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Assessment of Climate Change Effects on Rainwater Harvest in Edo State, Nigeria

Al-Hasan AZ[1]*, Olotu Y[2] Iyawe H[1], Ayilaran CI[3]

[1]*Department of Urban & Regional Planning, Auchi Polytechnic, Auchi, Nigeria*
[2]*Department of Agricultural & Bio - Envi. Engineering, Auchi Polytechnic, Auchi, Nigeria*
[3]*Department of Agricultural Technology, Auchi Polytechnic, Auchi, Nigeria*

Abstract

Global climate change (cc) might have severe impacts on every economy, and water resource is not an exception. The rainwater harvest (RWH) is considered a substitute water source, mostly in developing nations. The study presents the climate change (cc) impact on Edo State, Nigeria's rainwater harvesting system. Future daily precipitation was statistically-downscaled from an ensemble of three (3) general circulation models (GCMs) derived with climate change scenario (RCP 4.5) for the 2040s (2030-2060) and 2080 (2070-2100). Historical precipitation data from 1980-2010 were extracted from CRU 2.1 from eighteen (18) meteorological stations over the study region. Comparing the baseline and projected precipitation from all the GCMs simulation run showed that rainfall events decreased for the periods the 2040s and 2080s. The Centre for Canadian Climate Modeling & Analysis (CCCMA) model predicted the highest precipitation reductions of 15.4% and 24.4% for 2030-2060 and 2070-2100. In contrast, MPI projected 8.4% and 12.4% for the two future time slots. The changes in precipitation datasets were used to estimate future harvestable rainwater. Conversely, the selected GCMs predicted decreases in RWH for 2030-2060 and 2070-2100 in response to the historical period (1980-2010). Predicted changes in rainfall events affect the RWH system's performance, and thus, in turn, could force 2.1 million and 2.7 million people out of water security in the near and long term.

Keywords: Climate change; General circulation model; Rainwater harvest; Precipitation; Representative concentration pathways; Edo State

Introduction

Climate change can affect every sector of human endeavor, including water resources. Its impacts occur due to either progressive decrease or rise of climate properties which include precipitation and temperature. Most climate change studies have indicated the possibility of experiencing high temperatures and low future precipitation events. [1] Showed that climate change and global warming might increase temperature and strongly affect many aspects of the hydrological system, water resources, coastal zones, and oceans. Precipitation, runoff, flood, snows, drought, and river flow are significant for water availability [2]. Water quantity and availability are significant challenges in developing nations; climate change further complicated the already complicated situation. There has been a gross imbalance between water use and its availability; this situation could become even more intensified by CC [3]. Edo State like most Nigerian states is faced with a high case of water scarcity. Edo-South and North depend mainly on rainwater harvest for domestic and agricultural uses. Rainwater harvest (RWH) is generally practiced in Nigeria, with more predominance in the South-South region of the country. The rainwater harvest mechanism concept increases daily because this is the main alternative of water's source in this region. Domestic water use has increased progressively in Edo State due to the rapid population growth based on the influx of people to the region for its commercial centrality and relative peace as compared to other states in the South-South, Nigeria. The challenge of accessing safe drinking water was a massive issue in the region before the population explosion. Possible climate change will have unprecedented effects on present and future water resources in Edo State. Studies have shown that there has been a steady rise in temperatures globally since the 1960s consequently leading to increased reference evapotranspiration and reduction in precipitation events [3][4]. Several CC studies have been investigated in various fields such as crop water requirements, projections of climate parameters (rainfall, temperature), and crop yield, in contrast, there are few or no recorded studies pertaining to how CC affects rainwater harvest over the study area.

It is imperative to explore how CC affects rainwater harvest and develop mitigation strategies for future water security. Adequate water security is a significant socio-economic development in Edo State. CC impacts on projected precipitation over the region are a contributing factor to rainwater harvest. Suppose the effects of signifying a reduction in precipitation for the future period. In that case, this will significantly affect the volume of RWH for the growing population. An Investigation into how future precipitation, as well as its spatiotemporal variability, is modified by CC is a research area currently enjoying great attention [5]. The study explores the effects of cc on rainwater harvest using an ensemble of three general circulation models (GCMs) from the 5th Coupled Model Inter-comparison Project (CMIP5). Also, the simulation runs under the climate change scenario, Representative Concentrations Pathway (RCP 4.5). The projected precipitation changes would be simulated using a hindcast model to evaluate its effects on future rainwater harvest.

Materials and Methods

Study area

Edo State is one of the six states that constitute South-South

***Corresponding author:** Al-Hasan A Z, Department of Urban & Regional Planning, Auchi Polytechnic, Auchi, Nigeria, Tel: 08073135503; E-mail: az_hassan@auchipoly.edu.ng

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Nigeria with Benin as the capital. It lies between latitudes 05° 441N and 07° 301N of the equator and Longitudes 06° 041E and 5° 451 of the Greenwich meridian (Figure 1). The State experiences an average annual rainfall greater than 1,950mm, a relative humidity greater than 78%, and an air temperature of 26.5oc. The state is bordered by Kogi State to the North/North-East, Anambra to the East, Delta to the South, and Ondo to the West. It covers a landmass of approximately 19, 744 km2 with a population of 2,159, 848 [6].

Data

In this study, daily baseline precipitation (1980-2010) of Edo State was obtained from eighteen (18) meteorological stations. The rain gauges are of the wild tipping-bucket type (Wilh. Lambrecht GmbH model 1518) with a tip resolution of 0.1 mm and a sampling time resolution of 30-min. The future climate data (precipitation) used for the study was obtained using a statistical downscaling model from three (3) GCMs under RCP 4.5 for 2030-2060 and 2070-2070. The descriptions of some of the selected GCMs from the 5th Coupled Model Inter comparison Project are shown in (Table 1).

Statistical downscaling of future precipitation

Accurate projection of future precipitation is crucial in estimating the impact of CC on rainwater harvest. At present, the most appropriate tools employed for both short-term and long-term projections in climate parameters are the Global circulation models (GCMs) [7]. The outputs of GCMs are normally subjected the processes of downscaling for it to be compatible with the local scales. This is due to the fact that GCMs outputs has large resolutions and cannot be directly applied. The statistical downscaling model (SDSM) takes into consideration the relationships observed between local climate conditions and that of the large-scale phenomenon to produce fine-grain projections from GCM output [8]. Statistical downscaling has been grouped into 3 classes as regression methods, stochastic weather generators and weather pattern-based approaches [9]. ClimGen a spatial climate generator developed to explore uncertainties in CC at global and regional. CLIMGEN version 4.1.0.5 was used for RCP 4.5 for downscaling future precipitation under 3 GCMs. In CLIMGEN, the difference average climate of the future Near-Term (2030-2060), Long Term (2070-2099), and the referenced period (1980-2010) were calculated. The SDSM applies the additive of observed monthly mean precipitation, and the observed fluctuations in the monthly precipitation to the future scaled design of climate change (Pr*t) to obtain a new climate. The SDSM downscaling for precipitation (Pr), GCM (g), emission scenario (rcp), grid cell (i), year (yr) and month (m) is expressed in equation (1).

$$X_{prgrcptyrm} = (Oban\ 1980 - 2010)_{ptircp} + (Obidaan)_{priyrm} + (P_{prgrcpim} * t_{grcpyr}) \quad (1)$$

Where; *Oban* is observed annual mean, *Obidaan* is Observed deviation from observed annual mean

Rainwater harvest modeling

Rainwater harvest could be grouped as open-air collection, tree trunks, and gutter collection system [11]. RWH potential was estimated using the expression in equation (2). It is assumed that an

Table 1: Properties of selected CMIP5 climate models used in this study.

Model Name/ Agency	Abbreviations
Canadian Centre for Climate Modeling & Analysis (Canada)	CCCMA
Max Planck Institute for Meteorology (Germany)	MPI_ECHAMS
Met Office Hadley Centre	MOHC

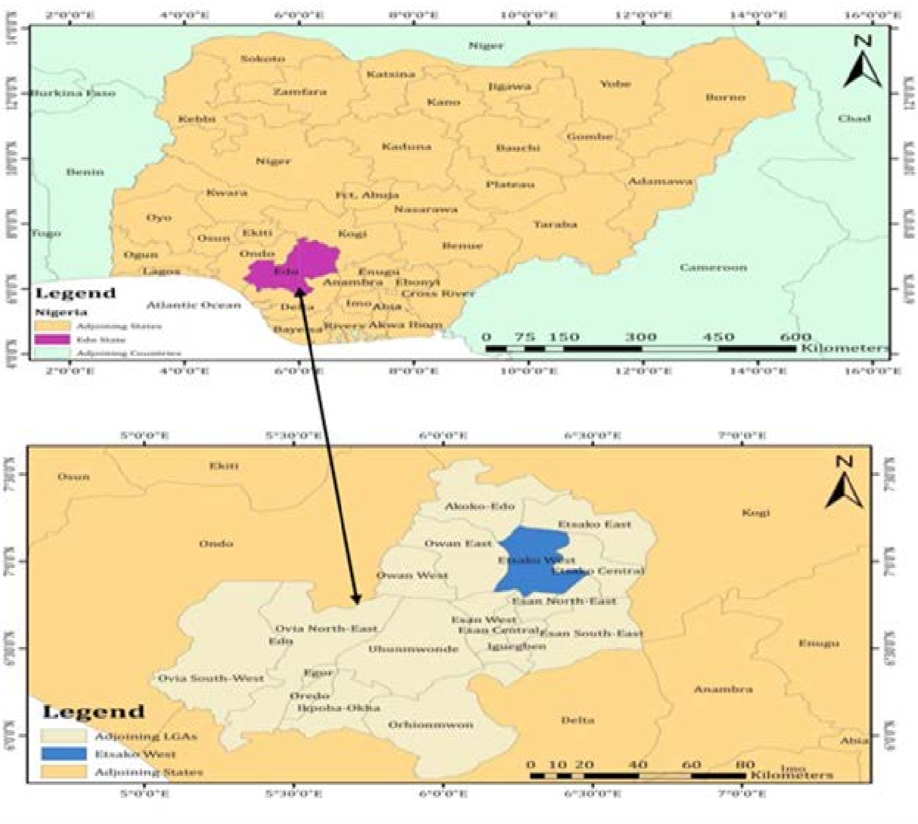

Figure 1: Shows the position of the study area in the map of Nigeria.

average roof plan size (Rp) of 400m2 per building for 800,000 houses were considered as the runoff catchment area for the baseline period over the study area. In Edo State, RHW is rapidly growing as a cheap and straightforward way of sourcing safe drinking water among the poor and medium-class dwellers. The GCMs for RHW projections were estimated in percentage change relative to the referenced RHW using equations (3):

$$R_{wh} = R_p * R_{ma} * \mu \quad (2)$$

Where; R_{wh} is Rainwater harvest (m^3), Rp is Roof plan size (m^2), R_{ma} is Monthly average (m), μ is collection efficiency. Collection efficiency ranges from 0.900-1.00.

$$CRHW_{(MPI_{2030}-2060)} = \frac{RHW_{(MPI)} - RHW_{(REFERENCED)}}{RHW_{(REFERENCED)}} * 100 \quad (3)$$

$$CRHW_{(MPI-2070\_2100)} = \frac{RHW_{(MPI)} - RHW_{(REFERENCED)}}{RHW_{(REFERENCED)}} * 100 \quad (4)$$

Where; CRHW is the changes in rainwater harvest (m^3), MPI is climate model. Equations (3) and (4) were repeatedly applied to estimate changes in rainwater harvest from CCCMA and MOHC models.

Validation of precipitation events in the referenced period

(Figure 2a) shows the distribution of precipitation events for the baseline period of 31-year (1980-2010). The analysis of precipitation occurrence over the study region showed an average annual increase of 5.63 mm. It is depicted from Figure1a that the lowest precipitation occurred from November through February with possible onset of rainfall starting from March, and at a peak in July and September. The most important factor affecting the potential of rainwater harvest (RWH) is the increase in the number of rainy days, rainfall depth, and duration. The roof planning size (Rf), storage tanks, and the gutter system are also significant to the process. [11] Showed that frequent precipitation increases the potential of domestic rainwater harvest. The study of [11] indicated that climatic factors, the quantity of precipitation, and roof size-building characteristics have potential impacts on domestic rainwater harvest. It is worthy to note that a sufficient quantity of rainwater could be captured from May through October. The captured rainwater can gradually be released during the dry season. The average peak for rainfall events during the observed (obs) period falls into July and September with rainy days of 17 and 20. Therefore, 50 percent of annual rainwater is harvestable during this season. If there is a large storage tank to store the captured rainwater, its gradual release during the dry season could be of great importance to alleviating water scarcity.

Precipitation projections

Persistent water scarcity in Edo State and its environs could further be complicated by climate change. Conversely, climate change is a primary impediment that may affect water resources' quantity and quality by altering hydrological cycles [12]. Climate change (cc) may lead to increased temperature and global warming, which could cause a shift in the hydrological processes and an increase in flooding events. It is essential to apply an ensemble of general circulation models (GCMs) and representative concentration pathways (RCPs) to project climate change. This would broaden the range of observations, increase the output of climate projections, and create windows of comparison among the chosen GCMs. According to [13], it is imperative not to depend on one GCM alone but several climate model predictions when developing assessment studies for climate change impacts. Based on this, an ensemble of three (3) GCMs selected from the 5th Coupled Model Intercomparison Project (CMIP5) used for this study. The projections of annual precipitation indicated reductions for the two-time slots 2030-2060 and 2070-2100. MPI and CCCMA models predicted the highest and the lowest precipitation reductions over the study area, as shown in Figure 2b-c. The projection's overall result indicated decreases in precipitation by all the climate models, which

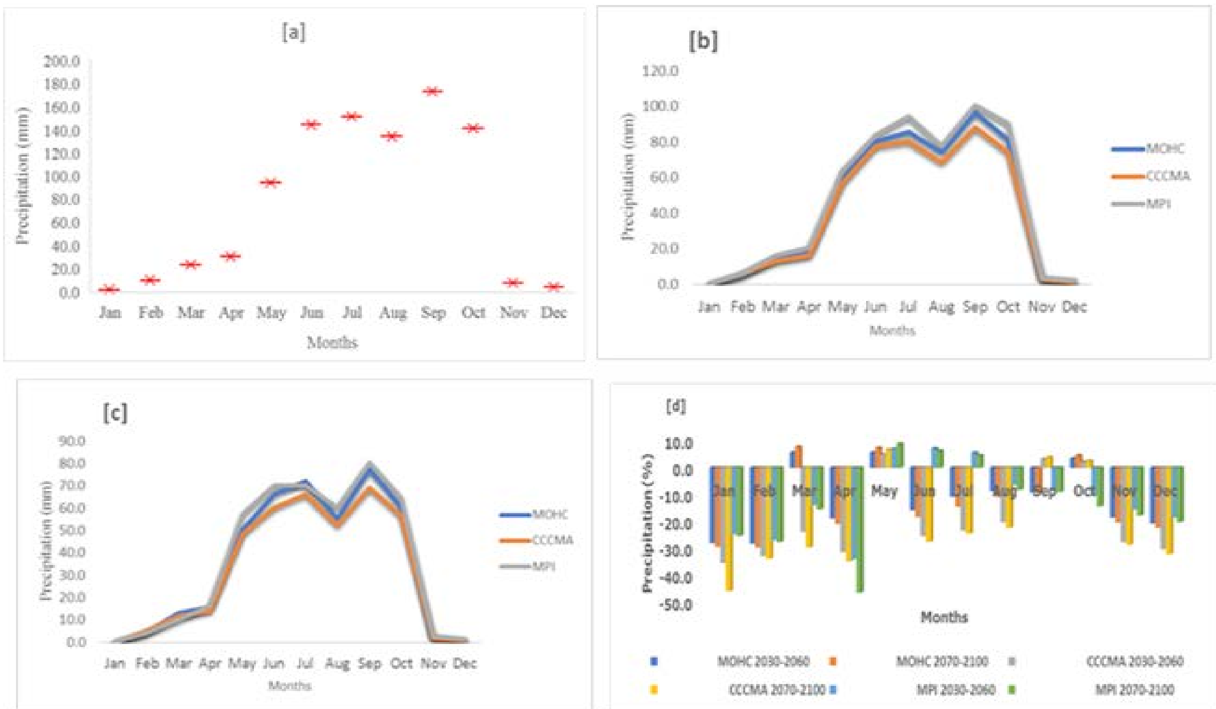

Figure 2: Monthly precipitation during the baseline period (1980-2010) in Edo State (a), projected monthly precipitation under 3 GCMs for periods 2030-2060 (b) and 2070-2100 (c), and percentage variation of precipitation relative tobaseline period over Edo State (d).

signifies the possibility of drier climate for the near and long term over the study region. This finding supports the study by NOAA [14], which reported that projections suggest that rainfall in the subtropical regions will decline while that of the sub polar latitudes and some equatorial areas will increase. The variability in precipitation from the projections by the chosen GCMs is depicted in Figure 2d. All the global climate models projected increases in precipitation in May for the two periods between 2030-2060 and 2070-2070.

Conversely, in January, February, April, November, and December, all the models predicted decreases in precipitation. The rest of the months indicated mixed predictions. Potential rainwater harvest could be achieved between May through October. The hindcast simulation indicated that no substantial rainwater might be harvestable from November through April for the future period.

Precipitation frequency and distribution events

Precipitation is the most important parameter to consider in the rainwater harvesting system. Accurate determination and predictions of its frequency, distribution, and variability are significant to understand the RWH system's mechanism. The rainfall frequency of Edo State for baseline (1980-2010) and projected (2030-2060) and (2070-2100) periods are shown in (Figure 3). The duration curve shows that rainfall was projected to decrease due to climate change, as indicated by different degrees of the shift of the projected distribution duration curve by the selected GCMs. The rainfall exceedance probabilities corresponding to 10th, 20th, 30th, 40th, and 50th to 100th are presented in (Table 2). The outputs of the percentile probability of exceedance for precipitation projected by the chosen GCMs showed different decreases for future periods. CCCMA model predicted the lowest reductions from 998.6 mm to 900.6 (9.8%) at 10th percentile exceedance probability (PEP), from 980.6 mm to 810.3 mm (17.4%) at 20th PEP, from 982.6 mm to 960.3 mm (2.3%) at 30th PEP, and from 690.2 mm to 600.4 mm (13.0 %) at 100th PEP respectively. However, Max Planck's Institute of Meteorology (MPI) projected the largest decrease in precipitation at 20%, 10%, 30% and 60% probabilities exceedance from 1600.4 mm to 1000.1 mm (37.5%), from 1110.6 mm to 1080.3 mm (27.2%), from 1080.7 mm to 810.2 mm (25.0%), and 1040.6 mm to 795.3 mm (23.5%) for the periods of 2030-2060 and 2070-2100. The simulation indicated an increase in precipitation probability of exceedance from 1600.4 mm (2030-2060) to 1200.1 mm (1980-2010), but decrease by 2070-2100 from 1200.2 mm to 1000.1 mm (16.6%) respectively. Climate change may have serious effects on the study area's RWH system due to the projection reduction in future precipitation events.

Climate change and rainwater harvest

The result presented in (Table 3) showed that climate change caused changes in rainwater harvest in a future time in response to the referenced period over the study area. The simulation used a constant rainfall catchment area of 400m^2 per building for an estimated 800,000 structures under the RCP 4.5 for the 2040s [2030-2060] and 2080s [2070-2100]. Compared with the referenced period [1980-2010] as depicted in (Figure 4). The observation is highly similar to the simulation outputs of projected precipitation, where all the selected GCMs indicated decreases for the near and long term. Conversely, the magnitude of precipitation contributes significantly to the volume of rainwater that could be captured at any given interval. [15] Reported that a likely increase in future precipitation will lead to higher reliability of expected rainwater. The finding by [16] indicated that the volume of rainwater harvested from the structure dramatically depends on the amount of precipitation. The simulation revealed that the RHW under the CCCMA model decreased from 220.1 Mm^3 to 116.2Mm^3 (47.2%) in 2030-2060 and 220.1Mm^3 to 92.5Mm^3 (57.9%) in 2070-2100 (Table 3

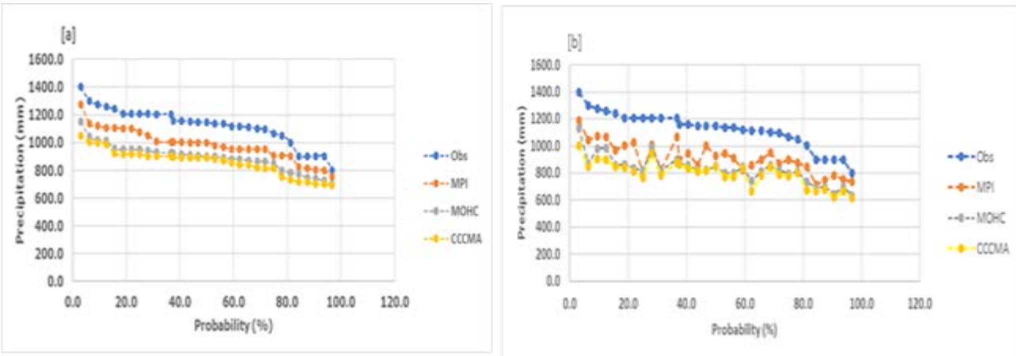

Figure 3: Precipitation distribution curves for observed (1980-2010) and projected precipitation under 3 GCMs for periods 2030-2060 (a) and 2070-2100.

Table 2: Precipitation exceedance probabilities over Edo State for baseline and future periods.

	Prec. (mm)	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**	**Prec. (mm)**
Periods	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Baseline: 1980-2010	1300.4	1200.1	1200.2	1180.6	1178.6	1170.4	1160.3	1020.6	960.4	795.4
Short-term: 2030-2060										
CCCMA	998.6	980.6	982.6	980.6	960.3	840.3	805.1	800.2	660.4	690.2
MOHC	1020.4	1000.1	1020.4	1010.2	970.1	980.4	860.4	780.4	760.4	700.1
MPI	1110.6	1600.4	1080.7	1060.6	1058.6	1040.6	980.2	890.4	801.4	780.2
Long-term: 2070-2100										
CCCMA	900.6	810.3	960.3	820.4	820.6	820.6	820.9	640.8	640.4	600.4
MOHC	980.2	840.3	1005.3	830.6	800.2	830.6	830.2	660.2	740.4	620.4
MPI	1080.3	1000.1	810.2	960.3	960.4	795.3	970.2	800.1	770.6	760.4

Table 3: Projected annual rainwater harvest (Million m3) over Edo State Nigeria.

	Baseline	Near Term	Long Term
Models	1980-2010	2030-2060	2070-2100
CCCMA	220,080,000.0	116,232,000.0	92,592,000.0
MPI	220,080,000.0	133,680,000.0	104,880,000.0
MOHC	220,080,000.0	124,320,000.0	100,320,000.0

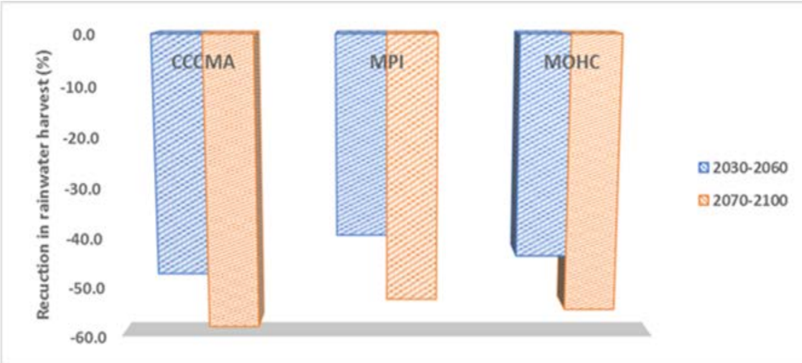

Figure 4: Changes in rainwater harvest for periods 2030-2060 and 2070-2100 in response to 1980-2010.

and Figure4). Conversely, MPI and MOHC models predicted decreases in rainwater harvest of 40.2%, 47.2%, and 43.7%;52.4% for the periods the 2040s and 2080s in response to the baseline (Figure4). The results indicated that the future performance of the RWH system could be affected by CC. The predicted reduction in rainwater harvest may likely force 2.1 million and 2.7 million people out of water security by 2040s and 2080s at a daily water demand of 60 litres per person. The size of the rainwater catchment area and storage tanks' capacity determine the rainwater system's performance. [17-18] reported that the volume of harvested rainwater is proportional to the size and length of the catchment structure. A 400m^2 rooftop-runoff catchment sizes and 10 m^3 reservoir storage capacities for the baseline and future periods were used for the simulations. It is nearly impossible to avert the possible effect of CC on the rainwater harvest. Therefore, the impacts could be mitigated using larger reservoir tanks with a specialized rooftop structure. The study agrees with the work of [18, 19, 20], which reported that many studies had proposed larger storage tanks to mitigate the effect of CC on the performance of the rainwater harvest system.

Conclusion

Climate change (cc) may negatively affect every sector of the economy, and water resource is not an exception. This study evaluated the possible effect of cc on the performance of the rainwater harvest (RWH) system across Edo State using a set of GCMs under RCP 4.5. The statistical metrics result showed that all the selected GCMs indicated decreases in precipitation for the near- and long-term periods (the 2040s and 2080s) in response to the baseline period. The observed and projected precipitation data was applied as input to estimate rainwater harvest (RWH). The projected and observed (RWH) by the 3 GCMs indicated decreases for the 2040s and 2080s, respectively. Therefore, it is concluded that the precipitation will continue to decrease under future climate; thus, it reduces the potential of RHW in Edo State. The result could be useful for the hydrologist and water resources decision-maker to design effective rooftop runoff-rainwater capture and reservoir storage facilities. Also, adopting the rainwater harvest system into the roof plan of every structure should be expanded and included in the housing development policies. Despite the predicted adverse effects of cc on the RWH system's performance, Edo State still has a substantial potential for the rainwater harvest system. It is essential to understand that the adoption of an integrated system of RWHs will increase water security. By large, it acts as a mitigation strategy to possible CC effects on water resources.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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