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Enhancing the accuracy of future projections for Sea-Level Rise by utilizing the ensemble of Global Circulation Models in the Egyptian Red Sea coastal regions

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Abstract: Concerning global warming, sea level rise is one of the most critical problems. Therefore, it is necessary to find reliable projections for estimating coastal flooding to help manage coastlines more effectively, as the future implications of climate change are uncertain. So, according to the Intergovernmental Panel on Climate Change (IPCC) reports, the rise in sea level poses a significant problem in many coastal areas; hence, studying flooding of low-lying lands along coasts has become a crucial issue and a matter of urgency for countries such as Egypt, which is highly vulnerable to Sea-Level Rise (SLR), raising the temperature and reducing precipitation due to climatic changes. According to IPCC's Fifth Assessment Report (AR5), Sea levels will increase by 2100, 78 cm, and up to 100 cm by the end of this century. However, their magnitude remains indefinite. This study establishes limits on the level of uncertainty in sea-level rise variability. The uncertainty is derived from the analysis of future projections using twenty-eight (28) Global Circulation Models (GCMs) on an annual basis. This study focuses specifically on the coastal zones along the Egyptian Red Sea, from Suez to Hurghada. Based on AR5, four Representative Concentration Pathways (RCP) scenarios were considered until 2100. It was found that there are ranges of possible rises in sea level concerning some models projecting very few centimeters while others go beyond a meter. Using optimal GCM ensembles significantly reduces the uncertainty about predicted values on SLR. Moreover, these results indicate that under each scenario, RCPs 2.6, 4.5, 6, and 8.5, the sea level will increase by 60.5 cm, 71 cm, 77 cm, and 104 cm, respectively.

Keywords: GCMs, RCPs, uncertainty, SLR, Red Sea

1. INTRODUCTION

Over the past 50 years, global awareness and concern over climate change have increased, leading to extensive research and countermeasures. Several Countries identified as more susceptible to climate change face immediate and long-term consequences. with extreme weather conditions deeply affecting the planet, particularly in coastal zones. The dangers of climate change are significant, but the actual impact is far more complex and varied [11]. About this matter, there is a definite differentiation between natural climatic occurrences and those that are caused by the release of greenhouse gases, such as nitrogen oxide, carbon dioxide, chlorofluorocarbons (CFCs), and methane, which are a result of human activities and the excessive utilization of fossil fuels in transportation and industry [4]. According to the Intergovernmental Panel on Climate Change IPCC [9], coastal communities will experience significant impacts as a result of rising sea levels. Sea levels were generally stable for at least three thousand years. However, in the 20th century alone, there was a global increase in sea levels at an average of 1.7 mm per year [25]. According to [16], Alternatively, additional factors contributing to these changes include tectonic shifts caused by coastal subsidence or uplifting, sediment compaction, alterations resulting from the loading or unloading of ice sheets, as well as variations in ocean circulation and wind patterns [2]. Various factors have contributed to the recent phenomenon of global warming on our planet, which is seeing an increase in temperature. The primary factors contributing to global sea level rise are predominantly thermal expansion, the deterioration of mountain glaciers and minor ice caps, the melting of the Greenland Ice Sheet, and the melting of the Antarctic Ice Sheet. This phenomenon is rooted in the observation that the temperature of saltwater rises as its volume expands. The extent of sea level rise is determined by the location of warming about the average warming of the ocean. The greatest increase in sea level will occur if warming is focused in these areas [13]. According to report [10], global sea levels rose by approximately seven inches during the last century because of the world's melting ice and heated water. This rise will not happen uniformly worldwide due to changes in how waves move near coastlines, shifts in where land sits up or down relative to the ocean surface, and differences in storm patterns over oceans. The most at-risk regions are low-lying deltas and estuaries [6] stated that the global community is currently facing the repercussions of increasing sea levels, resulting in the displacement of millions of individuals residing in coastal areas with low lying lands and small island states. Climate refugees face not just economic hardships but also health issues. Due to disruptions in food and water supplies, flooding becomes more common which increases the risk for waterborne diseases as well as malnutrition. The result is significant damage to infrastructure, homes and businesses from coastal flooding and storm surges leading to high repair costs and insurance claims [17].

Moreover, economic slumps occur in affected areas where properties depreciate in high-risk flood zones. As a consequence, many species have lost habitats and it has been noticed a decrease in biodiversity due to the destruction of mangroves, coral reefs, salt marshes among others that define coastlines. [8] Additionally, drinking water supplies and agricultural lands get contaminated by saltwater intrusion into freshwater systems which further worsen the whole matter by reducing availability of fresh water for irrigation purposes that results into soil degradation. The destructive ripple effects of rising sea levels are seen in all aspects of life ranging from environment through economy upwards as shown in Fig .1.

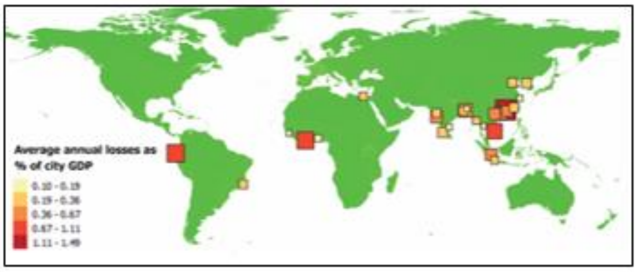

FIG1. average annual Losses in developing countries with at least 0.1 GDB in 2050 under RCP8.5 of 40 cm of SLR [7]

Some studies have examined possible future scenarios for coastal flooding under rising seas, but many knowledge gaps remain regarding these projections. First, there is uncertainty on how best to model them given their complex nature involving multiple interacting processes occurring across various temporal scales. Second, they often rely upon assumptions that may compromise quality outputs, especially when dealing with small spatial extents like beaches. Thirdly, how to consider the optimal protection strategy for coastal areas faced with increasing amounts of inundation from higher tides over time [1], SLR cannot be ignored as a severe threat because its inherent uncertainties make it difficult to allocate financial resources efficiently to adapt to this phenomenon so, to account for climate change uncertainties, the IPCC AR6 uses the CMIP6 sixth assessment report, which comes with different scenarios representing a range of possible futures based on Green House Gases emissions [14]. These scenarios are designed to illustrate the indeterminacy of future human behavior rather than make predictions since no probabilities are assigned to any scenario. The range of possible futures for GHG emissions is broad in these scenarios. They begin with a situation where CO2 emissions decline quickly enough to achieve carbon neutrality by 2050 and go negative before the close of this century but also include another that shows them rising steadily until 2050 at double today's rates [18] see Fig. 2.

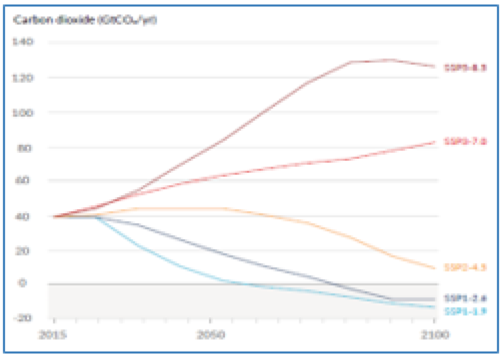

FIG 2. the Projected levels of carbon dioxide (CO2) emissions in the five hypothetical situations

Among these scenarios (Shared Socioeconomic Pathways1-2.6, Shared Socioeconomic Pathways 2-4.5, Shared

Socioeconomic Pathways 3-7.0, and Shared Socioeconomic Pathways 5-8.5), there are experiments of tier 1. These are shared socioeconomic pathways (SSPs) representing a set of climate policies in combination with projected greenhouse gas emission levels [19]. The continuity is established by radiative forcing that is similar between Coupled Model Intercomparison Project Phase 5 (CMIP5) Representative Concentration Pathways (RCPs) with SSP1-2.6, SSP2-4.5 and SSP5-8.5 being the same as RCPs in CMIP5. Furthermore, among other things, such as unmitigated baseline scenarios, the ‘gap scenarios’ are included in this scenario called SSP3-7.0. They give essential future projections about different forcing pathways, providing broader uncertainties. Tier 1 experiments also allow comparing data from previous studies with new ones [23]. Predictions for this century’s sea level rise from all sources can be as low as one meter [5] or exceed one meter [3] depending on the models used and the climate scenarios considered. The latest potential results obtained by the Physical Science Working Group I IPCC Assessment (AR6) expressed that the global mean sea level could rise by 2m in 2100 and 5m by 2150 “cannot be ruled out due to deep uncertainty in ice sheet processes” [12]. A good description of this issue would assume a rise of around one meter by the end of the century, but given model uncertainties and anticipated warming over coming decades higher estimates cannot be excluded. Many regions of the Egyptian coast face threats from natural and human activities, including geological subsidence, meteorological phenomena, and human actions [20]. These hazards can be categorized into short-term risks like storms and swells, and long-term risks like climate change effects, sea level rise, and damming of rivers. Areas are ranked based on their vulnerability to rising seas and extreme events, including surface elevation, subsidence rates, erosion rates, net sea level rise, permeability, and active/deep torrential rain spillways [24].

This study seeks to determine the maximum range of sea level increase resulting from changes in sensitivity analysis for twenty-eight General Circulation Models (GCMs) by the year 2100, using annual future projections considering four different Representative Concentration Pathways (RCPs) scenarios in the study area. Additionally, the study explains and discusses the certainty of why and how sea-level based (GCMs) under (RCPs) scenarios are developed and supported the sustainable development in the study area

DATA ACCUSATION

1.1 SITE DESCRIPTION

This study will be conducted along the Egyptian Red Sea Coastal zone from Suez to Hurghada, as indicated in Fig.3, as this region is crucial from an economic, industrial, social, and cultural development point of view. It also faces increasing temperatures, reduced rainfall, extreme events, and sea level fluctuations, making it vulnerable due to its coastlines. To mitigate threats posed by global warming towards marine life, policy formulation aimed at reducing risks and responding to submerging regions is necessary. Many researches have been conducted on rising sea levels along the Mediterranean coast. However, few have been done along the Red Sea, particularly along from Suez up to Hurghada. As this region is considered important due to its capital investments driven by the tourism industry and four major ports: Ain Sokhna, Safaga, Abu Ghosoun, and Suez.

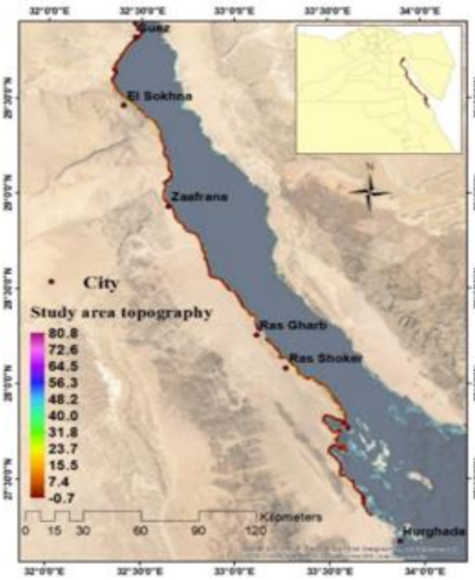

FIG 3. Study area location along the Red Sea

Using a regional climate model (RCM) as opposed to global climate models (GCM) clearly provides better resolution of the future patterns of climate change. Global climate model (GCM) outputs may have insufficient spatial resolution for accurate regional or local adaptation in some conditions. Furthermore, GCMs may lack the ability to accurately depict the climate of a particular location So to gain deeper insights into the climate patterns within the specified study region, Simclim's 27 regional circulation models (RCMs) [21] , *AFR-CanESM2-CRCM5, AFR-CanESM2-RCA4, AFR-CNRM-CM5-CCLM4-8-17, AFR-CNRM-CM5-RCA4, AFR-CSIRO-Mk3-6-0-RCA4, AFR-EC-EARTH-CCLM4-8-17, AFR-EC-EARTH-HIRHAM5, AFR-EC-EARTH-RACMO22T, AFR-EC-EARTH-RCA4, AFR-EC-EARTH-REMO2009, AFR-GFDL-ESM2M-RCA4, AFR-HADGEM2-ES-CCLM4-8-17, AFR-HADGEM2-ES-RCA4, AFR-IPSL-CM5A-LR-REMO2009, AFR-IPSL-CM5A-MR-RCA4, AFR-MIROC5-RCA4, AFR-MPI_ESM-LR-CRCM5, AFR-MPI-ESM-LR-CCLM4-8-17, AFR-MPI-ESM-LR-RCA4, AFR-MPI-ESM-LR-REMO2009, AFR-NorESM1-M-HIRHAM5, AFR-NORESM1-M-RCA4, MNA-22-EC-EARTH-RCA4, MNA-22-GFDL-ESM2M-RCA4, MNA-44-CNRM-CM5-RCA4, MNA-44-EC-EARTH-RCA4, MNA-44-GFDL-ESM2M-RCA4,* were utilized to provide an accurate projections of minimum (min) and maximum (max) temperature with high-resolution grid of 1 × 1 km through statistical downscaling techniques, the ensemble of 27 RCMs extending at 2100 were compiled adhere to the Representative Concentration Pathway (RCP) 4.5 (Optimistic Scenario), 8.5 (Pessimistic Scenario) as shown in table.1.

TABLE 1.Description of (RCPs) by (IPCC) at 2100

RCP 2.6	***RCP 4.5***	***RCP 6***	***RCP8.5***
Peak in radiative forcing at ≈ 3W/m^2 before 2100 and decline	Stabilization without overshoot pathway to 4.5 W/m^2 at 2100	Stabilization without overshoot pathway to 6 W/m^2 at 2100	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100

it can be inferred that, by 2100 the maximum temperature is projected to rise by around 2^{O}C during winter and by about 3^O C during summer, for RCP4.5 scenarios. In addition, the maximum temperature is projected to rise by approximately 4^{O}C during winter and by approximately 6^O C during summer for RCP 8.5scenario. In addition, the minimum temperature is projected to rise by around 1.5^{O}C during winter and by almost 2^O C during summer under the RCP4.5 scenario. In addition, the minimum temperature is projected to rise by around 2.5^O C during winter and by roughly 4.5^{O}C during summer under the RCP8.5 scenarios according to technical reports by Environmental and Climate Change Research Institute (ECRI), National Water Research Center (NWRC).

GLOBAL CIRCULATION MODELS SENSITIVITY

Because of the oceans warming and the melting of glaciers and ice sheets, during the 21st century, the global mean sea level rise could exceed under all RCPs scenarios what was observed between 1971 and 2010 which considered the rise would be (2mm yr-1). The temporal evaluation of Global Mean Sea Level (GMSL) from the AR5 projections could rise between 0.28m and 0.98m by 2100, furthermore, it is possible to suggest an upper limit for GMSL between 1.4 m and 1.6 m by the year 2100.These projections are higher than those reported in AR4 which projected a range of 0.18m to 0.59m by the end of 21st century [11]. Improved representation of land ice contributions has led to more significant projected increases in sea levels. For 1986-2005 compared with 2081-2100, three key processes are believed to dominate worldwide SLR according to [21], changes in glacier and ice-sheet meltwater input, thermal expansion of water bodies due to higher temperatures and, altered terrestrial storage caused by variations in rainfall patterns across river basins.

In order to explore the influence of (GCMs) on Future Sea-Level Rise Predictions in the study area as it simulates the warming of the global oceans, which leads to thermal expansion and contributes significantly to SLR. This process requires a global perspective, 28 GCMs, as shown in Table.2, under four different RCPs, were simulated to predict valuable values of the increased levels of sea water, which in turn helps to enhance the accuracy of the predictions for strategic planning and adaptation efforts in the face of climate change.

TABLE 2. Global Circulations Models (SimClim 4xessentials manual, 2018)

No	Model Name	Country	Spatial resolution for atmospheric variable (longitude*latitude)	Spatial resolution for ocean variable (longitude*latitude)
1	ACCESS1-0	Australia	192*145	360*300
2	ACCESS1-3	Australia	192*145	360*300
3	BCC-CSM1-1	China	128*64	360*232
4	BCC-CSM1-1-M	China	320*160	360*232
5	CanESM2	Canada	128*64	256*192
6	CCSM4	USA	288*192	320*384
7	CMCC-CM	Italy	480*240	182*149
8	CMCC-CMS	Italy	192*96	182*149
9	CNRM-CM5	France	256*128	362*292
10	CSIRO-MK3-6-0	Australia	192*96	192*189
11	GFDL-CM3	USA	144*90	360*200
12	GFDL-ESM2G	USA	144*90	360*210
13	GFDL-ESM2M	USA	144*90	360*200
14	GISS-E2-R	USA	144*90	288*180
15	GISS-E2-R-CC	USA	144*90	288*180
16	HADGEM2-CC	UK	192*145	360*216
17	HADGEM2-ES	UK	192*145	360*216
18	INMCM4	Russia	180*120	360*340
19	IPSL-CM5A-LR	France	96*96	182*149
20	IPSL-CM5A-MR	France	96*96	182*149
21	MIROC-ESM	Japan	128*64	256*192
22	MIROC-ESM-CHEM	Japan	128*64	256*192
23	MIROC5	Japan	256*128	256*224
24	MPI-ESM-LR	Germany	192*96	256*220
25	MPI-ESM-MR	Norway	192*96	802*404
26	MRI-CGCM3	Japan	320*160	360*368
27	NorESM1-M	Norway	144*96	320*384
28	NorESM1-ME	Norway	144*96	320*384

depending on the climatic variables, each GCM possesses a different set of data. Table.3 provides a convenient summary of the GCM variables' availability. These variables are SolRad, or solar radiation; Temp, or temperature (including mean, minimum, and maximum); Precip, or precipitation; RelHum, or relative humidity; Wind, or wind speed; and SLR, or sea level rise.

TABLE 3.Availability of climatic data by each GCM

	Model	***Temp***	***Precip***	***SolRad***	***RelHum***	***Wind***	***SLR***
1	ACCESS1.3	Yes	Yes	Yes	Yes	Yes	Yes
2	ACCESS1.0	Yes	Yes	Yes	Yes	Yes	Yes
3	BCC-CSM1-1	Yes	Yes	Yes	Yes	Yes	Yes
4	BCC-CSM1-1-m	Yes	Yes	Yes	Yes		Yes
5	CanESM2	Yes	Yes	Yes	Yes	Yes	Yes
6	CCSM4	Yes	Yes	Yes	Yes	Yes	Yes
7	CMCC-CM	Yes	Yes	Yes	Yes	Yes	Yes
8	CMCC-CMS	Yes	Yes	Yes	Yes	Yes	Yes
9	CNRM-CM5	Yes	Yes	Yes	Yes	Yes	Yes
10	CSIRO-Mk3-6-0	Yes	Yes	Yes	Yes	Yes	Yes
11	GFDL-CM3	Yes	Yes	Yes	Yes	Yes	Yes
12	GFDL-ESM2G	Yes	Yes	Yes	Yes	Yes	Yes
13	GFDL-ESM2M	Yes	Yes	Yes	Yes	Yes	Yes
14	GISS-E2-R	Yes	Yes	Yes	Yes	Yes	Yes
15	GISS-E2-R-CC	Yes	Yes	Yes	Yes	Yes	Yes
16	HadGEM2-CC	Yes	Yes	Yes	Yes	Yes	Yes
17	HadGEM2-ES	Yes	Yes	Yes	Yes	Yes	Yes
18	INMCM4	Yes	Yes	Yes	Yes	Yes	Yes
19	IPSL-CM5A-LR	Yes	Yes	Yes	Yes	Yes	Yes
20	IPSL-CM5A-MR	Yes	Yes	Yes	Yes	Yes	Yes
21	MIROC5	Yes	Yes	Yes	Yes	Yes	Yes
22	MIROC-ESM	Yes	Yes	Yes	Yes	Yes	Yes
23	MIROC-ESM-CHEM	Yes	Yes	Yes	Yes	Yes	Yes
24	MPI-ESM-LR	Yes	Yes	Yes	Yes	Yes	Yes
25	MPI-ESM-MR	Yes	Yes	Yes	Yes	Yes	Yes
26	MRI-CGCM3	Yes	Yes	Yes	Yes	Yes	Yes
27	NorESM1-M	Yes	Yes	Yes	Yes		Yes
28	NorESM1-ME	Yes	Yes	Yes			Yes

The pattern scaling approach has been used to process these models' outputs. Pattern-scaling functions more like a data compression approach than other downscaling techniques. It could be explained as follows as shown in equation (1). Climate parameter *V*, for a specific grid cell (*i*), month (*j*) and year or time period (*y*) inside (RCP) 4.5.

$$\Delta V^{*}_{yij} = \Delta T . \Delta V_{ij}' \quad (1)$$

ΔT the annual variation of the Global mean temperature

$$\Delta V_{ij}' = \frac{\sum_{y=1}^{m} \Delta T_y \cdot \Delta V_{yij}}{\sum_{y=1}^{m} (\Delta T_y)^2} \quad (2)$$

$\Delta V_{ij}'$ GCM simulation anomaly usage to compute the value of the local change pattern

ΔV_{yij} applying regression with linear least squares

The input data were subsequently resampled to a precise resolution of 25×25 km using a bilinear interpolation technique. This method estimates a new pixel value by calculating the weighted average of the four closest pixel values based on their distances. The four cell centers of the input raster that are nearest to each processing cell center of the output will be assigned weights depending on their distance and then averaged. This decision was made due to the high computational efficiency of the method, as stated in

[21]. The method specifically adheres to the guidelines set by the Intergovernmental Panel on Climate Change (IPCC).

DATA ANALYSIS AND RESULTS

3.1 CLIMATE SENSITIVITIES

The estimation of (SLR) can be determined solely by thermal expansion, taking into account three different Climate Sensitivities. These sensitivities, representing various aspects of the climatic systems, which categorized as Low, Medium, and High. The scientific community has reached a consensus that there is a 90% probability that the true sensitivity falls within the range of one and half °C to six °C. As a result, the Medium Sensitivity is focused on three °C, the Low on two °C, and the High on 4.5four and half °C, as outlined in the [21]. These sensitivities will be shown in Fig .4, below according to different RCPs.

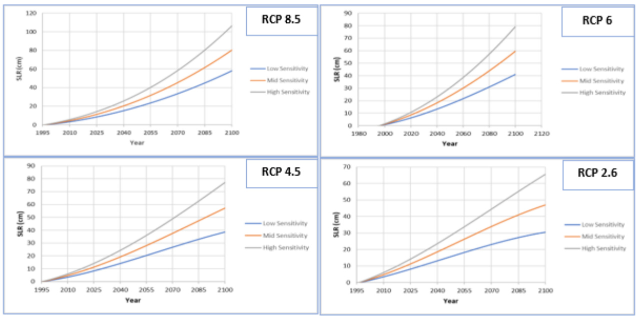

FIG 4. SLR values according to the Climate Sensitivities for different RCPs

This investigation aims to predict the rise in sea levels in the particular study area by the high sensitivity to sea-level changes. Graphical representations of these values will be provided through Fig .5.

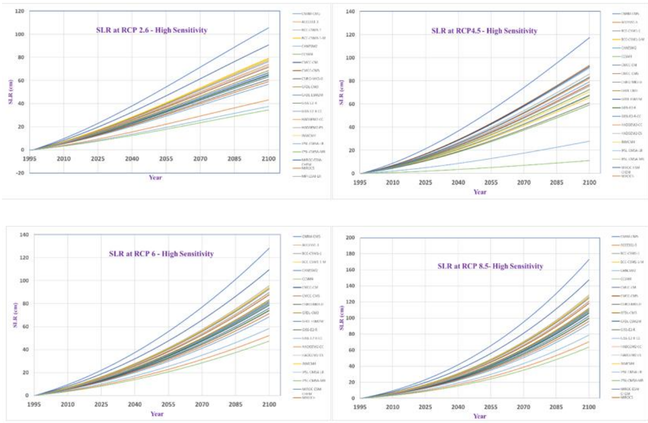

FIG 5. High Sensitivity-SLR values at 2100 due to 28 GCMs for different RCPs

Based on data presented in Table. 4, Extracted (IPCC-AR5), which sheds light on the potential impacts of climate change and the importance of using accurate and reliable GCMs in predicting future sea level rise. Researchers have identified the most effective Global Climate Models (GCMs) to predict variations in mean sea level rise, these models show that under different RCPs - 2.6, 4.5, 6, and 8.5 - the projected sea level rise will range from 0.28 to 0.61 meters, 0.36 to 0.71 meters, 0.38 to 0.73 meters, and 0.52 to 0.98 meters, respectively.

TABLE 4. Sea level rise ranges according to IPCC, AR5 through different RCPs

(RCP)	Emission scenario	Mean SLR (m)		Future Mean SLR (m)		
		2046-2065	2100	2200	2300	2500
2.6	Low	0.24 (0.17-0.32)	0.44 (0.28-0.61)			
4.5	Medium Low	0.26 (0.19-0.33)	0.53 (0.36-0.71)	0.35-0.72	0.41-0.85	0.5-1.02
6.0	Medium High	0.25 (0.18-0.32)	0.55 (0.38-0.73)	0.26-1.09	0.27-1.51	0.18-2.32
8.5	High	0.29 (0.22-0.38)	0.74 (0.52-0.98)	0.58-2.03	0.92-3.59	1.51-6.63

Table 5. SLR values across different (RCPs) and GCMs- high sensitivity.

No	Model Name	SLR at 2100 (cm)			
		RCP 2.6	RCP 4.5	RCP 6	RCP8.5
1	ACCESS1-0	63.17	73.3	76.33	102.73
2	ACCESS1-3	43.28	82.1	52.29	70.38
3	BCC-CSM1-1	78.74	86	95.65	128.73
4	BCC-CSM1-1-M	78.74	65.59	82.42	110.93
5	CanESM2	56.67	91.3	68.43	92.09
6	CCSM4	60.84	59.18	74.36	100.08
7	CMCC-CM	65.02	92.4	78.62	105.81

8	CMCC-CMS	71.58	93.5	87.8	118.17
9	CNRM-CM5	105.58	117.4	128.24	172.59
10	CSIRO-MK3-0	60.84	61.12	73.8	99.32
11	GFDL-CM3	68.6	77	83.35	112.19
12	GFDL-ESM2G	71.58	68.27	86.24	116.07
13	GFDL-ESM2M	63.23	77	76.1	102.43
14	GISS-E2-R	73.96	67.37	89.85	120.93
15	GISS-E2-R-CC	76.35	79.3	92.57	124.59
16	HADGEM2-CC	73.96	77	89.38	120.3
17	HADGEM2-ES	72.77	77	89.84	120.91
18	INMCM4	79.33	70.64	94.4	127.05
19	IPSL-CM5A-LR	37.49	27.9	58.45	78.66
20	IPSL-CM5A-MR	34.61	11.2	47.45	63.86
21	MIROC-ESM	99.61	77	120.92	162.74
22	MIROC-ESM-CHEM	90.67	77	109.53	147.41
23	MIROC5	59.05	77	71.32	95.99
24	MPI-ESM-LR	66.81	75.6	82.09	110.48
25	MPI-ESM-MR	77.54	83.1	93.49	125.82
26	MRI-CGCM3	66.81	83.3	80.71	108.62
27	NorESM1-M	64.42	72.6	79.63	107.18
28	NorESM1-ME	66.21	67.86	81.48	109.67
Ensemble values		60.5 cm	71 cm	77.7 cm	104.6 cm

Table 6. Comparison between PDF and the ensembles of GCMs

RCPs	**PDF**		**Ensemble of GCMs**	
	Means	**standard deviation**	**Ensemble**	**standard Deviation**
2.6	68.5	15.4	60.5	Single Value = 0
4.5	73.76	18.9	71	
6	83.5	17.2	77.7	
8.5	112.4	23.1	104.6	

Table 7. Comparison between CI and Ensemble data

Scenario	Lower Confidence	Upper Confidence	Ensemble Data
RCP 2.6	62.78	74.89	60.5
RCP4.5	66.385	81.33	71
RCP 6	76.94	90.53	77.7
RCP 8.5	103.56	121.84	104.6

1.2 ENSEMBLES of Optimum GCMs

Coastal human communities are formulating strategies to tackle local situations in response to coastal adaptation. different adaptation strategies should be presented taking into account the local sociocultural, geographical, and climatic conditions. While these adaptation policies rely on knowledge and monitoring. A comprehensive analysis was conducted to determine the most effective GCMs out of a pool of 28 models based on their high sensitivities, according to [22], Numerous authors have proposed reducing uncertainty by using ensembles of relevant models, which can enhance confidence in climate change projections. Moreover, following the recommendations of Simclim 4x Essentials for using ensemble techniques to reduce the uncertainties surrounding sea level rise projections, Table.5 presents the projected SLR values corresponding to 28

GCMs, under four different RCPs at 2100, highlighting the impact of high sensitivity to provide more robust estimate of these projections, ensembles comprising the most accurate models aligning with the mean SLR values outlined in IPCC AR5 were conducted, it was revealed that 7, 7, 5, and 5 optimal GCMs were identified for RCPs 2.6, 4.5, 6, and 8.5, respectively. The projected sea level rise corresponding to each scenario was estimated to be 60.5, 71, 77.7, and 104.6 cm. This meticulous selection procedure not only improves the accuracy of SLR forecasts but also offers critical insights for formulating future climate change mitigation strategies.

Computing probability density functions (PDFs) and confidence intervals is an essential procedure for comprehending and strategizing for future occurrences, such as the increase in sea-level. These statistical approaches improving the reliability of climate projections and facilitating more informed decision-making.

The alignment or highlighting of discrepancies between various sources of projections is guaranteed by comparing PDFs and confidence intervals with the ensemble results as it facilitates the validation of models and increases the confidence in the projections. Table.6 in addition to Fig 6, Providing a comparison between the Probability Density Function (PDF) results from 28 GCMs and the ensemble of the optimal GCMs results.

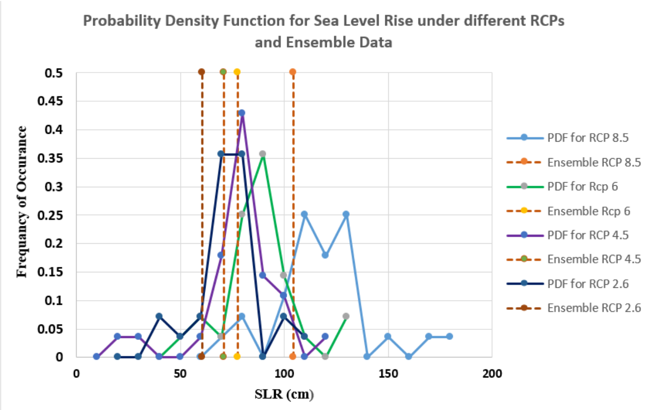

FIG 6. Comparison between PDF and Ensemble data

It can be found that for all RCPs, the PDF means is slightly higher than the ensemble values, the trend of the PDFs indicates a higher expected sea-level rise compared to the single ensemble values. And according to the standard deviation, the higher standard deviations in the PDFs reflect the uncertainty and variability inherent in the sea-level rise projections.

According to the Confidence Interval (CI), it could be calculated following the formula [15],

$$CI = x` \pm z.\frac{\sigma}{\sqrt{n}} \quad (3)$$

Where:

$x`$ is the sample mean

z is the Z score due to the confidence interval.

σ is the Standard Deviation

$\boldsymbol{n}$ is the sample size

Comparing to the ensemble data in Table 7, it can be observed that the value of the ensemble for RCP 2.6 falls outside the calculated CI, this referred to the input assumptions and processes of the utilized GCMs, which can result in different outcomes, where the ensemble data for the other RCPs generally aligns closely with the confidence intervals. This suggests that the ensemble prediction provide acceptable estimations and good agreement of the potential range of sea-level rise projections.

Confidence in a climate projection is a measure of how plausible the projected range of change is for a given emission scenario. But there is still uncertainty from emissions scenarios. [17].

Giving the correlation between IPCC and GCMs values for the increase in sea level, Fig 7, Demonstrates a robust correlation between SLR predictions by IPCC and the ensemble of GCMs. The high correlation suggests that the ensemble of GCMs may be relied upon to generate sea level rise estimates that align with the projections of IPCC, thereby making them a valuable resource for conducting climate change studies and impact assessments.

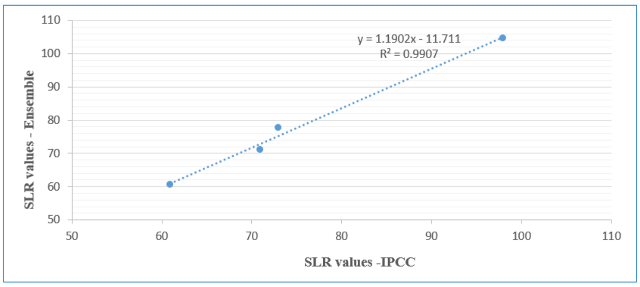

FIG 7. Correlation between SLR values due to IPCC and GCMs ensemble

In conclusion, addressing SLR ranges as shown in Table 8. across the coastal strip from Suez to Hurghada, resulting from the ensembles of the optimal models under different RCPs due to different sensitivities: low, medium to high sensitivity, is one of the most significant challenges, that supports the decision-makers in the adaptive plans for future coastal developments and investments.

Table 8. SLR values for the optimal models under (RCPs) from Suez to Hurghada.

Scenarios/	Mean sea level rise (cm)	Sensitivity	Name of Optimum Models
	2100		
Low- 2.6	60.5 * (37-61)**	Low	“ACCESS1-3, CanESM2, CCSM4, CSIRO-MK3-0, IPSL-CM5A-LR, IPSL-
		Medium	
		High	
Medium Low - 4.5	71 * (59 -70)**	Low	“ CCSM4, CSIRO-MK3-0, BCC-CSM1-1-M, GFDL-ESM2G, GISS-E2-R,
		Medium	
		High	
Medium High - 6	77.7 * (52 -71)**	Low	ACCESS1-3 , CanESM2, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5
		Medium	
		High	
High – 8.5	104.6 * (64 -96)**	Low	ACCESS1-3 , CanESM2, IPSL-CM5A-LR, IPSL-CM5A- MIROC5MR,
		Medium	
		High	

* optimum models value in high sensitivity, ** ranges of Optimum models in high sensitivity, Low sensitivity focused on 2 C°, medium for 3 C° and 4.5 C° for high

CONCLUSIONS

This study examined the variability in Temperature and sea level changes in the coastal areas along the Egyptian Red Sea, from Suez to Hurghada at the end of this century. The ensemble of 27 RCMs with a high resolution of 1×1 km was used to project maximum and minimum temperature during the winter and summer seasons under RCPs 4.5 and 8.5, which considered optimistic and pessimistic scenarios, respectively. The maximum temperature is projected to rise by (2^{O}C, 3^{O}C), the minimum temperature by (1.5^{O}C, 2^{O}C) under RCP 4.5, the maximum temperature by (4^{O}C, 6^{O}C), and the minimum temperature by (2.5^{O}C, 4.5^{O}C) under RCP 8.5. Furthermore, 28 GCMs with resolution 25 ×25 km under RCPs 2.6, 4.5, 6, 8.5 are utilized to assess the rising in sea level. An analysis was performed using the ensemble of the most effective GCMs for each scenario to minimize the uncertainty and forecast the anticipated SLR values. 7 GCMs were optimal for RCPs 2.6 and 4.5, with 5 GCMs were optimal for RCP 6 and 8.5, The projected changes in sea level along the study area, concentrating in particular on the four RCPs 2.6, 4.5, 6.0, and 8.5, will be 60.5 cm, 71 cm, 77.7 cm, and 104.6 cm, respectively. Utilizing the ensembles of the most effective General Circulation Models (GCMs) can reduce the fluctuations in sea level rise (SLR), which must be considered when planning adaptive measures and investing in coastal areas. this research assesses a specific values of the rising in sea levels which provide valuable insights for policymakers to address problems coming from the climate changes that could potentially hinder sustainable development in the region. while improving the reliability of (GCMs) in forecasting (SLR), it is essential to explore innovative research paths, by integrating observational data with model simulations, Also, it is imperative to intensify efforts to conduct on-site measurements, As it is essential to diminishing uncertainties in General Circulation Models projections, Simultaneously, establishing and maintaining long-term monitoring programs for sea level, ice sheets, glaciers, and oceanographic parameters is crucial in detecting trends, validating models, and refining projections. By delving into these new directions and developing regional downscaling techniques to bridge the gap between global projections and local impacts, local adaptation and mitigation strategies could be informed, in addition to researching local factors such as land subsidence, tectonic activity, and human-caused sea level variations, moreover developing effective coastal management and adaptation strategies to protect coastal ecosystems and human communities should be conducted to elaborate the impact of biodiversity and ecosystems such as wave propagation. Finally, due to the region's economic significance, it is crucial to consider these interim findings in future studies. These studies may include the creation of predictive maps to assess the potential issues and risks associated with sea level rise on investments in the region. Additionally, these findings can help determine safe boundaries for strategically important facilities, such as those in the mining and tourism industries, to promote sustainable development. Furthermore, they can aid in maintaining the environmental and biological equilibrium of the region.

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