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Assessing the Vegetation Condition of Herat Province, Afghanistan Using GIS

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Abstract: *Drought is a severe problem in Herat Province, Afghanistan where more than 80% of population relies directly or indirectly on agriculture and livestock sector. Severe drought, exacerbated by climate change, both results to the degradation of vegetation cover in rangelands and the reduction of soil fertility in agricultural lands. Rangelands and rainfed agricultural lands are most susceptible to drought due to limitation of irrigation facilities. The main objective of this study was to assess the vegetation condition of Herat Province in scale of time and space. MODIS-Aqua Normalized Difference Vegetation Index (NDVI) products (MYD13A1) of 2003-2014 were used to analyze spatial and temporal variation of Vegetation Condition Index (VCI) in a GIS domain. The results shown that 2008 was the driest year of the period 2003-2014 followed by 2006 and 2004; But 2009 proceeds to 2005 and 2003 were the greenest years of the period with limited drought conditions. Based on VCI index, 87%, 85%, 82%, 75%, 70% and 47% of rangelands in Herat Province experienced extreme and severe drought in June, July, August, May, April and March of 2008, respectively. Extension of this study in various regions of Afghanistan is recommended for sustainable management of communities' livelihoods as well as reduction of loss and damages associated with food insecurity and immigration.*

Keywords – *Afghanistan, Herat Province, Drought, MODIS, NDVI, VCI*

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I. Introduction

Drought is significantly associated with migration and food insecurity in Afghanistan. It is a creeping phenomenon and a slow-onset natural disaster that causes serious damages to the ecosystem services of the arid and semi-arid regions like Herat Province, Afghanistan. Rangelands and rainfed lands are very sensitive and completely dependent to amount and distribution of precipitation due to limitation of irrigation facilities. However, rangeland of Herat Province is the main source of grazing for livestock and along with rainfed agricultural lands are major livelihoods of rural communities. In recent decades, severe droughts caused degradation of vegetation cover in rangeland areas and rainfed agricultural lands of Western Afghanistan and increasingly prolonged food insecurity and migration problems.

Damages of drought could be very well managed and mitigated if we know and study the hazards in details. Spatial and temporal assessment of vegetation health and condition is significantly important for better management of agricultural activities and improvement of agriculture and livestock sector. Mainly vegetation condition is monitored in form of ground-based and/or satellite-based observations. The Standardized Precipitation Index (SPI) is among the most popular methods for estimation of drought extend and magnitude from meteorological data. Satellite-based methods usually use satellite imagery mainly Landsat, MODIS, etc. The Merits and limitations of NDVI and LST use for drought assessment was studied by [1]. They stated that there is a need to use empirical LST-NDVI relationships with caution and to restrict their application to drought monitoring to areas and periods where negative correlations are observed. Spatial monitoring of drought was researched by [2] in Thar Desert using satellite-based drought indices (NDVI and SPI). Their study revealed that vegetation in Thar showed an improving trend from 2002 to 2011 and a declining from 2011 till 2014. In addition, several researches were conducted about the impacts of drought on vegetation in Amazon rainforests [3–5], North America [6, 7], Mongolia Plateau [8], northern China [9–11] and southwestern China [12]. Very few studies have examined the responses of vegetation to drought in Afghanistan.

In order to ensure sustainable development of livelihood and improved agriculture and livestock in Afghanistan, it is crucially needed to study and research the factors, extent, magnitude, and impact of drought in the area. Therefore, the propose of this study was temporal and spatial assessment of vegetation condition in Herat Province during growth season of 2003-2014 using MODIS NDVI products (MYD13A1) and Geographic Information System (GIS).

II. Materials and Methods

1.1 Study Area

The study area, Herat Province, is located in northwestern Afghanistan between latitude 32.85°-35.62° North and longitude 60.52°- 64.49° East which occupies 54800 Km2. Herat has arid and semiarid climate with 254 mm mean annual precipitation. The altitude varies from 490 m in northwestern to 3804 m in eastern mountains. According to [13], major land cover types of the study area include bare lands (43.6%), rangelands (36.9%), rainfed agricultural lands (10.2%), irrigated agricultural lands (4.9%), water and snow cover (3%), forests (2.84%) and build up areas (0.5%) (Fig. 1).

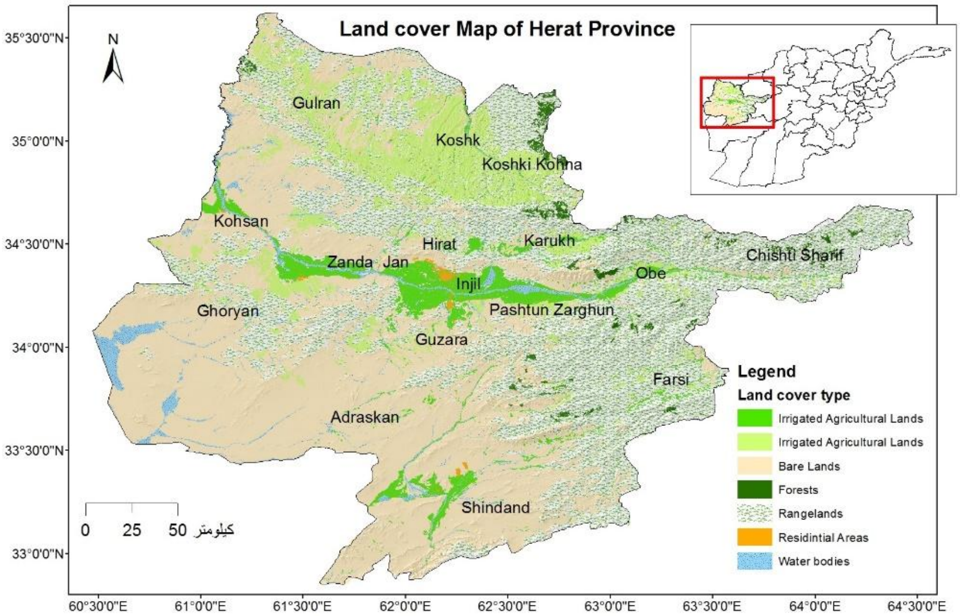

Figure 1. Study area and land cover types

1.2 Input Data and Vegetation Indices

MODIS-Aqua 16-day, 500-meter atmospheric corrected reflectance products (MYD13A1) were used to assess vegetation condition of Herat Province during the growth season (March-August) of 2003 to 2014 [14]. For spatial and temporal monitoring of vegetation condition in Herat Province, NDVI data of the study area was extracted and stacked in monthly based.

NDVI is Normalized Difference Vegetation Index the indicates photosynthesis activities and vegetation condition of an area. NDVI index is calculated from NIR (620-670 nm) and Red (841-876 nm), Band 1 and Band 2 of MODIS, respectively:

$$NDVI = \frac{NIR - \mathrm{Re}d}{NIR + \mathrm{Re}d} \quad \text{… (Eq. 1)}$$

NDVI values varies from +1 to -1. vegetation covers related to their density and canopy, occupy positive values of NDVI and close to +1. Soils and rocks NDVI values are close to zero (0), non-vegetation covers like water bodies and snow cover has negative values of NDVI (table 1).

Table 1. NDVI Values of Different land cover

Type of Land Cover		NDVI (scale from -1 to 1)
Vegetation Cover	Dense	0.500<=NDVI<= 1
	Medium	0.140<=NDVI< 0.500
	Scarce	0.090<=NDVI< 0.140
Bare ground		0.025<=NDVI< 0.090
Clouds		0.002<=NDVI< 0.025
Ice and snow		-0.046<=NDVI< 0.002
Water		-1<=NDVI< -0.046

adopted from [15]

VCI is a better indicator of the moisture deficit than NDVI because it allows the separation of the short-term climate signal from the long-term ecological signal [16]. VCI enables the comparison of simultaneously measured NDVI values not only under the different geographic conditions but also in the different vegetation types [17]. VCI index was used to remove climatic and topographic impacts on NDVI results [18]. VCI index indicates a vegetation condition index based on the relative NDVI change with respect to minimum historical NDVI value as following [19]:

$$VCI = \frac{NDVI_{x,y} - NDVI_{\min}}{NDVI_{max} - NDVI_{min}} \quad \text{… (Eq. 2)}$$

Where NDVI x,y is current NDVI value of a pixel. NDVI min and NDVI max are the minimum and maximum NDVI values of the related pixel during a time series. As it is shown in table 2, the VCI is ranged between 0 to 100 [20]. The lower values of VCI during a period of time shows the extreme drought and vice versa. The procedures of vegetation condition assessment were accomplished in GIS. MODIS-NDVI products were stacked on monthly-base. Mean, maximum and minimum of each month were extracted for further use in the VCI indices of the current date (x,y).

Table 2. VCI values and related drought conditions

Drought Condition	VCI
Extreme	< 10
Severe	10 – 20
Medium	20 – 30
Mild	30 – 40
No	≥ 40

III. Results and Discussions

1.3 Spatiotemporal Variability of Greenness (NDVI) in Herat Province

Vegetation cover has a significant season variability in Herat Province due to temporal distribution of water availability, temperature, day length and exposure to sunlight. vegetation cover was at its lowest level in January and February but increased to reach its peak in April. Herat is at its greenest stage during April and May, then the vegetation area gradually decreases. vegetation cover in Eastern and northern parts was spatially different from western Herat (Fig. 2).

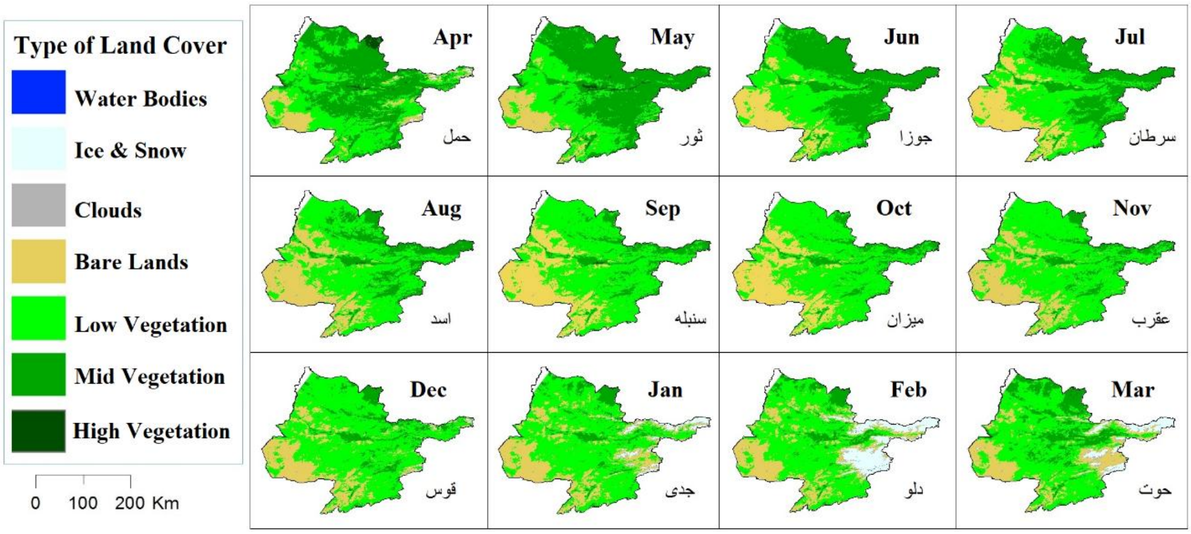

Figure 2. Spatiotemporal distribution of NDVI values shows significant greenness variabilities

There is a clear season pattern of NDVI associated to the type of vegetation cover. The NDVI values are less than 0.2 in the most of irrigated agricultural lands until early March. Then slightly increases in late March and dramatically increases in April and May to reach its peak; later, the NDVI values decline very fast (probably due to agricultural harvesting). However, greenness pattern varies according to the type of crops, though the start and end of the vegetation season is quite evident in early March and mid-June, respectively. The NDVI values of rainfed lands have the same sharp increase and decrease (as the irrigated lands do) but their canopy and vegetation percentage are lower than those of irrigated lands. In compare to agricultural land, forests and rangelands have stable NDVI values during the year. The growth season of the forest and rangelands are shorter and concentrated in spring season (Fig. 3).

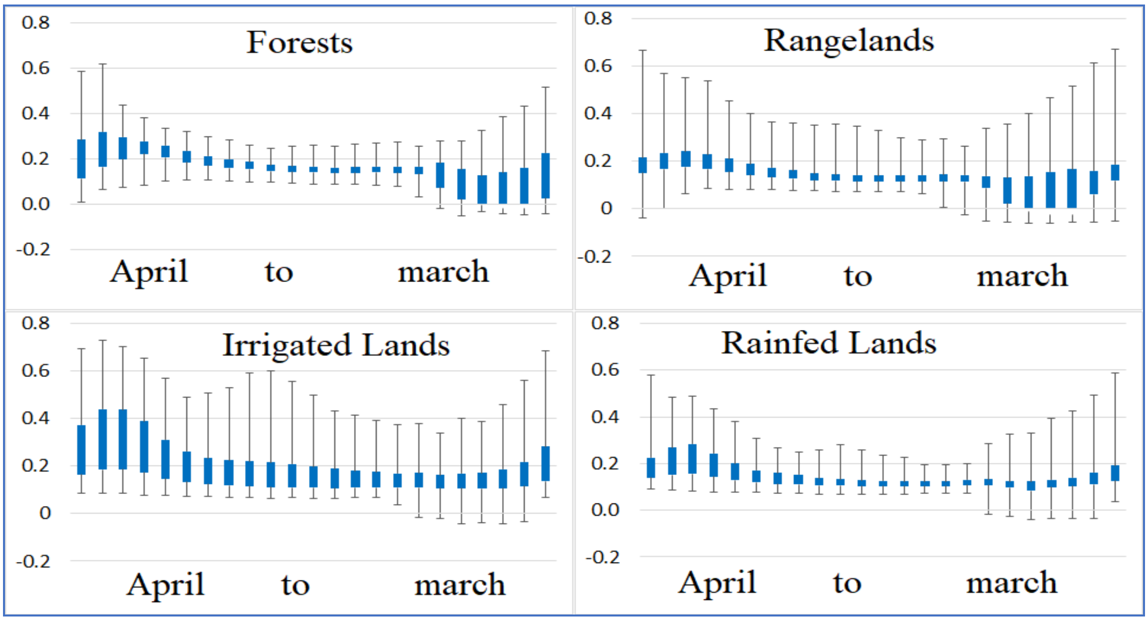

Figure 3. Boxplot of NDVI temporal distribution in Herat Province based on vegetation type

1.4 Spatial and temporal assessment of vegetation condition in Herat Province

Monthly median of VCI (2003-2014) shows that rainfed lands, forests and rangelands experienced the widest level of drought. Particularly, in June the extent of drought is at its peak in rainfed lands. In term of magnitude, some rainfed lands experience the extreme drought in May and June (Fig. 4).

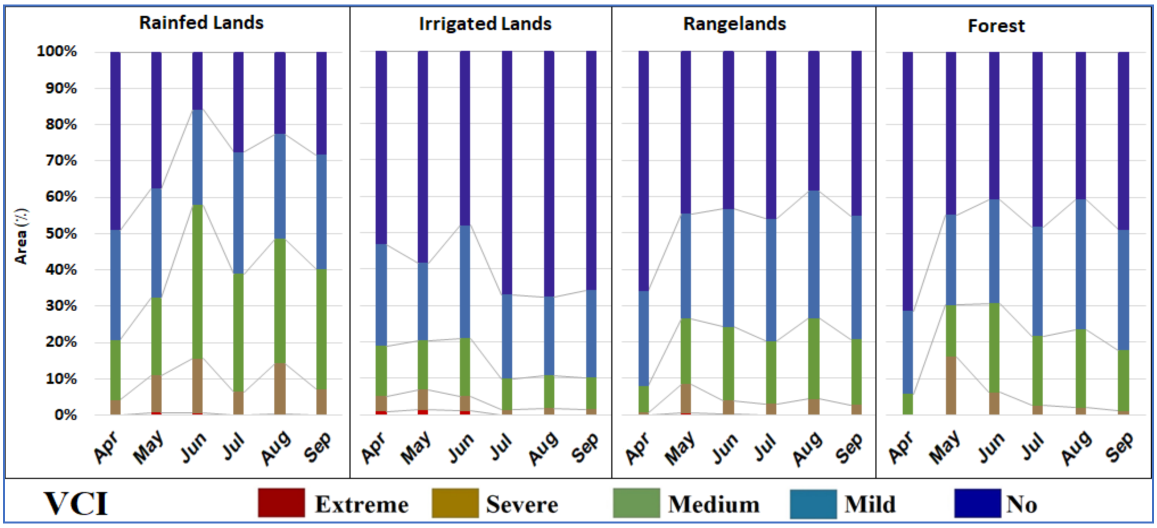

Figure 4. Impact of drought on different types of vegetation cover in Herat Province

The monthly VCI during 2003-2014 shows that in 2008 the VCI values are less than 10% in most part of the study area which shows extreme drought condition. Except in the month of April, Farsi District was extremely dry during vegetation season in 2004. The year 2009 was a green year with almost zero drought. However, 2003, except in some districts during April, the vegetation condition of Herat was normal (Fig. 5).

After analysis of VCI of Herat Province, its monthly median was calculated. Comparing to vegetation season, extent and magnitude of drought in April is scarce and spares, but in May not only the extend but also magnitude is increased particularly in Gulran, Kohsan, Ghuryan, Zindajan, Guzara, Adraskan and Shindand Districts. In June, the extend of the drought is decreased but magnitude is significantly increasing in surrounding areas of Harirud River. Shindand District in June and July, but Koshk Kohna and Rabat Sangi Districts were under high impacts of drought (Fig. 6).

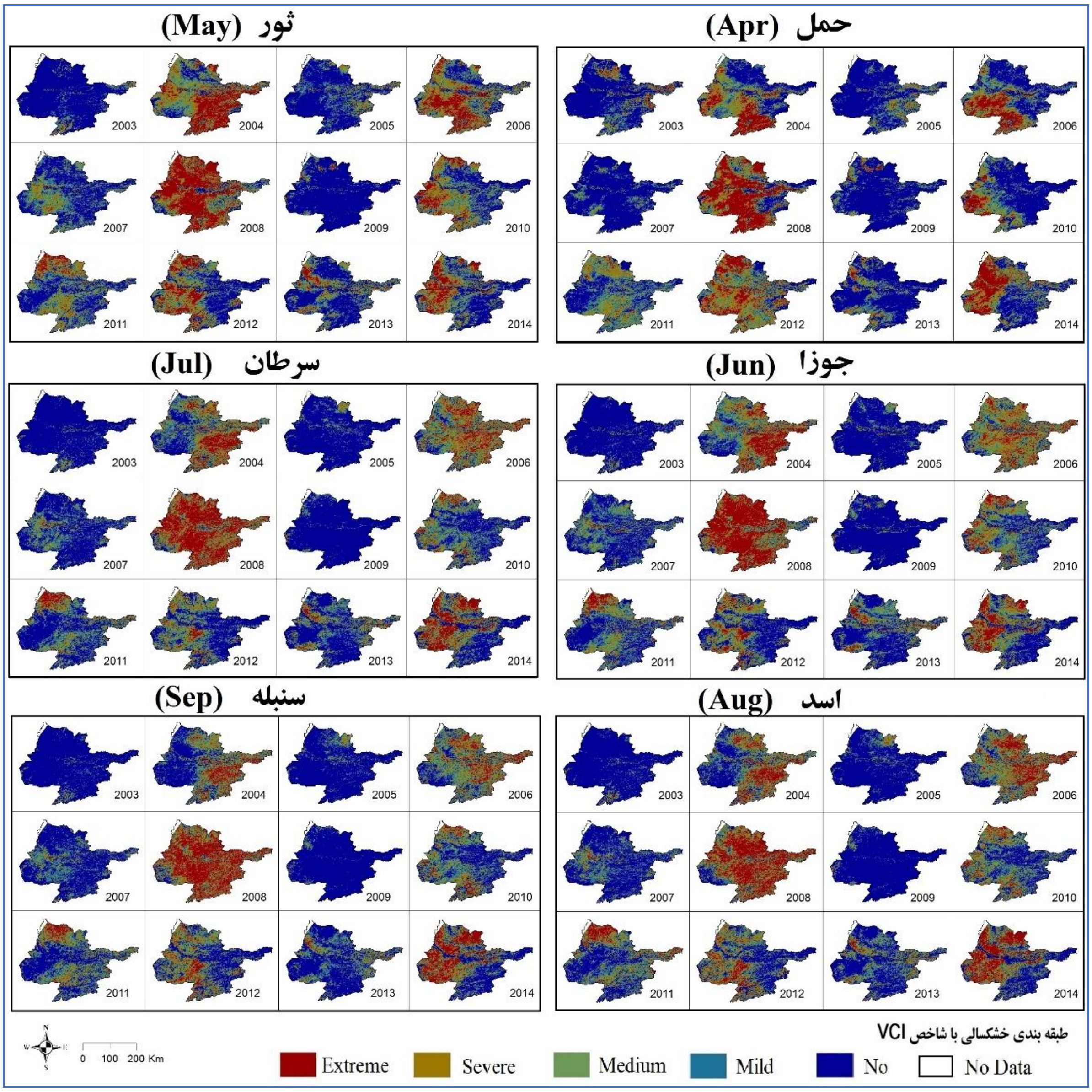

Figure 5. spatiotemporal distribution of drought in Herat Province during Apr-Aug of 2003-2014.

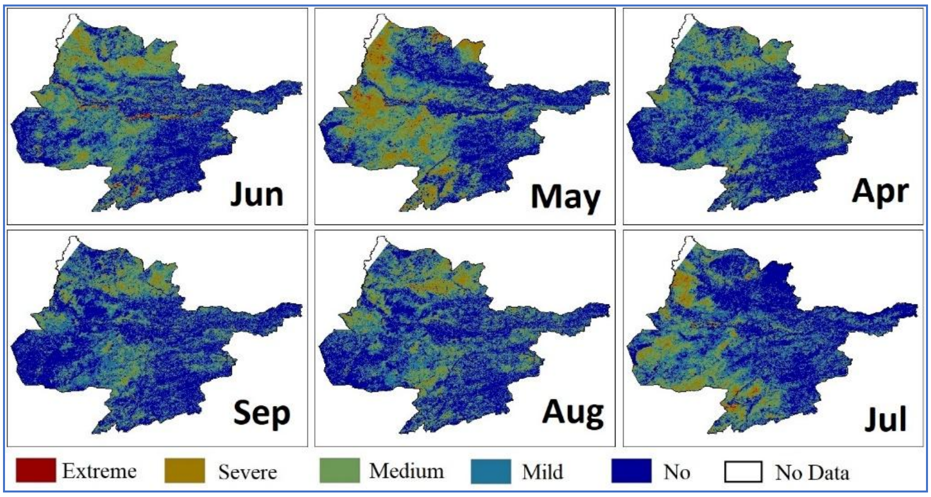

Figure 6. Monthly median of drought condition in Herat Province during vegetation seasons of 2003-2014 based on VCI.

IV. Conclusion and Recommendations

Drought conditions significantly decrease agricultural and livestock production, consequently causing food insecurity, migration to cities, and socioeconomic problems in Afghanistan.

Application of vegetation indices and use of MODIS data for spatial and temporal assessment of vegetation condition in developing countries like Afghanistan, do not only save time and money but also provide significant results and outputs for sustainable livelihoods of Afghans as well as improvement of agriculture and livestock sector due to better management of rangelands and agricultural activities. The most susceptible land cover type to drought are rangelands followed by rainfed agricultural lands where support livelihood and income of majority rural Afghans.

Since it requires less financial and time requirements, extension of the study in various regions of Afghanistan is recommended for sustainable management of communities' livelihoods as well as reduction of loss and damages associated with food insecurity and immigration.

Further researches on climatic, topographic, edaphic and anthropogenic factors in relation to agriculture as well as on climate change induced risks and community-based adaptation to climate change is suggested to insure better management of agricultural and animal husbandry activities and improvement of this sector in Afghanistan.

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