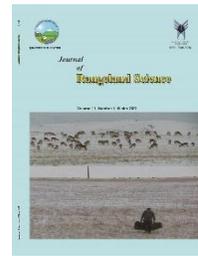


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Research and Full Length Article:

Assessment of MODIS-Derived NDVI and EVI for Different Vegetation Types in Arid Region: A Study in Sirjan Plain Catchment of Kerman province, Iran

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Abstract. Trend of vegetation in typology scale has remained uncertain, especially in arid ecosystems. Therefore, we aimed to assess two vegetation indices including the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Trends and their rates of indices in vegetation types were analyzed by the Mann–Kendall test and Theil–Sen trend estimator. To this end, we determined the typology maps of Sirjan plain catchment in Kerman province, Iran based on field operations; then, Moderate Resolution Imaging Spectroradiometer (MODIS) monthly data with the spatial resolution at 250×250 m from 2000 to 2019 were organized into the NDVI and EVI time series to investigate the trend. The results showed that some vegetation types which had no distinct trend were random and time-independent; however, the *Alhagi camelorum* type demonstrated the EVI and NDVI annual increase by 0.0009 and 0.0011 year⁻¹, respectively. The other types that changed dimensionally and were associated stochastically had different slopes of increase according to Theil–Sen estimate. The most increased rate of the NDVI was attributed to *Artemisia sieberi*-*Amygdalus lycioides*-*Ebenus stellata* type (0.0015 year⁻¹) whereas for the EVI *Artemisia aucheri*-*Astragalus parrowianus*, *Zygophyllum eurypterum*-*Artemisia sieberi*-*Astragalus arbusculus*, *Dendrostellera lessertii*-*Noaea minuta*, *Artemisia sieberi*-*Zygophyllum eurypterum* and *Cornulaca monacantha*-*Salsola orientalis* types were increased by 0.0008 year⁻¹. Of note, sudden NDVI and EVI changes (out of the confidence level of Theil–Sen estimate) were observed for the majority of types especially in 2008 and 2017. More investigations on environmental data and human activity in the mentioned years affecting as turbulator of majority of types are recommended.

Key words: MODIS, Vegetation indices, Trend, Arid ecosystem

Introduction

Vegetation cover is of crucial importance for maintaining the balance of various terrestrial ecosystems via carbon sequestration and photosynthesis and reduces the undesirable effects of worldwide climate change (Zhang *et al.*, 2013; Xiao and Moody, 2005). The vegetation of natural ecosystems (such as rangeland and desert) consists of dominant ecosystems in many countries that are paramount to preserve water resources and carbon accumulation in the soil (Naumburg *et al.*, 2005; Rigge *et al.*, 2013; Yeganeh *et al.*, 2016). They serve as medical sources for human and fodder sources for pastoral activity. They also offer scenic attractions with major tourism potential among other environmental services (Asadian *et al.*, 2017). These ecosystems include various homogenous units which are named vegetation types as management units (Lu *et al.*, 2015; Sharifi *et al.*, 2018). The structure and function of these ecosystems belong dramatically to their vegetation types (Bagheri, 2011; Amiri and Basiri, 2008; Mohamadi, 2016a). Each vegetation type without considering the extensiveness is named by dominant species having the most canopy covers (Ahmadi *et al.*, 2001). All decision makings including livestock stocking, and medical harvesting rates belong to knowledge about the types and variations of vegetation (Abtahi *et al.*, 2014). Vegetation patterns and types are striking features of many ecosystems and specialized models of their variations need more work, especially in arid natural ecosystems. The theoretical works of arid natural ecosystems dominate a large literature seeking to account for properties of vegetation patterns and types (Dunkerley, 2018). In this regard, dominant plants forming the name of vegetation types

have an important role whereas the coverage of annual ephemeral and non-dominant plants makes only a minor contribution to the ecosystem function (WenZhi and XueLi, 2014). Owing to the fact that the location and density of meristems, where plant growth occurs, differ in the vegetation types showing in the plant typology map (Yahdjian and Sala, 2006, Hadian, 2013), the response pattern can vary with fluctuations in environmental during the time. We assumed that vegetation types trend¹ strategy differs through their reaction to human-made and natural factors, especially climate variation over time. Duo to the existence of severe lack of data collection based on field study in vegetation type scale in arid ecosystems; remote sensing has provided the opportunity for researchers and practitioners to monitor the temporal and spatial variations. Research into the long-term variations in vegetation types which are recognized in the plant typology map can potentially detect early signals of slow degradation or improvement through the spectral vegetation index data in the satellite images (Jin *et al.*, 2016). Because of the vegetation with more absorption in red and reflectance in near-infrared (NIR) bands, these bands are mostly applied in satellite derived vegetation indices. In this regard, the satellite-derived Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) have been used extremely in the vegetation studies in the recent years (Huang *et al.*, 2014; Lu *et al.*, 2015; Chen *et al.*, 2018). Both of these indices can be regarded as indicators of vegetation reflectance (Nagai *et al.*, 2012; Moreira *et al.*, 2019). Different researches have demonstrated the shortcomings of the NDVI as a vegetation index. In this regard, due to the saturation effect it presents for

¹ - Trend is defined as a kind of response trough the increasing or decreasing changes in the average amount of a vegetation series to the time.

dense vegetation covers, another VIs such as the EVI have been designed to correct this drawback (Sobrino and Julien, 2013). The EVI incorporating the soil effects and atmospheric impacts has been utilized, especially in arid regions that canopy cover is low (Liu *et al.*, 2016, Lu *et al.*, 2015). In this regard, using MODIS data for the NDVI and EVI assessment has previously been done (Li *et al.*, 2015; Lu *et al.*, 2015; Jin *et al.*, 2016; Kermani *et al.*, 2017; Moreira *et al.*, 2019).

The analysis of time series of vegetation indices (VI's) has previously been focused to investigate the dynamic processes of various ecosystems and their relationships with different factors of the ecological environment on a different scale. Ahmedou *et al.* (2008) indicated rainfall and NDVI trends of grass and shrub lands in the semi-arid zone (Sahel) and sparse vegetation in the arid zone (Sahara) zones in the Mauritanian Sahel by Linear regression analysis and the non-parametric Mann-Kendall test. They found no significant trends for NDVI in the arid zone (Sahara). Pouliot *et al.* (2009) investigated trends in vegetation NDVI over Canada for the period 1985–2006 and discovered that 22% of the vegetated area in Canada was found to have a positive NDVI trend. Li *et al.* (2013) reported that the NDVI responses from 2005 to 2012 to rainfall events differed in two habitats including dune and desert of northwestern China due to biodiversity structure and the root systems' abilities to exploit moisture. Li *et al.* (2015) used MODIS-NDVI as a productivity of desert sites and pointed out that some parameters of the threshold-delay model differed among various desert sites of china including Shandan, Linze and Jiuquan. Abdalla *et al.* (2015) utilized MODIS images to distinguish different rangeland sites and reported that the differences in NDVI values between different rangeland sites may be attributed to differences in cover which represented variation in density and size of plant in each site. Liu *et al.* (2016) indicated that the most

dramatic declines in the NDVI and LAE occurred in open shrub-lands near center of Australia and in southwestern Australia. Jin *et al.* (2016) investigated NDVI dynamics in an arid basin (Qaidam Basin, China) and showed both areas of bare soil and low-density vegetation presented a decreased rate whereas medium, medium-high, and high-density vegetation indicated increase trends in the vegetation cover. Zhang *et al.* (2017) found that the NDVI presented a significant increase (0.0046/a) for all of China and all the regions over 16 years (1998–2013). Schucknecht *et al.* (2018) used MODIS data set to provide NDVI maps for supporting the rangeland management in Niger as a semi-arid environment. Moreira *et al.* (2019) studying the seasonal vegetation dynamic in various vegetation types of grasslands by MODIS-NDVI and EVI demonstrated the consistent EVI and NDVI profiles with the seasonal dynamics of grassland vegetation.

Although the previous studies have considered vegetation indices trend in different natural ecosystems such as desert, rangeland and forest, a few researches about vegetation trend detection have been focused on the structure of vegetative types; WenZhi and XueLi (2014) studied a desert climate area with yearly precipitation equal to 117 mm and revealed that the NDVI of *Haloxylon ammodendron* community which had 55.2% of canopy cover varied greatly. Sharifi *et al.* (2018) based on field data collections over 4 years (2009-2012) reported that annual canopy changes of dominant shrub forms in Moqan shrublands as an arid region were different. In this regard, *Artemisia fragrans* type changed significantly and *Salsola crassa* didn't change. Imani *et al.* (2018) comparing the NDVI and SAVI in three plant structures including annuals Forbs and bushes with different sampling intensity in Choghakhour Lake Rangelands of Charmahal and Bakhtiri province, Iran as a semiarid region observed that the NDVI had the most correlation with dominant vegetation form in each site.

Meanwhile, some other studies have already addressed the spatio-temporal dynamic of the arid natural ecosystems among other ecosystems, especially in Iran (Arzani *et al.*, 1999; Arzani *et al.*, 2005; Mohamadi, 2016b; Kermani *et al.*, 2017; Mirhoseini *et al.*, 2019), there is a lack of research aimed at identifying and characterizing patterns of annual variation with emphasizing on vegetation types of arid ecosystems. Owing to the fact that the trend in term of vegetation types has remained uncertain especially in arid ecosystems, our research aimed to determine the existence of MODIS-NDVI and MODIS-EVI trends and their rate by adopting the Mann–Kendall test and Theil–Sen trend estimator in various vegetation types of Sirjan plain catchment as an arid region over 2 decades (2000-2019).

Materials and Methods

Study area

Study area as a main catchment of Abargu-Sirjan has been located between eastern longitude 55°10' and 56°28'E and latitude 28°40' and 29°59' N in the central plateau basin of Iran. The study region with covering 7921 km² area and code number as 4419 is related to Kerman province, Iran. It has been illustrated among the other plains of the Kerman province in Fig. 1. The land is mainly covered by shrubs and bushy trees. The mean precipitation in plain and mountain were 113.5 and 198.3 mm, respectively considering both Sirjan and Sooch stations data from 2000 to 2019. The elevation of the region ranged from 1650 to 3813 m above sea level. Rangeland vegetation has generally dominated by shrublands having about 20% canopy cover. According to the latest census, this area has 553274 light livestock including sheep and goats (Management and Planning Organization of Kerman, 2016).

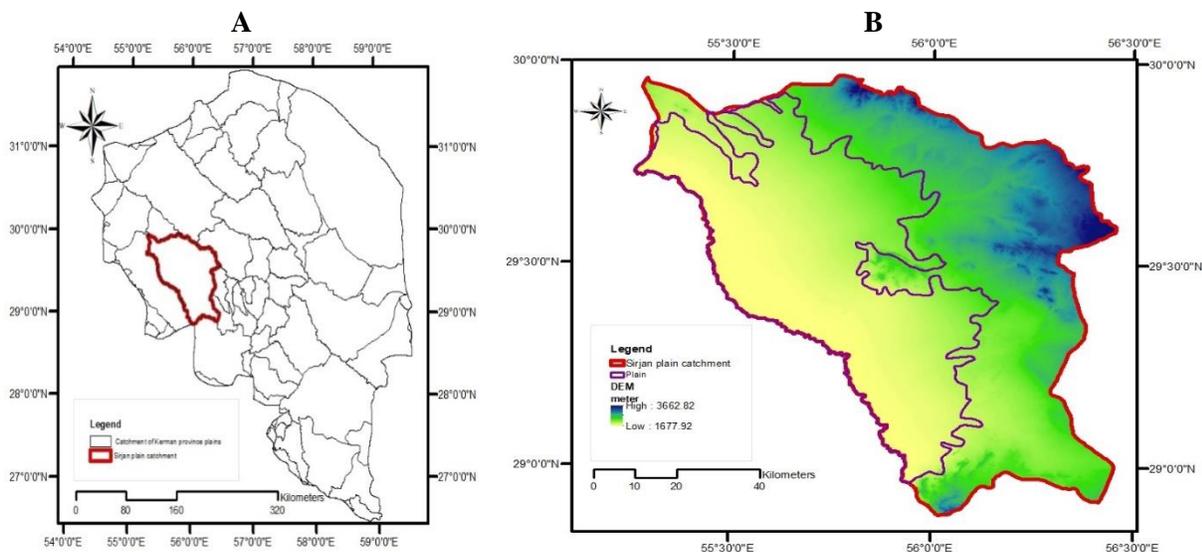


Fig. 1. Study area: A)-Location map in Kerman province of Iran B)- DEM characteristics of the study area

Methodology

According to the land use map provided by Research Institute of Forests and Rangelands of Iran (Engineering advisory company of resources development and improvement,

2012), natural ecosystem boundaries including rangeland and desert were extracted to provide vegetation types (showing further as typologies map) based on various field operations in spring, 2019. Vegetation types were distinguished in the study area classified

to mountain and plain units based on geomorphological classification. The flow chart illustrating the processes of research conduction was shown in Fig. 2. Having surveyed the typology map of the region at shape file format in Arc-GIS 10.4.1 package, MODIS-NDVI and EVI data were obtained from NASA's Earth Observing System from 2000 to 2019. Although satellite data have been corrected in terms of geometry and radiometry at different levels, it is possible to remain some primary errors or make new errors resulting from the primary correction process; thus, it is essential to review the images before performing any analyses. No radiometric errors including striped disruption and repeated pixels were found in the given images. After being assured of no mentioned errors, Internal Average Relative Reflectance (IARR) correction and contrast improvement operation of images were made with regard to the atmospheric errors using the ENVI 4.5 software. Then, the NDVI and EVI were calculated based on bellow formulas (Agapiou *et al.*, 2012);

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \quad (1)$$

$$\text{EVI} = G \frac{\text{NIR} - \text{Red}}{\text{Nir} + \text{C1Red} - \text{C2Blue} + \text{L}} \quad (2)$$

Where:

NIR, Red, and Blue are full or partially atmospheric-corrected (for Rayleigh scattering and ozone absorption) surface reflectance;

L is the canopy background adjustment for correcting the nonlinear, differential NIR and red radiant transfer through a canopy;

C1 and C2 are the coefficients of the aerosol resistance term (which uses the blue band to correct for aerosol influences in the red band) and

G is a gain or scaling factor.

The coefficients adopted for the MODIS EVI algorithm are L=1, C1=6, C2=7.5, and G=2.5.

It is necessary to note that the EVI additionally decouples the soil and atmospheric influences from the vegetation signal by including a feedback term for simultaneous correction.

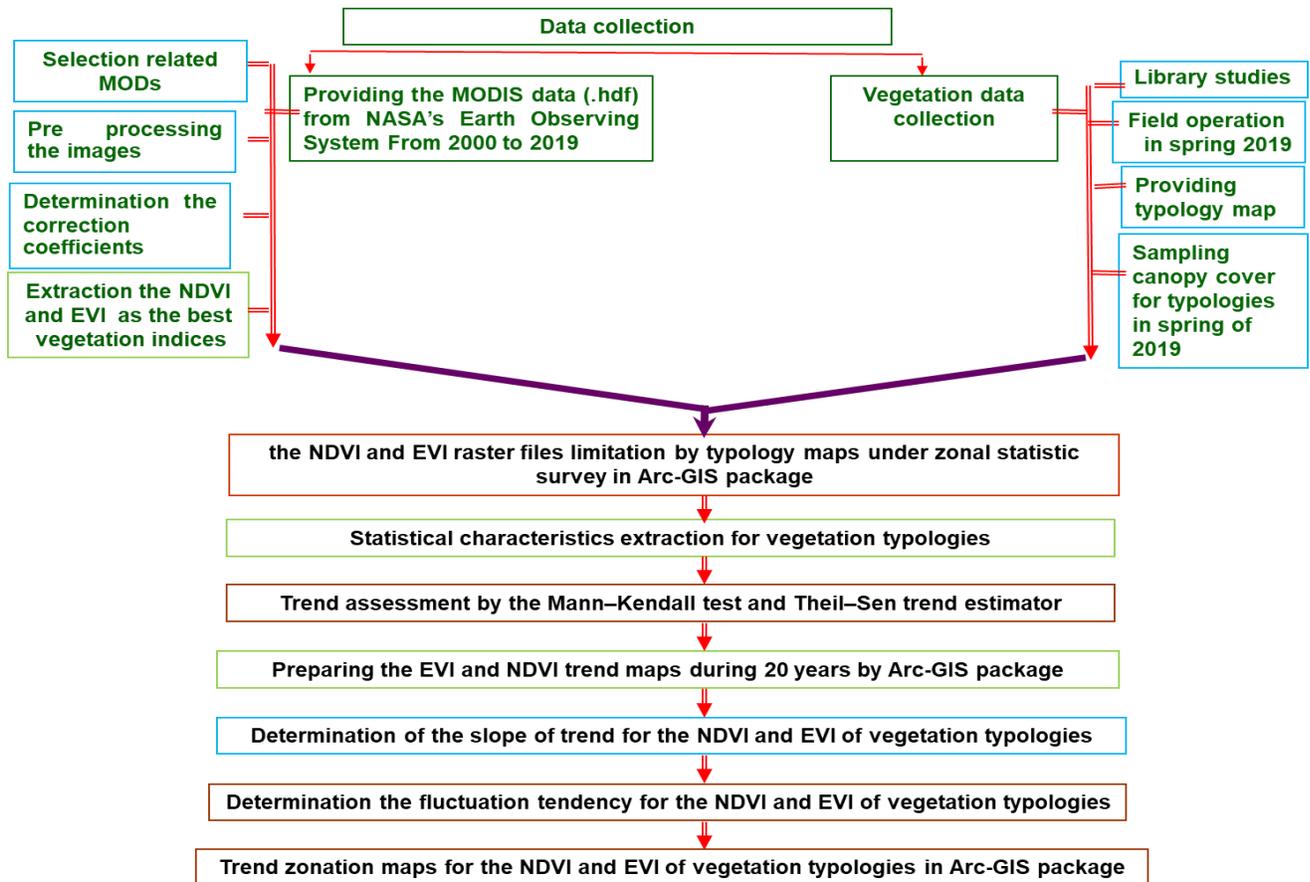


Fig. 2. Flowchart showing the processes of conducting the research

The spatial resolution of the data was 250×250 m and the temporal resolution was 16 days. Monthly, MODIS-NDVI and EVI value were calculated using the maximum value composite (MVC) method, which minimizes the following: atmospheric effects, scan angle effects, cloud contamination, and solar zenith angle effects (Holben, 1986). Annual value comprised the maximum value of the monthly datasets considered in January of 2 recent decades (2000-2019). By considering the corrected factor as 0.0001 on raster data, NDVI and EVI raster files were limited by typology maps to obtain indices data under zonal statistic survey. Data calculating for each vegetation type were tested for trend detection. The use of linear regression

analysis for estimating trends in the NDVI and EVI time series violates statistical assumptions such as the independence of observations (Forkel, 2013). Accordingly, the application of temporal autocorrelation structures or the use of the non-parametric Mann-Kendall test on NDVI and EVI time series was suggested to circumvent the limitations of regression analysis (Kendall, 1975). Since the annual aggregation of time series for trend analysis reduces the temporal resolution and is affected by the seasonal cycle, middle of spring associating with the maximum greenness was considered for providing MODIS-NDVI and EVI dataset. Mann-Kendall formula is as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}}, & s > 0 \\ 0, & s = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, & s < 0 \end{cases} \quad (3)$$

$$S = \sum_{j=1}^{n-1} \sum_{i=j}^n \underset{+1}{sgn} (VI_j - VI_i), \text{Var}(S) = \frac{n(n-1)(2n+5) - \text{sum}(d(d-1)(2d+5))}{18} \quad (4)$$

$$sgn(VI_j - VI_i) = \begin{cases} 1, & (VI_j - VI_i) > 0 \\ 0, & (VI_j - VI_i) = 0 \\ -1, & (VI_j - VI_i) < 0 \end{cases} \quad (5)$$

Where:

S is the sum of decreased signs of observation,

Var(S) is the standard deviation,

d is the number of sets,

n is the number of years,

i-is the index of years,

j-is the index of vegetation types,

sgn (VI_j-VI_i) is the function of signs and,

$$\beta = \text{Median} \frac{(VI_j - VI_i)}{(j-i)}, i < j \quad (6)$$

Where:

β is the Theil–Sen median slope,

Median is the median of a set of data values, and

VI_i and VI_j are vegetation indices (here the EVI and NDVI) values in years i and j.

Finally, the fluctuation tendencies of MODIS-NDVI and MODIS-EVI were investigated based on standard deviation. Standard deviation is a widely used measure of variability or diversity. It shows the degree of variation or “dispersion” from the average. A low standard deviation demonstrates that the NDVI and EVI values of each pixel tends to be very close to the mean; on the other hand, a high standard deviation shows the dispersion across a wide range of values in a time series (Tucker *et al.*, 2001). The standard deviation is calculated as follows:

$$S = \sqrt{\frac{1}{n} \sum_{i=1}^n (VI_i - VI_{mean})^2} \quad (7)$$

Z is a statistical parameter for Mann-Kendall that if exceeds of ± 1.96, trend can be significant.

In order to eliminate burly outliers and stochastic change of vegetation indices, Theil–Sen trend estimate associated with confidence level line was combined with the Mann–Kendall test. The computational formula used (Cao *et al.*, 2014) is:

Where:

S is the standard deviation,

i is the serial number of a year within the period of study, and

VI_i is the VI value (here, MODIS-NDVI and MODIS-EVI) in years i.

The higher the SD value, the greater the change in vegetation. To assess fluctuation in relation to vegetation dynamics, five categories of standard deviation with natural breaks were identified. These were the highest (S ≥ 0.11), higher (0.09 ≤ S ≤ 0.11), middle (0.07 ≤ S < 0.09), lower (0.05 ≤ S < 0.07), and the lowest (0.00 ≤ S < 0.05). In this regard, in order to obtain statistic characteristics such as standard deviation for each vegetation type, the EVI and NDVI maps were limited by the typologies map under zonal statistic survey in Arc-GIS 10.4.1 package.

Results

Investigation of the field operations showed that 42 vegetation types were distinguished in

the study area. The types depicting in Fig. 3 were distributed in mountain and plain units based on geomorphological classification.

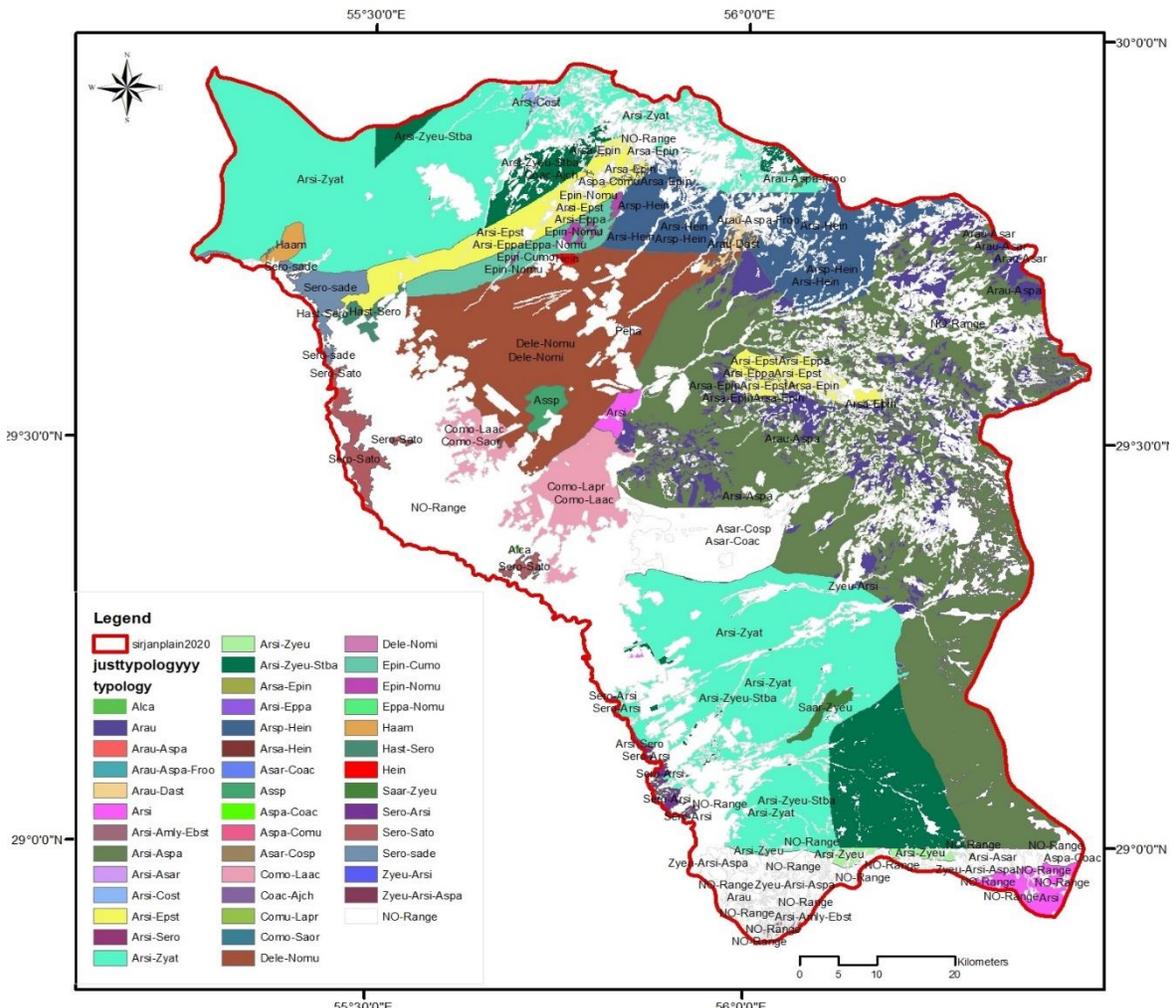


Fig. 3. Plant typology map of Sirjan plain catchment based on the map providing by Research Institute of Forests and Rangelands of Iran and field operations in the spring of 2019

The analysis of the annual variation of EVI and NDVI on plain typologies by Mann-Kendall test demonstrated that some vegetation types had a significant increasing trend over 20 years period and the others didn't change significantly ($p < 0.05$) (Table 1). In this regard, the EVI and NDVI indices results were consistent to show a positive trend of plain types including *Alhagi camelorum*, *Artemisia sieberi-Seidlitzia rosmarinus*, *Artemisia sieberi-Zygophyllum eurypterum-Stipa barbata*, *Astragalus spachianus*, *Cornulaca monacantha-*

Launaea acanthodes, *Cornulaca monacantha-Salsola orientalis*, *Dendrostellera lessertii-Noaea minuta*, *Halocnemum strobilaceum-Seidlitzia rosmarinus*, *Salsola arbusculiformis-Zygophyllum eurypterum* and *Seidlitzia rosmarinus-Artemisia sieberi*. The EVI and NDVI indices results differed about 3 vegetation types; An increasing EVI index trend was obtained in two types of plain as *Dendrostellera lessertii-Noaea mucronata* and *Seidlitzia rosmarinus-Salsola dendroides* whereas the NDVI index of these ones didn't change significantly. On the other hand, a

positive NDVI index trend in *Cornulaca monacantha-Launaea procumbens* type was

seen significantly and the EVI one wasn't changed.

Table 1. Mann-Kendall trend test for annual values of the EVI and NDVI of plain typologies

Vegetation types	EVI			NDVI		
	Z value	Sig	Trend	Z value	Sig	trend
<i>Alhagi camelorum</i>	4.57	**	Positive	4.70	**	Positive
<i>Artemisia sieberi-Seidlitzia rosmarinus</i>	3.34	**	Positive	3.18	**	Positive
<i>Artemisia sieberi-Zygophyllum eurypterum-Stipa barbata</i>	1.98	*	Positive	2.01	*	Positive
<i>Artemisia sieberi-Zygophyllum atriploides</i>	1.39	ns	No change	1.23	ns	No change
<i>Astragalus spachianus</i>	2.04	*	Positive	1.62	ns	Positive
<i>Cornulaca monacantha- Launaea acanthodes</i>	2.89	**	Positive	3.31	**	Positive
<i>Cornulaca monacantha-Launaea procumbens</i>	1.84	ns	No change	2.40	*	Positive
<i>Cornulaca monacantha-Salsola orientalis</i>	3.54	**	Positive	4.09	**	Positive
<i>Dendrostellera lessertii-Noaea mucronata</i>	1.98	*	Positive	1.62	ns	No change
<i>Dendrostellera lessertii-Noaea minuta</i>	2.88	**	Positive	2.56	**	Positive
<i>Ephedra intermedia-Cousinia multilobe</i>	1.52	ns	No change	1.23	ns	No change
<i>Ephedra pachyclada-Noaea mucronata</i>	0.97	ns	No change	1.20	ns	No change
<i>Halochnemum strobilaceum-Seidlitzia rosmarinus</i>	2.63	**	Positive	2.53	*	Positive
<i>Haloxylon ammodendron</i>	1.33	ns	No change	1.17	ns	No change
<i>Salsola arbusculiformis-Zygophyllum eurypterum</i>	2.43	**	Positive	2.92	**	Positive
<i>Seidlitzia rosmarinus-Artemisia sieberi</i>	3.15	**	Positive	3.57	**	Positive
<i>Seidlitzia rosmarinus-Salsola tomentosa</i>	1.72	ns	No change	1.82	ns	No change
<i>Seidlitzia rosmarinus-Salsola dendroides</i>	2.17	*	Positive	1.62	ns	No change

** - means significant in 0.99 confidence level, * - means significant in 0.95 confidence level and ns - means no significant for trend test

The annual changes of the EVI and NDVI evaluation in mountain typologies by Mann-Kendall test illustrated that the vegetation types having a significant positive trend over 20 years period were less than the vegetation types with no change at 95% confidence level (Table 2). The results of the EVI and NDVI indices were similar to show increasing/positive and constant trend of mountain types. In this regard, both indices were positive for 7 vegetation types as *Artemisia aucheri*, *Artemisia aucheri-Astragalus parrowianus*, *Artemisia sieberi*,

Artemisia sieberi- Zygophyllum eurypterum, *Artemisia sieberi-Ephedra pachyclada*, *Astragalus arbusculinus-Convulvulus acanthocladus* and *Zygophyllum eurypterum-Artemisia sieberi- Astragalus arbusculinus*. A positive NDVI index trend was seen at 3 vegetation types of mountain as *Artemisia sieberi-Amygdalus lycioides- Ebenus stellata*, *Artemisia sieberi-Astragalus parrowianus* and *Zygophyllum eurypterum-Artemisia sieberi* whereas their EVI index trend didn't change significantly.

Table 2. Mann-Kendall trend test for annual values of the EVI and NDVI of mountain typologies

Vegetation types	EVI			NDVI		
	Z value	Sig	Trend	Z value	Sig	Trend
<i>Artemisia aucheri-Astragalus arbusculus</i>	1.85	ns	No change	1.69	ns	No change
<i>Artemisia aucheri</i>	1.98	*	Positive	2.21	*	Positive
<i>Artemisia aucheri-Astragalus parrowianus</i>	1.98	*	Positive	2.08	*	Positive
<i>Artemisia aucheri-Astragalus parrowianus.-Ferula oopoda</i>	0.68	ns	No change	0.65	ns	No change
<i>Artemisia aucheri-Daphne staphii</i>	1.52	ns	No change	1.82	ns	No change
<i>Artemisia sieberi</i>	2.17	*	Positive	2.66	**	Positive
<i>Artemisia sieberi- Amygdalus lycioides- Ebenus stellata</i>	1.78	ns	No change	2.27	*	Positive
<i>Artemisia sieberi- Astragalus arbusculus</i>	1.52	ns	No change	1.69	ns	No change
<i>Artemisia sieberi- Zygophyllum eurypterum</i>	2.17	*	Positive	2.34	*	Positive
<i>Artemisia sieberi-Astragalus parrowianus</i>	1.91	ns	No change	2.27	*	Positive
<i>Artemisia sieberi-Cousinia stocksii</i>	0.81	ns	No change	0.52	ns	No change
<i>Artemisia sieberi-Ephedra strobilacea</i>	1.8	ns	No change	1.82	ns	No change
<i>Artemisia sieberi-Ephedra pachyclada</i>	1.98	*	Positive	2.21	*	Positive
<i>Artemisia sieberi-Hertia intermedia</i>	1.07	ns	No change	1.04	ns	No change
<i>Artemisia santolina-Ephedra intermedia</i>	1.59	ns	No change	1.56	ns	No change
<i>Artemisia santolina-Hertia intermedia</i>	0.94	ns	No change	0.91	ns	No change
<i>Astragalus arbusculus-Convulvulus acanthocladus</i>	2.88	**	Positive	2.86	**	Positive
<i>Astragalus arbusculus-Convulvulus spinosus</i>	1.52	ns	No change	1.10	ns	No change
<i>Astragalus parrowianus- Convulvulus acanthocladus</i>	1.85	ns	No change	1.95	ns	No change
<i>Convulvulus acanthocladus-Ajuga chamaecistus</i>	1.27	ns	No change	1.17	ns	No change
<i>Ephedra intermedia-Noaea mucronata</i>	1.59	ns	No change	0.91	ns	No change
<i>Hertia intermedia</i>	0.75	ns	No change	0.84	ns	No change
<i>Z. eurypterum- Artemisia sieberi-Astragalus parrowianus</i>	2.11	*	Positive	2.21	*	Positive
<i>Zygophyllum eurypterum-Artemisia sieberi</i>	1.46	ns	No change	2.08	*	Positive

**_-means significant in 0.99 confidence level, *- means significant in 0.95 confidence level and ns-means no significant for trend test

The estimate of Theil–Sen trend was used for the annual variation of the EVI on plain and mountain rangeland types whenever Mann-Kendall test of each type was changed significantly. Thus, the results of Theil–Sen trend analysis for the types EVI in plain and mountain units have been depicted in Figs. 4 and 5, respectively. According to the next graphs, some jump EVI data were observed out of confidence lines of Theil–Sen estimate for plain typologies. In this regard, *Dendrostellera lessertii-Noaea mucronata*

and *Halocnemum strobilaceum-Seidlitzia rosmarinus* types had the most turbulent and points out of confidence level lines. A sudden increasing *point* illustrating all plain vegetation types was related to 2017. This sharp increase dramatically affected 2 types including *Artemisia sieberi-Seidlitzia rosmarinus* and *Seidlitzia rosmarinus-Artemisia sieberi*. On the other hand, a sharp decreasing of the EVI in all plain types except to *Alhagi camelorum* and *Astragalus spachianus* happened in 2008.

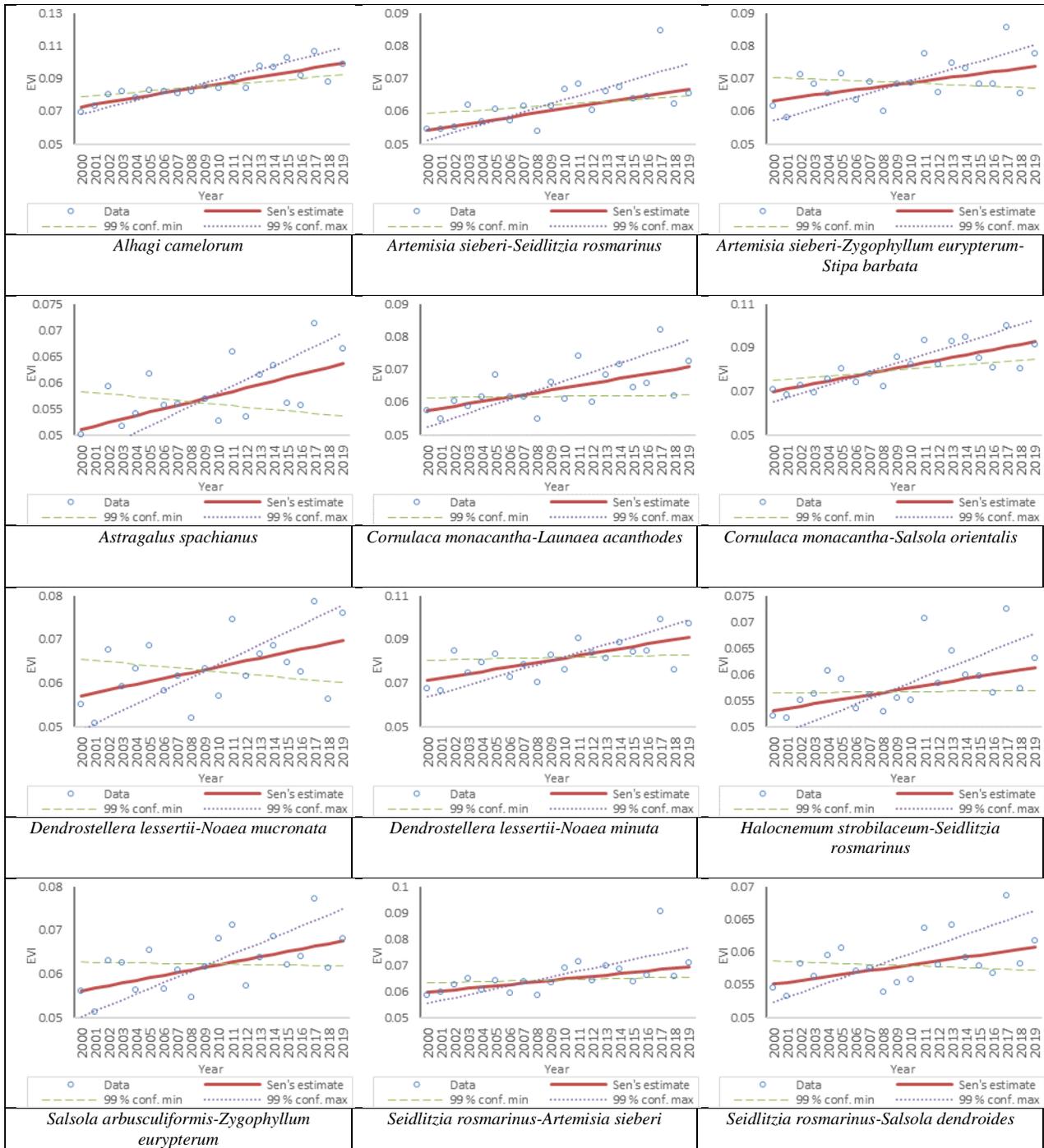


Fig. 4. Theil–Sen trend analysis for EVI indices of plain types

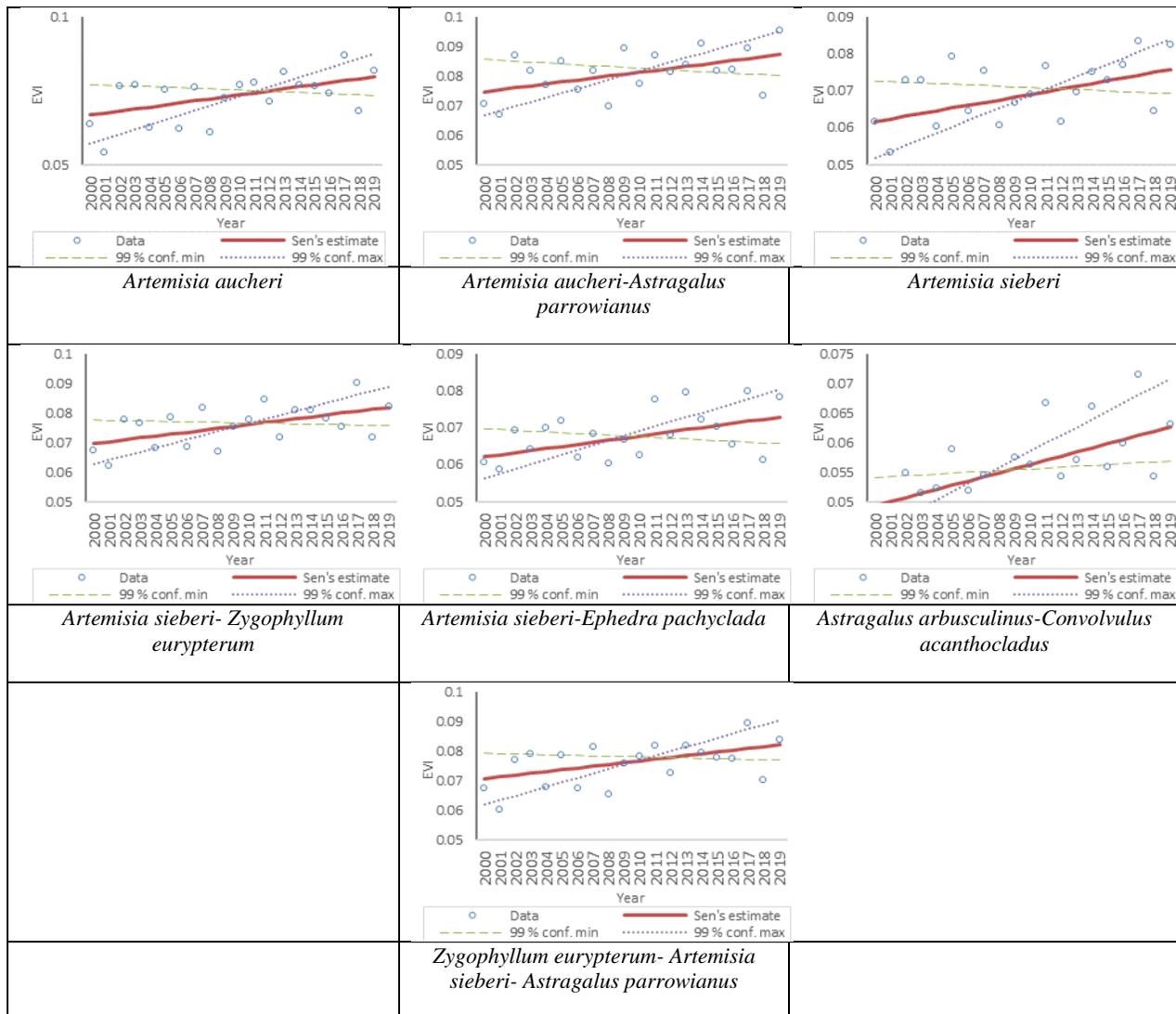


Fig. 5. Theil–Sen trend analysis for EVI indices of mountain types

The estimate of Theil–Sen trend was applied for the annual variation of the NDVI on plain and mountain rangeland typologies wherever Mann-Kendall test were changed significantly. Thus, the results of Theil–Sen trend analysis for NDVI of plain and mountain vegetation types are illustrated in Fig. 6 and Fig. 7, respectively. The results were considerably consistent to EVI section in order to indicate the sharp changes along with a significant trend. Some sharp

increasing points located in 2017 and affecting all vegetation types were more severely for the NDVI of 2 vegetation types including *Artemisia sieberi-Seidlitzia rosmarinus* and *Seidlitzia rosmarinus-Artemisia sieberi*. On the other hand, a sharp decreasing of NDVI in 2008 can be observed for all vegetation types of plain, specially *Astragalus spachianus* and *Salsola arbusculiformis-Zygophyllum eurypterum-Stipa barbata*.

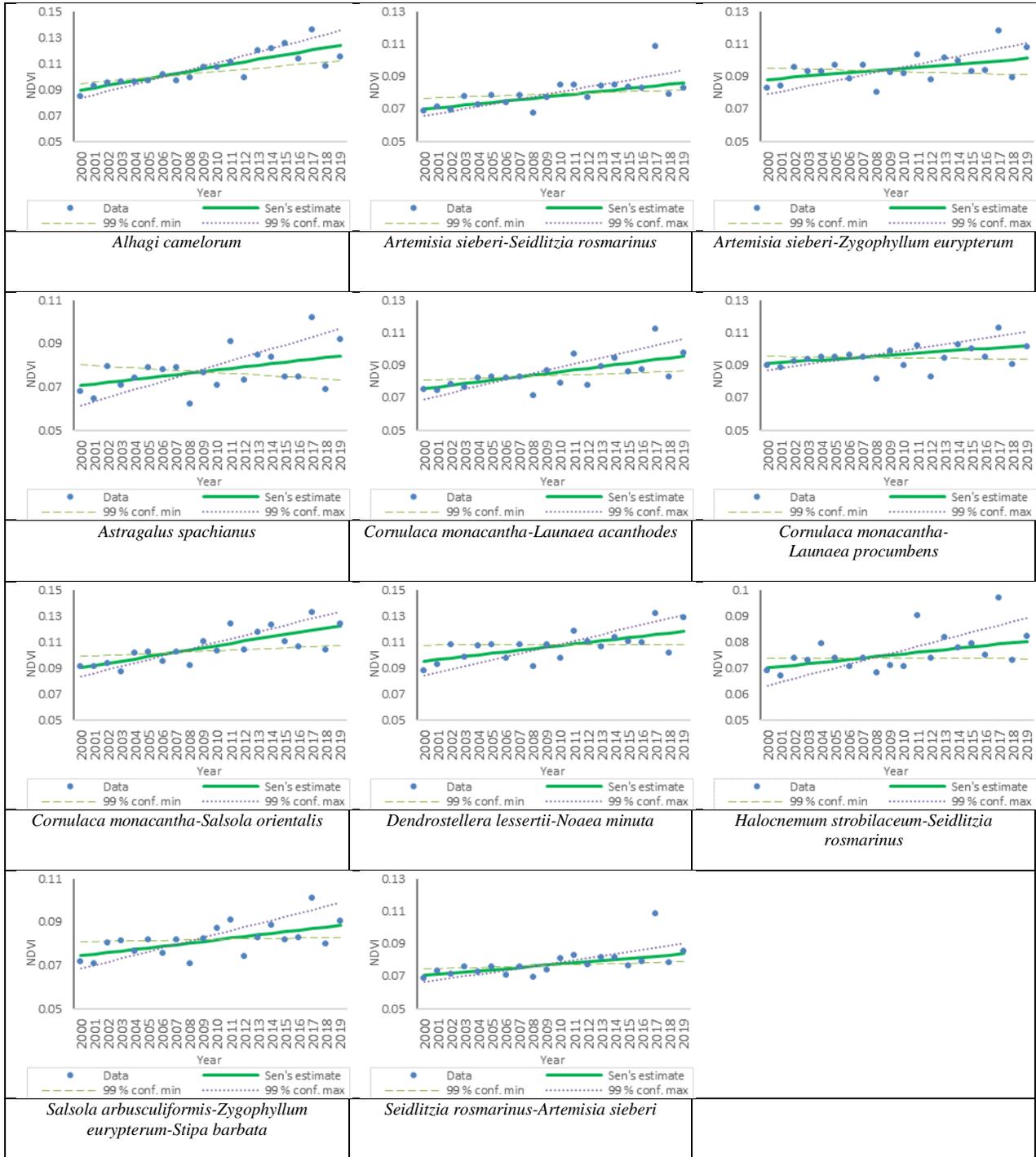


Fig. 6. Theil–Sen trend analysis for NDVI indices of plain types

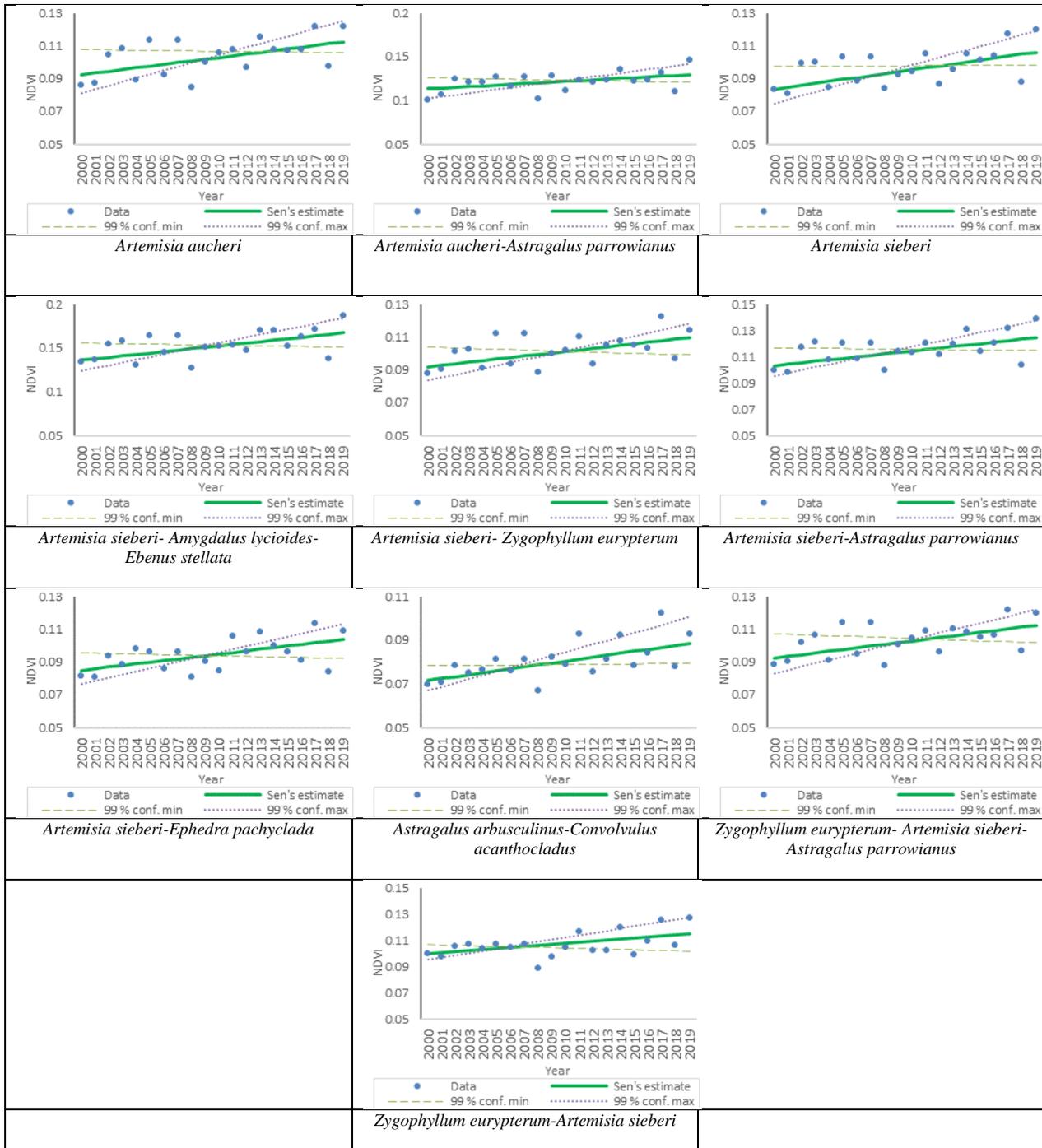


Fig. 7. Theil–Sen trend analysis for NDVI indices of mountain types

Tables 3 and 4 illustrate the averages, slopes of Theil Sen estimate, standard deviations and fluctuation tendencies for the NDVI and EVI of types, respectively. Investigation on the fluctuation tendency based on standard deviation criteria showed the lowest fluctuation of the EVI and NDVI for all

vegetation types that changed increasingly. The most increasing rate of the NDVI was attributed to *Artemisia sieberi- Amygdalus lycioides- Ebenus stellata* type as 0.0015 year⁻¹; meanwhile, the most increasing rate of the EVI trend was related to *Alhagi camelorum* type as 0.0009 year⁻¹.

Table 3. Some summarized properties of trend analysis by NDVI in plain and mountain types

Geomorphological units	Vegetation types	Mean	Slope	Standard deviation	Fluctuation tendency
Plain	<i>Alhagi camelorum</i>	0.106	0.0011	0.026	lowest
	<i>Artemisia sieberi-Seidlitzia rosmarinus</i>	0.079	0.0008	0.019	lowest
	<i>Artemisia sieberi-Zygophyllum eurypterum-Stipa barbata</i>	0.094	0.0009	0.022	lowest
	<i>Astragalus spachianus</i>	0.077	0.0008	0.019	lowest
	<i>Cornulaca monacantha-Launaea acanthodes</i>	0.085	0.0009	0.021	lowest
	<i>Cornulaca monacantha-Launaea procumbens</i>	0.095	0.0010	0.022	lowest
	<i>Cornulaca monacantha-Salsola orientalis</i>	0.106	0.0011	0.026	lowest
	<i>Dendrostellera lessertii-Noaea minuta</i>	0.107	0.0011	0.026	lowest
	<i>Halocnemum strobilaceum-Seidlitzia rosmarinus</i>	0.076	0.0008	0.018	lowest
	<i>Salsola arbusculiformis-Zygophyllum eurypterum</i>	0.082	0.0008	0.019	lowest
<i>Seidlitzia rosmarinus-Artemisia sieberi</i>	0.078	0.0008	0.019	lowest	
Mountain	<i>Artemisia aucheri</i>	0.104	0.0010	0.025	lowest
	<i>Artemisia aucheri-Astragalus parrowianus</i>	0.121	0.0012	0.029	lowest
	<i>Artemisia sieberi</i>	0.097	0.0009	0.024	lowest
	<i>Artemisia sieberi- Amygdalus lycioides- Ebenus stellata</i>	0.154	0.0015	0.037	lowest
	<i>Artemisia sieberi- Zygophyllum eurypterum</i>	0.102	0.0010	0.024	lowest
	<i>Artemisia sieberi-Astragalus parrowianus</i>	0.116	0.0011	0.027	lowest
	<i>Artemisia sieberi-Ephedra pachyclada</i>	0.094	0.0009	0.019	lowest
	<i>Astragalus arbusculinus-Convolvulus acanthocladus</i>	0.081	0.0008	0.022	lowest
	<i>Z. eurypterum- Artemisia sieberi- Astragalus parrowianus</i>	0.103	0.0010	0.020	lowest
	<i>Zygophyllum eurypterum-Artemisia sieberi</i>	0.107	0.0011	0.025	lowest

Table 4. Some summarized properties of trend analysis by EVI in plain and mountain types

Geomorphological units	Vegetation types	Average	Slope	Standard deviation	Fluctuation Tendency
Plain	<i>Alhagi camelorum</i>	0.087	0.0009	0.008	lowest
	<i>Artemisia sieberi-Seidlitzia rosmarinus</i>	0.062	0.0006	0.010	lowest
	<i>Artemisia sieberi-Zygophyllum eurypterum-Stipa barbata</i>	0.069	0.0007	0.007	lowest
	<i>Astragalus spachianus</i>	0.057	0.0006	0.007	lowest
	<i>Cornulaca monacantha-Launaea acanthodes</i>	0.064	0.0006	0.007	lowest
	<i>Cornulaca monacantha-Salsola orientalis</i>	0.081	0.0008	0.007	lowest
	<i>Dendrostellera lessertii-Noaea mucronata</i>	0.063	0.0006	0.009	lowest
	<i>Cornulaca monacantha-Salsola orientalis</i>	0.081	0.0008	0.008	lowest
	<i>Halocnemum strobilaceum-Seidlitzia rosmarinus</i>	0.058	0.0006	0.009	lowest
	<i>Salsola arbusculiformis-Zygophyllum eurypterum</i>	0.063	0.0006	0.006	lowest
	<i>Seidlitzia rosmarinus-Artemisia sieberi</i>	0.066	0.0006	0.006	lowest
	<i>Seidlitzia rosmarinus-Salsola dendroides</i>	0.059	0.0006	0.007	lowest
	Mountain	<i>Artemisia aucheri</i>	0.073	0.0007	0.004
<i>Artemisia aucheri-Astragalus parrowianus</i>		0.081	0.0008	0.008	lowest
<i>Artemisia sieberi</i>		0.070	0.0007	0.008	lowest
<i>Artemisia sieberi- Zygophyllum eurypterum</i>		0.076	0.0008	0.008	lowest
<i>Artemisia sieberi-Ephedra pachyclada</i>		0.068	0.0007	0.007	lowest
<i>Astragalus arbusculinus-Convolvulus acanthocladus</i>		0.056	0.0006	0.007	lowest
<i>Zygophyllum eurypterum- Artemisia sieberi- Astragalus parrowianus</i>		0.076	0.0008	0.007	lowest

Finally, according to the sampling of canopy cover for all typologies based on field operations in spring of 2019 and the indices of NDVI and EVI, we found the relations as following formulas:

$$\text{Canopy cover (\%)} = 284.92 * \text{NDVI} - 10.46 \quad (R^2=0.93) \quad (8)$$

$$\text{Canopy cover (\%)} = 387.71 * \text{EVI} - 10.38 \quad (R^2=0.90) \quad (9)$$

Modeling of vegetation type's trend in Arc-GIS package was done based on Z-score of Mann-Kendall test. The results are depicted in Fig. 8. According to these maps, the EVI is more sensitive to indicate increasing or decreasing trend among the

vegetation type in comparison to the NDVI. In other words, some of southern west sections of the study area appeared as non-

changed part in EVI map while these sections have an increasing (greenness) trend in NDVI map.

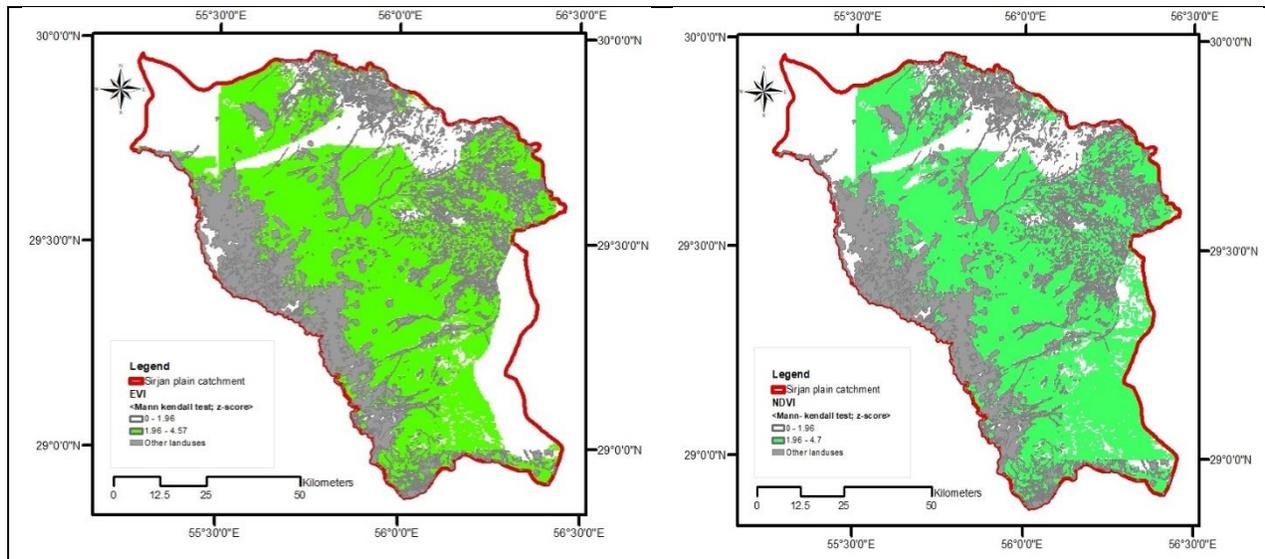


Fig. 8. The EVI and NDVI annual trend map by Mann kendall test in Sirjan plain catchment over 20 years period (2000-2019). Green color shows positive trend and colorless part showed no change trend in the natural ecosystem.

Discussion

Mann-Kendall test analysis on plain and mountain types of Sirjan plain catchment revealed that some vegetation types which stayed constant over the 20 years and hadn't a distinct trend, were independent to time and may change stochastically. In other words, in these vegetation types, the abrupt changes during two decades are more important than finding a dimensional (negative or positive) trend so that changes are nonlinear and discrete. This kind of variation belongs to arid and semiarid climates based on State and Transition Theory. In this regard, the changes of steady states in vegetation patterns of arid and semi-arid regions need to trigger by abrupt changes in environmental factors or management strategy (Li *et al.*, 2019). Since climate variables as the most effective environmental factor have highly changed in the recent years hence, scrutinizing abrupt changes in vegetation types (which were independent to time) coupled with sharp events of climate variables are recommended.

According to Theil-Sen estimate, the results revealed that *Alhagi camelorum* type had the most dimensional increase among the other types and the EVI and NDVI of this type will increase equal to 0.0009 and 0.0011 year⁻¹. Even though, the results of Theil-Sen estimate are confirmed by the lowest fluctuation tendency for all positive changes of vegetation types so that these types reacted dimensionally to unknown influencing factors, but some sharp or sudden changed points locating out of confidence level of Theil-Sen estimate were observed for both vegetation indices (MODIS-NDVI and EVI) of majority of types specially in 2008 and 2017. Based on this kind of changes, we propose that both stochastic and dimensional changes of these vegetation typologies transacted in the mentioned vegetation types of an arid ecosystem. Additionally, more investigations on environmental data and human activity in the mentioned years that had acted as turbulator of majority of types are recommended for understanding the affecting factors.

The types that changed dimensionally in association with stochastically had different slopes of increase according to Theil–Sen estimate. In this regard, range of the NDVI and EVI were 0.078–0.154 and 0.056–0.87, respectively. Additionally, from 2000 to 2019, the most increasingly rate of the NDVI was attributed to *Artemisia sieberi-Amygdalus lycioides-Ebenus stellata* type as 0.0015 year^{-1} whereas the EVI was related to *Artemisia aucheri-Astragalus parrowianus, Zygophyllum eurypterum-Artemisia sieberi-Astragalus parrowianus, Dendrostellera lessertii-Noaea minuta, Artemisia sieberi-Zygophyllum eurypterum* and *Cornulaca monacantha-Salsola orientalis* types as 0.0008 year^{-1} . This similarity in the amount of NDVI and EVI was inconsistent to Baniya *et al.* (2018) results reporting different slopes of NDVI trend in winter, pre-monsoon, monsoon and post-monsoon seasons in Nepal. This difference can be related to climate of study areas. As a result, the change rates of the NDVI and EVI which can be considered as the responses of vegetation types to the harshness of affecting factor can be recommended for classifying the similar vegetation types in term of function.

The NDVI results to vegetation type's trend were in accordance with the EVI for 15 and 21 vegetation types of plain and mountain parts, respectively. Lu *et al.* (2015) confirmed the similar phenological metrics derived from the NDVI and EVI for the most vegetation types. Moreira *et al.* (2019) demonstrated that according to the values of EVI and NDVI, grassland typologies were classified into four groups with similar temporal profiles. Therefore, our results were in accordance with Lu *et al.* (2015) and Moreira *et al.* (2019) findings in term of consistency of EVI and NDVI. The differences were seen just for 6 vegetation types of plain and mountain parts. Owing to the fact that only the NDVI illustrated a positive trend for 4 vegetation types, mostly in the mountain part (as *Artemisia sieberi-Amygdalus lycioides-*

Ebenus stellata, Artemisia sieberi-Astragalus parrowianus and *Zygophyllum eurypterum-Artemisia sieberi* and *Cornulaca monacantha-Launaea procumbens*), it can be found out that the changes of background soil reflectance in these types were consistent with annual changes of vegetation types during the time. Therefore, pedological and vegetation dynamics are proposed in this region. On the other hand, only the EVI showed a significant positive trend for 2 types of plain such as *Dendrostellera lessertii-Noaea mucronata* and *Seidlitzia rosmarinus-Salsola dendroides*. Since there did not exist accordance between changes of soil reflectance and vegetation changes, the EVI performed efficiently for showing better annual trend than NDVI.

According to our finding, the vegetation typologies that didn't change and stay constant over 20 years might be varied under the stochastic changes in comparison to dimensional trend. Duo to existences probability of sudden changes (jump) in vegetation indices of these types that were independent to time, the other analysis methods associated with field data collections are recommended to reveal the facts and recognize threshold of changes of each vegetation type based on the State and Transition Theory.

Conclusion

Based on the changes in vegetation types over 2 decades (from 2000 to 2019), vegetation types of arid regions can be classified to 3 categories including time-dependence/dimensionally changes, time-independence/stochastically changes and dimensionally associated to stochastically changes. As a result, these dramatic differences of the reactions illustrate the capabilities in vegetation type scale to respond the environmental factors. It necessitates the officials taking responsibility of the natural resources to implement the reduction of overgrazing aggravating the

harshness of affecting factors. Furthermore, we recommend the related officials to coordinate managing systems with the vegetation types in arid and semiarid climate in order to seize the reaction capabilities of vegetation types in management of natural resources.

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ارزیابی شاخص‌های NDVI و EVI تصاویر سنجنده مودیس برای تیپ‌های مختلف گیاهی در منطقه خشک (مطالعه موردی: حوزه آبخیز دشت سیرجان، استان کرمان، ایران)

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چکیده. روند پوشش گیاهی اکوسیستم‌های مناطق خشک در مقیاس تیپ گیاهی برای محققان علم اکولوژی مسائل مجهول زیادی دربر دارد. لذا این تحقیق با هدف تعیین روند شاخص‌های پوشش گیاهی NDVI² و EVI³ به کمک روش‌های من-کندال و تخمین گر تیل-سن انجام شد. به این طریق که ابتدا نقشه تیپولوژی گیاهی حوزه آبخیز دشت سیرجان بر اساس پیمایش صحرائی و سپس شاخص‌های یاد شده بر اساس تصاویر ماهانه ماهواره مودیس با دقت مکانی ۲۵۰ × ۲۵۰ متر طی دو دهه اخیر (۱۳۷۹-۱۳۹۸) برای مطالعه روند پوشش گیاهی تهیه شدند. نتایج نشان داد بعضی از تیپ‌های گیاهی روند مشخصی نداشتند و مستقل از زمان بودند ولی در مقابل تیپ گیاهی خارشتر دارای روند افزایشی سالانه مثبت به میزان ۰/۰۰۰۹ و ۰/۰۰۱۱ برای شاخص‌های EVI و NDVI داشت. سایر تیپ‌های گیاهی که ترکیب تغییرات تصادفی و وابسته به زمان را به خود اختصاص داده بودند، شیب‌های مختلفی افزایشی را به خود اختصاص دادند. در این راستا بیشترین نرخ افزایشی سالانه روند برای شاخص NDVI به تیپ درمنه دشتی-بادام کوهی-گلگ معادل ۰/۰۰۱۵ و برای شاخص EVI به تیپ‌های درمنه کوهی-گون زرد، قیچ درمنه دشتی-گون، سیاه گینه، خارگونی، درمنه دشتی-قیچ و طاروم-علف‌شور معادل ۰/۰۰۰۸ تعلق داشت. در این رهگذر تغییرات ناگهانی (مستقل از زمان) شاخص‌های EVI و NDVI (خارج از حد اطمینان تخمین گر تیل-سن) برای اکثر تیپ‌های گیاهی در سال‌های ۱۳۸۷ و ۱۳۹۶ رخ داده است. لذا تحقیقات بیشتر روی داده‌های محیطی و فعالیت‌های انسانی در این سال‌ها بعنوان عامل آشفستگی اکثر تیپ‌های گیاهی پیشنهاد می‌شود.

کلمات کلیدی: ماهواره مودیس، شاخص‌های پوشش گیاهی، روند، اکوسیستم خشک

² Normalized Difference Vegetation Index (NDVI)

³ Enhanced Vegetation Index (EVI)