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DISENTANGLING THE RESPONSE OF VAGETATION TO RAINFALL ANOMALIES FOR DROUGHT EVALUATION OVER THE INDUS BASIN

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ABSTRACT

Drought hazards induced by continuous water shortage may damage crop growth and cause severe grain loss. With one of the most intensive irrigation systems, the Indus basin has supported agriculture for millennia and feeds up more than 300 million people. The water supply for the basin scale irrigation is dominated by melting of glaciers and snowpack in the Himalaya and Karakoram mountain ranges, ground water as well as the Asian monsoon rainfall. To understand how ecosystems over the Indus basin with such complex water supply mechanism response to meteorological drought (rainfall shortage) is critical for future drought monitoring and evaluation applications. This study evaluated the spatiotemporal response pattern using correlation analysis of rainfall anomalies (3-month scale) and vegetation anomalies (1-month scale) with long-term satellite observations. The result found that the vegetation over northern Indus valley significantly coupled to rainfall variation during both summer (Kharif) and winter (Rabi) monsoon season. While significant response during Kharif season also was identified over the southern part, especially over the Punjab, where was well equipped with irrigation system. We concluded that special attention should be paid to drought assessment in terms of rainfall and vegetation anomaly over the Indus basin

Index Terms— Indus basin, rainfall, NDVI, drought

1. INTRODUCTION

A prolonged of shortage in water supply over a region may result in crop damage or ecosystem function degradation, which is normally referred as a drought hazard [1]. Drought has long been identified as one the most influential weather-related hazards which causes billions of US dollars loss globally each year [2]. Reliable near real-time drought monitoring and evaluation information is critical for effective drought risk management. Rainfall is the main and direct water supply to local ecosystem, and a shortage in rainfall is normally a cause (or driver) of a drought event. On the other hand, vegetation growth may response to water supply shortage, and thus can be used as an indirect indicator for drought conditions. Until now, numerous drought indices had been proposed to evaluate drought conditions based on rainfall and vegetation measurements because of their easier accessibility relying on either ground stations or satellite sensors. For example, the Standard Precipitation Index (SPI) and Vegetation Condition Index (VCI) were defined as the deviation of rainfall and vegetation greenness to their historical normal conditions respectively, which were widely used for regional drought monitoring [3-4]. Particularly, The World Meteorological Organization (WMO) recommended the SPI as the main meteorological drought index for global drought evaluation in 2009 [5].

The Indus basin valley is well-known by its most intensive irrigation system in the world, which feeds up more than 300 million people. As reviewed by Laghari [6], 95% water resource of the whole basin was used for irrigation, and the majority of water for irrigation originated from ground water and glacial and snowpack melting over the upper reach of the Indus basin instead of local rainfall. In this case, vegetation (or crops) over irrigated area may response stronger to water from upper stream or deep ground instead of local rainfall. Besides the broadly scattered irrigation area, there still other rainfed ecosystems exists in the Indus basin such as rainfed farmland over the northeastern Pothohar Plateau and the rangeland over the western mountain region. When evaluating drought events, one normally expects spatiotemporal consistency among different drought indices based either rainfall or vegetation greenness [7]. Therefore, how will ecosystems under different water supply paths such as the Indus basin response to meteorological drought (i.e. local rainfall shortage), and in turn, how these response pattern will impact the spatiotemporal consistency between rainfall and vegetation greenness derived drought indices, is critical for effective drought monitoring and evaluation. This study tried to address these questions.

2. STUDY AREA, DATA & METHODOLOGIES

The transboundary Indus river basin has a total area of 1.12 million km^2 distributed between Pakistan (47 percent), India (39 percent), China (8 percent) and Afghanistan (6 percent). The Indus river basin stretches from the Himalayan mountains in the north to the dry alluvial plains of Sindh province in Pakistan in the south and finally flows out into the Arabian Sea (Fig.1). The rainfall mainly concentrates in the foothill of the northeast mountain area where annual rainfall can reach 1000mm or even more, however most of the middle and low reach of the basin (plain area) normally receive much less rainfall. Groundwater withdrawal and surface water from rivers driven by intensive irrigation system contribute most of water demand from the middle and low reach of the basin. Most of the Indus basin valley dominated by two crop growth seasons, i.e. Kharif season (summer, June - November) and Rabi season (winter, December - May). The data source for the irrigation map over the Indus basin was extracted from "Global map of irrigated area" dataset provided by FAO [8].

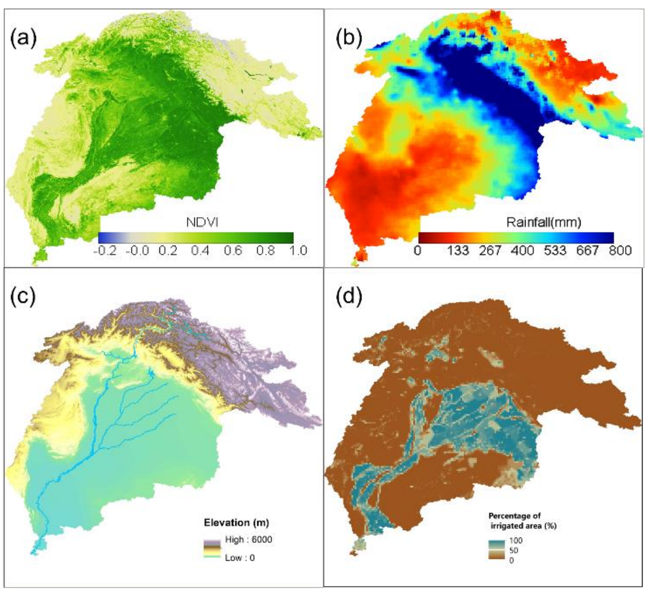

Fig.1. The maximum NDVI (a), average annual rainfall (b), elevation (c), and percentage of irrigated area for each cell (d) over the Indus basin.

The rainfall estimates in the Climate Hazard Infrared Precipitation with Stations (CHIRPS) (Version 2.0) dataset is derived by combining satellite rainfall estimates and ground rain gauge observations [9]. In this study, we used the pentad (5-day) CHIRPS dataset with 0.05° (~5 km) resolution to calculate monthly SPI during 2001-2018. In principle, SPI can measure rainfall deficit across a range of timescales such as 1-month, 3-month, 6-month, and 12-month [3]. In current preliminary study, we mainly used 3-month SPI, which has been proved closely related to agricultural drought [5].

In addition, the NDVI products, i.e. MOD13A2 and MYD13A2 retrieved from MODIS sensors onboard both Terra and Aqua satellites were used to composite monthly NDVI dataset by averaging concessive 8-day imagery within each month. In turn, monthly Standard Vegetation Index (SVI) during 2001 – 2018 was estimated according to Equation 1. In this case, the SVI has similar range as SPI and a negative SVI value indicates a less-than ideal vegetation condition caused by water shortage or other factors.

$$\text{SVI} = \frac{NDVI_{i,j} - \overline{NDVI_i}}{NDVI_{i,std}} \quad (1)$$

$NDVI_{i,j}$ – NDVI value of i-th (i = 1, 2, …, 12) month at j-th year (j = i = 1, 2, …, 18)

$\overline{NDVI_i}$ – average NDVI of i-th month across all years.

$NDVI_{i,std}$ – sample standard deviation of NDVI of i-th month across all years.

The correlation coefficient of paired monthly SVI and SPI dataset for each month of a year was calculated to evaluate the coupling strength between vegetation growth and rainfall variation. Additionally, the SVI and SPI were used to assess drought hazards dynamic during 2001 – 2018 respectively. The criterion for separate drought severity levels was given in table 1. All the analysis in this study was conducted on Google Earth Engine platform.

Table1. Drought Severity levels criterion of SPI and SVI.

SPI(SVI) value	Drought severity
-0.5 ~ -0.99	Slight Drought（D0）
-1.0 ~ -1.49	Moderate Drought（D1）
-1.5 ~ -1.99	Severe Drought（D2）
< -2.0	Extreme Drought（D3）

3. RESULTS

As shown in Fig.2, the annual NDVI anomaly was significantly correlated with annual rainfall anomaly over the rainfed ecosystems such as the northeastern Pothohar Plateau, the rangeland over the western mountain region (i.e. Balachistan province of Pakistan), and the Rajasthan province of India where local rainfall is only water supply for ecosystem development. In addition, the correlation became insignificant over the Sindh and western Punjab province of Pakistan as rare rainfall received and vegetation growth almost totally depended on irrigation. However, the annual vegetation greenness still correlated to annual rainfall over the eastern Punjab of Pakistan and Punjab of India where was well equipped with irrigation system. This meat that the local rainfall played an important role in agriculture in this area even though main water supply still originated from river flow or groundwater.

Regarding of the response pattern at monthly scale (Fig.3), the northern valley dominated by rainfed vegetation presented significant correlation between 1-month SVI and

3-month SPI at both Kharif and Rabi season, which verified that rainfall is the decisive factors for vegetation growth at both season over these area. In contrast, large-scale significant response pattern was identified the eastern Punjab of Pakistan and Punjab of India at Kharif season, which highlighted the importance of the monsoon rainfall to regional crop production.

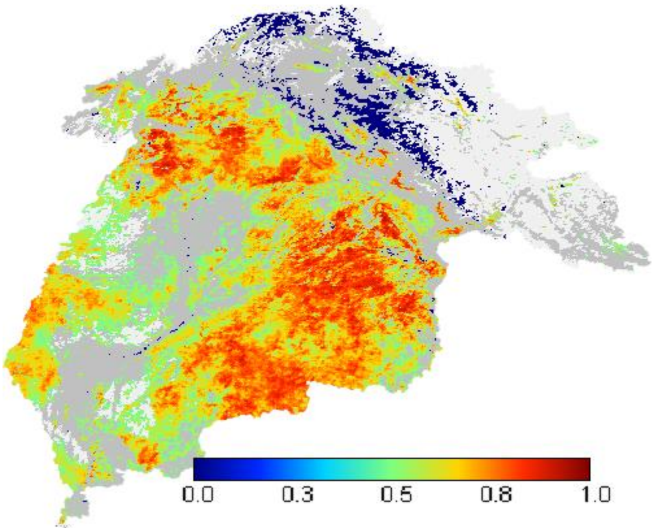

Fig. 2 Correlation of SVI and SPI at yearly scale. Pixels with significant correlation were presented in colorful. Pixels filled with light gray, and dark gray corresponds to persistent bare ground (maximum NDVI of all months across all years less than 0.2), vegetated but insignificant correlation, respectively.

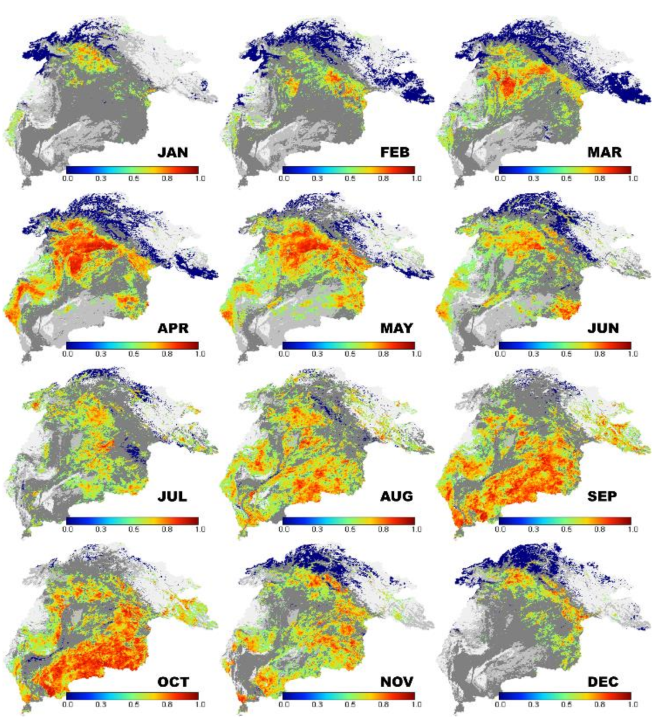

Fig.3 Monthly correlation between SVI (1-month) and SPI (3-month) during 2001 – 2018. Pixels with significant correlation were presented in colorful. Pixels filled with light gray, moderate gray, and dark gray corresponds to persistent bare ground (maximum NDVI of all months across all years less than 0.2), temporary bare ground (maximum NDVI of the investigated month across all years less than 0.2), vegetated but insignificant correlation, respectively.

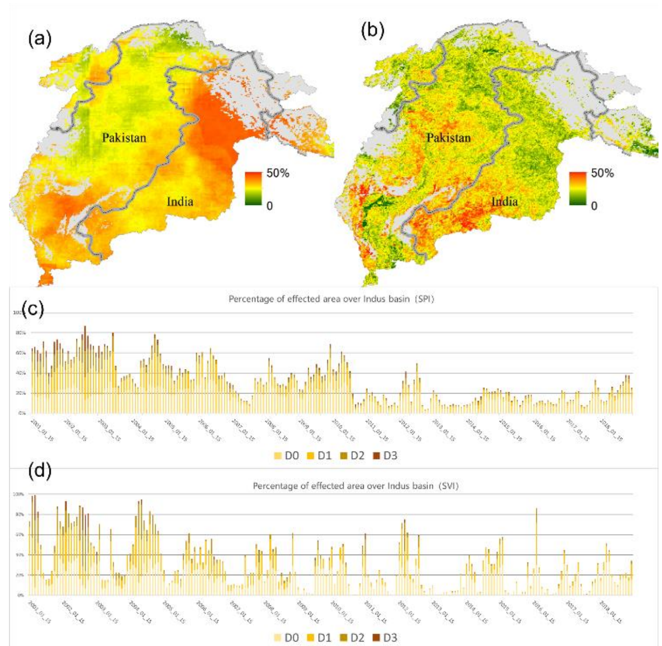

Fig.4 The drought hazards dynamic during 2001 – 2018 evaluated by SVI and SPI: (a) drought frequency based on SPI; (b) drought frequency based on SVI; (c) Percentage of drought effected area based on SPI; (d) percentage of drought effected area based on SVI.

According to the criterion given in Table 1, the statistic on the spatial drought frequency and temporal dynamic of drought effected area during 2001 - 2018 based on SVI and SPI respectively was presented in Fig.4. The southern basin seemed much prone to meteorological drought, especially over the Sindh province of Pakistan and the most valley located at Indian part (Fig.4a). Additionally, we noticed that the drought frequency of foothill region of the Indian part can approach or even exceed 50%, which may be caused by decreasing trend in rainfall during the 1981-2018. As for the drought frequency based on SVI (Fig.4b), frequent drought effected region mainly distributed over rainfed vegetation area. Drought effected area derived from SVI showed larger seasonal variation than the one derived from SPI. While a reduction in drought effected area was revealed by both indicators.

4. DISCUSSION & CONCLUSION

As both the rainfall and vegetation greeness based indicators has been widely used for drought monitoring and evaluation, the inter-consistency of these indicators was critical for effective drought risk management. This study investigated the correlation between rainfall anomaly (SPI) and NDVI anomaly (SVI) over the Indus basin with intensive irrigated area as well as rainfed ecosystems. We found the rainfed vegetation responded well to rainfall variation at both Kharif and Rabi season as expected. While part of well irrigated area, i.e. east Punjab of Pakistan and Punjab of India, also presented strong correlation between SVI and SPI. The drought frequency and drought effected area quantified by SVI and SPI showed large spatiotemporal divergency because of the complex response pattern of vegetation to rainfall anomaly. The complexity of drought posed challenges in its monitoring and evaluation especially rely on unique factors such as rainfall or vegetation greenness. The construction of comprehensive drought indicators by composite multiple factors relating to drought processes can improve our understanding of the hazards. The SPI can SVI can be combined directly to evaluate the drought over rainfed ecosystems. However, the response relationship between SVI and SPI should be evaluated before combining SPI as a factor for drought evaluation over irrigated region.

5. ACKNOWLEDGE

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