al., 2014). Other studies found that people prefer to use plant-based mosquito repellents because they fear that synthetic repellents may be more harmful than the use of plant-based repellents (Grison et al., 2020; Mendoza et al., 2020). However, studies that are needed to unveil people's perceptions, knowledge, and attitudes about repellents have received less attention (Potter et al., 2016), especially in the Ghanaian context. People's perception influences their actions, inactions, lifestyle, and choices (Tsai et al., 2020). In this case, the current study is aimed at understanding the perceptions of people about the use of these natural and synthetic mosquito repellents.

Materials and Methods

This study employed quantitative approaches to solicit the views of respondents on the use of mosquito repellent. To study the perception of people about the use of natural versus synthetic mosquito repellents, a questionnaire was designed using a Google document. This was shared with the researchers' contacts via email and WhatsApp. The respondents were conveniently sampled and the questionnaire was forwarded to 1,000 Ghanaian contacts. Questionnaires consisted of background characteristics which were treated as independent variables and dependent variables included their perception of the use of natural and artificial repellents.

Respondents were asked to reveal their perception regarding the use of mosquito repellents made from (i) natural and artificial ingredients, (ii) only natural or only artificial ingredients, and (iii) a combination of more than one natural-based ingredient. A five-point Likert scale was used to solicit the opinions of respondents. The questionnaire consisted of closed and open-ended questions to allow participants to share their thoughts and comments on the issues considered for the study. Since the data collection took place during the COVID period, between March to June 2021, the respondents were conveniently reached using a shareable Google-based link that enabled effective compliance with COVID-19 protocols. Ethical issues were taken into consideration.

Hence, participants from the public were (1) informed about the purpose of the study and (2) not coerced into participating in the study.

Even though online surveys have been employed in data collection (Moore et al., 2018), their application in the Ghanaian context had been limited. There was a challenge in getting more respondents for the online survey. Out of 1,000 people who were reached with the questionnaire through their emails and WhatsApp, only 303 respondents willingly filled out the questionnaire form within the stipulated period despite several reminders that were sent to all of them. The responses were retrieved in Excel format which were converted into SPSS version 23 format. Likert scale variables were treated as ordinal scale variables and the P-value used in this study is 0.05. Data obtained from the 303 respondents were analyzed using descriptive statistics and an ordinal regression model. The purpose of using ordinal regression was to predict the effects of dependent variables on the independent variables (Eshun et al., 2022). The independent variables were the demographic characteristics (age, education, religion, sex) and the dependent variables include respondents' perceptions of the use of mosquito repellents. This includes the extent to which they agree or disagree with the use of natural and synthetic mosquito repellents.

Results and Discussions

Results

This section presents the results of the study. It firsts highlights the background characteristics of respondents. This is shown in Table 1. The Table indicates that more respondents are males (51%) than females (49%). The highest age group is those who are between 36-45 (34%) followed by those who are 26-35 years (29%). Most respondents have attained post-graduate education (34%) followed by those with a first degree (28%) with a greater majority being Christians (82%). These demographic backgrounds are important as they helped the researcher to understand their perceptions and beliefs in the use of natural and synthetic mosquito repellents.

Table 1: Background Characteristics of Respondents

Item	Percentage (%)
Sex	
Male	51
Female	49
Age	
18-25	16
26-35	29
36=45	34
46-55	11
56-65	7
66+	3
Education	
JHS	6
SHS	8
First degree	28
Graduate	17
Post Graduate	34
N/A	7

Religious affiliation	
Christianity	82
Islamic	16
Traditional African religion	1
Other	0.7
N/A	0.3

The study further investigated the degree to which respondents agree or disagree with their use of mosquito repellents with natural or artificial ingredients. The results showed that most respondents with a mean of (4.2) agreed that they are likely to use mosquito repellents made from natural ingredients (see **Table 2**) because they believed repellents containing natural ingredients have lesser side effects whilst others were neutral on the use of synthetic mosquito repellents. Most respondents with a mean of (2.9) disagreed that they are likely to use mosquito repellent made from artificial (synthetic) ingredients because they believed artificially made ingredients have side effects (2.3). However, some respondents were neutral to the opinion that mosquito repellents containing natural ingredients are easy to find (3.0) whilst most believed that those with artificial ingredients are easy to find (4.0).

Table 2: The Mean of Respondents on the Perception of the Use of Mosquito Repellents made from Synthetic or Natural Ingredients

Serial number	Item	The mean number of respondents
1	I am likely to use mosquito repellent with natural ingredients	4.2 (1.0316)
2	I am likely to use mosquito repellent with synthetic ingredients	2.9 (1.199)
3	Repellents made from natural ingredients have lesser side effects	4.2 (0.948)
4	Repellents containing natural ingredients are easy to find	3.0 (1.173)
5	Repellents containing natural ingredients are more effective	3.7 (0.924)
6	Repellents made up of synthetic ingredients have lesser side effects	2.3 (1.024)
7	Repellents containing synthetic ingredients are more effective	3.2 (1.044)
8	Repellents containing synthetic ingredients are easy to find	4.0 (0.978)

Note: Standard deviation in parenthesis

Respondents were asked to indicate their preference for ingredients in mosquito repellents and the result is shown in Figure 1. The majority of respondents (57%) preferred mosquito repellents made from natural ingredients, followed by those who preferred repellents that will contain a combination of different natural ingredients (19%).

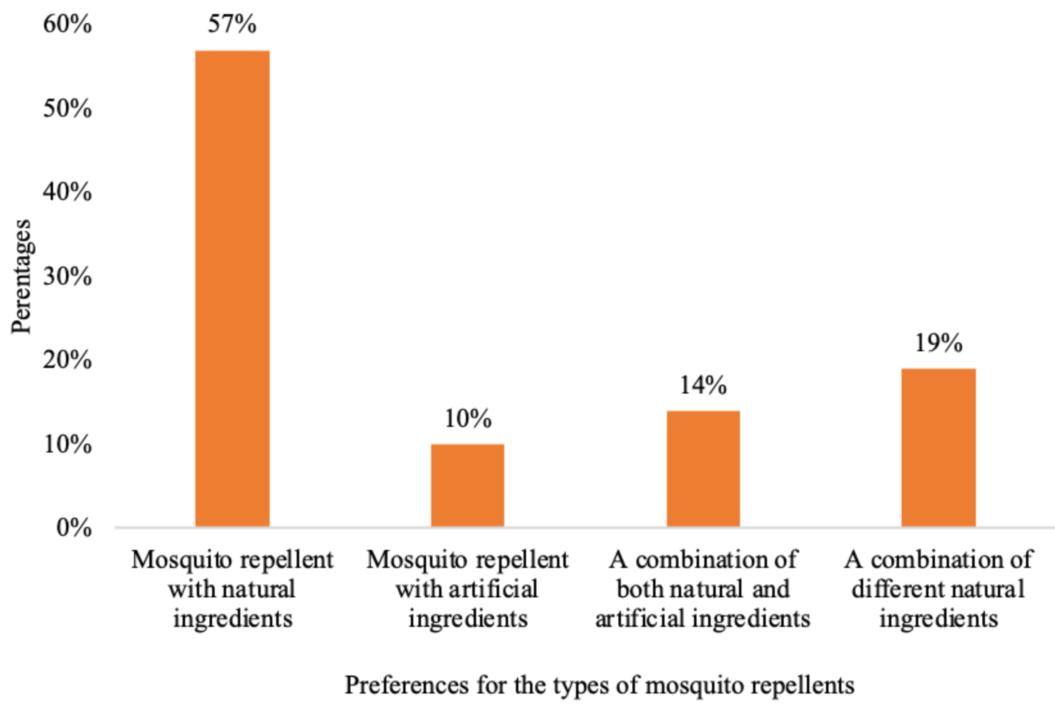

Figure 1: Respondents' preferences for categories of mosquito repellents.

Respondents were further asked to indicate the sources of their information on the use of mosquito repellents. For this, the results are shown in Figure 2.

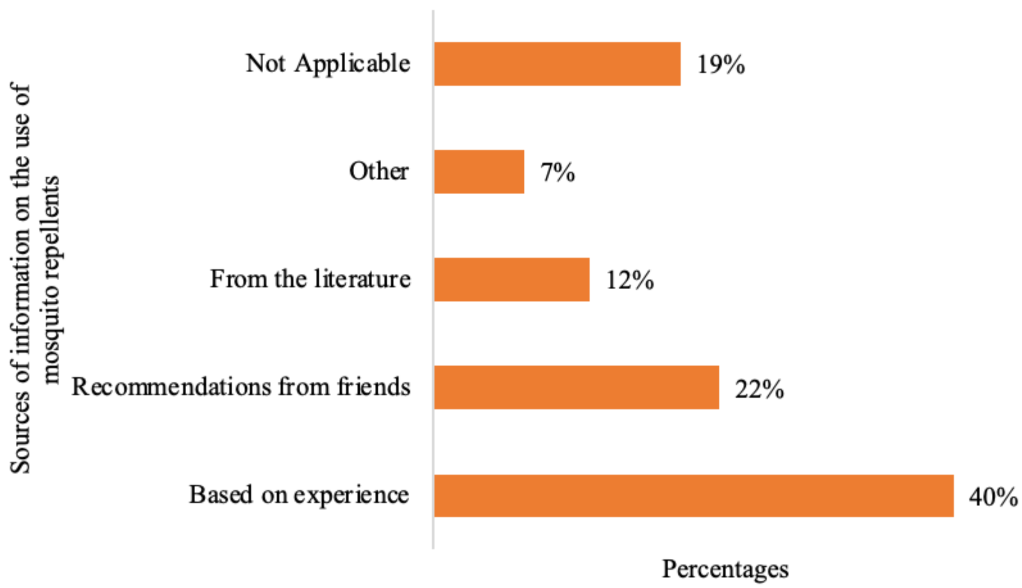

Figure 2: Sources of information on the use of mosquito repellents.

Most respondents (40%) have gained their knowledge based on experience whilst respondents (22%) said that their knowledge about the use of repellents was by recommendations from families and friends. These families and friends may have also made the recommendation based on their experience in the use of the products. An ordinal regression analysis of data was performed to ascertain the effects of socio-demographic characteristics on the use of natural versus artificial mosquito repellents. The results are shown in Table 3. The age of respondents influenced significantly the perception of respondents who believed that they were likely to use mosquito repellents made from natural ingredients. This is significant for those between the ages of (18-25, and 26-35) but has a decreased odds. This means that those aged 18-35 are less likely (-2.761) to use mosquito repellent with natural ingredients than those aged 26-35 and explains 10% of the model with a confidence interval of 95% ($p < 0.05$). Furthermore, the educational status of respondents significantly influences the likelihood to use mosquito repellents made from artificial ingredients, and those with postgraduates have decreased odds (-1.619) or are less likely to use synthetic repellents than those with graduate education (-1.763) with a Nigelkerke R^2 value of 18%. Religion happens to be the only socio-demographic variable influencing the belief that repellents from natural ingredients have lesser side effects. However, this has a decreased odds (-20.618) and explains 15% of the model. In addition, religion, and education significantly influence respondents' belief that mosquito repellents with natural ingredients are easy to find. This has a decrease odds and explains 17% of the model. Religion again significantly influences the perception that mosquito repellents with natural ingredients are more effective. Respondents from the various religious denominations have a decrease odds: Christianity (-21.102), Islamic (-21.532), and traditional religion (-20.988) which explains 7% of the model. Furthermore, the education of respondents significantly influences their perception that mosquito repellent with synthetic ingredients has lesser side effects with decrease odds (JHS: -1.732, First degree: -1.911, Graduates: -1.700, and Postgraduate: -2.097) and explains 16% of the model. Moreover, sex, education, and religion significantly influence the perception that repellents containing artificial ingredients are more effective with decrease odds which explains 14% of the model. Consequently, those with graduate education are less likely to believe in this than those with a first degree.

Table 3: Outputs of ordinal regression analysis applied to the survey data

Item	**Estimate**	***p*-value for significance**	**Lower**	**Upper**
I am likely to use mosquito repellent with natural ingredients:				
Religion				
Christianity	-19.911	0.000	-22.500	-17.323
Islamic	-19.941	0.000	-22.583	-17.299
Age				
18-25	-2.761	0.026	-5.190	-.331
26-35	-2.464	0.043	-4.845	-.082
Nagelkerke R^2 = 10%, ($p < 0.05$)				
I am likely to use mosquito repellent with synthetic ingredients:				
Educational status				
Graduate	-1.763	0.02	-3.243	-0.283
Postgraduate	-1.619	0.03	-3.064	-0.175
Nigelkerke R^2 18%, ($p < 0.05$)				
Repellents made from natural ingredients have lesser side effects:				
Religion				
Christianity	-20.618	0.000	-23.310	-17.926
Islamic	-20.754	0.000	-23.496	-18.013
Traditional religion	-20.023	0.000	-25.728	-18.318
Nagelkerke R^2 = 15%, ($p < 0.05$)				
Repellents containing natural ingredients are easy to find:				

Religion				
Christianity	-21.376	0.000	-23.958	-18.794
Islamic	-21.479	0.000	-24.105	-18.853
Traditional religion	-21.613	0.000	-25.241	-17.985
Education				
JHS	-2.596	0.000	-3.969	-1.222
SHS	-1.750	0.013	-3.131	-0.369
First degree	-2.055	0.001	-3.243	-0.868
Graduate	-1.900	0.002	-3.107	-0.693
Postgraduate	-2.625	0.000	-3.811	-1.439
Nigelkerker R^2 = 17%, ($p < 0.05$)				
Repellents containing natural ingredients are more effective:				
Religion				
Christianity	-21.102	0.000	-23.744	-18.460
Islamic	-21.532	0.000	-24.217	-18.847
Traditional religion	-20.988	0.000	-24.688	-17.289
Nagelkerke R^2 = 7%, ($p < 0.05$)				
Repellents that contain synthetic ingredients have lesser side effects:				
Educational status				
JHS	-1.732	0.012	-3.078	-0.386
First degree	-1.911	0.002	-3.071	-0.752
Graduate	-1.700	0.005	-2.880	-0.520
Postgraduate	-2.097	0.000	-3.250	0.944
Nagelkerke R^2 = 16%, ($p < 0.05$)				
Repellents containing artificial ingredients are more effective:				
Sex				
Male	-20.604	0.007	0.165	1.036
Educational level				
First degree	-1.543	0.008	-2.689	-0.397
Graduate	-1.280	0.032	-2.447	-0.113
Religion				
Christianity	-21.405	0.000	-24.195	-18.615
Islamic	-21.727	0.000	-24.561	-18.892
Traditional	-20.677	0.000	-24.482	-16.871

Nagerlkerke R^2 = 14.%, ($p < 0.05$)

Discussions

This study investigated the perceptions of respondents on the use of natural and synthetic-based mosquito repellents. People are becoming more conscious of the use of synthetic products and their perceptions influence their choice of products, although some people will use both synthetic and plant-based mosquito repellents. This study found that more respondents are interested in using mosquito repellents with natural ingredients because they are effective with lesser side effects. This resonates with what others have also found. Mosquito repellents

with natural ingredients are gaining popularity among consumers (Maia & Moore, 2011) as they are effective, and have fewer negative effects on human health (Khater et al., 2019; Yoon et al., 2015).
Furthermore, it has been established that mosquito repellents made from natural ingredients have not only proven to be effective and safer but have been environmentally friendly (Islam et al., 2022; Kwon et al., 2019). In this study, the preference for natural mosquito repellents had been high because of respondents' previous experiences or cherished knowledge of the use of such products. This suggests that even though education is important in changing the perceptions of people, their experiences in the use of products should be taken into account. People develop preferences for products once they believe in the efficacy of the products and it meets their taste. People use products that are recommended to them by trusted friends and families.

To a large extent, synthetic insect repellents that contain N,N-diethyl-3-methylbenzamide (DEET), N,N-diethyl-3-meta-toluamide (DEET) have side effects which include allergic reactions, neurologic, cardiovascular-related concerns, systemic toxicity in adults, and sensory challenges among users (Khater et al., 2019; Yoon, 2015). Even though plant-based repellents are traditionally used, little is known about their effectiveness (Asadollahi et al., 2019). This study indicates that some people are very much informed about the effects of synthetic ingredients in mosquito repellents. Therefore, they will prefer repellents made from natural ingredients because they believe these natural products are effective and have lesser side effects. People's desire to use repellents containing natural ingredients is based on experience and information from families and friends, whom they trust. People's perceptions influence their decision-making patterns (Tsai et al., 2020). When people have knowledge about a product and perceive it to be effective, they are likely to go for it. In the current study, it suggests that people will have an interest to use mosquito repellents made from natural ingredients. In this study, those who prefer mosquito repellents with natural ingredients believe that it is more effective. The perception of people about a product may influence the use of that particular product and requires scientific investigations to provide better ways to improve the effectiveness of the products. This is because as the taste and preferences of consumers change, research to uncover the various natural ingredients to produce more natural products with lesser side effects should be encouraged.

Even though respondents believed that mosquito repellents made from natural ingredients are effective and/or have fewer side effects when compared with synthetic ones, laboratory examinations to ascertain the veracity of such claims are warranted. However, this was a limitation in this study as resources could not permit the researchers to investigate this. The study further investigated the socio-demographic factors influencing their perceptions and found that the religion and educational background of respondents play greater roles and age and sex play lesser roles in their perception of the use of natural and synthetic repellents. Other studies have found that human behaviour plays a key role in the prevention of malaria (Gryseels et al., 2015). The education and religious beliefs of people can influence their perception of the use of certain products and cause them to behave in certain ways. Other studies have also found that age and education significantly influence people's ownership and use of treated mosquito nets (Darko et al., 2019). In this study age was significant only for the youth (18-35), an indication that policies and strategies to develop health products should consider the youth.

Conclusion and Recommendation

People have developed a taste for natural products as they believe that synthetic products have negative health implications. The study revealed that the education and experiences of people are crucial in their perception of the efficacy of products. The formal educational status of people can significantly influence their perception of the use of mosquito repellent. However, whether one has a higher formal educational status or not, their knowledge may not correspond to the risks of synthetic mosquito repellents. Hence, educational campaigns to increase awareness of the general public are critical. This study could not investigate the efficacy of plant-based mosquito repellents. Further studies to evaluate the efficacy of plant-based repellents in sub-Saharan Africa are recommended.

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PROJECTED CHANGES IN CLIMATE AND EXTREME INDICES IN ILORIN, KWARA STATE, NIGERIA

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Abstract

Purpose — This study examines the projected impact of climate change on rainfall, temperature, and climate extreme indices in Ilorin, Kwara State, Nigeria.

Methods — The study analysed rainfall and temperature extreme indices by considering eleven (11) climate change indices from the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI) using RClimdex in the R software package. With MAKESENS software, the magnitude and trends in rainfall and temperature extreme indices were calculated using the non-parametric Mann-Kendall test and Sen's slope estimator.

Findings — The study identified that most extreme rainfall indices were projected to decrease in the future (2020–2049), with the exception of consecutive dry days (CDD), which increased. The temperature extremes analysis shows an increasing trend in warm days (TX90p) and warm nights (TN90p), but a decreasing trend in cool days (TX10p) and cool nights (TN10p) for both the baseline and future periods.

Conclusion & Recommendation — These findings provide valuable insights into the anticipated changes in rainfall, temperature, and climate extreme indices, contributing to our understanding of the potential impacts of climate change on the study area and emphasizing the need for adaptive measures to address the projected challenges.

Keywords — RCMs, Rainfall, Temperature, Kwara State, Climate Extremes

Introduction

Climate change is a pressing global issue that has far-reaching effects on ecosystems, economies, and societies worldwide. The rise in climate-related extreme events poses a growing threat to the sustainability of socioeconomic development. Extensive studies have been conducted across various regions, shedding light on the implications of temperature, rainfall patterns, and climate extremes indices for sustainable development (e.g., Sekele, 2013; Singh *et al*., 2014; Alexander, 2016; Lelieveld *et al*., 2016; Stott *et al*., 2016; Shrestha *et al*., 2017; Susanto *et al*., 2020; Almazroui, 2020; Yaduvanshi *et al*., 2021; Wilson *et al*., 2022; Chemura *et al*., 2022; Ankrah *et al*., 2023).

These studies reveal that changes in temperature, rainfall patterns, and climate extreme indices have significant implications for sustainable development (Cramer *et al*., 2018; Lu *et al*., 2019; Agovino *et al*., 2019; Masson-Delmotte *et al*., 2022). Moreover, predictions indicate an increase in droughts and floods of unprecedented magnitude, posing threats to human and food security (Kotir, 2011; Parvin *et al*., 2015; Ebi and Bowen, 2016; Mbow *et al*., 2017; Alemu and Mengistu, 2019; Amoak *et al*., 2022; Pörtner *et al*., 2022).

Climate change projections suggest a decline in rainfall ranging from 0.5% to 40%, with an average of 10% to 20% by 2025, while other projections anticipate increases in rainfall and associated extreme events in West Africa (Kasei, 2014). Temperature analysis reveals a warming trend in Africa surpassing the global average, particularly across the continent (Nikulin *et al*., 2018). This warming trend is expected to persist and accelerate, increasing the frequency of extreme climate events (James and Washington, 2013; Niang, 2014). In Nigeria, like many other countries, the impacts of climate change are projected to be widespread and potentially devastating. Studies conducted by Abatan *et al*. (2018) and Abdussalam (2015) in Nigeria highlight significant trends in extreme temperature indices and temperature increases, particularly in southern Nigeria and during the winter season. However, rainfall-related indices show weak trends without spatial coherence.

General climate change projections for Nigeria, as suggested by the Intergovernmental Panel on Climate Change (IPCC, 2014), indicate a warming trend with increased daytime and nighttime temperatures. This poses risks such as heat-related illnesses, heightened water demand, reduced crop yields, and threats to agricultural production. Additionally, Nigeria may experience more intense rainfall events, increasing the risk of flooding and consequent damage to crops and infrastructure (IPCC, 2014). Climate change projections and extreme weather events pose significant concerns for Nigeria, given the vulnerability of its agriculture sector, which employs over 60% of the population and contributes about 30% to the Gross Domestic Product (GDP) (Adeola, 2018). Kwara State, a prominent agricultural hub, faces unique challenges due to its distinct geography and topography. Unfortunately, limited studies have specifically addressed climate projections and extreme indices in this region, hindering the understanding of local climate dynamics.

The absence of localized research and insufficient information on climate projections and extremes exacerbates the vulnerability of farmers and hampers the prediction and mitigation of devastating climate events (Ogundele *et al*., 2019). Consequently, this lack of knowledge impedes long-term sustainable development in the agriculture sector and the formulation of appropriate adaptation strategies for farmers and stakeholders.

To address this gap in knowledge, this study aims to analyze rainfall and temperature projections and their extreme indices in Ilorin, Kwara State, Nigeria. The findings of this study will contribute to the development of policies and programs aimed at promoting effective adaptation in the agricultural sector, not only in the study area but also across Nigeria and other countries sharing similar climatic and ecological characteristics as Kwara State.

Materials and Methods

Study Area

The study was conducted in Zone C of the Kwara State Agricultural Development Project (KWADP) in Kwara State, which falls under the southern Guinea Savanna agro-ecological zone of Nigeria (Figure 1). Geographically, Kwara State is located between latitudes 8° 05′ N and 10° 05′ N, and longitudes 2° 50′ E and 6° 05′ E, covering an area of about 32,500 km^2. The state shares a common internal boundary with Niger State in the north, Kogi State in the east, and Oyo, Ekiti, and Osun States in the south. The study area (Zone C) extends from latitudes 8° 05′ N to 9° 05′ N and longitudes 4° 20′ E to 5° 5′ E, covering an area of about 4,978.44 km^2. The area lies within a region described as having a tropical climate and is characterized by double rainfall maxima (Olanrewaju, 2009). The area experiences a rainfall regime from the end of March to October, with a mean annual rainfall ranging from 1000 mm to 1500 mm (Larbi *et al.*, 2016). The temperature remains uniformly high, ranging between 25°C and 30°C throughout the wet season, except in July and August, when it reaches between 33°C and 34°C during the dry season. Relative humidity in the wet season ranges from 75% to 80% and approximately 65% in the dry season (NBS, 2009). Food crops produced in this area are mostly yam, cassava, water yam, sweet potato, maize, and sorghum, which constitute the main staple food aside from cereals.

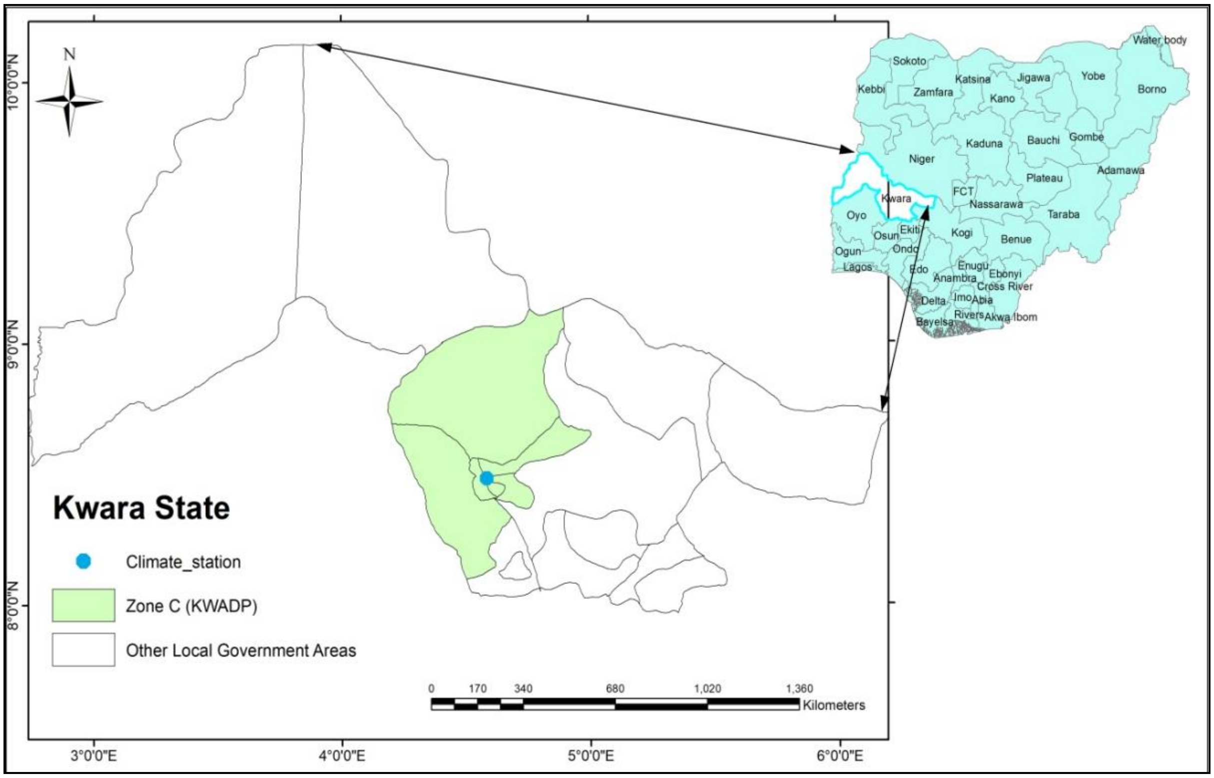


Figure 1: Map of Nigeria showing Zone C of Kwara State

Data Collection

Data on daily rainfall (mm) and maximum and minimum temperatures (°C), covering the period from 1981 to 2010, were collected from the Hydrology Section of the Lower Niger River Basin and Rural Development Authority in Ilorin, Kwara State, as well as from the Nigerian Meteorology Agency (NiMet) in Abuja. Data quality control was performed using Microsoft Excel and the Rclimdex package. The 12km resolution regional climate models' output from the Weather Research and Forecasting Model WRFv3.5.1, which was driven by the General Fluid Dynamics Laboratory Earth System Model (GFDL-ESM2M) and the Hadley Global Environment Model (HadGEM2-ES) for Representative Concentration Pathways (RCP4.5), was obtained from the West African Science Service Center on Climate Change (WASCAL) geoportal (Heinzeller *et al.*, 2016). The choice of RCP4.5 was driven by its realistic mitigation pathway, policy relevance, comparability with other scenarios, and availability of supporting data and models, as well as its role as a reference for a strong mitigation strategy (Van Vuuren *et al.*, 2011). It allows for a focused investigation of a potential future trajectory that aligns with the climate targets set by the Paris Agreement, which aims to limit global warming to around 2°C above pre-industrial levels. Furthermore, it has implications for policy and decision-making on various aspects of society, such as agriculture, water resources, ecosystems, and human health (Ibid.). The data from RCMs used in this study cover the baseline period (1981-2005) and the future period (2020-2049) for daily rainfall, minimum temperatures, and maximum temperatures.

Table 1: Description of the Regional Climate Models

GCM	RCM	Institution	Resolution
HadGEM2-ES	WRF-H	WASCAL / KIT/IMK-IFU	12km
GFDL-ESM2M	WRF-G	WASCAL / KIT IMK-IFU	12km

Data Analysis

Bias-Correction of RCMs Datasets

The biases in the rainfall and temperature outputs from the two RCMs were corrected using Local Intensity Scaling and Variance Scaling bias-correction methods found in the Climate Model Data for Hydrologic Modelling (CMhdy) tool (Rathjens *et al*., 2015). The Variance Scaling method was used to correct both the mean and variance of temperature time series (Chen *et al.*, 2011). Additionally, the Local Intensity Scaling method, known for effectively improving RCMs rainfall data, was employed to correct mean biases, wet-day frequencies, and intensities of rainfall (Schmidli *et al.*, 2007). For the future (2020-2049) climate analysis of the study area, an ensemble mean of the bias-corrected RCMs was utilized.

Climate Extreme Indices: Computation and Trend Analysis

Several indicators have been established by the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI) for understanding climate extremes and trends (Mouhamed *et al*., 2013). These indicators have been applied in various regions for the analysis of extreme events (N'TchaM'Po *et al.*, 2017; Larbi *et al*., 2021). Table 2 presents the eleven climate indices selected for this study, which were computed using RClimdex on the R programming software interface. The indices were calculated based on a common 30-year baseline for historical (1981-2010) and future (2020-2049) periods. In the analysis of extreme climate index trends, a non-parametric Mann-Kendall (MK) test and Sen's slope estimator were employed, which are widely used statistical methods for trend detection and quantification of hydro-climatic variables (Okafor *et al*., 2017). These analyses were conducted using MAKESENS software. The MK test (Equations 1 and 2) assumes a null hypothesis (Ho) of no trend, which is tested against the alternative hypothesis (H_1) of the presence of a trend (Önöz and Bayazit, 2003). The null hypothesis (H_0) is rejected when $|Z_s| \geq Z_{\alpha/2}$ at a significance level of $\alpha = 0.05$. The standard normal test statistic Z_s (Equation 2) indicates a trend in the data series, with a positive or negative value indicating increasing or decreasing trends, respectively.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{Sgn}(X_j - X_k) \qquad (1)$$

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, for\ s > 0 \\ 0, for\ s = 0 \\ \frac{S+1}{\sqrt{VAR\ (S)}}, for\ s < 0 \end{cases} \qquad (2)$$

Table 2. Climate Extreme Indices

Indices	Descriptive Name	Definition	Units
RX5day	Max-5-day rainfall amount	Annual maximum consecutive 5-day rainfall	mm
R99p	Extremely wet days	Annual total rainfall on the days when daily PRCP > 99^{th} percentile	mm
R20mm	Number of very heavy rainfall days	Annual counts of days when PRCP ≥ 20mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with PRCP ≥ 1mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with PRCP< 1mm	days
TX90p	Warm days	Percentage of days when Tmax > 90^{th} percentile	days
TN90p	Warm nights	Percentage of days when Tmin > 90^{th} percentile	days
TX10p	Cool days	Percentage of days when Tmax < 10^{th} percentile	days
TN10p	Cool night	Percentage of days when Tmin < 10^{th} percentile	days
TXx	Warmest day	Annual maximum value of the daily max temperature	^{o}c
TNx	Warmest night	Annual maximum value of daily min temperature	^{o}c

Results and Discussion

Temperature and Rainfall Projections

Figures 2 and 3 display the time series of the ensemble mean projection of monthly and annual mean rainfall and temperature for Ilorin under the RCP4.5 climate change scenario, relative to the baseline period.

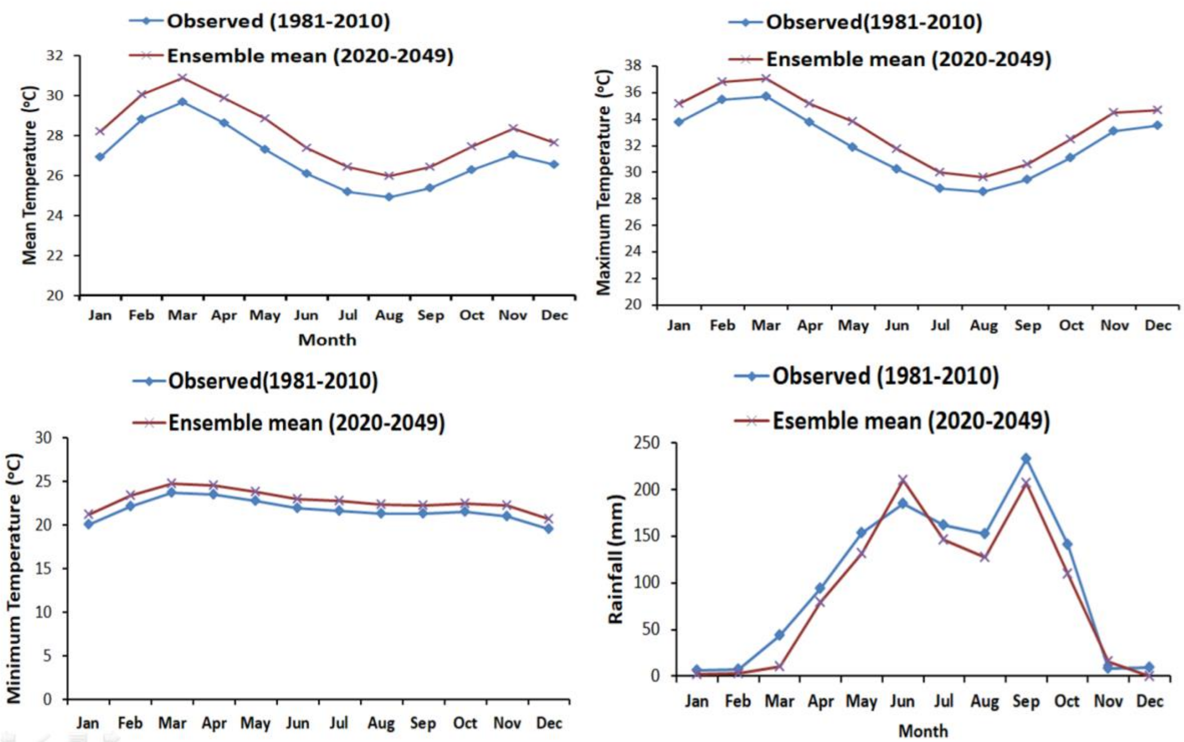


Figure 2: Mean monthly temperature and rainfall projections for Ilorin based on the ensemble mean under the RCP4.5 scenario

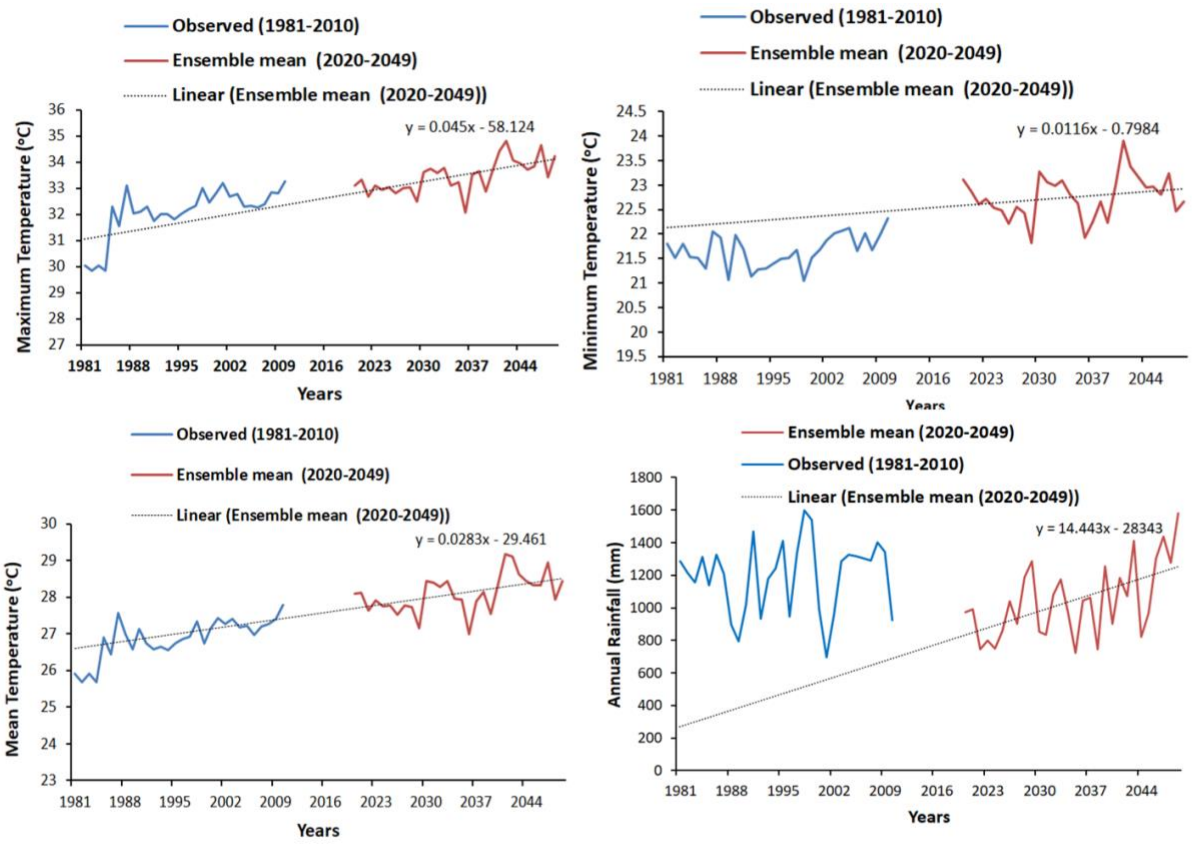


Figure 3: Mean annual temperature and rainfall projections for Ilorin based on the ensemble mean under the RCP4.5 scenario

On a monthly scale, as shown in Table 3, the mean monthly temperature is projected to increase by 1.2°C for both the rainy season (AMJJASO) and the dry season (NDJFM). This finding aligns with Coumou *et al.*'s (2013) study on the global increase in record-breaking monthly mean temperatures. Their study suggests an 80% chance of mean monthly temperature increases in most countries in Africa due to climate change impacts, such as prolonged heatwaves. These temperature increases will have implications for agriculture and other climate-dependent sectors. Additionally, other studies indicate that the rise in mean monthly temperature not only affects people's livelihoods but also has adverse effects on health, as the number of malaria cases is expected to increase over time (Antwi-Agyei *et al*., 2014; Ampadu *et al*., 2018; Agyekum *et al*., 2021).

Table 3: Mean seasonal rainfall and temperature projections for Ilorin, Kwara State under RCP4.5 Scenario

Climate Variable	AMJJASO Season		NDJFM Season	
	1981-2010	2020-2049	1981-2010	2020-2049
Maximum temperature (°C)	30.53	31.93 (1.39)	34.31	35.63(1.34)
Minimum temperature (°C)	21.96	23.02 (1.06)	21.27	22.41(1.14)
Mean temperature (°C)	26.25	27.47 (1.2)	27.79	29.0 (1.2)
Rainfall (mm)	160.02	144.16 (-4.5%)	14.95	6.39(-57.0%)

NB: Values in brackets indicate the changes that had occurred over the two periods.

Table 4: Mean annual rainfall and temperature projections for Ilorin, Kwara State

Climate Variable	Baseline (1981-2010)	RCP4.5 (2020-2049)	Change (%)
maximum temperature (°C)	32.08	33.45	1.37
minimum temperature (°C)	21.66	22.76	1.09
mean temperature (°C)	26.85	28.10	1.23
rainfall (mm)	1194.9	1041.1	-12.87%

The maximum temperature is projected to increase by 1.39°C (rainy season) and 1.34°C (dry season), which is higher in both seasons compared to the increase in minimum temperature of 1.06°C (rainy season) and 1.14°C (dry season). This finding is consistent with the minimum and maximum temperature trends observed globally, as studied by Easterling *et al*. (1997), which show that both rainy and dry seasons are likely to be characterized by high maximum temperatures due to the impacts of climate change and climate variability. The mean annual temperature is projected to increase by 1.3°C in the future (2020-2049). This increase is accompanied by a warming trend of 0.02°C per year (Figure 3). In the future (2020-2049), the annual maximum temperature is projected to increase by 1.37°C at a faster rate of 0.045°C per year compared to the increase in minimum temperature of 0.01°C per year. A study by Engelbrecht *et al*. (2015) suggests that the rate of increase in maximum temperatures is relatively higher than that of minimum temperatures across countries on the African continent, which supports the findings of this study. According to Misra (2014), these observed increases in minimum and maximum temperatures have implications for hydrological regimes, with varied impacts on crop yield, water productivity, and food security across most countries in Africa. Regarding rainfall, the research findings indicate a projected decrease of 12.87% in mean annual rainfall for the future compared to the baseline period (Table 4). This decrease suggests that the study area may experience reduced rainfall in the coming years. However, it is important to note that changes in rainfall patterns in the study area may not be uniform across the country. As observed by Shiru and Park (2020) under two scenarios, RCPs 4.5 and 8.5, while some regions of Nigeria, such as the Northwest, may experience a decrease in annual rainfall, others may see an increase, leading to spatial variations in rainfall patterns.

The peaks of the rainy season were observed to increase by 5% for the month of June, implying a potential intensification of rainfall events during that period. On the other hand, there was a decrease of 2% in the peaks of the rainy season month for September, indicating a potential decrease in rainfall intensity during that time. These findings highlight the variable nature of rainfall patterns in the area. The mean monthly rainfall over the study period was found to decrease by 4.5% during the rainy season and by a significant 57.0% during the dry season. These decreases in rainfall align with previous studies that indicate future projections of a shorter rainy season and growing season in West Africa, along with an extension of torrid, arid, and semi-arid climate conditions (Sylla *et al*., 2016a; Sylla *et al*., 2016b). These changes in rainfall can be attributed to global climate change impacts, including alterations in temperature and surface water supply (De Wit and Stankiewicz, 2006). The observed decrease in rainfall patterns raises concerns about the availability of freshwater resources, not only in the study area but also globally. This decrease in rainfall has implications for water management and potential conflicts over water resources (Unfried *et al*., 2022). As rainfall becomes more variable and potentially decreases in the study area, the overall availability of freshwater resources may be further strained.

Projected Changes in Climate Extreme Indices

Rainfall Indices

The results of the Mann-Kendall trend test statistics for the extreme rainfall indices over the baseline and future periods are presented in Table 5 and Figure 4. The findings suggest that most of the rainfall indices are projected to decrease in the future, with the exception of consecutive dry days (CDD), which shows an increase of 53%. Specifically, the annual maximum consecutive 5-day rainfall is observed to decline at a rate of 1.04mm/year. This decline indicates a decreasing trend in prolonged heavy rainfall events, which can have implications for water availability and management in the study area and other regions of Nigeria. It is important to note that consecutive wet days (CWD) exhibit a decreasing trend, while consecutive dry days (CDD) display a slight increasing trend, although it is not statistically significant. The decrease in consecutive wet days may adversely affect aquatic ecosystem productivity (Benavides-Gordillo *et al*., 2019), and changes in rainfall patterns can impact agriculture and livestock production in rangeland ecosystems (Alkemade *et al*., 2013). With fewer consecutive wet days, the availability of water for crops, grazing lands, and livestock can be compromised, posing challenges for food security and livelihoods. Furthermore, the observed trends in rainfall indices have implications for renewable groundwater supplies in communities (Döll, 2009). As consecutive dry days increase and rainfall decreases, the replenishment of groundwater sources may be negatively affected. This situation can pose threats to water security, particularly when adequate climate change adaptation measures are not implemented.

Table 5: Projected Changes in Rainfall Extreme Indices in Ilorin, Kwara State

Descriptive names (Units)	**Baseline (1981-2010)**	**Ensemble (2020-2049)**	**Change**
Consecutive wet days, CWD (days)	6.2 (0.01)	5.4(0.07)	-0.8(12.9%)
Consecutive dry days, CDD (days)	100.7 (0.44)	154.3 (0.33)	53.5 (53%)
Max-5-day rainfall amount, RX5day (mm)	122.8 (0.02)	92.0 (0.65)	-30.0 (25%)
Extremely wet days, R99p (mm)	89.1(0.00)	42.3 (0.02*)	-46.7(52%)
Number of very heavy rainfall days, R20 (days)	20.3 (0.04)	9.2 (0.09)	-11.0 (54%)

Values in the bracket indicate Sen's slope; negative/positive value indicates a decrease/increase in trend respectively; * means statistically significant at 5% level

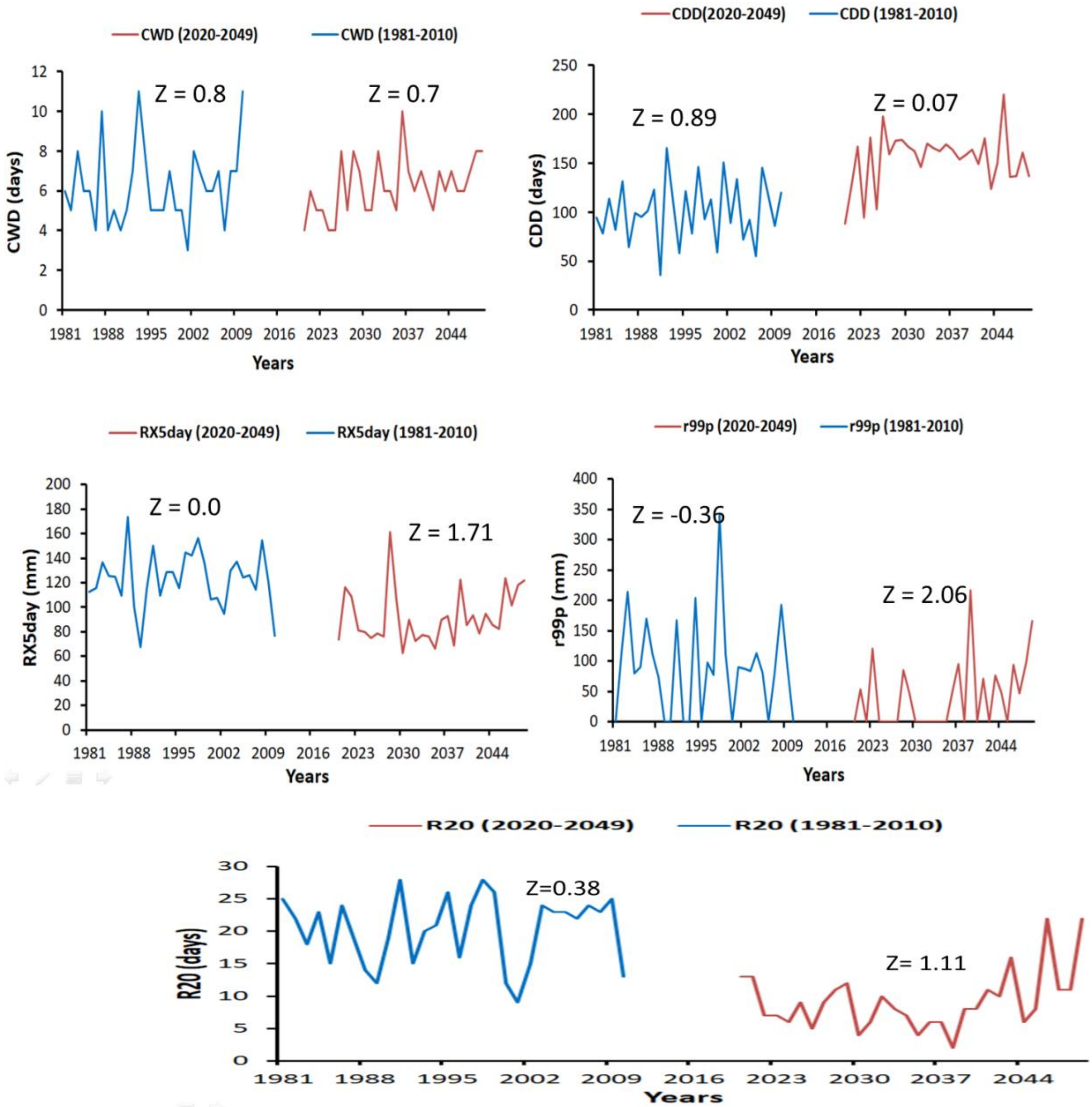


Figure 4: Extreme rainfall Indices in Ilorin for the baseline line (1981-2010) and Future (2020-2049) periods with Man-Kendall trend statistics (Z)

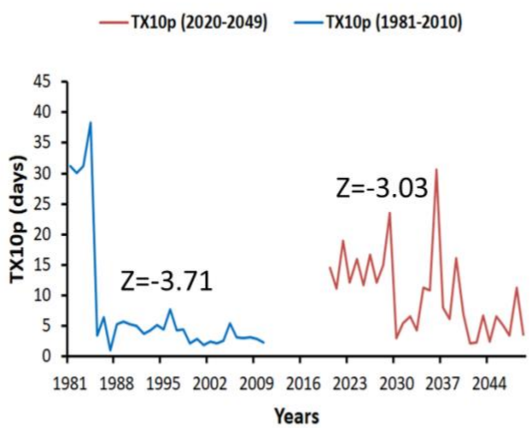
Temperature Indices

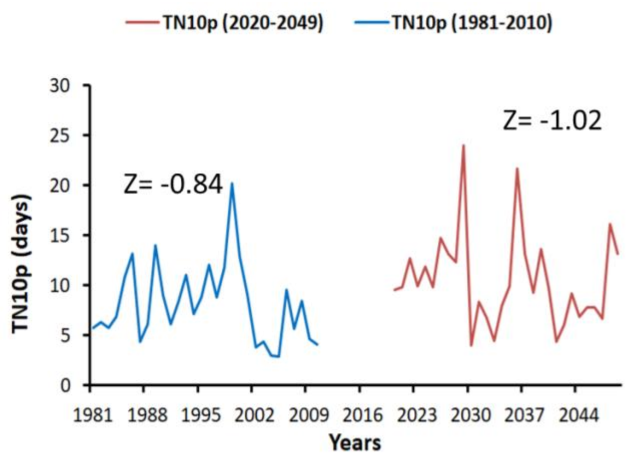
The analysis of temperature extreme indices shows a significant increasing trend in the annual number of warm days (TX90p) and warm nights (TN90p) in the future period of 2020-2049 (Table 6 and Figure 5).

Table 6: Projected Changes in Temperature Extreme Indices in Ilorin, Kwara State

Descriptive names (Units)	**Baseline (1981-2010)**	**Ensemble (2020-2049)**	**Change**
Warm days, TX90p (days)	7.3 (3.53)	10.5 (0.403*)	3.1 (42%)
Warm nights, TN90p (days)	7.1 (3.27*)	10.5 (0.255*)	3.4 (47%)
Cool days, TX10p (days)	7.7 (-0.177*)	10.2 (-0.378*)	2.4 (31%)
Cool night, TN10p (days)	8.2 (-0.06)	10.5 (-0.07)	2.3 (28%)
Warmest day, TXx (^{o}c)	38.9 (0.01)	40.3 (0.01)	1.4 (3%)
Warmest night, TNx (^{o}c)	26.3 (0.02)	28.0 (0.029)	1.7 (6%)

Values in bracket indicate Sen's slope; negative/positive value indicates a decrease/increase in trend respectively; * means statistically significant at 5% level





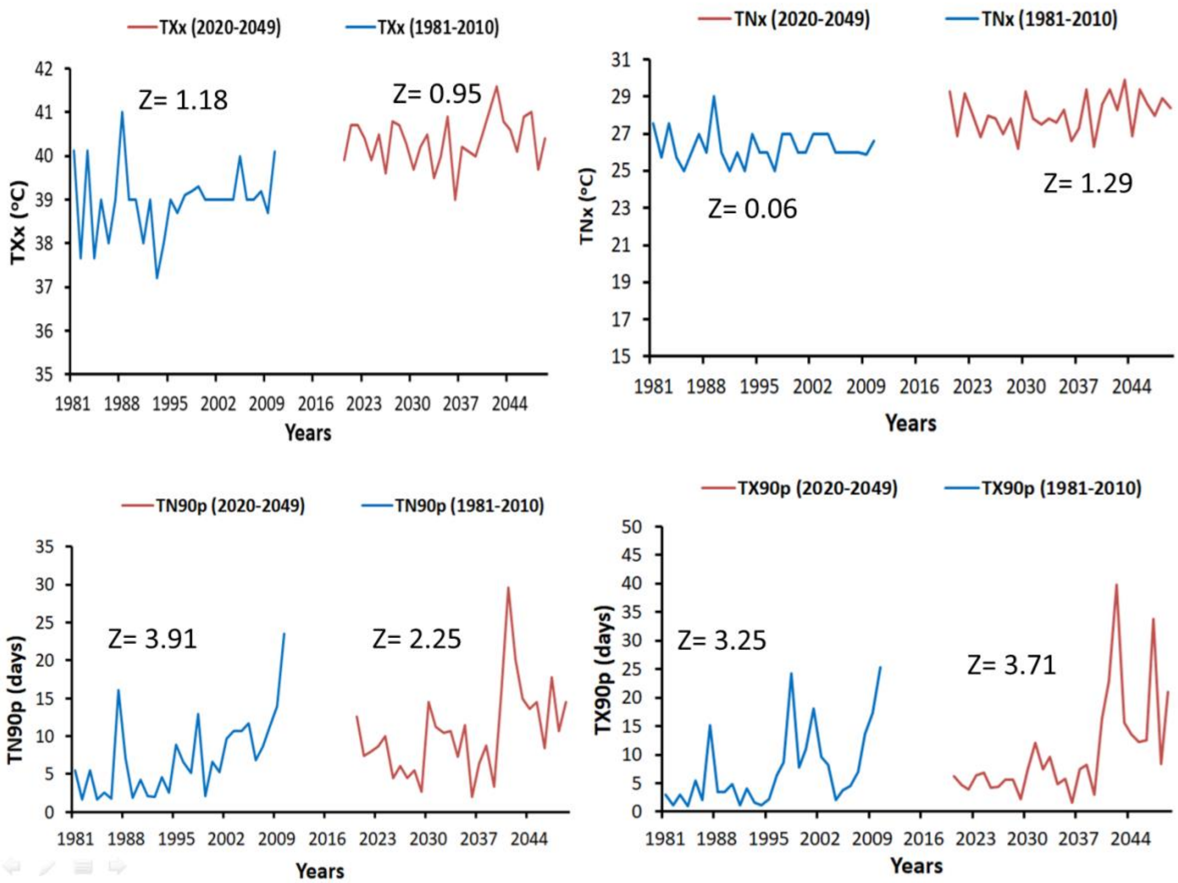


Figure 5: Extreme temperature indices in Ilorin for the baseline line (1981-2010) and Future (2020-2049) periods with Man-Kendall trend statistics (Z)

Decreasing trends were observed for cool days (TX10p) and cool nights (TN10p), with the trend for cool days being significant in both the historical and future periods. This indicates that both nighttime and daytime temperatures are getting warmer, which aligns with the findings of Abdussalam's study (2015) conducted in the north-western part of Nigeria. The findings are also consistent with other previous studies that indicate a general warming trend in Nigeria, projecting an increase in average temperatures for both daytime and nighttime (Akinsanola and Ogunjobi, 2014; Ragatoa *et al*., 2018; Gbode *et al*., 2019). Shiru *et al*.'s study (2020) specifically suggests that temperature increases are expected to be more pronounced in the northern regions of Nigeria, including the Northwest, compared to the southern regions. The annual maximum values of daily minimum temperature (TNx) and maximum temperature (TXx) are projected to increase by 1.7°C and 1.4°C, respectively, in the future. The Mann-Kendall (MK) test indicates an increasing trend in TNx (0.02°C/year) and TXx (0.01°C/year) for both the baseline and future periods. This indicates a higher warming of nighttime temperatures compared to daytime temperatures, which aligns with the findings of Abatan *et al*.'s study (2018) on trends in extreme temperature indices across Nigeria.

The higher nighttime temperatures in the area can have far-reaching implications for various sectors, especially the energy sector, as the population may resort to higher energy consumption through the use of cooling devices such as air conditioners and fans. Additionally, the population without access to energy may be at risk of heat-related diseases. The analysis of extreme indices provides evidence of significant changes in the occurrence of extreme climate events, particularly regarding temperature, over the past decades (1981-2010). In general, the study area exhibits significant changes in climate extremes, especially in relation to temperature. These findings are consistent with Auwal *et al*.'s study (2022), which suggests that heatwaves and extremely high temperatures are likely to become more frequent in Nigeria, resulting in increased risks to human health, agriculture, and water resources. Auwal *et al*. (2022) further posit that heatwaves are expected to increase in intensity and duration in Nigeria, posing risks to human health and increasing energy demands for cooling.

Conclusion and Recommendation

The study assessed the impact of climate change under the RCP4.5 scenario on rainfall, temperature, and their extreme indices in Ilorin, Kwara State. The ensemble mean of the regional climate model analysis of rainfall and temperature projections for the area shows a drier and warmer climate in the future, 2020-2049. Extreme climate indices analysis revealed a decrease in most of the extreme rainfall indices in the future, 2020-2049, except for consecutive dry days (CDD), which shows an increase. The temperature extreme indices, on the other hand, show significant increasing trends in the future, especially with the percentile-based indices. There has been a warming trend over the past decades, mostly dominated by an increase in the daily minimum temperature, though not significant. Among other challenges, the projected changes could lead to water scarcity, decreased agricultural productivity, and increased health risks. It is, therefore, crucial for policymakers in Kwara State and other areas with similar climatic conditions to take action to build the resilience of the communities to be able to adapt to the effects of climate change and the changing conditions to minimize their impact on the population and the local economy. This should include the dissemination of climate information and various adaptation strategies to ensure future food security in the area.

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