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Environmental resilience of rangeland ecosystems: assessment drought indices and vegetation trends on arid and semi-arid zones of Central Asia

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Abstract

The Central Asian (CA) rangelands is a part of the arid and semi-arid ecological zones and spatial extent of drylands in CA (Tajikistan, Kazakhstan, Uzbekistan, Kyrgyzstan, and Turkmenistan) is vast. Projections averaged across a suite of climate models, as measured between 1950-2012 by Standardised Precipitation-Evapotranspiration Index (SPEI) estimated a progressively increasing drought risks across rangelands (Turkmenistan, Tajikistan and Uzbekistan) especially during late summer and autumn periods, another index: Potential Evapotranspiration (PET) indicated drought anomalies for Turkmenistan and partly in Uzbekistan (between 1950-2000). On this study, we have combined a several datasets of drought indices (SPIE, PET, temperature_T°C and precipitation_P) for better estimation of resilience/non-resilience of the ecosystems after warming the temperature in the following five countries, meanwhile, warming of climate causing of increasing rating of degradations and extension of desertification in the lowland and foothill zones of the landscape and consequently surrounding experienced of a raising balance of evapotranspiration (ET_0). The study concluded, increasing drought anomalies which is closely related with raising (ET_0) in the lowland and foothill zones of CA indicated on decreasing of NDVI indices with occurred sandy and loamy soils it will resulting a loss of vegetation diversity (endangered species) and raising of wind speeds in lowlands of CA, but on regional level especially towards agricultural intensification (without rotation) it indicated no changes of greenness index. It was investigated to better interpret how vegetation feedback modifies the sensitivity of drought indices associated with raising tendency of air temperature and changes of cold and hot year seasons length in the territory of CA.

Keywords: drought, SPIE, arid vegetation, PET, Central Asia, ecosystem resilience.

Introduction

Inter -annual climate variability is highly sensitive to agricultural production, livestock husbandry as expressed in growing season weather. Currently, these zones are gradually experiencing reduced moisture availability which has observed in recent global climate change impacts and raising aridity indexes (**fig.1b**) with frequent increasing of drought periods. According results of Dai et al (2004) in the former Soviet Union countries, where soil moisture data are available, the Palmer Drought Severity Index (PDSI) is significantly correlated ($r = 0.5$ to 0.7)

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with observed soil moisture content within the top 1-m depth during warm-season months. The strongest correlation is in late summer and autumn, and the weakest correlation is in spring, when snowmelt plays an important role. It is clear that one of the most important consequences of the temperature increase in arid lands is the increase of evapotranspiration (ET_0), and therefore aridity [24]. Potential a negative impacts of climate change on vegetation dynamics in CA are well reported by researchers [6,7,8]; [20]; [13]; [21,22], [32,33] and results indicated that high ET_0 and cumulative accumulation of anions are causing soil salinization in large areas of CA. Cumulative effects of climatic stress and anthropogenic pressure contribute to increased rates of biodiversity loss locally and regionally. Climatic stress contributes to an overall loss of valuable biodiversity at the large scale. An NDVI is often used worldwide to monitor drought, monitor and predict agricultural production, assist in predicting hazardous fire zones, and map desert encroachment. The NDVI is preferred for global vegetation monitoring because it helps compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors [29].

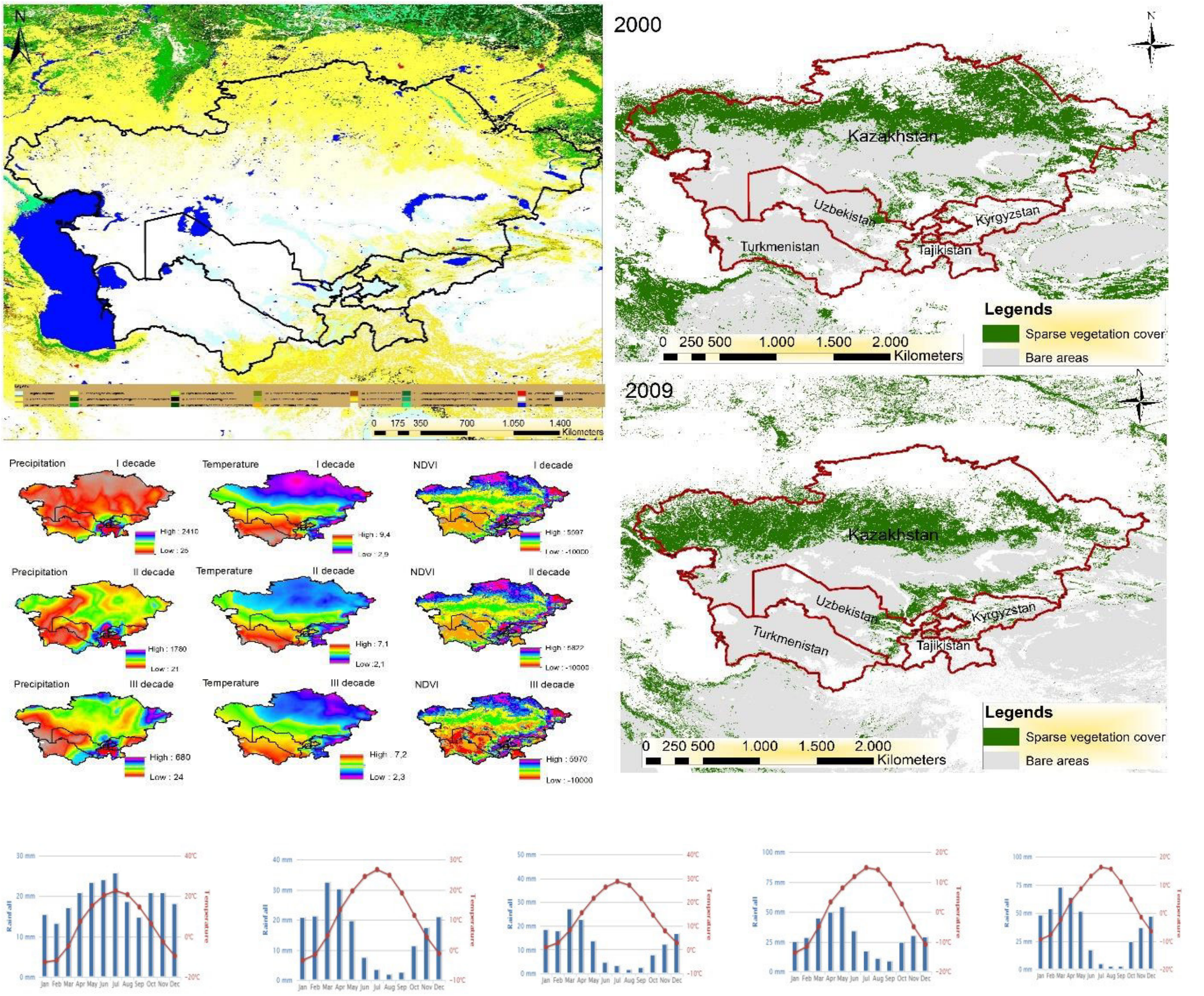
In general, arid and semi – arid regions particularly has a high evaporation loss ratings, and therefore observed a high ET_0 where the water supply is most limited and valuable. A reduction in precipitation due to climate change will affect the severity of droughts [1], within these objects we have obtained to simulate datasets for better estimation anomalies dataset. Rangeland diversity in CA remains one of the important task of these countries, understanding a current condition and future status is important to provide measures to establish adaptation mechanism for biodiversity ecosystems and evaluating the adaptation ecosystem strategies with action plans in CA. However, climate change scenarios also shown a temperature increase during the 20th century. In some cases, such as the A2 greenhouse gas emissions scenario [2], the models predict a temperature increase that might exceed 1-2ºC with respect to the 1960−1990 average, computed with real data between 1910 and 2007, also considers a progressive increase of 2−4ºC in the mean temperature series. Our results also indicated that these five countries are faced on drought anomalies which occurred on decreasing PET indexes then following ET_0.

Performance of utilization of satellite images within drought indexes given affordable and visual information for current and past condition to analyze and developing information systems for early drought detection. According land use classification to account for surface biophysical properties of various habitats (**fig.1**) and to assess temporal movement dynamics of vegetation pattern in these cold desert and semi desert ecosystems we have modified of quantity trends of vegetation responses in these ecosystems and several study sites have been selected: **a)** to assess spatio–temporal patterns of land-surface vegetation dynamics and drought indices **b)** explore their relationships with climate and anthropogenic variables over the past three decades with estimation resilience of the ecosystem on further anomlies. Although remote sensing data provide useful insights into the relationship between the NDVI and precipitation, the duration of such observations is still too short to describe climate change variations and trends realistically [23]. Combining analyses of NDVI trends and land-cover changes, [36,37] found a pattern of increasing greenness associated with agricultural abandonment (i.e.cropland to grassland) in the southern range of the Eurasian grain belt coinciding with statistically significant negative NDVI trends and likely driven by regional drought. In the northern range of the grain belt they found an opposite tendency towards agricultural intensification; in this case, represented by land-cover change from cropland mosaic to pure cropland, and also associated with statistically significant negative NDVI trends [11, 12].

Brief description of study area

The irrigated crop farming is major agriculture sector in these areas and intensive salinization of arable lands is core environmental problem currently. The effects of shrinking of the Aral Sea Basin coupled with the USSR collapse have caused increased population migration and uncontrolled grazing, which lead to salinization and further deterioration of rangeland ecosystems in the region. The area covered lies between *34°57'30''N* and *55°47'30''N* and *46°12'29''E* and *87°52'29''E*. Vegetation trends in this area are mostly driven by precipitation and temperature dynamics. According to soil anions/cations changes, which correspond with habitat heterogeneity and species diversity at finer scales on halophytic vegetation zones of CA. On the base of classification United Nations Environmental Program (UNEP) (1992) CA lies in the zone in which the aridity index varies between 0.05 and 0.5 and consequently is defined as "arid" and "semi-arid" zones, also Köppen categories of classification (Köppen et al.,1800) are described as a high evapotranspiration and less precipitation zones in these areas.

Precipitation and temperature patterns are most important for dryland ecosystems that are strongly dependent on these two factors. Dryland zones in CA (**fig.1**.) are mostly in a temperate continental arid climate: very hot (dry) summer and cold winter, total precipitation ranges from 0-200 mm, a vast majority of the land in the area is low lying <200 m but there are peaks of >5000 m. General overview describes on (**fig.1**), as requested robust understanding interrelations drought anomalies process in CA it was determined the onset, duration of drought conditions (June, July, August ,September) with respect to normal conditions period (middle of October till late spring) in a variety of natural and managed systems such as crops is best suited for drought monitoring and early warning purposes.



a). Average monthly rainfall and temperature for Kazakhstan during 1900-2012

b). Average monthly rainfall and temperature for Uzbekistan during 1900-2012

c). Average monthly rainfall and temperature for Turkmenistan during 1900-2012

d). Average monthly rainfall and temperature for Kyrgyzstan during 1900-2012

e). Average monthly rainfall and temperature for Tajikistan during 1900-2012

Figure 1. Overview of CA climate (CRU TS3.23 dataset), and land use and land cover change (LULC) datasets modified after MODIS for 2000-2009 (right side).

Material and Methods

Datasets

A most commonly used measure of aridity (fig.2c) is Thornthwaite's index of aridity [35] defined as a ratio of precipitation and evapotranspiration (P: PET), another method is PET which is temperature based equations. Also, one actual indices is SPIE measured monthly climatic water balance with following equation (P- ET_o). We utilized simple kriging methodology that was developed to classify further vegetation pattern indexes which is identifying with associated factors (Prec/Temp/NDVI/SPIE) and well influenced to the solid earth. General datasets and data of source listed on **table 1**.

Table 1. A summary of input datasets for parameterizing methodology to predict further status of vegetation and drought anomalies.

Data	Indices	Temporal Scale	Time Span (extracted)	Spatial Scale	Data Source
NDVI	Vegetation	Bi-monthly	1982-2011	Grid 8 km	AVHRR-GIMMS (NDVI 3g)
SPIE	Drought	monthly	1982-2011 & 1950-2011	0.5x0.50	SPIEbase v.2
Average air temperature	Climate	monthly	1981-2011	0.5x0.50	CRU-TS (ver. 3.23)
Average Precipitation	Climate	monthly	1981-2011	0.5x0.50	CRU-TS (ver. 3.23)
PET	Drought	annually	1950-2000	30 arc seconds or ~ 1km at equator	WorldClim Global Climate Data
Aridity index	Drought	annually	1950-2000	30 arc seconds or ~ 1km at equator	WorldClim Global Climate Data

A drought index: the ***Standardised Precipitation-Evapotranspiration Index (SPEI)***

The SPEI based on climatic data (CRU TS3.23 dataset), and it's a multiscalar drought index with a 0.5 degrees spatial resolution and a monthly time resolution. Available to download on following https://climatedataguide.ucar.edu/data-type/climate-indices/drought/spei; The SPEI is obtained from the monthly climatic water balance with following equation (P- ET_o), which is adjusted using a three-parameter log-logistic distribution. The values are accumulated at various time scales, we measured between 1-12 month (annually) and converted to standard deviations with respect to average values [36]. We have explored and divided five countries separately to visualize SPIE anomalies for last 30 years, within this purpose to be able compare with NDVI values (1982-2011) and for longest monitoring we have computed periods 1950-2012 as graph interpretation. The equation modified by [36]

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \qquad (1)$$

The constants are: C_0=2.515517, C_1=0.802853, C_2=0.010328, d_1=1.432788, d_2=0.189269, d_3=0.001308. The average value of the SPEI is 0, and the standard deviation is *1*.

where

$$W = -2\ln(P), \qquad (2)$$

for $P \leq 0.5$, P being the probability of exceeding a determined D value, P=1-F(x). If P>0.5, P is replaced by $1-P$ and the sign of the resultant SPEI is reversed.

A drought index: the ***Potential Evapotranspiration*** (Global-PET)

Global-PET (**fig.2b**) and Aridity Index (**fig. 2c**) are both modeled using the data available from the WorldClim Global Climate Data [18] as input parameters, these two datasets are modified on base ICARDA Classification [43]. These datasets based on a high number of climate observations and SRTM topographical data, is a high-resolution global geo-database (30 arc seconds or ~ 1km at equator) of monthly average data (1950-2000). Global-PET parameters calculated using the Hargreaves method and insufficient to fully parameterize physical radiation-based PET equations (i.e. the FAO-PM), though can parameterize simpler temperature-based PET equations by [15] uses, as shown below:

$$PET = 0.0023 \cdot RA \cdot (T_{mean} + 17.8) \cdot TD_{0.5}\ (mm / day) \qquad (3)$$

mean monthly temperature (T_{mean}), mean monthly temperature range (*TD*) and mean monthly extra-terrestrial radiation (*RA*, radiation on top of atmosphere) to calculate mean *PET.*

Quantify Drought Indices for better estimation vegetation – water stress

This NDVI index outputs values between -1.0 and +1.0 (*NDVI multiplied on *1000*), mostly representing green color (high accumulated) and yellow (low accumulated) zones, where any negative values are mainly generated from desert ecosystems, and values near zero are mainly generated from rock and bare soil in the visible range than in the near-infrared range (**fig.2d**), while the difference is almost zero for rock and bare soil. A vast area of study site located under values 0.01-0.1; for better estimation of anomalies divided on decades (**fig.2d, top**) and proposed and compared with SPIE datasets (**fig.3**) between same periods of time: 1982-2011.

The PET and Aridity Index dataset provides high-resolution raster climate data related to ET_0 processes and rainfall deficit for potential vegetative growth. We are considering to demonstrate SPIE dataset as responsible to loss of energy in the balance (vegetation patterns) due to outgoing a high ET_0 in the drylands of CA (**fig.3**). But same time, we are not able to modify ordinary kriging methodology with utilize datasets (PET and Aridity Index) with update version (dataset available till 1950-2000). Regarding on these suggestions, we have applied simple kriging standard error map (**fig.3**) to receive a less errors within applying certain datasets (Prec/Temp/NDVI/SPIE) for prediction status of patterns (loss and gain productivity) and resilience areas of CA. A model is equally good at describing the data ($r_2 = 0.77$ (the power law model) and $y = 0.96 * x + 0.80$) but extrapolation beyond the range of the data is always fraught with difficulties. And on reality, it may opposite occasions, anyhow some errors of the data are still available and more accuracy expected with adding extra thaw datasets for better estimation gradual change patterns.

Results

As usual, in arid and semi- arid zones are gradually faced with anomalies related to decreasing of precipitation in last decades, but same time the results of NDVI indicated of accumulation greenness indexes are increased following two decades (1992-2001 & 2002-2011). Several previous studies have reported increased vegetation greenness over the northern high-latitude region over the past 20–30 years [4]. In the past, extensive agricultural development resulted in native vegetation being cleared across vast areas of the CA, especially converting desert zones to agricultural and it might be also one factor to assist greenness indexes. We analyzed PET under methodology by [42] process on those five regions (**fig. 1a**.); also utilize long time series data of NDVI and applied SPIE database (1982-2011) to better interpret vegetation cover status on different seasonality and annually. Results indicated that drought anomalies are not correspondence factor for decreasing of agricultural productivity in Kazakhstan, Kyrgyzstan, same time drought anomalies are response of altering a native vegetation. Mostly, palatable vegetation is occurred to decrease phytocenosis activity in drylands. These methods are modify structural and functional traits of ecosystems leaving and their anthropogenic and natural phenomena imprint on the amount and seasonality of photosynthetic activity.

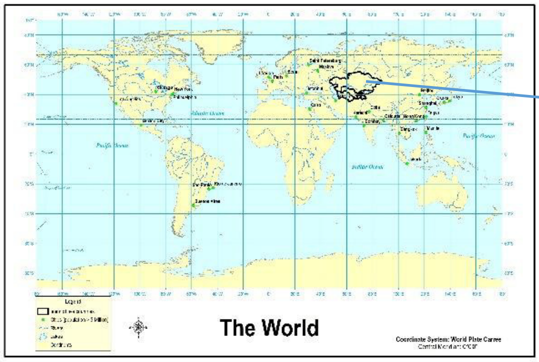


Figure 2a. Overview of locations CA on the northern hemisphere.

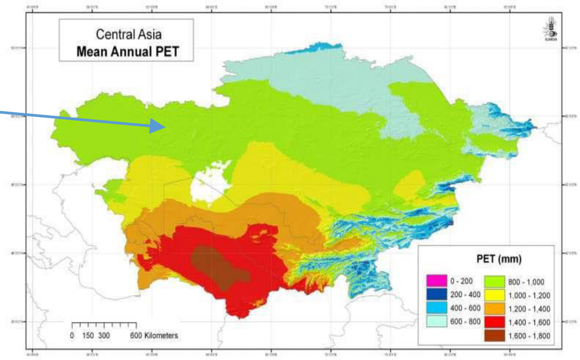


Figure 2b. Mean annual potential evapotranspiration (PET) grid for Central Asia at 30 arc-second (about 1 km) resolution. Source: (http://www.cgiar-csi.org)

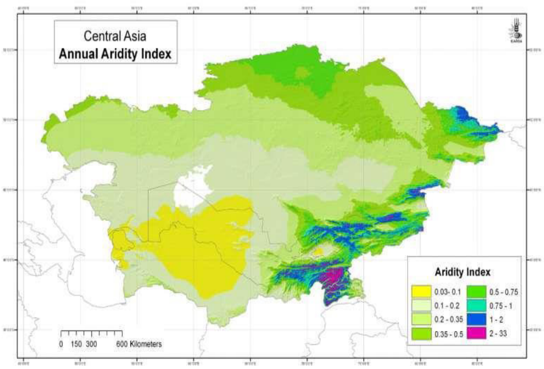


Figure 2c. Annual Aridity Index in Central Asian countries at 30 arc-second (about 1 km) resolution. Source: (http://www.cgiar-csi.org)

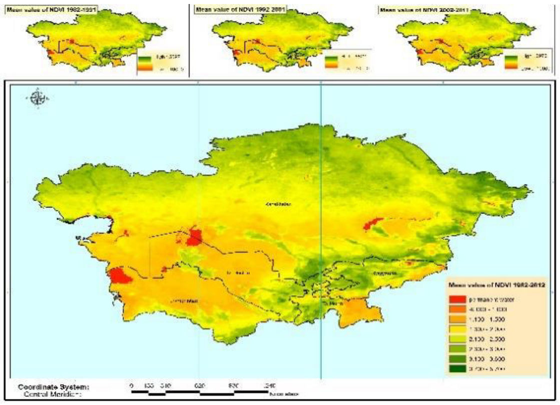


Figure 2d. NDVI- vegetation monitoring enables to describe density and intensity of green vegetation growth using the spectral reflectivity of solar radiation.

The main drought episodes occurred in decades 1970´s for all five countries. On Fig.3, we have added extra basic requirements for better understanding anomaly decades of time (*Y* coordinate values reached until ≥ -2, it means a very drought period of decades in the region) and inserted with shapes a quickly able to see a high drought period for each decades and visualize with comparison of anomaly decades for each country.

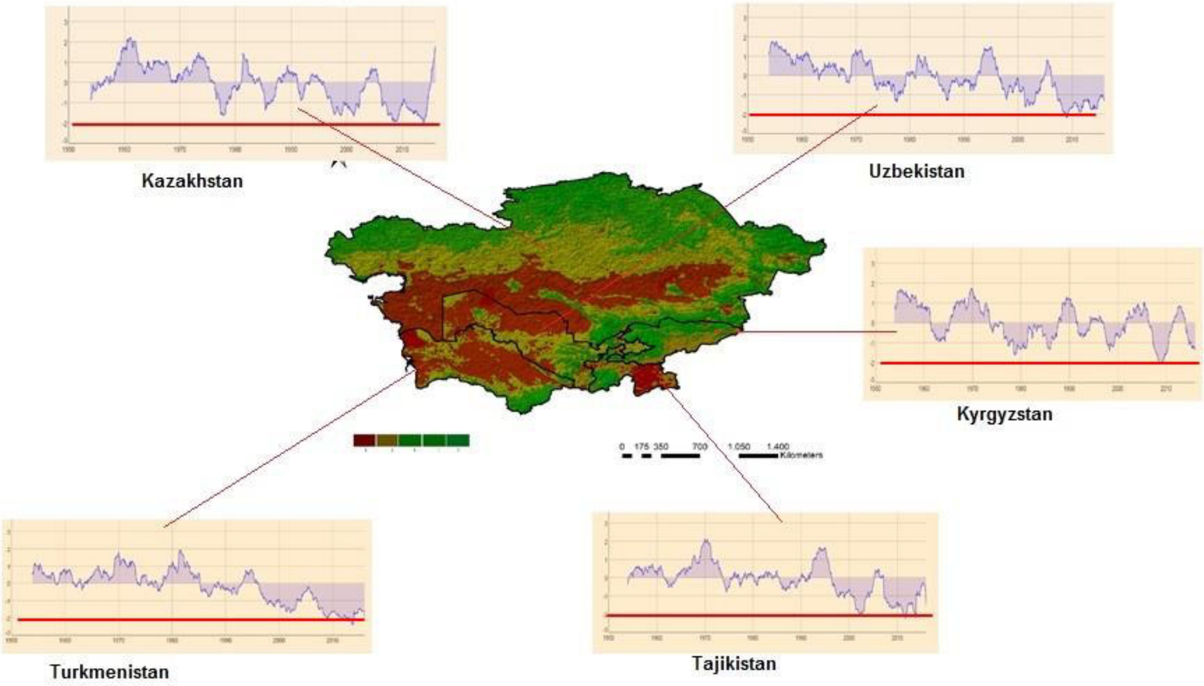


Figure 3. Determining annually drought variability (1982-2011) and multiplicative year of trends (1950-2010) in targeted areas with positive and negative trends of SPIE (object-based). Inserted shapes (red line) indicated to observe a high anomaly decade periods in the regions. Trends modified after and updated on the database SPIEbase 2.

This simple experiment clearly shows an increase in the duration and magnitude of droughts at the end of the century (**fig.3**), which is directly related to the temperature increases and decreasing of precipitation. It uses a 0 as normal, and drought is shown in terms of negative numbers; for example, -2 is severe drought, -3 is extreme drought. Algorithm also is used to describe wet spells, using corresponding positive numbers. It estimated a progressively increasing drought risks across rangelands (Turkmenistan, Tajikistan and Uzbekistan) especially during late summer and autumn periods. On the base results, each country have explored a very drought anomaly periods a minimum 2 times during observed period (1950-2012), occasionally it is not similarity for each country. This phenomena which vary with time related to develop particular span of time. Based on observed result, the SPEI is a good indicator to predict a further drought anomalies or alternatively to be able develop crop failure or less productive zones. Appropriate phytoindicators for modifying and designing different ecological zones, especially trends of spatial changes of vegetation cover over time trends which are associated with climate patterns, assessed a better understanding vegetation movement dynamics and their mechanisms.

The persistent drought conditions during this period are also clearly identified by the SPEI, especially in Turkmenistan and Uzbekistan observed anomaly periods longer than other three countries (Kazakhstan, Kyrgyzstan and Tajikistan). Southern part of Kazakhstan is currently also indicated of raising drought indices, such as Aridity Index (**fig.2c**) indicated a less aridity (1950-2000) on these ecosystems compare SPIE datasets (1982-2011).

Results indicated that negative trends of drought severity index (red color) is related on low accumulation of NDVI values, and positive drought index included a high values of NDVI, in case of CA a high values of NDVI ranged between 0.35-0.50 or 0.15-0.30; and a negative trends of severity index indicated accumulation of NDVI values between 0.01-0.05 (very low values). It is clearly, when leaves are water stressed, diseased, or dead, they become more yellow and reflect significantly less in the near-infrared range.

Discussion

This trajectory zone (**fig.4**) is demonstrated distinct temporal patterns of bioclimatic synchronies for different land use patterns. If we will able to describe an image (**fig.4**), then northern part occupies/covers high vegetation zones and southern part described inverse of this condition. Factors that must be considered when defining scenarios for changing threats to biodiversity on this area include the following: extensive using fertile lands in Uzbekistan and Turkmenistan, partly Kazakhstan and Tajikistan, where over 30-40 % of original arid and semi-arid lands vegetation has been removed. A native vegetation is no longer a common occurrence, agricultural intensification, including expansion of irrigated horticulture into areas that traditionally practiced dryland grazing and cropping enterprises, but vast areas continuing pressures on remnant vegetation. Slight changes of vegetation communities under overgrazing and long term of use of lands already under pressure (without rotation) developed degradation processes (erosion, salinity, soil structure decline, loss of vegetative cover) on the rangelands [27].

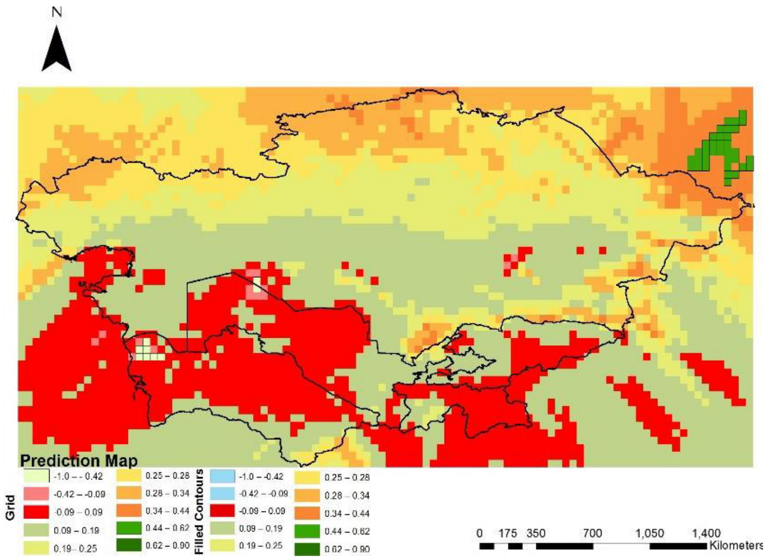


Figure 4. Kriging methodology that was developed to classify further vegetation index (resilient zones) which is identifying as index certainty associated factors *(Prec/Temp/NDVI/SPIE)* influenced to the solid earth.

This model, it can capture the basic effect of global warming on drought through changes in potential evapotranspiration. Temperature range (TD) is an effective proxy to describe the effect of cloud cover on the quantity of extra-terrestrial radiation reaching the land surface and, as such, it describes more complex physical processes with easily available climate data at high resolution. By using surface air temperature and precipitation takes into account the basic effect of global warming through PET measures. Such as without thaw and snow covering datasets this prediction map it may have some pros and cons. Within prediction standard error surface that locations (five countries) near sample points generally have lower error and more accuracy for receiving further status of vegetation and describe resilient and non-resilient ecosystems. A study published by *U.S. Global Change Research Program* suggests that higher temperatures lead to the evaporation of moisture from soils, thereby increasing the frequency, intensity and duration of droughts in the region.

There have been reports from land users about an alarming decrease in the frequency and intensity of snowfall over the past few years as well as the consistent rise in temperatures being witnessed over the years. Key limitations of these datasets that are not allowed calibrate or not account for thaw, snow or ice (delayed runoff); making it difficult to correlate with specific water resources like runoff, snowpack and etc.

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