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ORIGINAL ARTICLE

The effects of climate change on normalized difference vegetation index (NDVI) in the Northeast of Iran

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Abstract
On the basis of land use/land cover map, satellite derived images of NDVI, air temperature and precipitation, the correlations between NDVI-air temperature and NDVI-precipitation over time period of 1987–2016 in inter-annual/monthly scales were analyzed. The present study investigated the relationships between inter-annual/monthly variations of climate features and the fluctuations of NDVI by four vegetation types in Mashhad-Chenaran plain, northeast of Iran. It was revealed that yearly precipitation by all vegetation types has close correlations with NDVI fluctuations. The inter-annual NDVI-precipitation showed that rich ranges were most affected by precipitation, followed by moderate ranges, dry farming and irrigated farming, where the correlation coefficient *R* varied between 0.419 and 0.488 ($P \leq 0.05$), ($P \leq 0.01$). Furthermore, the correlations between monthly NDVI-air temperature by all vegetation types were remarkably significant. The responses of the NDVI to monthly variations of air temperature exhibited that rich range were most affected by monthly temperature fluctuations followed by dry farming, moderate range, and irrigated farming. Accordingly, the values of correlation coefficient *R* ranged from 0.769 to 0.845 ($P \leq 0.01$). The finding results confirmed the utility of NDVI index to express vegetation variability in semi-arid climate conditions and improved our knowledge about the relations between climate features and vegetation growth for rehabilitation programs in watershed scale.

Keywords Climate change · Air temperature · Precipitation · NDVI · Remote sensing · GIS

Introduction

Vegetation is the most important factor that link the soil, atmosphere, and moisture together (Chuai et al. 2013). The natural vegetations change due to seasonal and yearly climate changes (Cui and Shi 2010; Zhang et al. 2011). However, vegetation could be a criterion for global climate changes (Schimel et al. 2001; Weiss et al. 2004), number of different factors such as animal interactions, anthropogenic activities and/or changes in topsoil can affect it (Schultz and Halpert 1993). Investigating vegetation fluctuations in monthly or yearly scales can illuminate the changes of regional or global climate. The normalized difference vegetation index (NDVI) which proposed by Rouse et al. (1974) is a perfect indicator of green biomass. NDVI is based on differences between near-infrared (NIR) and pigment absorption in red (VIS or visible red). NDVI = (NIR − VIS)/(NIR + VIS).

The amount of NDVI can vary between −1.0 to 1.0. Positive values with an increasing trend to 1.0 indicate an increasing proportion of green vegetation while the 0 or negative values exhibit non-vegetational elements e.g. rock, water, snow, clouds and etc. (Schnur et al. 2010). Chuai et al. (2013) showed that NDVI for each vegetation types is changeable. Air temperature and precipitation as well as soil air temperature and moisture are the most important features that affect the vegetation. They have an impact on the water balance of the ecosystem and hence the amount of the soil moisture which affect the plants growth (Wang et al. 2003). In addition, Wang et al. (2001) showed that in the central Great Plains of the USA precipitation and NDVI have a strong correlation with each other, except in the flood years which due to heavy rainfalls the growth of plants and NDVI decrease. Schultz and Halpert (1993) found that in

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cold regions air temperature limited the vegetation, however, in warm regions as the air temperature is normally above the minimum necessary of the plants need it has a little effect on vegetation growth. They also demonstrated that in temperate regions both precipitation and air temperature are two limiting factors. Ichii et al. (2002) found that in high-latitude of the northern hemisphere there is a significant positive correlation between the air temperature and NDVI in both spring and autumn months. However, there may be a regional correlation between the air temperature or/and precipitation with NDVI. Schultz and Halpert (1995) investigated a worldwide analysis for the relationships among precipitation, air temperature, and NDVI of the land surface but they could not find any significant relevance between them. NDVI has been widely used for many studies such as investigating the climatic effects on the vegetation productivity (e.g. Ichii et al. 2002; Nemani et al. 2003; Meng et al. 2011). The response of different vegetations to different climate features and their impact on regional ecosystem can be demonstrated with the help of remote sensing (RS) application (Hao et al. 2012). With respect to remote sensing data the land cover changes at different spatial and temporal scales can be estimated, specially using high temporal resolution satellite data (Carlson and Arthur 2000; Wittenberg et al. 2007). NDVI helps to indicate environmental changes that occur due to natural factors like climate changes (Qiu and Cao 2011), and/or human activities (Fung and Siu 2000), furthermore it helps to evaluate crop production (Wardlow and Egbert 2008) and net primary productivity (NPP) of vegetation (Piao et al. 2006, 2008), hence investigating NDVI could provide a data which can be used for different research aspects. The aim of the present study is to assess the relation between NDVI as the index of natural vegetations and four major climate factors including air temperature, precipitation, soil, air temperature and root zone soil moisture over 1987–2016 time period to find the most important climatic factors affecting NDVI in Mashhad-Chenaran basin, northeast of Iran.

Materials and methods

Study area

The present study was conducted in Mashhad-Chenaran basin with surface area of about 9909 km^2 in Khorasan-e-Razavi Province, Northeast Iran (Fig. 1). The study area is located between latitude 35° 59′ N–37° 04′ N and longitude 58° 22′ E–60° 07′ E including lands less than 1500 m asl. The general physiographic trend of the plain extends in a NW–SE direction with an average of 160 km in length surrounded by the two mountainous zones of Kopet-dagh in the northward and Binaloud in the southward. The topographical elevation values of the study area vary between 900 and 1500 m a.s.l, while the main topographical elevation ranges over 1200 m a.s.l (Fig. 1). The mean annual air temperature of the basin is 11.8 °C and the average annual precipitation is 230.8 mm.

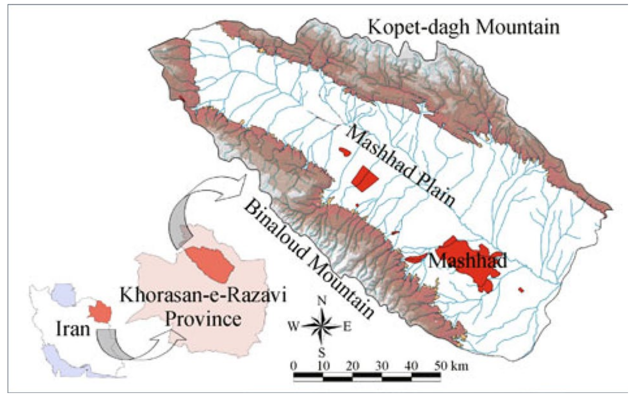

Fig. 1 The geographical position of the study area

Data collection and processing

The monthly values of climate factors including air temperature and precipitation in time period of 1987–2016 were collected from NASA earth observations (https://neo.sci.gsfc.nasa.gov/) and Global Modeling and Assimilation Office-NASA (https://gmao.gsfc.nasa.gov/) derived from the source of MODIS-Terra satellite with spatial resolution of 0.05°. The monthly values of NDVI in the time period of 1987–1999 were gathered from NASA earth data (https://urs.earthdata.nasa.gov/) and in the time period of 2000–2016 from NASA earth observations (https://neo.sci.gsfc.nasa.gov/) derived from the source of MODIS-Terra satellite with spatial resolution of 0.1°, which by resampling function in ArcGIS changed to 0.05°. The average monthly values of NDVI, air temperature, and precipitation associated with a particular land cover/land use type were calculated from the averages of all grid cells belonging to the same land cover/land use type. A Kriging interpolation function was employed to zonate the inter-annual/ monthly variations of NDVI in the study area using ArcGIS10.6. The values of NDVI grid images for each month were calculated by mean values of ten days interval. The spatial variation of two climatic factors was expressed at a grid resolution of 0.05°, which have the same resolution of NDVI data after processing. A Pearson's correlation coefficient and an exponential regression equation between monthly/yearly values of NDVI with corresponding values of air temperature and precipitation were calculated and the two-tailed P values were estimated for each case to determine the significance using SPSS software (version 16.1). A land use/landcover map of the study area was adapted to enable stratification of

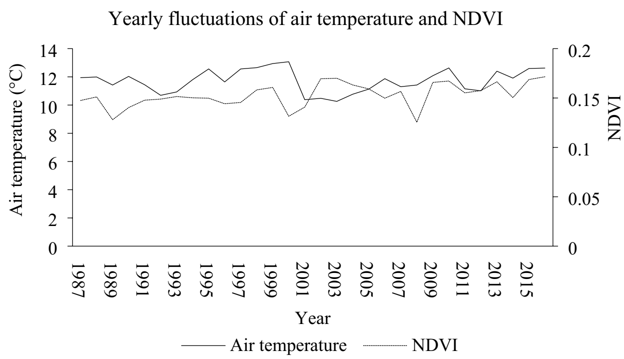

Fig. 2 Yearly fluctuations of air temperature and NDVI in time period of 1987–2016

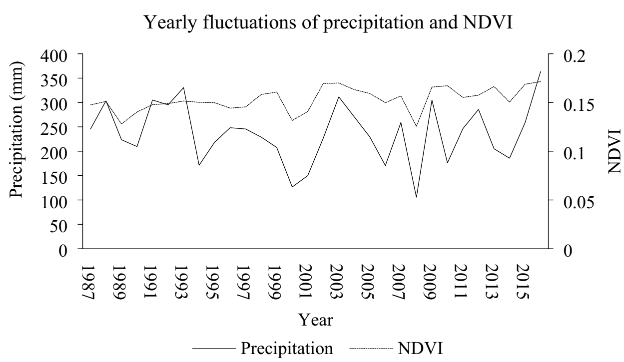

Fig. 3 Yearly fluctuations of precipitation and NDVI in time period of 1987–2016

analyses according to the categories of irrigated farming, dry farming, rich rangelands and moderate rangelands of the basin.

Results and discussion

General fluctuations of NDVI in the study area

Inter-annual correlation analysis

The yearly fluctuations of air temperature, precipitation, and NDVI values during 1987–2016 time period in the study area has been shown in Figs. 2 and 3. The trends of yearly precipitation corresponds well with NDVI fluctuations. While the lowest and the highest values of precipitation (105.38 and 363.56 mm) and NDVI (0.126 and 0.172) were occurred in 2008 and 2016, the lowest and highest values of air temperature (10.26 and 13.07 °C) were observed in 2003 and 2000, respectively. Statistically, the fluctuations of yearly air temperature had no significant effect on the yearly NDVI values ($R^2 = 7 \times 10^{-6}$), while the values of NDVI varied remarkably with the fluctuations of the yearly

Table 1 The exponential regression equation and statistical values between monthly/inter-annual mean values of NDVI with corresponding air temperature and precipitation over 1987–2016 time period in the study area

Equation formula	*R*-Pearson	R^2	*P* value
$NDVI_{monthly} = 0.1127e^{0.0233 \times Temp}$	0.805**	0.650	0.002
$NDVI_{monthly} = 0.1631e^{-0.005 \times Precipit}$	0.304	0.092	0.336
$NDVI_{yearly} = 0.1521e^{0.0003 \times Temp}$	0.003	7×10^{-6}	0.989
$NDVI_{yearly} = 0.1295e^{0.0007 \times Precipit}$	0.514**	0.264	0.004

Significant at $*P \leq 0.05$ and $**P \leq 0.01$ levels

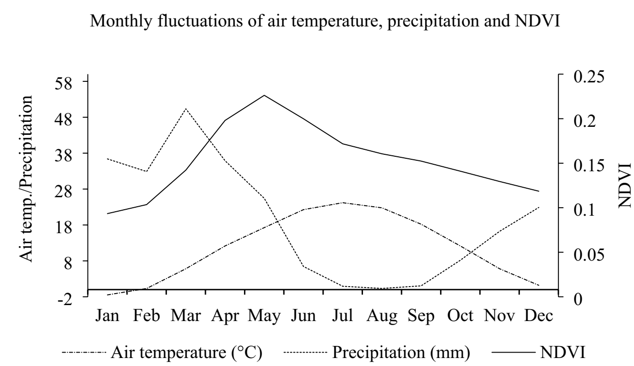

Fig. 4 Monthly fluctuations of air temperature, precipitation, and NDVI in time period of 1987–2016

precipitation in the study area ($R^2 = 0.264$) (Table 1). It was revealed that there is moderate correlation coefficient between yearly NDVI-precipitation ($R = 0.514$, $P = 0.004$), while the correlation coefficient between yearly NDVI-air temperature was very negligible ($R = 0.003$, $P = 0.989$) (Table 1). In yearly dimensions, NDVI-precipitation correlations are higher than those of NDVI-air temperature, which indicate that the precipitation is considered to have the dominant influence on vegetation growth in the study area. In agreement with our findings Wang et al. (2001) demonstrated that in yearly scale precipitation is a strong predictor of regional spatial patterns of NDVI by inferencing on the patterns of plant productivity.

Monthly correlation analysis

The monthly fluctuations of air temperature, precipitation and NDVI during 1987–2016 time period has been demonstrated in Fig. 4. As shown, while the lowest values of air temperature (− 11.02 °C) and NDVI (− 0.011) were occurred in January, the lowest values of precipitation (0.00 mm) was observed in June. The highest values of air temperature (26.52 °C) and NDVI (0.274) were occurred in July and May respectively, while the highest value of precipitation (103.94 mm) was detected in March. The fluctuations of monthly air temperature had significant effect on NDVI values ($R^2=0.650$), while statistically the monthly fluctuations of precipitation had no effect on the variations of NDVI in the study area ($R^2=0.092$) (Table 1). It was found that there is a strong correlation coefficient between monthly NDVI-air temperature ($R=0.805$, $P=0.002$), while the correlation coefficient between monthly NDVI-precipitation was weak ($R=0.304$, $P=0.336$) (Table 1). The correlations between monthly NDVI-precipitation and NDVI-air temperature revealed that monthly fluctuations of air temperature have greater effect on vegetation growth than monthly precipitation, where by elevating air temperature during the growing season the precipitation has a decreasing trend. In consistent with our results Wang et al. (2001) demonstrated that in yearly scale precipitation is a strong predictor of regional spatial patterns of NDVI by inferencing on the patterns of plant productivity.

Climatic features: NDVI correlations by considering vegetation types

It is supposed that significantly positive correlations may occur between air temperature, precipitation and NDVI values by different vegetation types. The dominant land cover type in the study area was mountainous moderate range, which occupied 57.4% of the study area. Farmlands including irrigated and dry farming were accounted for 26.3% and 12.2% of the whole area, respectively. Rich rangelands and steppes with scattered trees in mountainous areas higher than 1200 m a.s.l. covered 4.1% of the study area (Table 2). To assess correlation between air temperature and precipitation with NDVI the inter-annual/monthly mean values of NDVI by each vegetation type were calculated to show the effect of these climatic features on NDVI fluctuations by different land use/land covers.

Table 2 Land use/land covers, their surface area, and percent

Land cover	Surface area (km^2)	Percent
Irrigated farming	2590	26.11
Dry farming	1207.4	12.17
Rich rangeland and step with scattered trees	398.3	4.02
Mountainous moderate rangeland	5681.8	57.29
Poor rangeland on flood plains and hills	40.7	0.41

Inter-annual correlation analysis by considering vegetation types

Inter-annual correlations between NDVI-air temperature and NDVI-precipitation has been shown in Table 3. It was revealed that yearly fluctuations of air temperature had no significant effect on NDVI values by any vegetation type in the study area. The NDVI-air temperature correlations had negligible relationship with NDVI by different vegetation types, where the values of R^2 varied between 0.00005 by moderate range and 0.027 by rich range. The correlation coefficient R between yearly NDVI-air temperature by all vegetation types were weak and ranged from 0.007 by moderate range to 0.164 by rich range and the corresponding P values varied between 0.386 by rich range and 0.972 by moderate range. The inter-annual NDVI-precipitation correlations showed significant linkage between precipitation and NDVI by all vegetation types, where the values of R^2 ranged from 0.176 by irrigated farming to 0.238 by moderate range. Meanwhile correlation coefficient R ranged from 0.419 by irrigated farming to 0.488 by moderate range and the corresponding P values varied between 0.006 by moderate range and 0.021 by irrigated farming (Table 3).

Monthly correlation analysis by considering vegetation types

Monthly correlations between NDVI-air temperature and NDVI-precipitation by different vegetation types has been illustrated in Table 4. It was indicated that monthly fluctuations of precipitation had no significant effect on NDVI values by any vegetation type in the study area. The NDVI-precipitation correlations had a negligible relationship with

Table 3 The exponential regression equation and statistical values between inter-annual values of NDVI-air temperature and NDVI–precipitation over 1987–2016 time period in the study area

Land cover	Equation formula	R-Pearson	R^2	P value
Irrigated farming	$NDVI_{yearly}=0.1687e^{-0.007\ Temp}$	0.059	0.003	0.758
Dry farming	$NDVI_{yearly}=0.1363e^{0.0069\ Temp}$	0.063	0.004	0.741
Moderate range	$NDVI_{yearly}=0.1544e^{-0.0007\ Temp}$	0.007	0.00005	0.972
Rich range	$NDVI_{yearly}=0.1194e^{0.0177\ Temp}$	0.164	0.027	0.386
Irrigated farming	$NDVI_{yearly}=0.1329e^{0.0007\ Precipit}$	0.419*	0.176	0.021
Dry farming	$NDVI_{yearly}=0.1259e^{0.0007\ Precipit}$	0.479**	0.229	0.007
Moderate range	$NDVI_{yearly}=0.131e^{0.0007\ Precipit}$	0.488**	0.238	0.006
Good range	$NDVI_{yearly}=0.1339e^{0.0004\ Precipit}$	0.479**	0.229	0.007

Significant at $*P \le 0.05$ and $**P \le 0.01$ levels

Table 4 The exponential regression equation and statistical values between monthly NDVI-air temperature and NDVI–precipitation over 1987–2016 time period in the study area

Land cover	Equation formula	*R*-Pearson	R^2	*P* value
Irrigated farming	$NDVI_{monthly} = 0.1182e^{0.0208\ Temp}$	0.769**	0.592	0.003
Dry farming	$NDVI_{monthly} = 0.1087e^{0.0249\ Temp}$	0.821**	0.674	0.001
Moderate range	$NDVI_{monthly} = 0.1141e^{0.0227\ Temp}$	0.798**	0.636	0.002
Rich range	$NDVI_{monthly} = 0.0989e^{0.0294\ Temp}$	0.845**	0.714	0.001
Irrigated farming	$NDVI_{monthly} = 0.1598e^{-0.003\ Precipit}$	0.169	0.029	0.600
Dry farming	$NDVI_{monthly} = 0.1543e^{-0.004\ Precipit}$	0.250	0.063	0.433
Moderate range	$NDVI_{monthly} = 0.1603e^{-0.004\ Precipit}$	0.237	0.056	0.459
Rich range	$NDVI_{monthly} = 0.1638e^{-0.007\ Precipit}$	0.352	0.124	0.262

Significant at $*P \leq 0.05$ and $**P \leq 0.01$ levels

NDVI by different vegetation types, where the values of R^2 varied between 0.029 by irrigated farming and 0.124 by rich range. The correlation coefficient *R* between monthly NDVI-precipitation by all vegetation types were weak, where *R* values ranged from 0.169 by irrigated farming to 0.352 by rich range and the corresponding *P* values varied between 0.262 by rich range and 0.60 by irrigated farming. Monthly NDVI-air temperature correlations exhibited significant linkage between air temperature and NDVI by all vegetation types, where the values of R^2 ranged from 0.592 by irrigated farming to 0.714 by rich range. In the meantime, correlation coefficient *R* ranged from 0.769 by irrigated farming to 0.845 by rich range and the corresponding *P* values varied between 0.003 by irrigated farming and 0.001 by rich range (Table 4).

The zonation map of NDVI

The zonation map of NDVI fluctuations in ten years interval in the study area exhibited an increasing trend in NDVI values from 0.148 in 1987 to 0.144 in 1996, 0.150 in 2006 and 0.172 in 2016 by elevating precipitation (Figs. 5, 6, 7, 8, 9, 10). The annual precipitation in the corresponding years ranged from 216.2 mm in 1987, 224.1 mm in 1996, 197.9 mm in 2006 to 359 mm in 2016 and the mean annual air temperature varied between 11.97, 11.67, 11.90 and 12.67 °C, respectively. It was found that the most land use/land cover types affected by precipitation over the selected years were rich range, followed by moderate range, dry farming, and irrigated farming, which correspond to 0.370, 0.283, 0.278, and 0.240-unit NDVI fluctuations, respectively. Spatial distribution map of monthly NDVI in the selected years exhibited that along with elevating air temperature and decreasing precipitation over the growing season from March to May the values of NDVI has a significant increasing trend and then a decreasing trend till end of the vegetation growth (September). The most fluctuations of NDVI over the growing season months were observed by rich range (0.147–0.261) followed by moderate range (0.166–0.263), dry farming (0.159–0.254) and irrigated farming (0.174–0.267), respectively (Table 5).

Conclusion

Correlation analyses between NDVI and climate features including air temperature and precipitation are powerful tools for analyzing responses of ecosystem function to climate change (Piao et al. 2006). The present study analyzed inter-annual and monthly relationships between NDVI and air temperature and precipitation in monthly/yearly scales over time period of 1987–2016 to assess the correlations between NDVI and climatic features in four dominant land use/landcover types in Mashhad plain, northeast of Iran. The correlation coefficients confirmed significant relationships between NDVI and climate features in the study area. It was revealed that there is a strong inter-annual correlation between NDVI-precipitation by all land use/land cover types, which was different from the monthly correlation patterns. The vegetation types which remarkably affected by precipitation were rich range, followed by moderate range, dry farming and irrigated farming, respectively. Vice versa, the monthly correlation between NDVI-temperature had the most pronounced impact on vegetation types over the study period. It was found that by monthly temperature variations the most affected vegetation types were rich range followed by moderate range, dry farming, and irrigated farming. The findings of our results can help decision-makers to provide answers to the challenges posed by changing climate conditions on plant vegetations in the study area.

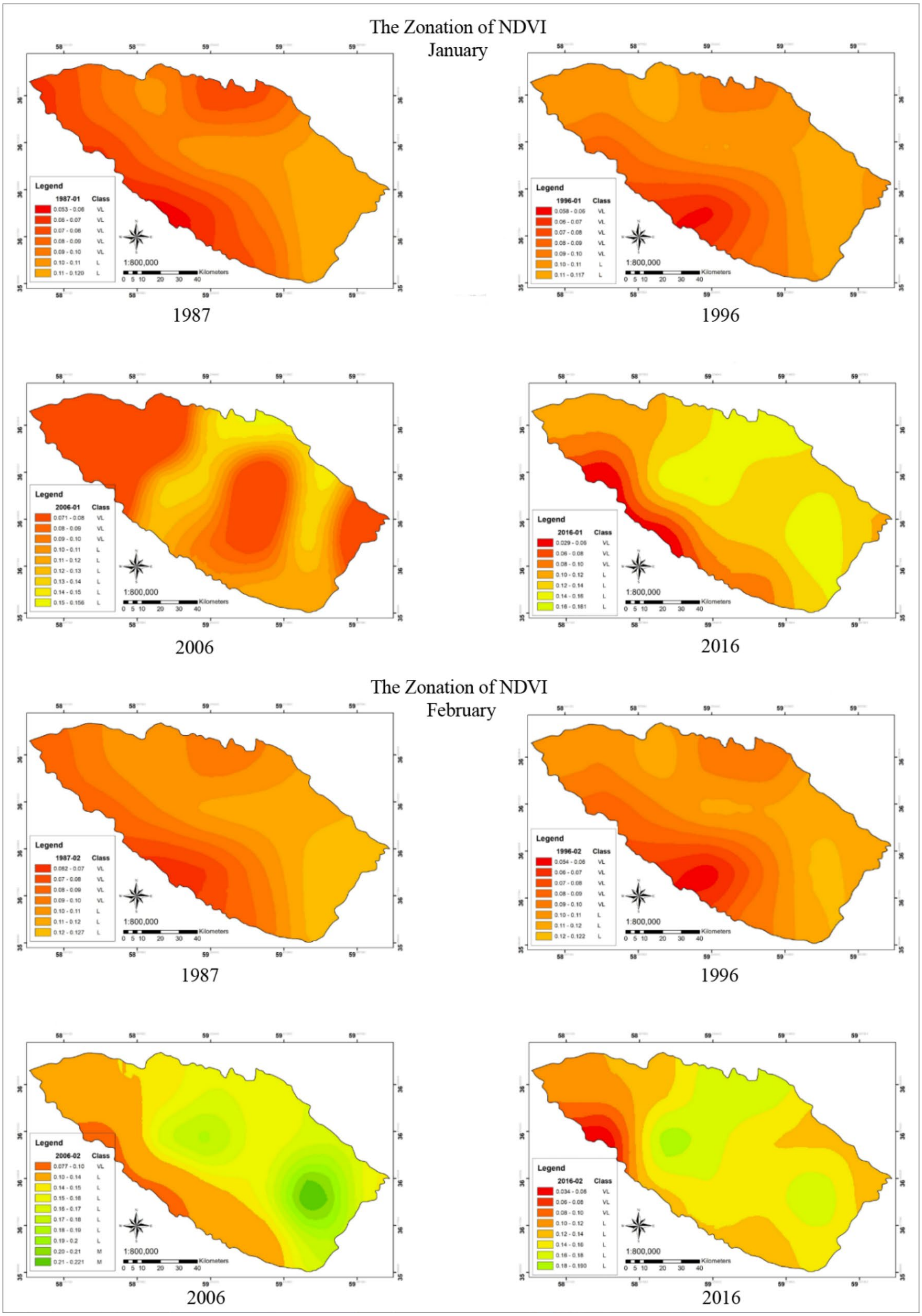

Fig. 5 The fluctuations of NDVI zonation in the January and February of 1987, 1996, 2006, and 2016

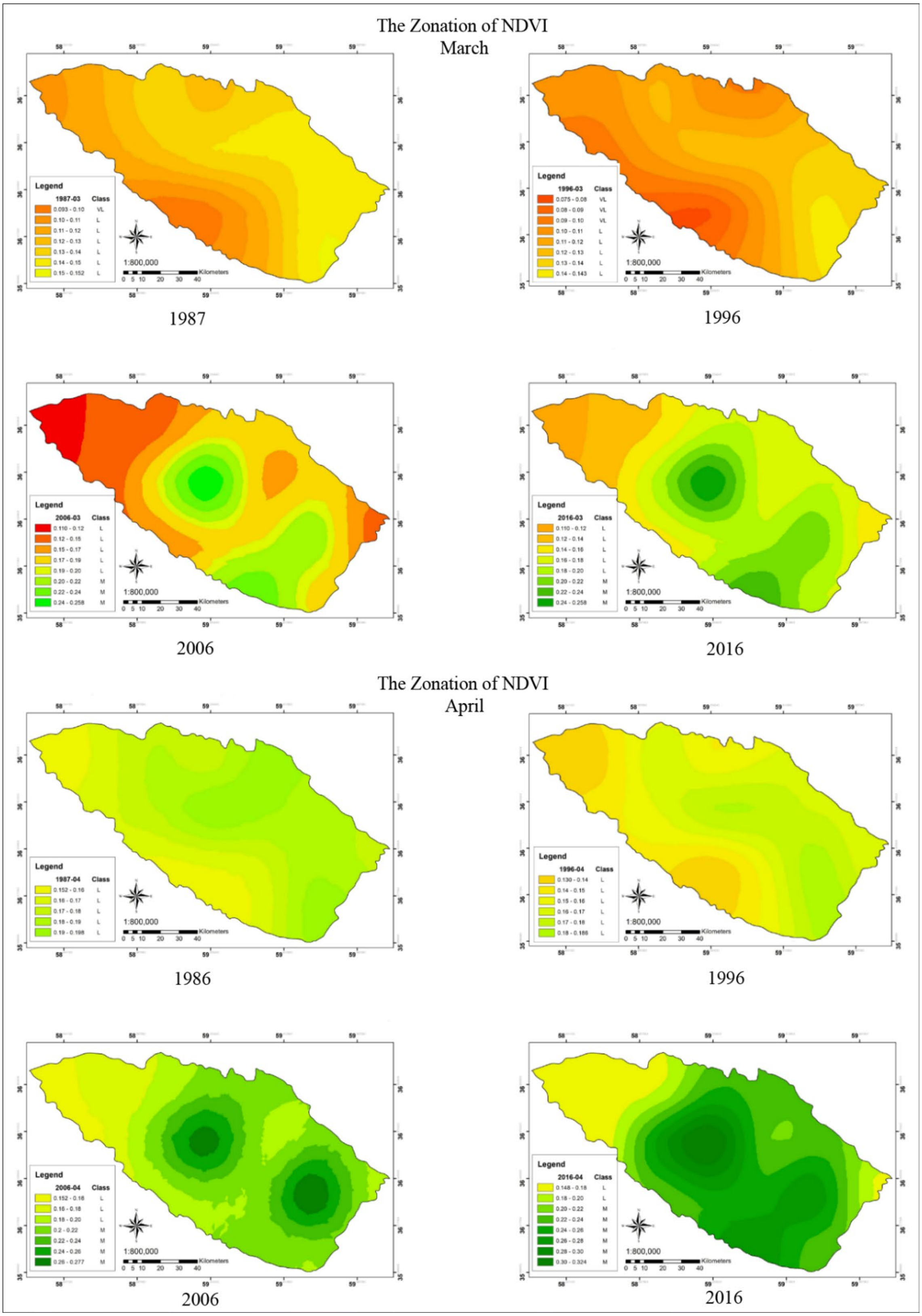

Fig. 6 The fluctuations of NDVI zonation in the March and April of 1987, 1996, 2006, and 2016

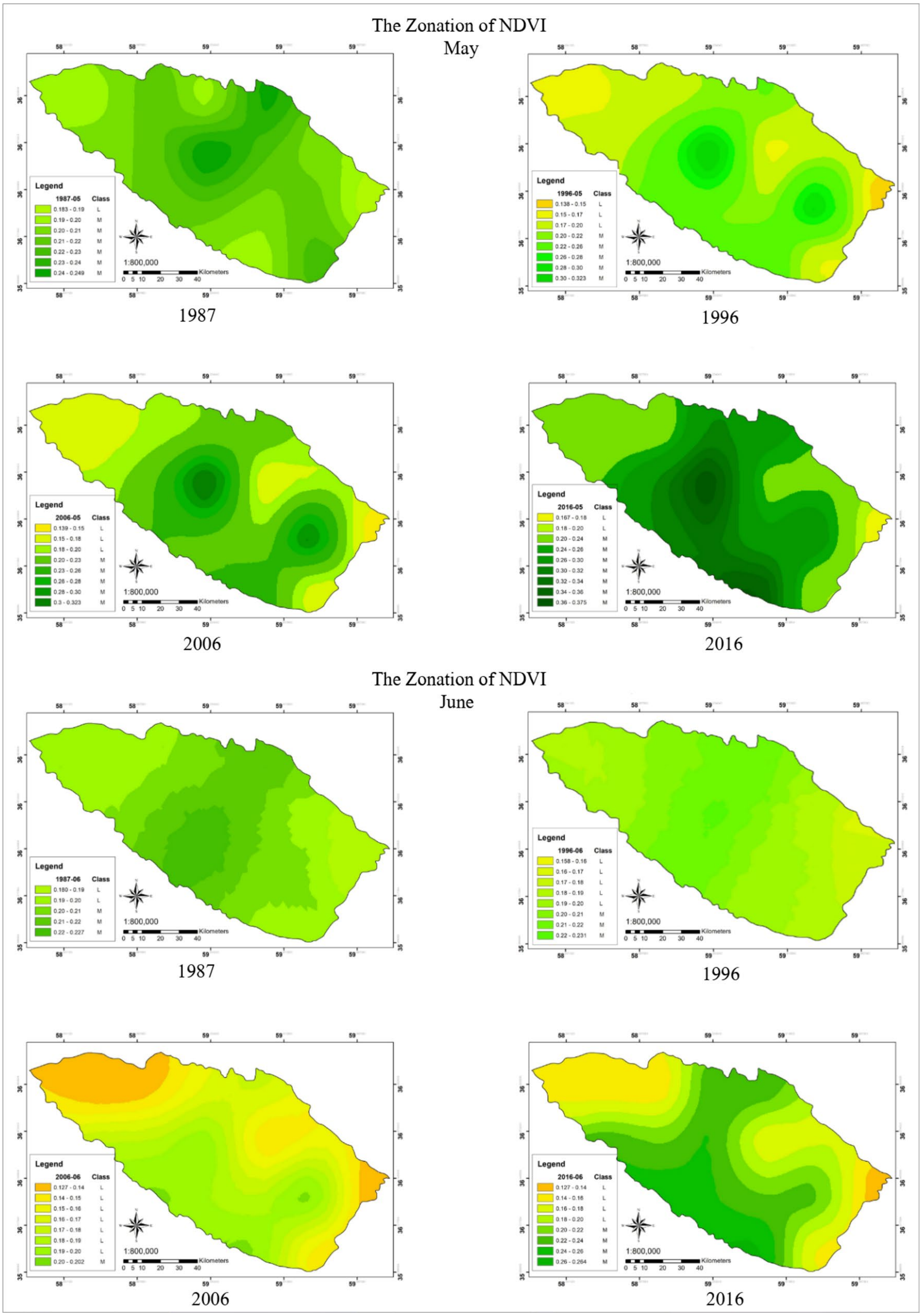

Fig. 7 The fluctuations of NDVI zonation in the May and June of 1987, 1996, 2006, and 2016

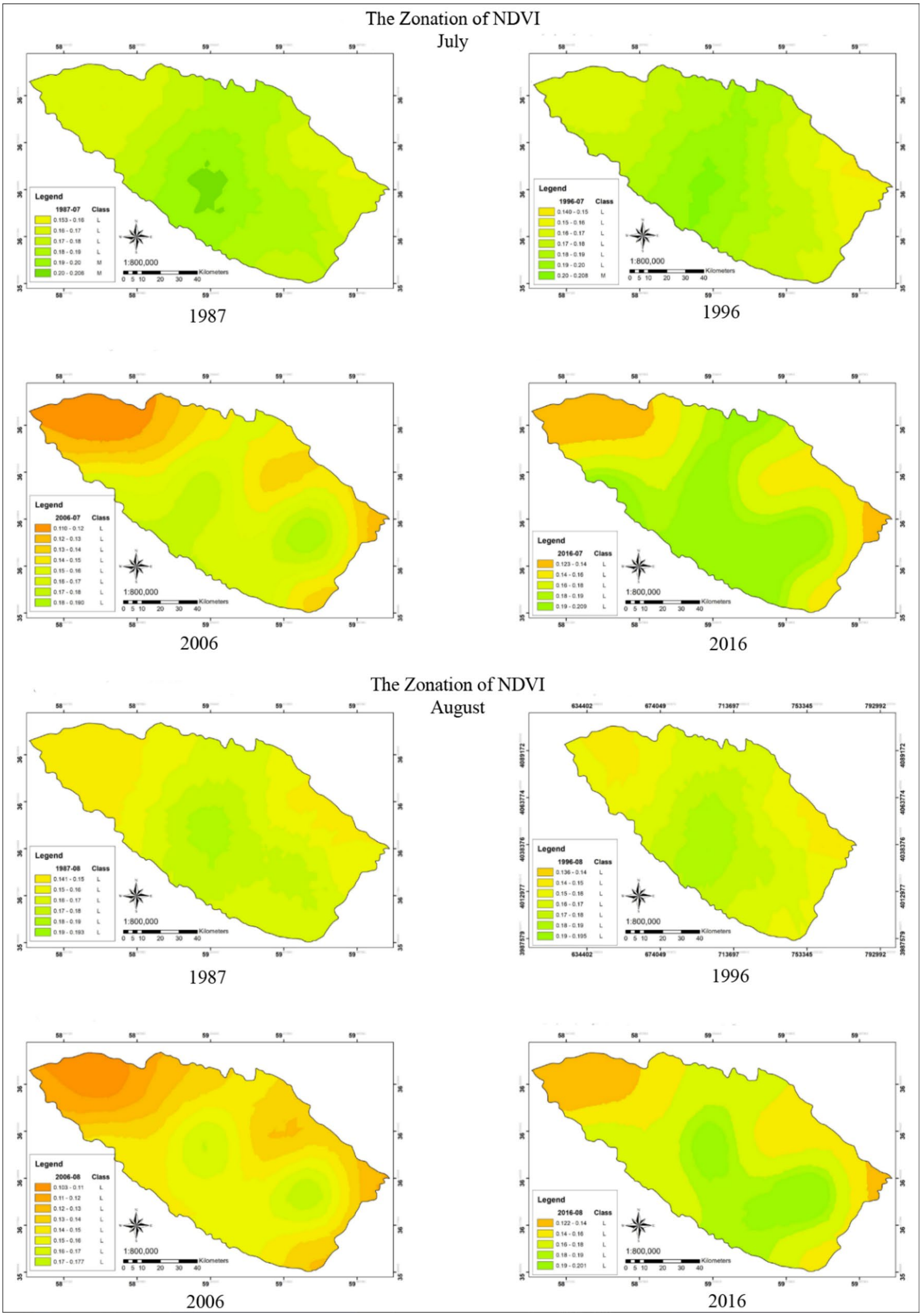

Fig. 8 The fluctuations of NDVI zonation in the July and August of 1987, 1996, 2006, and 2016

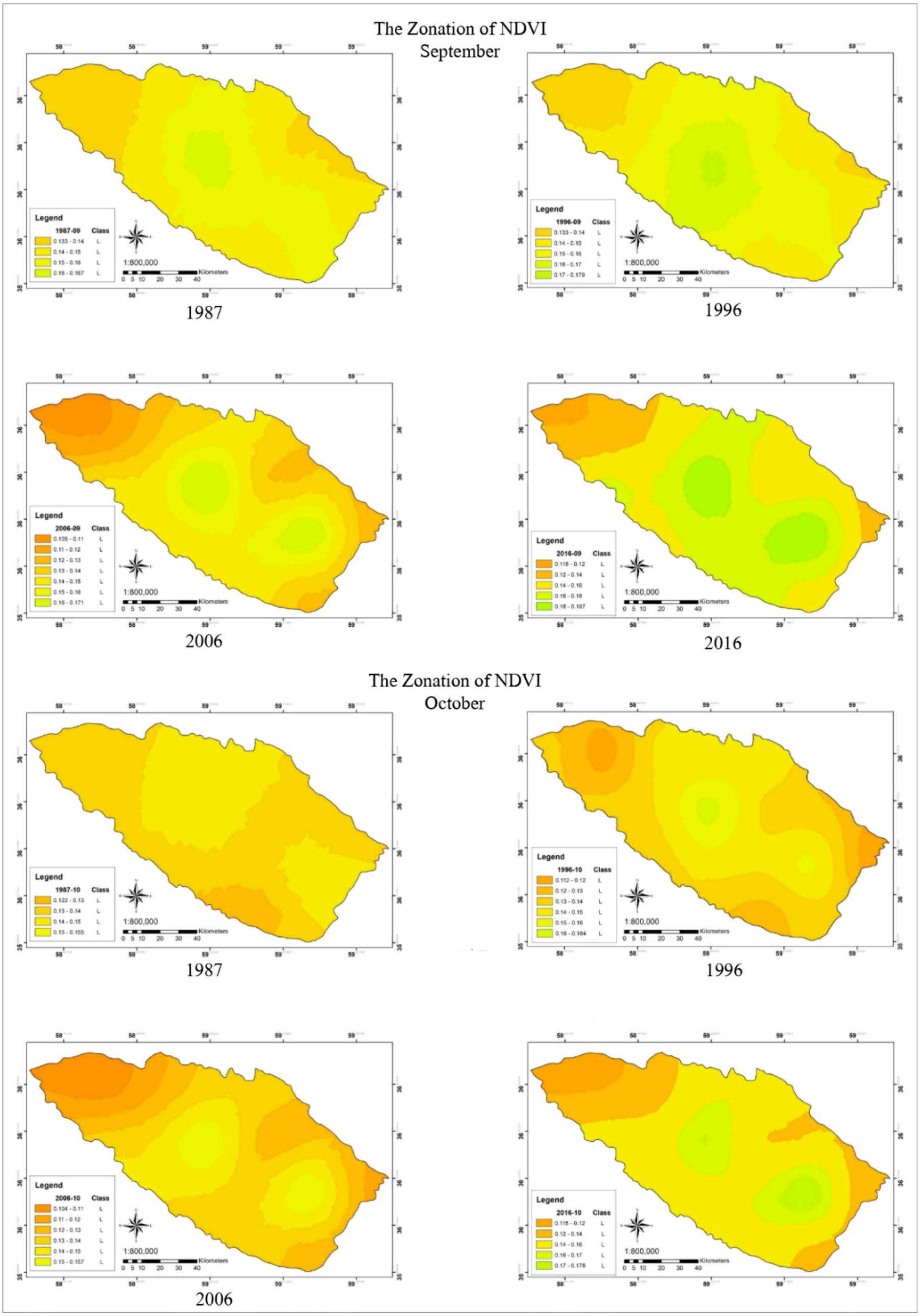

Fig. 9 The fluctuations of NDVI zonation in the September and October of 1987, 1996, 2006, and 2016

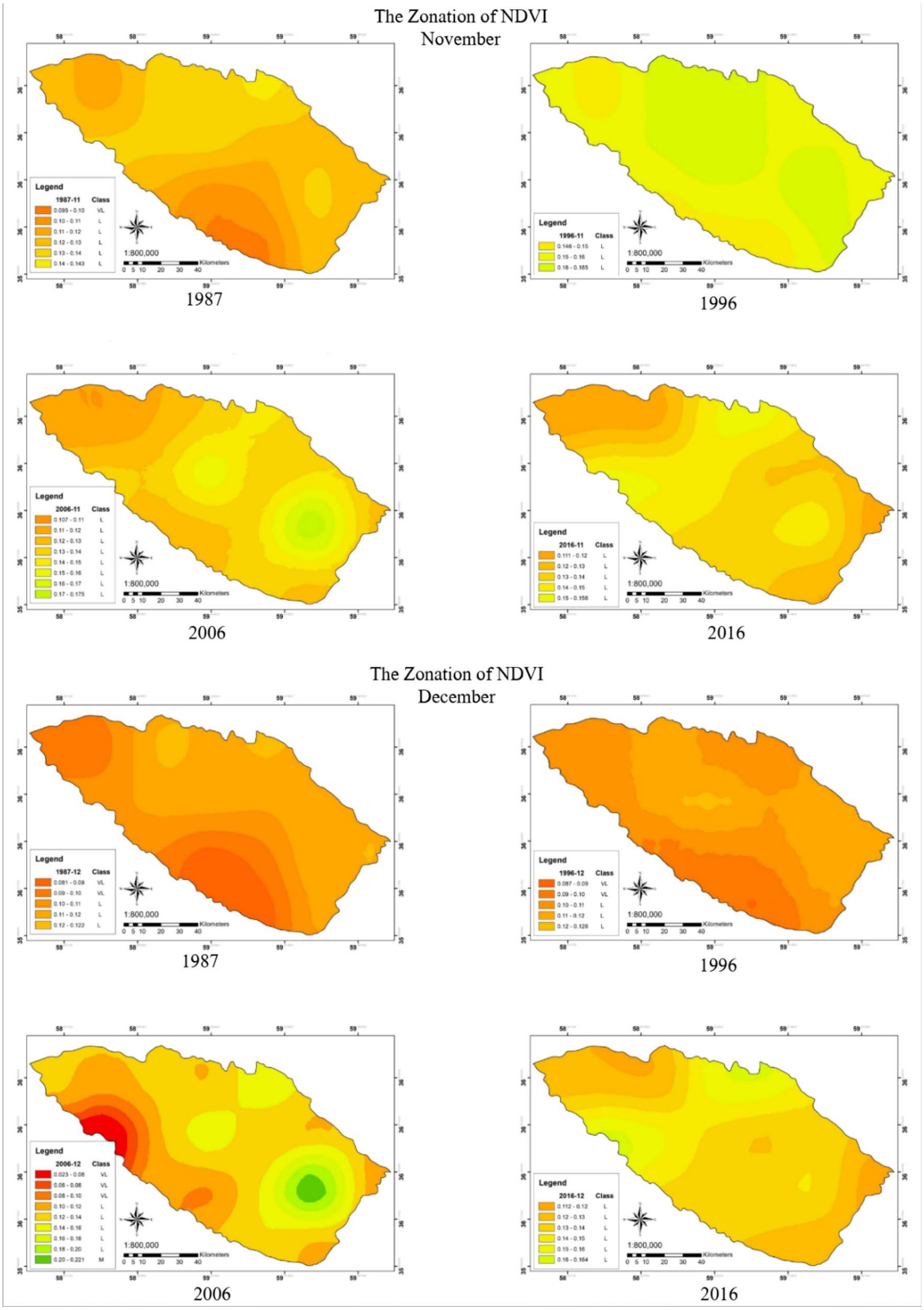

Fig. 10 The fluctuations of NDVI zonation in the November and December of 1987, 1996, 2006, and 2016

Table 5 The statistical values of NDVI in 1987, 1996, 2006, and 2016 by different land covers in the study area

Year	NDVI									
	Irrigated farming					Dry farming				
	Min	Max	Mean	STD	CV	Min	Max	Mean	STD	CV
1987	0.133	0.172	0.150	0.011	0.071	0.132	0.164	0.145	0.008	0.057
1996	0.128	0.171	0.147	0.011	0.074	0.129	0.162	0.141	0.006	0.043
2006	0.111	0.225	0.152	0.032	0.211	0.112	0.192	0.145	0.021	0.145
2016	0.129	0.226	0.171	0.030	0.176	0.129	0.217	0.169	0.025	0.148
	NDVI									
	Rich range					Moderate range				
	Min	Max	Mean	STD	CV	Min	Max	Mean	STD	CV
1987	0.135	0.161	0.145	0.008	0.055	0.130	0.172	0.147	0.008	0.055
1996	0.134	0.152	0.141	0.005	0.038	0.124	0.171	0.144	0.008	0.058
2006	0.116	0.163	0.149	0.012	0.078	0.113	0.225	0.150	0.021	0.138
2016	0.140	0.192	0.178	0.014	0.078	0.126	0.226	0.172	0.021	0.123

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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