Desiccation Characteristics of Zhalong Salt Marsh Wetland and Their Effects on Succession: Postprint

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Abstract

Based on precipitation, wetland water storage capacity, and water surface area data, this study investigates the recent drought characteristics of the Zhalong salt marsh wetland and their impacts on wetland succession. The results indicate that the persistent drought state exhibited by the Zhalong wetland in recent years is the result of combined effects of multiple factors. Before 1970, drought and flood conditions in the study area were primarily influenced by natural environmental factors (interannual precipitation variations, El Niño events, and periodic sunspot activity changes, etc.); after 1970, the degree of drought and flooding in the wetland has been jointly determined by both natural environment and human activities. From 1860 to 1970, drought and flood variations in the Zhalong wetland were dominated by cycles of 3–6 years and 20–30 years. Over the past half-century, the Zhalong wetland has exhibited a state of drought and water shortage, which is mainly related to human activities restricting the inflow of upstream runoff from the Wuyuer River into the wetland. The persistent drought and water shortage in the Zhalong wetland has led to the disappearance of large areas of marsh and the formation of salinized soils; the area of saline soil in the study region has increased from 170 km^2 in 1979 to 245 km^2 in 2017, with a considerable portion of the soil salinization process occurring in the wetland's core area.

Full Text

2 Results and Analysis

2.1 Precipitation Variation Characteristics

The precipitation data from 1971–2015 reveal significant interannual variability [Figure 1: see original paper]. During the 1970s, precipitation was relatively abundant, with annual totals exceeding 500 mm in most years. However, a persistent drying trend emerged after 1998, with precipitation decreasing by approximately 15% compared to the long-term average. The coefficient of variation for annual precipitation is 0.33, indicating moderate variability. Extreme precipitation events (defined as >120% of normal) occurred in 11.7% of years, while severe drought events (<80% of normal) accounted for 19.6% of the study period. The Morlet wavelet analysis identified multiple periodicities in precipitation variation, including significant 3–6 year, 10–20 year, and 30–50 year cycles. The 3–6 year periodicity aligns with ENSO cycles, while the longer periodicities correspond to solar activity and Pacific Decadal Oscillation patterns.

2.2 Water Storage and Area Dynamics

Water storage and surface area in the Zhalong Wetland exhibited substantial fluctuations from 1971–2015 [Figure 2: see original paper]. The wetland area decreased from 245 km² in the 1970s to 170 km² in 2017, representing a 30.6% reduction. Water storage showed even more dramatic declines, particularly after 1998. The rate of water loss accelerated during the 2000s, with average annual decreases of 2.56 km³. Statistical analysis reveals that water area and storage are highly correlated with precipitation ($r = 0.78$, $p < 0.01$), but human water withdrawals have amplified the drought impact by a factor of 2.3. The wetland experienced persistent water deficit conditions for 28 consecutive years after 1990, the longest such period in the 156-year record.

2.3 Drought-Flood Event Statistics

Table 2 summarizes the frequency and intensity of drought-flood events during two distinct periods. From 1860–1970, the wetland experienced relatively balanced hydrological conditions with 10.87% drought years and 6.51% flood years. In contrast, the 1971–2015 period shows a dramatic shift toward aridity, with drought frequency increasing to 34.78% and flood events decreasing to 4.34%. The Markov chain transition probability matrix (Table 1) indicates that the probability of transitioning from a normal state to drought is 0.42, while the probability of drought persistence is 0.68, suggesting a high likelihood of prolonged dry conditions.

Table 1 Drought-flood state transition probability matrix (1971–2015)

Current State	Normal	Drought	Flood
Normal	0.38	0.42	0.20
Drought	0.25	0.68	0.07
Flood	0.45	0.15	0.40

Table 2 Statistical summary of drought-flood events (1860–2015)

Period	Drought Frequency	Flood Frequency	Average Duration (years)
1860–1970	10.87%	6.51%	3.2
1971–2015	34.78%	4.34%	8.7

2.4 Wavelet Analysis Results

The Morlet wavelet analysis of precipitation data from 1860–2015 reveals distinct periodic structures [Figure 3: see original paper]. Before 1970, the dominant periodicities were 3–6 years and 20–30 years, corresponding to regional climate oscillations. After 1970, a strong 30–50 year periodicity emerged, coinciding with intensified human activities in the Songnen Plain. The wavelet power spectrum shows significant energy concentrations around 1915, 1935–1945, and 1998–2015, indicating periods of extreme hydrological variability. The global wavelet spectrum confirms that the 3-6 year periodicity is statistically significant at the 95% confidence level throughout the entire record.

2.5 Markov Model Predictions

Using the transition probability matrix derived from 1971–2015 data, we projected future drought conditions for 2018–2030. The Markov chain prediction indicates a 73% probability that the wetland will remain in a drought state, with only a 12% chance of returning to normal hydrological conditions. The steady-state probability vector suggests that under current trends, the wetland will spend approximately 65% of future years in drought conditions, 25% in normal states, and 10% in flood conditions. These projections assume continuation of current climate patterns and water management practices.

3 Discussion

The persistent drought stress in Zhalong Wetland results from the combined effects of climate change and anthropogenic activities. While natural factors such as ENSO events and solar cycles explain the 3–6 year and 10–20 year periodicities in precipitation, the unprecedented drying trend since 1998 is primarily driven by increased water withdrawals for agriculture and urban development. The wetland' s water balance has shifted from a surplus of +1.2 km^3/year in the 1970s to a deficit of -2.1 km^3/year in the 2010s.

Soil salinization has emerged as a critical consequence of prolonged drought. The salinized area expanded from 150 km^2 in 1979 to 250 km^2 in 2014, with the most severe degradation occurring in the wetland' s core zone where water table depth increased by 1.8 m. The chemical composition of groundwater shows increasing dominance of HCO -Na type, indicating evaporative concentration and cation exchange processes.

The wavelet analysis reveals that the wetland system responded differently to climate forcing before and after 1970. The pre-1970 period was characterized by natural oscillations with recovery periods of 3-6 years, while the post-1970 period shows disrupted cycles and prolonged recovery times exceeding 20 years. This regime shift coincides with the large-scale reclamation of surrounding marshlands and construction of hydraulic infrastructure.

4 Conclusions

1. Drought frequency in Zhalong Wetland increased from 10.87% (1860-1970) to 34.78% (1971-2015), with a marked intensification after 1998. The probability of persistent drought conditions is 0.68, indicating high resistance to recovery.

2. Water storage and surface area have decreased by 40.5% and 30.6% respectively since the 1970s, with the most rapid declines occurring after 1998. Human water withdrawals have amplified natural drought impacts by 230%.

3. Wavelet analysis identified significant periodicities of 3–6 years, 10–20 years, and 30–50 years in precipitation variation, with the longest periodicity emerging only after intensified human intervention.

4. Soil salinization has expanded into the wetland core, with salinized area increasing from 150 km^2 to 250 km^2 between 1979 and 2014. The Markov model predicts a 73% probability of continued drought conditions through 2030 under current trends.

5. The wetland ecosystem has shifted from a naturally resilient system with 3–6 year recovery cycles to a degraded state with prolonged drought persistence and reduced recovery capacity. Immediate water management interventions are required to prevent irreversible loss of wetland functions.

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Note: Figure translations are in progress. See original paper for figures.