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Trends in monthly precipitation over the northwest of Iran (NWI)

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Abstract Increasing global temperatures during the last century have had their own effects on other climatic conditions, particularly on precipitation characteristics. This study was meant to investigate the spatial and temporal monthly trends of precipitation using the least square error (LSE) approach for the northwest of Iran (NWI). To this end, a database was obtained from 250 measuring stations uniformly scattered all over NWI from 1961 to 2010. The spatial average of annual precipitation in NWI during the period of study was approximately 220.9–726.7 mm. The annual precipitation decreased from southwest to northeast, while the large amount of precipitation was concentrated in the south-west and in the mountainous areas. All over NWI, the maximum and minimum precipitation records occurred from March to May and July to September, respectively. The coefficient of variation (CV) is greater than 44 % in all of NWI and may reach over 76 % in many places. The greatest range of CV, for instance, occurred during July. The spatial variability of precipitation was consistent with a tempo-spatial pattern of precipitation trends. There was a considerable difference between the amounts of change during the months, and the negative trends were mainly attributed to areas concentrated in eastern and southern parts of NWI far from the western mountain ranges. Moreover, limited areas with positive precipitation trends can be found in very small and isolated regions. This is observable particularly in the eastern half of NWI, which is mostly located far from Westerlies. On the other hand, seasonal precipitation trends indicated a slight decrease during winter and spring and a slight increase during summer and autumn.

Consequently, there were major changes in average precipitation that occurred negatively in the area under study during the observation period. This finding is in agreement with those findings by recent studies which revealed a decreasing trend of around 2 mm/year over NWI during 1966–2005.

1 Introduction

Climatic elements are changing at all timescales, which has attracted considerable attention from surveys focusing on climatic changes over the last few decades. To make the nature of the climatic changes operationally defined, researchers have subscribed to the evolution of the mean of climatic elements.

Precipitation is one of the most important variables involved in characterizing some major facets of a regional climate. Thus, any changes in precipitation behaviour might result in socioeconomic consequences. Therefore, understanding tempo-spatial patterns of precipitation is a crucial issue in socioeconomic development. Moreover, precipitation variations over time constitute a major part of the changes in the earth's atmospheric system. In general, there is a universal concern about the variability of precipitation as evidence of variation in climate. For instance, the spatial and temporal variability of precipitation has long been highlighted in the scientific community (see, for example, Singh 1997; Rodriguez-Puebla et al. 1998; Liebmann and Marengo 2001; Zhang et al. 2008; and Shi et al. 2013).

Precipitation over Iran is governed by a number of physical, spatial and temporal factors. There are therefore different regional types of precipitation. NWI, as a unique region where precipitation is determined by the complexity associated with dominant topographical, latitude and atmospheric conditions, is located in a sub-humid region.

Long-term change in precipitation is a complex concept which can cause a number of consequences that dramatically

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affect natural and socioeconomic aspects of the environment. Accordingly, understanding these changes is of paramount importance.

In the present study, in order to discover trends of precipitation, the trends of monthly precipitation in NWI were investigated using a least square error (LSE) approach.

In general, unknown factors have led to few studies on dominant climatic trends in NWI. Nevertheless, in recent years, some research (e.g. Razi and Azizi 2007; Asakereh and Razmi 2012; Asakereh and Razmi 2014) has been conducted on the precipitation variability of NWI. Therefore, the researcher deemed it necessary to carry out the present study on precipitation trends of NWI to fill the gap noted in the literature. Asakereh and Razmi (2012) studied annual precipitation change over NWI. They showed that there was a decreasing trend up to 2 mm/year over NWI during 1966–2005, but they did not show the monthly change in their study. Accordingly, the current paper concerns monthly trends in NWI during a wider time interval (1961–2010) compared with the previously mentioned study. Asakereh and Razmi (2011) and Asakereh and Razmi (2014) only studied the temporal distribution of precipitation of NWI without examining long-term trends of precipitation.

2 Data and methodology

2.1 Geographic situation

The major part of the region, NWI, extends south over the borders of Armenia, Azerbaijan and the west of Turkey and the northwest of Iraq (Fig. 1). It occupies an area of approximately 126,600 km^2 (about 7.2 % of all Iran's territory), including various landscape units covering the following area:

$$E : 44^\circ \quad 2^{'} \quad 5^{''} - 49^\circ \quad 26^{'} \quad 27^{''}$$
$$N : 35^\circ \quad 32^{'} \quad 54^{''} - 39^\circ \quad 46^{'} \quad 27^{''}$$

NWI consists of a high plateau, with increasingly rough and mountainous surface features toward the west. The elevation in this region ranges from 200 to more than 4800 m. Many scattered high volcanic peaks, such as Sahand (about 4800 m high) and Sabalun (about 3000 m high) appear, particularly in the central parts; these mountains rise to over 4000 m. Lake Urmia is a salt lake in NWI near the borderline between Iran and Turkey. Today, due to many factors, the lake contains only 5 % of the amount of water it used to have 20 years ago. This lake, along with its approximately 102 islands, is protected as a national park by the Iranian Department of Environment (IDE).

The region is often under the influence of the Mediterranean winds during the rainy seasons; consequently, it experiences wet spells for about 6–8 months. Sometimes, during winter time, this region incidentally comes under the influence of the high pressure of Siberia through the Caucasus Mountains, which can lead to cold spells (Alijani 1996). In addition to Mediterranean winds and Westerlies, the Red Sea incidentally causes extreme precipitation (Mofidi 2005). In the spring, and even in the summer, showers and thunderstorms may occur due to the lifting of convective air masses (Alijani 1996).

2.2 Data

In order to study precipitation trends during the recent decades in NWI, the researcher selected the stations with regard to the sufficient spatial distribution records for carrying out interpolation, and also with regard to sufficient accuracy that extends until the end of the year 2010, which is the longest accessible precipitation data record in Iran. Accordingly, 250 stations were chosen based on the aforementioned criteria. The geographic locations of these stations are illustrated in Fig. 1. The stations' data for monthly total precipitation were obtained from the Meteorological Organization of Iran (MOI) and the Ministry of Energy of Iran (MOE).

Due to the fact that the original data set of precipitation contained noticeable missing values before 1961 and the fact that the precipitation data after 2010 were not accessible, the present study followed a continuous time period from January 1961 to December 2010.
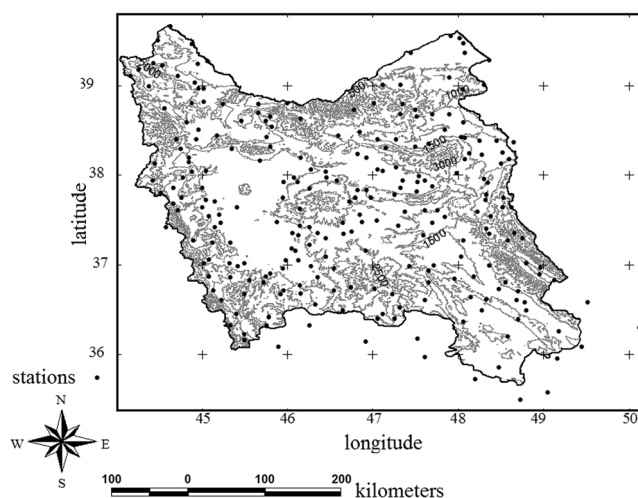
Fig. 1 Digital elevation pattern and spatial distribution of 250 stations in northwest of Iran (NWI). In order to increase the accuracy of interpolation, a total of 14 stations were selected from out of the province. The lines illustrate elevation contours

2.3 Methodology

The average of monthly precipitation data dealt with in this study was interpolated from the abovementioned stations over NWI. In order to investigate the homogeneity of the data, methods proposed by Buishand (1982); Alexandersson (1986) Gonzalez-Rouco et al. (2001) was employed. As the tests used in this study have been rendered thoroughly in many related sources, further explanations are not provided in this part. The criterion for the selection of the stations was acceptance of null hypothesis of homogeneity at 95 % confidence level. They were thus reduced to the 250 stations. In addition, missing data were taken into account for the selection of the stations. Therefore, there were a number of missing data in some stations often related to low precipitation months in summer. To compensate for the missing data, interpolation method was employed. For each month with missing data, interpolation was applied and the data of the station were estimated.

Accordingly, 600 monthly contour maps of NWI were created using the simple Kriging method (Deutsch and Journel 1998; Mallet 2002; Ripley 2004) which had the lowest root mean square errors (RMSE) in comparison to other spatial interpolation methods. These maps enjoyed a spatial resolution 10 km × 10 km. Therefore, the gridded data set for each month has 1266 grid points covering NWI. The temporal and spatial behaviour of precipitation shown by a 1266 × 600 matrix of grid points was thus derived from the aforementioned maps.

The mean of the 50-year monthly precipitations is employed for each pixel in NWI. This gridded precipitation climatology was subjected to trend tests. Therefore, temporal variability of the annual and monthly precipitation over the NWI was also investigated. Moreover, linear trends for the series of monthly total precipitation were calculated using LSE regression. This method has been discussed by several experts in the field (see, for example, Kariya and Kurata 2004; Wilks 2006; and Rao et al. 2008). The linear trend test of precipitation was previously employed by Bodri et al. (2005); Feidas et al. (2007) and Kottegoda et al. (2008). The estimated slopes were tested against the hypothesis of null slope by means of a two-tailed t test at a confidence level of 95 %. The trend analysis was applied for each pixel of these values using linear regression. Linear regression is illustrated in many texts (for example, see Rawlings et al. 1998; and Weisberg 2005). The least squares linear model is the most common method used for detecting trends in all climatic elements (for example, see Karl and Knight 1997; Huth 1999; and Sadiq 2010), and it is the most common technology for statistical diagnosis and forecast in modern climate studies (Wei et al. 2008). The other reason for applying the linear trend was that it is the simplest model for an unknown trend (Wilks 2006). The value of any negative or positive trend (b)

in the precipitation time series (P) was thus determined by regression analysis for each pixel as follows:

$$P = a + bt$$

Finally, in order to reveal the pattern of temporal trend in detail, the maps of b were produced and compared for all months.

3 Discussion

3.1 General features of precipitation

The spatial distribution of annual precipitation based on the study period is shown in Fig. 2. The amount of annual precipitation is generally modest in NWI. The spatial average of annual precipitation in the NWI during the period of study was approximately 220.9–726.7 mm. However, the spatial distribution of annual precipitation in NWI varied greatly. The spatial mean of annual precipitation in NWI was around 350 mm. Furthermore, the annual precipitation decreased from south-west to north-east, while the large amount of precipitation was concentrated in the south-west and in the mountainous areas (more than 500 mm) of the central parts. There was a broad area of precipitation between 300 and 400 mm in the NWI, with the exception of an area around the highest mountains (more than 400 mm).

The effect of elevation is obvious in Fig. 2. The mountain chains crossing the western part of NWI from north to south,
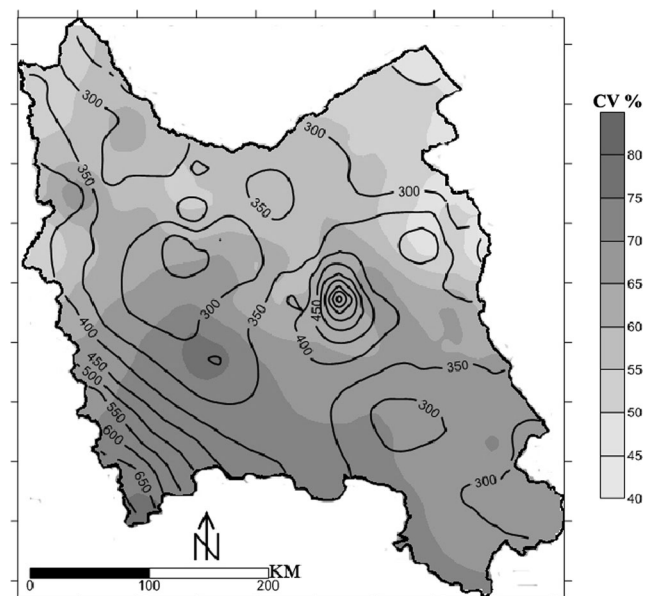
Fig. 2 Spatial distribution of annual precipitation and its coefficient of variations (CV) in NWI. The amount of precipitation is shown by isohyets, and the background indicates the coefficient of variations. Precipitation increases from southwest toward northeast and toward mountainous areas

for instance, affect the arrangements of precipitation contours, resulting in significant differences in annual precipitation and also in changes in contour direction in comparison with other parts of NWI. However, there is no definite geographic coherence between the elevation and the amount of precipitation because the precipitation pattern is usually complex due to considerable variety in altitude, orientation and the slope of its relief. In general, Lake Urmia and the plain around it, between the western and central mountainous parts, and the northeast lowland, received relatively low annual precipitation owing to the lee effect caused by western mountains and their deep location below the surrounding areas. In the centre, a large amount of precipitation, which is due to the existence of Bozghoosh mount, can be seen. Owing to the height of the mountain, a multitude of precipitation occurs in spring as the result of convection. Moreover, the penetration of warm and humid weather of Caspian Sea into this area causes local weather fronts.

In order to assess the stability of month-to-month precipitation, the coefficient of variation (CV = standard deviation times 100 divided by the mean) of monthly precipitation throughout the year is defined. By definition, the closer the CV's value is to zero, the greater the stability that occurs in the precipitation of the successive month. The result of CV calculation is illustrated by the grey background scale in Fig. 2. The coefficient of variation is greater than 44 % in all NWI and may reach above 76 % in many places.

In order to make the contribution of the monthly precipitation to the annual precipitation in NWI more compressible, the spatial distribution of monthly precipitation based on the study period was also calculated. Monthly precipitation in the study area is shown in Fig. 3. The precipitation in high precipitation months varied irregularly with latitude, but was more regular with altitude, while in other months the opposite was true. Maximum (minimum) precipitation records appeared during March to May (July to September) all over NWI. However, the monthly precipitation values during these months ranged from 44.5 mm up to 59.7 mm (5.1 mm up to 9 mm). As can be understood from Fig. 3, the spatial ranges are small in August (about 13.7 mm), while April and May experienced a noticeable spatial range (90.9 and 98.1, respectively). The results of spatial pattern also were investigated by Asakereh and Razmi (2012) in spite of a small difference in amounts, which may be due to the length of the study period.

In this region, most precipitation took place in the spring. According to Trigo et al. (1999) and Trigo et al. (2002), Mediterranean low-pressure cells can proceed to the far north during this season and cause significant spring precipitation. However, the spring precipitation showed no clear spatial patterns. In general, it was higher in the south-west throughout the 3 months, and there were some more spots in the central parts. Prevalence of spring precipitation is a specific feature of the climate in NWI, while the annual distribution of

precipitation may differ in surrounding areas, as studied by, e.g. Kadioglu et al. (1999) in Turkey, Hamidianpoor et al. (2010) in the north-east of Iran, Janbaz Ghobadi et al. (2011) in the coast of the Caspian Sea, Jahanbakhsh and Zolfaghari (2002) in the west of Iran and Masodian (2009) in all of Iran.

The spatial variation of precipitation with latitude was more evident during the summer months. The figure suggests that the precipitation increases rapidly from south to north during this season. In summer, precipitation is higher in the northern half, particularly the northwest, while in farther south and southwest it decreases. The decrease in summer precipitation chiefly depends on retreating Westerlies (Alijani 1996). In the southern hilly region, annual precipitation was around 350 mm. This amount was lower than that it was in the north despite its higher elevation. The major cause of this decrease in precipitation in this region is the wind tracks which are associated with frontal systems (Asakereh 2011). In the north-western part of NWI, the precipitation probably originates from the Black Sea (a sea wind track which is humid), whereas the wind track in the southern region originates from the very hot parts in Iran, located in the south of NWI (Alijani 1996). According to Alijani (1996) and Masodian (2011), such a pattern can largely be attributed to convective processes during summer. Toward the east of the hills, the altitude decreases rapidly, and precipitation, chiefly of orographical origin, declines by less than 5 mm.

A clear north-south gradient could be observed in autumn and winter precipitation. From autumn toward winter, the precipitation values increased, especially in southern and southwestern parts. The autumn precipitation was highest in the south-western of NWI. The winter precipitation in the northern strip was very low. In contrast, the highest percentages were found in the southern parts of the area, where precipitation was more than 40 mm. According to Alijani (1996), this pattern can be explained by the lack of convectional precipitation during the winter in northern parts, and the prevailing westerly winds with cyclones providing significant precipitation in the south of NWI (Jahanbakhsh and Zolfaghari 2002). The precipitation turned into mountain snowpack in winter and was then released in spring and early summer. The lowest values of precipitation occurred during the summer months (June, July and August) over the northwest of NWI.

The decrease of precipitation far away from the mountainous areas (as can be seen in Fig. 3) is often attributed to the roles of mountains in the spatial distribution of precipitation (e.g. Barry and Chorley 1998). However, the role of latitude cannot be overlooked in many months. Yet the characteristics of precipitation during these months are much more orographic than in the former months, and spatial changes in monthly precipitation during winter are noticeable. Peaking in the mountainous region of the NWI, the monthly precipitation
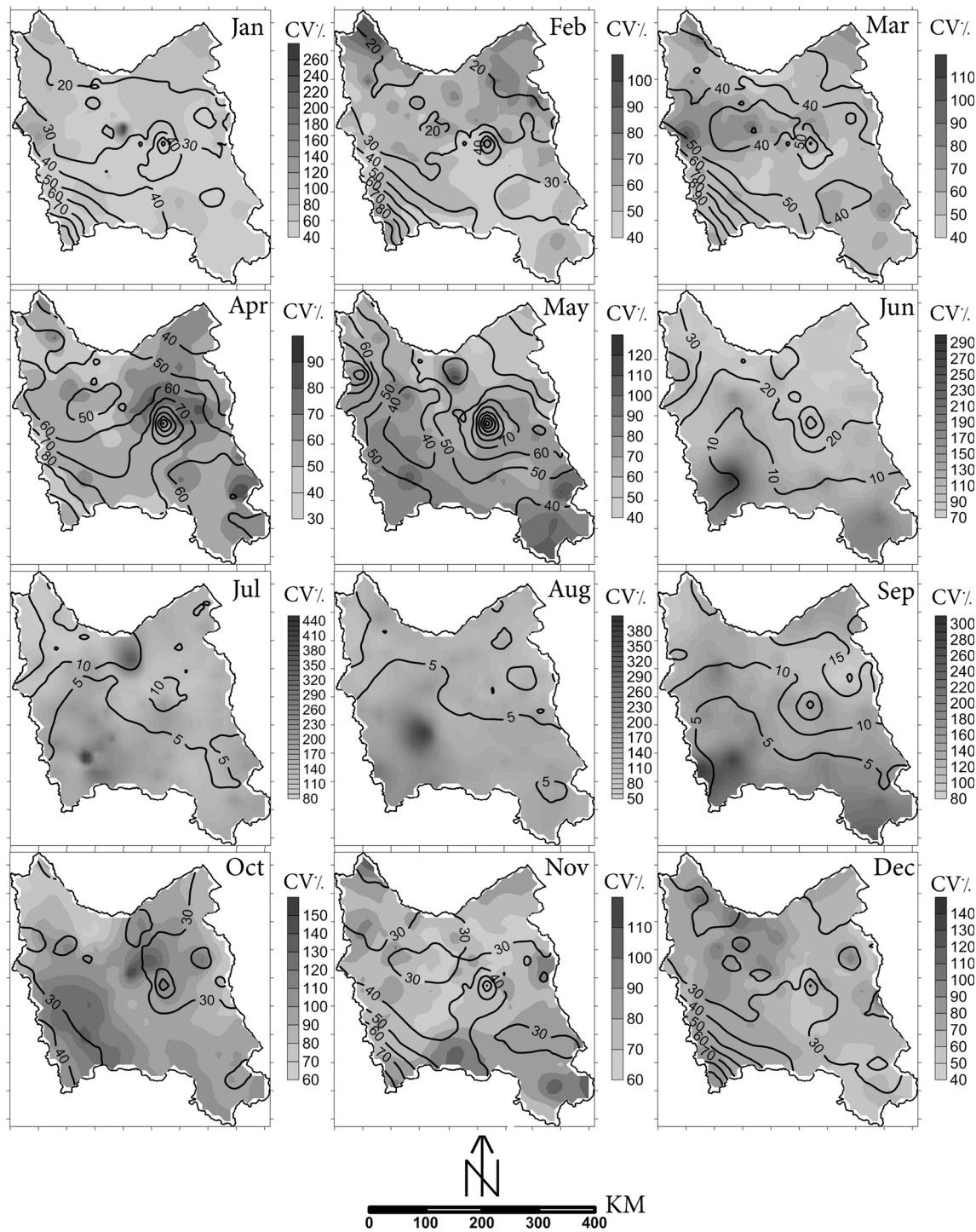
Fig. 3 Spatial distribution of monthly precipitation (mm) and its annual coefficient of variations in NWI. The contours show the amount of precipitation, and the background shows the coefficient of variations (CV). The maximum amount of precipitation occurs in March and May while the minimum amount takes place in July and September. Coefficient of variations follows monthly and annual amount of precipitation

contours are almost parallel to the topography of the region. Similar precipitation patterns but with much shorter recorded lengths were observed by Asakereh and Razmi (2011); Asakereh (2007); Masodian (2011) and Asakereh and Syfipour (2013) in NWI and all the territory of the country.

In Fig. 3, the relative year-to-year stability in precipitation values for each month is shown by CV values. These differences among CV patterns seem to be due not only to the topography feature and the month of the year but also to the latitude and amount of precipitation which cause a

complicated feature in the spatial distribution of precipitation. The greatest range of CV, for instance, happened during July. In this month, the CV sustained its maximum values over the southwest of NWI (approximately 426 %), while the other parts, particularly in the northeast and northwest of NWI, had the lowest values of CV (about 87 %). This indicates a higher confidence level of precipitation over the northeast and northwest of NWI, although precipitation stability was not significant. As can be seen in Fig. 3, the spatial values of CV as well as the spatial values of precipitation were more (less) varied during the months with (without) high precipitation.

3.2 Precipitation trend analyses

As already mentioned, many experts in the field tend to conduct a linear trend analysis due to its simplicity in order to detect changes in precipitation. In this study, in order to show NWI precipitation changes, the monthly precipitation trend was illustrated. Furthermore, to assess the geography of the monthly precipitation trend, the linear time trend over the period under study and at each land-surface grid node was estimated, and the rates of change (mm/year) for each month were mapped. Figure 4 gives the results of the application of the least square linear fitting to the precipitation series in each grid node, which shows considerable spatial variability. As can be seen, the spatial presentation of the detected precipitation trends enables a better understanding of precipitation trends in NWI over the last 50 years, especially in terms of the spatial distribution of precipitation trends. Accordingly, all months represent either positive or negative significant trends. However, there was a gradual change of precipitation for all months from 1961 to 2010 (Fig. 4).

Although significant decrease of precipitation (except in July and November) was more noticeable and was more uneven, especially over the whole NWI, the areas experiencing the effects of this kind of change differed. For instance, 92–97.7 % of NWI during the months in which high precipitation happened (January, March, April, May and October) showed a significant negative trend. Having examined the changes for the individual months between January, March, April, October and May, the researcher found that the rates of decline seem to be similar. However, the trends were spatially less uniform in these months. The greatest mean decline was identified for October (0.96 mm/year). In other months (except for July and November), around 64–79 % of the NWI showed negative trends. For instance, only a few positive trends occurred in September. The areas with positive trends in December were low, and mainly located in the southwest. The strongest reduction was estimated for each month, in the range of 0.78–2.3 mm/year (December to June), while there were gridded points where a slight increase was identified.

There was no evidence of a similar change in precipitation in July and November. In fact, in July and November, the downward trend in precipitation ceased and an increasing trend began to dominate. There were positive trends in July and November in almost 95.7 and 71.5 % of NWI, respectively, and a significant upward trend was seen in July. The values on the map indicate that less than 1 % of the areas possessed a negative trend of precipitation, with an average increase of less than 0.2 mm/year, while the other parts of the area showed a positive trend of precipitation with an average increase of 0.2 mm/year. The value of the trend decreases from west to east and from north to south reaching approximately zero in the southeast. The maximum values were more visible in the northern parts of NWI. Accordingly, there was a tendency toward an increase in summer precipitation in NWI.

A dominant feature of the trends in November was an extended region with positive trends stretching from north to south in western and eastern parts of NWI. The areas with mainly negative trends were over the central parts. Negative trends were concentrated in the north-southeast of NWI. The high number of negative precipitation trends in November mainly stemmed from the northern and central parts, whereas isolated, highly positive precipitation trends occurred in the high mountainous regions of the southwest of NWI. However, low positive precipitation trends occurred in north-eastern lowlands. The areas with negative and positive trends were spread widely over central parts of NWI. Increase dominated in the mountainous and highland areas, whereas decrease or trends close to zero were prevalent in the lowland regions, mainly in the eastern part of the region under study; as Slonosky et al. (2000); Jacobeit et al. (2001); Jacobeit et al. (2003) and Jacobeit et al. (2009) pointed out, the reason for such a phenomenon in Europe can be attributed to the enhanced influence of windward slopes under more frequent and intense zonal circulation in winter.

An extensive array of measurements going back to the mid-nineteenth century have been used to investigate large-scale changes in precipitation over Northern Hemisphere land areas. The results of precipitation trends in the present study are in agreement with those found by Asakereh (2007) for the whole of Iran's territory during 1961–2003, in which he showed that more than 51 % of Iranian territory had experienced its precipitation changes in the area of the western mountains; also the findings are in line with those of Razi and Azizi (2007) for NWI during 1965–2000. Moreover, the results obtained for this part of the study are in accordance with the findings of Asakereh and Razmi (2012) for NWI precipitation during 1966–2005, in which after 1995, a major decrease in precipitation was identified. To sum up, the precipitation decreased from 1961 to 2010 in most areas of NWI. The present analysis partly supports an emerging global picture of prevailing tempo-spatial difference in change (Liu et al. 2012; Niu 2013) and also of negative trends in precipitation over the

Fig. 4 Monthly precipitation trend (mm/year) during 1961 to 2010 in NWI. The Contours show the slope of the trend. In all the months, except for July and November, and especially in months with high precipitation, decreasing trend was more noticeable
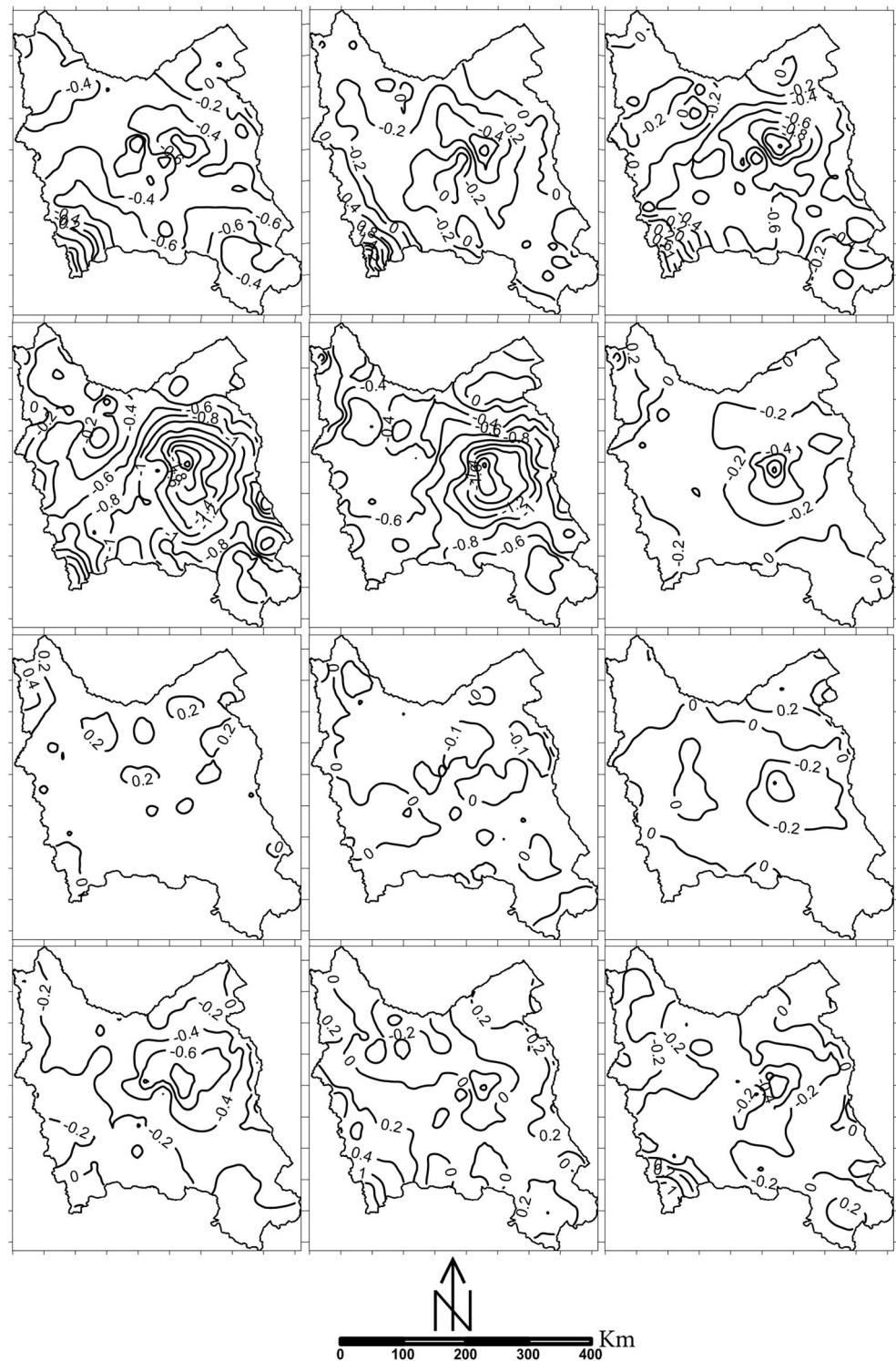
mid-latitudinal land areas of the Northern Hemisphere (Rahimzadeh et al. 2009; Philandras et al. 2011). However, they contradict the findings of the studies by Xu et al. (2003); Kyselý (2009); Zhang et al. (2010) and Wang et al. (2013). For instance, according to Bradley et al. (1987), significant increases in mid-latitude precipitation and concurrent decreases

in low-latitude precipitation have occurred over the last 30 to 40 years. Although these large-scale trends were consistent with general circulation model projections of precipitation changes associated with doubled concentrations of atmospheric carbon dioxide, they should be viewed as defining large-scale natural climatic variability. Further investigation

might be required to refine regional variations and address a potential network in homogeneities to corroborate the findings of the present study.

4 Conclusion

In the present study, attempts were made to improve the limitations existing in the literature. Therefore, a large number of stations and long-term data have been used in the present study. Moreover, the use of interpolation technique in this study can make the findings more generalizable and also cover more areas. Besides the simplicity of the methods used in the present study, they can be effective for other Iranian experts in the field to investigate precipitation of other areas in the country.

A least square error approach was employed to measure the changes of precipitation based on 245 stations in NWI from 1961 to 2010. This approach showed that spatial characters of precipitation had basically unstable traits. Moreover, due to spatial differences of precipitation, spatial interpolation appears to be a very useful approach for displaying the spatial characteristics of precipitation. This study thus took a descriptive approach to the explanation of NWI's spatial distribution of annual and monthly precipitation and monthly trends over the period under investigation. The differences in the amount and the more complex spatial patterns of precipitation in NWI led to the insight that precipitation tended to be more spatially variable in spring months than in other months, and it was unlikely to identify spatially coherent precipitation in spring from the relatively coarse continental-scale datasets. The roles of geographical factors thus caused different patterns during the months.

The spatial precipitation pattern of NWI for the monthly average data clearly indicated that the amount of precipitation increased to its maximum during January, March, April, May and October. Precipitation in these months followed the Mediterranean cyclones which also passed over NWI and brought moist air with high humidity from the Mediterranean Sea. On the other hand, in some cold months such those of autumn, the cold and dry air mass came from the Caucasus Mountains to NWI.

The spatial variability of precipitation was consistent with a tempo-spatial pattern of precipitation trends. There was a considerable difference between the amounts of change during the months and the negative trends mainly attributed to areas concentrated in eastern and southern parts of NWI far from the western mountain ranges. Moreover, limited areas with positive precipitation trends can be found in very small and isolated regions. This is observable particularly in the eastern half of NWI, which is mostly located far from Westerlies. On the other hand, seasonal precipitation trends indicated a slight decrease during winter and spring and a slight increase during summer and autumn. Consequently, there were major changes in average precipitation that occurred negatively in the area under study during the observation period. This finding is in agreement with Asakereh and Razmi (2012), who showed that there was a decreasing trend of round 2 mm/year over NWI during 1966–2005. More than 90 % of NWI during January, March, April, May and October showed a significant negative trend, while in July and November the downward trend in precipitation ceased and an increasing trend was dominant during these months.

Since the trends were generally reported more in the western than in the eastern parts of NWI, this could indicate that some of the changes (e.g. in winter) were linked to the modes of the Northern Hemisphere's patterns and variability (e.g. the North Atlantic Oscillation) and larger-scale circulation changes. This is beyond the scope of the present study and requires further investigation. It shows that the water percentage of the soil in which there was plant growth was reduced, causing a wilted condition during recent years. If this trend is maintained, the economy of the area could be seriously affected, something which requires the implementation of new strategies if we are to avoid a decrease of production.

Since winter precipitation is primarily snowfall, the decline of winter precipitation in especially high elevated regions can have a significant impact on water storage, while the decline of precipitation in spring can affect the yield of vegetation, and might also have a dramatic impact on agriculture because most agricultural activities in this area rely heavily on precipitation of this season. The decline of the annual precipitation may lead to the decrease of the water table. It is recommended that farmers overcome the problem of lack of precipitation by planting drought-resistant crops or early maturing species. Another way of coping with this problem is diversifying the economic base of the populace through emphasizing independence from rain-fed agriculture. Moreover, it is also recommended that government policies in this area should be based on recent precipitation trends.

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