Climate change and Water Harvesting possibilities in arid regions

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Abstract: In arid and semi-arid regions, water resources are scarce and need climate change impact assessment for water conservation after each storm rainfall as rainfall harvesting in urban areas and runoff harvesting in rural areas. It is the main purpose of this paper to present necessary Water Harvesting (WH) preparation principles by considering simple climate change models for the Arabian Peninsula in general, and for the Kingdom of Saudi Arabia in particular. The proposed model is a mixture of the Global Circulation (Climate) Model (GCM)'s output scenarios with historical local rainfall records, and hence, prediction of monthly rainfall amounts up to 2100.

Keywords: arid region; climate change; down scaling; harvesting rainfall; scenario; Saudi Arabia; water.

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1 Introduction

Various studies have shown that the increasing severity of weather/climate-related events results mostly either from an increase in heat waves and droughts or storms and floods (Trigo et al., 2004). Both of these variables are used in climate change studies, with a little more use of the former compared to the latter. There is clear evidence of an increase in global mean surface temperatures over the 20th century, which became undoubted particularly in the last two decades of that century (Jones et al., 2001; Jones and Moberg, 2003).

Important sectors such as agriculture, water resources, energy, urbanisation and biodiversity for sustainable development are subject to future climate change impacts, and therefore, their vulnerability requires future predictions. Such predictions on monthly basis provide a dynamic and effective foundation for the planning, operation, conservation and management of scarce rainfall amounts in arid and semi-arid regions. In particular, the effects of climate change on stream flow and groundwater recharge vary regionally and between climate scenarios, largely following projected changes in rainfall occurrences and amounts. Unprecedented global and local changes are taking place in climate structure. A recent IPCC Report (2007) report shows that the climate started to warm at the beginning of the industrial revolution in the middle of the 19th century, and that it will become more pronounced in the coming years. Global warming as described by the IPCC is unequivocal and very likely (more than 90% certainty) to be related to human activities, and so will continue in the future. Among the unprecedented events over the Arabian Peninsula are the increases in rainfall frequency and intensity, which are significant input parameters in any WH procedure. Climate change induces changes in atmospheric variables, such as temperature, rainfall, and synoptic weather patterns, and can have serious impacts on the environment, infrastructure and society (ACSAD, 2006).

According to assessments of the IPCC Report (2007), in general, the Arabian Peninsula might receive more rainfall than before and to have the maximum benefit from such a situation, it is necessary to make preliminary refined and extensive researches from now on concerning the rainfall pattern coupled with WH possibilities leading to groundwater recharge. Such works are considered of utmost significance because in the near and long terms, water resources planning, operation, and management can be successful only if such researches are ready for applications in hydrology, agriculture, urbanisation, land use, and similar domains.

Climate change due to global warming has a huge impact particularly on the environment, weather patterns, sea level, farming, plants, animals, etc. It has been observed in the Red Sea and Arabian Sea that the population of some species (coral reef bleaching) has decreased significantly as a result of the ongoing global warming. The Arab region as a whole, and the Arabian Peninsula in particular, is among the world's most water-scarce regions, and is dependent on climate-sensitive agricultural products. Per capita renewable water resources in the region, which in 1950 were 4000 m^3/year, fell down to 1100 m^3/year recently. Projections indicate that they will further drop by half, reaching 550 m^3 per person per year in the coming years (World Bank, 2006). On the other hand, according to an IPCC Report (2007) report and projections, annual average ranges of precipitation decrease in the Mediterranean region and the northern Arab Peninsula by 10–20%, and between 30 and 40% in Morocco and northern Mauritania. However, a 10–30% increase in precipitation is expected in the south-western part and some other parts of the Kingdom of Saudi Arabia (KSA), Yemen, UAE and Oman. It is most important to locate the rainfall increase sites and then design suitable WH structures such as bunds, dams, bends, dikes and subsurface dams.

Climate change impacts need a more severe adjustment in the management of water resources in arid and semi-arid regions than in any other region, and at this junction water (rainfall and runoff) harvesting applications gain increasing significance in the region. This is due to the fact that as the temperature increases evaporation losses also increase and hence, available rainfall events and especially the subsequent runoff, flood and flash flood waters must be entered into the subsurface as quickly as possible through WH methodologies (Nedunchezhian et al., 2001; Krishna, 2003; As-Sefry et al., 2005; Abdulla and Al-Shareef, 2006) for later exploitation. One must take into consideration that evaporation is a rather complex phenomenon and is a function of several other hydro-climatic variables.

Rainfall intensity increase is expected to cause infiltration reduction and decrease in potential aquifer recharge. Hence, WH structures will enhance groundwater recharge at convenient locations along the Wadis (Şen, 2008). The potential sensitivity of aquifer recharge to rainfall is modelled by Döll and Flörke (2005) and they find that an increase in surface temperature and reduction in rainfall will result in a 30–70% reduction in recharge in an aquifer located in the eastern and southern Mediterranean coast. However, at many locations in the Arabian Peninsula, rainfall intensity and frequency increases will need support for artificial groundwater recharge, which can be supplemented by WH structures. Global warming is expected to increase Evapotranspiration (ET) rates, thereby reducing soil moisture, infiltration and aquifer recharge. For instance, a study of aquifers in the KSA shows that increase in temperature by 5°C will reduce groundwater recharge by 465×10^6 m^3/year (First Climate Change Report of KSA, 2005). Moreover, increasing ET will significantly increase crop water requirement and irrigation demands (ACSAD, 2006). Among the adaptation and mitigation recommendations by ACSAD are the promotion of rainfall harvesting techniques in general for rainwater storage as an alternative source of drinking water, so that communities may not solely rely on available groundwater resources. However, in this paper, in addition to rainfall harvesting, further runoff harvesting is also recommended for groundwater storage enhancements through artificial recharge alternatives, and both harvesting types will be referred to as WH.

Although many climate change studies have been performed in various research centres worldwide, in the KSA, where very few investigations have been conducted, such studies are still in their infancy. These few investigations are based either on a very short period or on a very limited number of surface stations. Al-Jerash (1985) performed a thermal classification of KSA based on a very short period and Almazroui (2006) studied surface temperature using only four stations: Riyadh, Madinah, Dhahran and Jeddah.

Available meteorological data need to be analysed in a way suitable for the desired application and temporal variation of climatic data, which is an important consideration for the design of a particular system. It is recommended in this paper that design of any WH systems should be based not only on recorded meteorological data, but additionally on their future replicates that take into consideration climate change possibilities. Unfortunately, such future data are not available as desired, even for the Riyadh area, in accurate form. Hence, the objectives of the study can be summarised as follows.

- to assess recorded rainfall data of Riyadh area for the design of WH systems
- to present available rainfall data in a readily usable form for planning of WH systems
- to generate future rainfall occurrences by exploiting GCM model scenario data together with local model and data at Riyadh station.

A number of independent agencies are involved in measuring meteorological data in KSA. The Meteorology and Environmental Protection Administration (MEPA), and the Department of Water Resources under the Ministry of Water and Agriculture are the two agencies which have climatic records going back a long way (Said and Kadry, 1990).

The main purpose of this paper is to present simple climate change model predictions within KSA, around Riyadh city, with a combination of GCM scenario outputs and local rainfall records through a rather straightforward local model. Combined model outputs indicate long-term increase in the rainfall intensity and frequency, which implies important surface runoff occurrences and, especially in arid regions, scope for enhancement of groundwater recharge by constructing WH systems along the major streams of suitable Wadis (Şen, 2008). Under the light of expected frequency and intensity increases in the KSA, WH structure uses are recommended for groundwater recharge enhancements.

2 Arabian Peninsula climate change model

Arid and semi-arid regions are in need of additional water resources presently, and in the future, given present development plans, demand for water resources is expected to increase on one hand, while on the other, climate change is an extra impact on water resources, due to increasing temperature and hence, increasing evaporation losses. One of the best forms of combat against climate change in arid and semi-arid regions is the conservation of surface water in groundwater storages by groundwater storage enhancement, which is where WH structures come into the picture. Such alternatives have been used in the past, but with the increase in the frequency and intensity of rainfall events according to GCM results, extra additional surface water can be directed into shallow Quaternary aquifers for use at times of need. Such future planning, operation, management and maintenance of water resources are possible with new and innovative extensions of traditional approaches in WH techniques.

Many remarkable climate change features can be concluded from the GCM and the local model that is suggested as a simple Quadrangle Downscaling Model (QDM). For instance, the highest rainfall increase occurs in summer in all regions. Obviously, this is trivial for areas with no summer rain. However, in the south and southwest regions, where the rainfall regime is characterised by two peaks (one in summer and one in spring), such increases have an important synoptic implications, particularly when compared to changes in spring.

In the First Climate Change Report of KSA, any increase in ET will result in increasing the evaporation rates and decreasing the available water supplies from annual participation by lowering the annual recharge to aquifers and lowering the surface runoff. The calculated total annual recharge to all aquifers in the Arabian Shelf is about 2762 million m^3 (MCM) based on several hydro-geological studies. The annual recharge to shallow aquifers in the Arabian Shield is 1196 MCM. Thus, the total annual recharge to all aquifers in the Kingdom is about 3958 MCM. The average increase in reference ET, which reduces the recharge to all aquifers, has been defined as 2.3% and 12% of the total annual recharge at 1°C and 5°C increases in temperature, respectively. On the other hand, the calculated reduction in the values of total annual recharge is about 91.4 MCM and 475 MCM at 1°C and 5°C increases in temperature, respectively.

The most extensive, rich and significant recharges in arid regions are due to indirect recharge, which spreads the flood waters over thousands of square kilometres on both sides along the main wadi channel. Sometimes, both direct and indirect recharges occur simultaneously in many places. WH technology is one among the indirect groundwater recharge possibilities. Recharge volume calculation is comparatively easier due to,

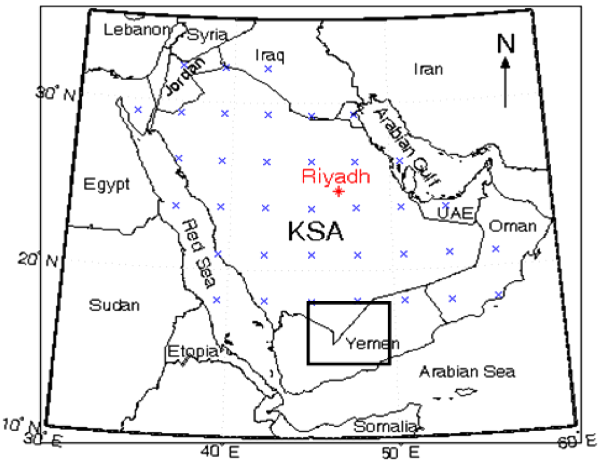
- the earth surface area giving rise to indirect recharge such as the WH is smaller than the direct recharge, and hence, the estimations are more reliable
- due to smaller influence areas, the geometrical composition of indirect recharge areas are more homogeneous
- since harvested water flows in the simplest and shortest way to groundwater storage, its quality is closer to rainwater composition than to groundwater composition
- the water movement is almost vertical and hence, there is less probability of contact with lateral geological variations.

There are different causes and mechanisms that play a role in WH leading to the recharge process. Among such dominant mechanical factors are surface processes (topography, morphology, runoff, depression dimensions and vegetation) atmospheric processes (temperature, evaporation, humidity, solar irradiation, and wind speed), land use (agriculture, transportation roads, and urban areas), drainage pattern (streams, creeks, rivers, and sub-basins), geology (soil type, rock type, fracturing) and unsaturated zone (granular composition, thickness, effective porosity). The roles of these factors change from humid to arid regions and in arid regions, the basic mechanisms are indirect recharge in wadi channels, depressions, limestones and sabkhas, volcanic rocks, sand dunes and contact lines between different lithologies. All of these factors affect the WH location in arid regions along the main wadi channels.

3 Study area and data

Riyadh station with its number 40,438, longitude 24° 43′ 00″, latitude 46° 44′ 00″ and elevation 660 m above the mean sea level has precipitation records available from 1961 to 1996 (Figure 1). There was no gap or missing data in this long series. Dry and arid conditions are the general features of the Riyadh climate, with extreme heat and minimal rainfall amounts all the year round in the inlands of the Arabian Peninsula.

Figure 1 Arabian Peninsula, KSA and Riyadh City locations (see online version for colours)



Annual average rainfall is about 15 mm and in Riyadh, the bulk of rainfall occurs in the months from January to May, averaging 100 mm/year. The climate at Riyadh also includes a remarkably hot summer caused by the inland winds. During this season, temperatures can run as high as 50°C, with 45°C temperatures being common. In the winter months, daytime temperature averages are around 14°C. Nights on the Arabian Peninsula are chilly, and winter temperatures in Riyadh at night can plunge some points below freezing. The Riyadh climate is characterised by average day temperatures of 8–21°C in January and 26°C to 42°C in July.

The weather data for the period 1961–1996, collected from meteorological stations in Riyadh and published by the General Meteorological Department, are used in this study. The records of the main meteorological stations show the absolute maximum, the absolute minimum, and the mean of the monthly values for each meteorological element. The parameters included temperature, relative humidity, wind speed and wind direction, sky condition, and atmospheric pressure. Monthly rainfall patterns between 1961 and 1996 are presented in Figure 2, where the extremes are above 100 mm/month several times. For vulnerability assessment due to climate change on some activities such as agriculture and water resources, it is necessary to construct models for prediction of what the future climate would be under physically reasonable assumptions of greenhouse-gases concentrations. These visions, the climate change scenarios, are then to be compared with a picture representing a non-changed climate, the baseline climate scenario.

This is a good indication that in the future, due to natural record breaking of rainfall events, more severe extremes above 120 mm/month are expected. Actually, this is the most significant question: can more frequent extremes be expected in the future? An answer to this question is possible only through future rainfall modelling as presented in this paper. Generally, it can be stated that the frequency and intensity of the rainfall amounts are expected to increase according to the IPCC Report (2007) report, but it is necessary to check this point through reliable models for Riyadh rainfall. Figure 3 shows the monthly rainfall histogram, which relates the frequency to the rainfall amount to the monthly rainfall intensity. This histogram is prepared for 36 years of data, i.e., $36 \times 12 = 432$ months. In general, there is an inverse relationship between the frequency and intensity. Low rainfall events with rainfall almost less than 10 mm occur most frequently than any other rainfall intensity.

Figure 2 Historical monthly rainfall amounts at Riyadh station (see online version for colours)

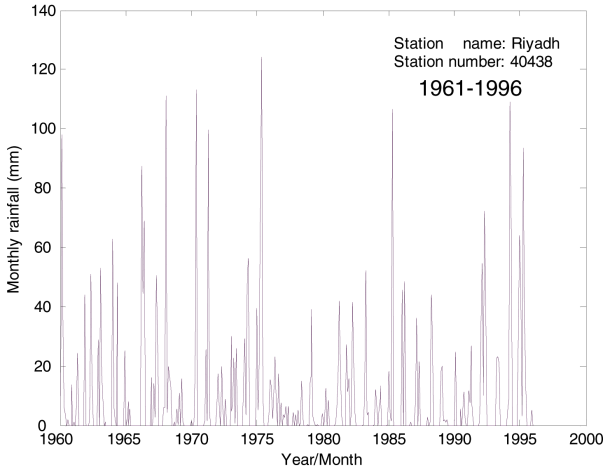
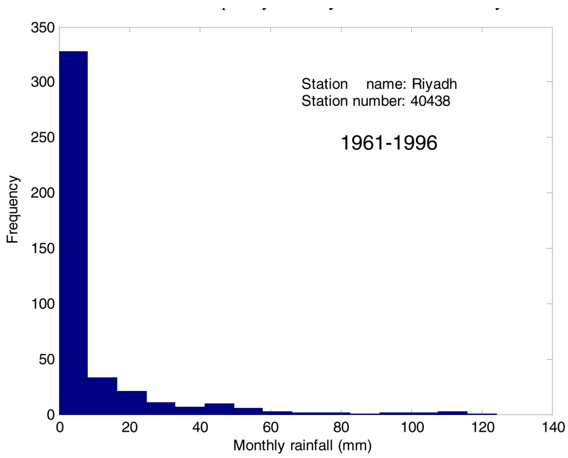


Figure 3 Riyadh observed monthly rainfall histogram (see online version for colours)



4 QDM

Arid and semi-arid regions face the most impact of climate change on socio-economic development of any society and especially on its water resources. It is, therefore, a necessary step for each country to assess its water resources according to GCM scenario outputs as time series about precipitation, temperature, humidity, solar irradiation, etc. In this research, the NCAR's GCM scenario outputs are used. NCAR provides the university and teaching community with the tools, facilities, and support requirements to perform innovative research. Unfortunately, GCM scenario outputs are available on a course scale as in Figure 1 and it is necessary to bring them down to smaller local scales through proper downscaling procedures. This figure shows grid points at a set of regular nodes shown by crosses given by NCAR.

Since the grid interval to retrieve information using GCM approach is quite coarse (5° latitude and 5° longitude, which corresponds to about 300 km distance between two nodes), it is difficult to interpolate information at micro-level in the KSA. Therefore, efforts were concentrated on retrieving available data for the region from the IPCC database, which are GCM simulation products. This database stores global level data for different climatic scenarios up to the year 2100. Different climate change scenarios developed by various IPCC groups are reviewed and the main focus in this study is on A2 climate scenario from NCAR, USA. According to this scenario, the future of the world is considered to be very heterogeneous, because the main emphasis is on family values with local traditions and cultural identity preservations. The global population of this scenario has a continuous increase with a lesser concern on economic development.

In this manner, it is possible to foresee the future trends in the water resources climate factors and their direct as well as indirect effects on the hydrological cycle, all reflected in flood, drought and other hydrological phenomena.

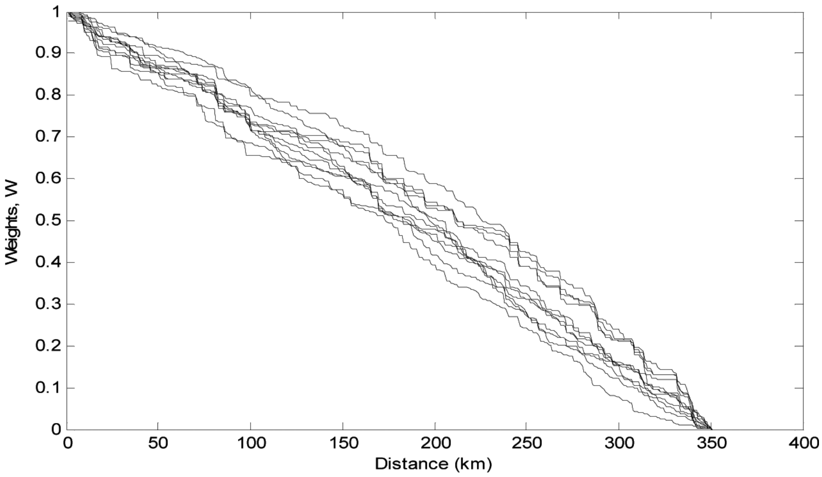
Although there are various models for the climate change downscaling procedure from the GCM outputs at a set of grid points to local station positions (such as Riyadh City) or to any desired point in the study area, it is preferred herein to use a rather straightforward approach for preliminary assessment of the monthly rainfall amounts. An important point in any downscaling model is to consider a spatial estimation procedure, where there are different approaches, as explained by Şen (2009). For instance, in the well know Regional Climate Model (RegCM), spatial downscaling resolution is achieved by the Cressman (1959) radius of influence, which is rather subjective because the definition of the radius is not known objectively. In any downscaling methodology the spatial estimation method is the most significant ingredient and it cannot be fixed for the whole of the study area (Şen, 2008).

Herein, the regional model is adopted as the spatial weighted average by considering four grid points and the station location within the quadrangle domain area. At each quadrangle point, global scenario monthly rainfall amounts are available. These rainfall amounts are the outputs of the GCM at NCAR from 2000 to 2100. If these four-corner (grid points) rainfall amounts are R_{S1}, R_{S2}, R_{S3} and R_{S4} with the station (Riyadh City) distances to each one of these grid points D_1, D_2 D_3 and D_4 then the spatial weighted average estimation, R_E, at the station location can be expressed as,

$$R_E = \frac{\sum_{i=1}^{4} R_{Si} D_i}{\sum_{i=1}^{4} D_i}. \qquad (1)$$

Such a spatial weighting cannot be valid because equation (1) gives maximum weight to the grid point that is at the farthest location, and on the contrary, the nearest point takes the least share in the overall spatial estimation value, R_E. It is, therefore, necessary to modify this formulation in such a manner that as the station location falls on any one of the grid points, then the spatial estimation will be identical with this grid point's scenario monthly rainfall amount. For this purpose, the Regional Dependence Function (RDF) concept as suggested by Şen (2010) is adopted by considering all the available rainfall stations around the Riyadh city. This leads to the RDF shown in Figure 4. This figure implies that as the distance between any two points increases, the RDF value (weight) decreases accordingly. In this figure, there are 12 RDFs, one for each month. This is a very typical pattern in arid regions, where the rainfall occurrences are rather scarce and haphazard.

Figure 4 Riyadh City RDF



This figure implies that the radius of influence around Riyadh city has a maximum extension up to 350 km, which would suggest that stations of rainfall record or grid points (nodes) of the GCM located more than about 350 km away from Riyadh cannot have any influence on rainfall prediction for Riyadh city. To calculate plausibly the rainfall at the estimation location, it is necessary to rewrite another version of equation (1) as follows.

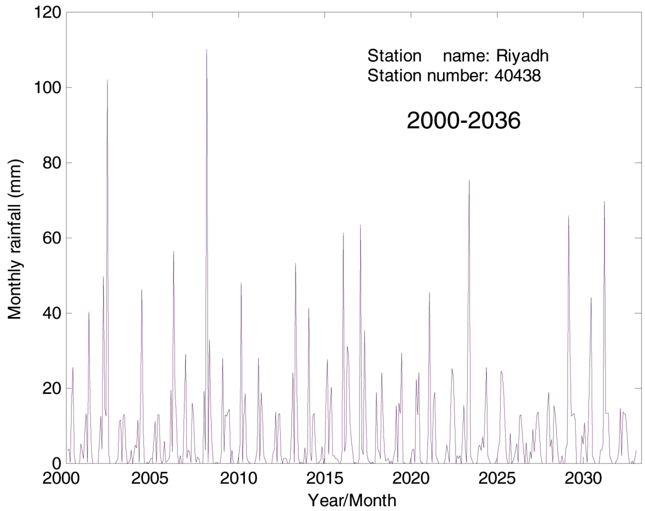
$$R_E = \frac{\sum_{i=1}^{4} R_{Si} f(D_i)}{\sum_{i=1}^{4} f(D_i)} = \frac{\sum_{i=1}^{4} R_{Si} w_i}{\sum_{i=1}^{4} w_i} \tag{2}$$

where $f(D)$ indicates the RDF and w_i's are the weights corresponding to each distance, D_i. Now the application of equation (2) is plausible, because as the distance increases the corresponding weight function from Figure 4 decreases. In the applications, any GCM grid point distance to Riyadh (see Figure 1) is measured and this value is entered on the horizontal distance axis in Figure 4, and then the corresponding weight is found from the horizontal axis. The justification for the QDM originates from the fact that the RDF has its maximum distance, as mentioned earlier, at about 350 km and its comparison with the GCM scale of about 300 km states that whatever the prediction point selection there will be always four grid points within the radius of influence.

Finally, spatial estimation according to equation (2) for each month from 2000 to 2100 gives rise to a series of scenario rainfall in a form unadjusted to the actual monthly rainfall records at the station. This unadjusted series exhibits future trends for wet and dry spells relatively, but they must be adjusted with the available monthly rainfall amounts at the station concerned.

To depict what the future features of rainfall frequency and intensity at Riyadh station are, the scenario series are considered for the same duration as 36 years (432 months). For this purpose, Figure 5 provides the rainfall scenario amounts between 2000 and 2036. Its general appearance provides the information that compared to historical rainfall amounts in Figure 2, the rainfall extremes (maxima) will decrease with less frequency in the case of less than almost 10 mm/month.

Figure 5 Scenario monthly rainfall amounts at Riyadh station (2000–2036) (see online version for colours)



The frequency rainfall amount relationship corresponding to the 36-year duration from 2000 to 2036 is given in Figure 6 for the same station. It is obvious that compared to the 1961–1996 period, there are decreases in the frequency and intensity at the extremes, but the frequency of monthly rainfall amounts between almost 10 mm and 15 mm increases at about 60%.

Riyadh station scenario monthly rainfall amounts between 2064 and 2100 are presented in Figure 7, which has extremely high values compared with the two previous periods, 1961–1996 and 2000–2036. It implies that there is frequency and intensity increases within the second half of the 21st century. This point is further confirmed with the frequency distribution in Figure 8.

Both monthly rainfall frequency and intensity increase compared to the 1961–1996 and 2000–2036 periods. Increase in the low rainfall amount frequency is about 30%, whereas monthly rainfall intensity increment is almost 67%.

On the basis of all explanations above, it is possible to conclude that monthly rainfall frequency and intensity increments are expected in the second half of the 21st century. This supports the idea of WH because more runoff volumes can be expected to appear in the wadis near the Riyadh area. To further elaborate this point, observed yearly and scenario monthly rainfall amounts are presented in Figures 9 and 10, respectively. Similar patterns are also available in the scenario rainfall amounts.

Figure 6 Riyadh scenario monthly rainfall histogram (2000–2036) (see online version for colours)

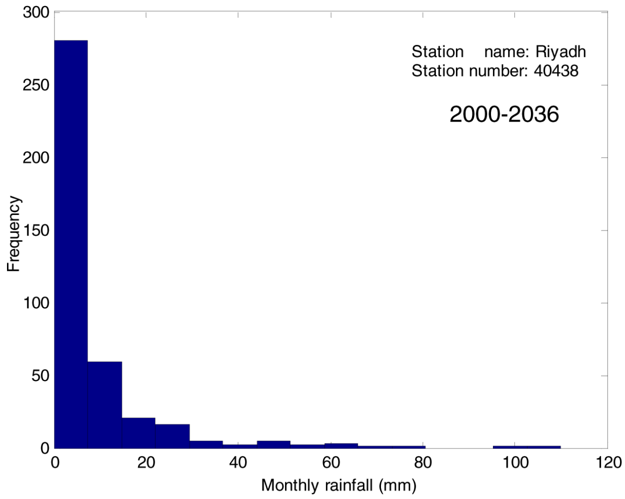
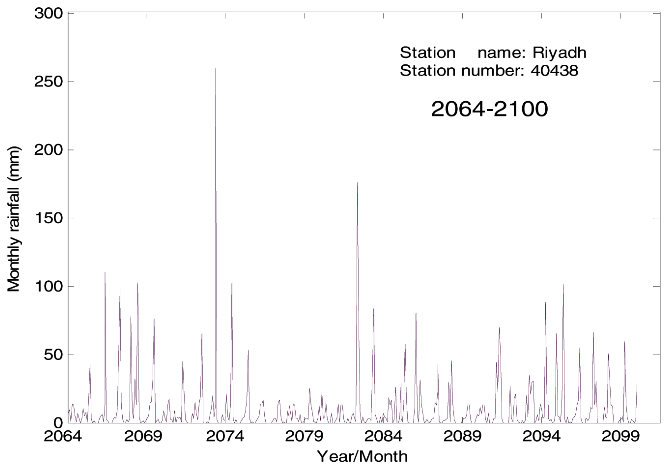


Figure 7 Scenario monthly rainfall amounts at Riyadh station (2064–2100) (see online version for colours)



From the 1961–1996 period records of annual rainfall amounts at Riyadh station in Figure 8, it is obvious that there are two distinctive wet (1966–1976) and dry (1977–1993) spells at this location. The overall scenario annual rainfall amounts in Figure 9 shows explicitly that after 2035 a more wet spell can be expected in Riyadh station, and hence, in the surrounding Riyadh area. Comparison of Figures 8 and 9 reveals the fact that in the future, the number of low rainfall amounts is expected to decrease.

Additionally, the maximum rainfall increase occurrences are expected in summer in all regions. Obviously, this is trivial for areas having no summer rain. However, in the south and southwest regions, where the precipitation regime is characterised by two peaks (one in summer and one in spring), such increase has an important synoptic implication, particularly when compared to the spring change.

Figure 8 Riyadh scenario monthly rainfall histogram (2064–2100) (see online version for colours)

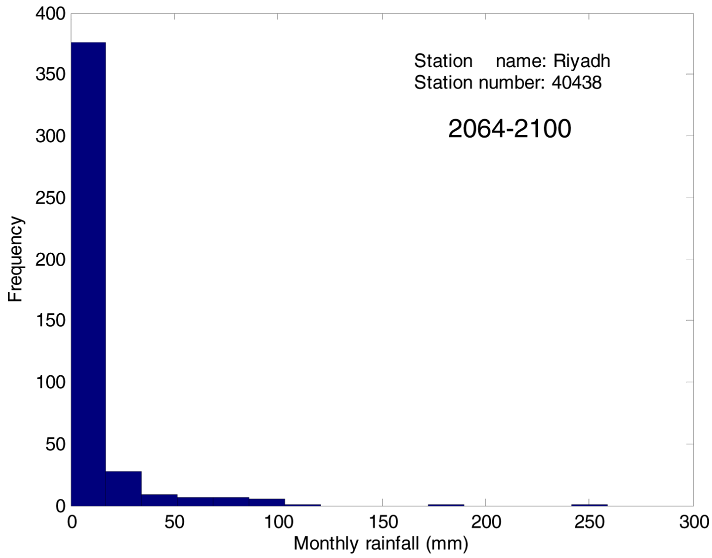


Figure 9 Riyadh observed annual rainfall amounts (see online version for colours)

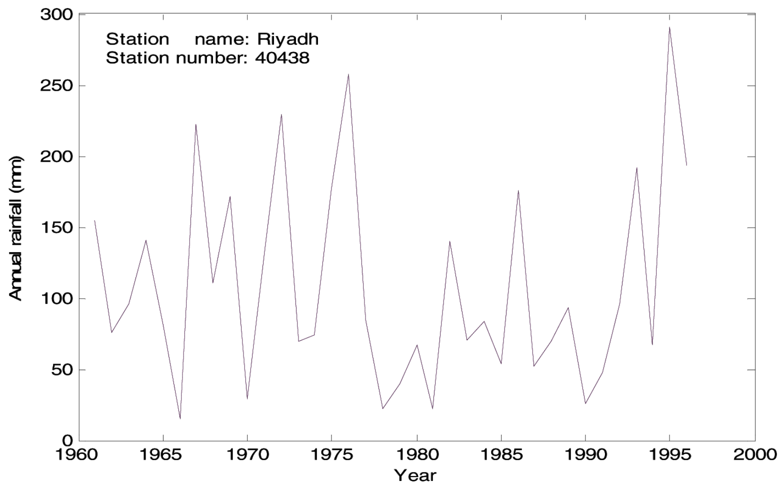
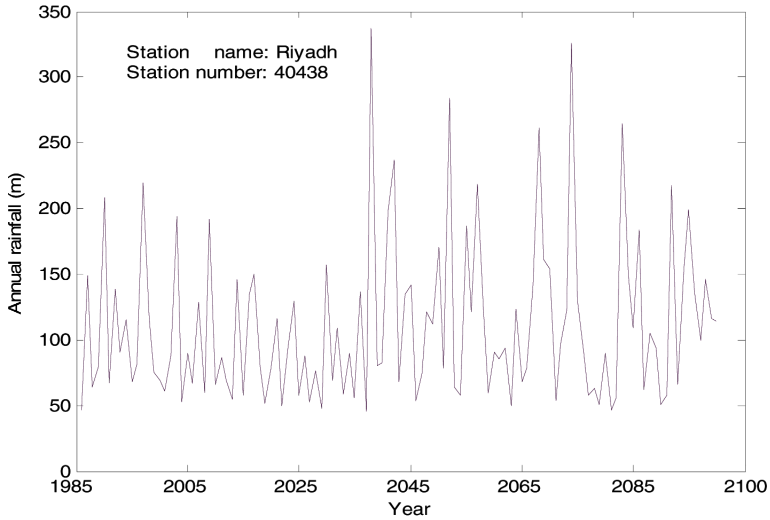


Figure 10 Riyadh scenario annual rainfall amounts (see online version for colours)



5 Adaptation

Each climate change research and modelling study should indicate the possible sets of actions or adaptation against the danger of setbacks, specially droughts and occasional floods and especially flash floods. WH in central Saudi Arabia near the capital city, Riyadh, is reported by the Prince Sultan Center for Water and Environment, which aims at the identification of potential WH areas by using GIS mapping as well as climate change models. Such maps will be used by decision makers for planning WH activity within the KSA, which are proven to be very effective. Given WH techniques which adapted farming systems to the bio-physical and agro-climatic condition of the KSA, there is more hope and preparedness as this country faces climate change. As for preparation for climate change effects within the KSA, WH is one of the most effective steps – a method that does not require extensive capital and international conventions. It is a technology and a management approach for providing water resources at the community level. The WH project in the KSA aims to improve water availability for household activities and productive use for local settlers such as Bedouins. The WH distinguishes itself as built entirely on local experience and knowledge in the implementation, and it has high ambitious desires for its application and local support while providing access to a reliable source of water.

As this information of water availability is realised, WH techniques can be adapted to meet the needs of the local people in different parts of the KSA. It is hoped that the WH studies will directly improve the efficiency of WH. The Quaternary alluvium layers in the wadi systems on the Arabian Peninsula are efficient storage media for groundwater storage after WH artificial recharge.

The expected climate change over the Arabian Peninsula highlighted the need to have a new basis or framework for planning, one that rests on exposure to new and changing information and knowledge and one that gives priority to adaptive actions. Public awareness is of prime importance, as individual responsibility in the end will be crucial to facing the impact of fierce weather. Information for the public should be enriched by experience exchange. Top down plans on vulnerability, sensitivity and capacities should be shared and complemented by communities.

WH is an efficient technology with the potential of contributing immensely as a coping mechanism for climate change and variability. This system captures, conveys, stores and releases water. WH is a traditional practice picked up by a group of scientists and development practitioners, as a focus of their interest, study, and practice to help poor and rural communities in their quest for water.

The following points indicate the types of information expected as relevant to water resources of the KSA, in particular, and of arid and semi-arid regions in general.

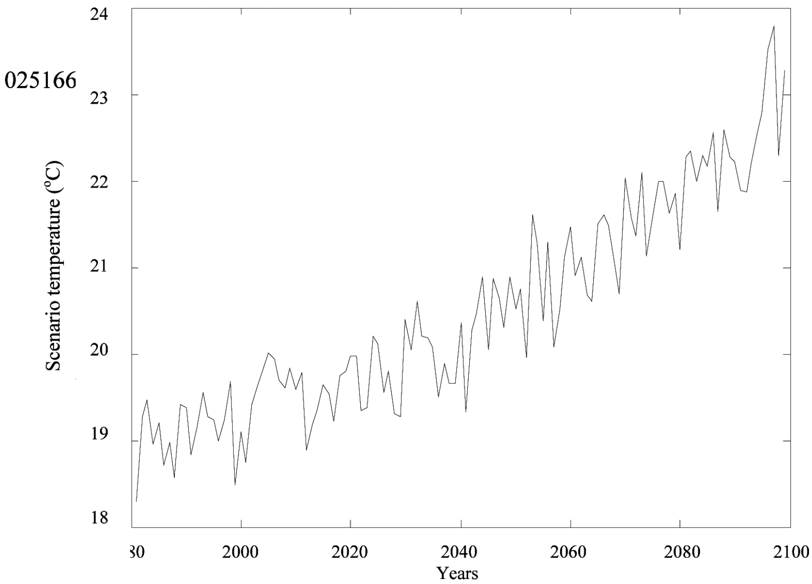
- future climate change scenario predictions by taking into consideration the local temporal and spatial data variability
- based on the relevant climate scenarios future water availability, supply and demand
- future regional data base development on water resources including extreme events (droughts and floods)
- assessments of combined effects of future land use, climate change and variability on water resources
- information on frequencies and effects of climatologic and hydrological extreme events
- identification of WH locations depending on the future climate change scenarios together with the local geological, morphological and demographical features.

Certain sectors are subject to vulnerability under climate change, which requires objective and regionally suitable models for future predictions and physically reasonable assumptions. It is always necessary to compare such predictions with a historical baseline climate horizon, which is adopted usually as a 30 consecutive year period. The differences between the future climate change predictions and the baseline climate indicator provide information or climate change vulnerability, adaptation and possible mitigation studies. In Riyadh, the city synoptic station is used for the climate baseline covering the period from 1961 to 1996.

It has been stated in the First National Climate Change Report of the Kingdom (2005) that on average there is a general warming trend all over the country, but at different rates according to the topography and air masses movement on synoptic scale. Figure 11 indicates future minimum temperature trends from the NCAR-SRES-A2 scenario at one of the GCM nodes near Riyadh.

This figure indicates the expectation of a patchy warming trend of about 4°C temperature increase during this century around Riyadh. In particular, there is a steeper increase in temperatures after 2040. The temperature pattern exhibits a clear systematic distribution with a stronger warming area elongating over the interior part of the country and an area of weaker warming along the western and eastern coasts, the far north and the far south.

Figure 11 NCAR-SRES-A2 Scenario (1980–2100)



6 Conclusion

Climate change impacts are expected in any part of the world at different rates and patterns concerning the temperature and precipitation occurrences. The impact types are different for arid and semi-arid regions as compared to the humid zones of the world. As for temperature increases, arid and semi-arid regions will not have significant differences from their existing environments. However, rainfall pattern and its consequent impact on water resources in the form of groundwater storages are significant for sustainable development in these regions. This paper provides a simple downscaling model for the Arabian Peninsula and its application near Riyadh City in the KSA for monthly rainfall scenario predictions up to 2100 by considering the General Circulation Model (GCM) output scenarios together with a simple but effective local model, the QDM. It is also suggested that WH systems should be developed further and applied in arid regions as one of the adaptation means against climate change impacts. This is due to the fact that in the future, rainfall increments are expected within the Arabian Peninsula and therefore, extra water due to floods and occasional flash floods can be used for artificial groundwater recharge through WH structures.

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