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Regional Climate Models Assessments at Egyptian North Western Coast Zone (NWCZ)

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Abstract - *The North Western Coast zone (NWCZ) is one of the promising zones for development. So, it is important to prepare development strategy. Since rainfall is the main water resources there, it is important to check the accuracy of precipitation data before running at any hydrological applications. In this research, three regional climate models (REGs) with resolutions 50*50 km "EC-EARTH13, CNRM-CM514 and GFDL-ESM2M15" are used and corrected to assess the model compatible with historical data at the domain of the study area. Salloum and Sidi- Barrani sites are used to investigate the models suitability. Comparisons were made on the basis of a thirty-year retrospective (1975-2005) with rainfall ground observation. Selected quantitative statistics are used such Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR), probability density function (PDF), precipitation concentration index (PCI) and cumulative distribution function (CDF) to test the performance of the rainfall data against the REGs models. The results revealed that EC-EARTH13 has the best performance at two locations which produces the different concentrations patterns of rainfall in all data than the other models. The best model that produces accurate precipitation has been applied in near future period for two representative concentrations pathway (RCP 4.5 and RCP 8.5) relative to observed during 2006 to 2018 whereby confirm its suitability for the future projected data at the region*.

Key Words: Regional model, climate change, rainfall analysis, PCI, PDF, NSE, RSR, CDF

1.INTRODUCTION

The North Western Coast zone (NWCZ) is considered one of the pioneer areas applicable for development at national level and climate change is expected to change the hydrologic processes in the Mediterranean Region (MR) due to its one of the Earth 's primary hot spot area for climate change, due to the magnitude of expected value of temperature and rainfall patterns[1]. Global weather is now characterized by an increase in the frequency and magnitude of extreme even[2],[3].According to the World Meteorological Organization (WMO), the 2001–2010 decade was the second wettest decade since 1901. The year 2010 was the wettest year in that period, with worldwide record 2013). One of the most important goals of African countries in the 21st century is the adaptation to development limits associated with climate change. The results of these studies show that the African climate is characterized by considerable variability in precipitation. So, to achieve the effective sustainable development for study area, climate change impact should be considered so precipitation data must be handled before use it in calculating continuous hydrograph in future.

Simulated Climate data for this research were collected from the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) which is a project aims to assess the impacts of climate change on freshwater resources in the Arab region and to examine the implications of these impacts for environmental vulnerability based on regional specifications.

In this research, the three regional climate models assessment will be conducted to select which model has the same performance of the historical data for the study area. salloum and sidi- Barrani sites locations are used to investigate the models suitability. Comparisons were made on the basis of thirty-year retrospective (1975-2005) with ground observation of rainfall data that include the reference period for the three models representative of 1986-2005. The best fitting climate model for the study area was tested in producing the near future rainfall projection under two representative concentrations pathway RCP 4.5 and RCP 8.5 that developed by Intergovernmental Panel on Climate Chang (IPCC) as intermedia and extremes socioeconomic scenarios respectively.

2. Study area

2.1 Study area Description

The study area is located in the northwestern part of Egypt between the city of Sidi Barani in the east and the city of salloum in the west. The study area comprised within 25º 00´00" and 30º 25´ 00" longitude E and 30º 45´ 00" and 31º 45´ 00" latitude N. It is bordered by the Mediterranean Sea to the north, Alexandria to the east, and the Libyan border (Salloum crossing) to the west. It covers an area of about 4,648 square kilometers. The average altitude is about 250 m above the mean sea level. The climate belongs to (NWCZ) area is subtropical Mediterranean climate with mild and wet winters and hot and dry summers. The annual precipitation ranges between 92 mm in Salloum and 150 mm in Sidi-Barrani, [4] which indicates that rainfall increases towards the eastern parts near Sidi-Barrani[5]. Local inhabitants depend mainly on shallow groundwater and run-off water which is collected in cisterns by different water harvesting techniques, [6] ,[7], [8]. Figure (1) shows the digital elevation model for the study area.

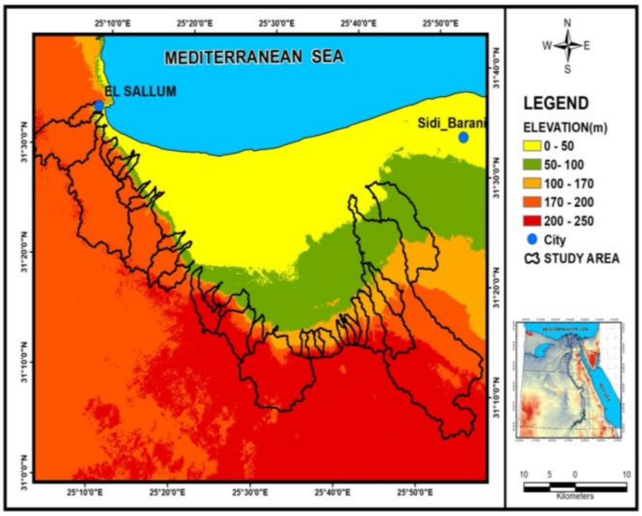

Figure 1: Digital elevation model (DEM) for the study area, Source:(United States Geological Survey 90X90m)

3. Methods and Data

3.1 Data Description” observed and Regional climate models”

In this research, two types of the rainfall data are used; observed and climate models data. Climate data includes historical and future projections from three regional climate experiments. Historical data from Egyptian Meteorological Authority (EMA) in daily basis from (1975 to 2005) at two rainfall stations” (salloum and sidi barrani) are available. Meanwhile, three regional climate models supported by the (RICCAR) will be used to collect simulated data for the same period of observed data. Climate datasets originate as measurements of sub-daily or daily weather variables collected over time and merged to create climate records. “Fifth Assessment Report” (AR5) for IPCC simulated 4 “Representative Concentration Pathways” (RCPs) trajectories (i.e. RCP2.6, RCP4.5, RCP6.0 and RCP8.5) that represent possible ranges of radioactive values for year 2100. Two Scenarios from Representatives concentration pathway (RCPs); RCP 4.5 and RCP 8.5 which developed by (IPCC) are applied as intermedia and extremes socioeconomic scenarios respectively as shown in figure (2). It has been analyzed in term of cumulative distribution and probability density function to test the performance of the best fit climate model in producing the rainfall projections. The fourth version of the Ross by Centre Regional Atmospheric Model (RCA4) developed at Swedish Meteorological and Hydrological Institute (SMHI), [9] is the Regional Climate Model (RCM) available for analysis for future simulations in RICCAR. The evaluated simulation is used to assess how well RCM to represent recent climate over the domain of the study area (Middle East North Africa (MENA)” regional domain with horizontal resolution of |0.44° (50km). For the scenario simulation runs performed under RICCAR, three experiments downscaled simulations by RCA4 were driven by lateral boundary conditions from three climate models under CMIP5 GCMs, namely EC-EARTH13, CNRM-CM514 and GFDL-ESM2M15 that will be tested in study area.

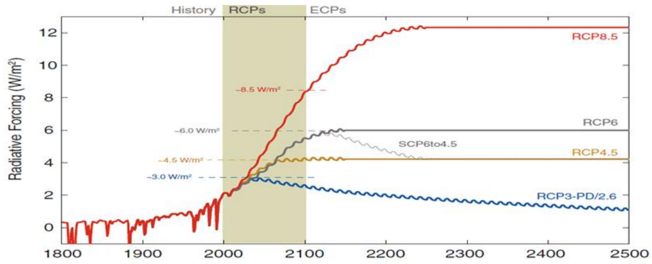

Figure 2: Representative concentration pathway (RCPs) scenarios, [10]

3.2 MODELS EVALUATION TECHNIQUES

The techniques that have been conducted to evaluate the models in this research for rainfall data analysis are generally fall into variability and trend analysis categories. These include the use of Precipitation Concentration Index (PCI), Nash-Sutcliffe efficiency (NSE), probability density function (PDF) , root mean square Error (RSR), percent bias (PBIAS) and cumulative distribution function (CDF).

Nash-Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance [11]. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in equation (1).

$$NSE=1-\frac{\sum_{i=1}^{n}(y_i^{obs}-y_i^{sim})^2}{\sum_{i=1}^{n}(y_i^{obs}-y_i^{mean})^2} \quad (1)$$

Where: Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, Y_i^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations. NSE ranges between −∞ and 1.0 (1 inclusive), with NSE =1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

NSE is very commonly used, which provides extensive information on reported values, [12]. It was found also, the best objective function for reflecting the overall fit of a hydrograph [13].

RMSE-observations standard deviation ratio (RSR)

Rout mean squire error (RMSE) is one of the commonly used error index statistics [14], [15], [16]. A modified model evaluation statistic, named RMSE-observations standard deviation ratio (RSR), was developed by [15]. It is standardizing RMSE using the observations standard deviation, and it combines both an error index. RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation (2). RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistic and reported values can be applied to various constituents. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower RSR, the lower the RMSE, and the better the model simulation performance. Table (1) illustrate performance rating for (NSE&RSR).

$$RSR=\frac{RMSE}{STDEV_{obs}}=\frac{\sqrt{\sum_{i=1}^{n}(y_i^{obs}-y_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}(y_i^{obs}-y_i^{mean})^2}} \quad (2)$$

Table (1): Performance ratings for statistics data analysis

Performance Rating	RSR	NSE
Very good	0.00 < RSR < 0.50	0.75 < NSE < 1.00
Good	0.50 < RSR < 0.60	0.65 < NSE < 0.75
Satisfactory	0.60 < RSR < 0.70	0.50 < NSE < 0.65
Unsatisfactory	RSR > 0.70	NSE < 0.50

Source: Moriasi, et. al., 2007 [17]

Precipitation concentration index (PCI)

PCI is used to examine the variability (heterogeneity pattern) of rainfall at different scales (annual, monthly or seasonal). The PCI values were computed, as given by [18] and modified by [19], as equation (3):

$$PCI_{annual}=\frac{\sum_{i=1}^{12}P_i^2}{(\sum_{i=1}^{12}P_i)^2}*100 \quad (3)$$

Where: P_i the rainfall amount of the ith month. According to [18], Table (2) illustrates temporal PCI concentration.

Table (2): PCI concentration limit

PCI Value	Temporal PCI concentration
PCI≤ 10	Uniform (low precipitation concentration)
PCI>10≤ 15	Moderate
PCI>16≤ 20	Concentrated
PCI >20	Very concentrated

Probability density function (PDF)

Probability density is the relationship between observations and their probability. Some outcomes of a random variable will have low probability density and other outcomes will have a high probability density. The overall shape of the probability density is referred to probability distribution. The calculation of probabilities for specific outcomes of a random variable is performed by a probability density function or PDF for short. It is useful to know the probability density function for a sample of data in order to know whether a given observation is likely, or so unlikely as to be considered an outlier or anomaly and whether it should be removed. It is also helpful in order to choose appropriate learning methods that require input data to have a specific probability distribution. The first step in density estimation is to create a histogram of the observations in the random sample. A histogram is a plot that involves first grouping the observations into bins and counting the number of events that fall into each bin. The counts or frequencies of observations, in each bin are then plotted as a bar graph with the bins on the x-axis and the frequency on the y-axis.

Percent bias (PBIAS)

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts, [20]. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias, [20]

. PBIAS is calculated with the equation (4):

$$\text{PBIAS} = \frac{\sum_{i=1}^{n} \left(y_i^{obs} - y_i^{sim}\right) * 100}{\sum_{i=1}^{n} \left(y_i^{obs}\right)} \qquad (4)$$

4. Results and discussion

The results from the comparisons between the three climate model experiments and the observed date at the two locations of salloum and Barrani are displayed. In additions to the outcomes of the statistical testes to evaluate the best fitting climate model experiments to reproduce the rainfall projections at the different catchments in the region of western north coast line were presented. Furthermore, the near future projections of the best model during (2006:2018) were examined under the two scenarios of RCP 4.5 and 8.5 watt/m^2 related to accurate observed rainfall to confirm their consistency and suitability.

Precipitation Concentration Index (PCI)

The compiled total monthly rainfall data at two stations for historical data for simulated models versus observed show a range of variability that need to discuss and analysis as shown in figure (3) and (4). To evaluate the concentration and variability of rainfall in time, the Precipitation Concentration Index (PCI) used based on monthly precipitation over 30 years from 1975:2005 at the two locations (salloum & Barrani) for observed and simulated data models. The results clarified that according to [18]and referring to table (2), it is clear that all values of PCI between (16 to20) and (21 and above) and this mean that all data has high and very high concentration, figures (5) and (6). This could be resulting from difference in boundary conditions of the driving GCMs models ‘parametrizations or other sources of data uncertainty that need further sensitivity analysis and correct before use in producing the future projections and then applied in adaptation strategies or other hydrologic applications.

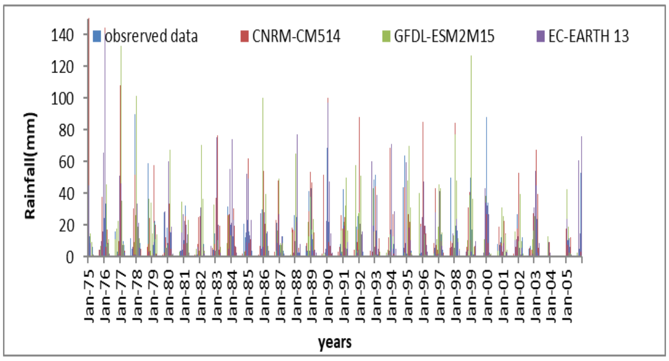

Figure (3): Comparison between observed and RCM raw precipitation for 1975–2005, at Salloum Station

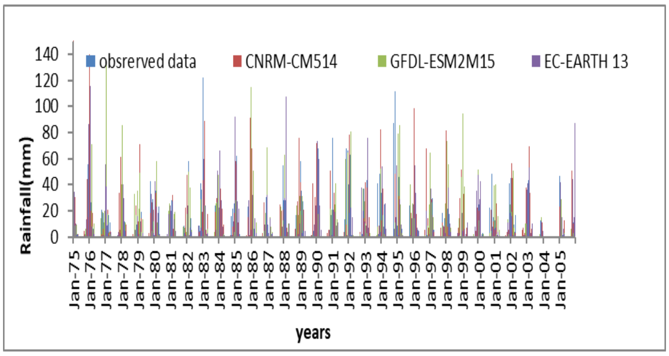

Figure (4): Comparison between observed and RCM raw precipitation for 1975–2005, at Barrani Station

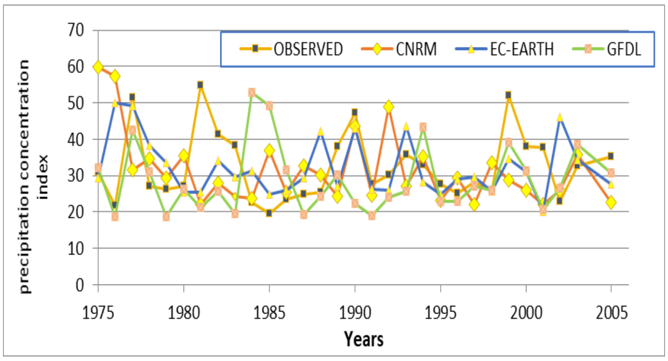

Figure (5): Annual PCI variations at Salloum for period (1975-2005)

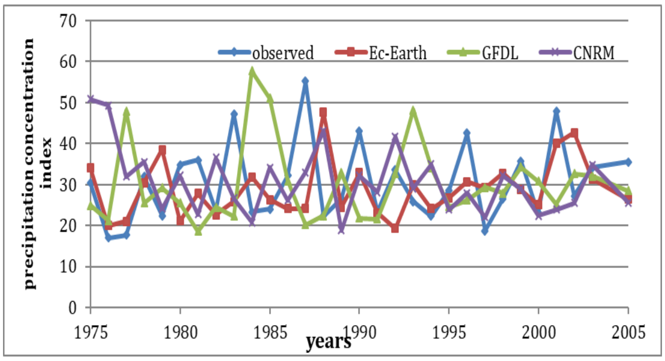

Figure (6): Annual PCI variations at Barrani for period (1975-2005)

Mean& Standard deviation

Calculations of mean and standard deviation for all models and observed information illustrate that, there is a variance around the arithmetic mean for all models at the two locations, salloum &Barrani. EC-EARTH13 model is the least value of Standard deviation comparing with other models and has the closest mean from the observed mean value as show in table (3).

Table (3): Mean and Standard deviation for rainfall data at Saloum and Barrani

Climate Models and observation	Salloum		Barrani	
	Mean	Standard deviation	Mean	Standard deviation
Observed	13.6	11.8	15	20
EC-EARTH13	15	14.6	14	20
GFDL-ESM2M15	17.2	14.6	16	21.7
NRM-CM514	17.7	16.2	18.2	28.25

Nash-Sutcliffe efficiency (NSE), Root mean square error (RSR) and percentage of bias (PBIAS):

As a very important index to evaluate the simulated data models, Nash-Sutcliffe efficiency (NSE), Root mean square error (RSR) and percentage of bias (PBIAS) that are calculated during the historical period also for 1975: 2005 at the two stations. Referring to table (1) for their limits, the results show that the Ec-earth13 model has a good performance for the two stations. NSE& RSR analysis show that Ec-earth13 model has very good performance which 0.75< NSE ≤1 and 0≤ RSR≤ 0.5 for Salloum station and has unsatisfactory performance for Barrani station which RSR > 0.70 and NSE < 0.50. It has NSE value about 0.06 and this value between 0.0 and 1.0 which are generally acceptable levels of performance. Also from the analysis GFDL-ESM2M15 model that has a good performance for salloum which has 0.50<RSR< 0.60 and 0.65 < NSE < 0.75 but has unsatisfactory performance for barrani station which RSR > 0.70 and NSE < 0.50 and it is noted that NSE for this model less than zero, which indicates unacceptable performance. CNRM mode has Satisfactory performance which has 0.60 < RSR < 0.70& 0.50 < NSE < 0.65. Also NSE for this model less than zero which also indicates unacceptable performance., as shown in Table (4) and Figure (7). Regarding to Percent bias (PBIAS), calculations indicate that all models have negative values at Salloum and this mean that all models overestimation bias but Ec-earth 13 has the lowest value of bias about -0.17 and has 0.13 at Barrani compared with CNRM-CM514 and GFDL-ESM2M1 models which have values about -0.51 &-0.37 at Salloum and -0.11&-0.01 at Barrani respectively.

Table (4): Quantified statistical indicators at Salloum and Barrani for three regional climate models

Climate Models	Salloum			Barrani		
	NSE	RSR	P bias	NSE	RSR	P bias
EC-EARTH13	0.92	0.29	-0.17	0.06	0.97	0.13
GFDL-ESM2M15	0.75	0.50	-0.37	-0.12	1.05	-0.01
CNRM-CM514	0.62	0.61	-0.51	-0.36	0.35	-0.11

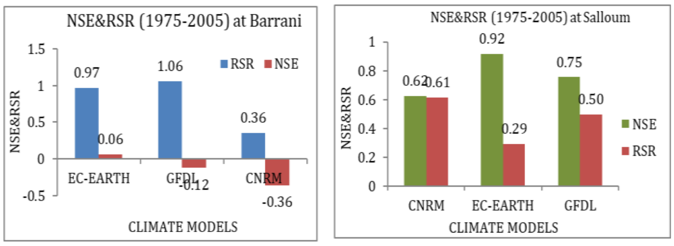

Figure (7): NSE& RSR during 1975 to 2005 at Barrani at left and Salloum right

Probability Density Function (PDF)

Probability density functions (PDFs) was estimated for monthly rainfall period (1975-2005) in two locations of western north coast (salloum &Barrani) to trace the performance of the three different climate models with observed data. Figures (8) and (9) show PDF charts for Salloum & Barrani.

From (PDF) for Salloum rainfall data it is clear that Ec-earth model is closest to the observed data and nearly has the same behavior of actual data at small and big values of rainfall, so it has very good performance at this location. On the other hand, GFDL model has a bad performance compared with observed data for estimating the probability of occurrence which give high estimation for small values. Also, CNRM model has a bad performance which gives low estimation in small values and high estimation in big values.

Also, PDF for Barrani station represents that all models have the same behavior for simulating the probability of occurrence for rainfall data compared with observed data which gives high simulation at small values and good simulation at medium and big values. With the note that Ec-earth model still gives the closest estimation to the actual data.

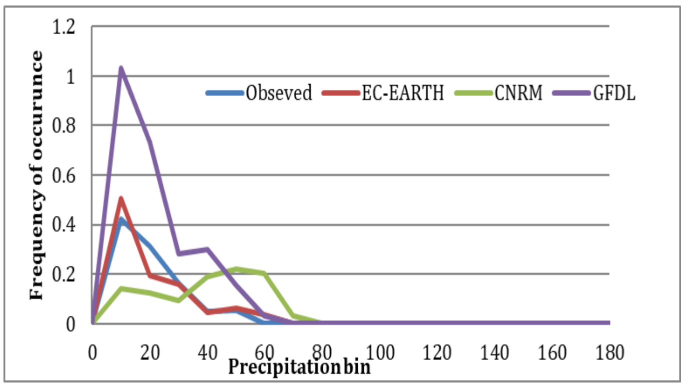

Figure (8): Monthly PDF for Salloum station from 1975 to 2005.

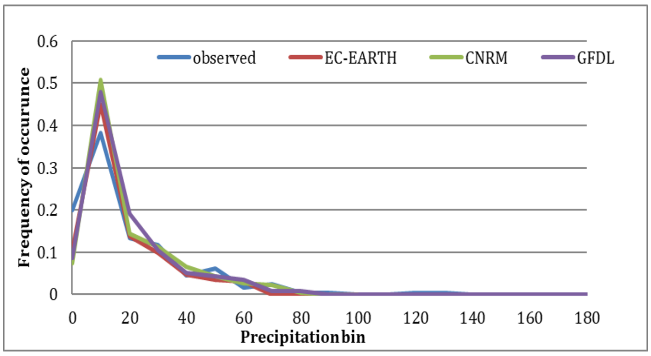

Figure (9): Monthly PDF for Barrani from 1975 to 2005

5- Evaluation the performance of EC-EARTH13 in future period (2006-2018)

- **Probability Density Function (PDF) and Cumulative Distribution function (CDF)**

(PDFs) and (CDF) were estimated for monthly rainfall at the two locations of western north coast (Salloum &Barrani) in which evaluate the performance of EC-EARTH13 model in the future period from (2006: 2018) that considered future projection of the model relative to observed value at same period. These have been conducted for intermediate and high scenarios of concentration radiative forces (RCP4.5 & RCP 8. 5). Figures (10) and (11) show PDF and figure (12), (13) CDF for Salloum & Barrani at scenarios (RCP4.5 & RCP 8.5).

It is clear that Ec-earth model is closest to the observed data in the future period and nearly has the same behavior of actual data at small and big values of rainfall, so it confirms that it has very good performance at two locations for intermediate and high scenarios. Figure (10) at El Salloum station shows that the intermediate rainfall values between 10:25 mm will be increased in frequency at RCP 4.5 and RCP 8.5. Meanwhile the rainfall values between 40 and 60 mm will increase in frequency at Barani as shown in figure (11). Which mean that the selected model needs more enhancement and fine tuning regarding to source of data or even for fine horizontal resolutions.

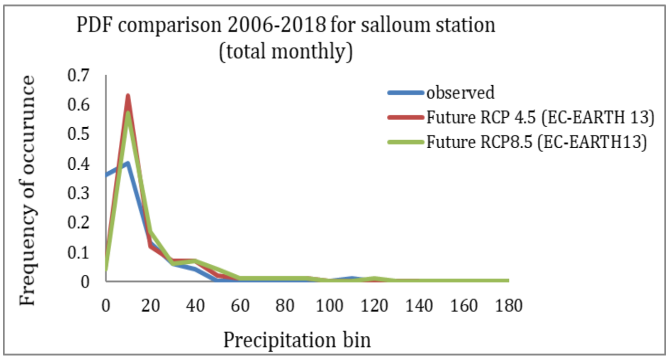

Figure (10): Monthly PDF for Salloum station from 2006-2018 for RCP4.5& RCP 8.5 with observed

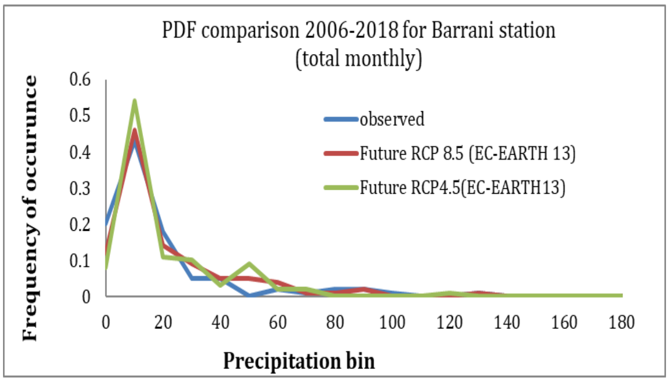

Figure (11): Monthly PDF for Barrani station from 2006-2018 for RCP4.5& RCP 8.5 with observed

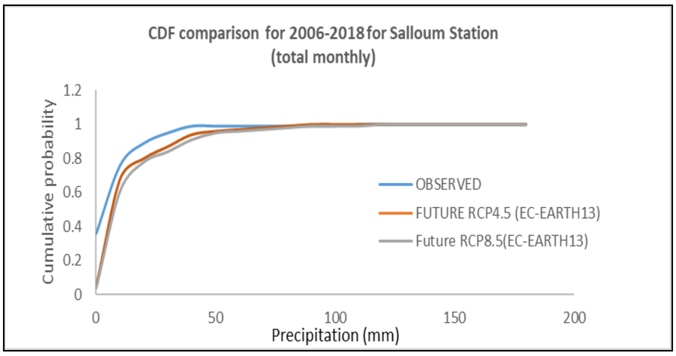

Figure (12): CDF for observed and future projection monthly basis at Salloum station during 2006:2018 for RCP4.5& RCP 8.5

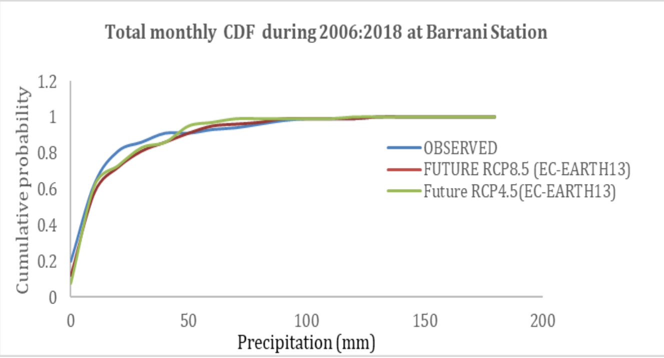

Figure (13): CDF for observed and future projection monthly basis at Barrani station during 2006:2018 for RCP4.5& RCP 8.5

The results at this research could be summarized as fallowing:

Salloum Station

- Ec-earth model is the nearest model compared with other models from observed data in mean and standard deviation (SD) which has mean = 15 & (SD) =14.6 and observed data has mean= 13.6 & (SD) = 11.8, table (3).
- PCI analysis clarified that all data for all models have high and very high concentration, figure (5).
- Ec-earth model has very good performance which has 0.75< NSE ≤1 and 0≤ RSR≤ 0.5.
- GFDL model has a good performance which 0.50<RSR< 0.60 and 0.65 < NSE < 0.75
- CNRM mode has satisfactory performance which 0.60 < RSR < 0.70& 0.50 < NSE < 0.65, table (4) and figure (7)
- (PDF) analysis show that Ec-earth model is closest to the observed data and nearly has the same behavior of actual data at small and big values of rainfall, so it has very good performance at this location. On the other hand, GFDL model has a bad performance compared with observed data for estimating the probability of occurrence which give high estimation for small values. Also, CNRM model has a bad performance which gives low estimation in small values and high estimation in big values figure (8).
- CDF and PDF for rainfall projection at near future show the same trend for the model data and observed with partially reduction in rainfall at RCP 4.5 and the reduction increases at RCP 8.5 especially at medium values ranged between 20:50 mm, figures (10&12).

Barrani Station

- Ec-earth model is the nearest model compared with other models from observed data in mean and standard deviation (SD) which has mean = 14& (SD) =20 and observed data has mean= 15 & (SD) = 20, table (3).
- PCI analysis clarified that all data for all models have high and very high concentration, figure (6).
- All models have unacceptable performance which RSR > 0.70 and NSE < 0.50, table (4) and figure (7)
- PDF for all models have the same behavior for simulating the probability of occurrence for rainfall data compared with observed data which gives overestimate at small values and good simulation at medium and big values. But Ec-earth model still gives the closest estimation to the actual data, figure (9)
- CDF and PDF for rainfall projection at near future show the same trend for the model data and observed with slightly reduction in rainfall at RCP 4.5 and RCP 8.5 respectively at medium values ranged between 30and 50 mm, figures (11) and (13)
- From the above analysis; There are very high variability in data concentration, this could be resulting from difference in boundary conditions of the driving GCMs models 'parametrizations or other sources of data uncertainty that need further sensitivity analysis and correct before use in producing the future projections and then applied in adaptation strategies or other hydrologic applications. Furthermore, and from the results of NSE, RSR and PBIAS and other statistical analysis, it is concluded that the Ec-earth model has the best performance. Wherever, the assessment of CDF and PDF at near future confirms the goodness of the EC-EARTH13 at study region.

5. CONCLUSIONS

This research aims to evaluate the performance of three different regional climate models experiments under the fourth version of the Rossby Centre Regional Atmospheric Model (RCA4) developed at Swedish Meteorological and Hydrological Institute (SMHI) which driving from three GCM models named ("EC-EARTH13, CNRM-CM514 and GFDL-ESM2M15") to produce the future rainfall projections by using long observed historical rainfall data. Salloum and Sidi- Barrani site locations are used to investigate the models suitability. Comparisons were made on the basis of a thirty-year retrospective (1975-2005). The result confirmed by examine the best fitting model to reproduce the projection of rainfall at intermediate and extreme scenarios "RCP 4.5 and 8.5 watt/m^2" with ground observation during the model near future (2006:2018). The quantitative statistics of NSE, RSR, PCI, PBIAS, PDF, and CDF have been applied for model evaluation techniques as shown in many reviewed publications. It was clear that PCI analysis clarified that all models ranged between high and very high concentration. Meanwhile, the results for NSE, RSR values for Ec-earth model show that it is better than the other models, PDF is closest to the observed data and almost has the same behavior at low and high values of rainfall, so it is the best fitting model to reproduce the rainfall at this region. The CDF and PDF for future projection of Ec-earth model under RCP 4.5 and 8.5 watt/m^2 during near future confirm its goodness. Whereby it could be used to address the impact of climate change and draw the adaptation strategies at this region with enhancement of the source of model data sources and fine tuning the horizontal resolution.

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