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Precipitation trends and suitable drought index in the arid/semi-arid southeastern Mediterranean region

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Abstract The Mann-Kendall test was applied on homogeneous Jordanian and Israeli precipitation series to test for trends. Overall, 37 precipitation series with continuous data for the time period 1961–1990 were identified as homogeneous. During this time period a non-significant negative precipitation trend could be observed on annual sum. The same analysis was thereafter applied at the same stations, but with longer time series. The data availability differed from station to station, but the mean time period with available data was 1950–1997. The new result showed a stronger negative precipitation trend. This demonstrates how time series of different length can influence the result of trend analysis. As a step to identify a suitable drought index for the region, the correlation between precipitation and the Normalized Difference Vegetation Index (NDVI) received from remote sensing was investigated. A correlation would indicate that a precipitation based drought index could be suitable to assess the impact of possible precipitation trends. A high correlation was generally observed on natural vegetated areas; the correlation on irrigated land was lower. This suggests that a drought index based on precipitation alone may be applicable to the region, but the performance on non-rainfed agricultural areas may increase with consideration to irrigation.

Key words drought index; Mann-Kendall test; precipitation; trend analysis

INTRODUCTION

This study had two aims. The first aim was to investigate how the detection of precipitation trends is dependent on the length of the time period evaluated. The second aim was to investigate whether a precipitation-based drought index could be applied to the arid/semi-arid southeastern Mediterranean region.

Some of the previous studies regarding precipitation trends in the southeastern Mediterranean region contradict each other. Steinberger & Gazit-Yaari (1996) analysed data from 99 stations located in Israel and detected that during the time period 1960–1990, precipitation amounts increased in the southern coastal areas and decreased in the northern coastal- and mountainous areas. Dahamsheh & Aksoy (2007) did not find any trends in Jordanian precipitation data at the 13 stations investigated for the years 1953–2002. Zhang *et al*. (2005) concluded that precipitation trends in the Middle East are weak and not very significant. The significance did, however, depend on the time period evaluated. The contradiction of previous studies motivates to further investigate the relationship between the detection of a trend and the length of the time period used within the analysis.

A suitable drought index is desired for the region in order to assess the spatial impact of a possible increase or decrease of precipitation. The Normalized Difference Vegetation Index (NDVI) can be used to estimate the green biomass and its spatial distribution (Anyamba & Tucker, 2005). Many authors have observed a correlation between precipitation and NDVI (Wang *et al*., 2003; Song *et al*., 2008; Fabricante *et al*., 2009). NDVI has been shown to have a strong correlation with Jordanian field site measurements of percentage vegetation coverage at places where the vegetation is dense, but a lower correlation at sites with sparse coverage (Edwards *et al*., 1999). In the project region, NDVI shows a clear vegetation phenology with biomass peak in March/April. Since the development of biomass is dependent on the availability of water, NDVI could be used to validate the desired drought index. The correlation between precipitation and NDVI (as received from remote sensing) was investigated within this study. A high correlation was seen as necessary to accept a drought index based only on precipitation. If the correlation was low, further variables, like air temperature or irrigation, could have been included in the desired drought index.

STUDY AREA

The study area is located in the arid/semi-arid southeastern Mediterranean region. The present study includes data from weather stations located in Israel and Jordan. Within the water scarce study region, both a south–north and an east–west precipitation gradient exist. The southern parts receive dry winds from the Sinai desert, while the northern parts receive moist sea wind (Dahamsheh & Aksoy, 2007). The precipitation at the Red Sea in the south is less than 100 mm/year. In the northern elevated areas the amount exceeds 700 mm/year. The west–eastern precipitation gradient, with more precipitation in the west, is due to the distance from the coast and orographical factors resulting in an eastern lee side (Dahamsheh & Aksoy, 2007).

DATA

Precipitation

Data from 37 precipitation stations (located in Israel and Jordan) were used within the trend analyses. Daily observations were aggregated to monthly values. The monthly series were checked for homogeneity and the trend analyses were applied to precipitation sum, on an annual and quarterly (Jan.–Mar., Apr.–Jun., Jul.–Sep. and Oct.–Dec.) basis. The years 1961–1990 were considered, since between these years no data were missing. Thereafter, further applications were done with all the data available. The data availability differed from station to station, but the mean time period with available data was 1950–1997.

Within the correlation analyses between precipitation and NDVI, gridded precipitation was used on a 1 × 1 km raster. The data had been prepared by performing a multiple regression analysis according to Schlaffer & Menzel (2008) and Wimmer *et al.* (2009).

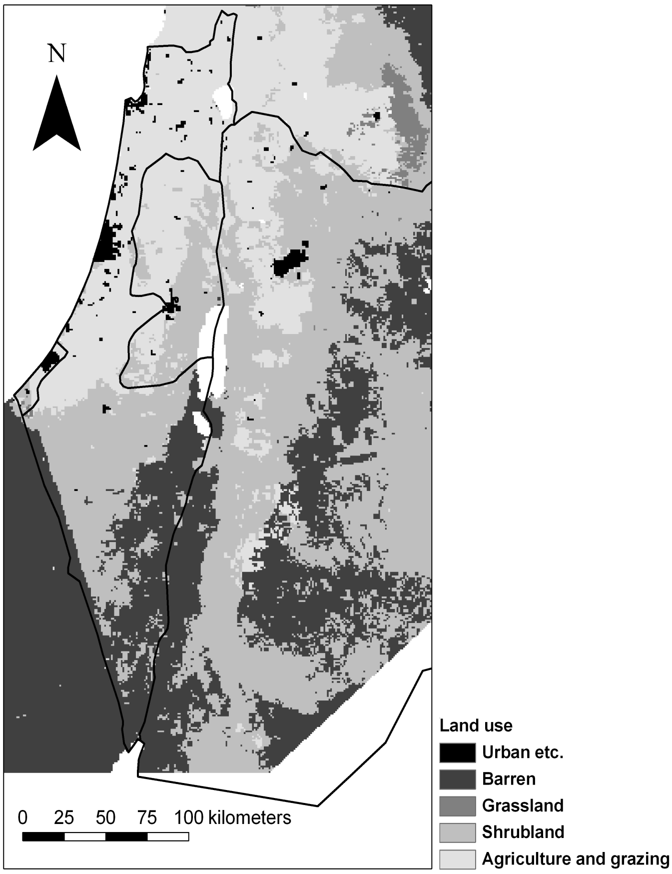

Fig. 1 The land use within the southeastern Mediterranean project region.

Land use

Within this study, land-use data from the Global Land Cover Characterization (GLCC) data set were used (Loveland, 2002). Nine land use classes were considered, namely: barren (covering 31% of the study area), mosaic (natural vegetation and crops) (10%), shrubland (41%), grassland (1%), vegetables (1%), fruits (1%), cereals (3%) and cropland (9%) (Fig. 1). Land-use classes that were not considered were urban areas and wetlands, as well as small-sized areas of forest and woody savannas. To facilitate the reading of Fig. 1 the classes were further divided into urban, etc. (urban, wetland, forest and woody savannas), barren, grassland, shrubland, as well as agriculture and grazing (cereals, cropland, fruits, vegetables and natural vegetation and crops).

NDVI

NDVI is calculated from the spectral reflectance in the near-infrared (NIR) and red visible (RED) regions:

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

NIR is reflected by healthy vegetation and RED is absorbed by leaf chlorophyll during photosynthesis. NDVI data from the Advanced Very High Resolution Radiometer (AVHRR) were used on an 8 × 8 km resolution for 1982–1990. The data set had been prepared by Pinzon *et al*. (2005) and Tucker *et al*. (2005), who made corrections for calibration, view geometry, volcanic aerosols, as well as for other effects not related to vegetation change. To receive an annual value of the highest biomass level of the main vegetation season, the maximum NDVI value for each pixel was derived for March/April each year.

METHODS

Identification of homogeneous time series

Within meteorological trend analyses, it is important that the data are homogeneous, i.e. that the measured variable is only influenced by weather and climate (Peterson *et al*., 1998). Some non-climatic factors that can highly influence precipitation series are the re-allocation or replacement of weather stations, introduction of a windshield, growth of trees or placing of new buildings near the station. The Standard Normal Homogeneity Test (SNHT) was developed by Alexandersson (1986) to test whether a data series is homogeneous or not. A test series (measured at one station) and a reference series (a mean series calculated from observations made at nearby stations) are created. The ratio between the test and the reference series is calculated. The reference series is assumed to be homogeneous and the null-hypothesis is that the test series is also homogeneous. This requires an adequate correlation between the test and the reference series and that the ratio between the two series remains fairly constant over time. If a single shift of mean in the test series (compared to the reference series) is detected, the null hypothesis will not be accepted. The data series is then classified as non-homogeneous and it is not suitable to use within trend analysis. The test is based on statistics and can be applied with different significant levels. Daily precipitation was aggregated to monthly series. The data were thereafter processed in four steps:

- Time series having missing values were removed.
- All series were tested for serial correlation according to Haan (2002). Serial correlated precipitation series were removed.
- Within the original daily precipitation series, a missing value means either an unknown rainfall or a null precipitation. In the first step, time series that had complete months without data were identified and removed. To further identify time series with only a low amount of data the annual precipitation sum was plotted as a function of time for each single station (test series), together with a mean series calculated from neighbouring stations (reference series). The series were thereafter visually examined. If the test series had periods with comparable low precipitation it could be suspected that the (original daily) test series had a high amount of missing values. Hence, the test series was not further considered within the analysis.

– Eventually, to statistically prove the homogeneity of the data series, the Standard Normal Homogeneity Test (SNHT) developed by Alexandersson (1986) was applied. Series that did not pass the test were removed.

The Mann-Kendall test

The nonparametric Mann-Kendall test (MK-test) has been used in many studies regarding precipitation trends (Karabork *et al*., 2007; Jiang *et al.*, 2007; Liu *et al.*, 2008). The null hypothesis suggests that no trend is present in the meteorological series. This hypothesis may then be rejected at a certain significance level, often 1, 5 or 10%. When applying the MK-test no assumption of distribution must be made. The test assigns a relative score to every observation and is therefore insensitive to outliers. The MK-test was applied to the homogeneous data series for the years 1961–1990. To test the importance of long-term time series within trend analysis, all the available data were used in additional trend analyses. The trend analyses were made on an annual and quarterly basis.

Correlation between precipitation and NDVI

Gridded precipitation (1 × 1 km) was compared to NDVI (8 × 8 km). The overlapping time period was 1982–1990. The precipitation sum between October of one year, until March the following year was calculated for each pixel on a 1 × 1 km resolution. The NDVI maximum in March/April was derived for all the pixels with the lower (8 × 8 km) resolution. Thereafter, each 1 × 1 km pixel had a time series of precipitation sum (Oct.–Mar.) and a corresponding series of maximum NDVI (Mar.–Apr.) for the years 1982–1990. The Spearman's Rank Correlation Coefficient between the two series was calculated to evaluate the correlation for each pixel (1 × 1 km). With this technique, areas with a high and low correlation could be identified, although the low amount of overlapping years cannot deliver a statistical significant result.

To further investigate the correlation on different land uses, the precipitation sum and maximum NDVI values of each pixel were aggregated to form annual mean values according to land use. The correlation coefficient between the series was then calculated.

RESULTS

Identification of homogeneous time series

A low amount of precipitation series had data gaps. These series were removed. Serial correlation only existed at a few precipitation stations. Several precipitation series were identified to be non-homogeneous when SNHT was applied; these series were, along with the serial correlated series, not studied further. Altogether 37 precipitation series, distributed over Israel and Jordan could be identified as homogeneous.

Precipitation trends

The MK-test was applied on homogeneous data series at a significance level of 1 and 5% and for the time period 1961–1990. The MK-test was also applied for all the years with available data (result given in brackets). A statistically significant trend (hereafter referred to as trend) of decreasing precipitation could be observed at 1 (5) station (Table 1). The precipitation trends were also evaluated based on quarterly data. During Jan.–Mar., which is the quarter of the year with the most precipitation, a negative trend could be observed at 0 (7) stations (Table 1) and during Apr.-Jun. at 2 (7) stations (not shown). However, the mean precipitation during these 3 months is very low and the trend is therefore of less importance. The months Jul.–Sep. lacked precipitation and during Oct.–Dec. a negative trend could be observed at 0 (1) stations (not shown). The annual trends could be observed at stations in the northern and southern Jordanian Highlands, in the Jordan Valley and in Jordan's western desert (Fig. 2).

Table 1 Stations with trends in quarterly (Jan.–Mar.) and annual precipitation. A test statistic value (u_c) of ±1.96 is considered as a significant trend at a significance level of 5% (indicated by *) and a value of ± 2.54 is considered as a significant trend at a significance level of 1% (indicated by **), negative trends are indicated by "–". The station number refers to Fig. 2.

Station	Nr.	Lat.	Long.	Year	u_c Jan–Mar	u_c Annual	Year	u_c Jan–Mar	u_c Annual
Amman Airp.	1	31.97	35.60	1961–1990	–0.43	–0.57	1938–2001	–1.59	–2.24*
Buseira	2	30.75	35.60	1961–1990	–1.46	–1.41	1938–1993	–3.00**	–2.84**
Deir Abi Said	3	32.50	35.68	1961–1990	–0.39	–0.98	1938–1993	–2.26*	–2.04*
Husn	–	32.48	35.88	1961–1990	–0.25	–1.02	1943–1993	–1.97*	–1.94
Kufrinja	4	32.30	35.70	1961–1990	–0.05	–0.84	1938–1993	–2.63**	–2.07*
Ramtha	–	32.57	36.02	1961–1990	–0.84	–0.71	1938–1993	–2.03*	–1.43
Sukhna	5	32.13	36.07	1961–1990	–1.21	–1.16	1952–2001	–2.57**	–3.26**
Um Qeis	6	32.65	35.68	1961–1990	–1.89	–2.03*	1938–1993	–2.90**	–1.39

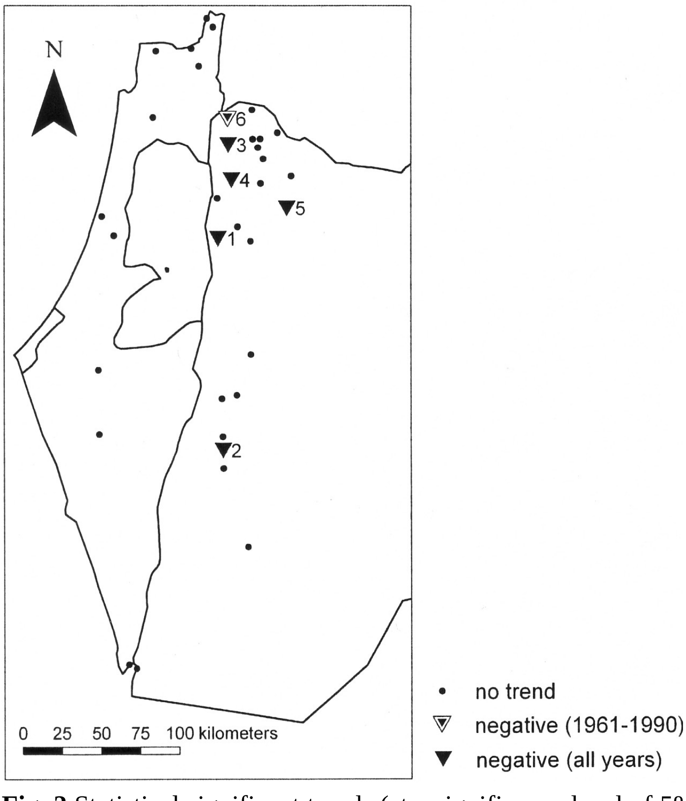

Fig. 2 Statistical significant trends (at a significance level of 5%) of annual precipitation of the stations listed in Table 1.

Correlation between precipitation and NDVI

When the correlation for each pixel was determined, areas with high and low correlation could be identified. The best correlation could be observed in the central and more vegetated parts of the study region and along the Jordanian Highlands stretching from north to south, east of the Dead Sea. Areas with lower correlation could be observed at the mosaic areas of natural vegetation and crops west of the Sea of Galilee. Other regions with a lower correlation were the barren areas stretching between the Dead Sea and the Gulf of Aqaba, and the scarcely vegetated shrubland in the southeastern part of the study region.

The precipitation sum (Oct.–Mar.) and maximum NDVI (Mar.–Apr.) was also aggregated according to land use. The highest correlation could be observed at natural vegetated shrubland and grazing land. A lower correlation could be observed at the mosaic areas and cropland. The lowest correlation was observed at grassland (Table 2).

Table 2 The correlation coefficient between precipitation and NDVI (1982–1990) aggregated according to land use.

Grazing Land	Mosaic	Shrub-land	Grass-land	Barren	Vegetables	Fruits	Cereals	Cropland
0.86	0.69	0.92	0.34	0.77	0.78	0.72	0.78	0.78

CONCLUSIONS

Precipitation series obtained at 37 weather stations were tested for trends for the years 1961–1990. The full length time series were also tested for trends. This was to investigate how time series of different length can influence the result. On an annual basis a negative (statistical significant) trend could be identified at 1 station (when the study was limited to the years 1961–1990) and at 5 stations (when the full length time series were used). During Jan.–Mar. a negative trend could be observed at 0 and 7 stations. If this study would have been limited to the years 1961–1990 then almost all the time series with a trend that were identified when all the available data were used, would have been missed. Although the result shows how time periods of different length can influence the trend analysis, the amount of stations with a trend is too low to draw any further conclusions about the importance of using long time series within the analyses.

Even though the spatial correlation between precipitation and NDVI could not be applied to deliver statistical significant results, it could be seen that the correlation was in general high for the natural vegetated areas but, not unexpectedly, lower for the land-use classes, which are known to be irrigated. An exception was the rain-fed grassland which had the lowest correlation of all. These results suggest that a precipitation based drought index would be applicable to the region, but further considerations are required to assess the irrigated areas. As a next step, the correlation between soil moisture modelled by the spatially distributed hydrological model TRAIN (Menzel *et al*., 2009) and NDVI will be investigated. The TRAIN model sets up a vertical water balance by considering precipitation, air temperature, relative humidity, wind speed and solar radiation. The model can also consider irrigation, which is believed to improve the correlation with NDVI on irrigated areas.

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