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A Composite Approach to Assessing Similarity in the Risk Level of Agricultural Drought: An Example of the Tensift and Moulouya Watershed in Morocco

Ismaguil Hanadé Houmma, Sébastien Gadal, Loubna El Mansouri, Rachid Hadria, and Paul Gérard Gbetkom

Abstract

In this chapter, a per-pixel trend analysis approach and the temporal variance of drought risk were used to compare the seasonal dynamics of the multivariate risk level of agricultural drought in two hydrological systems (Tensift and Moulouya watersheds in Morocco). The multivariate risk level is calculated from the time series of the enhanced composite model for agricultural drought monitoring constructed from anomalies in precipitation, evapotranspiration, soil moisture, NDVI and land surface temperature (LST). These five factors of agricultural drought are obtained from multi-sensor remote sensing data (MODIS, CHIRPS) for the period 2004 to 2022. In both watersheds, the results show a significant upward trend in the level of extreme and moderate risk and a very contrasting seasonal variance. At the same time, over the past two decades, risk levels (normal and low) have shown a marked downward trend. The multivariate frequency of generalized extreme risk is identical in both hydrological systems. Over the data period, the seasonal occurrence of multivariate risk is 6/19 (extreme risk),

7/19 (moderate risk) and 6/19 (low to normal risk). The recent spatio-temporal dynamics of the level of extreme risk have significant negative correlations (−0.6 at Tensift and −0.62 at Moulouya) with cereal yield anomalies. Multivariate risk is positively correlated with the SPI index at the seven-month scale of the growing season. The maximum correlation is 0.86 with a p-value of 0.0000 at Tensift and 0.74 with a p-value of 0.0004 at Moulouya. Depending on the year, the multivariate extreme risk can vary from 0 to 100% in terms of exposed areas in both the Tensift and the Moulouya watersheds. It is generalized over all the spatial extents of these watersheds for the years 2022, 2020, and 2016 and non-existent for the years 2004, 2006, 2009, 2010, 2013, and 2015.

Keywords

Drought risk • Index • Multivariate mapping • Remote sensing • Watershed

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1 Introduction

In traditional approaches, weather station data are used in drought risk assessments based on hydroclimatic indices such as the Standardized Precipitation Index (SPI), the Palmer Drought Severity Index (PDSI). However, in most underdeveloped countries, weather station networks do not reflect local variability related to topography or latitude, and therefore, the spatial diversity of agricultural and climatic landscapes are poorly considered (Nam et al., 2018). To address this limitation, several studies (Enenkel et al., 2016; Hanadé et al., 2022; Nam et al., 2018) agree on the importance of multivariate mapping based on the integration of multiple climate and biophysical variables. Multivariate drought risk mapping is an essential component of prospective drought modelling in highly changeable

69 environments. By aggregating the historical variance of
70 drought co-variables into a single indicator, multivariate
71 risk-level mapping is useful for assessing the magnitude of a
72 drought during its development. In semiarid regions due to
73 high local climate variability, it is commonly observed that
74 even when precipitation is around normal, the extreme
75 variability of other stress factors most often leads to more
76 severely stressed conditions than expected. This situation is
77 frequently observed in many Mediterranean watersheds that
78 have been affected by intense and severe drought episodes,
79 because of very intense heat waves. As a direct consequence,
80 the question of water resources rationalization in the case of
81 prolonged severe droughts arises. Here, reliable indicators
82 are necessary to establish the diagnosis and provide early
83 warning indications of drought onset. In this respect, mul-
84 ti-variate risk mapping is a support to decision making
85 because a zonal classification of multivariate risk level
86 allows for the development of emergency measures to pri-
87 ority areas. Thus, this study proposes a comparative
88 approach of multivariate mapping of the level of risk of
89 agricultural drought in two watersheds in the Mediterranean
90 climate of Morocco.

91 2 Study Area

92
93 A comparative analysis of the multivariate risk of drought
94 concerns the Tensift watershed with an area of 20,450 km²
95 in west-central Morocco and the Moulouya watershed with
96 an area of 55,500 km² of eastern Morocco (Fig. 1). Both
97 areas are characterized by arid and semiarid conditions of a
98 Mediterranean climate. They are particularly vulnerable to
99 the increased frequency of extreme events that often occur
100 simultaneously and significantly impact the agricultural
101 sector.

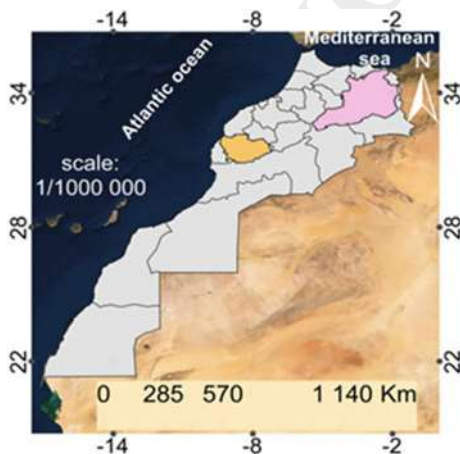


Fig. 1 Location of the study area

Moulouya is characterized by an annual rainfall varying
between 230 and 380 mm and temperatures 5 °C to 31 °C,
strong winds reaching a maximum speed of 50 m/s and its
main wadi takes its source in the High Atlas at 2000 m
altitude. It has a major socio-economic importance, espe-
cially for irrigated crops as it hosts the third largest citrus
region of Morocco on an area of 21,200 ha in 2018. Tensift
is one of the most important watersheds due to its extent, the
heterogeneity of its relief and its strong mobilization of
water resources. It extends from 4 to 4141 m altitude and its
climate is subject to influence of the Atlantic Ocean. Annual
precipitation varies between 300 and 700 mm in the
mountainous upstream part and the temperatures are very
high in summer (37.7 °C maximum average) and low in
winter (4.9 °C minimum average). More than 60% of its
land use is used for cereal crops. It is characterized by poor
vegetation which varies according to the altitude and the
nature of the land and the irrigated area of Haouz Haouz
Center.

3 Data and Methods

The remote sensing data used are the 10-day NDVI, the
8-day LST product of MODIS MOD11A2, the monthly
evapotranspiration anomaly of the MODIS MOD16A pro-
duct, the cumulative precipitation over 10 days of the
CHIRPS with their spatial resolutions of 250 m, 1000 m,
500 m and 5 km respectively. These data series covering the
period 2003–2021 were resampled at a spatial resolution of
250 m. Soil moisture was estimated by considering the
difference between the LST day and night values. Each of
the variables was transformed into a biophysical indicator
through normalization based on the maximum and minimum
values of each pixel over the study period. In addition to
these remote sensing data, performance anomaly data and
data from six weather stations were used as auxiliary data for
statistical validation of the approach. Rainfall data from
stations were acquired at <https://www.infoclimat.fr/climatologie/>
and yield anomalies data were based on a World Bank
database of major cereal crops (barley, durum, and soft wheat).

After data processing, the improved composite model for
drought monitoring (CDMIa_RF) developed by Houmma
et al. (2022) was used to evaluate the dynamics of drought
conditions in the two watersheds (Eq. 1). After assessment
of the state of the historical dynamics of drought given by
CDMIa_RF, to assess the multivariate drought risk level,
the approach of Enenkel et al. (2016) was used to assess the
drought risk level using the composite index (ECDI) in
Ethiopia. Thus, the drought risk alert level based on the
CDMIa_RF was calculated as shown in Eq. 2. Multivariate
risk was classified into four intensity levels for comparative

mapping between the two watersheds and statistical analyses. After this step, an R code was used to assess the magnitude of the trend per pixel over the last two decades (2004–2022). The pixels of significant trends were classified as follows: from (−2.5 to −1.8) very significant trends; (−1.8 to 1.6) significant trends and (−1.6 to −1.4) slightly significant trends.

$$\text{CDMIa}_{\text{RF}} = 0.36 \times \text{PCI} + 0.16 \times \text{TCI} + 0.12 \times \text{VCI} + 0.17 \times \text{ETCI} + 0.2 \times \text{ISMA} \quad (1)$$

$$\text{MRL} = \frac{\text{Seasonal values of the CDMIa}_{\text{RF}} \text{ for the year } (i) - \text{Average values of the series}}{\text{Standard deviation values}} \quad (2)$$

The standardized precipitation index (SPI) at the seven-month scale of the agricultural season (October to April) was used to validate the reliability of the developed approach. Precipitation data (2003 to 2021) from the three stations per watershed were used to calculate the SPI (Eq. 3). The stations of Marrackech, Safi and Essaouria were considered for the Tensift watershed and for the Moulouya watershed the stations of Taza, Oujda and Nador were used.

$$\text{SPI} = \frac{P(i) - P_m}{\sigma P} \quad (3)$$

where p : Total precipitation of a period (mm); P_m : Historical mean precipitation of the period (mm) and σP : Historical standard deviation of precipitation of the period (mm).

4 Results

4.1 Spatio-Temporal Analysis of Multivariate Risk Similarities

The comparative mapping of five levels of multivariate risk of agricultural drought (Fig. 2) shows high accordance in the spatio-temporal evolution of drought risk in the two watersheds. This accordance is observed in its temporal occurrence, the intensity of the multivariate risk level, and its spatial magnitude. The level of extreme to moderate risk is dominant at the expense of normal conditions (zero risk). Over the period 2004 to 2022, the exceptional and generalized normal conditions of 2009 remained atypical.

Fig. 2 Comparative mapping of the level of multivariate risk from 2004 to 2022

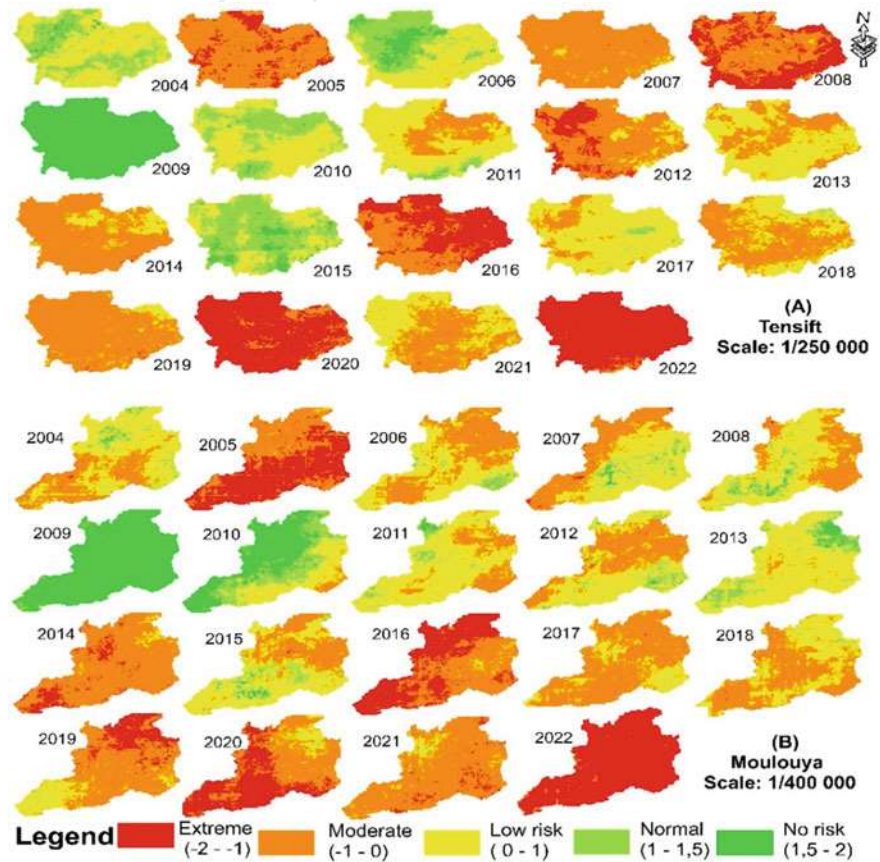
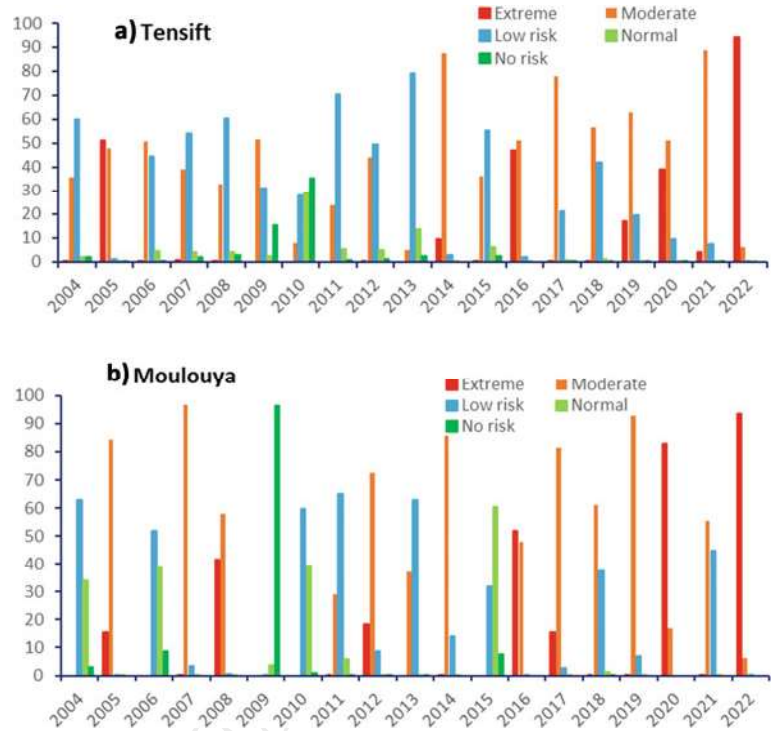


Fig. 3 Proportion in percentage of the distribution of the chronological occurrence of five multivariate risk level classes from 2004 to 2022, **a** Tensift and **b** Moulouya



4.2 Comparative Histograms of the Level of Multivariate Risk

Figure 3 shows the proportional variation of five classes of multivariate risk of the agricultural season at the watershed scale of Tensift and Moulouya. The multivariate risk of drought reflects very high interannual variability, but it has great similarity in terms of occurrence in the two watersheds. High annual differences in extreme risk are observed in both Tensift and Moulouya. The level of risk can vary from 0 to 100%. It was zero for the exceptionally wet year (2009) and generalized at 94% in Tensift and 93.6% in Moulouya for the hot and dry year of 2022 which is distinguished by the highest multivariate risk. The seasonal occurrence of multivariate risk is 6/19 (extreme risk), 7/19 (moderate risk) and 6/19 (low to normal risk). However, the proportional occurrence of low and moderate risk is very dominant at 12 out of 19 years. Overall, the proportion of the level of extreme risk is increasing sharply and the occurrence of normal conditions translates into a clear decrease over the last decade of the series.

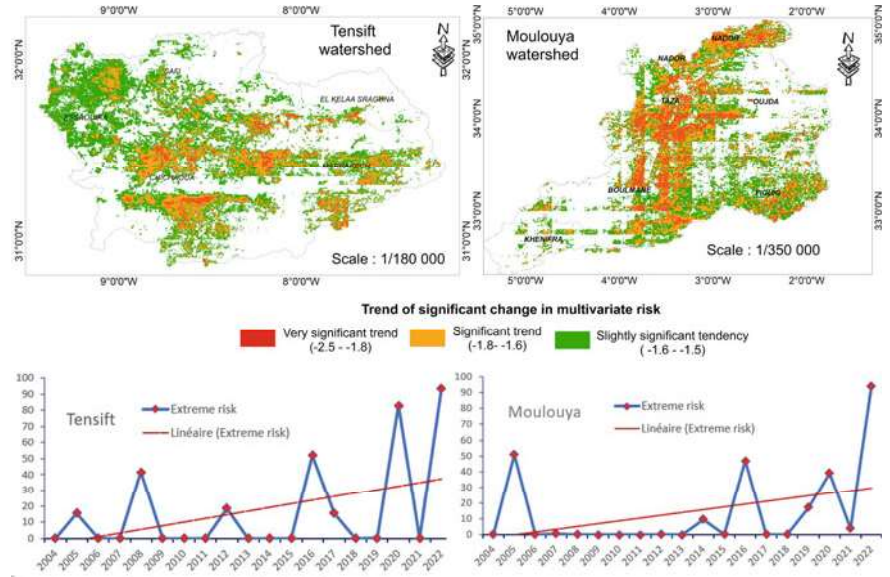
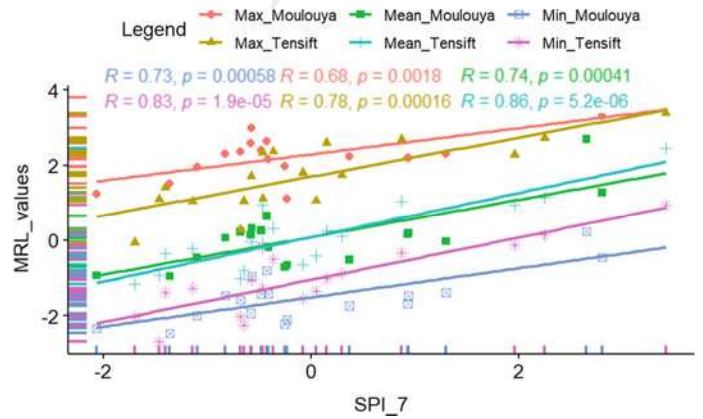
4.3 Comparative Trend Analysis of Risk Level

Analysis of chronological trends per pixel (Fig. 4) reveals a highly significant magnitude of changes in the level of multivariate risk in both watersheds. In Tensift and Moulouya, the intensity of the change in multivariate risk is

mainly driven by seasonal vegetation cover. In a large part of the watersheds, the trend of change in multivariate risk is not significant. But the most significant trend is mainly observed in rainfed areas such as the province of Taza. The temporal trend in the proportion of pixels of extreme risk illustrates the magnitude of the change.

4.4 Validation of Multivariate Modeling of Drought Risk Level

The multivariate risk of drought derived from five variables was statically evaluated using the standardized precipitation index recommended by the World Meteorological Organization as a reference index. The results in Fig. 5 show positive and very high correlations between the Min, Max and Mean values of multivariate risk and the SPI at the seven-month scale of the agricultural season. These correlations range from 0.78 to 0.86 in the Tensif watershed and slightly less in the Moulouya watershed from 0.68 to 0.74. However, the p-value test suggests that the statistical relationship between SPI and multivariate risk level is statically significant (0.0017 to 0.0000) in both watersheds. Similarly, when considering cereal yield anomalies on a national scale as a reference variable, recent spatio-temporal dynamics of the level of extreme risk show significant negative correlations (-0.60 in Tensift and -0.62 in Moulouya) with cereal yield anomalies. These correlations may be higher by considering only the agricultural yield data at the scale of the

Fig. 4 Temporal variability of extreme risk level and trend magnitude per pixel**Fig. 5** Statistical relationship between SPI (October to April) and multivariate drought risk level

242 two watersheds, as this would reduce the imprecision that
 243 may affect the yield data as a carrier of the impact of climate
 244 stress.

245 5 Discussion and Conclusions

247 In this chapter, agricultural drought risk was assessed by
 248 adopting a multifactorial approach based on open-source
 249 remote sensing data. Given the multifactorial dimension of
 250 drought, the approach would be more suitable for spatialized
 251 drought risk assessment than using hydroclimatic indices
 252 based on in situ measurements. Unlike approaches based on
 253 in situ measurements, it allows a spatially continuous
 254 assessment of agricultural drought risk at different intensity
 255 levels. The drought risk warning level is provided in five
 256 multivariate risk levels and was statistically assessed by the
 257 SPI index for the growing season. In both watersheds, it was
 258 found to be strongly correlated with the SPI index with a
 259 maximum correlation of 0.86 on the Tensift scale and a very

significant p-value ($0.0000 < 0.05$). Spatio-temporal analy-
 260 sis of the similarities of the multivariate risk established
 261 reveals a very large interannual variability in the level of risk
 262 of agricultural drought but a high accordance is highlighted
 263 between the two watersheds. Three categories of years can
 264 be distinguished according to the spatial magnitude of the
 265 level of risk: years when extreme multivariate risk is gen-
 266 eralized, intermediate years of moderate risk, and years
 267 when extreme risk was almost zero. In terms of occurrence,
 268 we can also distinguish an alternation of years of extreme
 269 peaks as well as a succession of years of normal conditions.
 270 The differences between years are such that the level of
 271 multivariate risk can increase from 0 to 94% from one year
 272 to the next. In the Tensift area, the year 2009, which was
 273 distinguished by the lowest level of risk, the flow of rivers
 274 was about four times higher compared to 2008. Similarly, in
 275 2015, which was characterized by a low risk, the annual
 276 rainfall total (256 mm) was three times greater than the
 277 rainfall of 2016 (73 mm) which clearly has a higher risk
 278 level than in 2008. The difference in terms of river flow was
 279



also 10 times larger (11.04 m³/s) in 2015 compared to 1.25 m³/s in 2016). Based on frequency analysis of the level of risk, the study shows that there is two times more risk of having a dry year than a wet year in both watersheds. This corroborates with the results of several other studies based on the analysis of climate data series that have highlighted a growing trend of increasingly dry conditions and a downward trend in wet conditions (Fniguire et al., 2017; Hadri et al., 2021). In both hydrological systems, the chronological evolution of extreme risk is characterized by an increasing trend. Occurrence of generalized multivariate risk is 9/19 or on average every other year. At the same time, the chronological proportion of normal to moderate risk levels shows a significant decrease. Based on these findings, one should therefore expect an increase in multivariate risk of agricultural drought in coming years. Thus, given the results of the study, the integration of multivariate agricultural drought risk into drought impact prediction modeling is an avenue to explore in future research. Nevertheless, in this analysis, lagged effects of variables were not considered. Recent studies such as Khatun et al. (2022) have shown that the delayed impacts of rainfall and temperature on vegetation condition are about four months and 5.2 to 3 months respectively. Future studies on multivariate agricultural drought risk assessment may explore this avenue.

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