Temporal and spatial distribution characteristics of drought and flood considering the influence of underlying surface in Hainan Island, tropical areas of China

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Abstract
Most studies of temporal and spatial distribution characteristics for droughts and floods analysis were conducted only from the perspective of a single factor (precipitation), while ignoring the impact of the underlying surface on the formation of droughts and floods. Based on the daily precipitation data of 88 meteorological stations in Hainan Island from 1970 to 2019, 30 m resolution DEM data and land use dataset, etc., the precipitation Z index was used to evaluate the level of drought and flood in Hainan Island. The analysis results were revised by underlying surface data to evaluate the spatiotemporal characteristics of the drought and flood areas. The drought- and flood-prone areas in Hainan Island were divided. The results show that the overall drought areas show an obvious downward trend, while the flood areas present an increasing trend. The drought-prone areas throughout the year are more concentrated in the northeast of Hainan Island, while the flood-prone areas are mainly distributed in the eastern coastal areas. The drought- and flood-prone areas before and after the revision by the underlying surface were compared. It can be seen that the overall trend is relatively similar and obvious before and after the revision. The drought- and flood-prone areas before revision are 7.97 and 2.91 times larger than that after revision, respectively. Finally, combining climate and underlying surface factors, suggestions for drought and flood prevention are put forward.

Keywords Drought and flood · Spatial and temporal distribution · Underlying surface correction · Hainan Island

1 Introduction
Climate change is a global environmental problem which will lead to a series of phenomena, such as accelerating surface evaporation rate, increasing atmospheric water retention capacity, accelerating water circulation rate and decreasing system stability (Held and Soden 2006; Huntington 2006). Two exemplary climate extremes that are closely associated with the expected changes in hydrological cycle are drought and pluvial flood (Shao and Kam 2020). The frequent occurrence of extreme weather phenomena, such as drought, flood, and the alternation of drought and flood, has caused negative effects on natural ecosystem and social system from many aspects (Li and Ye 2015). The phenomenon of climate disasters has attracted increasing attention due to the frequency and severity of its occurrence.

Mathematical statistical methods were often used to study the temporal and spatial distribution characteristics of drought and flood. Scholars combined some commonly used methods, such as Mann–Kendall mutation test, trend analysis, correlation analysis, moving average, cumulative anomaly, ensemble empirical mode decomposition (EEMD), inverse distance weighted interpolation (IDW), empirical orthogonal function (EOF), and other methods to further analyze the temporal and spatial characteristics of regional drought and flood (Wang et al. 2022; Qi et al. 2020). The Mann–Kendall mutation test, as a non-parametric test...
method recommended by the World Meteorological Organization, has the advantages of a wider detection range, fewer human factors, a higher degree of quantification, and can intuitively show the trend of change and has been widely used. For example, an existing study uses a variety of methods including Mann–Kendall inspections to the drought and flood disaster of China’s important commodity grain production base Huang-Huai-Hai Plain (Ling et al. 2021).

There are several commonly used indexes to analyze drought and flood characteristics. In the study of comparing and evaluating the temporal and spatial dynamics of drought in 6 climatic regions of Iran, scholars have conducted a comparative analysis of 6 drought indexes including the precipitation Z index. The research suggests that the Z index can still be used as one of the better drought prediction indicators in Iran considering the dry season, duration, and climate conditions (Shahabfar and Eitzinger 2013). In order to evaluate the sensitivity of drought index based on precipitation to different record length, 7 drought indexes were discussed, including the China Z index (CZI), the modified China Z index (MCZI), percent of normal precipitation index (PNPI), deciles index (DI), the Z-score index (ZSI), effective drought index (EDI), and standardized precipitation Index (SPI). The research found that the China Z index (the precipitation Z index) has good time stability and high sensitivity to different record lengths (Mahmoudi et al. 2019). With the strengthening of the severity of flood disasters, research on flood disasters has gradually increased. Based on the method of artificial bee colony algorithm and back-propagation neural network, the precipitation was forecasted in Wujiang River basin which not only reveals the interannual variation trend and abnormal situation of precipitation in the basin, but also uses Z index to identify the years of flood and drought. The results provided a new idea for climate prediction, flood prevention and drought relief (Wang et al. 2020a).

The superiority of the Z index was demonstrated by comparing the responses of different drought and flood indices to drought and flood in many tropical regions of the world. For instance, Shahabfar and Eitzinger (2013) pointed out in their research on drought in Iran using multiple indices that the Z index is not limited by the existing input data, and can better predict drought in different seasons, different times and different climatic conditions. Also, the Z index can be a good substitute when the SPI is limited by the availability of long-term climate data and low sensitivity to agrometeorological drought conditions (Shahabfar and Eitzinger 2013). For studies in Mexico and parts of Mauritania, there are similar studies showing similar results for the Z index and SPI, and a systematic application is recommended (Yacoub and Tayfur 2016; Campos-Aranda 2017). Compared with SPI, Z index can better monitor drought and flood disasters, which has been demonstrated by many studies. For example, Wu et al. (2001) selected four regions with different climates for drought and flood studies in China and found that the Z index provides the same measure of conditions as the SPI except under extremely dry or wet conditions. And in some cases, the Z index can be considered more suitable than the SPI for monitoring drought and flood research because it is easier to calculate. In addition, according to compare and analyze the temporal and spatial evolution characteristics of drought and flood, He et al. (2014) found that the Z index has a better indication effect than SPI in the classification of extreme drought and flood grades, such as extreme flood and extreme drought in Donjiang River Basin, South China, which is geographically close to Hainan Island. In summary, the Z index is used frequently to study drought and flood disasters because it involves parameters such as skewness coefficients and standard variables in the calculation process, which enables it to better consider the temporal and spatial distribution of rainfall. Among them, for extreme precipitation, the larger the skewness coefficient, the better the Z index analysis effect, and the more it can reflect the degree of extreme drought and flood (He et al. 2014).

Many scholars have conducted various studies on drought and flood disasters. However, most studies aimed at regional droughts and floods, and most of them evaluated regional droughts and floods from the perspective of a single factor (precipitation), while ignoring the impact of the underlying surface on the formation of drought and flood. The sensitivity of drought and flood is different based on different carriers. Among them, the most prominent carrier affected by drought and flood disaster is agricultural production (Zhang et al. 2015). It is generally believed that in the process of interaction between meteorological conditions and underlying surface factors, when the distribution of moisture on the underlying surface has direct or indirect adverse effects on human survival, production, and life, it is called a drought and flood disaster. The formation of the underlying surface is the result of the long-term action of various geological forces. For example, geological processes have led to the formation of regional landforms, thus affecting the distribution of flood and drought disasters. Shao et al. (2001) studied the spatial and temporal distribution characteristics of drought and flood in Hebei Province in China and explored the influence of underlying surface factors on the formation of drought and flood; they revised the index method and established a drought and flood assessment system suitable for the actual situation in Hebei Province. Changes in underlying surface conditions such as vegetation conditions and water conservancy projects will affect the redistribution process of pre-drought precipitation and the temporal and spatial distribution of water resources during drought, which is one of the main driving factors affecting the temporal and
spatial evolution of drought events in the basin. The underlying surface conditions have an impact on regional flood events mainly by affecting the storm runoff processes and the river flood discharge process (Xing et al. 2014). There are many analyses of drought and flood disasters, however, most studies on drought and flood have not taken account the underlying surface factors. Wang et al. (2021a, b) pointed out that the flood disasters in the Yangtze River Delta region of China are mainly affected by the characteristics of torrential rain and natural geographical features (including topography, vegetation, soil, and geology). Rainfall and underlying surface conditions are the two main factors that affect the process of flood subsidence in mountainous areas under the condition that human activities have little effect (Khaleghi et al. 2011). Moreover, different underlying surface conditions will also lead to differences in the flood process (Cheng et al. 2021).

Hainan Island is mainly affected by tropical cyclones, tropical storms, and typhoons, while there are few studies on its drought and flood disasters. Zhang et al. (2017) analyzed the drought and flood disasters in Hainan Island from 1998 to 2011 based on analytic hierarchy process and entropy method, which helps farmers and policymakers reduce the risk of red pepper from major meteorological disasters. It focuses on the assessment of the risk, sensitivity, vulnerability and prevention capability for flood, chilling and drought disaster. Hainan Island is one of the areas most affected by meteorological disasters. Natural disasters have reduced agricultural production by more than 10% in Hainan Province and have reduced the crop planting area by more than 30% (Xu et al. 2015). There are many studies on the drought and flood of disasters in tropical regions (Firoz et al. 2018; Yamamoto et al. 2021). For example, in the tropical regions of Indonesia's rivers, the extent of inundation caused by future flood events is predicted for better watershed management (Yamamoto et al. 2021). There are many kinds of flood risk assessment methods adopted to evaluate the flood risk caused by extreme flood (Kvočka et al. 2016). The underlying surface has a major impact on the occurrence and development of drought and flood disaster. Consequently, on the basis of using the traditional meteorological index to evaluate the regional drought and flood, it is necessary to correct the initial situation according to the underlying surface condition.

Therefore, this paper takes typical Hainan Island as the research area, and discusses the influence of island’s underlying surface on the distribution characteristics of drought and flood disasters. It can provide reference for the prevention and control of flood and drought disasters in other similar regions. The goals of this study were as follows: (1) to evaluate the vulnerability of drought and flood disasters, and to consider the influence of potential factors such as unique topography and land use/cover on the formation of drought and flood events; (2) to zone drought and flood areas using land use data sets and DEM data base on the precipitation Z index.

## 2 Materials and methods

### 2.1 Study area

Hainan Island is located in the northwest of the South China Sea, bordering Guangdong Province and the Qiongzhou Strait to the north. The total land area of Hainan Province is 35,400 km², of which Hainan Island is 33,900 km² (Fang et al. 2021). The geographical coordinates of Hainan Island are 18° 09′–20° 10′ N and 108° 37′–111° 03′ E (Fig. 1). Its land area accounts for 42.5% of China’s tropical area. Affected by the tropical oceanic monsoon climate (Dodson et al. 2019; Zhang et al. 2020), Hainan Island is warm and hot throughout the year, with heavy rainfall, and relatively abundant water resources. Hainan Island has different terrains, including mountains, hills, plains, terraces, and other topography (Sun et al. 2020). The dry and wet seasons are obvious in Hainan Island. Its climate zone can be divided into humid, semi-humid and semi-arid regions with an average annual rainfall of 2095.9 mm.

There is great potential for modern agriculture with tropical characteristics in Hainan Island. Changhua River, Nandu River, and Wanquan River are the three main rivers in Hainan Island. The three river basins have diverse water systems, abundant precipitation, and abundant hydropower resources (Hu et al. 2013; Tan et al. 2020). Agricultural production is the mainstay in Hainan Island. When faced with drought, tropical cyclones, flood, and other disasters, the water storage capacity of rivers is far from meeting the needs of industrial and agricultural production as well as urban life in the dry season. Meanwhile, it will also have an impact on agricultural production.

### 2.2 Source of data

The underlying surface data and land use dataset were processed to obtain 30 m resolution DEM and land use dataset of Hainan Island (Fig. 1). The precipitation data are derived from the daily precipitation data of 88 meteorological observation stations in Hainan Island from 1953 to 2019. The continuous precipitation data from 1970 to 2019 were used as the base data for the analysis. By summarizing the daily precipitation data of the study year, the precipitation data of the four seasons are obtained. The division of four seasons refers to the division of seasons by the China Meteorological Administration, namely spring from March to May, summer
from June to August, autumn from September to November, and winter from December to February.

### 2.3 Grade evaluation of regional drought and flood

The regional precipitation data of Hainan Island from 1970 to 2019 were transformed using the inverse distance weighting method (IDW) (Papari and Petkov 2009). The precipitation Z index is used to classify drought and flood grades, which is closely related to the spatial and temporal distribution of precipitation. The precipitation series for the four seasons and the whole year are normalized, assuming that the precipitation follows the Pearson-III curve. The probability density function is converted to a standard normal distribution, and the Z value is the new variable.

\[
f(x) = \frac{\beta}{\Gamma(\alpha)} \cdot (x - \alpha_0)^{\alpha-1} \cdot e^{-\beta(x-\alpha_0)} (x > \alpha_0)
\]

In Eq. (1), \(\alpha_0, \alpha, \beta\) are three parameters, and the mathematical expectations of gamma distribution is as follows.

\[
m = \frac{\alpha}{\beta} + \alpha_0
\]

In addition, the variance, the deviation coefficient, and the coefficient of variation are as follows.

\[
s^2 = \frac{\alpha}{\beta^2}
\]

\[
c_v = \frac{2}{\sqrt{\alpha}}
\]
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\[ c_v = \frac{\sqrt{a}}{a + \beta a_0} \]

Therefore, \( \alpha_0, \alpha, \beta \) in Eq. (1) can be expressed by \( m, c_v, \) and \( c_v \).

\[ a_0 = m(1 - \frac{2c_v}{c_s}) \]

\[ \alpha = \frac{4}{c_s^2} \]

\[ \beta = \frac{2}{mc_v c_s} = \frac{2}{\sigma c_s} \]

In summary, the precipitation \( x \) is normalized.

\[ x = \frac{a}{\beta} [1 - \frac{1}{9a} + z\left(\frac{1}{9a}\right)^{1/3}] + a_0 \]

Finally, the formula of the \( Z \) index can be obtained according to the derivation of the series (Ju et al. 1998). According to the size of the \( Z \) index, the dry and flood level of each grid point can be judged (Wang et al. 2020b).

\[ Z_i = \frac{6}{C_s} \left( \frac{C_s}{2} \varphi_i + 1 \right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6} \]

In the formula, \( x_i, \sigma, n, \varphi_i, \) and \( C_s \) refer to the rainfall in year \( i \), the standard variance, observable number, standard variable, and the deviation coefficient, respectively. The specific calculation formula is as follows:

\[ \sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} \]

\[ C_s = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^3}{n \sigma^3} \]

\[ \varphi_i = \frac{(x_i - \bar{x})}{\sigma} \]

\[ \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \]

### 2.4 Correction of underlying surface

In order to consider the impact of land use and topographic features on drought and flood, the study takes dryland and plain platform as the underlying surface factors affecting drought and flood disasters. Combined with the precipitation \( Z \) index, the original regional meteorological drought and flood evaluation results were revised. The division of dryland is to enable the results to provide guidance for agricultural production in Hainan Island. On the GIS platform, grids with \( Z \leq -0.842 \) and distributed in dryland (cultivated land mainly supported by precipitation to support the growth of xerophytic crops in land use classification) are divided into modified dryland (Fig. 2a). For the flooded area, it is related to the terrain of the area and is affected by the process of production and confluence, which mostly occurs in plain area (Yang et al. 2013). The flooded area is the area distributed in the common area of dryland and plain, and

![Fig. 2](image-url)
the grid \( Z \geq 0.842 \). The difference between the maximum elevation and the minimum elevation of each grid point in the study area is defined as the degree of relief (Deffontaines et al. 1994). After processing the regional DEM data in Hainan Island, the topographic elevation distribution map of the study area is obtained. The regional distribution maps of the Hainan Island plain mesa with fluctuation heights less than 30 m were extracted, as shown in Fig. 2b. The degree of relief was used to characterize the effects of terrain characteristics on drought and flood disasters. The spatial distribution result of the precipitation \( Z \) index was corrected with degree of relief data and dryland data.

2.5 Analysis of temporal and spatial distribution characteristics of drought and flood

Time series analysis method was used to study the trend of drought and flood areas in spring, summer, autumn, winter and whole year of 1970–2019. We take a time scale every 5 years to calculate the drought and flood areas and the frequency of drought and flood disasters respectively. The drought and flood disasters of the five-year repeated interval were represented by the Annual Exceedance Probability of 0.2, that is, 20% in any given year. The frequency data of drought and flood were calculated for each grid point, and the grid points with frequency \((p)\) greater than 0.2 were classified as drought- and flood-prone areas (Yang et al. 2013).

3 Results analysis

3.1 Test of spatial and temporal distribution characteristics of drought and flood based on underlying surface correction

The agricultural drought and flood disaster affected areas in Hainan Island refers to The Bulletin of Wind Flood Drought Disaster of Hainan Province published by Hainan Water Affairs Department in 2017 and The China Flood and Drought Disaster Bulletin published between 2006 and 2018. Comparing the calculation results of the drought and flood areas in Hainan Island from 1990 and 2018 (Fig. 3), the recorded typical drought and flood years are basically consistent with the calculated typical years. For example, typical drought years are 1993, 2004, and 2010, and typical flood years are 2000, 2013, and 2016. Since the recorded data refers to the areas where droughts and floods occur, the theoretical values refer to the areas prone to droughts and floods. Therefore, the recorded value is smaller than the theoretical value.

According to the book of Meteorological Disasters in China: Hainan Volume, there are more continuous drought phenomenon in winter and spring in Hainan Island. Among them, Ding’an County, Wanning City, Wenchang City, and other northeastern regions have higher drought frequency. In summer and autumn, the Hainan Island is prone to flood disasters. The results of this study are relatively consistent with those described in the records (Fig. 4), indicating that the research method is feasible.

3.2 Drought- and flood-prone areas of Hainan Island

Figure 5 shows the distribution of drought-prone areas in spring, summer, autumn, winter, and the whole year in Hainan Island. As a whole, the drought-prone areas throughout the year are distributed in the northeast of Hainan Island, about 2754.39 km². Among them, the drought-prone areas in other seasons except summer are widely distributed and concentrated, and the spring drought-prone areas are more prominent in the western part of Hainan Island. With the change of four seasons, the distribution trend of drought-prone areas gradually migrated from west to northeast.

The area of flood-prone areas is about 6325.10 km², mainly distributed in the eastern coastal areas (Fig. 6). Except for the central region, the distribution of flood-prone areas in autumn in the whole Island is relatively even. The area of the flood-prone areas in autumn is about
10,480.12 km², which is significantly larger than other months. The autumn of Hainan Island is still in the flood season (May–October), mainly due to the strong influence of tropical cyclones in autumn, resulting in increased precipitation. The probability of flood in winter is relatively small, and they are mostly concentrated in the eastern and northern regions of Hainan Island. Baisha County, Qionghzhong County, and Wuzhishan City are all located in the central part of Hainan Island, with high terrain and the least distribution of plain mesa and agricultural land. The area is rich in rainfall and has the most concentrated and best-preserved island tropical rainforest in China. Therefore, there are few drought- and flood-prone areas in the region (Figs. 5 and 6).

3.3 Temporal characteristics of drought and flood areas in Hainan Island

The spring, summer, autumn, winter seasons, and the whole year of drought areas and flood areas in Hainan Island were counted. The average drought and flood areas in Hainan Island are 1074.40 km² and 2163.58 km² in the past 50 years, respectively. On the whole, the areas of drought showed a decreasing trend, among which, the autumn drought areas fluctuate. The flood areas are larger than the drought areas, and the floods are more pronounced in autumn. Overall, the areas of flood are increasing, and in recent years, winter flood disaster has
Fig. 6  Distribution of flood-prone areas in Hainan Island

been on the rise (Fig. 7). Based on the analysis of the special climatic conditions in Hainan Island, the flood season is from May to October, while September to October is already autumn. However, the unique geographical location of Hainan Island has caused it to be affected by tropical cyclones, and the rainfall is still heavy. Even in winter, rainy weather often occurs due to the influence of winter wind and cold waves. And it lasts for a long time and is relatively cold and humid. In general, the areas of drought decreased, and the areas of flood increased. It is worth noting that the areas of flood in winter have increasing trend in recent years. Topography and the northeast monsoon are the main factors affecting the winter drought in Hainan Island (Yang et al. 2019). The western part of Hainan Island is a drought-prone area. The continuous drought in winter and spring is the seasonal characteristic of drought in Hainan Island. According to Fig. 5, the distribution of drought-prone areas along the eastern coast of Hainan Island is not significant in winter, and the distribution of drought-prone areas in the western semi-arid climate zone areas is also less. On the contrary, in Fig. 6, the distribution of flood-prone areas along the east coast is obvious in winter. Previous research has found that the intensity of drought in Hainan Island is decreasing year by year, and the range of drought tends to decrease (Yu et al. 2006). The rainfall in winter showed an obvious increasing trend (Sun et al. 2017). The topography has a significant effect on increasing the winter rainfall in Hainan Island (Yang et al. 2019). In addition, the frontal precipitation when the northern cold air transits in winter and the bottom precipitation of the denatured high pressure after the transit are important ways to improve the drought in time. As a result, the flooded areas increased and the drought areas decreased in winter, affecting the drought areas of the island, slightly easing the drought trend.

4 Discussion

The underlying surface is a complex of multiple factors, mainly referring to the land use type, topography, and geological structure of the watershed (Xing et al. 2014). Different land cover types mean different evaporation rates, and the changes in land cover are related to the increase or decrease of runoff (Delgado et al. 2010; Zheng et al. 2022; Wang et al. 2021a, b). The urbanization process can cause drastic changes in the underlying surface conditions, thereby affecting the flood characteristics of the watershed (Zhao et al. 2021). Therefore, climate and land cover changes are in response to the temporal and spatial evolution of water resources. For drought analysis, this study extracts drylands from land use data. Considering the influence of the underlying surface, the flood analysis is carried out by selecting a plain mesa that conforms to the topographical characteristics of Hainan Island. Based on the previous research on drought- and flood-prone areas, it is possible to correct the areas simulated by the system. Finally, after applying the underlying surface for correction, the drought- and flood-prone areas with good spatial–temporal distribution characteristics can be obtained (Fig. 7).
4.1 Compare areas with and without underlying surface correction

Figure 8 shows the comparisons of the drought and flood areas before and after the revision by the underlying surface. The overall trend is relatively similar and obvious before and after the revision. The areas of drought and flood before the revision in the four seasons and throughout the year is much larger than the areas after the revision. The drought and flood areas throughout the year before the revision are 21,946.86 and 18,379.92 km², respectively. Compared with the areas of the revised drought- and flood-prone areas of the underlying surface (2754.38 km² and 6325.14 km²), the difference were 7.97 times and 2.91 times, respectively.

During the comparison of the area before and after the revision, the multiples of the area contrast of drought and flood in the four seasons were about 7 and 3 times respectively. In terms of drought, the ratios of the uncorrected area to the corrected area of the underlying surface in the four seasons were 6.21, 8.72, 7.89, 7.27, and 7.97 times, respectively. For flood, in the four seasons, the area ratios before and after the underlying surface correction were 3.72, 3.26, 2.99, 2.51, and 2.91 times. The reason is that it has not been able to locate the prone areas after interpolation and correction of precipitation index. The delineated areas are far beyond its prone areas, causing errors in the results. In addition, the area that has not been corrected by the underlying surface is the area where the drought and flood distribution are divided by the drought and flood index. What we obtained after using the underlying surface to modify is the areas of drought- and flood-prone areas. In order to prove the theoretical data that is in line
with the actual situation, the agricultural areas affected by drought and flood in Hainan Island recorded in *The China Flood and Drought Disaster Bulletin* (report) was taken as a reference. Theoretically, the areas with extreme drought and flood are more prone to agricultural drought and flood. Therefore, the areas of extreme drought and flood corrected by the underlying surface were compared with the recorded data (Fig. 9). First of all, since 2008, the theoretical drought areas have been relatively close to the actual drought-prone areas and spatial distribution. In the years when the values are quite different, the change trend of the actual and theoretical value is still more consistent. Secondly, the theoretical flood zone years in different years are consistent with the actual flood zone years. Mainly in 1993, 1994, 1995, 2002, 2003, 2004, 2006, and 2015.

### 4.2 Similarities and differences between the climate pattern and the distribution pattern of drought and flood in Hainan Island

Due to the difference in dryness and humidity caused by the distribution of the ocean and land, there is a dryness and humidity zonal in which the climate changes regularly with the dryness and humidity. According to the classification of *Chinese National Geography* Web site and the book of *Hainan Island Climate*, the geographical climate of Hainan Island can be divided into five major climate zones. Northern semi-humid zones (Danzhou, Lingao, Chengmai, Ding’an, Tunchang, and Haikou), eastern humid zone (Wenchang, Qionghai, and Wanning), central mountain humid zone (Baisha, Wuzhishan, and Qiongzhou), western semi-arid (Dongfang and Changjiang), and southern semi-arid
Fig. 8 Comparison of the drought and flood areas before and after the revision by the underlying surface

Fig. 9 Comparison of the drought/flood areas after the revision by the underlying surface and the actual agricultural disaster area

semi-humid zone (Sanya, Ledong, Baoting, and Lingshui) (Gao et al. 1988). On the whole, the humid area in the east and the semi-humid area in the north are more consistent with the areas where the flood-prone areas are located, while in the northern Danzhou area, the flood and drought are not obvious. The spring drought-prone areas are obviously distributed in the western semi-arid areas. Western Hainan Island is the only distribution area of China’s savanna. And the tropical coastal desert is also distributed in the western part of Hainan Island. In other seasons and even throughout the year, drought-prone areas are only distributed in the northwest and middle of Changjiang Li Autonomous County. According to the flood-prone areas, it can be known that the flood in the west is not obvious. Comparing the distribution of drought- and flood-prone areas in the southern region, it can be seen that the prone areas are less distributed in this area and the locations are relatively close. In addition, drought- and flood-prone areas are rarely distributed in the central mountainous regions.

In summary, the difference between Hainan’s climate pattern and the distribution of prone areas were analyzed as follows: (1) the drought and flood in Danzhou are not significant because the terrain is dominated by hills, accounting for 76% of the city’s area, while plain mesa only accounts for 23.6%. (2) The annual average precipitation in Changjiang county is much lower than the island’s average precipitation, and the seasonal contradiction between water supply and demand and regional differentiation are obvious. In addition, the special topography of the island is also one of the main factors leading to the drought in the Changjiang
area. Wuzhishan and Bawangling Mountains are located in the central part of Hainan Island, which blocks the entry of water vapor from the Pacific Ocean in the southeast, and it is difficult for the warm and humid air flow from the southeast to pass through the western area on the leeward slope. The distribution of drought-prone areas in the coastal areas is obvious (Fig. 5). Therefore, the semi-arid climate in this region is consistent with the drought flood pattern. (3) Hainan Tropical Rainforest National Park is distributed in the humid area of the central mountainous region. The forest coverage in the area is high, and there are many peaks. Thus, the central region has a strong water conservation capacity, and the forest ecosystem has a good ability to distribute, intercept, and store precipitation, and the probability of drought and flood disasters is relatively small. Thus, the mountainous humid climate in this area conforms to the pattern of drought and flood.

4.3 Preventive measures against drought and flood

The sensitivity of drought and flood is different due to the influence of different carriers. The formation of flood is significantly affected by topographical factors and the hydrological and their dynamic changes. The phenomenon of flooding in plain areas is particularly obvious. The terrain of Hainan Island gradually extends from the towering zone in the middle to the surroundings in a decreasing trend. Both dryland and plain mesa areas are concentrated in the coastal areas of Hainan Island. However, due to the influence of underlying surface factors, drought and flood in the region are more likely to occur than in the central mountainous areas. Therefore, with reference to the drought and flood-prone areas (Figs. 5 and 6), the water resources of each area should be rationally allocated to increase water storage and water retention capacity to achieve a better effect of prompting agricultural production and development (Table 1).

Combining the land use type data, it can be seen that there are more cultivated land and less woodland in the Nandu River Basin and its surrounding areas prone to drought and flood. The distribution of cultivated land at the mouth of the Wanquan River is more than other areas in the basin. Forest land and soil and water conservation are closely related, and have direct and potential relationships. The water and soil loss of arable land is fast, and the response to drought and flood disasters is more obvious. According to the analysis of the annual change trend of drought and flood according to Fig. 7 and Table 2, drought and flood show the opposite change trend. The two have a better mutual relief effect in the same prone areas. Therefore, (1) for drought-prone areas in the abovementioned concentrated areas, it is necessary to appropriately return farmland to forests, strengthen water and soil conservation capabilities. Dredging the Nandu River Basin and Wanquan River Basin, and renovating and building new dams along the banks, in order to improve the flood regulation and storage capacity of the two major river basins, and achieve the effect of drought prevention and flood prevention. (2) For large cities such as Haikou, Wenchang, and Wanning where the flood-prone areas are located, urban waterlogging is more serious. Therefore, it is necessary to continuously upgrade the urban drainage system and appropriately construct urban permeable pavements as well as actively build a sponge city. It can reduce the occurrence of urban flood disasters and alleviate drought disasters at the same time.

5 Conclusion

The precipitation Z index, the Mann–Kendall trend analysis and the inverse distance weight interpolation method were selected to analyze the spatiotemporal evolution characteristics of the drought- and flood-prone areas in Hainan Island, combined with the characteristics of the underlying surface. In addition, the 5-year moving average change of the drought-flood areas and the inter-annual

| Table 1 Drought and flood levels with Z value as the standard |
| Code | Z index | Grades |
|------|---------|--------|
| 1    | Z ≥ 1.645 | Extreme flood |
| 2    | 1.037 ≤ Z < 1.645 | Severe flood |
| 3    | 0.842 ≤ Z < 1.037 | Partial flood |
| 4    | −0.842 < Z < 0.842 | Normal |
| 5    | −1.037 < Z ≤ −0.842 | Partial drought |
| 6    | −1.645 < Z ≤ −1.037 | Severe drought |
| 7    | Z ≤ −1.645 | Extreme drought |

| Table 2 Drought and flood areas and Kendall statistics of Hainan Island in four seasons and all year round |
| Season | The drought area/km | Kendall value | The flood area/km | Kendall value |
|--------|---------------------|--------------|------------------|--------------|
| Spring | 1077.99             | 0            | 2056.46          | −0.59        |
| Summer | 1075.01             | −0.58        | 2017.40          | 0.13         |
| Autumn | 1088.16             | 0.3          | 2335.12          | −0.52        |
| Winter | 1056.42             | −1.72        | 2245.36          | 1.53         |
| Throughout the year | 1074.40 | −0.42 | 2163.58 | 0.02 |
Temporal and spatial distribution characteristics of drought and flood considering the…

change and trend of the drought-flood areas were analyzed. The main conclusions obtained are as follows:

1. Over the past 50 years, the average drought and flood areas in Hainan Island were respectively 1074.40 km² and 2163.58 km², with the most serious drought and flood in autumn. The drought areas showed a downward trend, while the flood areas showed a significant growth trend throughout the year.

2. Drought- and flood-prone areas are widely distributed. With the change of four seasons, the distribution areas of drought- and flood-prone areas are as follows: the drought-prone areas shifted from west to northeast, and flood-prone areas were concentrated in the eastern coastal areas. The drought- and flood-prone areas are respectively 2754.39 km² and 6325.10 km².

3. The overall change trend of the drought- and flood-prone areas after correction of the underlying surface are consistent with the uncorrected regions, and the change trends are obvious. Regardless of whether it is a drought- or flood-prone area, the area after correction is smaller than the area before correction. The area of drought- and flood-prone areas after the correction was compared with the recorded agricultural areas affected by drought and flood disasters. The areas of extreme drought in recent years are close to the recorded value. The areas of extreme flood are relatively close in some years.

4. Considering the influence of underlying surface and other factors, the climate pattern of Hainan Island is compared with the distribution pattern of drought and flood. Overall, the drought- and flood-prone areas are relatively close to the climate pattern of Hainan Island. There is a significant feature of the underlying surface in Danzhou City, Changjiang Li Autonomous County, and the central mountainous area. Finally, on the basis of considering the underlying surface factors, suggestions on the prevention and control of drought and flood in Hainan Island are put forward.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Changqing Ye, Yi Zou, Yanhu He, Youwen Lin, Dan Li, and Lirong Zhu. Changqing Ye designed the content and ideas of the research. Yi Zou and Dan Li calculated the data and analyzed the results. Youwen Lin provided data resources. Yanhu He and Lirong Zhu revised and improved the quality of the research. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval We declare that we have complied with ethical responsibilities before submitting the manuscript.

Informed consent Human participants and animals were not involved in this study.

Consent to participate Not applicable.

Consent for publication All authors gave their consent for the publication in the journal.

Data availability The data analyzed in the current study are not publicly available due to a non-disclosure agreement.

Code availability Not applicable.

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