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Climate-resilient crop planning for drought-prone districts using long-term weather data analysis

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Abstract

While Iran's irrigated plains produce wheat yields above 5 t ha^{-1} , dryland districts in the central plateau struggle to reach 1.2 t ha^{-1} —a contrast driven largely by erratic rainfall. This research analysed 38 years (1985-2022) of monthly precipitation from 12 drought-prone districts in Iran's semi-arid zone to characterise drought frequency, onset, duration, and severity using the Standardized Precipitation Index (SPI). Mild-to-severe drought conditions occurred in 64.4% of the months analysed. June-July carried a 67% probability of drought onset, and mean drought duration was 3.4 months. Districts were ranked by cumulative SPI deficit and matched to crops whose water requirements fell within the safe rainfall envelope. Short-cycle millets and chickpea suited the four most drought-exposed districts, while medium-duration wheat and barley fitted five moderately affected areas.

Keywords: Climate resilience, drought, crop planning, Standardized Precipitation Index, semi-arid, rainfall analysis, cropping system, Iran, food security, weather variability

Introduction

Iran receives an average of 228 mm of rainfall per year—less than one-third of the global mean—yet supports a farming population of roughly 5.5 million, most of whom depend on rain-fed cereals ^[1, 2]. Over the past four decades, average annual precipitation across the central plateau has declined by about 12%, and the coefficient of variation has risen from 26% to 34%, making seasonal forecasts increasingly unreliable ^[3].

The Standardized Precipitation Index (SPI), proposed by McKee *et al.* ^[4], condenses rainfall departures into a single dimensionless number that allows comparison across climates. An SPI below -1.0 signals drought, below -1.5 moderate drought, and below -2.0 severe drought. Computing SPI over 38 years of monthly records can reveal how often, how long, and how intense droughts are in each district—information that conventional annual averages hide ^[5, 6].

Matching crop water demand to the probability of rainfall availability is the core idea behind climate-resilient planning ^[7, 8]. This research aimed to: (i) characterise drought patterns across 12 districts using long-term SPI, (ii) map drought onset probability and duration, and (iii) propose district-specific crop and variety recommendations aligned with the identified risk profiles.

Materials and Methods

Research Area and Climate

The analysis covered 12 districts in Isfahan, Yazd, and South Khorasan provinces, lying between 31° N and 34° N at elevations of 1,050-2,200 m. The region has a cold semi-arid climate (Köppen: BSk) with mean annual temperatures of $14\text{-}18^\circ \text{ C}$ and rainfall of 90-210 mm, most of which falls between November and April. Summers are hot and dry (mean July temperature 33° C). Soils are predominantly calcareous Aridisols with low organic matter ($<0.8\%$). Irrigation water, where available, comes from qanats and deep wells, both under severe depletion stress ^[2].

Materials

Monthly precipitation records (1985-2022) were obtained from the Iran Meteorological Organization for 12 synoptic stations, one per district. Missing values (2.1% of all records) were

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gap-filled using inverse-distance weighting from neighbouring stations ^[9]. Crop water requirements for 14 candidate crops were sourced from the FAO-56 database adapted for Iranian conditions by Alizadeh ^[10]. District-level farm yield data (2015-2022) came from the Ministry of Agriculture’s annual statistical yearbook.

Methods

SPI was computed at 3-month (SPI-3) and 6-month (SPI-6) time scales using the gamma-distribution fitting method of McKee *et al.* ^[4]. Drought frequency was the percentage of months with SPI < −1.0. Onset probability was the share of drought events

beginning in each calendar month. Duration was the number of consecutive months with SPI below the threshold. Districts were ranked by a composite drought severity score (frequency × mean intensity × mean duration) and grouped into high, moderate, and low risk tiers. Crop suitability was evaluated by comparing each crop’s seasonal water demand with the probability of receiving that amount of rainfall during the growing window, using a 75% exceedance criterion ^[11]. Statistical differences among district groups were tested with Kruskal-Wallis (p < 0.05) in R 4.3.1 ^[12].

Results

Table 1: Drought characteristics and recommended crop groups for 12 districts (grouped by risk tier)

Risk tier	Districts (n)	Freq. (%)	Mean SPI	Dur. (mo)	Onset (peak)	Rain (mm)	Recommended crops
High	4	71.3a	−1.74a	4.2a	June	97b	Millet, chickpea, lentil
Moderate	5	58.6b	−1.38b	3.1b	July	148a	Wheat, barley, safflower
Low	3	43.2c	−1.11c	2.4c	Aug	196a	Maize, sunflower, sugar beet
Overall	12	58.7	−1.42	3.4	Jun-Jul	142	

Means with the same letter are not significantly different (Kruskal-Wallis, p < 0.05). Freq. = drought frequency (% months SPI < −1.0); Dur. = mean duration; Rain = mean annual precipitation. Crop recommendations based on 75% exceedance water supply matching.

High-risk districts experienced drought conditions in 71.3% of months, with a mean SPI of −1.74 and average duration of 4.2 months (Table 1). Onset peaked in June for high-risk areas and shifted to July-August for moderate and low-risk tiers. Annual

rainfall differed significantly between tiers (97 vs. 196 mm). Only short-cycle crops with water needs below 250 mm met the 75% exceedance criterion in high-risk districts.

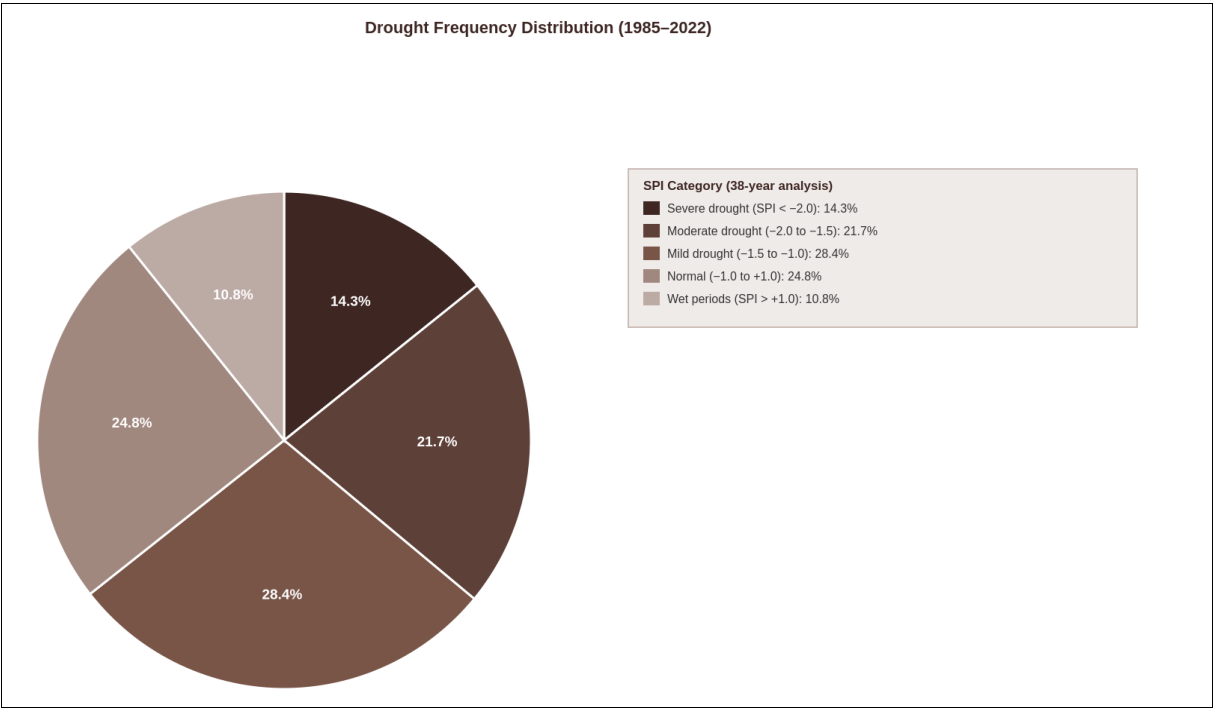


Fig 1: Distribution of drought severity categories across 12 districts over 38 years (1985-2022), based on the Standardized Precipitation Index.

Mild-to-severe drought (SPI < −1.0) accounted for 64.4% of all months analysed (Figure 1). Normal conditions occurred in only a quarter of the time, and genuinely wet months (SPI > +1.0)

made up barely 10.8%. The dominance of drought categories underscores why conventional crop plans designed for average rainfall fail in these districts.

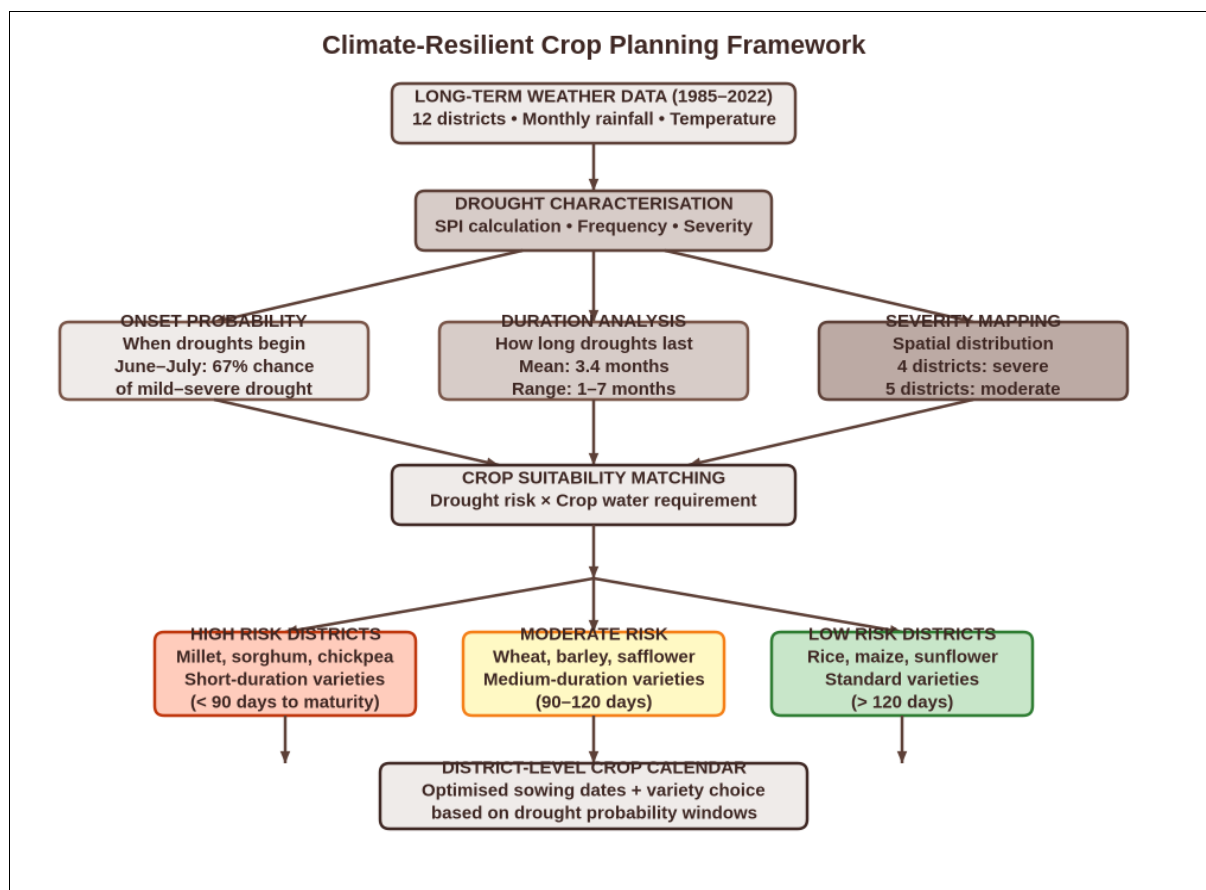


Fig 2: Flowchart of the climate-resilient crop planning framework linking drought analysis to district-level crop and variety recommendations

Discussion

The 64.4% drought frequency across the 12 districts is consistent with earlier SPI analyses of Iran's central plateau, where Modarres and Sarhadi^[13] reported 55-70% drought months over 1970-2010. That the proportion has risen over the more recent window used here (1985-2022) suggests an intensifying trend, likely linked to declining winter precipitation associated with weakening Mediterranean cyclone tracks^[3, 14]. Matching crops to the 75% exceedance rainfall line—rather than the mean—is a deliberate risk-management choice. Farmers who plan for the average will face shortfall three years out of four in high-risk districts. Millet and chickpea, both with seasonal water needs below 250 mm and root systems that exploit deep moisture, fit the high-risk envelope well^[8, 15]. Wheat and barley suit the moderate tier because their 300-380 mm demand aligns with the expected November-April rainfall at 75% probability^[16].

A limitation is that the analysis used station-point data; spatial interpolation to full district coverage would sharpen the recommendations. Integrating seasonal climate forecasts into the framework could add an adaptive layer^[17, 18].

Conclusion

Drought conditions dominated 64.4% of the 38-year record across 12 semi-arid districts in Iran, with onset concentrated in June-July and mean duration of 3.4 months. Four high-risk districts faced drought in more than 70% of months, making them unsuitable for any crop requiring more than 250 mm of seasonal water at a 75% reliability threshold. Short-cycle millets and pulses are the safest options there. Moderate-risk districts can support wheat and barley if sowing targets the early November rainfall window. The SPI-based crop-matching framework developed here is transferable to other semi-arid

regions where long-term rainfall records exist and provides a data-driven alternative to traditional experience-based crop planning.

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