CLIMATE CHANGE AND FUTURE PRECIPITATION IN AN ARID ENVIRONMENT OF THE MIDDLE EAST: CASE STUDY OF IRAQ

Abstract

The aim of this paper is to test a commonly-used weather generator, namely LARS-WG, at 5 sites of arid environment in Iraq and to generate the future projection of daily precipitation. 7 climate models (GCMs) have been employed to account for any uncertainty with the future projection from these GCMs for three future periods, 2011-2030, 2046-2065 and 2080-2099. The performance of the stochastic LARS-WG models was evaluated based on a statistical performance indicator Kolmogorov-Smirnov test for wet/dry days. The developed LARS-WG models in the studied sites are found of to perform good and skilful in simulating the current arid climate of Iraq as judged by the statistical test carried out and the comparison made. The models were then used to obtain future climate projections of precipitation for the IPCC scenario SRES A2. Results show that most of the Iraq regions are projected to suffer a reduction in annual mean precipitation, especially by the end of 21st century, while on a seasonal basis most of the studied sites are anticipated to be wetter in autumn and winter.

Keyword: Arid environment, climate change, LARS-WG, precipitation, Iraq

1. Introduction

Since 1970s, average global temperatures over land have increased by around 0.7 ^{o}C. The Intergovernmental Panel on Climate Change (IPCC) projects a future rise of between 0.7 ^{o}C and 1 ^{o}C by the end of this century (IPCC, 2007a). Unlike temperature, which has increased almost everywhere on the planet, precipitation increases in some parts of the world and decreases in others (Archer and Rahmstorf, 2010).

Distribution and circulation of the waters of the Earth become increasingly difficult to determine because of additional uncertainty related to anthropogenic emissions. According to the sixth Intergovernmental Panel on Climate Change (IPCC) Technical Paper on Climate Change and Water (Bates et al., 2008), changes in the large-scale hydrological cycle have been related to an increase in the observed temperature over several decades. Despite beneficial impacts in some regions, the overall net impact of climate change on water resources is mostly negative (Parry et al. 2007).

Iraq is considered one of the Arab region's most vulnerable countries to climate change; as it faces a unique set of environmental challenges. The impacts of changing weather patterns have already made themselves felt in recent years, with a higher frequency and intensity of extreme weather events and rising environmental degradation throughout the country. As demographic growth puts further strain on natural resources that are themselves ever more scarce, the Government's capacity to devise and implement the necessary adaptation and mitigation policies is undermined by a daunting context of post-conflict reconstruction (IAU et al., 2012). Iraq relies on precipitation falling outside its borders for more than half of its water. This high dependency rate makes it vulnerable to climate change and storage projects in Turkey, Syria and Iran (FAO AQUASTAT, 2009). Discharge rates in the Tigris and Euphrates Rivers, Iraq's primary sources of surface water, have already fallen to less than a third of their normal capacity and are expected to drop further in the coming years. Therefore it is very important to study the region to investigate the climate change impact on the precipitation as very limited research has been conducted in this region which is vulnerable to drought.

Therefore the main aim of this study is to develop a general understanding of the qualitative and quantitative impact of climate change on precipitation (mean and, extremes) in the arid regions of Iraq under scenario A2 of the IPCC greenhouse emission for future periods 2011-2030, 2046-2065 and 2080-2099. Awareness of the type and the extent of the impacts would help the authorities and planners to take more optimized and effective management strategies on water resources to cope with the expected conditions.

In order to develop such strategies and to make informed decisions about the future water allocation for different sectors and management of available water resources, planners need climate change information (usually in terms of watershed scale precipitation and temperature) that can directly be used by the hydrologic impact models. Atmosphere-ocean coupled Global Climate Models (GCMs) are the main source tools used to simulate present and future climate of the earth under different climate change scenarios (e.g. SRES, 2000). The computational grid of the GCMs is very coarse (a grid box covers more than 40000 km^2), and thus they are unable to skilfully model the sub-grid scale climate features like topography or clouds of the area in question (Wilby & Dawson, 2002). Thus, there is a need for downscaling, from coarse resolution of the GCM to a very fine resolution or even at a station scale.

The downscaling methodologies developed to date can be broadly categorized as statistical and dynamical. Among the statistical downscaling methods, the use of stochastic weather generators is very popular. They are not computationally demanding, simple to apply and provide station scale climate change information (Dibike and Coulibaly, 2005; Kilsby et al., 2007). Among various WGs, LARS-WG was intensively tested over diverse climatic zones (Semenov et al. 1998, Qian et al. 2004, Qian et al. 2008, Semenov 2008, Street et al. 2009, Haris et al. 2010, Lazzarotto et al. 2010, Semenov et al. 2010, Luo & Yu 2012, Semenov et al. 2013). The overall performance of LARS-WG in representing the statistical characteristics of observed climatic variables, including extreme events, was generally very good (Qian et al. 2008, Semenov 2008, Iizumi et al. 2012a) which motivated its use in the present study.

2. Study area and data

Five sites have been selected across Iraq to represent as much as possible major climatic regions in the country (cf. Fig 1). A majority of the rainfall in the studied sites occurs from December through to April and is more abundant in the mountainous region. Annual rainfall in the selected sites ranges between 118-633 mm a year (Table 1).

Sinjar area is located in northwestern of Iraq and is very close to the Syrian-Iraqi border. Its population reaches 21,500 and the most prominent terrain is Sinjar Mountain which is approximately 1400 m. a.s.l. while the city is at 522m.a.s.l. (Fig. 1). Sulaimaniyah is located northeastern Iraq close to the Iraqi-Iranian border. Sulaimaniyah is surrounded by the Azmer Range, Goyija Range and the Qaiwan Range in the northeast, Baranan Mountain in the south and the Tasluja Hills in the west. Its height reaches 882 m.a.s.l. The population is more than 1600000 inhabitants (Fig. 1). Rutbah is 110km from both the Iraqi-Jordanian and Iraqi Saudi Arabia borders. It is in the western desert of Iraq. It is about 618 meters above the mean sea level. The city is occupied by 139000 inhabitants (Fig. 1). Baghdad is the capital of Iraq. Its area reaches 204 km^2 and the population exceeds 7 million inhabitants. It is located on the Tigris River. The height of the city is about 41 m.a.s.l. Basrah is located at the extreme south of Iraq. Its total area is 181km^2 and the population reaches more than 3.5 million inhabitants. Basrah is only few meters above the sea level.

Relatively long records of daily precipitation must be available for each selected site in order to make a reasonable comparison of the sites. There is no formal constraint on the number of years of observed data, and, for example, LARSWG can operate with as little as 1 year of data. However, fairly long records are required to calculate robust and representative generator parameters for the site. The rainfall data used in this study was obtained from the Iraqi National Meteorological Organisation for purpose of model calibration and validation in all sites. Length of rainfall data used in each site is presented in Table 1.

Fig 1 Location of Iraq Meteorological Stations (5 have been used in this study, Singar (1), Sulaimaniya(2), Rutba (3), Baghdad (4) and Basrah (5)

Table 1 Details of the location of five stations and average annual rainfall

Serial No	Stations	Latitude	Longitude	Altitude(m)	Length of Record	Annual rainfall
1	Sinjar	36º 19´	40º 51´	522	1970-2001	318.22
2	Sulaimaniya	35º 33´	45º 25´	882	1961-2000	633.04
3	Rutba	33º 02´	40º 17´	618	1961-1978	118.4
4	Baghdad	33º 18´	44º 24´	41	1961-2000	256.5
5	Basrah	30º 31´	47º 47´	5	1961-2000	143.7

3. Methodology

Projection of precipitation in different Iraq regions has been simulated using LARS-WG. LARS-WG is a model simulating time-series of daily weather at a single site (Semenov and Barrow, 1997; Semenov et al 1998; Semenov and Doblas-Reyes; 2007). It can be used to serve as a computationally inexpensive tool to produce daily site-specific climate scenarios for impact assessments of climate change. LARS-WG software version 5.5 includes climate scenarios based on 15 Global Climate Models (GCMs) which have been used in the IPCC AR4 (2007b). The current application used 7 GCMs with Multi-model ensembles which allow exploring the uncertainty in climate predictions resulting from structural differences in the global climate model design as well as uncertainty in variations of initial conditions or model parameters.

3.1 Descriptions of LARS-WG

LARS-WG uses observed daily weather data for a given site to compute a set of parameters for probability distributions of weather variables as well as correlation between them. These parameters are then used to generate synthetic weather time series of arbitrary length by randomly selecting values from the appropriate distributions. To approximate probability distributions of dry and wet series of daily precipitation, Tmax and Tmin, LARS-WG uses a semi empirical distribution (SED) that is defined as the cumulative probability distribution function (CDF). The number of intervals (n) used in SED is 23 in the new version (Version 5.0), which offers more accurate representation of the observed distribution compared with the ten used in the previous version. For each climatic variable 'v', a value of climatic variable $v_i$corresponding to the probability $p_i$is calculated as:

$$v_i = min\{v: P(vobs \leq v) \geq p_i\} \quad i = 0, \ldots\ldots, n \tag{1}$$

Because the probability of very low daily precipitation (<1 mm) is typically relatively high and such low precipitation has very little effect on the output of a process-based impact model, only two values are used, v_1 = 0.5 mm and v_2 = 1 mm to approximate precipitation within the interval [0, 1] with the corresponding probabilities calculated as p_i = P ($vobs$ ≤v_i) i = 1, 2. To account for extremely high long dry and wet series, two values close to 1 are used in SEDs for wet and dry series, p_{n-1} = 0.99 and p_{n-2}= 0.98.

For maximum and minimum temperatures, two values close to 0 and two close to 1 are used to account for extremely low and high temperatures, i.e., p_2 = 0.01, p_3 = 0.02, p_{n-1} = 0.99 and p_{n-2}= 0.98. All p_i values (0 < I < n). In the new version of LARS-WG (5.5), the maximum and minimum temperature for dry and wet days are approximated by SEDs calculated for each month (Semenov and Stratonovitch, (2010); Semenov (2007)).

3.2 Performance of LARS-WG

LARS-WG should be tested to ensure that the data that it produces is satisfactory for the purposes for which it is to be used. The accuracy required will depend on the application of the data, and the performance of the generator may vary considerably for different climates.

Statistical tests were selected to compare a variety of different weather characteristics of the observed and synthetic weather data such as, for example, the lengths of wet and dry series, mean, standard deviation and the distribution of precipitation. Moreover, the adequacy of LARS-WG model to simulate the precipitation was tested by the p-value of the Kolmogorov-Smirnov (K-S) test. The Kolmogorov-Smirnov (K-S) test is performed on testing equality of the seasonal distributions of wet and dry series (WDSeries) and distributions of daily rainfall (RainD) calculated from observed data and downscaled data. The test calculates a p-value, which is used to accept or reject the hypotheses that the two sets of data could have come from the same distribution (i.e., when there is no difference between the observed and simulated climate for that variable). A very low p-value and a corresponding high KS value means the simulated climate is unlikely to be the same as the observed climate; hence must be rejected.

Although a *p-value* of 0.05 is the common significance level used in most statistics, the authors Semenov and Barrow, (1997) of LARS-WG suggests a p-value of 0.01 to be used as the acceptable significance limit of the model results. Significant differences between the observed and simulated data may arise from the model smoothing the observed data, errors in the observed data, random variation in the observed data, and unusual climate phenomenon at a climate station making a particular year's climate very different.

3.3 Generation of Future Projection

Downscaling of precipitation using LARS-WG is based on the daily precipitation output of a GCM. This GCM output is used for the derivation of monthly relative change factor (RCF) of the average precipitation amount and the average length of dry/wet spell. In the present study, the daily precipitation time series of the CNCM3, GFCM21, HADCM3, INCM3, IPCM4, MPEH5 and NCCCS GCMs, details of each is presented in Table 2, representing current climate forcing for 1961–2000 and the future time series of 2011- 2030, 2046-265, and 2080-2099, are used in calculating the relative change factors. The future time series is based on the SRES A2 scenario. The daily precipitation data extracted from the GCMs output for the two periods (baseline and future) were used by LARS-WG to calculate the monthly RCFs of the mean daily precipitation and average length of wet and dry spells as in Eq. 2. Hashmi, (2012)

$$RCF = 1 + \left[\frac{Future\ precipitation - basline\ precipitation}{basline\ precipitation}\right] \quad (2)$$

The difference of these properties between the two time slices gave the change (positive or negative) between two climate regimes, projected by the chosen GCM.

Table 2: Selected 7 global climate models from IPCC AR4 incorporated into LARS-WG 5.5

No.	GCM	Research center	Grid
1	CNCM3	Centre National de Recherches France	1.9×1.9°
2	GFCM21	Geophysical Fluid Dynamics Lab USA	2.0×2.5°
3	HADCM3	UK Meteorological Office UK	2.5×3.75°
4	INCM3	Institute for Numerical Mathematics Russia	4×5°
5	IPCM4	Institute Pierre Simon Laplace France	2.5×3.75°
6	MPEH5	Max-Planck Institute for Meteorology Germany	1.9×1.9°
7	NCCCS	National Centre for Atmospheric USA	1.4×1.4°

4. Results and Discussion

4.1 LARS-WG calibration and validation

Observed daily rainfall series from each station was used to calibrate and validate LARS-WG model of the site. To assess the ability of LARS-WG, in addition to the graphic comparison, some statistical tests are also performed. The Kolmogorov–Smirnov (K–S) test is performed on testing equality of the seasonal distributions of wet and dry series (WDSeries) and distributions of daily rainfall (RainD) calculated from observed data and downscaled data. The test calculates a p-value, which is used to accept or reject the hypotheses that the two sets of data could have come from the same distribution (i.e., when there is no difference between the observed and simulated climate for that variable). A very low p-value, and a corresponding high K- S value means the simulated climate is unlikely to be the same as the observed climate; hence must be rejected. Although a p-value of 0.05 is the common significance level used in most statistics, the authors (Semenov and Barrow, 2002) of the model suggests a p-value of 0.01 be used as the acceptable significance limit of the model results. Significant differences between the observed and simulated data may arise from the model smoothing the observed data, errors in the observed data, random variation in the observed data, and unusual climate phenomenon at a climate station making a particular year's climate very different. Test results for the capabilities of LARS-WG to model the seasonal observed rainfall in each site are presented in Table 3. Assessment of the LARS-WG performance in simulating the seasonal precipitation in each site is inserted in the "Assessment" column in Table 3. For seasonal wet/dry series distributions (cf. Table 2); the KS-test showed no or little difference between the generated and observed rainfall data in all studied sites. This has been judged by the higher *p-values* >0.01 which range between 0.359 and 1.0. Baghdad in the central Iraq is the only location where the model has poor fit of *p-value* of zero for the wet series during the summer season.

The KS-test for the distribution of daily precipitation (12 tests per site) in Tale 4 showed no significant differences between the observed and simulated precipitation at all studied sites for most of the months, as shown in the "Assessment" column in the table. However there are 2 significant differences at four sites during the summer months (June, July, August) and month September; when LARS-WG was unable to replicate the observed precipitation (having poor fit), partly because this period is classified as a dry one. As there is no or rare rain recorded in this period, the weather generator would not be able to fit any wet spell and thus it would perform poorly.

From the results in Tables 3 and 4, it can be noted that LARS-WG is more capable in simulating the seasonal distributions of the wet/dry spells and the daily precipitation distributions in each month. These two properties are very important when using the model results in impact studies.

Table 3: Summary of statistical test results: significant; KS, Kolmogorov-Smirnov test for seasonal wet/dry SERIES distributions

Season	Singar				
	Wet/Dry	**N**	**K-S**	**P-Value**	**Comment**
DJF	wet	12	0.092	1.000	Perfect fit
	dry	12	0.086	1.000	Perfect fit
MAM	wet	12	0.068	1.000	Perfect fit
	dry	12	0.077	1.000	Perfect fit
JJA	wet	12	0.000	1.000	Perfect fit
	dry	12	0.261	0.359	Good fit
SON	wet	12	0.070	1.000	Perfect fit
	dry	12	0.094	1.000	Perfect fit

Season	Sulaimaniya				
	Wet/Dry	N	K-S	P-Value	Comment
DJF	wet	12	0.129	0.985	Perfect fit
	dry	12	0.053	1.000	Perfect fit
MAM	wet	12	0.073	1.000	Perfect fit
	dry	12	0.043	1.000	Perfect fit
JJA	wet	12	0.174	0.842	Very Good fit
	dry	12	0.174	0.842	Very Good fit
SON	wet	12	0.192	0.744	Very Good fit
	dry	12	0.114	0.997	Perfect fit

Season	Rutba				
	Wet/Dry	**N**	**K-S**	**P-Value**	**Comment**
DJF	wet	12	0.110	0.998	Perfect fit
	dry	12	0.071	1.000	Perfect fit
MAM	wet	12	0.175	0.837	Very Good fit
	dry	12	0.120	0.994	Perfect fit
JJA	wet	12	0.174	0.842	Very Good fit
	dry	12	0.095	1.000	Perfect fit
SON	wet	12	0.110	0.998	Perfect fit
	dry	12	0.103	0.999	Perfect fit

Season	Baghdad				
	Wet/Dry	N	K-S	P-Value	Comment
DJF	wet	12	0.050	1.000	Perfect fit
	dry	12	0.157	0.916	Very good fit
MAM	wet	12	0.231	0.514	Good fi
	dry	12	0.068	1.000	Perfect fit
JJA	wet	12	0.913	0.000	Poor fit
	dry	12	0.130	0.984	Very good fi
SON	wet	12	0.108	0.999	Very good fit
	dry	12	0.078	1.000	Perfect fit

Season	Basrah				
	Wet/Dry	**N**	**K-S**	**P-Value**	**Comment**
DJF	wet	12	0.091	1.000	Perfect fit
	dry	12	0.100	1.000	Perfect fit
MAM	wet	12	0.276	0.294	Moderate fit
	dry	12	0.193	0.738	Very Good fit
JJA	wet	12	0.000	1.000	Perfect fit
	dry	12	0.217	0.595	Good fit
SON	wet	12	0.123	0.991	Very good fit
	dry	12	0.055	1.000	Perfect fit

Table 4: KS-test for daily RAIN distributions

Month	Singar			
	N	K-S	P-Value	Comment
J	12	0.070	1.000	Perfect fit
F	12	0.058	1.000	Perfect fit
M	12	0.067	1.000	Perfect fit
A	12	0.061	1.000	Perfect fit
M	12	0.100	1.000	Perfect fit
J	12	0.478	0.006	Poor fit
J	12	0.000	1.000	Perfect fit
A	12	0.000	1.000	Perfect fit
S	12	0.348	0.096	Moderate fit
O	12	0.074	1.000	Perfect fit
N	12	0.066	1.000	Perfect fit
D	12	0.059	1.000	Perfect fit

Month	Sulaimaniya			
	N	K-S	P-Value	Comment
J	12	0.010	1.000	Perfect fit
F	12	0.063	1.000	Perfect fit
M	12	0.056	1.000	Perfect fit
A	12	0.058	1.000	Perfect fit
M	12	0.058	1.000	Perfect fit
J	12	0.261	0.359	Good fit
J	12	0.348	0.096	Moderate
A	12	0	1	Perfect fit
S	12	0.348	0.096	Moderate
O	12	0.151	0.937	Perfect fit
N	12	0.058	1.000	Perfect fit
D	12	0.057	1.000	Perfect fit

Month	Rutba			
	N	K-S	P-Value	Comment
J	12	0.347	0.097	Poor fit
F	12	0.038	1.000	Perfect fit
M	12	0.135	0.976	Perfect fit
A	12	0.513	0.003	Poor fit
M	12	0.051	1.000	Perfect fit
J	12	0.522	0.002	Poor fit
J	12	0.000	1.000	Perfect fit
A		No precipitation		
S	12	0.566	0.001	Poor fit
O	12	0.354	0.086	Good fit
N	12	0.072	1.000	Perfect fit
D	12	0.06	1.000	Perfect fit

Month	Baghdad			
	N	K-S	P-Value	Comment
J	12	0.110	0.998	Perfect fit
F	12	0.024	1.000	Perfect fit
M	12	0.048	1.000	Perfect fit
A	12	0.037	1.000	Perfect fit
M	12	0.119	0.994	Perfect fit
J	12	0.500	0.004	Poor fit
J	12	0.957	0	Poor fit
A		No precipitation		
S	12	0.397	0.038	Moderate fit
O	12	0.049	1.000	Perfect fit
N	12	0.03	1.000	Perfect fit
D	12	0.063	1.000	Perfect fit

Month	Basrah			
	N	K-S	P-Value	Comment
J	12	0.077	1.000	Perfect fit
F	12	0.045	1.000	Perfect fit
M	12	0.058	1.000	Perfect fit
A	12	0.053	1.000	Perfect fit
M	12	0.079	1.000	Perfect fit
J	12	0.478	0.006	Poor fit
J		No precipitation		
A	12	0	1.000	Perfect fit
S	12	0.566	0.001	Poor fit
O	12	0.354	0.086	Good fit
N	12	0.072	1.000	Perfect fit
D	12	0.06	1.000	Perfect fit

To increase confidence in LARS-WG capability to predict future precipitation, comparisons between statistics calculated from the simulated precipitation with the corresponding ones calculated from the observed data are carried here. Figure 2 show plots of the monthly mean and standard deviation calculated from the observed and simulated precipitation in all studied sites. Close examination of the plots in figure 2 reveals a very good performance of LARSWG in all sites. Overall, the mean monthly totals are well represented by LARS-WG, but are slightly overestimated by 0.84-7.65 mm or underestimated by 0.25-12 mm in all sites. In terms of standard deviation, LARS-WG shows an excellent performance for June, July August and September, while for the rest of months, LARS-WG underestimates the standard deviation by 1.6-11.9 mm for all sites. The Basrah site, in the southern end of Iraq, appears to be modelled better than the other sites, reflecting the combination effects of altitude and rainfall pattern in model performance. The relatively lower and moderate rainfall in this site compared to the other sites (cf. Table 3) made the LARSWG model run smoothly.

Good simulation of wet/dry spell lengths is very essential in precipitation modelling, as it can be used for assessment of drought risk or drainage network efficiency for big cities. The simulation results of LARS-WG are shown in Figure 3 and 4 for the wet and dry spell lengths. Examination of Figures 3 and 4 shows LARSWG has a remarkable skill in simulating the dry spells' lengths, as the lines representing observed and simulated values are almost overlapping throughout. However the wet spell lengths tend to be slightly underestimated than the observed one for most of the months in all sites by 0.01-1.5 days. Summer months models tend to be matched well to the observed wet spell lengths.

Further, the capability of LARS-WG to simulate the extremes intense event was also explored in the present study. Comparison of the observed and the LARS-WG simulated annual maximum series is shown in Figure 5 for all sites. As explained earlier, LARS-WG generates random data which is comparable to the observed data in its statistical properties only. Observation of the plots in Figure 5 reveals mix results of over and under estimation for the observed extreme values at all sites, however orders of the observed extreme event magnitudes are reasonably represented by LARS-WG.

Based on the above analyses and comparisons, it can be concluded that the LARS-WG model has very good performance in generating daily and extreme precipitation in all studied sites and can reasonably be used to predict daily precipitation for near, medium and far future for purposes of impact studies.

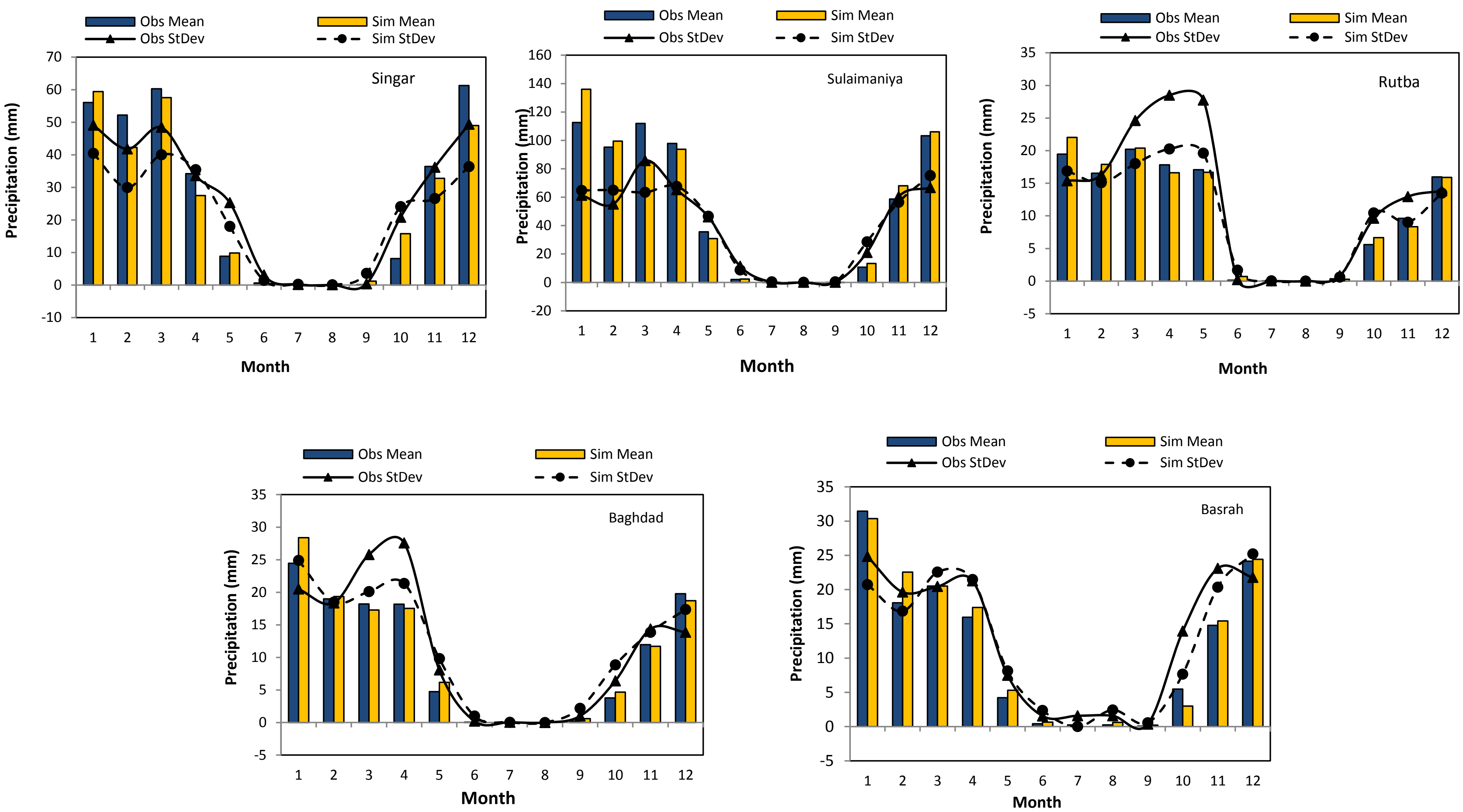


Fig 2 Monthly mean and standard deviation of the obesrevd and simulated precipitation

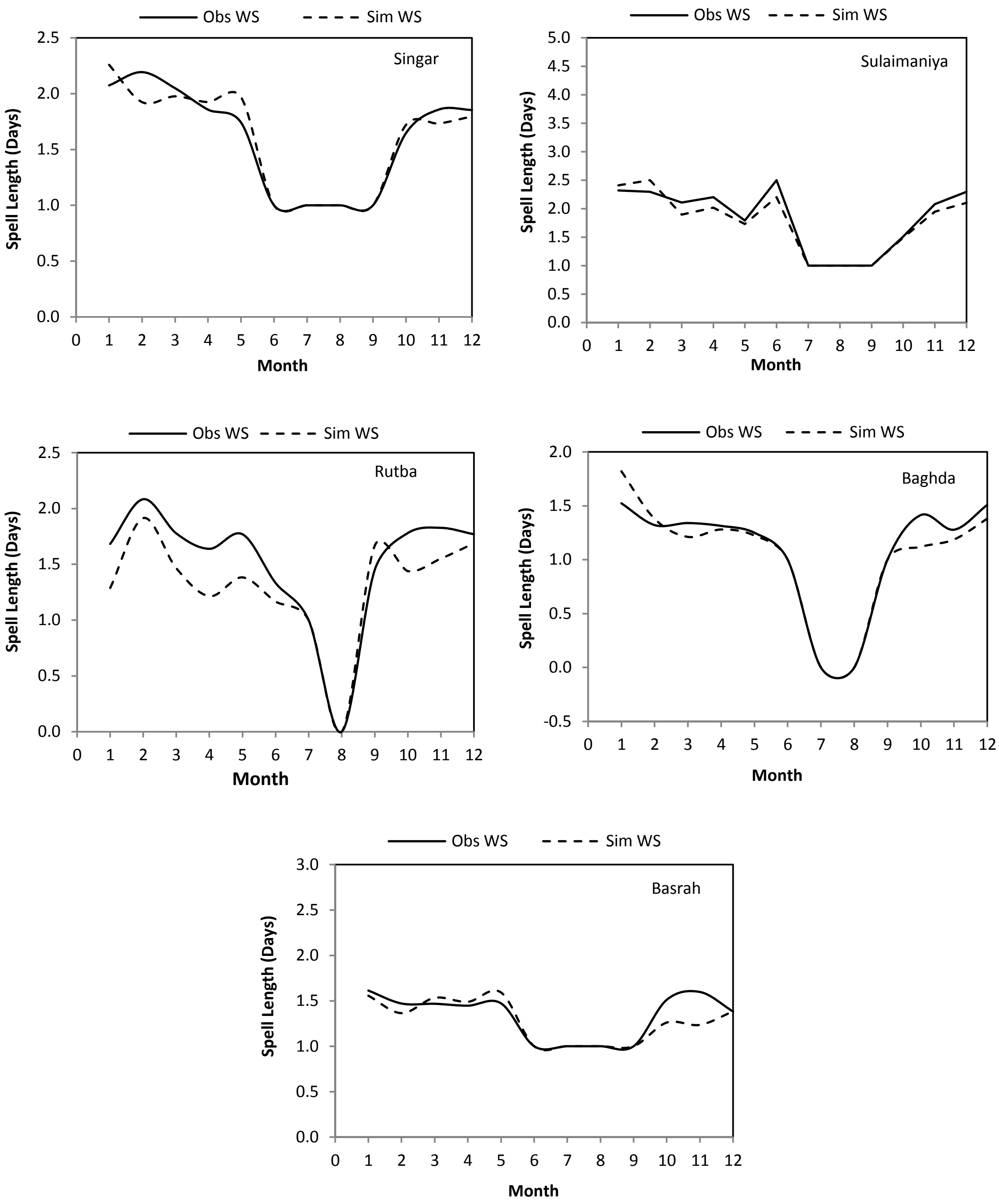


Fig 3 Comparison of observed and simulated average wet spell lengths at the studied sites

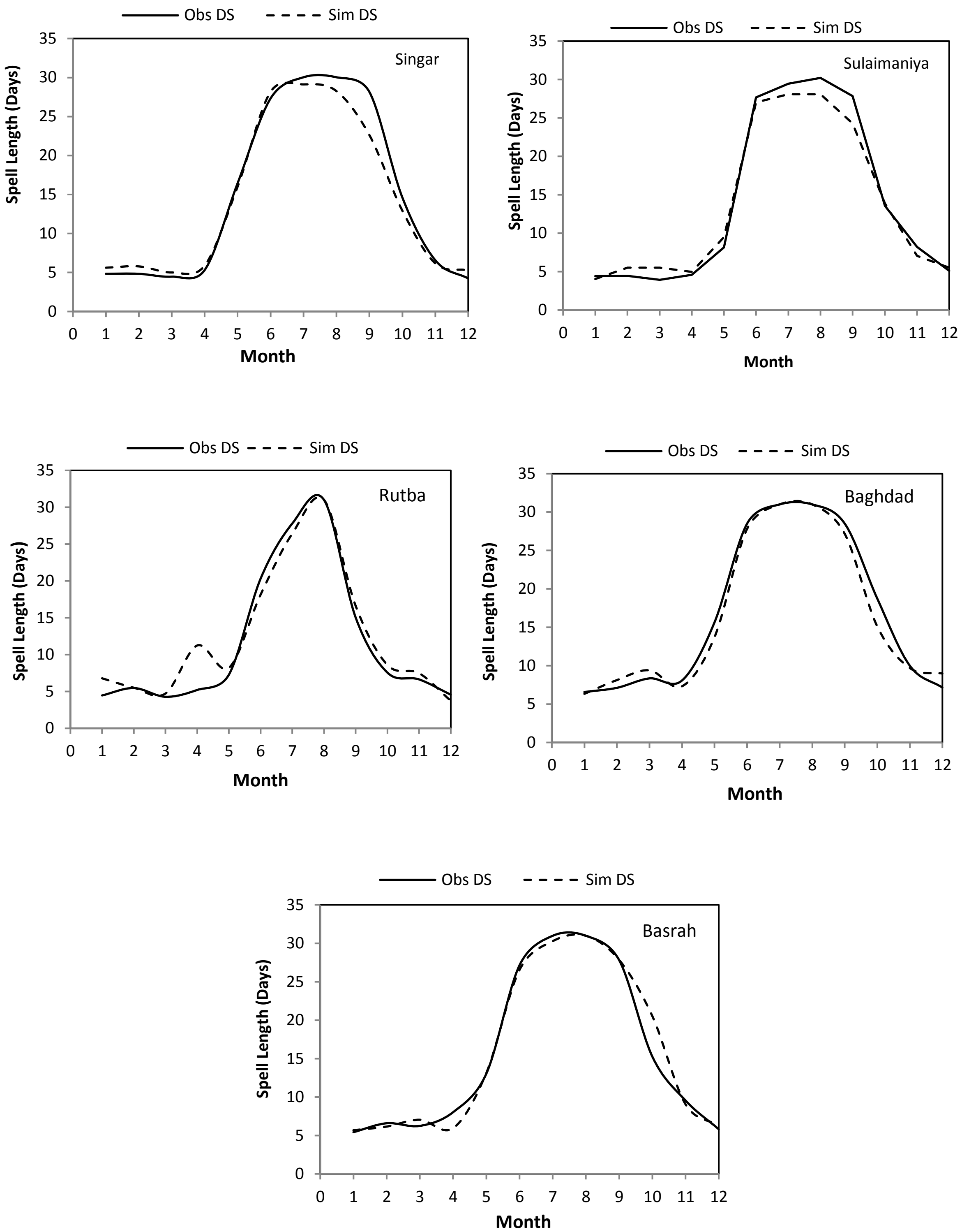


Fig 4 Comparison of observed and simulated averag dry spell lengths at studied sites

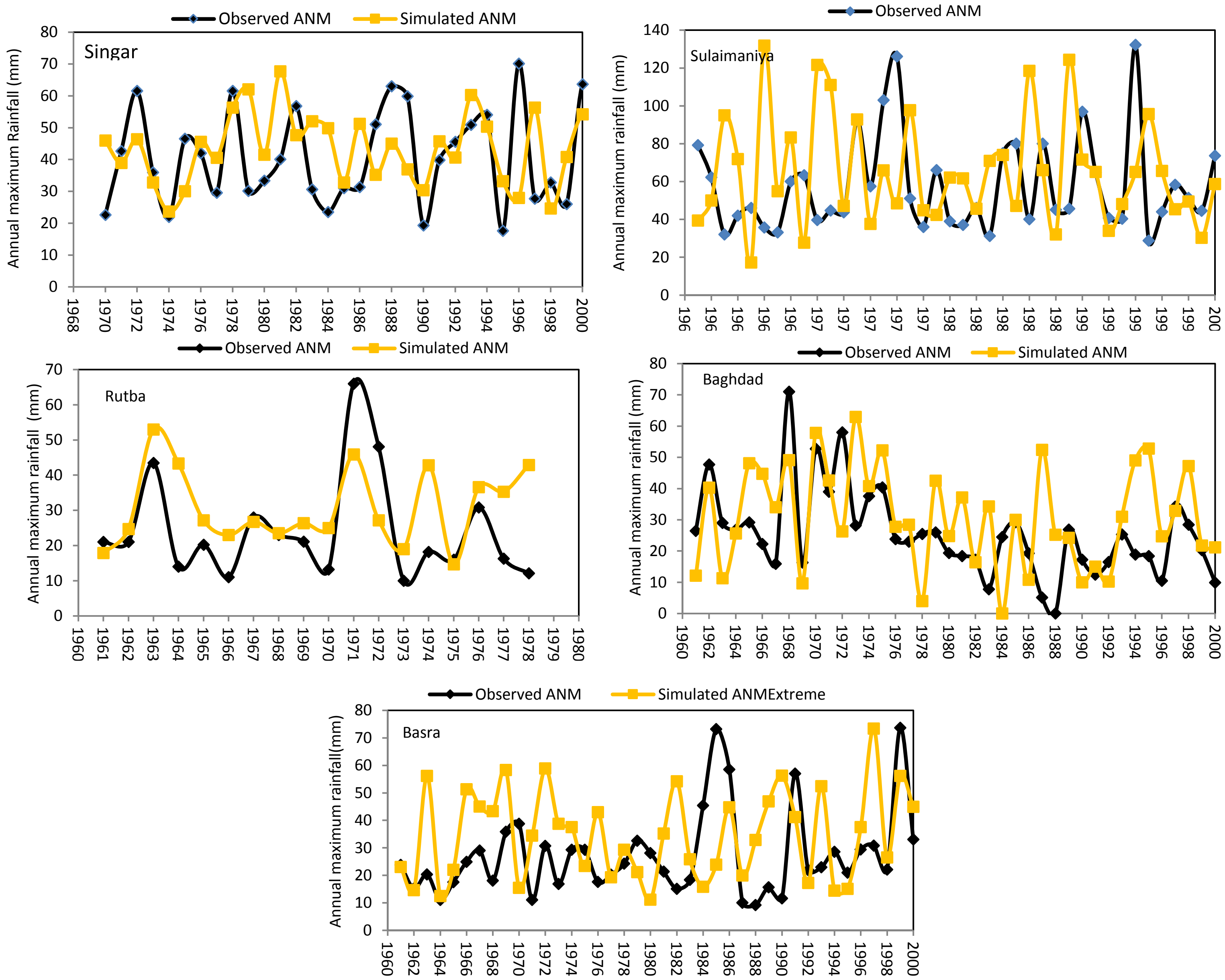


Fig 5 Comparison of observed and LARS-WG simulated annual maximum series

4.2 Projection of Future Precipitation

The LARS-WG model developed for each site was used to predict future daily precipitation in the site for the periods of 2011-2030 (near future), 2046-2065 (medium future), and 2080-2099 (far future) based on the SRA2 scenarios generated from the seven GCMs (Table 1). As per the projected future precipitation in figure 6, Singar in the northern-western part of Iraq, has consistently shown no or minor changes in the annual mean as projected by all GCMs for future periods 2011-2030 & 2046-2065; whereas an apparent reduction in the mean annual precipitation is projected by 6 GCMs for the far future (period 2080-2099). The no and minor changes projected for the near and medium futures in Singar can be attributed to the altitude of the site, which would contribute to the amount of precipitation and temperature in the site. The plots for future changes in seasonal precipitation for the same site in figure 7, shows that most of the increase in precipitation would be during the autumn season and the reduction would mainly be during winter and spring as projected by ensemble of the seven GCMs. So, where there would be no or minor change in the total annual precipitation however sessional the site is project to undergo minor stress in its main water resource and thus planners must be alerted to this.

The picture of future precipitation in all other four sites is somewhat similar to the situation in Singar. In Sulaimaniya site for example, the seven GCMs projected the same pattern of change in future annual mean precipitation, whereas the ensembles of GCMs projected different scenario for the total seasonal precipitation. The projected reduction in the annual mean precipitation is more pronounced in the Sulaimaniya than in Singar site (cf. Fig 6) whilst the seasonal change in the near future (2011-2030) (cf. Fig. 7) will be an increase in winter precipitation.

Rutba and Baghdad are the only two sites in which all GCMs agree that there will be a decrease in precipitation for 2080-2099 and a mixed projection of no change and an increase in the other near and medium future periods (cf. Fig 6) with the changes vary among the different GCMs. For the Basrah site, all GCMs project relatively no change for the three future periods (cf. Fig 6).

A clearer picture emerges for the annual mean precipitation by the period 2080-20099, with all GCM models predicting a decrease in precipitation of varying range amongst the studied sites due to variation of their geographical regions.

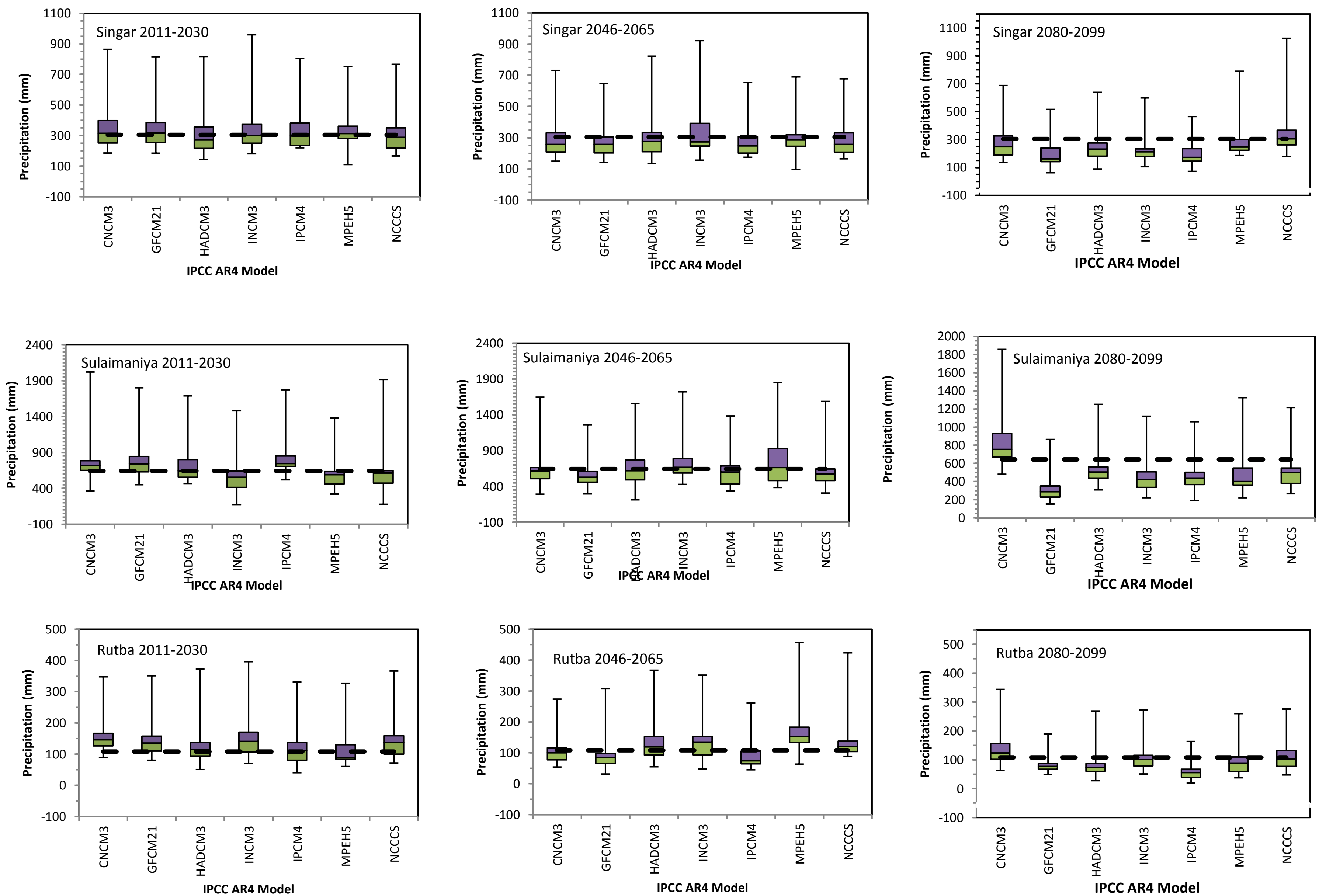
The change in seasonal precipitation for each site is represented here as the difference between the average future time periods of interest obtained from the ensemble of the seven GCMs and the baseline period as illustrated in Figures 7 (2011-2030, 2046-2065 and 2080-2099). Most of the sites are projected to experience some increase in precipitation during the autumn season which ranges between 4mm in Basrah to 14 mm in Baghdad. The projections for other seasons are a slight increase or decrease of few mms.

5. Conclusion

This paper presented application for the LARS-WG stochastic model in the arid environment of Iraq under climate change, representative here by five sites covering different climatic regions. Precipitation was projected under scenario A2 for three future periods (2011-2030, 2046-2065 and 2080-2099) using seven GCMs documented by the IPCC AR4.

Mixed 7 climate projection was obtained for precipitation at the studied sites. On an annual mean precipitation basis, all sites are projected to have some dry climate, especially in far future period 2080-2099 (Singar, Sulaimaniya, Baghdad and Rutba) as confirmed by most of the GCMs, while projections for the near and medium futures periods have shown no or minor change of increase and decrease. Basrah is the only site the projection for which maintains the same pattern of precipitation in present and future with no or minor changes.

While uncertainties arising from the derived models were not accounted for, GCM and emissions uncertainties could be tentatively approached by employing a number of GCMs. The results also highlight the importance of using multiple GCMs when conducting climate change research, as the magnitude of change can vastly be different between GCMs and in some cases even different in directions. If the suggested changes in precipitation are realised, then large sectorial impacts of these changes are likely to be felt in Iraq.


Singar 2011-2030
Singar 2046-2065
Singar 2080-2099
Sulaimaniya 2011-2030
Sulaimaniya 2046-2065
Sulaimaniya 2080-2099
Rutba 2011-2030
Rutba 2046-2065
Rutba 2080-2099
Precipitation (mm)
IPCC AR4 Model
CNCM3
GFCM21
HADCM3
INCM3
IPCM4
MPEH5
NCCCS

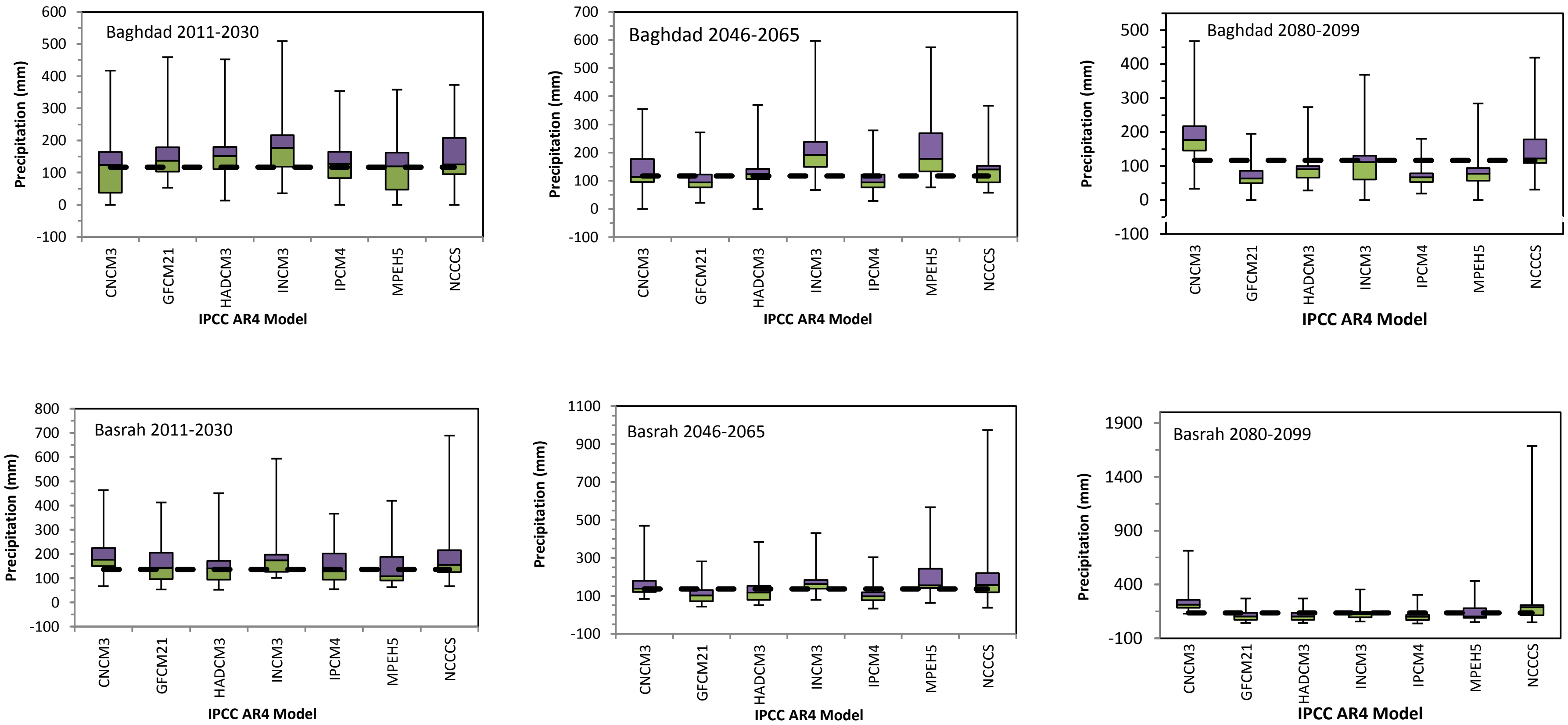


Fig 6 Box-whisker plots for change in future precipitation in the studied sites downscaled from 7 GCMs by LARS-WG during the future periods compared to the baseline period shown as a dashed line

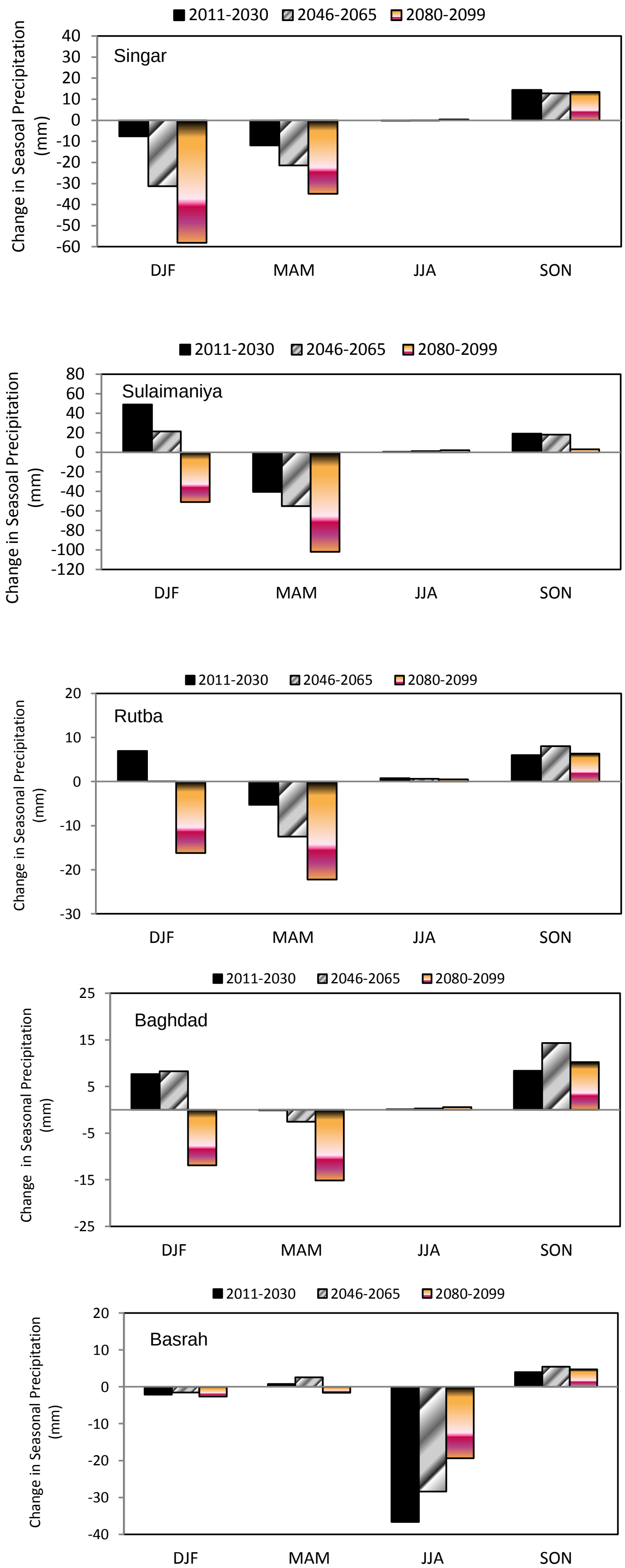


Fig 7 The differences of precipitation between the future periods and the baseline period in the studied sites

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