Original Research Article

Suitability of Representative Concentration Pathway Climate Change Scenarios to Project weather elements in the Agro-climatic Zones of Egypt

ABSTRACT

The objective of this study was to compare between measured weather data (2010-2019) and projected data for the same period obtained from three global climate models (HadGEM2-ES, CSIRO-Mk3-6-0, and MIROC5), with its four RCPs scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) developed for the five agro climatic zones of Egypt and determine the most suitable scenario to be used in each agro-climatic zone for projection of the effect of climate change in the future on the agro-climatic zones of Egypt. Our results revealed that the four climate change scenarios developed from the three models show high level of suitability in the projection of the three studied weather elements. Climate change scenario RCP6.0 and RCP8.5 developed by HadGEM2-ES and CSIRO-Mk3-6-0 attained the highest agreement between measured and projected values of the studied weather elements. Whereas, climate change scenario RCP2.6, RCP6.0 and RCP8.5 developed by MIROC5 attained the highest agreement between measured and projected values of the studied weather elements. Thus, we recommend the use these models in the projection of the effect of climate change in the future in the agro-climatic zones of Egypt.

Keywords: HadGEM2-ES;, CSIRO-Mk3-6-0;, MIROC5;, RCP2.6;, RCP4.5;, RCP6.0;, RCP8.5;, agro climatic zone.

1. INTRODUCTION

Uncertainty in climate information form limitations in our ability to model climate system, as well as in our understanding of how future greenhouse gas emissions will change [1]. This situation due to the impacts of climate change on the environment and society will depend not only on the response of the Earth system but also on how humankind responds through changes in technology, economy, lifestyle and policy, which are uncertain [2]. Climate projections are based on a variety of scenarios, models and simulations procedures, which contain a number of embedded assumptions. [3] Noted that the level of certainty associated with climate change and impact projections is a key in determining the extent to which such information can be used to formulate appropriate adaptation responses. Nevertheless, [4] indicated that global climate models are probably the only way to investigate the non-linear interactions between the four major components of the climate system: atmosphere, biosphere, oceans and sea-ice. These models that describe global climate are mathematical

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representations of physical and dynamical processes to simulate the interaction within and in between the atmosphere, land surface, oceans and sea ice [4].

The new global climate change models for new projection, mitigation and adaptation scenarios involving policy decisions and options for targeted climate change stabilization at different levels [5]. These models were developed during the IPCC Fifth Assessment report (AR5) of the Intergovernmental Panel on Climate Change [6]. Its findings were based on a new set of scenarios that replace SRES scenarios [7]. A scenario is a description of potential future conditions produced to inform decision-making under uncertainty [5]. Scenarios are descriptions of different possible futures, a series of alternative visions of futures (storylines) which are possible, plausible, and internally consistent but none of which is necessarily probable [8]. The efforts included in the Fifth Assessment report (AR5) of the Intergovernmental Panel on Climate Change in 2013 are enormous, with a larger number of more complex models run at higher resolution, with more complete representations of external forcings, more types of scenario and more diagnostics stored [9].

Starting from the early 2000s, most of climate change studies in Egypt to assess the effect of climate change on crops [10; 11; 12; 13] and on its water requirements [14] have been done using the IPCC climate change scenarios published in 2001 and 2007. In 2011, IPCC scenarios published in Fourth Assessment report (AR4) were used to project productivity of cotton in salt affected soil [15], to project productivity of cultivated crops under rain fed area in Egypt [16], to project water requirements for four economically important crops in Egypt [17]. An ensemble AR4 model for North Nile Delta was published by [18] to lower uncertainty in evapotranspiration projection under climate change.

The climate change scenarios released by four models from the Fifth Assessment report (AR5) were used by [19] in a simulation model to project wheat and maize productivity in 2030 in nine governorates in Egypt and to develop the most suitable adaptation strategies under climate change conditions in these governorates. Similarly, [20] compared between measured weather data and projected data (2006-2014) from four global climate models, with its four Representative Concentration Pathways scenarios (RCPs) to determine the suitable climate change scenario in 2030. They recommended the use the RCP6.0 scenario developed by CCSM4 model as it was found to be suitable scenario for Egypt.

Furthermore, [21] used RCP6.0 climate change scenario resulted from MIROC5 climate change model to quantify how climate change will affect the value of Kc and water consumptive use of 14 field crops, 7 fruit crops and 13 vegetable crops in the five agro-climatic zones of Egypt in 2030 in Egypt.

In the light of warming phenomena that was prevailing lately in Egypt, a need was arisen to define the agro-climatic zones in Egypt to facilitate water management. Therefore, [22] studied trends of mean evapotranspiration (ETo) values calculated from 30-year interval (1986-2015), and compared it with the mean value of 20-year time interval (1996-2015) and the 10-year interval (2006-2015) in an attempt to define agro-climatic zones responded to the warming. They found that the highest mean values of ETo was the calculated mean in the 10-year interval (2006-2015) and they use it to define the five agro-climatic zones of Egypt.

Thus, the objective of this work was to compare between measured weather data (2010-2019) and projected data for the same period obtained from three global climate models (HadGEM2-ES, CSIRO-Mk3-6-0, and MIROC5), with its four RCPs scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) developed for the five agro-climatic zones of Egypt and determine the most suitable scenario to be used in each agro-climatic zone for the projection of the effect of climate change in the future on the agro-climatic zones of Egypt.

2. MATERIAL AND METHODS

Three climate change models were used in this study, namely HadGEM2-ES, CSIRO-Mk3-6-0, and MIROC5. The selection of models in this study was designed to include models with differing levels of sensitivity to Green House Gases (GHG) forcing.

2.1 HadGEM2-ES ~~m~~Model

HadGEM2-ES ESM is a coupled AOGCM with atmospheric resolution of N96 (1.875° X1.25°) with 38 vertical levels and an ocean resolution of 1° (increasing to 1/3° at the equator) and 40 vertical levels. HadGEM2-ES ESM also represents interactive land and ocean carbon cycles and dynamic vegetation with an option to prescribe either atmospheric CO2 concentrations or to prescribe anthropogenic CO2 emissions and simulate CO2 concentrations [23].

2.2 CSIRO-MK3.6.0 ~~m~~Model

The CSIRO-Mk3.6.0 model, hereafter called Mk3.6, is an upgrade from the CSIRO-Mk3.5 GCM [24]. The atmospheric component has a horizontal resolution of approximately 1.9° x 1.9° and every atmospheric grid-point is coupled to two ocean grid-points. This enhanced north-south resolution in the ocean component is expected to increase the capacity for the ocean to simulate important tropical and extra-tropical seasonal interactions [25].

2.3 MIROC5 ~~m~~Model

MIROC5 model has updated and newly-developed parameterizations in both of the atmospheric and oceanic components, including a cumulus convection scheme, a prognostic large-scale condensation scheme [26], a radiative transfer scheme [27], a land surface model [28].

2.4Climate ~~c~~Change ~~s~~Scenarios

The CMIP5 GCMs outputs provide four RCPs; these scenarios are RCP2.6, RCP4.5, RCP6.0 and RCP8.5, where the numbers refer to forcings for each RCP. The radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, measured in watts per square meter. Each RCP defines a specific emissions trajectory and subsequent radiative forcing. The scenarios are described as following:

2.4.1 RCP2.6

The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a "peak-and-decline" scenario; its radiative forcing level first reaches a value of around 3.1 W/m^2 by mid-century, and returns to 2.6 W/m^2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially over time [29].

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2.4.2RCP4.5

It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level [30].

2.4.3 RCP6.0

It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions [31].

2.4.4 RCP8.5

It is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels [32].

2.5 The agro-climatic ~~z~~Zones of Egypt

Ouda and Noreldin[22] ~~U~~used ~~ETo~~ values of reference evapotranspiration (ETo) for 10-year time period from 2005 to 2014 to develop agro-climatic zones for Egypt. In that methodology, monthly means of weather data for 10-year were calculated for each governorate. Analysis of variance was used and the means was separated and ranked using least significant difference test (LSD 0.05). Zoning using 10-year values of ETo resulted in five agro-climatic zones (Table 1).

Table ~~(~~1.~~)~~ Agro-climatic zones of Egypt as determined using 10-year values of ETo~~.~~

Zone number	Governorate	~~P~~ETo (mm/day)
Zone 1	Alexandria	4.28~~79~~
	Kafr El-Sheik	4.85~~2~~
Zone 2	Demiatte	5.12~~3~~
	El-Dakahlia	5.34~~4~~
	El-Behira	5.19~~2~~
	El-Gharbia	5.12~~5~~
Zone 3	El-Monofia	5.80~~0~~
	El-Sharkia	5.87~~69~~
	El-Kalubia	5.96~~4~~
	Giza	5.70~~1~~
	Fayom	5.59~~87~~
Zone 4	Beni Sweif	6.14~~39~~
	El-Minia	6.14~~0~~
	Assuit	6.12~~2~~
	Sohag	6.13~~27~~
Zone 5	Qena	6.48~~0~~
	Aswan	6.60~~0~~
Average		5.67~~3~~
Rang		2.32~~1~~
LSD0.05		0.217

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2.6 Comparison Procedure

The observed daily measured weather data in the five agro-climatic zones during the period from 2010 to 2019 were compared with the daily projected climate data from the studied three models. The goodness of fit between the measured and projected data was examined by calculating the following measurements:

2.6.1 Willmott Index of Agreement (d)

It is the standardized measure of the degree of model prediction error which varies between 0 and 1. A value of 1 indicates a perfect match, and value of 0 indicates no agreement at all [33].

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}[(|(S_i - \bar{O})| + |(O_i - \bar{O})|)^2]} \quad (1)$$

Where Oi, $\bar{O}$ and Si represent the observed, observed average and simulated values.

2.6.2 Root Mean Square Error per Observation (RMSE/obs)

It gives the general standard deviation of the model prediction error per observation [34].

$$RMSE/obs = \sqrt{\left(\frac{\sum_{i=1}^{n}(S_i - O_i)^2}{n}\right)} \quad (2)$$

Where, n represents the number of observed and simulated values used in comparison.
Depending on the above analysis, the suitable RCP scenario for each model can be determined.

3. RESULTS AND DISCUSSION

3.1 The First Agro-climatic Zone

The results in Table (2) indicated that the highest value of d-stat and the lowest value of RMSE/obs for solar radiation, maximum temperature and minimum temperature were obtained under RCP6.0 predicted by CSIRO-MK3.6.0 and HadGEM2-ES models. Whereas, RCP8.5 predicted by MIROC5 model attained the highest value of d-stat and the lowest value of RMSE/obs for these weather elements in the first agro-climatic zone. [20] indicated that the RCP6.0 developed by CCSM4 model and RCP8.5 and MIROC5 models were acceptable for to predict weather elements in governorates located in the first agro-climatic zone.

Table (2): Goodness of fit between measured and predicted weather data by three climate change models averaged from 2010-2019 in the first agro climatic zone.

	CSIRO-MK3.6.0											
	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
	SR	Mx	Mn	SR	Mx	Mn	SR	Mx	Mn	SR	Mx	Mn
d-stat	0.91	0.90	0.97	0.91	0.94	0.96	0.97	0.95	0.96	0.91	0.95	0.96
RMSE/obs	0.20	0.12	0.11	0.18	0.10	0.14	0.11	0.10	0.14	0.19	0.12	0.13
	HadGEM2-ES											
d-stat	0.91	0.95	0.97	0.90	0.95	0.97	0.97	0.96	0.97	0.91	0.90	0.97
RMSE/obs	0.19	0.14	0.12	0.19	0.10	0.11	0.18	0.09	0.10	0.18	0.13	0.13
	MIROC5											
d-stat	0.88	0.95	0.95	0.88	0.94	0.97	0.90	0.93	0.97	0.91	0.95	0.97
RMSE/obs	0.21	0.10	0.10	0.21	0.11	0.11	0.21	0.12	0.10	0.18	0.10	0.10

SR = solar radiation (MJ/m²/day),MX: maximum temperature *(°C)*; Mn: Minimum temperature *(°C)*.

3.2 The Second Agro-climatic Zone

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The results in Table (3) indicated that, in the second ago-climatic zone, the highest value of d-stat and the lowest value of RMSE/obs for solar radiation, maximum temperature and minimum temperature were obtained under RCP6.0 predicted by CSIRO-MK3.6.0 model. Furthermore, the projection of HadGEM2-ES and MIROC5 models showed that the highest value of d-stat and the lowest value of RMSE/obs for the three weather elements were obtained under RCP8.5. [20] reported that the suitable scenarios some of the governorates located in the second agro-climatic zone was RCP6.0 developed by CCSM4 model and RCP8.5 developed by MIROC5 model.

Table (3): Goodness of fit between measured and predicted weather data by three climate change models averaged from 2010-2019 in the second agro-climatic zone.

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	CSIRO-MK3.6.0											
	RCP2.6			**RCP4.5**			**RCP6.0**			**RCP8.5**		
	SR	**Mx**	**Mn**	**SR**	**Mx**	**Mn**	**SR**	**Mx**	**Mn**	**SR**	**Mx**	**Mn**
d-stat	0.96	0.97	0.84	0.96	0.97	0.83	0.97	0.98	0.95	0.96	0.99	0.84
RMSE/obs	0.13	0.03	0.26	0.13	0.05	0.26	0.11	0.04	0.10	0.23	0.04	0.26
	HadGEM2-ES											
d-stat	0.96	0.99	0.85	0.96	0.99	0.84	0.86	0.98	0.86	0.96	0.99	0.87
RMSE/obs	0.13	0.03	0.25	0.13	0.03	0.25	0.17	0.06	0.23	0.13	0.03	0.23
	MIROC5											
d-stat	0.95	0.99	0.85	0.96	0.99	0.86	0.96	0.99	0.85	0.97	0.99	0.86
RMSE/obs	0.14	0.05	0.24	0.13	0.05	0.24	0.13	0.05	0.25	0.12	0.03	0.24

SR = solar radiation (MJ/m^2/day),MX: maximum temperature *(°C)*; Mn: Minimum temperature *(°C)*.

3.3 The ~~t~~Third ~~a~~Agro-climatic ~~z~~Zone

Average measured and predicted weather data by CSIRO-MK3.6.0 model in the third agro-climatic zone, Table (4) showed that the highest value of d-stat and the lowest value of RMSE/obs for solar radiation, maximum temperature and minimum temperature were obtained under RCP8.5 predicted by CSIRO-MK3.6.0 and HadGEM2-ES models. Whereas, the projection of RCP2.6 climate change scenario resulted from MIROC5 model attained the highest value of d-stat and the lowest value of RMSE/obs for these weather elements.

Table (4): Goodness of fit between measured and predicted weather data by three climate change models averaged from 2010-2019 in the third agro-climatic zones.

	CSIRO-MK3.6.0											
	RCP2.6			**RCP4.5**			**RCP6.0**			**RCP8.5**		
	SR	**Mx**	**Mn**	**SR**	**Mx**	**Mn**	**SR**	**Mx**	**Mn**	**SR**	**Mx**	**Mn**
d-stat	0.76	0.97	0.92	0.82	0.98	0.93	0.71	0.95	0.88	0.83	0.98	0.93
RMSE/obs	0.32	0.08	0.19	0.27	0.06	0.18	0.32	0.10	0.23	0.27	0.05	0.19
	HadGEM2-ES											
d-stat	0.84	0.98	0.92	0.84	0.99	0.92	0.78	0.96	0.92	0.85	0.98	0.93
RMSE/obs	0.26	0.06	0.19	0.26	0.06	0.19	0.27	0.08	0.19	0.25	0.05	0.18
	MIROC5											
d-stat	0.84	0.98	0.93	0.83	0.97	0.92	0.74	0.94	0.91	0.79	0.98	0.92
RMSE/obs	0.29	0.06	0.18	0.27	0.06	0.19	0.30	0.10	0.20	0.30	0.07	0.19

SR = solar radiation (MJ/m^2/day),MX: maximum temperature *(°C)*; Mn: Minimum temperature *(°C)*.

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3.4 The ~~f~~Fourth ~~a~~Agro-climatic ~~z~~Zone

The highest value of d-stat and the lowest value of RMSE/obs for solar radiation, maximum temperature and minimum temperature in the fourth agro-climatic zone were obtained for RCP8.5 predicted by CSIRO-MK3.6.0 model. Furthermore, the projection of

HadGEM2-ES model showed that the highest value of d-stat and the lowest value of RMSE/obs for the three weather elements were obtained under RCP6.0. Whereas, the projection of climate change scenario RCP2.6 resulted from MIROC5 model attained the highest value of d-stat and the lowest value of RMSE/obs for these weather elements (Table 5). [20] Reported RCP8.5 and RCP6.0 scenarios developed by CCSM4 model were found suitable for some governorates located in the fourth agro-climatic zone.

Table (5): Goodness of fit between measured and predicted weather data by three climate change models averaged from 2010-2019 in the fourth agro climatic zones.

	CSIRO-MK3.6.0											
	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
	SR	Mx	Mn	SR	Mx	Mn	SR	Mx	Mn	SR	Mx	Mn
d-stat	0.57	0.97	0.87	0.62	0.98	0.90	0.51	0.97	0.92	0.64	0.98	0.93
RMSE/obs	0.63	0.09	0.25	0.56	0.07	0.23	0.60	0.05	0.21	0.55	0.05	0.20
	HadGEM2-ES											
d-stat	0.61	0.98	0.89	0.57	0.98	0.98	0.62	0.98	0.99	0.57	0.86	0.98
RMSE/obs	0.39	0.07	0.23	0.39	0.06	0.13	0.38	0.06	0.12	0.41	0.26	0.13
	MIROC5											
d-stat	0.62	0.98	0.89	0.51	0.98	0.88	0.55	0.96	0.92	0.59	0.98	0.86
RMSE/obs	0.38	0.06	0.24	0.39	0.07	0.24	0.42	0.09	0.21	0.40	0.06	0.26

SR = solar radiation (MJ/m^2/day),MX: maximum temperature *(°C)*; Mn: Minimum temperature *(°C)*.

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3.5 The ~~f~~Fifth ~~a~~Agro-climatic ~~z~~Zone

The results in Table (6) indicated that highest value of d-stat and the lowest value of RMSE/obs for solar radiation, maximum temperature and minimum temperature were obtained under RCP6.0 predicted by CSIRO-MK3.6.0 and MIROC5 models. Furthermore, the projection of HadGEM2-ES model showed that the highest value of d-stat and the lowest value of RMSE/obs for the three weather elements were obtained under RCP8.5 for the three studied weather elements in the fifth agro-climatic zone.

Table (6): Goodness of fit between measured and predicted weather data by three climate change models averaged from 2010-2019 in the fifth agro climatic zones.

	CSIRO-MK3.6.0											
	RCP2.6			**RCP4.5**			**RCP6.0**			**RCP8.5**		
	SR	**Mx**	**Mn**	**SR**	**Mx**	**Mn**	**SR**	**Mx**	**Mn**	**SR**	**Mx**	**Mn**
d-stat	0.69	0.97	0.94	0.63	0.97	0.93	0.70	0.98	0.92	0.66	0.96	0.94
RMSE/obs	0.32	0.07	0.17	0.34	0.07	0.12	0.30	0.06	0.11	0.30	0.09	0.12
	HadGEM2-ES											
d-stat	0.69	0.97	0.94	0.70	0.98	0.93	0.68	0.98	0.93	0.72	0.98	0.94
RMSE/obs	0.31	0.07	0.17	0.31	0.07	0.18	0.32	0.07	0.17	0.30	0.07	0.16
	MIROC5											
d-stat	0.70	0.97	0.92	0.69	0.97	0.92	0.69	0.98	0.93	0.69	0.97	0.92
RMSE/obs	0.33	0.09	0.20	0.32	0.08	0.18	0.32	0.07	0.17	0.32	0.08	0.18

SR = solar radiation (MJ/m^2/day),MX: maximum temperature *(°C)*; Mn: Minimum temperature *(°C)*.

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3.6 Determination of the ~~s~~Suitable RCP of the ~~s~~Studied ~~c~~Climate ~~m~~Models in the ~~f~~Five ~~a~~Agro-climatic ~~z~~Zones in Egypt.

The above analysis defined one scenario obtained from the studied climate change models for each agro-climatic zone that could be recommended to be used. Table (7) indicated that the suitable scenarios for most zones were RCP6.0 and RCP8.5 resulted from CSIRO-MK3.6.0 and HadGEM2-ES models. Whereas, the RCP8.5, RCP2.6 and RCP6.0 resulted from MIROC5 model were the suitable scenarios for most agro-climatic zones.

Table (7): The suitable RCP scenarios resulted from the studied climate models in the five agro-climatic zones in Egypt.

Zones	CSIRO-MK3.6.0	HadGEM2-ES	MIROC5
Zone 1	RCP6.0	RCP6.0	RCP8.5
Zone 2	RCP6.0	RCP8.5	RCP8.5
Zone 3	RCP8.5	RCP8.5	RCP2.6
Zone 4	RCP8.5	RCP6.0	RCP2.6
Zone 5	RCP6.0	RCP8.5	RCP6.0

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4. CONCLUSION

In this study, we compared between measured solar radiation, maximum temperature and minimum temperature in the period from 2010-2019 and projected data for the same period obtained from three global climate models, namely HadGEM2-ES, CSIRO-Mk3-6-0, and MIROC5 differing in the levels of sensitivity to Green House Gases forcing with its four RCPs scenarios, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5 developed for the five agro-climatic zones of Egypt to determine the most suitable scenario to be used in each agro-climatic zone for irrigation determination purposes. Our results revealed that the four climate change scenarios developed from the three models show high level of suitability in the projection of the three studied weather elements. Climate change scenario RCP6.0 and RCP8.5 developed by HadGEM2-ES and CSIRO-Mk3-6-0 attained the highest agreement between measured and projected values of the studied weather elements. Whereas, climate change scenario RCP2.6, RCP6.0 and RCP8.5 developed by MIROC5 attained the highest agreement between measured and projected values of the studied weather elements. Thus, we recommend the use these models in the projection of the effect of climate change in the future on the agro-climatic zones of Egypt.

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