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Water vapor pressure trends in south and southwest Iran

YOUNES KHOSRAVI, HASAN LASHKARI* and HOSEIN ASAKEREH**

Faculty of Sciences, Department of Environmental Sciences, University of Zanjan, 45371-38791, Zanjan, Iran

**Faculty of Earth Sciences, Department of Geography, Shahid Beheshti University, Tehran, Iran*

***Department of Physical Geography, University of Zanjan, Zanjan, Iran*

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e mail : Khosravi@znu.ac.ir

सार – जलवायु परिवर्तन के मॉनीटरन में जलवायु प्राचलों की प्रवृत्ति की पहचान करना और उनका पता लगाने का कार्य इसमें महत्वपूर्ण योगदान देते हैं। इस अध्ययन में, एक सर्वाधिक महत्वपूर्ण प्राचल, जल वाष्प दाब (WVP) के विश्लेषण की जाँच की गई है। इस उद्देश्य के लिए, दो गैर प्राचलिक तकनीकों, मान-कैंडल और सेन्स स्लोप एस्टीमेटर का क्रमश: WVP प्रवृत्ति का विश्लेषण करने और प्रवृत्ति के परिमाण का निर्धारण करने के लिए उपयोग किया गया है। इन परीक्षणों के विश्लेषण के लिए ईरान के दक्षिण और दक्षिण पश्चिम में भू-केंद्र प्रेक्षणों [44 वर्ष (1967-2010) की अवधि के 10 केंद्रों] और ग्रिडिड आँकड़ों (30 वर्ष की अवधि, (1981-2010) में 9 × 9 कि.मी. के आयाम वाले पिक्सेल्स) का उपयोग किया गया है। MATLAB सॉफ्टवेयर में प्रोग्रामिंग द्वारा मासिक, मौसमी और वार्षिक WVP समय श्रृंखला निकाली गई और MK और सेन स स्लोप एस्टीमेटर परीक्षण किए गए। भू केंद्र प्रेक्षणों में मासिक MK परीक्षण के परिणाम से पता चला कि वृद्धि की प्रवृत्ति की तुलना में कमी की प्रवृत्ति बहुत कुछ परखने योग्य है। इससे यह भी पता चला कि अप्रैल से सितम्बर के गर्म महीनों में WVP की अधिकतम आवृत्ति अधिक थी और फरवरी और मई में महत्वपूर्ण प्रवृत्ति स्लोप की आवृत्ति अधिक थी। मासिक ग्रिडिड WVP समय श्रृंखला के MK परीक्षण के स्थानिक वितरण से अगस्त में पश्चिमी क्षेत्र में और फारस की खाड़ी के पास वृद्धि की प्रवृत्ति का पता चला है। दूसरी ओर कमी की प्रवृत्ति प्रत्येक माह में अलग अलग रही। सकारात्मक प्रवृत्ति स्लोप के अधिकतम और न्यूनतम मान क्रमश: गर्म और ठंड के महीनों में रहे। वार्षिक WVP समय श्रृंखलाओं के MK परीक्षण के विश्लेषण से अध्ययन के क्षेत्र के दक्षिण पूर्व और दक्षिण पश्चिम क्षेत्रों में महत्वपूर्ण वृद्धि की प्रवृत्तियों का पता चला है।

ABSTRACT. Recognition and detection of climatic parameters in have an important role in climate change monitoring. In this study, the analysis of one of the most important parameters, water vapor pressure (WVP), was investigated. For this purpose, two non-parametric techniques, Mann-Kendall and Sen's Slope Estimator, were used to analyze the WVP trend and to determine the magnitude of the trends, respectively. To analyze these tests, ground station observations [10 stations for period of 44 years (1967-2010)] and gridded data [pixels with the dimension of 9 × 9 km over a 30-year period (1981-2010)] in South and Southwest of Iran were used. By programming in MATLAB software, the monthly, seasonal and annual WVP time series were extracted and MK and Sen's slope estimator tests were done. The results of monthly MK test on ground station observations showed that the significant downward trends are more considerable than significant upward trends. It also showed that the WVP highest frequency was more in warm months, April to September and the highest frequency of significant trends slope was in February and May. The spatial distribution of MK test of monthly gridded WVP time series showed that the upward trends were detected mostly in western zone and near the Persian Gulf in August. On the other hand, the downward trends through months. The maximum and minimum values of positive trends slope occurred in warm months and cold months, respectively. The analysis of the MK test of the annual WVP time series indicated the upward significant trends in the southeast and southwest zones of study area.

Key words – Trend, Mann-Kendal, Sen's slope estimator, Water vapor pressure, South and southwest Iran.

1. Introduction

Identification and analysis of time-series of climatic parameters and processes upon them are the fundamental principles of climate science. Tracking this behaviour helps us to know more about climate change. Through the recent decades, climate change has been considered as an important issue among researchers. But in this context, most studies have focused on temperature (Fayram *et al*., 2014; Abraham *et al*., 2011; Stainforth *et al*., 2013; Telemeco *et al*., 2013; Kaufmann *et al*., 2011; Sorte *et al*., 2011; Brooks *et al*., 2014), precipitation

(Cheng *et al*., 2005; Gemmer *et al*., 2004; Lin *et al*., 2014; Ye, 2014) and other climatic parameters (Hoover *et al*., 2014; Kousari and Ahani, 2012; Choudhury *et al*., 2012; Pierce *et al*., 2013) in different regions of the world.

Recent studies in Iran focused on the long-term variability of temperature and precipitation (Zarenistanak *et al*., 2014; Marofi *et al*., 2012) and other parameters for example evapotranspiration (Tabari *et al*., 2011), wind (Kousari *et al*., 2013). Although many studies have focused on these important climatic parameters, some of them have been less considered. The water vapor pressure (WVP) is one of these parameters that has an important role in explaining the climate change, because (*i*) it is the main source of rainfall in all weather systems, (*ii*) it supplies the latent heat in this process and controls the heat in the troposphere (Trenberth and Stepaniak, 2003; Serrano *et al*., 1999; Wentz *et al*., 2007) and (*iii*) it is the resonator of the storm's speed (Allen and Sodden, 2008). So, it can be said that, among other parameters in the analysis of the climate change, it is of high significance to survey this climatic parameter.

One of the most useful methods for analyzing the climate change is investigating the trends through time series. It should be noted that, the existence of significant trends in a time series of WVP cannot prove the climate change theory in a region lonely, but it will strengthen the events hypothesis of climate change (Serrano *et al*., 1999). In general, the behaviour of climate elements is observed in three forms, *viz*., trend (long-term changes), Oscillation (short-term changes) and fluctuations (Asakereh, 2009). Trend analysis of the long-term change, using ground station observations of meteorological variables, can enhance our knowledge of the dominant processes in an area and contributes to the analysis of future climate projections (Ahani *et al*., 2013). There are varieties of methods for analyzing the climatic parameters trend.

The methods for investigating the climatic parameters trend can be classified as parametric and non-parametric (Zhang *et al*., 2006). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. This is while, non-parametric trend tests require that only the data be independent and can tolerate outliers in the data (Shadmani *et al*., 2012). But, they are insensitive to the type of data distribution (Hamed and Rao, 1998; Yue *et al*., 2002). Two non-parametric tests, Mann-Kendall trend test and Sen's slope estimator, are used to analyze the trend and magnitude of possible trends in-temporal observed data, respectively (Yaning *et al*., 2009; Tonkaz *et al*., 2007; Kahya & Kalayci, 2004; Kukul *et al*., 2007).

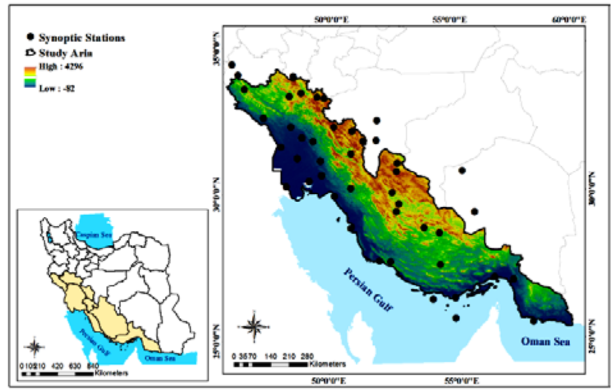


Fig. 1. Distribution of 46 synoptic stations in south and southwest Iran

Recent studies about trend analysis have focused mainly on long-term variability of temperature (Begert *et al*., 2005; Brunetti *et al*., 2000) and precipitation (Kampata *et al*., 2008; Yue and Hashino, 2003). WVP, as the third most important climatic parameter, is a dominant greenhouse gas and strongly influences the transfer of moisture between the surface and atmosphere and consequently, the water balance at local to regional scales (Kimball *et al*., 1997). Accordingly, not many researchers around the world have focused on WVP's changes. For example, Kuttler *et al*. (2007) surveyed the trend in time series (2001-2002) of urban/rural atmospheric WVP in Krefeld, Germany. The results of these studies have clearly shown a diurnal course of UME that was found for summer but not for winter and frequency maxima in the second half of the night. Hoinka (1998) surveyed the time series of annual WVP (1979-1993) and argued that this parameter has an upward trend. Similarly, Kaiser (2000) employed this approach in China during 1954-1994. The results of these studies have shown an increase in surface WVP in northwestern and a decrease in northeastern China. Trenberth *et al*. (2005) have analyzed the global datasets on column-integrated water vapor and have shown that in the tropics, the trends are also influenced by changes in rainfall, which, in turn, are closely associated with the mean flow and convergence of moisture by the trade winds.

We are aware of the climate change importance. Besides, we know that for the analysis of changes, we have to survey the trend of climatic parameters such as temperature, precipitation, humidity etc. So, this study was conducted to evaluate the WVP trends in south and southwest Iran by using Mann-Kendal test, spatially and temporally in three time series (monthly, seasonal and annual). The changes magnitude of the significant trends was also identified by the Sen's slope estimator

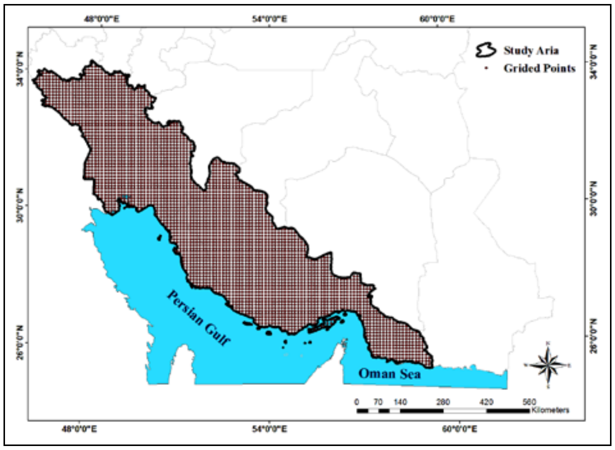


Fig. 2. The daily WVP gridded data interpolated by Kriging method in pixels with dimension of 9 × 9 km

test (Sen, 1968). The results of this study can help researchers and decision makers in Iran to achieve more information about WVP trends, spatially and temporally, in south and southwest Iran.

2. Materials and method

In this study, WVP data from 46 synoptic stations was used. It was collected by the Iranian Meteorological data website (http://www.weather.ir). The locations of these stations are also shown in Fig. 1. The methodology of this study includes detect of trends and its magnitude by MK and Sen's slope estimator tests, respectively based on (*i*) ground station observations and (*ii*) gridded data. For surveying trends and their slope based on stations, 10 stations with reasonable distribution and acceptable long-term period of 44 years (1967-2010), were used.

For spatial survey of MK and Sen's Slope tests in the study area, 46 synoptic stations were used. The WVP data was interpolated by Kriging Method in pixels to the dimension of 9 × 9 km in the time interval 1981-2010 (Fig. 2). The daily WVP gridded data is prepared in an array of 3338 × 10957 (3338 cells over row and 10957 days over column). The Lambert Conformal Conic was chosen as coordinate system. By programming in MATLAB software, the monthly, seasonal and annual WVP time series were extracted and MK tests and Sen's slope estimator in all of stations and also pixels have been done.

2.1. *Statistical tests*

Through the present study in order to detect trends and to identify the slope magnitude of the significant trends in monthly, seasonal and annual WVP time series, MK test and Sen's slope estimator were used, respectively. The methods used are described as follows:

2.1.1. *MK non-parametric test*

Trend analysis was conducted using the Mann-Kendall non-parametric test (Mann, 1945; Kendall, 1975). As stated in Zhai and Feng (2009), this test has a number of advantages: (*i*) the data do not need to conform to a particular distribution, thus extreme values are acceptable (Hirsch *et al*., 1993), (*ii*) missing values are allowed (Yu *et al.*, 1993) (*iii*) relative magnitudes (ranking) are used instead of the numerical values , which allows ‘ trace ’ or ‘below’ detection limit’ data to be included, as they are assigned a value less than the smallest measured value, and (*iv*) in time series analysis, it is not necessary to specify whether the trend is linear or not (Sneyers, 1990;Yu *et al*., 1993; Silva, 2004). The MK statistics S is given as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}\left(X_j - X_i\right)$$

The application of trend test is done to a time series x_i that is ranged from i = 1, 2, ..., n-1 and x_j, which is ranged from $j = i$ + 1, 2, ..., n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$\operatorname{sgn}(\theta) = \begin{cases} +1 \text{ if } \left(x_j - x_k\right) > 0 \\ 0 \quad \text{if } \left(x_j - x_k\right) = 0 \\ -1 \text{ if } \left(x_j - x_k\right) < 0 \end{cases}$$

It has been documented that, when $n \geq 8$, the statistic S is approximately normally distributed with the mean. The variance statistic is given as:

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t(t-1)(2t+5)}{18}$$

where, t_i is considered as the number of ties up to sample i. The test statistics Z_c is computed as:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & \text{if} \quad S < 0 \end{cases}$$

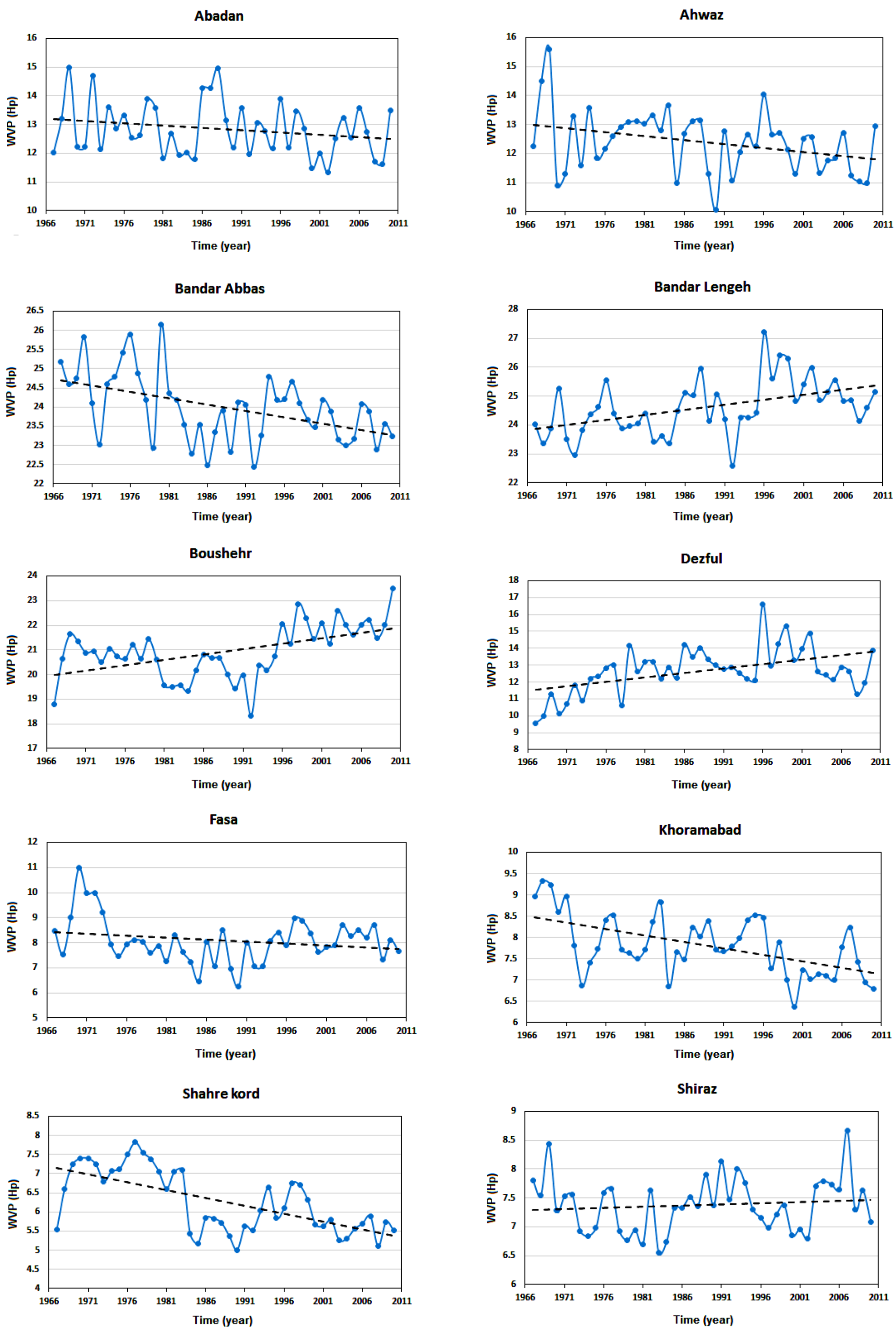


Fig. 3. WVP annual time series in surveyed stations in south and southwest of Iran

TABLE 1

Z factor derived by MK test on monthly and yearly WVP time series

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Abadan	0.73	0.35	-0.89	-0.41	-1.97*	-2.31*	-1.86	0. 73	-1.41	-0.07	-1.2	0.37	-1.29
Ahwaz	0.79	-0.28	-1.21	-0.68	-3.74*	-2.53*	-1.98*	-1.02	1.51	-0.62	-1.3	0.06	-4.13*
Bandarabbas	-0.97	0.27	-1.37	-2.48*	-3.11*	-2.32*	-1.14	-2.01*	-0.97	-0.94	-1	-1.6	-4.28*
Bandarlengeh	0.2	1.03	1.59	2.54*	2.18*	2.31*	3.23*	1.27	0.88	0.92	0.67	0.19	3.12*
Boushehr	1.55	1.92	1.04	1.91	0.54	1.5	2.72*	3.68*	2.9*	2.35*	0.51	1.54	3.62*
Dezful	1.18	0.85	0.62	1.3	0.07	2.65*	2.56*	2.19*	3.62*	3.04*	0.64	0.4	0.52
Fasa	0.22	0.17	-0.29	0.27	-1.61	-0.79	0.12	-1.11	-0.75	-0.39	-0.8	-0.1	-0.35
Khoramabad	-2.18*	-1.63	-2.71*	0.25	-1.88	-3.97*	-3.43*	-3.29*	-3.42*	-1.56	-1.2	-1.5	-5.35*
Shiraz	-0.31	0.44	-1.83	-0.93	-1.63	0.5	0.6	2.11*	2.03*	1.29	0.15	0.05	0.31
Shahrekord	1.01	1.49	-1.97*	-1.34	-4.06*	-3.81*	-3.64*	-5.12*	-4.25*	-3.26*	-0.2	0.06	-4.14*

Z values more than 1.96 represent upward significant trends, less than -1.96 show the decreasing trends at $\alpha<0.05$. * Significant trend at the 0.05 level

Positive value of Z_{MK} indicates increasing trends, while negative Z_{MK} values indicate decreasing trends in the time series. When $\left|Z_{MK}\right| > Z_{1-\frac{\alpha}{2}}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\frac{\alpha}{2}}$ is the critical value of Z from the standard normal table, for 5% level the value of $Z_{1-\frac{\alpha}{2}}$ is 1.96. In this study MK test was calculated by MATLAB software.

2.1.2. *Sen's slope estimateor*

The magnitude of trend is predicted by the Sen's estimator. Here, the slope (T_i) of all data pairs is computed as (Sen, 1968):

$$T_i = \frac{X_j - X_k}{j-k} \quad \text{for } i = 1, 2..., N$$

where,

X_j and X_k are considered as data values at time j and k ($j > k$) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases}$$

TABLE 2

MK trend test results at the 5% level

Variable	No. of decreasing trends	No. of increasing trends
January	1	-
February	-	-
March	2	-
April	2	-
May	4	1
Jun	5	2
July	3	3
August	3	3
September	2	3
October	1	2
November	-	-
December	-	-
Yearly	4	2

Sen's estimator is computed as $Q_{med} = \frac{T(N1)}{2}$ if N appears odd and it is considered as $Q_{med} = \frac{\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right)}{2}$ if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1 - α)% confidence interval and then a true slope can be obtained by the non- parametric test. Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series.

TABLE 3

Sen's slope estimator results in monthly and yearly WVP time series

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Abadan	0.015	0.006	-0.017	-0.012	-0.056	-0.046	-0.04	0.028	-0.036	-0.004	-0.028	0.006	-0.014
Ahwaz	0.017	-0.005	-0.028	-0.016	-0.078	-0.053	-0.05	-0.033	-0.037	-0.017	-0.028	0.001	-0.026
Bandarabbas	-0.014	0.007	-0.022	-0.031	-0.09	-0.071	-0.023	-0.045	-0.028	-0.037	-0.039	-0.035	-0.032
Bandarlengeh	0.003	0.022	0.027	0.04	0.061	0.059	0.051	0.025	0.019	0.03	0.02	0.005	0.034
Boushehr	0.026	0.032	0.016	0.029	0.015	0.052	0.061	0.162	0.061	0.065	0.006	0.023	0.041
Dezful	0.017	0.013	0.012	0.032	0.002	0.069	0.097	0.086	0.111	0.082	0.012	0.011	0.05
Fasa	0.002	0.002	-0.006	0.002	-0.023	-0.015	-0.003	-0.026	-0.011	-0.008	-0.014	-0.002	-0.008
Khoramabad	-0.02	-0.014	-0.032	0.003	-0.033	-0.076	0.63	-0.059	-0.062	-0.032	-0.004	-0.018	-0.03
Shiraz	-0.003	0.004	-0.02	-0.011	-0.02	0.003	0.009	0.033	0.024	0.013	0.003	0.001	0.003
Shahrekord	0.007	0.012	-0.017	-0.014	-0.046	-0.095	-0.093	-0.102	-0.083	-0.043	-0.002	0.005	-0.043

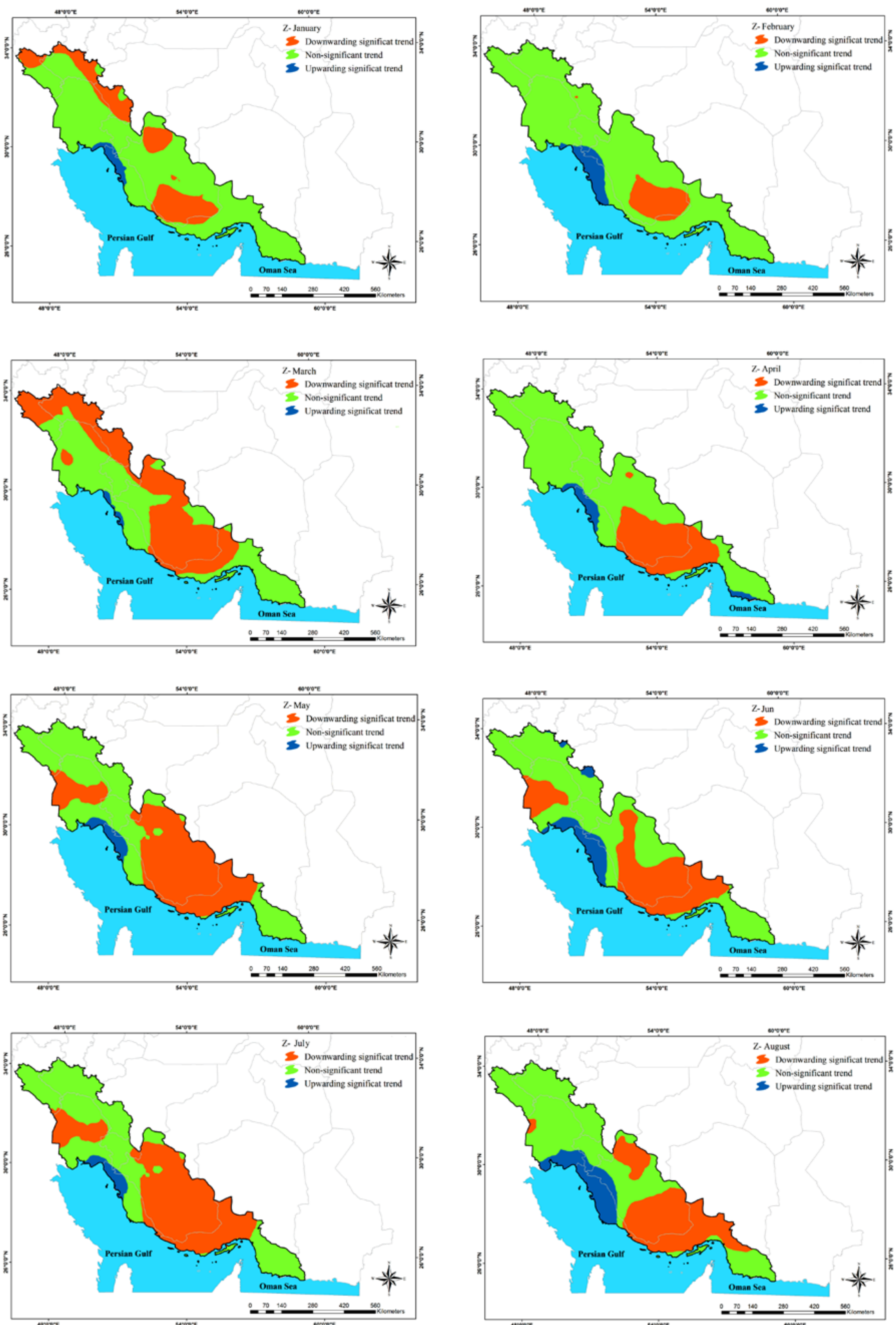
According to Ahani *et al*. (2012), if a time series presents a linear trend, the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). All the calculation of Sen's slope estimator has been done by MATLAB software.

3. Results and discussion

Fig. 3 shows the WVP annual time series in surveyed stations and also the fitted lines (first order) on each time series. Based on this figure, the increasing trend of WVP occurred in Abadan, Ahwaz, Bandarabbas, Fasa, Khorramabad and Shahrekord stations. This figure also shows the decreasing trend in Bandar Lengeh, Boushehr, Dezful and Shiraz. Therefore, it can be said that, in most cases, WVP increasing trends occurred in west of study area and decreasing trends occurred in east of study area.

The result of MK test for trend identification (Z parameter in the MK statistics) in all synoptic stations are shown in Table 1. Table 2 summarizes the total numbers of significant decreasing and increasing trends in all months. As Table 1 indicates, the significant trend at the 0.05 significant level is shown by *, including upward trends (*Z* parameters more than 1.96) and downward trends (*Z* parameters less than 1.96). Monthly *Z* factors of WVP showed that significant trends occurred in 37 cases. In this scale, about 69% of *Z* factors show non-significant trends, while 23% and 13% have decreasing and increasing trends, respectively. As shown in these tables, both trends, upward and downward, occurred in most of the months; while, November, December and February had and significant trend. During January, March and April there was no upward trend. The frequency of downward trends was more in summer and less in autumn. According to these tables, 3, 1, 8 and 11 cases of downward trends have accrued in winter, autumn, summer and spring, respectively. On the other hand, there are 3, 9 and 2 cases of upward trends in spring, summer and autumn, respectively. There was no significant trend in winter. Therefore, the results showed that the number of significant downward trends is more considerable than that of significant upward trends. The frequency of increasing or decreasing significant trends was more in warm months, April to September. It was realized that, most of the stations such as Abadan, Ahwaz, Bandarabbas, Khoramabad and Shahrekord had more frequency of decreasing trends. On the other hand, Bandar Lengeh, Boushehr, Dezful and Shiraz had upward trends. Fasa station had no significant trend. In investigation of MK statistics on the monthly WVP, Shahrekord and Abadan showed a maximum and minimum decreasing trend, while Dezful and Shiraz had maximum and minimum increasing trend, respectively. The results of MK statistics on the yearly WVP (Table 1) showed both increasing and decreasing trends. In Ahwaz, Bandarabbas, Khoramabad and Shahrekord stations, increasing trends and in Bandarlengeh, Bousher and Lengeh decreasing trends were shown. It also didn't show any trends in Abadan, Fasa and Shiraz.

In this study, the Sen's slope estimator was used to clarify the magnitude of positive or negative WVP trends. Table 3 presents the Sen's slope estimator which also indicates slope magnitude of trends. It was realized that in February and May, the highest frequency of increasing


Z- January
Downwarding significat trend
Non-significant trend
Upwarding significat trend
Persian Gulf
Oman Sea
Z- February
Downwarding significat trend
Non-significant trend
Upwarding significat trend
Persian Gulf
Oman Sea
Z- March
Downwarding significat trend
Non-significant trend
Upwarding significat trend
Persian Gulf
Oman Sea
Z- April
Downwarding significat trend
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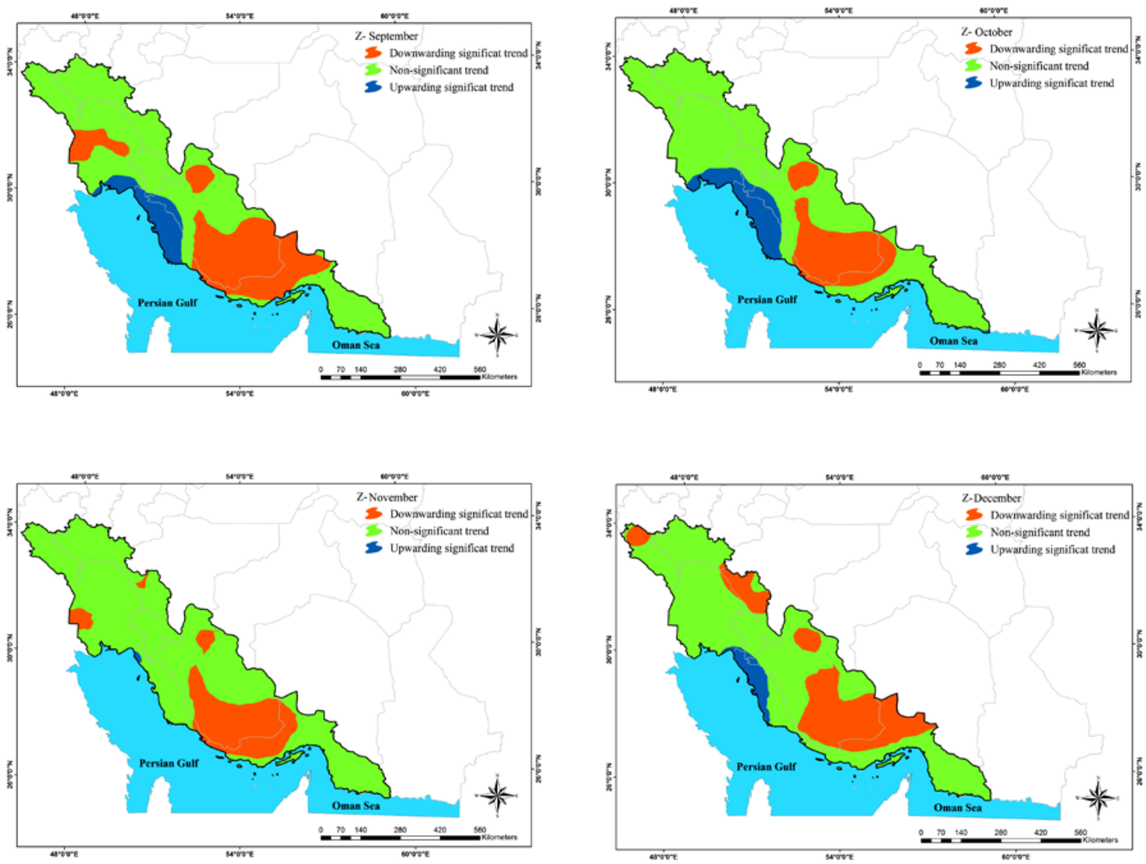
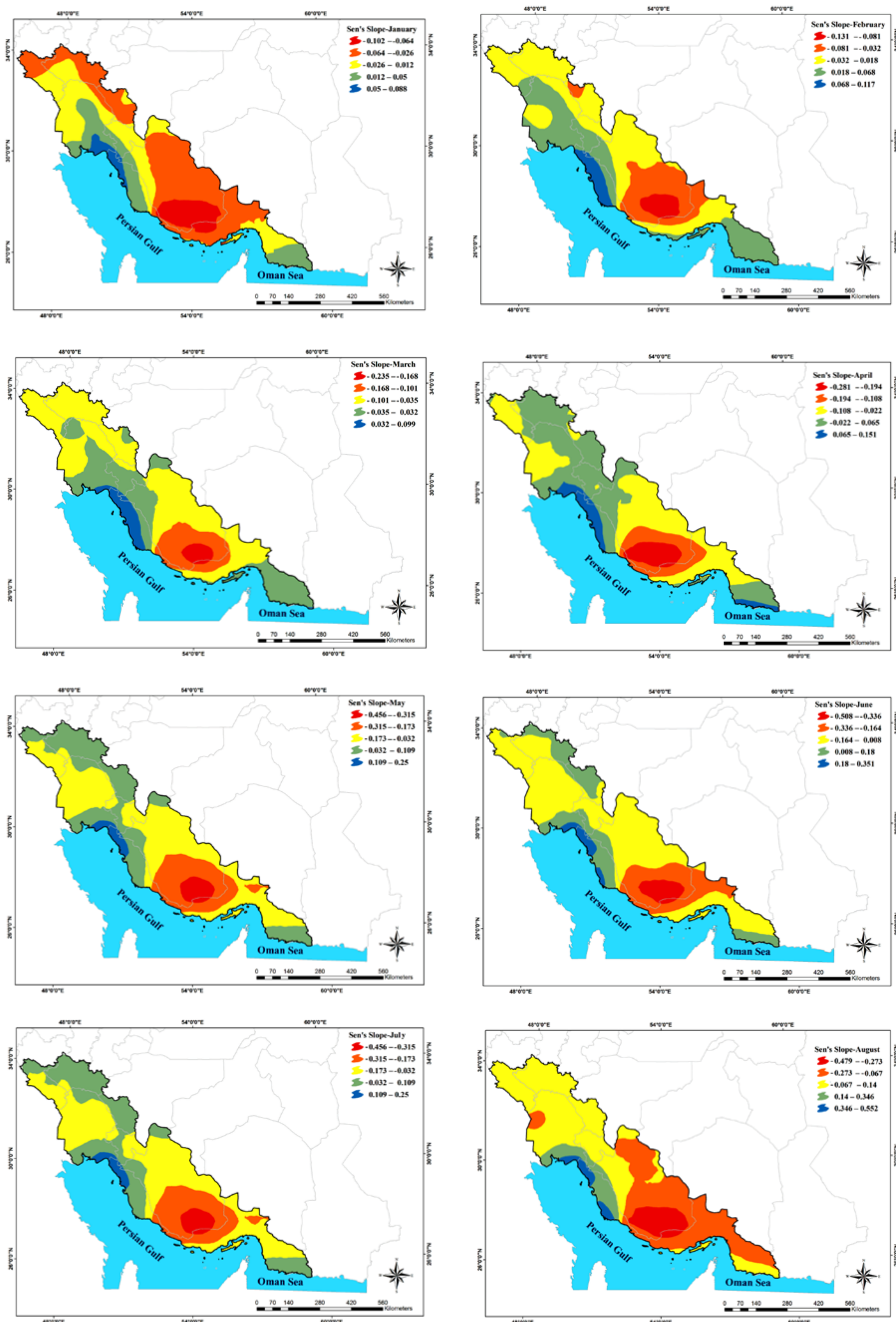


Fig. 4. Spatial distribution of increasing, decreasing and non-significant trends at the 5 % significant level for the monthly WVP time series

and decreasing trends was seen, respectively. The results of Sen's slope estimator showed that the WVP frequency of negative slopes was more considerable in warm months, so that in June, the maximum values of trends slope were seen in all stations. Considering the fact that the highest temperature occurred in warm month, it is clear that when temperature is low, the WVP changes are negligible. The maximum of positive trends slope was seen in Bandarlengeh, Boushehr and Dezful and that occurred in warm months, April to October. By considering the stations, it can be construed that in Bandarabbas, in all months, the negative slope was seen, while in February the trend's slope was low, 0.007. The maximum of negative and positive trends slope was seen in August in Shahrekord, -0.102 and September in Dezful, 0.111, respectively.

As mentioned previously through methodology, another spatial survey method in whole study area has been done by gridded WVP time series that were prepared in pixels. The spatial distributions of Mk test and their Slop's on monthly WVP are plotted in Fig. 4 and Fig. 5 Based on this picture, upward and downward significant trends and non-significant trends were illustrated. In this figure, upward trends were detected mostly in western zone and near the Persian Gulf in August. The upward trends area was less than the other months in November. In October, the trends, upward and downward, were more spatially uniform. In March, about half of the study area was covered by downward trends that clearly occurred in high elevations. Based on spatially variability, it was realized that the upward trends in all months occurred in western zone and near the Persian Gulf. It didn't move, but the area was changed. On the other hand, the downward trends based on month's change, were changed. So that, the period between April to September, had maximum area of downward trends. After September, downward trends moved towards the high elevations and some of them were appeared in the low elevations, near the Persian Gulf. According to the trends Slope maps (Fig. 5), during most of months, maximum of positive trends slope appeared in the southwest of the study area and in some months in eastern part. The maximum and minimum values of positive trends slope


Sen's Slope-January
- 0.102 – -0.064
- 0.064 – -0.026
- 0.026 – 0.012
0.012 – 0.05
0.05 – 0.088
Sen's Slope-February
- 0.131 – - 0.081
- 0.081 – - 0.032
- 0.032 – 0.018
0.018 – 0.068
0.068 – 0.117
Sen's Slope-March
- 0.235 – -0.168
- 0.168 – -0.101
- 0.101 – -0.035
- 0.035 – 0.032
0.032 – 0.099
Sen's Slope-April
-0.281 – -0.194
-0.194 – -0.108
-0.108 – -0.022
-0.022 – 0.065
0.065 – 0.151
Sen's Slope-May
- 0.456 – - 0.315
- 0.315 – - 0.173
- 0.173 – - 0.032
- 0.032 – 0.109
0.109 – 0.25
Sen's Slope-June
- 0.508 – -0.336
- 0.336 – -0.164
- 0.164 – 0.008
0.008 – 0.18
0.18 – 0.351
Sen's Slope-July
-0.456 – -0.315
-0.315 – -0.173
-0.173 – -0.032
-0.032 – 0.109
0.109 – 0.25
Sen's Slope-August
- 0.479 – -0.273
- 0.273 – -0.067
- 0.067 – 0.14
0.14 – 0.346
0.346 – 0.552
Persian Gulf
Oman Sea
0 70 140 280 420 560 Kilometers

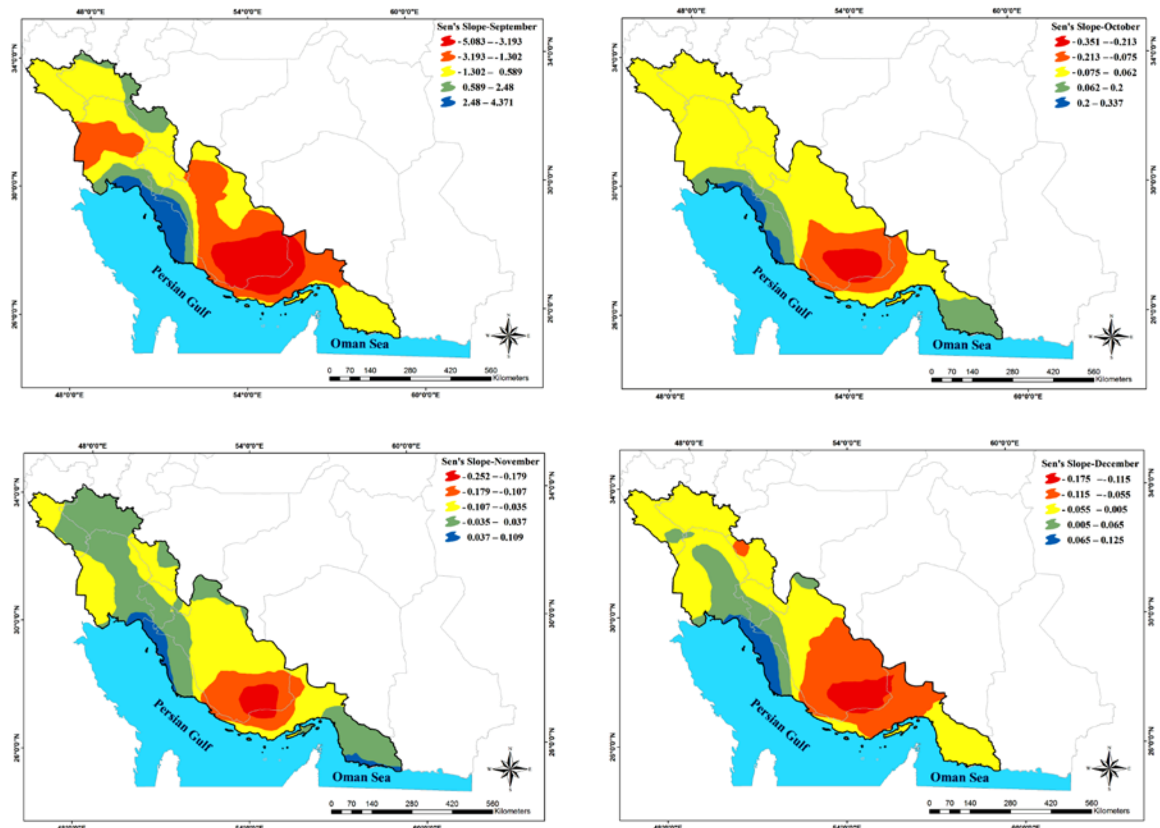


Fig. 5. Spatial distribution of the Sen's slope estimator for the monthly WVP time series

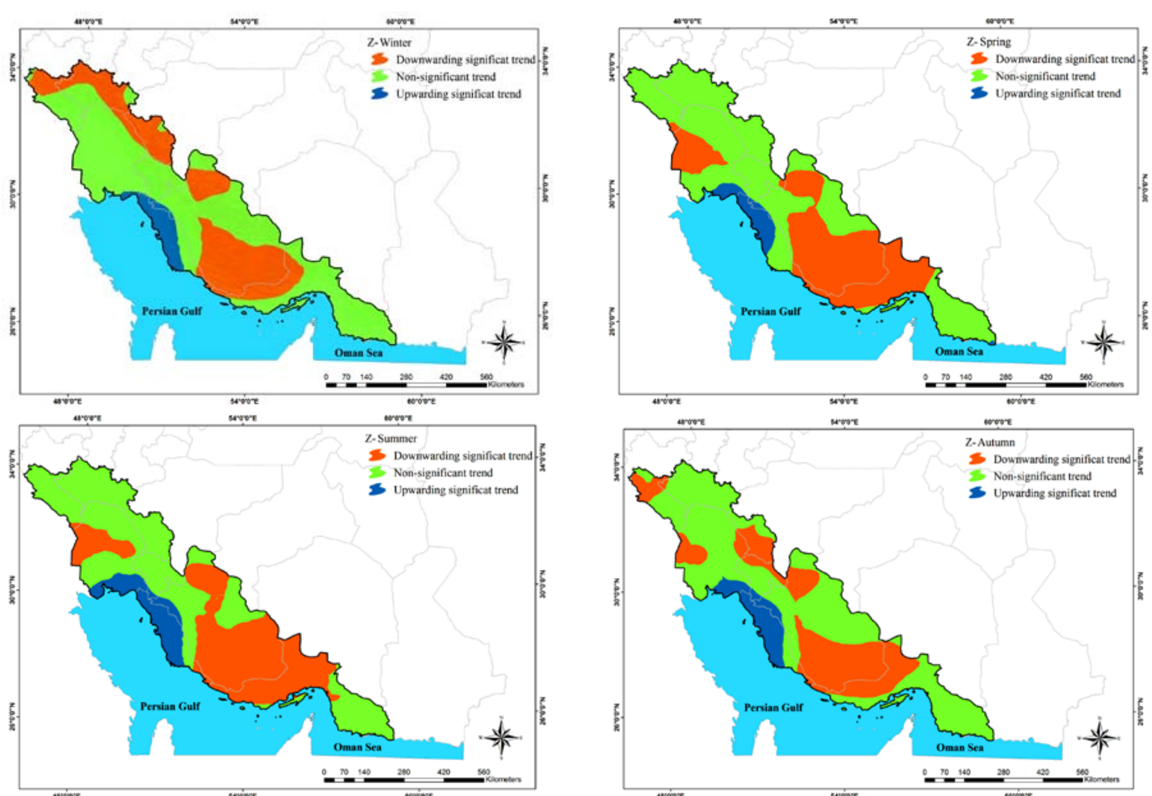


Fig. 6. Spatial distribution of increasing, decreasing and non-significant trends at the 5% significant level for the seasonal WVP time series

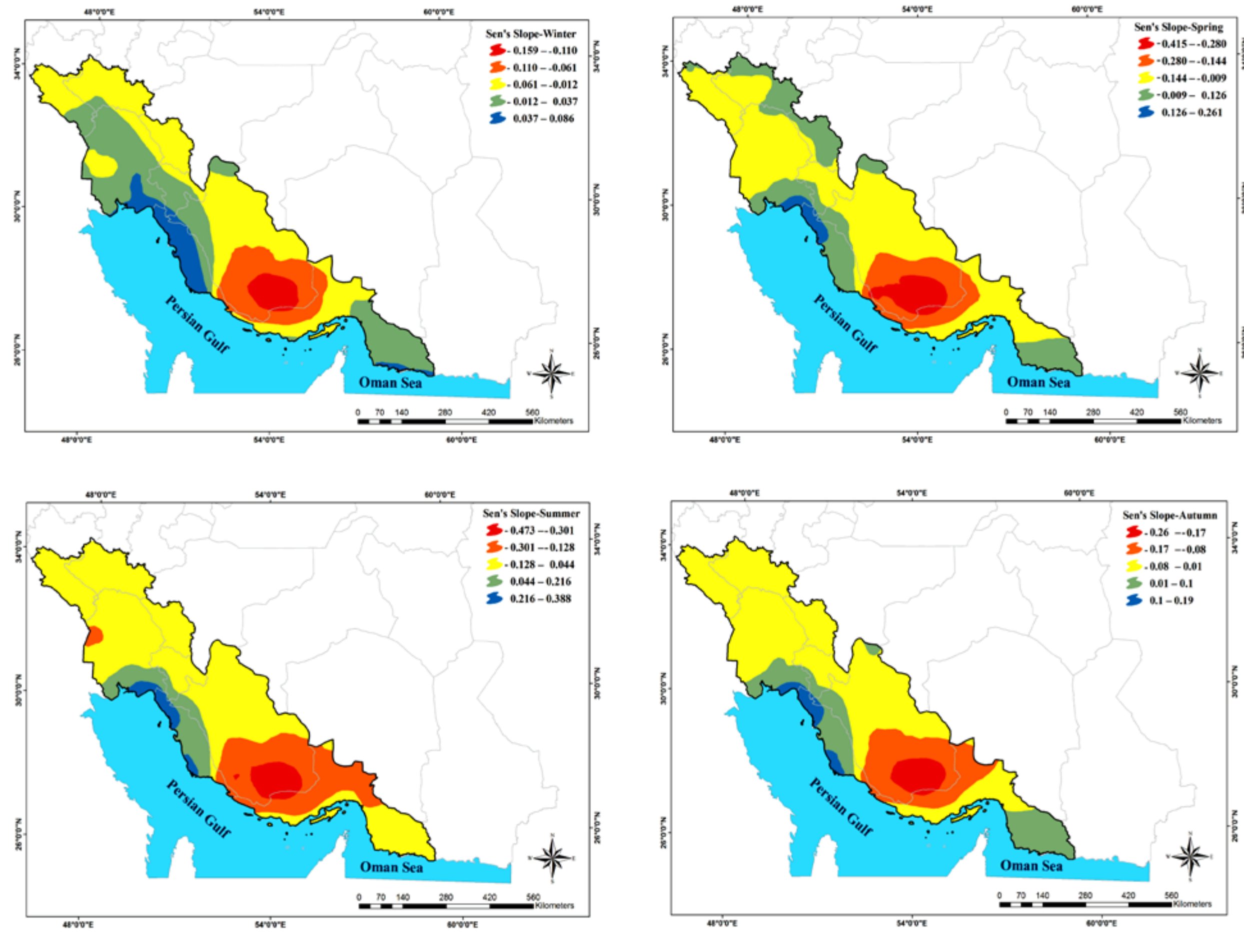


Fig. 7. Spatial distribution of the Sen's slope estimator for the seasonal WVP time series

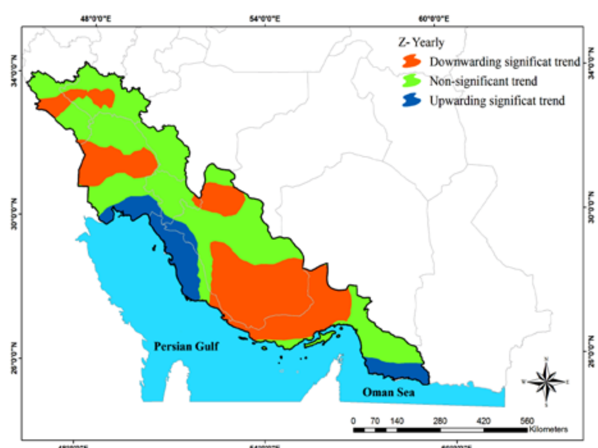


Fig. 8. Spatial distribution of increasing, decreasing and non-significant trends at the 5% significant level for the

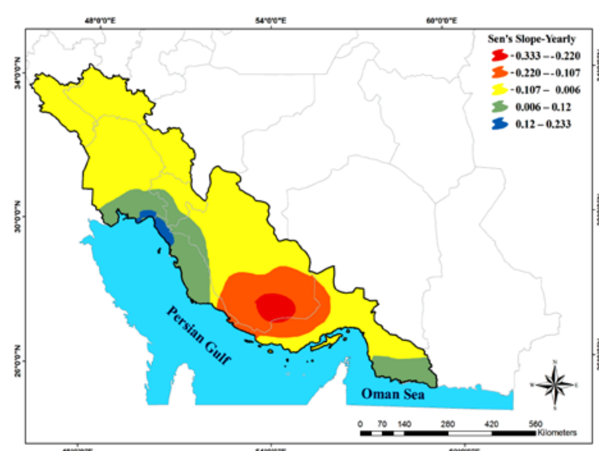


Fig. 9. Spatial distribution of the Sen's slope estimator for the yearly WVP time series

occurred in warmmonths and cold months, respectively. So that, WVP of about 0.97 hpa and 0.14 hPa in warm and cold months increased, respectively. It was revealed that the negative trends slope appeared in the central and eastern zones, in the southern Zagros. In September, it extended and had maximum values of negative trends slope. So that, the WVP values in September decreased about 5 hPa, while the minimum values of negative trends slope were seen in January, 0.102 hPa. The seasonal analysis of WVP time series (Fig. 6), indicated that the maximum and minimum frequency of positive trend occurred in summer and winter, respectively. On the other hand, maximum and minimum frequency of negative trend were found in summer and autumn, respectively. Analysis of the MK test in seasonal scale showed that the increasing trend mainly occurred in summer. According to the direct relationship between WVP and temperature, it can be said that one of the main causes of WVP increasing trend in summer can be increase in air temperature. On the other hand, because of cooling tendency in winter, the WVP increasing trend had no more frequency. Spatial distribution of trends slope of seasonal WVP time series is shown in Fig. 7. According to this figure, trends slope (increasing or decreasing) during different seasons almost occurred in the same place but with different values. So that, the maximum of increasing trend slope, following the monthly trend slope, was shown in north of Boushehr with 0.38 hPa in summer. It also indicated that, maximum decreasing trends slope occurred in the same season, at a rate of 0.47 hPa. According to the Fig. 7, decreasing trends slope of WVP had more and less slope in summer and winter, respectively. Figs. 8 and 9 exhibit the spatial distribution of Z values of MK test and Sen's slope estimator in annual time series. It can be said that upward significant trends were appeared in south east and south west zones of study area. Between these two zones and also in some parts of west and northwest, downward significant trends were seen. In this scale, stronger increasing trends slope was identified in southwest and southeast (Fig. 9). The decreasing trends slope was seen between zones with increasing trends.

4. Conclusions

In this study, trends of monthly, seasonal and annual WVP were evaluated based on more than 30 years data from 46 synoptic stations in south and southwest Iran based on ground observations and gridded data. The results of monthly MK test showed that the number of significant downward trends is more than that of significant upward trends. It also showed that the frequency of increasing or decreasing significantly trends are more in warm months, April to September. The Sen's slope estimator of monthly WVP time series indicated that the highest frequency of increasing and decreasing trends is seen in February and May respectively. The maximum negative and positive trends slope was seen in August, (-0.102) and September, (0.111), respectively. Based on the spatial distribution of MK test of monthly gridded WVP time series, upward trends were detected mostly in western zone and near the Persian Gulf in August. The upward trends area was less in November than the other months. In October, the trends' changes, upward and downward, were more spatially uniform. In March, about half of the study area was covered by downward trends. Based on this time scale, in most of the months, maximum southwest of positive trends slope appeared in the west south of the study area and in some months in eastern part. The maximum and minimum values of positive trends slope occurred in warm months and cold months, respectively. Analysis of the MK test in seasonal scale showed that the increasing trend mainly occurred in summer. It also showed that the increasing or decreasing trends slope changes almost occurred during different seasons in the same place but with different values. Based on the MK test of the annual WVP time series, upward significant trends appeared in the southeast and southwest zones of study area. In this scale, stronger increasing trends slope was identified in southwest and southeast. Finally, It should be noted that, the existence of significant trends in a time series of WVP alone cannot prove the climate change theory in a region. It is emphasized the need for more analysis of the other climatic parameters over the region.

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