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Evaluation of Indices for an Agricultural Drought Monitoring System in Arid and Semi-Arid Regions

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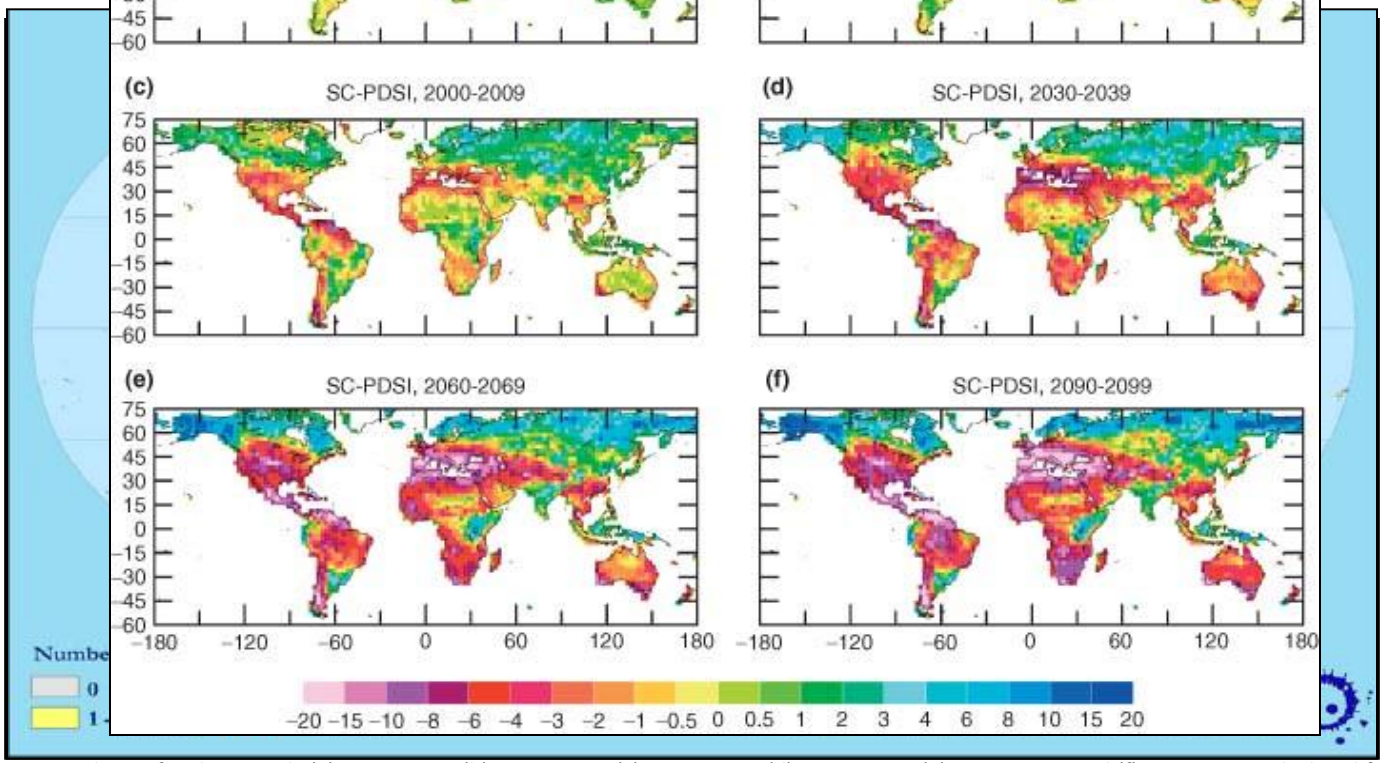
Outlines:

- Background
- Methodology
- Study area
- Data description
- Definitions
- Results
- Summary & conclusion

Background

- Drought is o and socio-economic de



Mean annual PDSI for the periods (a) 1950–1959, (b) 1975–1984, (c) 2000–2009, (d) 2030–2039, (e) 2060–2069, and (f) 2090–2099 calculated from the 22-model ensemble-mean surface air temperature and precipitation fields used in the IPCC AR4 from the 20th century and SRES A1B 21st century simulations. Red to pink areas are extremely dry (severe drought) conditions while blue colors indicate wet areas relative to the 1950–1979 mean.

Source: CRED CRUNCH newsletter, December 2006. Centre for Research on the Epidemiology of Disasters - Brussels

Source: Dai, A., 2010. Drought under global warming: a review. Wiley Interdisciplinary Reviews: Climate Change, n/a.

Methodology

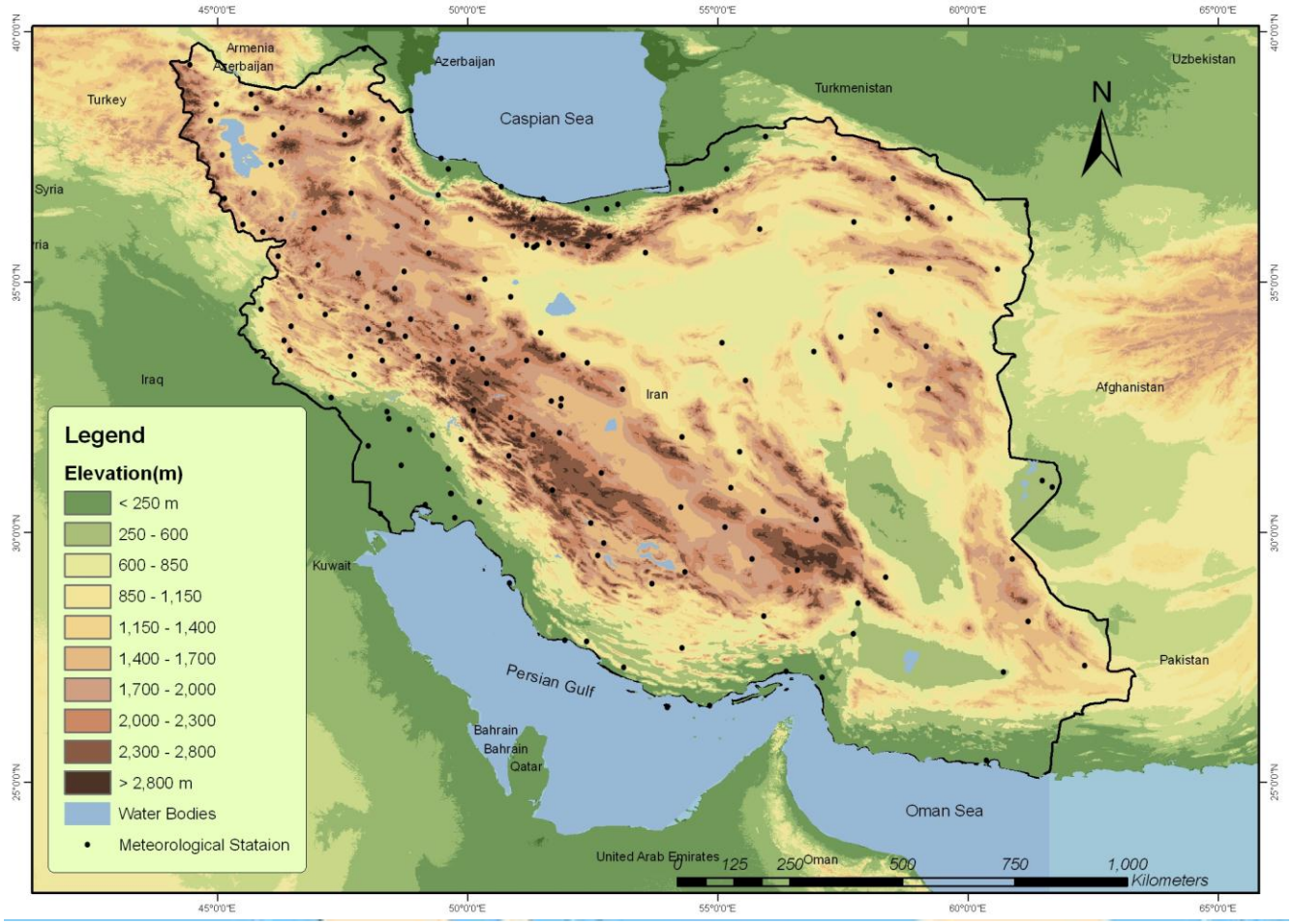
- The main goal of this research is the evaluation of optical remote sensing based indices in detection and measuring of agricultural drought in Iran.

- To reach this goal In this section, the performance of four remote sensing drought indices include; PDI, MPDI, EVI, VCI in detecting of occurrence and intensity of drought phenomena base on temporal and spatial extension evaluated.
- In this mention the relationship of these indices with four crop water parameters include; CL, CR , ET0, ETc, I were computed according to FAO's suggestions for winter wheat crop for growing period and crop coefficients in different agro-climatic zones of Iran during Feb 2000 to Dec. 2005.

- With the best performing RS indices, it should be possible to develop a large scale, high resolution drought monitoring system for Iran or similar semi-arid regions.

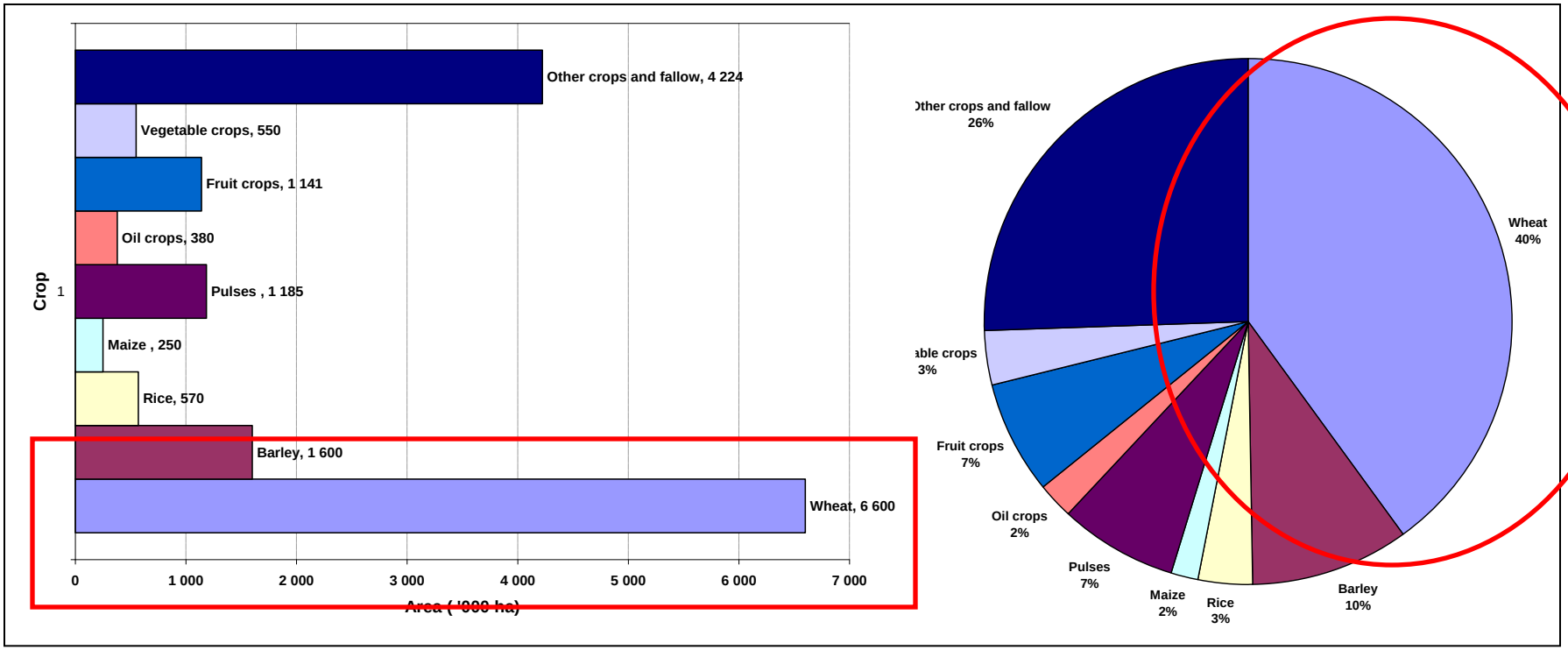
Case study area

- With an area of 1,648,000 square kilometers, Iran ranks sixteenth in size among the countries of the world.



Topographic map of Iran.

Case study area



Areas of the major crops in Iran
(Source: FAO, 2005)

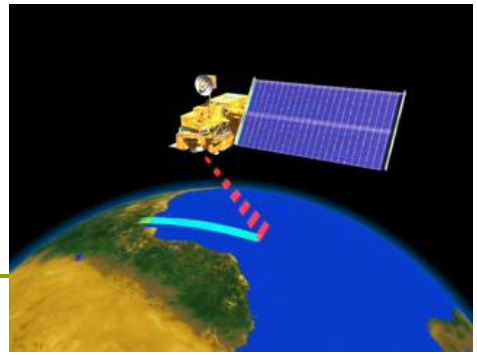
Case study area

Summarized Table of Natural Disasters in Iran from 1900 to 2008

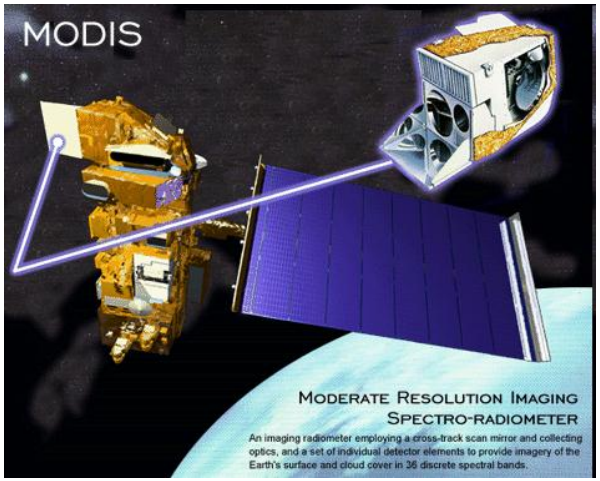
Disaster		Killed	Total Affected	Damage US$(000's)
Drought	Drought	-	37625000	3,300,000
Earthquake	Earthquake	147100	2579024	10,518,628
Epidemic	Diarrhoeal/Enteric	372	2500	-
Extreme Temperature	Heat wave	158	-	-
Flood	Unspecified	1281	1374034	6,002,028
	Flash Flood	60	4453	28,000
	Flood	6404	2272567	1,622,500
Slides	Avalanche	73	44	-
	Landslide	43	100	-
Wild Fires	Scrub	-	-	-
Wind Storm	Cyclone	12	160009	-
	Storm	217	11700	15,240
	Winter	91	8085	13,300

Source: OFDA/CRED International Disaster Database

Data description



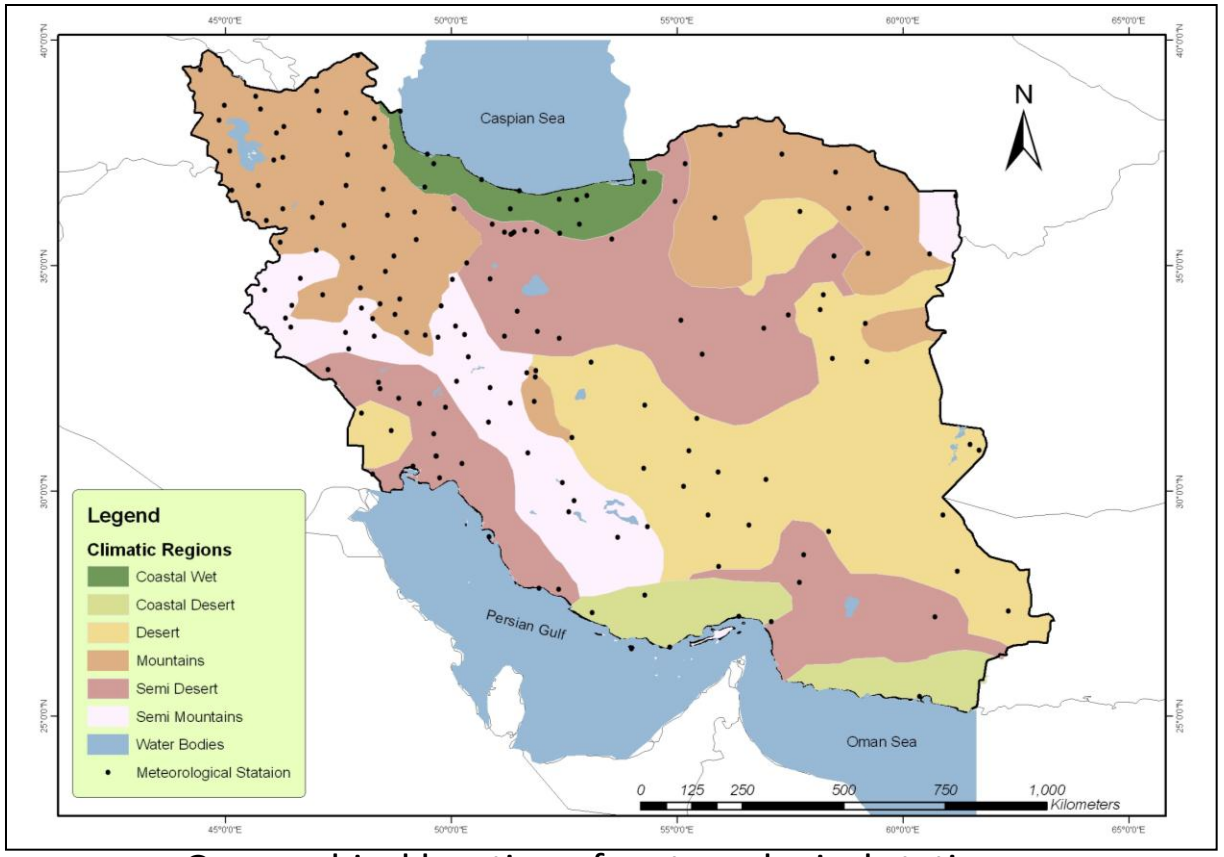
- **Remote sensing data**
- Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites.
- MOD13A3- MODIS Terra Vegetation Indices Monthly L3 Global 1 km SIN Grid V005- has been applied.
- Pre-processing of satellite data: All of the images were converted to Tagged Image File Format (TIFF) which is applicable for all remote sensing and GIS software by using the MODIS Reprojection Tool (MRT).



http://modis-sr.ltdri.org

Data description

- **Meteorological data**
- All of meteorological data including monthly average temperature and monthly total precipitation recorded in 180 synoptic meteorological stations located in variety climatological regions in Iran from the construction of stations up to December 2005 gathered and analyzed



Geographical location of meteorological stations.

Definitions

- Drought indices assimilate thousands of bits of data on rainfall, snowpack, stream flow, and other water supply indicators into a comprehensible big picture.

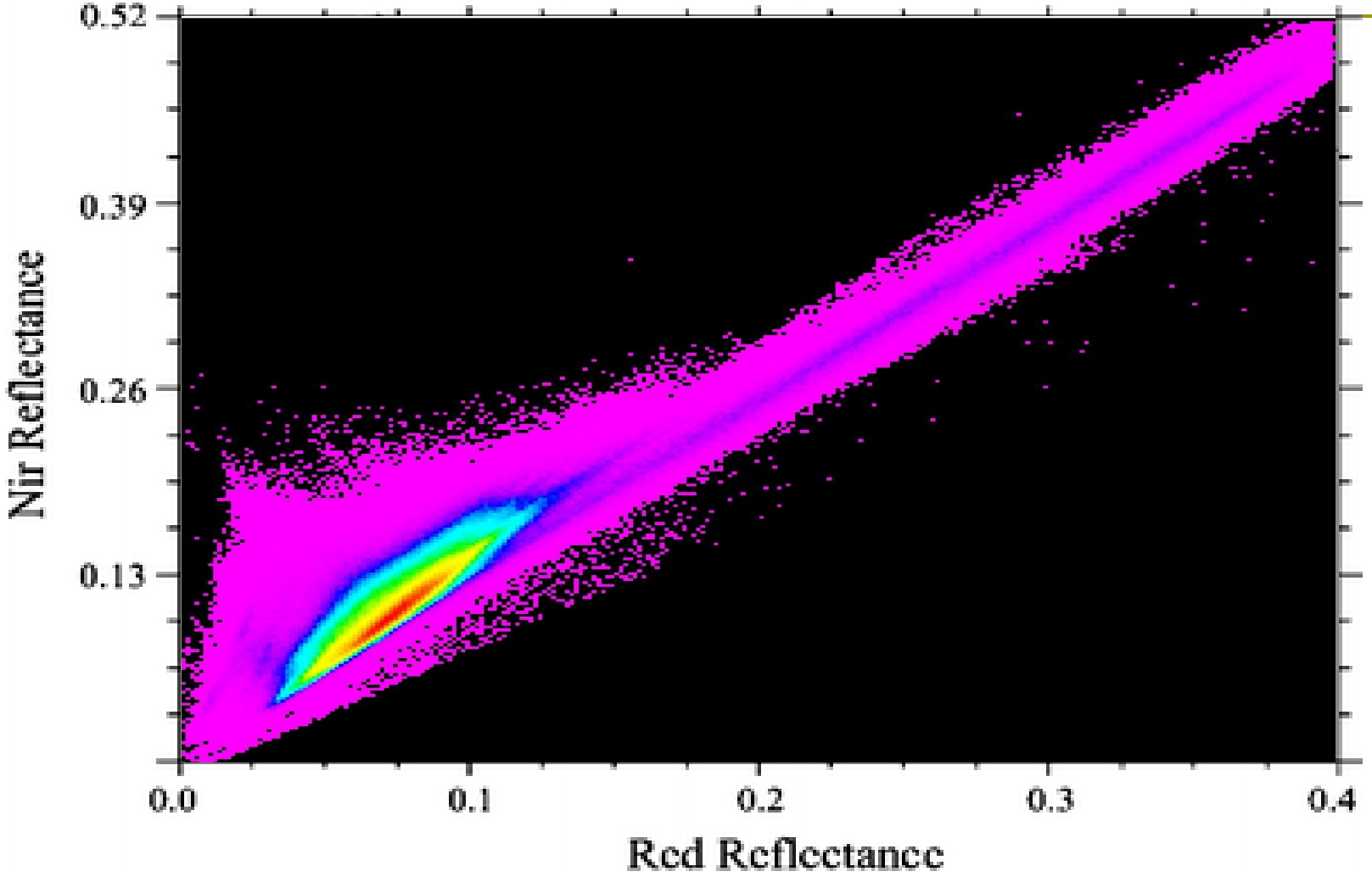
Remote sensing based drought indices:

- Perpendicular Drought Index (PDI)
- Modified PDI (MPDI)
- Enhanced Vegetation Index (EVI)
- Vegetation Condition Index (VC I)

Water balance indices (agrometeorological drought indices):

- Climatic Water Balance Model (CL)
- Crop Water Balance Model (CR)
- Required Irrigation Water (I)

Definitions



A demonstrated typical triangle shape on NIR–Red spectral space from MODIS data.
(Source: Ghulam et al. 2007)

Definitions

- **Remote sensing based drought indices:**

- **Perpendicular Drought Index (PDI)**

$$PDI = \frac{1}{\sqrt{M^2 + 1}} \left(R_{\mathrm{Re}\,d} + M R_{NIR} \right)$$

Definitions

- **Remote sensing based drought indices:**
- **Modified Perpendicular Drought Index (MPDI)**

$$MPDI = \frac{R_{Red} + MR_{NIR} - f_v\left(R_{v,Red} + MR_{v,NIR}\right)}{\left(1 - f_v\right)\sqrt{M^2 + 1}}$$

$$f_v = 1 - \left(\frac{NDVI_{\max} - NDVI}{NDVI_{\max} - NDVI_{\min}}\right)^{0.6175}$$

Definitions

- **Remote sensing based drought indices:**

- **Enhanced vegetation index (EVI)**

$$EVI = G \cdot \frac{R_{NIR} - R_{\mathrm{Re}\,d}}{R_{NIR} - C_1 R_{\mathrm{Re}\,d} - C_2 R_{Blue} + L}$$

R_{Red} , R_{NIR} and R_{Blue} are the reflectance of Red, NIR, Blue bands

C_1 and C_2 are atmosphere resistance Red and Blue correction coefficients respectively

L is canopy background brightness correction factor

G is Gain factor.

Definitions

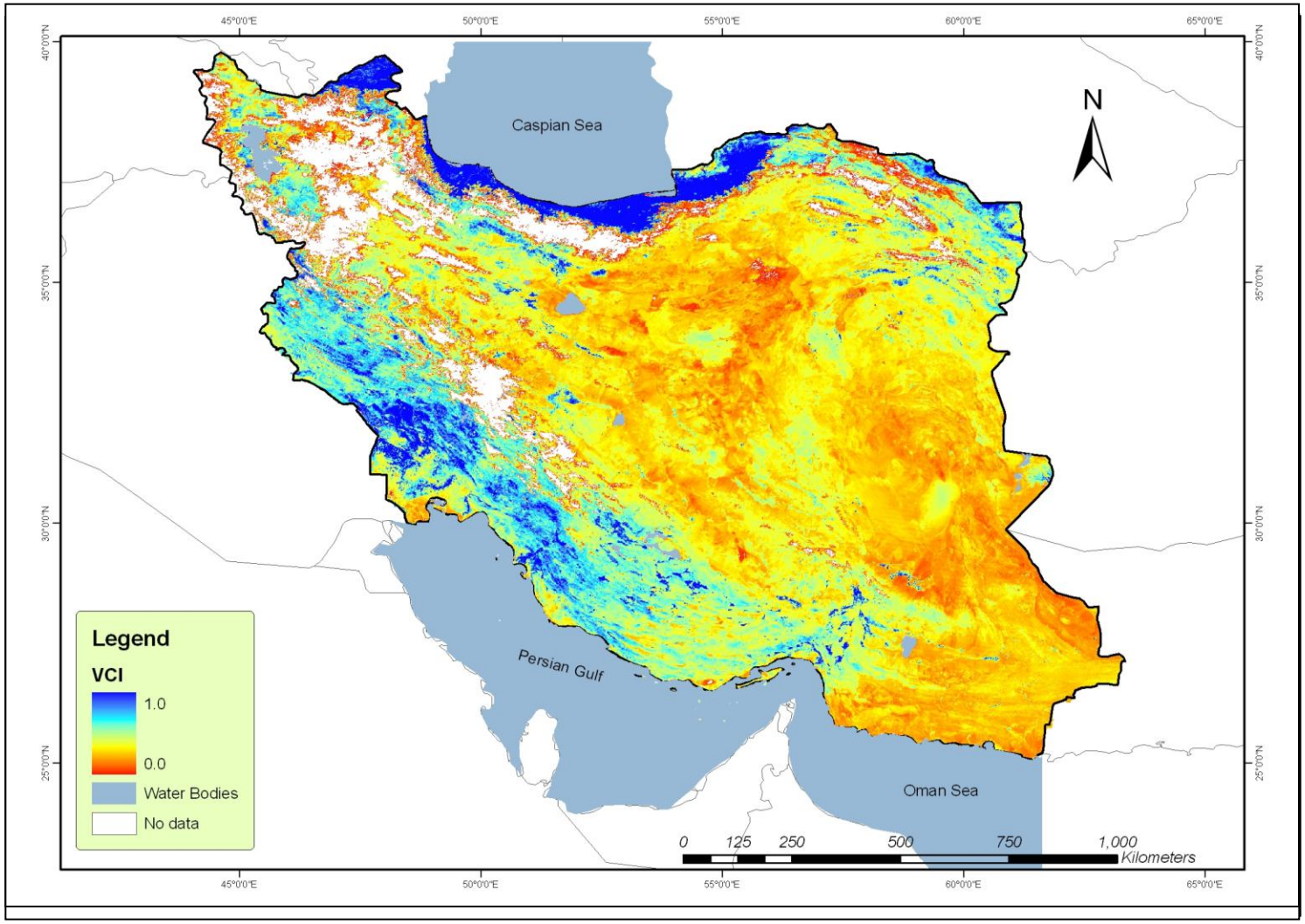
- **Remote sensing based drought indices:**

- **Vegetation condition index (VCI)**

  This index was first suggested by Kogan (1995 and 1997). It shows, effectively, how close the current month's NDVI is to the minimum NDVI calculated from the long-term record of remote sensing images.

$$VCI_i = \left(\frac{NDVI_i - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right) \times 100$$

Definitions



Some samples of calculated RS drought indices derived from MODIS data in Feb. 2000 over Iran.

Definitions

- **Agrometeorological drought indices:**
- **Climatic water balance model (CL)**

$$CL_i = P_i - ET_{0,i}$$

$$ET_0 = \frac{0.408\Delta(R_n - G) + r\,\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + r(1 + 0.34U_2)}$$

ET_0 is the reference level of crop evapotranspiration (mm day^{-1}),
R_n represents the net radiation at the crop surface (MJ m^{-2} day^{-1}),
G denotes the density of soil heat flux (MJ m^{-2} day^{-1}),
r is the psychrometric constant (kPa °C^{-1}),
T is the mean air temperature at 2 m height (°C),
U_2 represents the wind speed at 2 m height (ms^{-1}),
e_s is the saturation vapour pressure (kPa),
e_a denotes the actual vapour pressure (kPa),
$e_s - e_a$ represents the saturation vapour pressure deficit (kPa),
Δ denotes the slope of vapour pressure curve (kPa °C^{-1}).

Definitions

- **Agrometeorological drought indices:**

- **Crop water balance model (CR)**

The crop water balance accounts for the difference between precipitation and water requirements of crops during crop growth periods. From studies by Zhao (1996) and Li et al. (2004)

$$CR_i = P_i - ET_{c,i}$$

$$ET_c = K_c \times ET_0$$

Definitions

- **Agrometeorological drought indices:**
- **Required Irrigation Water (I)**

$$I_i = \mathrm{Re}_i - ET_{c,i}$$

I_i is the required irrigation water in month i (mm),
R_{ei} represents the effective precipitation during month i (mm) that calculated according to USDA.
ET_c is the monthly crop evapotranspiration (mm),

(Source: FAO Irrigation and Drainage Papers 25, 1978).

Results

Spatial analysis of relationship between remote sensing drought indices and crop water parameters

Significant correlations between drought indices and crop-related water balance indicators in the different agro-climatic zones of Iran (from highest to lowest; numbers refer to the agro-climatic zones)

	PDI	MPDI	VCI	EVI
	High>>Low	High>>Low	High>>Low	High>>Low
ET_0	5>4>1>2>6>3>9>7>8>10*	5>1>2>4>6>9>7>8>3	3>10>1>2>5>8	2>1>3>10>4>7>8
ET_c	5>4>1>2>8>6>9>3>7	5>1>4>2>6>9>8>7>3*	3>10>5>1>2>8	2>3>10>4>7*>8*
I	5>4>1>2>8>6>9>3>7	5>1>4>6>2>9>8>7>3	3>10>5>2>1>8	3>2>1>10>4*>7*>8*
CL	5>4>1>2>6>7>3>9>8>10*	5>1>4>6>2>7>9>8>3	3>10>1>5>8>2	3>1>10>2>7>4>8*>5*
CR	5>4>1>2>7>8>6>3>9	5>1>4>6>2>7>9>8>3	3>10>5>1>8>2*	3>1>10>2>7>4>8*

*: Correlation in this zone is significant at the 0.05 level (2-tailed); others are significant at the 0.01 level (2-tailed)

Results

Spatial analysis of relationship between remote sensing drought indices and crop water parameters

- There are different relationships between RS indices and crop water balance indices, depending on location and the relevant agro-climatic zone.
- In the regions where the vegetation coverage varies from dense to average, the MPDI performed best for drought detection.
- In the regions which has poor vegetation coverage or bare soil, the PDI showed the best relative performance.
- The VCI and EVI in all zones are less correlated with the applied water balance indicators compared to PDI and MPDI, except at the sites northwest and northeast of Iran.
- At the test sites covered with complex and heterogeneous vegetation types, neither the MPDI nor the PDI perform satisfactorily.

Results

Temporal analysis of relationship between remote sensing drought indices and crop water parameters

Significant correlations between drought indices and crop-related water balance indicators in the different agro-climatic zones of Iran (from highest to lowest; numbers refer to months, starting with January=1).

	PDI	MPDI	VCI	EVI
	High>>Low	High>>Low	High>>Low	High>>Low
ET_0	4>12>5>2>11>10>6>3>7>8>1	2>4>5	7>6>10>8>11>5>4>12>3>1*	6>7>8>10>5>4>11*
ET_c	4>12>5>2>11>10>6>3>7>8>1	2>4>5	7>6>10>8>11>5>4>12>3>2*	6>7>8>10>5>4>11*
I	4>5>11>6>8>10>7>12>3>2>1*	1>4>2>5*>12*	7>6>10>8>11>5>4>12>3>1>2	6>7>10>5>8>4>11*>3*
CL	4>5>12>11>2>6>10>3>8>7>1	4>2*>5*>1*	7>6>8>5>10>11>4>12>3>1>2	6>7>8>5>4>10*
CR	4>5>6>11>7>8>10>12>3>2>1	4>5*>1*	6>7>5>8>4>11>10>3>1>12>2*	6>7>5>4>8*

*: Correlation in this month is significant at the 0.05 level (2-tailed); others are significant at the 0.01 level (2-tailed)

Results

Spatial analysis of relationship between remote sensing drought indices and crop water parameters

- In several winter wheat growing periods, there is a strong relationship between the PDI and MPDI and the applied crop water balance parameters.
- The MPDI shows the best results in April during the heading and flowering stages of winter wheat.
- The PDI shows the best results during January, February and April during the jointing stage of winter wheat with less vegetation coverage.
- Both the PDI and MPDI in combination show the best performance during the full winter wheat growing season where this crop is very sensitive to drought.
- The VCI and EVI performed better than the perpendicular indices in June and July. These months represent the final growing stage of winter wheat when the use of drought monitoring or water management is less beneficial.

Summary & conclusion

- Because of different agro-climatic conditions throughout Iran and considering winter wheat as a major agricultural crop, the MPDI and PDI can be used as simply structured and cost-efficient drought indices that are derived from MODIS satellite images.

- This finding also has significant potential in other developing countries with similar climatic conditions.

- To further improve and develop these results e.g. increasing the accuracy of the achieved results and reduction of the level of uncertainties, the additional use of field observations, including more ground based soil moisture measurements, the consideration of other important crops and increasing the temporal resolution of remote sensing indices (weekly or daily images) is recommended.

Thank you for attention!