Scientific Research Publishing

American Journal of Climate Change, 2023, 12, 21-38
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Predicting Groundwater Level Using Climate Change Scenarios in the Southern Part of Mali

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How to cite this paper: Diancoumba, O., Toure, A., Keita, S., Konare, S., Mounir, Z. M., & Bokar, H. (2023). Predicting Groundwater Level Using Climate Change Scenarios in the Southern Part of Mali. *American Journal of Climate Change, 12,* 21-38.
https://doi.org/10.4236/ajcc.2023.121002

Received: November 12, 2022
Accepted: January 15, 2023
Published: January 18, 2023

Abstract

Groundwater is mainly demanded in all the activities for the population of the southern part especially in the Koda catchment, the studied area. These resources are affected by various factors especially climate change. Therefore, knowing the impact of projected climate change on groundwater recharge is an important issue for water resources management, especially for those responsible for the Koda catchment. In this work, the impact of climate change on groundwater resources in the study area in Mali, West Africa is investigated. The Hydrogeological modeling was performed using the Gardenia model, and the monthly precipitation and temperature data were used as the Baseline. These data considered the past 30-year period (1987-2016) and the projections for the next 30 years (2021-2050). Projected precipitation and air temperatures, extracted from the Rossby Centre regional Atmospheric climate model (RCA 4) statistically downscaled from the GCM-IHEC-EC-EARTH and the GCM-MPI-M-MPI-ESM-LR under the Representative Concentration Pathways RCP 4.5 and RCP 8.5 and corrected with the Multiscale Quantile Mapping bias correction method, were used as input data to the gardenia model. Potential evapotranspiration (PET) values estimated from Blaney Criddle method and groundwater levels measured in three piezometers were used to calibrate the Gardenia model. The outputs display the reduction of groundwater level in the three piezometers in the Koda catchment for all the two Regional Climate Models (RCMs) during the periods of rainy season from July to October. From the results of GCM IHEC-EC-EARTH, the projected decline in GWL reaches 1.09 m for the RCP 4.5 and it up to 1.26 m for the RCP 8.5 in the study area while the GCM MPI-M-MPI-ESM-LR presentes the decline in groundwater level (GWL) during winter season from about

0.62 m for the RCP 4.5 up to 1.93 m for the RCP 8:5. Both RCMs project a reduction trend of groundwater recharge over time. It is noticeable that this decline is greater in RCP8.5 for all the three piezometers. The results also show that the average groundwater recharge (90 mm) in the future (2021-2050) is lower (180 mm) than that of the current drought (1987-2016), which could lead to severe drought events. The projected impacts of climate change would have a significant impact on groundwater in the period of 2029-2039; this situation could have a negative impact the socioeconomic activities especially on agriculture, which depends on water resources. The results will help also to take some adaptation measures to climate change, the famers could have a possibility to know the period of groundwater recharge where they have more water infiltration therefore, where to seek crops that need less or more water. The study area presents numerous potential of groundwater, the results could be a tool for groundwater management and to determine the favorable sites to implant new boreholes.

Keywords

Climate Change, RCM-GCMs, Groundwater, Projection, Mali

1. Introduction

The most appreciated and widespread natural water resource on Earth is groundwater (Pathak et al., 2018). This vital resource is used for water needs and irrigation in semi-arid regions. 86% percent of all water is effectively consumed in irrigation over the study area, Diancoumba (2020). Groundwater modeling is crucial in the development and management of water supply systems in the context of climate change in the Sahel, where precipitation is projected to decline. This research focuses on assessing the impact of global change (climate and Land Use/Land Cover, LULC changes) on groundwater resources in the study area. Livestock production is the second most important source of income for the inhabitants of Koda after agriculture. To date, all of these activities are water supplied by groundwater and seasonal rainfall, suggesting that groundwater is the principal water resource of the catchment. Groundwater is very significant in the Koda catchment since it is the only permanent water resources and most of the population depend on groundwater to meet their water demand. Certain impacts of global change have been experienced worldwide in the form of floods, droughts and also the variability of precipitation (Boko et al., 2007; World Bank, 2008; Ibrahim et al., 2014; Yin et al., 2017; Sekela & Manfred, 2019; Quenum et al., 2019). The decline in rainfall patterns was predicted by Taylor et al. (2002) over the whole Mali.

Previous studies (Traore, 1985; ARP Developpement, 2003; Henry, 2011, Bokar et al., 2012; Toure et al., 2016; Diancoumba et al., 2020) conducted in the southern part of Taoudeni concluded that infiltration in the tabular infracambrian aquifers including the study area is linearly related to rainfall. Therefore, the decrease in annual precipitation leads to a decrease in groundwater levels in the Koda catchment.

The Malian government's goal is to improve knowledge of natural resources and to manage with the impacts of climate change on natural resources. Water is one of the most important factors controlling development especially in rural areas where the economy is based on agriculture, livestock, etc.

The hydrogeological reply of the Koda catchment with a set of Regional Climate Model (RCM) driven by Global Climate Model (GCM) has not been studied. This area is home to many people (116,837 inhabitants), so, it would be better to appreciate how climate and LULC changes will affect the accessibility of groundwater resources in this part of Mali. The effects of climate change and variability on groundwater resources are more complex to understand than its effects on surface water resources (Holman, 2006).

A set of GCM/RCMs pairs have been judged as a good tool for Climate Change Impacts Studies (CCIS) in West Africa (Karambiri & Garc, 2011; Angelina et al., 2015; Yira, 2016; Sylla & Nikiema, 2016; Aziz, 2017; Boko et al., 2020). According to Kirchner (2003), the projected impacts of climate change and the rise in groundwater needs in the future require a prediction of groundwater recharge. More studies on the climate change and variability impacts of hydrological variables is required, theses studies improve our understanding and modelling of climate changes related to hydrological systems at scales relevant to decision making (Aizebeokhai, 2011).

This work is the first of its kind on Koda related to climate change impacts on groundwater resource availability. To sufficiently quantify the uncertainties connected with climate projections used in Climate Change Impacts Studies (CCIS), this study used a series of RCMs driven by GCMs. The results of this study could be used to develop a comprehensive management strategy for the Koda catchment to implement adaptation measures in the Koda catchment to address climate change. Finally, the results should be used to a guide for future studies.

The Koda catchment is located in southern Mali and covers an area of 4921 km^2 (Diancoumba et al., 2018). Therefore, the knowledge of the predicted impacts of Climate Change (CC) on Groundwater Resources (GR) is then the keyword for Water Resources management, especially, for the decision makers of the Koda Catchment.

For more details on the location of the Koda catchment refers to Diancoumba et al., (2022).

The main goal of this work is to assess the impact of Climate Change on Groundwater Resources through a series of climate simulations in a semi-arid catchment in Mali, West Africa.

2. Methodology

A combination of methods was used to assess the impacts of climate change on groundwater resources in the Koda catchment (**Figure 1**). Analysis of projected

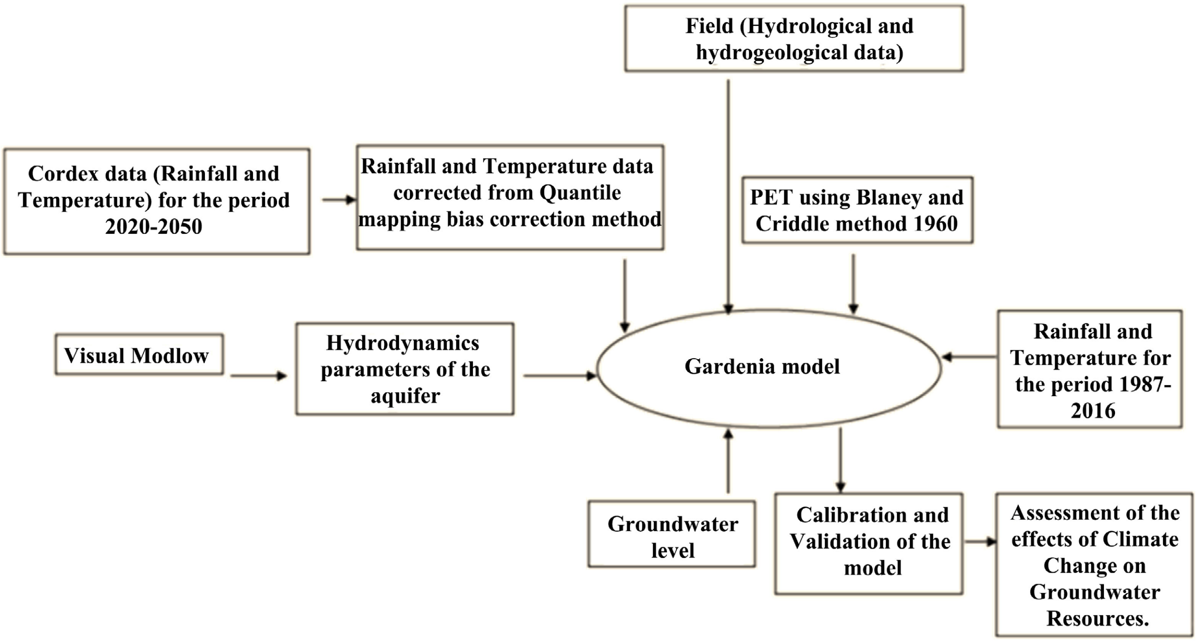


Figure 1. Flow chart of the methodology used in this method.

changes in precipitation and air temperature patterns in the Koda catchment for the period 2021-2050 has been completed in this study. Evaluating the performance of the simulated models is a necessary step for model projections.

The empirical quantile-mapping transformation technique for bias correction of the precipitation and temperature data was useful to reduce the bias in the RCMs (Bardossy & Pegram, 2011; Teutschbein & Seibert, 2012). We used the quantile mapping biais correction at different time (daily, monthly and yearly) scales which makes it multiscale. The corrected output data matched the observed data much better than the uncorrected data ones. Fobs and FRCM, the two cumulative distribution functions developed were created using observations and RCM outputs, respectively, during the calibration period. Bias Corrected RCM (XBC) simulations were created for the validation period and future periods using the transformation explained by Equation (1).

$$XBC = Fobs^{-1}(FRCM(XRCM)) \tag{1}$$

where XRCM is the variable extracted from raw simulated RCM data. The Dry day correction, maximum and minimum temperatures values were taking account in order to produce corrected future RCM simulations close to the observations.

For the model GARDENIA, the observed monthly precipitation data for the past 30 years (1987-2016) for the Katibougou station were used.

GARDENIA is a lumped hydrological model developed by the Bureau de Recherches Géologiques et Minières (BRGM). The model GARDENIA focuses on the water balance equation for aquifers. Great simulation to determine aquifer recharge using numerical models such as the Gardenia model has been performed under various geological and climatic conditions (Thiery, 1987; 1988, 2013). We have applied three methods to estimate the ET$_0$ such as Pennam, Blaney & Criddle (1962), and Thornwaite methods. Due to the lack of observation data the Penman-Monteith method (Penman et al., 2003) was not appropriate in our case, it has been overestimated the ET$_0$ value. Then, the Blaney & Criddle (1962), and Thornwhaite formula (Thornthwaite, 1948) require knowledge of components of which were available over the study area. We used both to estimate the ET$_0$ and the Thorwhaite method underestimated the ET$_0$ patterns. The values of ET$_0$ estimated of Blaney Criddle method were very closed to the overall mean value of the three methods. Therefore, these values of ET$_0$ estimated from Blaney & Criddle (1962) were used in this study.

The historical and climate projection data were also used as inputs data of Gardenia model. Evalution of the Gardenia model has been done using two parameters such as correlation coefficient and Nash and Sutcliffe (1970).

Piezometric data from three piezometers were used to calibrate the Gardenia model. The correlation coefficient is estimated according to Equation (2):

$$R^2 = \frac{\left(\sum\left(O-\bar{O}\right)\left(S-\bar{S}\right)\right)^2}{\sum\left(O-\bar{O}\right)^2 \sum\left(S-\bar{S}\right)^2} \tag{2}$$

The NSE was suggested by Nash and Sutcliffe (1970). The Nash coefficient estimates the relative magnitude of the residual variance compared to the observed data variance (Equation (3)):

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}\left(O-S\right)^2}{\sum_{i=1}^{n}\left(O-\bar{O}\right)^2} \tag{3}$$

where O is the observed value, S the simulated value, $\bar{O}$ is the mean of observed dataset and S the mean simulated dataset.

In addition, the Root Mean Square Error (RMSE) also has been calculated to assess the performance of the model. The RMSE is a good measure of how close the modeled values are to the observed values. If the RMSE is close to 0, it means that the difference between simulated and observed value is small. The RMSE is computed as follows Equation (4):

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O-S\right)_i^2} \tag{4}$$

where n is number of samples, O is observed data and S is simulated data.

The outputs of Rossby Centre regional Atmospheric climate model RCA4 and CCLM4 of the Coordinated Regional Climate Downscaling experiment (CORDEX) at 50 km resolutions by the by the three driving GCMs (IHEC-EC-EARTH, MOHC-HadGEM2-ES and MPI-M-MPI-ESM-LR) were downscaled statistically and corrected using Quantile Mapping method. The simulation has been done under two RCPs (Representative Concentration Pathways) RCP4.5 and RCP8.5. The RCA4 by the driving GCM-HadGEM-MOHC shows the unsatisfactory performance of NSE and RMSE with regards to the correlation coefficients. Furthermore, the output of the RCM CCLM4 by HadGEM-MOHC has shown the poor correlation between the modeled and observed climate time series data.

The statistical parameters between the historical data and the observed data recorded at Katibougou station were calculated in order to select the best set of RCM with best correlation parameters. Therefore, RCA4 and CCLM4 by the two driving GCMs (**IHEC-EC-EARTH** and **MPI-M-MPI-ESM-LR**) have been seen to show very good performance between the modeled and the observed climate time series data. In this study, RCA4 and CCLM4 by the two driving GCMs (**IHEC-EC-EARTH** and **MPI-M-MPI-ESM-LR**) have been used.

The corrected precipitation and temperature data (T_{max} and T_{min}) for the period 2021-2050 have been used in this study. The T_{max} and T_{min} data have been used to obtain the projected potential evapotranspiration (PET) values using the Blaney and Criddle (1962) formula.

A value of 9999, which was considered missing data. Besides, the Thornthwaite method has been used to calculate the future recharge for the period 2021-2050. A Thornthwaite Monthly Balance Method has been applied by several authors under diverse climatic zones to assess the hydrologic impacts of climate change (McCabe & Ayers, 1989; Yates, 1996; Wolock & McCabe, 1999).

The Thornthwaite method required the mean monthly temperature, soil moisture and the monthly precipitation as input data. In this current study, the monthly temperature and precipitation data used from 1987 to 2016 and were registered at Katibougou station

The Comparison of the groundwater recharge of the two methods (Gardenia and Thornthwaite) has been performed to fix which RCM/ GCM set is more indicate for Climate Impacts Studies in the study area.

Groundwater levels recorded for piezometers have been used to calibrate and validate the Gardenia model. The flowchart (**Figure 1**) describes the methods and data used in this study.

Finally, the application of the various Regional Climate Models (RCMs) and Global Climate Models (GCMs) to the catchment is highlighted.

3. Results and Discussion

3.1. Changes in GWL for the Period 2021-2050 under RCP4.5 and RCP8.5 Scenarios Compared to the Baseline Period (1987-2016) in Piezometers Using the Gardenia Model

The analysis of the Water Table Fluctuation in three piezometers has been performed using the RCM/GCM pairs (IHEC-EC-EARTH and MPI-M-MPI-ESM-LR) under RCP 4.5 and RCP8.5 and the results are discussed below:

1) Piezometer Fansiracoura F1:

For the RCA/IHEC-EC-EARTH under the RCP4.5 scenario, the decline in GWL is observed throughout over the year (January to December). During the aquifer recharge period (September, October and November), the average monthly

GWL registered from the scenario RCP4.5 was slightly lower than the observed GWL (decline from 0.04 to 0.07 m). From December to August, the decline in GWL was up to 0.28 m compared to the GWL for June and July, whereas under the scenario 8.5, the decline in GWL compared to the historical observation period is reported to be 0.20 m during the water recharge period. The decrease is about to 0.30 m during the months of June and July. MPI-M-MPI-ESM-LR predicts (under the RCP4.5 scenario) the monthly GWL below the monthly observed GWL and the value is ranges from 0.09 m (May) to 0.21 m (September, October and November). A raise in GWL of 0.06 m has been observed in the months (June and July). The higher scenario RCP8.5 shows an increase of 0.12 m in July, though the reduction was observed throughout the year, with a significant decline of up to 0.75 m was registered in August. **Figure 2** shows the GWL changes of RCA4/IHEC-EC-EARTH and RCA4/MPI-MMPI-ESM-LR in the piezometer F1 under scenarios 4.5 and 8.5.

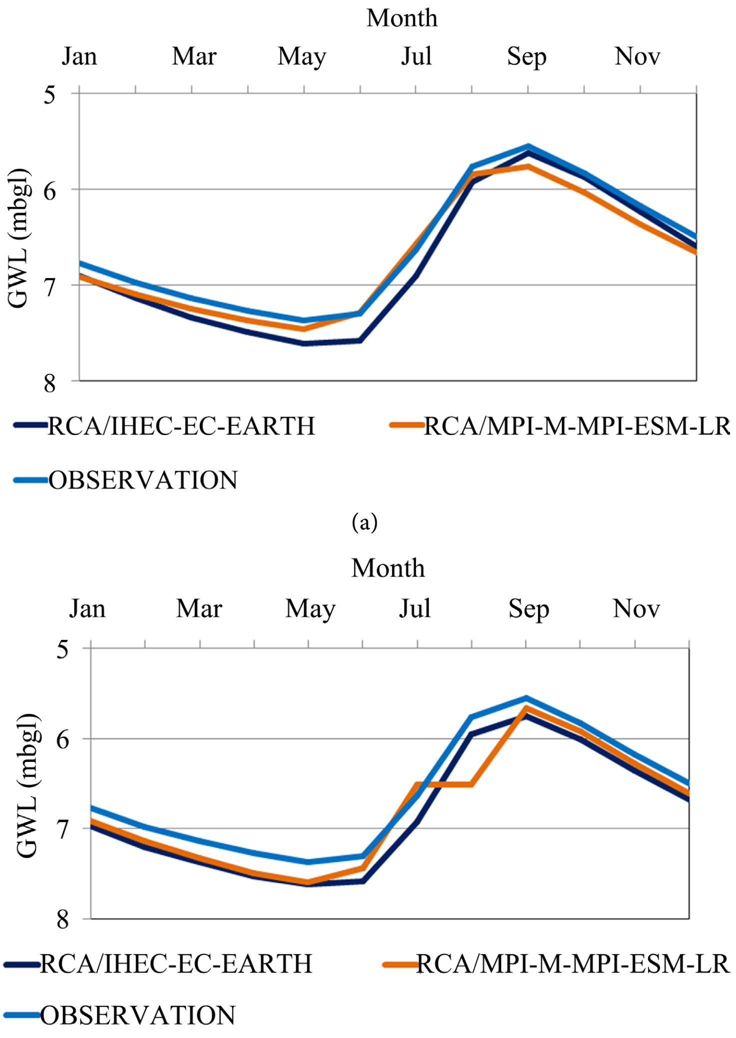


Figure 2. Changes in GWL for the period 2021 compared to the baseline period (1987-2016) in Piezometer F1; (a) Scenario RCP 4.5 and (b) Scenario RCP 8.5.

2) Piezometer Kossaba K1

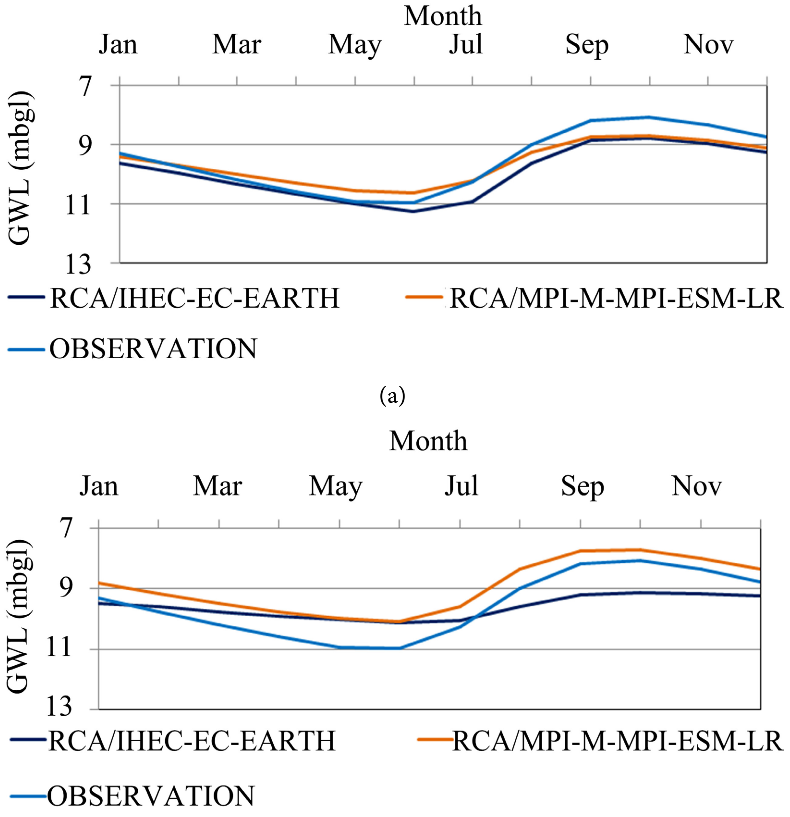
For the RCA/IHEC-EC-EARTH under the RCP 4.5, the decline in GWL was registered over a one-year period. The maximum values were observed from July to November and the values varied between 0.63 m and 0.71 m. The RCP 8.5 displays a rise of up to 1 m from February to July and a reduction in GWL from August to January where the maximum value is estimated to be 1.05 m (Figure 3).

Under RCP 4.5, the MPI-M-MPI-ESM-LR, shows a decline in projected groundwater level of up to 0.7 m compared to the observed value from August to January. An increase in GWL of about 0.5 m was reordered from February to July. Compared to the RCP 8.5, the increase in groundwater level was reordered during the entire year. The rise is up to 1 m in May and June (Figure 3).

Figure 3 shows the GWL evolution of RCA/IHEC-EC-EARTH and RCA/MPI-MMPI-ESM-LR in the piezometer K1 under the scenario 4.5 and 8.5.

3) Piezometer Nossombougou N1

Under the steady state RCP4.5 scenario, the RCA4/IHEC-EC-EARTH and RCA4/M-MPI-ESM-LR display a decline in GWL from June to October and from July to October, respectively. In July and August, the RCA4/IHEC-EC-EARTH shows a decline of 1.1 m, although the RCA/M-MPI-ESM-LR forecasts



(a)

(b)

Figure 3. Changes in GWL for the period 2021-2050 compared to the baseline period (1987-2016) in Piezometer K1, (a) scenario RCP 4.5 and (b) scenario RCP 8.5.

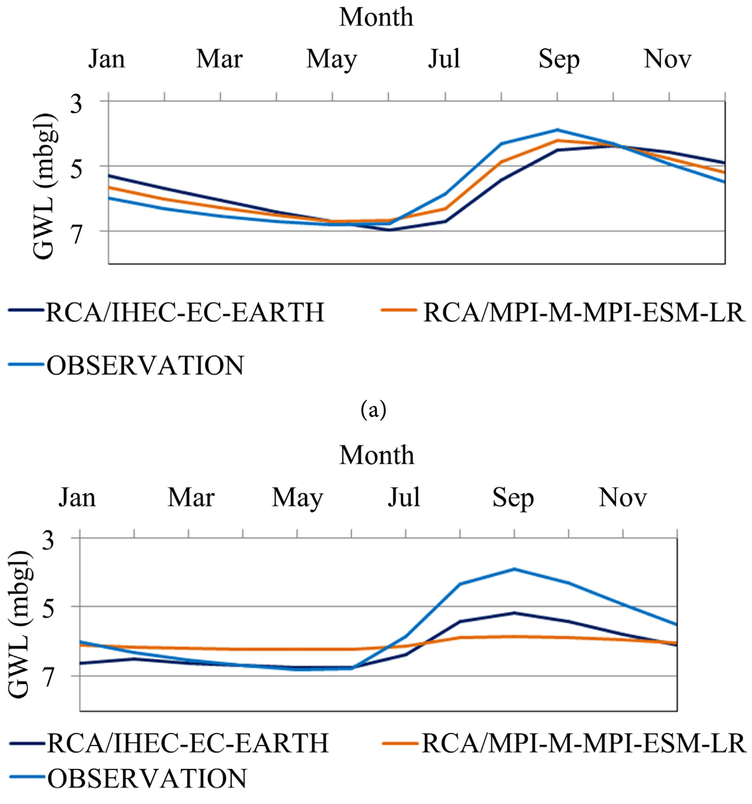
a decline of 0.6 m. In contrast to the RCP 4.5, the RCA4/IHEC-EC-EARTH under the RCP 8.5 projects a decline in GWL between 0.20 m and 1.26 m from July to March, with the highest GWL is detected in August, September and October. RCA4/M-MPI-ESM-LR, on the other hand, registers a decline in GWL from July to January increasing to 2 m in September. The GWL changes of RCA4/IHEC-EC-EARTH and RCA4/MPI-MMPI-ESM-LR in the piezometer N1 under scenarios 4.5 and 8.5 are highlighted in Figure 4.

3.2. Changes in Groundwater Recharge for the Period 2021-2050 under RCP4.5 and RCP 8.5 Scenarios Compared to the Baseline Period (1987-2016) in Piezometers

The projected changes in groundwater recharge for the period 2021-2050 in the three piezometers F1, K1 and N1 under RCPs 4.5 and 8.5 of the RCA4 from IHEC-EC-EARTH and MPI-M-MPI-ESM-LR are shown in the following tables (Tables 1-3).

1) Piezometer Fansiracoura F1

The recharge value projected by the two RCM/GCM pairs in the piezometer F1 ranges from 11.8 mm/year to 46.1 mm/year under the scenario RCP4.5, though the recharge under RCP8.5 scenario is estimated from 6.4 mm/year to 44 mm/year. The RCA4/IHEC-EC-EARTH and RCA4/MPI-M-MPI-ESM-LR under the



(a)

(b)

Figure 4. Changes in GWL for the period 2021-2050 under RCP4.5 scenario compared to the baseline period (1987-2016) in Piezometer N1; (a) RCP 4.5 and (b) RCP 8.5.

scenario RCP8.5 shows the overall decrease in groundwater recharge value compared to the scenario RCP4.5 and the historical observation period 1987-2016. The maximum, minimum and the mean values of groundwater recharge in piezometer F1 for the historical and projected period of the various RCM/GCM pairs are shown in Table 1.

2) Piezometer Kossaba K1

Regarding the piezometer K1, the scenario RCP8.5 does not show the similar trend as in the Piezometer F1 described below. The recharge ranges from 11.51 mm/y to 209.4 mm/y under the scenario. However, the recharge is estimated from 15.9 mm/y to 271 mm/y for the high scenario 8.5. The overall mean annual recharge decreases as compared to the historical observed period.

The maximum, minimum and the mean values of groundwater recharge in piezometer K1 for the historical and projected periods of the different RCM/GCM pairs are outlined in Table 2.

3) Piezometer Nossombougou

All the scenarios are projecting the recharge from 11 mm/y to 250 mm/y. The scenario 8.5 shows the greatest range of recharge compare to the scenario 4.5. However, the observed historical period was the period which showed more recharged water in that part of the studied catchment.

The maximum, minimum and the mean values of groundwater recharge in piezometer N1 for the historical and projected period of the different RCM/GCM pairs are outlined in Table 3.

Table 1. Groundwater recharge calculated in Piezometer F1for periods of observation and projected of the RCM/GCMs pairs (RCA4/IHEC-EC-EARTH and RCA4/MPI-M-MPI-ESM-LR) under 4.5 and 8.5 scenarios.

OBSERVATION period 1987_2016				
	Recharge (mm)		Recharge/rainfall (%)	
Maximum	125.7		12.0	
Mean	104.8		10.0	
Minimum	83.8		8.0	
RCA4/IHEC-EC-EARTH period 2021_2050				
	Scenario 4.5		Scenario 8.5	
	Recharge (mm)	Recharge %	Recharge (mm)	Recharge %
Maximum	46.1	4.6	44.0	3.3
Mean	33.1	3.6	25.2	2.1
Minimum	20.1	2.6	6.4	0.9
RCA4/MPI-M-MPI-ESM-LR period 2021_2050				
	Scenario 4.5		Scenario 8.5	
	Recharge (mm)	Recharge %	Recharge (mm)	Recharge %
Maximum	33.9	3.0	31.0	2.0
Mean	22.9	2.3	22.6	1.8
Minimum	11.8	1.7	14.2	1.6

Table 2. Groundwater recharge recorded in Piezometer K1 of observation and projected periods of the RCM/GCMs pairs (RCA4/IHEC-EC-EARTH and RCA4/MPI-M-MPI-ESM-LR) under 4.5 and 8.5 scenarios.

OBSERVATION period 1987_2016				
	Recharge (mm)		**Recharge/rainfall (%)**	
Maximum	303.88		29	
Mean	251.49		24	
Minimum	199.10		19	
RCA4/IHEC-EC-EARTH period 2021_2050				
	Scenario 4.5		**Scenario 8.5**	
	Recharge (mm)	**Recharge %**	**Recharge (mm)**	**Recharge %**
Maximum	209.44	18.09	271.2	16.33
Mean	128.49	11.72	143.57	9.18
Minimum	47.542	5.35	15.94	2.03
RCA4/MPI-M-MPI-ESM-LR period 2021_2050				
	Scenario 4.5		**Scenario 8.5**	
	Recharge (mm)	**Recharge %**	**Recharge (mm)**	**Recharge %**
Maximum	196.43	15.34	228.30	13.73
Mean	103.97	8.59	152.19	10.69
Minimum	11.51	1.83	76.09	7.64

Table 3. Groundwater recharge recorded in Piezometer N1 of observation and projected periods of the RCM/GCMs pairs (RCA4/IHEC-EC-EARTH and RCA4/MPI-M-MPI-ESM-LR) under 4.5 and 8.5 scenarios.

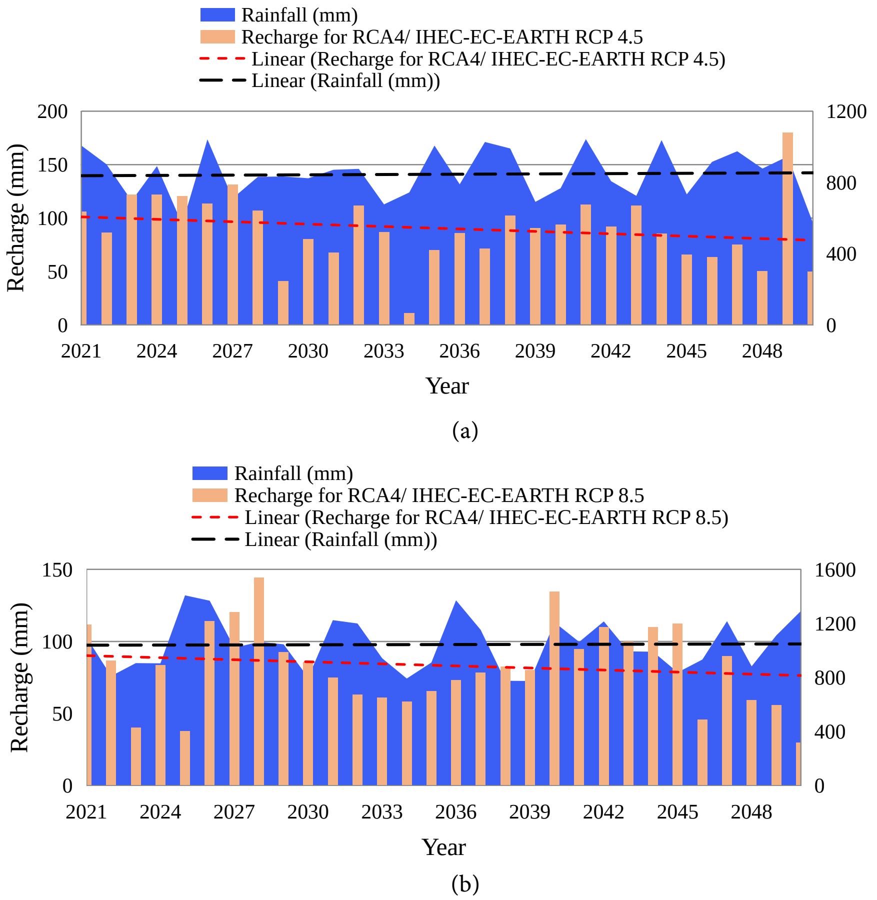
OBSERVATION period 1987_2016				
	Recharge (mm)		**Recharge/rainfall (%)**	
Maximum	251.69		31.23	
Mean	147.06		20.08	
Minimum	42.42		8.94	
RCA4/IHEC-EC-EARTH period 2021_2050				
	Scenario 4.5		**Scenario 8.5**	
	Recharge (mm)	**Recharge %**	**Recharge (mm)**	**Recharge %**
Maximum	185.15	16.03	251.99	14.85
Mean	102.77	9.21	131.56	8.16
Minimum	20.39	2.39	11.14	1.47
RCA4/MPI-M-MPI-ESM-LR period 2021_2050				
	Scenario 4.5		**Scenario 8.5**	
	Recharge (mm)	**Recharge %**	**Recharge (mm)**	**Recharge %**
Maximum	196.43	15.34	200.77	12.72
Mean	103.97	8.59	127.69	8.87
Minimum	11.51	1.83	54.61	5.03

The results expose that, the water table in the piezometers in the Koda catchment decreases during the rainy season for the two RCMs compared to the observed data. The results of RCA4/IHEC-EC-EARTH projected a decline in GWL in the Koda catchment up to 1.1 m for the RCP 4.5 and 1.3 m for the RCP 8.5 while the RCA4/MPI-M-MPI-ESM-LR shows a drop in groundwater level during the winter period from 0.7 m for the RCP 4.5 to 2 m for the RCP 85. The decline is more important for the RCP 8.5 than for the RCP 4.5 with the exception of the piezometer Kossaba located close to the outlet of the study area where the RCA4/MPI-M-MPI-ESM-LR predicts a rise in observed GWL of up to 1 m in May–June under RCP 8.5.

3.3. Changes in Annual Recharge for the Period 2021-2050 under RCP4.5 and RCP 8.5 Scenarios for the RCA4/IHEC-EC-EARTH and RCA4/MPI-M-MPI-ESM-LR Climate Simulations

3.3.1. Recharge for RCA4/IHEC-EC-EARTH

The recharge for RCA4/IHEC-EC-EARTH in the RCP 4.5 scenario decreases for the years from 2029 to 2034 and from 2044 to 2047. The dry period is observed in the years 2023, 2025 and 2029 to 2039, and 2046-2050 under the RCP 8.5 scenario (**Figure 5**).



(a)

(b)

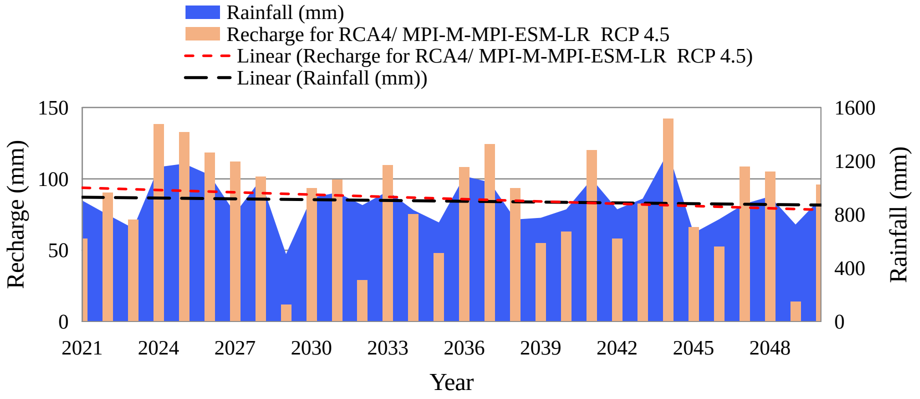
Figure 5. Changes in annual Recharge for the period 2021-2050 for the RCA4/IHEC-EC-EARTH. (a) RCA4/IHEC-EC-EARTH-RCP 4.5; (b) RCA4/IHEC-EC-EARTH-RCP 8.5.

The recharge is declining over time for both scenarios, but is more pronounced in RCP 8.5 than in RCP 4.5. The projected average annual recharge for the RCA4/IHEC-EC-EARTH is equivalent to 90 mm (11% of the Mean Annual Rainfall, MAR) for the RCP 4.5. The RCP 8.5 scenario predicts the mean annual recharge of 84 mm (8% of MAR).

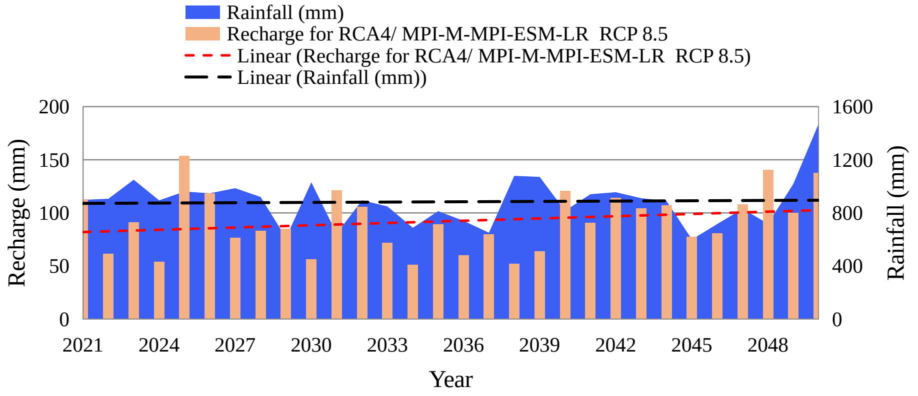
3.3.2. Recharge for RCA4/MPI-M-MPI-ESM-LR

The RCA4/MPI-M-MPI-ESM-LR predicts a decline in annual recharge for the period 2029 to 2050 under the RCP 4.5 scenario, with some wet periods observed in 2024, 2041 and in 2044. The RCP 8.5 scenario shows an overall raise in projected recharge for the period 2021-2050, with decreases decrease observed in the year 2024, 2009, 2034 through 2039 (Figure 6). In the RCP 4.5 scenario, the projected recharge is 86.06 mm (9.5% of MAR), although in the RCP 8.5 scenario, the mean annual recharge is about 92 mm, which is 10.4% of MAR. The recharge decreases in the RCP 4.5 scenario, while it increases in the RCP 8.5.

The recharge declines from 2021-2050, with severe drought events projected in the period 2029-2039. This trend was also observed in the Thornthwaite method used to estimate the projected annual recharge for the period 2021-2050. The recharge estimated is based on the mean recharge value attained from the



(a)



(b)

Figure 6. Changes in annual recharge for the period 2021-2050 under (a) RCP4.5 and (b) RCP 8.5 scenarios for the RCA4/MPI-M-MPI-ESM-LR.

Gardenia model. The Soil Moisture Storage (SMS) capacity was considered to be 250 mm by comparing the groundwater recharge from the two models (Gardenia and Thornthwaite).

These results are accordance with other recent studies done in West Africa espcially in Sahel and arid zones. According to Al-Gamal (2021), the recharge diminishes over West Africa from 1970 to 2050 with regular events of extreme dry seasons. These results have been explained by Aizebeokhai (2011), According to that study, the decrease of groundwater recharge is due to the projected decrease in precipitation patterns and increasing droughts in the Sahel and Savannah regions. The increase of drought in Savannah areas is linked to the result of increasing desertification (Diancoumba et al., 2022; Koubodana et al., 2019). According to Aizebeokhai (2011), groundwater stress would be more severe in most part of West Africa by 2050. West African areas are projected to suffer a decrease of water resources (including groundwater) due to climate change (Cook et al., 2022).

In one of the piezometers over the study area, the recharge decreases in the RCP 4.5 scenario, while it increases in the RCP 8.5 scenario. Our findings broadly confirm the results of this study undertaken by focussed recharge are also likely to increase predominantly due to increases in projected rainfall (Taylor et al., 2013; Cuthbert et al., 2019).

4. Conclusion

The hydrogeological response of a watershed to climate change is highly dependent on the input data. Gardenia model was run using results from RCA4 downscaled from two GCMs (IHEC-EC-EARTH and MPI-M-MPI-ESM-LR) under RCP 4.5 and RCP 8.5. The outputs exhibit that, the groundwater level decreases during the rainy season, in the piezometers within Koda catchment for all the two RCMs compared to the observed data. The results from the RCA4/IHEC-EC-EARTH projected a decline in GWL of up to 1.1 m for the RCP 4.5 and 1.3 m for the RCP 8.5 in the Koda catchment, while the RCA4/MPI-M-MPI-ESM-LR exposed a decline in GWL from 0.7 m for the RCP 4.5 to 2 m for the RCP 85 during the rainy season. Both of the RCMs predict a decline in groundwater recharge over time. Obviously this decline is more important in RCP8.5 scenario in the Koda catchment. The outcomes also expose that the projected mean annual recharge (90 mm) in the future is under the recharge of the current dry conditions, which is 180 mm. This could lead to the future groundwater scarcity.

From both models (Gardenia and Thornthwaite), the RCP 4.5 scenario predicts a dry period in IHEC-EC-EARTH model and in MPI-M-MPI-ESM-LR model. The opposite is observed in the prediction of RCP8.5 scenario, *i.e.*, the recharge declines in IHEC-EC-EARTH model why it increases in MPI-M-MPI-ESM-LR model for the RCA4-IHEC-EC-EARTH, the recharge is declining over time for both scenarios (RCP 4.5 and RCP 8.5), but it is more pronounced in the

RCP8.5 scenario than in the RCP4.5 scenario. The RCA4-IHEC-EC-EARTH showed the best simulation over the Koda catchment for the Gardenia model as well as for the Thornthwaite model.

All the two RCMs predict a decline of groundwater recharge over time.

1) The results of this work could be used as a good tool for Integrated Water Resources Management (IWRM) at the Koda catchment scale.

2) The projected impacts of climate change would be evident in the period 2029-2039 (where the simulated droughts events are expected) on groundwater scarcity. Consequently, it is essential to develop a proper water management plan of these resources to offset these issues.

The results will help also to take some adaptation measure to climate change, the famers could have a possibility to know the period of groundwater recharge where they have more water infiltration therefore, where to seek crops that need less or more water.

The study area presents enormous potential of groundwater, the results can be a tool for groundwater management and to determine the favorable sites to implant the new boreholes.

Acknowledgements

The authors thank the National Directions in Mali which provided hydrologically and climate data (DNH of Bamako, DRH of Koulikoro and DNM of Bamako).

Fundings

This study was not funded by any institutions

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Souleymane KEITA: Methodology, Writing review & editing.

Seriba KONARE and Zakari Mahamadou MOUNIR: Writing review & editing.

Hamadoun BOKAR: Supervision and Validation.

Conflicts of Interest

The authors declare no conflits of interests.

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