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

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In this paper impact of climate change on precipitation in the arid environment of Iraq is examined. LARS-WG weather generator was applied to 5 representative regions to model current and future precipitation under climate change. Seven Global Climate Models (GCMs) have been employed to account for any uncertainty on future projection for three selected periods, 2011-2030, 2046-2065 and 2080-2099. Performance of LARS-WG in each site was first evaluated using the Kolmogorov-Smirnov statistical test for fitting wet/dry days in each site, as well as comparison of the mean and standard deviation between the observed and simulated precipitation. The developed LARS-WG models were found to perform well and skilful in simulating precipitation in the arid regions of Iraq as evidenced by the tests carried and the comparison made. The precipitation models were then used to obtain future projections for precipitation using the IPCC scenario SRES A2. Future precipitation results show that most of the Iraq regions are projected to suffer a reduction in annual mean precipitation, especially by the end of the 21st century, while on a seasonal basis most of the regions are anticipated to be wetter in autumn and winter.

INTRODUCTION

Since the 1970s, average global temperatures over land have increased by around 0.7 ºC. The Intergovernmental Panel on Climate Change (IPCC) projects a future rise of between 0.7 ºC and 1 ºC by the end of this century (IPCC, 2007a). Temperature has already increased almost everywhere on the planet with the largest warming over the northern continents (e.g. UK), where in a few places it already exceeds 2^0C. However, unlike temperature, precipitation increases in some parts of the world and decreases in others (Archer and Rahmstorf, 2010).

Distribution and circulation of waters on earth become increasingly difficult to determine because of additional uncertainty related to anthropogenic emissions (Nishi Bhuvandas, et al., 2014). 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. For example average UK temperature has risen since the mid-20th century as in Central England which has risen by about a degree Celsius since the 1970s, and in Scotland and Northern Ireland has risen by about 0.8 ºC since about 1980 (Jenkins, 2008). 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 (i.e. increase in temperature and decrease in availability of water resources). 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 (IAU et al., 2012). 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 due to climate change which prompted human intervention with the environment (IAU, 2010). Therefore, it is very important to study the region water resources to investigate the impact of climate change on such resources, as very limited research has been conducted in this vulnerable region.

The main aim of this study is to develop a general understanding for the qualitative and quantitative impacts of climate change on future precipitation (mean and, extremes) in the arid regions of Iraq. 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.

Therefore the study aim is planned to be achieved here by realising the following three objectives. First, develop a downscaling model capable of estimating current and future precipitation in each region. Second, use the developed downscale model together with some climate change information to project precipitation for specified future periods. Third, analyse the obtained results to assess the future precipitation in the studied regions.

The downscaling methodologies developed to date can be broadly categorized as statistical (computationally inexpensive) and dynamical (requires significant computing resources) (Wilby et al., 2004). Due to lack of specific data from Iraq to use with dynamical downscaling models, statistical downscaling models are the only option to use in this study. Among the statistical downscaling methods, the use of stochastic weather generators (WGs) 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).

The downscaling model chosen to use in the present research is the stochastic weather generator LARS-WG. 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). It simulates 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. 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. LARS-WG software, which developed in its current form by Rothamsted Research UK, can be downloaded with user manual for free (Rothamsted Research website http://www.rothamsted.ac.uk/mas-models/larswg) in order to share the knowledge obtained from its application in different regions with the academic community.

STUDY AREA AND DATA

Five sites have been selected across Iraq to represent as much as possible, various climatic regions in the country, north, south, east and west (cf. Figure 1). Climatic regions are roughly defined here based on location and the dominant topographical feature in the region (desert, mountains, drainage network, sea, etc.). Most of the precipitation in the studied sites occurs between December and April. Annual rainfall in the selected sites ranges between 118-633 mm a year (cf. Table 1).

The total water withdrawal in Iraq in 1990 was about 42.8 km^3, which is used for agricultural (90%), domestic (4%) and industrial (6%) purposes. The cropped land is about 1.9 million ha in recent years out of 4 million ha arable lands. According to Iraqi Ministry of Planning (MoP), Iraq is planning to increase the agricultural area cropped by wheat and barley, achieving in 2017, by 14% and 21%, respectively. In the case that all arable land is cropped then the water requirement will be 50 km^3 per annum, assuming good irrigation efficiency. Available data indicates that 11.5 million hectares are cultivated which form 26% of the total area of Iraq. The area used for agriculture is 8 million hectares which forms 70% of the cultivated area. Due to fallow practices and unstable political situation only 3 to 5 million hectares are now actually cultivated annually (Al-Ansari, 2013).

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

Many of the Iraqi industries starting from 2003 or earlier, which are considered as water consumers, are out of duties or need rehabilitation campaigns to be functional. Iraqi Government is looking for external investments for these industries and in case they succeed, extra water demands will be imposed on the water resources of the country (Al-Ansari et al., 2014).

The first of the selected five sites is Sinjar region, which is located in north western part of Iraq and is very close to the Syrian-Iraqi border. The 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. (Figure 1). The second is the Sulaimaniyah region located in north-eastern Iraq close to the Iraqi-Iranian border. It 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

Table 1. Details of the location of five stations and rainfall data

Serial No	Station	Latitude	Longitude	Altitude (m)	Length of Record	Mean annual rainfall (mm)	Percentile (mm)	
							20th	80th
1	Sinjar		40° 51′	522	1970-2001	318.22	0.7	9.94
2	Sulaimaniya	35° 33′	45° 25′	882	1961-2000	633.04	0.1	4.6
3	Rutba	33° 02′	40° 17′	618	1961-1978	118.4	0.1	2.7
4	Baghdad	33° 18′	44° 24′	41	1961-2000	256.5	0.1	4.6
5	Basrah	30° 31′	47° 47′	5	1961-2000	143.7	0.4	6.12

more than 1600000 inhabitants (Figure 1). The third region is the Rutbah region located 110 km 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 about 139,000 inhabitants (Figure 1). The fourth region is Baghdad the capital of Iraq. Its total area reaches 204 km^2 and the population exceeds 7 million inhabitants. It is located on the Tigris River. The altitude of the city is about 41 m.a.s.l. The fifth region is Basrah located at the extreme south of Iraq. Its total area is 181 km^2 and the population reaches more than 3.5 million inhabitants. Basrah is only few meters above the sea level.

The rainfall data used in this study for these five regions 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. Relatively longer records of daily precipitation must be available for each selected region in order to make a reasonable comparison of the regions. There is no formal constraint on the number of years of observed data to use in LARS-WG as it can operate with as little as 1 year of data (Semenov et al., 1998). However, fairly long records are required to calculate robust and representative generator parameters for each site (see Table 1 for record length). Moreover other criteria have been used for selection of precipitation record such as quality of data and station location in order to cover most of Iraq climate.

METHODOLOGY

Projection of precipitation in different Iraq regions has been simulated using LARS-WG software version 5 that includes climate scenarios based on 15 Global Climate Models (GCMs) which have been used in the IPCC AR4 (2007b). More information on development of LARS-WG version 5 and the 15 Global Climate Models and their version which are incorporated in it can be found in Semenov and Stratonovitch (2010). The current application used 7 GCMs, listed in Table 2 below, 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.

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 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), which offers more accurate representation of the observed distribution compared with the ten used in the previous versions. For each climatic variable, v, a value of climatic variable, v_i, corresponding to the probability, p_i, is calculated as:

$$v_i = min\left\{ v : P\left(v_{obs} \leq v \right) \geq p_i \right\} i = 0, \ldots.., n \tag{1}$$

where $P(\,)$ is probability of the observed variable v_{obs}.

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 $p_i = p(v_{obs} \leq v_i)$, $i = 1, 2$. 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 $p_{n-2} = 0.98$.

Performance of LARS-WG

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

A number of statistical tests were carried out to check the performance of LARS-WG in generating synthetic precipitation in each site. These includes comparing the mean, the lengths of wet and dry series and standard deviation of the observed precipitation with those from the synthetic series generated by LARS-WG. Moreover, the adequacy of LARS-WG model in reproducing the distribution of the daily and seasonal precipitation was tested by the p-value of the non-parametric Kolmogorov-Smirnov (K-S) test. The non-parametric 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 of LARS-WG suggested in Semenov and Barrow (1997) and Semenov and Barrow (2002) that 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.

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 the 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 were projected from CNCM3, GFCM21, HADCM3, INCM3, IPCM4, MPEH5 and NCCCS GCMs, details of each is presented in Table 2. The future time series is based on the IPCC scenario SRES A2. 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 Equation (2) Hashmi (2012).

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

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.

Modelling process with LARS-WG

The modelling process with LARS-WG, as followed in this study, to generate current and future daily precipitation for each of the five studied regions is outlined as follows:

1. Preparation of input data: LARS-WG requires two input files, the first file is the observed daily weather and the second the site file which containing information about the site (name, location). Formats of the two input files are well described in LARS-WG manual. These two files are prepared for each of the five station using all available precipitation data in each site (as stated in Table 1) before starting the analysis.
2. Analysis of site data: LARS-WG analyses the Observed daily weather for each site to compute site parameters. This information is stored in two files: the site parameters file and another file with some additional statistics. Both files are kept unchanged during the modelling process.
3. Generation: The site parameter file derived from observed weather data (step 2) is used to generate synthetic daily weather for each site which statistically resembles the observed weather. LARS-WG applies changes in climate derived from a global or regional climate model to generate site-specific daily weather with characteristics specified in the future global climate file.

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°

RESULTS AND DISCUSSION

LARS-WG calibration and validation

Test results for the capabilities of LARS-WG to model the seasonal observed precipitation 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 "Comment" 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 precipitation distribution 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 Table 4 showed no significant differences between the observed and simulated precipitation at all studied sites for most of the months, as shown in the "Comment" column in the table. However there are 2 significant differences at four sites during the summer months (June, July, and August) and month September; when LARS-WG was unable to replicate the observed precipitation, partly because this period is classified as a dry one.

From the results in Tables 3 and 4, it can be noted that LARS-WG is more capable in simulating both the seasonal distributions of the wet/dry spells and the daily distributions of precipitation in each month. These two properties (distribution of daily precipitation and dry /wet spell) are very important features to account for 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**					**Sulaimaniya**				
	Wet/Dry	N	K-S	P-Value	Comment	Wet/Dry	N	K-S	P-Value	Comment
DJF	wet	12	0.092	1.000	Perfect fit	wet	12	0.129	0.985	Perfect fit
	dry	12	0.086	1.000	Perfect fit	dry	12	0.053	1.000	Perfect fit
MAM	wet	12	0.068	1.000	Perfect fit	wet	12	0.073	1.000	Perfect fit
	dry	12	0.077	1.000	Perfect fit	dry	12	0.043	1.000	Perfect fit
JJA	wet	12	0.000	1.000	Perfect fit	wet	12	0.174	0.842	Very Good fit
	dry	12	0.261	0.359	Good fit	dry	12	0.174	0.842	Very Good fit
SON	wet	12	0.070	1.000	Perfect fit	wet	12	0.192	0.744	Very Good fit
	dry	12	0.094	1.000	Perfect fit	dry	12	0.114	0.997	Perfect fit
Season	**Rutba**					**Baghdad**				
DJF	wet	12	0.110	0.998	Perfect fit	wet	12	0.050	1.000	Perfect fit
	dry	12	0.071	1.000	Perfect fit	dry	12	0.157	0.916	Very good fit
MAM	wet	12	0.175	0.837	Very Good fit	wet	12	0.231	0.514	Good fi
	dry	12	0.120	0.994	Perfect fit	dry	12	0.068	1.000	Perfect fit
JJA	wet	12	0.174	0.842	Very Good fit	wet	12	0.913	0.000	Poor fit
	dry	12	0.095	1.000	Perfect fit	dry	12	0.130	0.984	Very good fi
SON	wet	12	0.110	0.998	Perfect fit	wet	12	0.108	0.999	Very good fit
	dry	12	0.103	0.999	Perfect fit	dry	12	0.078	1.000	Perfect fit
Season	**Basrah**									
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					

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 used here. Figure 2 shows plots of the monthly mean and standard deviation calculated from the observed and simulated precipitation in all the studied regions. Close examination of the plots in Figure 2 reveals a very good performance of LARS-WG 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 the months in the year, LARS-WG underestimates the standard deviation by 1.6-11.9 mm for all sites. But this is insignificant here as precipitation is not exactly normal at these 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 low variable precipitation in this site, compared to the other sites (cf. Table 3), made LARS-WG model to 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 relevant simulation results for the wet and dry spell lengths by LARS-WG are shown in Figures 3 and 4. Examination of Figures 3 and 4 shows LARS-WG 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

Table 4. KS-test for daily RAIN distributions

Singar					**Sulaimaniya**			
Month	N	K-S	P-Value	Comment	N	K-S	P-Value	Comment
J	12	0.070	1.000	Perfect fit	12	0.010	1.000	Perfect fit
F	12	0.058	1.000	Perfect fit	12	0.063	1.000	Perfect fit
M	12	0.067	1.000	Perfect fit	12	0.056	1.000	Perfect fit
A	12	0.061	1.000	Perfect fit	12	0.058	1.000	Perfect fit
M	12	0.100	1.000	Perfect fit	12	0.058	1.000	Perfect fit
J	12	0.478	0.006	Poor fit	12	0.261	0.359	Good fit
J	12	0.000	1.000	Perfect fit	12	0.348	0.096	Moderate
A	12	0.000	1.000	Perfect fit	12	0	1	Perfect fit
S	12	0.348	0.096	Moderate fit	12	0.348	0.096	Moderate
O	12	0.074	1.000	Perfect fit	12	0.151	0.937	Perfect fit
N	12	0.066	1.000	Perfect fit	12	0.058	1.000	Perfect fit
D	12	0.059	1.000	Perfect fit	12	0.057	1.000	Perfect fit
Rutba					**Baghdad**			
Month	N	K-S	P-Value	Comment	N	K-S	P-Value	Comment
J	12	0.347	0.097	Poor fit	12	0.110	0.998	Perfect fit
F	12	0.038	1.000	Perfect fit	12	0.024	1.000	Perfect fit
M	12	0.135	0.976	Perfect fit	12	0.048	1.000	Perfect fit
A	12	0.513	0.003	Poor fit	12	0.037	1.000	Perfect fit
M	12	0.051	1.000	Perfect fit	12	0.119	0.994	Perfect fit
J	12	0.522	0.002	Poor fit	12	0.500	0.004	Poor fit
J	12	0.000	1.000	Perfect fit	12	0.957	0	Poor fit
A	No precip				No precip			
S	12	0.566	0.001	Poor fit	12	0.397	0.038	Moderate fit
O	12	0.354	0.086	Good fit	12	0.049	1.000	Perfect fit
N	12	0.072	1.000	Perfect fit	12	0.03	1.000	Perfect fit
D	12	0.06	1.000	Perfect fit	12	0.063	1.000	Perfect fit
Basrah								
Month	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 precip							
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				

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 events of extreme intensity 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 mixed results of over and under estimation for the observed extreme values at all sites, however the orders of the observed extreme event magnitudes are reasonably represented by LARS-WG.

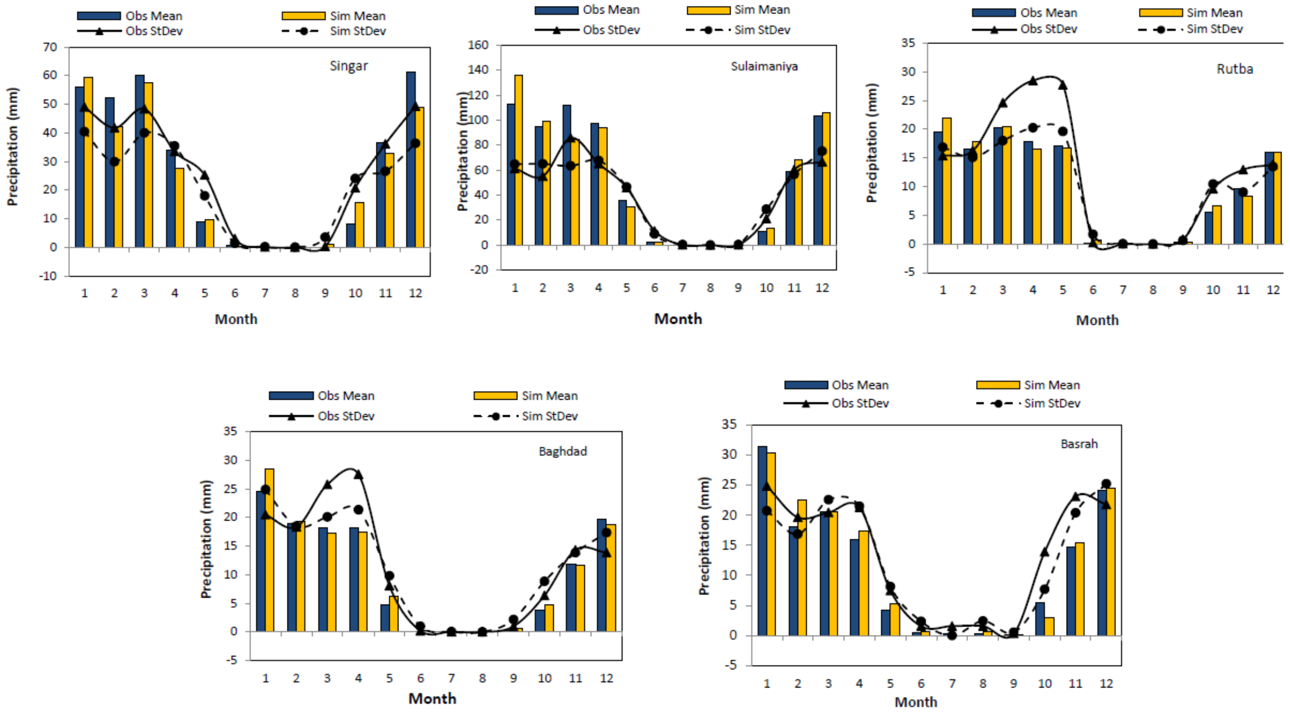

Figure 2. Monthly mean and standard deviation of the observed and simulated precipitation

Based on the above analyses and comparisons, it is highly probable to conclude that the LARS-WG model developed 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.

The adequate performance of LARS-WG in replicating the observed precipitation in this study clearly indicates that the software is suitable for use in the Middle East. Similar adequate performance in generating precipitation has been found for LARS-WG in different parts of the world, as documented in Semenov et al (1998) and Charlie & Koch (2013), which increase confidence in using the downscaling model in this study.

Projection of Future Precipitation

The LARS-WG model developed for each site was used to predict future daily precipitation in the site for periods 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 precipitation 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 its amount of precipitation and temperature. The mechanism by which altitude can contribute to increasing amount ofprecipitation is by forcing more air over the higher ground which help it to cool and causing the moist air to condense and fall as precipitation. The plots for future changes in seasonal precipitation

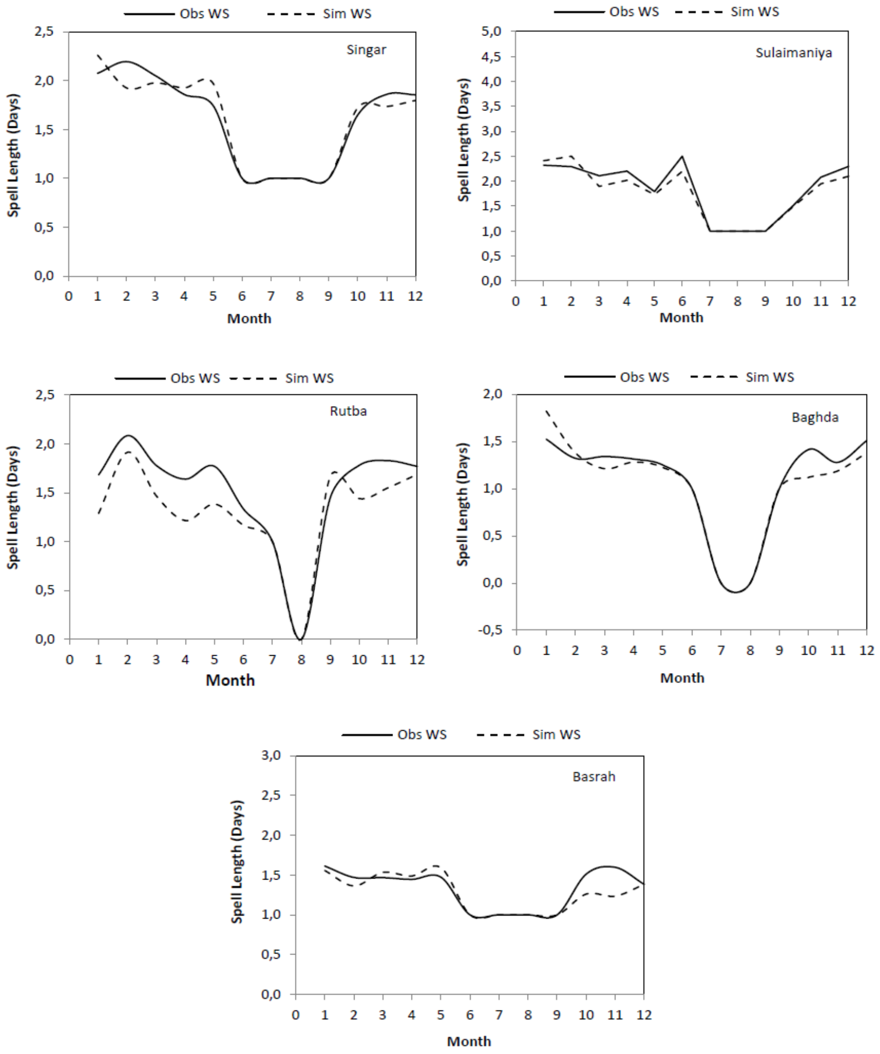

Figure 3. Comparison of observed and simulated average wet spell lengths at the studied sites

for the same site in Figure 7, show that most of the increase in precipitation would be during the autumn season and the reduction would mainly be during the winter and spring seasons as projected by the ensemble of the seven GCMs. So, although there would be no or minor change in the total annual precipitation in the site, however seasonally, the site is projected to undergo minor stress in its main water resource and thus planners must be alerted to this.

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

Rutba and Baghdad are the only two regions in which all the seven GCMs agree that there will be a decrease in the precipitation for the 2080-2099 period and a mixed projection of no change and increase in the other near and medium future periods (cf. Figure 6) with the changes varying among the

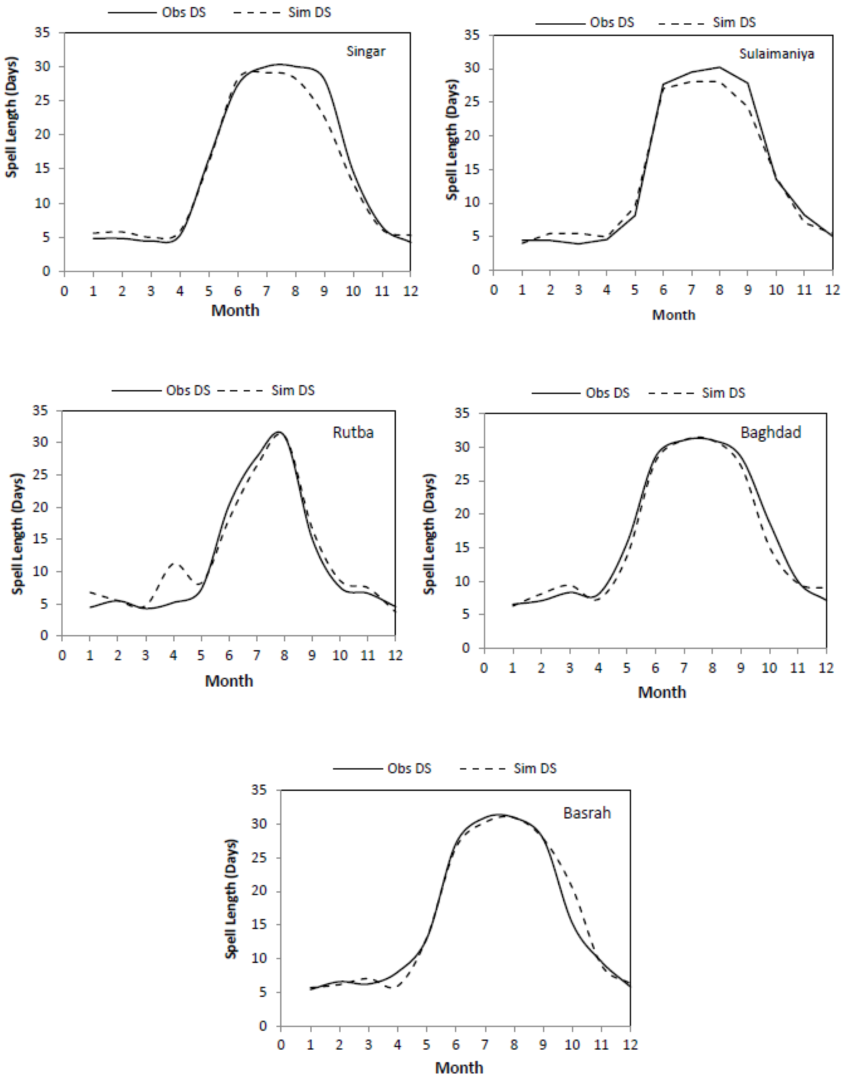

Figure 4. Comparison of observed and simulated average dry spell lengths at studied sites

different GCMs. For the Basrah region, all the seven GCMs project relatively no change in annual precipitation in the three future periods (cf. Figure 6).

A clearer picture for the variation of annual mean precipitation is projected to emerge in the future period 2080-2099 in all studied regions, as all the seven GCMs predict a decrease in the annual mean precipitation. The decrease amount varies amongst the sites due to variation in their geographical features.

The change in the seasonal precipitation for each site is represented here as a 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 4 mm in Basrah to 14 mm in Baghdad. The projections for other seasons vary between slight increases to decrease of few mms.

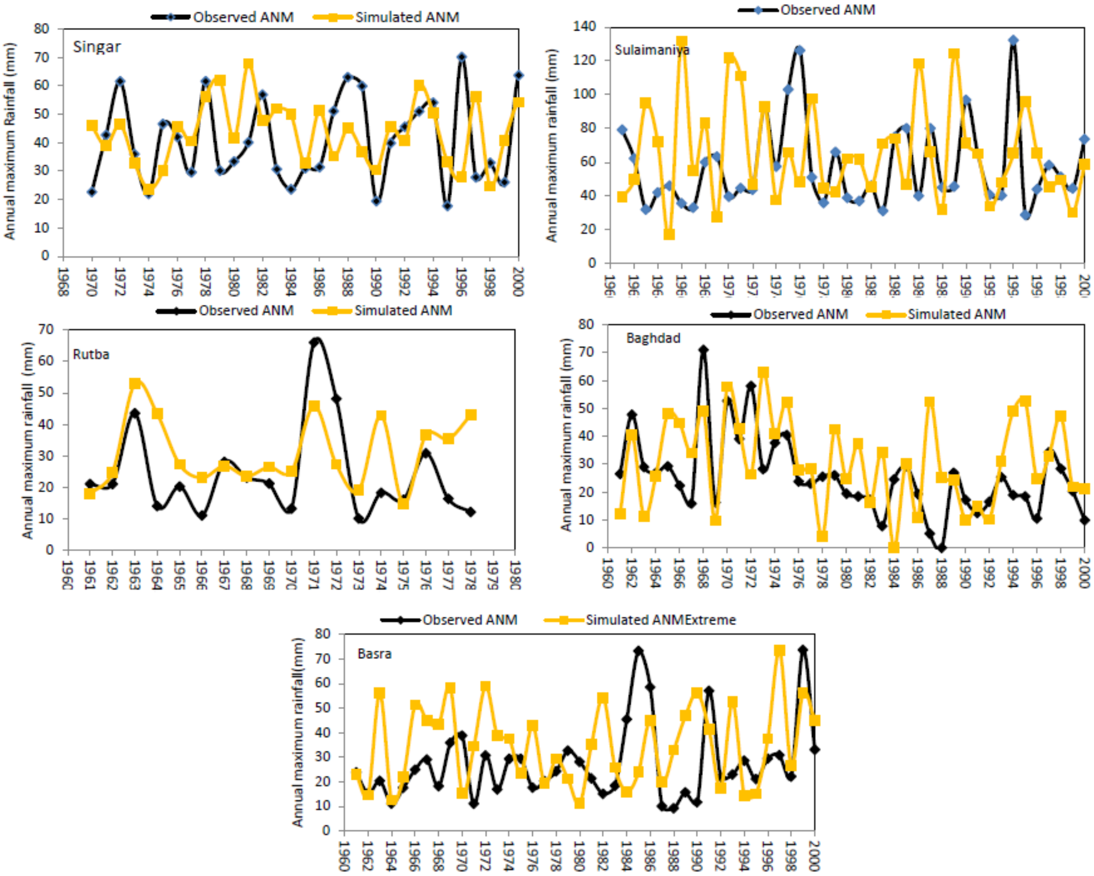

Figure 5. Comparison of observed and LARS-WG simulated annual maximum series

CONCLUSION

This paper presented results for changes on projected future precipitation in arid environment of Iraq using five sites to represent different climatic regions across the country. The aim was to establish an understanding for the relationship between water resources in the region and climate change. LARS-WG stochastic weather generator was used to downscale and model the present and future precipitation. IPCC SRES Scenario A2 of greenhouse emission simulated by seven GCMs was used to project precipitation for three future periods (2011-2030, 2046-2065 and 2080-2099).

Suitability and capability of LARS-WG to model precipitation in the region has been shown by the adequate calibration results obtained. This gives confidence in using the model for downscaling and modelling precipitation in this hot part of the world and on the results obtained in the study.

Results of projected precipitation obtained from the impact models showed mixed pictures for precipitation at the studied sites. On an annual scale, precipitation in four of the five studied sites (Singar, Sulaimaniya, Baghdad and Rutba) is projected to decrease by most of the GCMs in the far future period 2080-2099. Whilst precipitation in the same sites are projected to have no or minor changes of increase or decrease in the near (2011-2030) and medium (2046-2065) futures periods.

Results of precipitation projection in the Basrah site is somewhat different as it almost maintains the same pattern of present precipitation in the three future periods with no or minor changes.

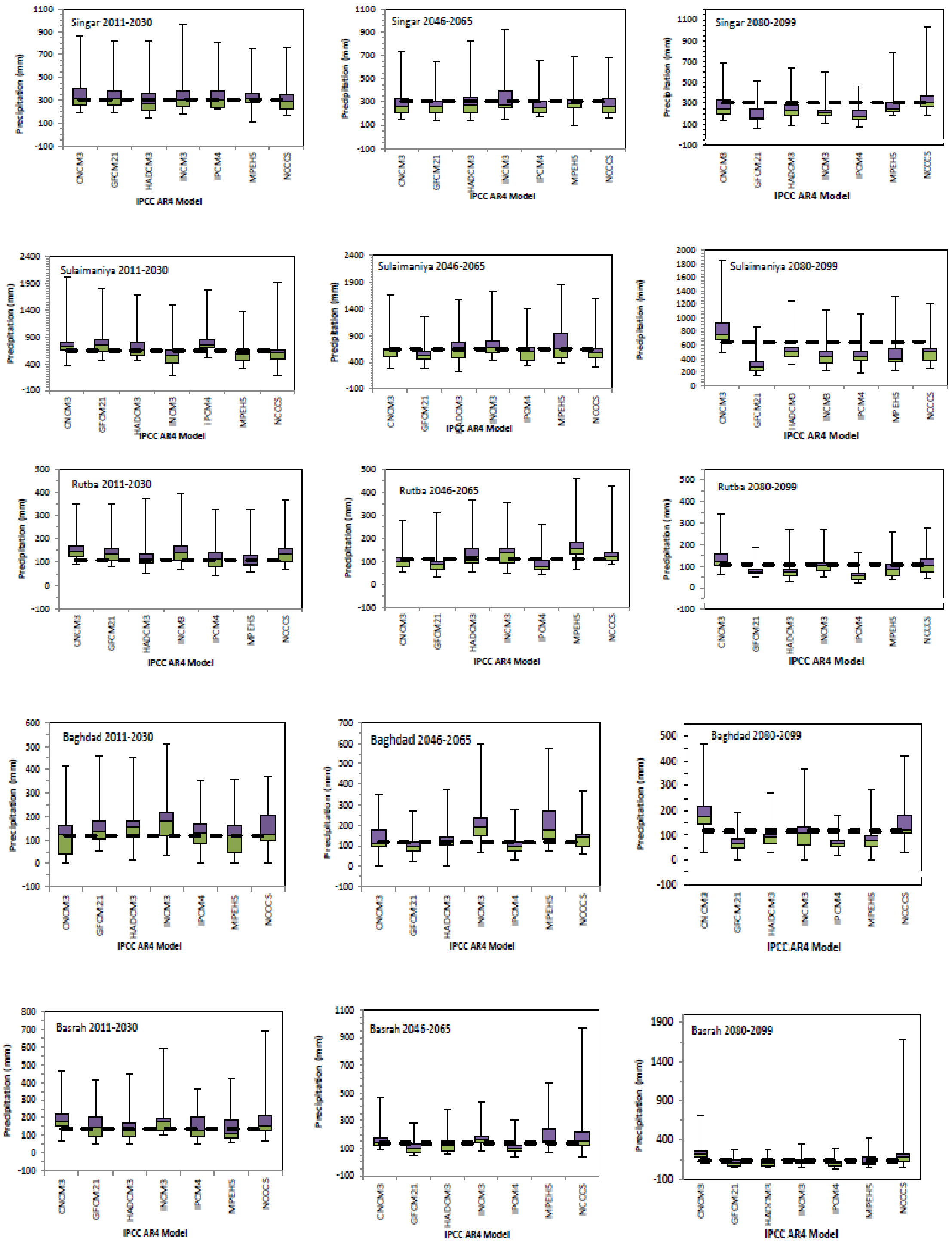

Figure 6. Box-whisker plots for change in future precipitation in the studied sites downscaled from 7 GCMs by LARS-WG during the future periods compared to the baseline period shown as a dashed line. In these plots the minimum, maximum, median and percentiles (green box for 25 percentile and purple box for 75 percentile) of precipitation from each GCM.

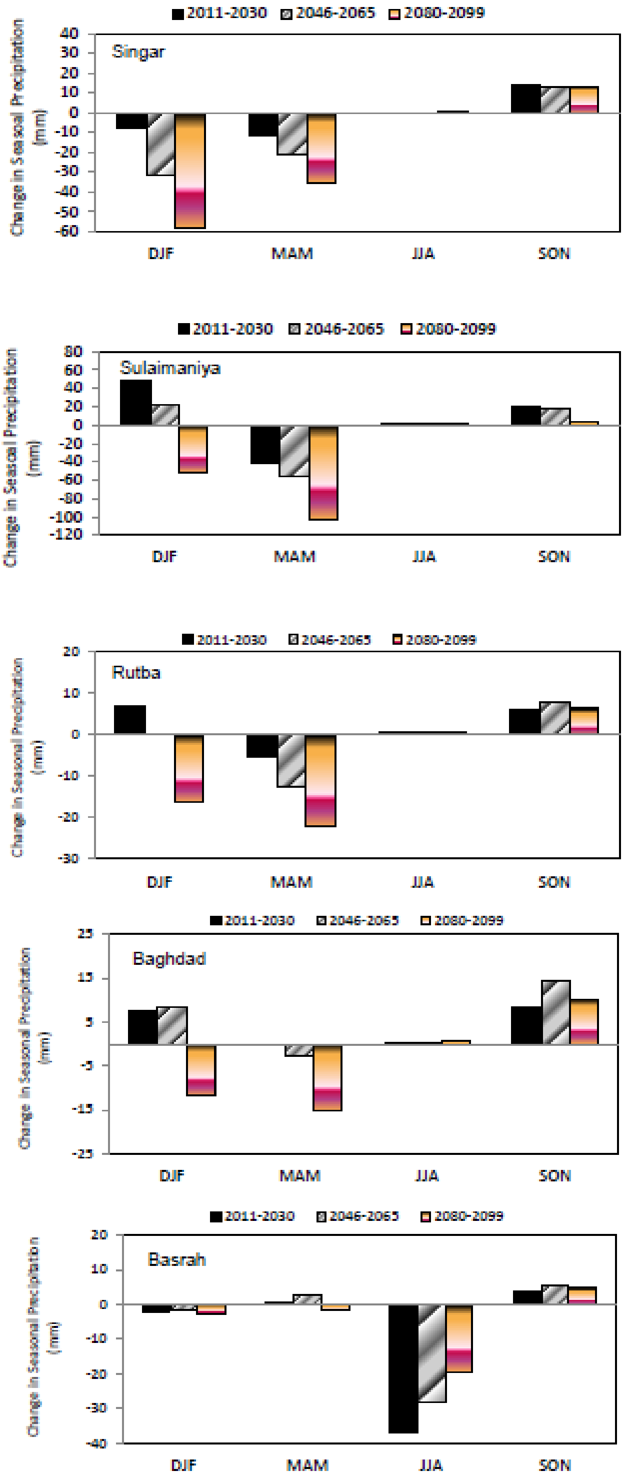

Figure 7. The differences of precipitation between the future periods and the baseline period in the studied sites

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 an annual scale, precipitation in four of the five studied sites (Singar, Sulaimaniya, Baghdad and Rutba) is directions. If the suggested changes in precipitation are realised, then large sectorial impacts of these changes are likely to be felt in Iraq.

As this study is among the first in the region, there is no current information in the literature to compare with, however, the general pattern of the results obtained is in agreement with the IPCC reports AR4 and AR5 on the impacts of climate change on the region water resources.

The results from this study, as informed by the objectives set out earlier, have helped to form an understanding for the future pattern of precipitation in this part of the world, which is the primary source for water in the region. This understanding would be beneficial to water resources planners in these regions to inform their strategies for managing resources in the country.

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