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International Journal of Environmental Science and Technology

ISSN 1735-1472
Volume 10
Number 1

Int. J. Environ. Sci. Technol. (2013)
10:27-36
DOI 10.1007/s13762-012-0096-9

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ORIGINAL PAPER

Adaptation of climate variability/extreme in arid environment of the Arabian peninsula by rainwater harvesting and management

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Received: 7 April 2011 / Revised: 5 November 2011 / Accepted: 3 March 2012 / Published online: 10 July 2012

Abstract Water management in Saudi Arabia is facing major challenges due to the limited water resources and increasing uncertainties caused by climate change. The rainfall and temperature records of the Saudi meteorological data for more than three decades were analyzed for policy suggestions in water sectors based on the changing rainfall patterns. The trends in the annual aridity and rain indices were also examined to define the changing climate conditions and for determining the dry months in different cities of the Kingdom. An increased annual and maximum rainfall was observed for six cities while a decreasing trend in both annual and maximum rainfall was observed for the same number of cities highlighting the variability of rainfall in the whole region. An increasing maximum rainfall with decreasing annual rainfall was observed for the rest of the cities signifying the more extreme rainfall evens and resulting floods of short durations. The changing rainfall trends were also observed for different months during 31 years of the recorded period in addition to the varying climate pattern for different cities within the same district. Finally, these preliminary assessments of any systematic changes in view of the increased rain intensities and extreme climate events are viewed to demonstrate the value rainwater harvesting and management as a local adaptation to the climate variability and extreme in the Kingdom.

Keywords Climate change · Rain intensities · Rainwater harvesting · Saudi Arabia · Water resources

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Introduction

Saudi Arabia is located in one of the driest regions in the world with an average annual precipitation ranging from 80 to 140 mm, except for the southwestern mountains (Alkolibi 2002). Also, the rainfall is highly variable on both monthly and yearly basis and annual totals are sometimes exaggerated by occurrence of a few high rainfall events (Elagib and Addin Abdu 1997). Water resources, which are already very few in this arid country, will be further stressed due to the predicted climate change (Ferrari et al. 1999). General Circulation Models (GCMs), the most reliable predictors of climatic change (Mintzer 1993), indicate that the Saudi Arabia will experience a decrease in the water supply in future. Schmandt and Clarkson (1992) also predicted the reduced likelihood of rainfall in this region based on GCMs indicating the decreased variability in precipitation. The worldwide construction of new dams can increase the accessible runoff by about 10 % over the next 30 years, whereas the population is projected to increase by more than 45 % during the same period (Pandey et al. 2003; Postel et al. 1996). With climate change representing a major challenge for urban water planning and increased risk of flooding, there is a need of adaptive management, collaboration of different professionals and public engagement in water planning (Arnbjerg-Nielsen and Fleischer 2009; Fane and Turner 2010). Finally, given the fact of extreme climate events in the form of increased rainfall intensities (Kleidorfer et al. 2009), rainwater harvesting (RWH) can be considered crucial for flooding control and mitigating the drought effects. Water harvesting to reduce the rainwater runoff through maintenance of the abandoned and damaged terraces was practiced in the past to grow food and other crops in Saudi Arabia (El Atta and Aref 2010). RWH for supplying drinking water for urban areas has a long history in semi-arid areas (Abdelkhaleq and Ahmed 2007; Pandey et al. 2003). Building dams to tap stream water and storing in reservoirs was done by ancient Jordanians, about 5,000 years ago, to provide drinking water to the old city of Jawa (Abdelkhaleq and Ahmed 2007). Case studies in semi-arid areas have shown that collection of rainwater through construction of dams to recharge groundwater has increased groundwater level, for example, by 2 m in India (Raju et al. 2006) and by more than 7 m in United Arab Emirates (Murad et al. 2007). The same technique has largely been used for some time in the arid and semi-arid areas of the Arab world and more than 650 dams were built in Saudi Arabia, Oman, Qatar and United Arab Emirates to increase groundwater for urban areas and for protection from flash floods (Murad et al. 2007). Sendil et al. (1990) and Al-Muttair et al. (1994) have also suggested ways to improve the efficiency of reservoir recharging in Saudi Arabia.

Roof catchment is an old method of RWH that has widely been used to provide urban dwellers with potable water supply in many parts of the developing world (Handia et al. 2003; Kumar 2004; Preul 1994; Thomas 1998). The usage of such systems is growing (Amin and Han 2007; Han 2007) and is receiving an increased attention worldwide as an alternative source of potable (Dillaha and Zolan 1985; Handia et al. 2003; Heyworth et al. 2006; Pinfold et al. 1993) as well as non-potable water supplies (Hatibu et al. 2006; Ghisi and Ferreira 2007; Meera and Ahammed 2006; Olem and Berthouex 1989; Simmons et al. 2001). The use of rainwater in domestic hot water systems can produce optimal environmental and economic results for urban water cycle management (Spinks et al. 2006; Sturm et al. 2009). A recent case study in Sudan has shown RWH to provide an additional source of drinking water in a changing physical environment associated with urban population growth (Ibrahim 2009). In Palestine, RWH systems have shown to reduce the annual environmental impact of the in-house water usage by about 40 % (Nazer et al. 2010). RWH is an entirely new water supply, quite apart from existing surface and ground water supplies, rather than a conservation technique (Critchley and Siegert 1991). Many regions around the world are adopting RWH to reduce the impact of climate change on water supply. There are many reasons for the adoption of RWH to overcome the increasing demand of water besides the climate changes (Jackson et al. 2001). The goal of this paper is to identify the changing pattern of rainfall in different cities of the Kingdom of Saudi Arabia based on the climate data of 31 years (from 1980 to 2010) and highlight the need of rooftop RWH systems for harvesting and managing rainfall. The analysis was performed by the year 2011 to predict any signs of climate change during period of more than three decades in the Kingdom of Saudi Arabia. Overall, the paper aims to contribute to the ongoing development of environmentally sound and economically viable approaches to water management in Saudi Arabia.

Materials and methods

Data collection and sites descriptions

To investigate the existence of any sign of climatic changes in Saudi Arabia, the climatic data of temperature and precipitation during the period 1980–2010 were analyzed. The study incorporates the daily total rainfall and daily minimum, maximum and average temperatures for 31 years. The data analyzed in this study were recorded at 29 different locations or stations covering the wide areas of all 13 districts in the Kingdom including the eastern, western and central part of the country, and the northwest. Nineteen stations were selected to investigate the trend in rainfall variations and the spatial distribution of these stations covers wide areas of the country, as shown in Fig. 1, which represents the three-layered map of Saudi Arabia showing the topography and districts (ElNesr et al. 2010).

The weather stations studied are presented in Table 1. These stations are numbered according the changes in the rainfall trends that is explained in the following sections. The climatic data covered 31 years of daily meteorological records for 17 stations and 26 years for the remaining 2 stations (AlBaha and Najran). The data could not be recorded during the first 5 years at these two stations due to some technical problems and hence has not been included in the analysis.

Statistical analysis

The monthly and annual means and standard deviations were calculated by simple and known statistical methods. The magnitudes of the trends of increasing or decreasing rainfall were derived from the slope of the regression line using the least squares method. This trend was also supported by the Durbon–Watson (D–W) statistic which is used to test for autocorrelation (Montgomery et al. 2001). The D–W co-efficient (co-eff.), '*D*', is calculated using the Eq. (1).

$$D = \frac{\sum_{i=2}^{n} (e_i - e_{i-1})^2}{\sum_{i=2}^{n} e_i^2} \quad (1)$$

where 'n' is the number of observations and $e_i = y_i - \hat{y}_i$ and y_i and $\hat{y}_i$ are, respectively, the observed and predicted values of the response variable for individual 'i'. 'D' becomes smaller as the serial correlations increase. The upper and lower critical values, dU and dL, for $n = 31$ (total number of recorded years from 1980 to 2010), $k = 1$ (one independent variable, i.e., rainfall) and 5 % significance, were takes as

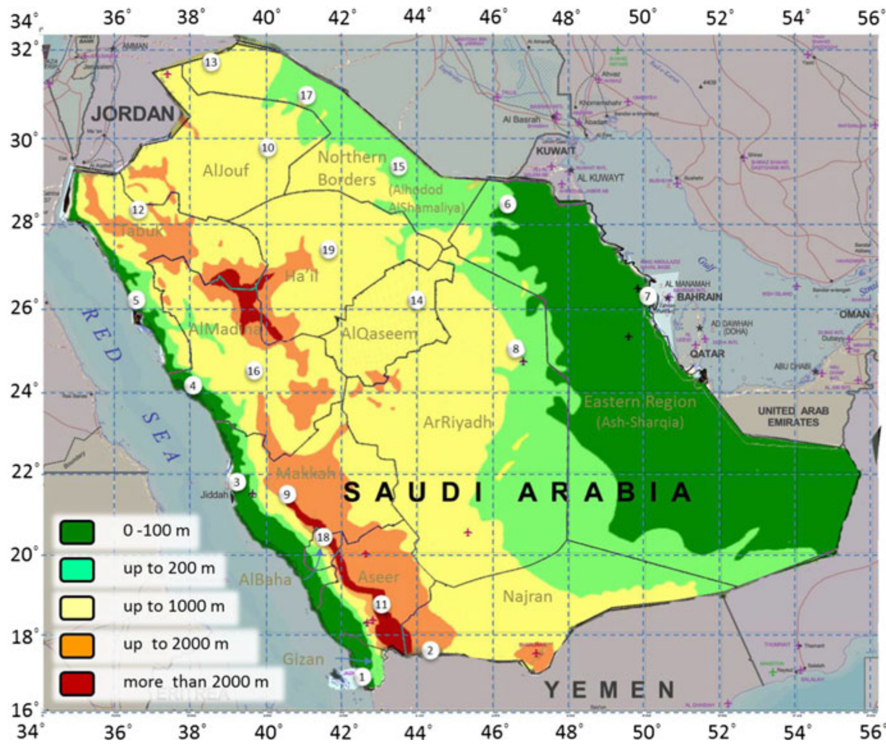

Fig. 1 Three-layered map of Saudi Arabia showing the investigated meteorological stations

1.496 and 1.363, respectively, from the D–W table (Savin and White 1977).

Because, most of the regression problems involving time series data exhibit positive autocorrelation, the hypotheses usually considered in the D–W test are;

H_0: $p = 0$ (residuals are not correlated)
H_1: $p > 0$ (autocorrelation is present)
If $D < \mathrm{d}L$ reject H_0: $p = 0$
If $D > \mathrm{d}U$ do not reject H_0: $p = 0$
If $\mathrm{d}L < D < \mathrm{d}U$ test is inconclusive.

The possible range of 'D' is between 0 and 4 and for H_0 to be true; 'D' should be close to 2. A value <2 may signal positive autocorrelation while 'D' >2 may signal negative autocorrelation. In this study, the D–W test statistic 'D' was calculated using the PHStat software in Microsoft Excel 2007.

Rain and aridity indices

The rain index (RI) defining the dry period of the year was calculated using the Eq. (2). The equation is proposed by Bagnols and Gaussen (UNESCO 1977) and is already used for analysis by Elagib and Addin Abdu (1997):

$$\mathrm{RI} = P/T \tag{2}$$

where 'P' is the long-term (i.e., over entire period of data collection) mean monthly precipitation in millimeters and 'T' is the mean monthly temperature in °C. Another parameter, Aridity index (AI) is also evaluated in this paper which can more or less define the permanent climate (Elagib and Addin Abdu 1997). The AI, characterized by the dearth of water (Parry 1986) or by scarcity of water can be estimated as follows (Kamil 1983):

$$\mathrm{AI} = P_\mathrm{A}/T_\mathrm{A} \tag{3}$$

where 'AI' is Lang's Index, 'P_A' is the mean total annual precipitation, and 'T_A' is the mean annual temperature.

Results and discussion

The daily total rainfall data of 31 years was used to calculate the monthly mean, monthly total, the annual total and annual maximum rainfall while mean monthly and mean annual temperature was calculated from the data of daily temperature records of 31 years. These parameters were used further to derive the monthly and annual rainfall trends and for deriving the rain and aridity indices. Both time series and regression analysis were performed for statistical significance of the data and D–W co-eff. was used to validate the analysis. A 5-year centered moving average technique was also employed. In this technique, each value of the actual observation is replaced by the average of the sum of the value itself plus the two preceding and the two subsequent values.

Table 1 Detailed information of the 19 meteorological stations

Station coordinates			City (district)	Stn. #
Altitude (m)	Longitude (East)	Latitude (North)		
3	42.35	16.54	Gizan (Gizan)	1
1,210	44.26	17.37	Najran (Najran)	2
17	39.12	21.3	Jeddah (Makkah)	3
6	38.04	24.09	Yenbo (AlMadina)	4
21	36.28	26.12	AlWajh (Tabuk)	5
358	46.13	28.32	AlQaisoomah (Eastern Region)	6
17	50.1	26.16	AdDhahran (Eastern Region)	7
624	46.77	24.63	AlRiyadh (AlRiyadh)	8
1,454	40.33	21.29	Taif (Makkah)	9
671	40.06	29.47	AlJouf (AlJouf)	10
2,057	42.48	18.18	Khamis Mushait (Aseer)	11
776	36.38	28.22	Tabuk (Tabuk)	12
818	38.4	31.41	Turaif (Northern borders)	13
650	43.46	26.18	AlQaseem (AlQaseem)	14
447	43.29	29.38	Rafha (Northern borders)	15
636	39.42	24.33	AlMadina (AlMadina)	16
600	41	31	Ar'ar (Northern borders)	17
1,652	41.63	20.3	AlBaha (AlBaha)	18
1,013	41.41	27.26	Ha'il (Ha'il)	19

Annual total and maximum rainfall trends

Five-year centered moving average and regression analyses covering the 31-year period from 1980 to 2010 for each of the 19 stations were applied to the annual and monthly total and maximum rainfall. Figure 2 represents the linear regression models for the 5-year centered moving average of the annual total and maximum rainfall at in capital city (Riyadh). In Fig. 2, solid and dotted lines represent the regression model lines for the annual total and annual maximum rainfall, respectively. The maximum of total annual rainfall, about 250 mm, was received in 1995 while the minimum of 18 mm in the year 1999. There were only three occasions when the rainfall was more than 150 mm, i.e., during the years 1993, 1995 and 1997 (Fig. 2). The records for the total annual rainfall do not show any signs of increase or decrease in precipitation in 31 years of study period (1980–2010). There were, however, signs of increased rainfall with respect to the annual maximum 1-day rainfall, during this period. Figure 3 represents the linear regression models for the 5-year centered moving averages of the annual maximum 1-day rainfall expressed as percentage of the annual total rainfall and for the percentage distribution of the total rainfall in Riyadh during 1980–2010.

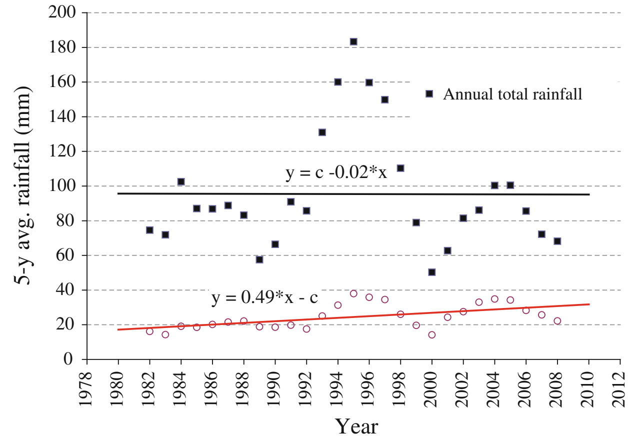

Fig. 2 Linear regression models for the 5-year centered moving averages of the annual total and annual maximum 1-day rainfall in Riyadh during 1980–2010

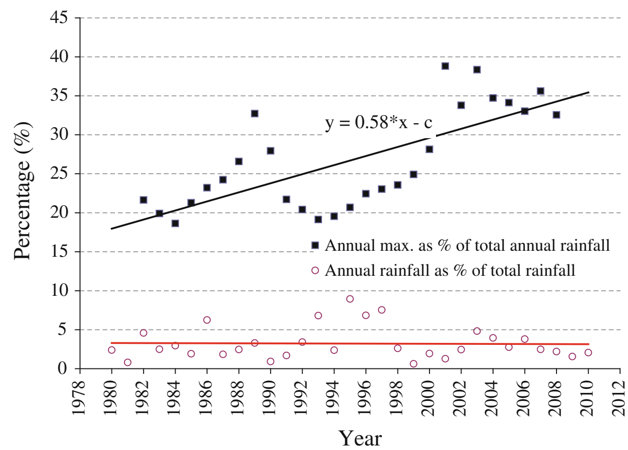

Fig. 3 Linear regression models for the 5-year centered moving averages of the annual maximum 1-day rainfall expressed as percentage of the annual total rainfall and total annual rainfall as percent of total rainfall in Riyadh during 1980–2010

It is evident from Fig. 3 that maximum 1-day rainfall increased over the period of last three decades showing an increase in the rainfall intensity or the duration of the single rainfall event. A noticeable rise can be observed with $R^2 = 51$ % and $F = 0.002$—a significant value. In Riyadh, the annual 1-day maximum rainfall of 50 mm or above occurred only on one occasion, i.e., in the year 1995 during the data reporting period. The annual percentage of the total rainfall remained almost constant throughout the recording period of 31 years, as is clear from Fig. 3 (dotted line).

Table 2 Slope values and '*D*' for the regression lines of annual total and daily maximum rainfalls

D–W co-eff.		Slope values		City	Stn. #
Annual max.	Annual total	Annual max.	Annual total		
2.200	1.825	1.30	3.19	Gizan	1
1.937	1.919	0.72	1.72	Najran	2
2.076	1.803	1.01	1.64	Jeddah	3
2.063	1.523	0.52	0.69	Yenbo	4
1.641	1.493	0.41	0.66	AlWajh	5
1.863	1.671	0.30	0.15	AlQaisoomah	6
2.161	2.267	0.29	−0.11	AdDhahran	7
1.764	1.500	0.40	−0.14	AlRiyadh	8
1.822	1.830	0.24	−0.26	Taif	9
1.616	1.876	0.25	−0.32	AlJouf	10
2.039	1.627	−0.25	−0.38	Khamis Mushait	11
1.742	1.798	−0.24	−0.68	Tabuk	12
2.413	2.542	0.06	−0.95	Turaif	13
2.132	2.026	0.40	−1.61	AlQaseem	14
2.008	1.566	0.02	−1.71	Rafha	15
2.268	2.060	−0.06	−1.14	AlMadina	16
2.000	2.001	−0.25	−1.76	Ar'ar	17
1.915	1.609	−0.44	−3.02	AlBaha	18
1.716	2.133	−0.60	−3.12	Ha'il	19

The coefficient of determination (R^2) for the linear correlation between time and rainfall for both annual total and maximum 1-day rainfall was insignificant. Despite these small values, however, a statistically significant correlation can be considered since the D–W co-eff. was greater than the upper critical value, i.e., $D > 1.496$ for both parameters (Table 2, stn. #1–6).

A noticeable result of the rainfall analysis was that the data for later years included records of high levels of annual maximum rainfall; however, there has been no strong and clear increase in annual total rainfall at Riyadh during the reporting period. This was not surprising since research has concluded that indications of climatic change are less than certain in many parts of the world, including Saudi Arabia (Hansen et al. 1998). For six cities of the Saudi Arabia (Gizan, Najran, Jeddah, Yenbo, AlWajh and AlQaisoomah) an increasing trend in both total annual and maximum 1-day rainfall was observed, as shown in Table 2 (stn. #1–6). This increasing trend is predicted based on the slope values of the linear regression models for both parameters. The significance of the trends was statistically validated with the reasonable values of D–W co-eff. except for the regression analysis of the annual total rainfall in AlWajh, where $dL < D < dU$. A maximum increase in both annual total and maximum 1-day rainfall was observed at Gizan while the minimum increase in both of these parameters was seen at AlQaisoomah. These trends demonstrate an increase in the annual total rainfall in two districts of Gizan and Najran in addition to an increase in the duration of rainfall or rainfall intensity at both these districts. This combination of wetter antecedent conditions and larger rainfall events would result in more runoff being generated. A decreasing rainfall trend was observed for Khamis Mushait, Tabuk, AlMadina, Ar'ar, AlBaha and Ha'il, where a decrease in both annual total and maximum 1-day rainfall was observed during the reporting period as is clear from the slope values of the linear regression lines in Table 2 (stn. #11, 12 and 16–19). Again, the regression analysis was significant in ease case with '*D*' values of about 2 and higher. Both Yenbo and AlMadina are situated in one district, i.e., AlMadina but a different rainfall trend at both places highlights the climate variability within one district. In Yenbo (Table 2, stn. #1–6), an increased annual total and maximum 1-day rainfall was seen while in AlMadina (Table 2, stn. #11, 12 and 16–19), a decreasing trend was observed. A maximum decrease in both annual total and maximum 1-day rainfall was observed in Ha'il. Table 2 (stn. #7–10 and 13–15) represents somewhat different rainfall patterns than mentioned earlier and hence more climate variability for the remaining seven cities of the Kingdom. In these cities, total annual rainfall decreased over the period of 31 years but an increase in annual maximum 1-day rainfall was monitored. In Riyadh and AlQaseem, a maximum increase in annual maximum 1-day rainfall intensity or increased rainfall duration was seen while an insignificant increase in maximum 1-day rainfall was observed for both Turaif and Rafha (slope values of regression lines in Table 2, stn. #7–10 and 13–15). This phenomenon could be attributed to the enhanced greenhouse effect. Accordingly, less rainfall is projected with the possibility of a slight increase in interannual variability and this would result in a decrease in flows and an increase in flow variability. The regression analysis was significant in ease case with '*D*' values of about 2 in most of the cases. Notwithstanding the localized nature of this country, the similar rainfall trends have also reported in other parts of the world, i.e., less, but more intense rainfall (Van Wageningen and du Plessis 2008; Lumsden et al. 2009). By comparison the rainfall trends among Turaif, Rafha and Ar'ar, climate variability within one district was demonstrated since these three cities are situated along the Northern borders of the Saudi Arabia. The similar climate variability within a district was also demonstrated for three more districts, i.e., Makkah, Tabuk and Eastern when a comparison of rainfall trend between Taif, Tabuk and AdDhahran (Table 2, stn. #7–10 and 13–15) was performed with that of the rainfall trend in Jeddah, AlWajh and AlQaisoomah (Table 2, Stn. #1–6), respectively.

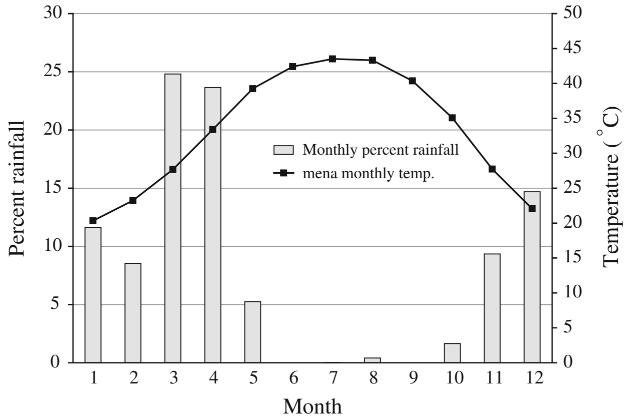

Fig. 4 Monthly rainfall as percent of the total annual rainfall and mean monthly temperature in different months at Riyadh during 1980–2010

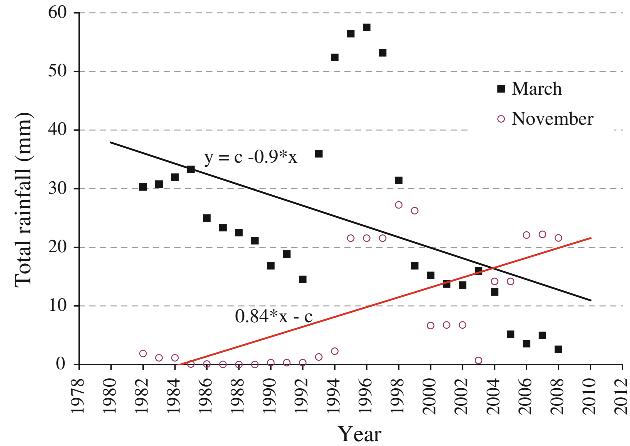

Fig. 5 Monthly 5-year centered moving averages of the total annual rainfall in March and November in Riyadh during 1980–2010

Monthly variation in precipitation

Figure 4 represents the percent distribution of the total rainfall (presented as bars) and mean temperature (presented as solid line) during different months over the observed period of 31 years at Riyadh. There was very little rainfall in June and August while July and September can be regarded as totally dry months.

Most of the rainfall occurred in March and April then in December and January followed by November, February and May. The maximum of mean temperature, about 43 °C, was observed in August while the minimum of about 20 °C was recorded in January during the recording period of 31 years. The maximum of monthly rainfall, about 109 mm, was collected in March 1995. The seasonal pattern of rainfall shows that only 2 % of the total rainfall during 1980–2010 occurred in August and October while almost half of the total rainfall was observed during March and April (Fig. 4). Twelve regression models (one for each month) were produced for the 5-year centered moving averages of the rainfall data during the period of 1980–2010 each at Riyadh and other cities. Figure 5 represents the linear regression models for the 5-year centered moving averages of the monthly rainfall in March and November rainfall at Riyadh. Two different rainfall trends were observed with an increasing total rainfall in November and a decreasing total rainfall in March during the observed period. These trends demonstrated the significant increase in total rainfall in November with $R^2 = 41$ % and $F = 0.001$—a significant value. It can be seen concluded from this analysis that the rainfall is highly variable on both monthly and yearly scales in Saudi Arabia. Furthermore, it is characterized by high seasonality with annual totals, sometimes, exaggerated by occurrence of a few high rainfalls (Elagib and Addin Abdu 1997).

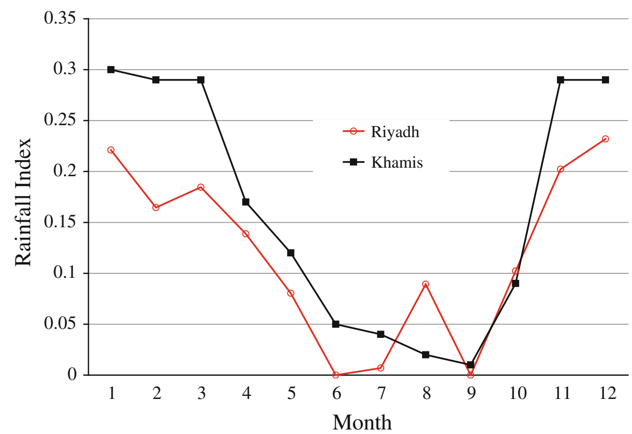

Fig. 6 Rainfall index variation with mean monthly rainfall in Riyadh and Khamis Mushait during 1980–2010

Dry periods and rain index

The RI which signifies the dry period of the year over the entire span of 31 years was calculated for each city and the results are shown only for Riyadh and Khamis Mushait in Fig. 6. The trend in RI at Khamis Mushait was presented due to the fact that the total rainfall in Khamis Mushait was almost double than that at Riyadh over the reporting period of 31 years. Equation (2) was used to calculate the AI. The maximum value of P/T, 0.23 was obtained in the month of December. It is clear from Fig. 6 that the values of RI always remained <2 which means that all months can be regarded as dry in Riyadh. June, July and September remained almost dry while there was some rainfall in August. The dryness decreased from September to December and then increased afterward up to May and remained almost constant at maximum value for 4 months up to September.

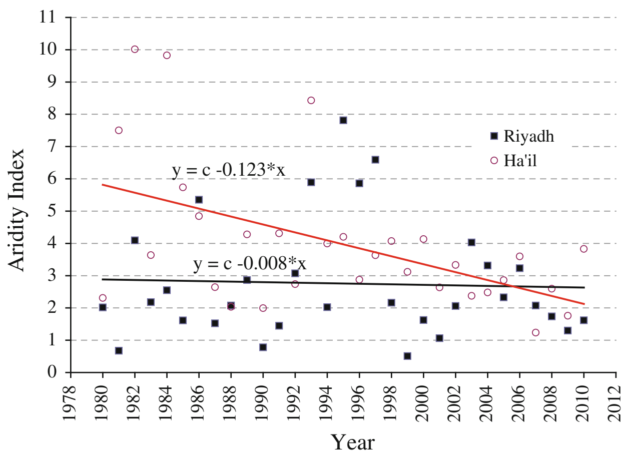

Fig. 7 Aridity variation with mean annual rainfall in Riyadh and Ha'il during 1980–2010

Aridity index for climate pattern

The AI can more or less define the permanent climate and is characterized by the deficiency of water. The AI was calculated using Eq. (3). Figure 7 shows the AI variations with time (years) in Riyadh and Ha'il. The results of AI in Ha'il were presented due to the fact that the maximum decrease of the rainfall was observed in Ha'il over the reporting period of 31 years (Table 2, stn. #11, 12 and 16–19).

The linear regression equation fitted to the 31 years data for Riyadh is shown in Fig. 7 with a significant '*D*' value of 1.584 (Table 3). It is apparent from Fig. 7 that an insignificantly decreasing trend, which could be considered as constant, was obtained in annual AI values over the reporting period. This could be in accordance with the insignificant decreasing trend of annual total rainfall in Riyadh (Fig. 2). The AI variations, however, do not follow the rainfall trend for many cities when comparing the slope values of linear regressions models for all 19 cities (Table 3) with that of the corresponding slope values for rainfall trends in Table 2. The statistical significance of the slope values is highlighted by the corresponding '*D*' value for each city, as shown in Table 3, which was well above the upper critical limit, i.e., $D > 1.496$, except for AlWajh. Although, AI variations were not in accordance with the rainfall trends, however, it is well understood that rainfall is the main source of water on the planet and hence can be treated as the most indicative parameter of water shortage or surplus.

Response and policy

With increasing rainfall intensities and likelihood of the future rainfall variability in Saudi Arabia, it is important that policy makers take into account the effects of climate extremes and variability on water resources (Mukheibir 2007). Most visible effects of climate change in Saudi Arabia include the increased flooding and prolonged droughts. Although, the rainfall is not high in this region but the increased rain intensities have resulted into severe short-duration floods and damage in well-developed urban areas. In one of the several cases, it has even resulted in four deaths in Kingdom's second largest city (Jeddah) due to the flooding caused by high intensity rainfall of longer duration (AlJazeera 2011). One of the reasons for the resulting damage due to short-duration flooding could be the designing of the drainage systems in these cities which is based on dry weather of the country. So, a single rainfall event of higher intensity or longer duration can destroy the infrastructure and cause the economical disaster. RWH can play a vital role for flood management by holding back the storm water runoff in addition to solving the problems of water shortages at household level. The results of rainwater use in the rural township of Western Australia has shown rainwater tanks much more effective in intercepting roof runoff with the maximum stormwater reduction of about 50 % (Zhang et al. 2010).

Table 3 Slope values and 'D' for the regression lines representing the aridity indices

D–W co-eff.	Slope	City	Stn. #
1.825	0.089	Gizan	1
1.919	0.048	Najran	2
1.803	0.045	Jeddah	3
1.523	0.017	Yenbo	4
1.493	0.020	AlWajh	5
1.584	−0.008	AlRiyadh	8
1.671	−0.010	AlQaisoomah	6
2.263	−0.015	AdDhahran	7
1.938	−0.016	AlJouf	10
1.872	−0.023	Taif	9
1.889	−0.026	Tabuk	12
1.608	−0.031	Khamis Mushait	11
2.069	−0.037	AlMadina	16
2.608	−0.049	Turaif	13
1.590	−0.060	Rafha	15
2.074	−0.067	Ar'ar	17
2.035	−0.073	AlQaseem	14
1.716	−0.117	AlBaha	18
2.099	−0.123	Ha'il	19

Alternative water resources and stricter water use policy

To cope with the changing rainfall pattern because of climate change, there is a need for adaptation of quite different development and management strategies in Saudi

Arabia. The investments need to be made to increase storage capacity in small projects, such as RWH systems, in managing both the shortage of water and flooding problems. Recommendations are made for policy makers to consider the economically feasible RWH in its water development projects to adapt the climate change in this country. Long-term interventions should be the integration of RWH systems in domestic and commercial buildings as one of the sustainable approaches to cope with the water shortage due to climate change in Saudi Arabia and hence reducing the demand on water resources. Recent agricultural, municipal, and industrial use of water is not based on strict conservation and maximization of efficient uses of water in Saudi Arabia due to a very low price of water for all three main users. A strict water use policy with higher water prices for conservation and efficient use of water should be applied (Smith and Dennis 1989). Climate change can affect the agriculture through increased frequency and severity of adverse weather and it can also have adverse impacts on livestock due to extreme variations in rainfall. These two problems can be overcome by rainwater storage in ponds which can be used for livestock or for irrigation.

RWH as small decentralized systems

A simple rooftop RWH system consists of its catchment area, a treatment facility, a storage tank, a supply facility and pipes, and if the system is designed well, it requires little or no electricity, chemicals or maintenance (Han and Mun 2008; Amin and Han 2011). In these small-scale and decentralized rooftop RWH systems, rainwater is collected from roofs and stored in cisterns to be used afterward thus providing an alternative water resource (Baguma et al. 2010).

RWH offers benefits such as; it promotes self-sufficiency and encourages water and energy conservation (Retamal and Turner 2010). The stored water using rooftop RWH systems can be used for gardening, toilet flushing or even for car washing. If properly stored and boiled, the stored rainwater can be used for potable purposes with minimum treatment (Amin and Han 2009a, b). In short, RWH systems are profitable for the community and result in permanent decrease in mains water demand (Grandet et al. 2010).

Active participation of all parties involved

One important element of the RWH and management is the establishment of stakeholder participation through multidisciplinary teams at various levels to understand and bring together different views and perspectives on water resources management (Radif 1999). Participatory approaches, such as RWH, ensure the community ownership and long-term sustainability through the emergence of local management system (Amin and Han 2009c). Co-operation between official efforts and local NGOs (public participation) yields better results in water supply management (Handia et al. 2003; Balooni et al. 2008). The success of RWH systems requires the involvement of all stakeholders, and these include policy makers (leading thinkers and experts), investors (governments/private sector companies), managers (public and private sectors) and users.

Conclusion

To investigate the existence of any signs of climatic changes in Saudi Arabia, the climatic records of the temperature and precipitation during the 31 years of period (1980–2010) were analyzed. Nineteen cities were selected to present the rainfall trend in the whole Kingdom covering the wide areas of the country. The magnitudes of the rainfall trend were derived from the slope values of the regression lines and were supported by the Durbon–Watson statistic. The annual total and maximum 1-day rainfall values were calculated for these cities. Trends in the annual aridity index which is characterized by the scarcity of water are examined to define the changing climate conditions in addition to analyzing the rain index for determining the dry months in different cities of the Kingdom. An increased annual total rainfall trend was observed in six cities with an increasing trend in annual maximum 1-day rainfall in 13 cities. These rainfall trends highlight the higher rainfall intensities or rainfall with longer duration in addition to the variability of climate pattern in different cities of the same district and in different months of the years. The resulting floods of short duration due to increased rain intensities have caused more damage in well-developed cities and urban centers in recent years. The results of the analysis of this study indicate that an appropriate policy should be implemented to respond to the higher rain intensities of longer duration due to the possible climatic change in the context of the water management in Saudi Arabia. Given the factors of climate change and increasing urban population, RWH can be a reasonable solution for water shortage in remote areas and for flooding problems in urban areas. It is required that both government and non-government sectors promote the practice on a regional community and family basis.

Acknowledgments The authors wish to express their deep thanks and gratitude to "Shaikh Mohammad Bin Husain Alamoudi" for his kind financial support to the King Saud University, http://www.ksu.edu.sa, through the research chair "Shaikh Mohammad Alamoudi Chair for Water Researches" (ACW), http://awc.ksu.edu.sa, where this study is part of the AWC chair activities in the "Projects and Research" axis. Thanks should also be expressed to the Presidency of

Meteorology and Environment in Riyadh, KSA, who kindly provided the meteorological data.

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