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 characteristics of the underlying surface on the formation of droughts and floods. Using the daily precipitation data of 88 meteorological stations in Hainan province from 1970 to 2019, the 30m resolution DEM data and land use dataset, etc, the precipitation Z index is used to evaluate the drought and flood levels in Hainan. The analysis results were revised by underlying surface data to evaluate the spatiotemporal characteristics of the drought and flood area in Hainan. The drought-prone areas and flood prone areas in Hainan Island were divided, and on this basis, the set pair analysis method was used to identify the regions with alternating drought and flood areas in Hainan. The results show that the overall arid area shows an obvious downward trend, while the flood area presents an increasing trend. The drought-prone areas throughout the year are more concentrated in the northeast of Hainan Island, while flood prone areas are mainly distributed in the eastern coastal areas. The regions where drought and flood occur alternately are small but concentrated. The drought and flood prone areas and alternate drought and flood 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 result of drought areas before revision is 7.97 times larger than that after revision. The flood prone areas before revision are 2.91 times larger than that after revision. Finally, combining climate and underlying surface factors, suggestions for drought and flood prevention are put forward.

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 increasingly 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 MK mutation test method, trend analysis method, correlation analysis method, moving average method, cumulative anomaly method, ensemble empirical mode decomposition method (EEMD), inverse distance weighted interpolation method (IDW), empirical orthogonal function method (EOF) and other methods to further analyze the temporal and spatial characteristics of regional drought and flood (Lu et al. 2018; Min et al. 2017; Wang et al. 2017). Based on precipitation data from 1960-2019, existing studies have analyzed the drought and flood disasters in the Huang-Huai-Hai plain, an important commercial grain production base in China. Methods such as Mann-Kendall test, wavelet analysis, EOF and center of gravity model were used to analyze the temporal and spatial distribution characteristic of total precipitation at different time scales in the Huang-Huai-Hai plain (Ling et al. 2021). In the study of the changes in extreme drought and flood events in Iran, the Mann-Kendall test was used to assess the changing trends of flood disasters. The standardized precipitation index was used to study regional drought disasters (Modarres et al. 2016). Therefore, the Mann-Kendall method, 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.

There are several commonly used indexes to analyze drought and flood characteristics. In the study of comparing and evaluating the time and space dynamics of drought in 6 climatic regions of Iran, scholars have conducted a comparative analysis of 6 drought indexes including the Z index. The research suggest 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 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 gradually increases. 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 flood and drought years. The results provided a new idea for climate prediction, flood prevention and drought relief (Wang et al. 2020a). In summary, the Z index is used frequently to study drought and flood disasters because the Z index involves parameters such as skewness coefficients and standard variables in the calculation process, which enables the Z index 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 characteristics 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. Therefore, geological action has led to the formation of regional landforms, thereby affecting the distribution of flood and drought disasters. Scholars have studied the spatial and temporal distribution characteristics of drought and flood in Hebei Province in China, and put forward the influence of underlying surface factors on the formation of drought and flood. It revised the index method and established a drought and flood assessment system suitable for the actual situation in Hebei Province (Shao et al. 2001). According to the survey data of rainstorm and flood disasters in 637 counties (districts) in eastern China, the distribution and change patterns of rainstorm and flood disasters in eastern China were analyzed (Shi et al. 2020). There are many analyses of drought and flood disasters in China, however, most studies on drought and flood have not taken account the underlying surface factors.

Hainan Island is mainly affected by tropical cyclones, tropical storms and typhoons, but there is little research on its drought and flood disasters. Zhang Lei et al., (2017) analyzed the drought and flood disasters in Hainan Province from 1998 to 2011 based on analytic hierarchy process and entropy method. The scholars aim to help farmers and policy makes reduce the risk of red pepper from major meteorological disasters (Zhang et al. 2017). It focuses on the assessment of the risk, sensitivity, vulnerability and prevention capability for flood, chilling and drought disaster. Hainan Province is one of the provinces which is affected by meteorological disasters. Natural disasters have reduced agricultural production by more than 10% in Hainan, and have reduced the crop planting area by more than 30% (Xu et al. 2015). The climatic characteristics of tropical regions are relatively unique, and 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 Indonesia's rivers, which are also tropical regions, the extent of inundation is predicted caused by future flood events, so as to better manage the watershed (Yamamoto et al. 2021). There are many kind of flood risk assessment method should be 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, the goals of this study were: (1) to evaluate the vulnerability of drought and flood disasters, and 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 Z index of precipitation. (3) to analysis the spatial and temporal distribution characteristics of drought and flood disasters in Hainan Island, and to put forward targeted measures to prevent drought and flood.

2 Materials And Methods

2.1 Study area

Hainan is the province in China whose entire region is tropical area. It is located on the southern edge of China, facing Guangdong with the Qiongzhou S-trait in the north. The total land area of Hainan province is 35400 km^2, of which Hainan Island is 33900 km^2. The geographical coordinates of Hainan Island are

18°09'-20°10'N and 108°37'-111°03'E (Fig. 1) (Fang et al. 2021). Affected by the tropical oceanic monsoon climate (Dodson et al. 2019; (Zhang et al. 2020), Hainan is warm and hot throughout the year, with heavy rainfall, and relatively abundant water resources. Hainan island has different terrains and is composed of mountains, hills, plains, terraces and other topography (Sun et al. 2020). The drought and flood seasons are obvious in Hainan Province, which can be divided into humid, semi-humid and semi-arid regions, with an average annual rainfall of 2095.9 mm.

There are three rivers on the island, Changhua River, Nandu River and Wanquan River. Three major rivers and multiple water systems flow through Hainan Province, rich in precipitation and hydropower reserves (Hu et al. 2013; Tan et al. 2020). The basin is dominated by agricultural production. When faced with drought, tropical cyclones, floods 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 industrial and 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 Province (Fig. 1). The precipitation data are derived from the daily precipitation data of 88 meteorological observation stations in Hainan Province from 1953-2019. The continuous precipitation data were selected from the observation data from 1970-2019 as the basic data in this study. 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 inverse distance weight method (IDW) was used to transform the precipitation data of Hainan regional meteorological station from 1970 to 2019 (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. Assuming that the precipitation series follow the Pearson III curve, the seasonal precipitation series are standardized, the probability density function is transformed into a standard normal distribution, and the new variable is the Z value. According to the size of the Z index, the drought and flood level of each grid point can be judged (Wang et al. 2020b).

$$Z_i = \frac{6}{C_s}\left(\frac{C_s}{2}\phi_i + 1\right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6}$$

1

In the formula, x_i σ, n, ϕ_i, and C_s refer to the rainfall in year i, the standard variance, observable number, standard variable, and polarization coefficient of the water sequence, respectively. The specific calculation formula is as follows:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

2

$$C_s = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^3}{n * \sigma^3}$$

3

$$\phi_i = \frac{\left(x_i - \bar{x}\right)}{\sigma}$$

4

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

5

2.4 Correction of underlying surface

The study considered the influence of the underlying cushion on regional drought and flood disasters (Yang et al. 2013b). The evaluation results of the original meteorological drought and flood based on the precipitation Z index were revised from the aspects of land use and topographic characteristics, combined with the distribution map of xerophytic crops farmland which mainly dependent on precipitation for planting (Fig. 2(a)). On the GIS platform, the grid Z≤-0.842 distributed in dry land is divided into arid zones (Yang et al. 2013b). The division of dry land is to enable the results to provide guidance for agricultural production in Hainan Province. For the flood 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. On the GIS platform, the grid Z≥0.842 and distributed in the common part of dry land and plain are divided into flood areas. The height of terrain relief refers to the difference between the maximum elevation and the minimum elevation of each grid point in the analysis area (Table 1) (Bao et al. 2004).

After processing the regional DEM data in Hainan Province, the topographic elevation distribution map of the study area is obtained. Taking the fluctuation height less than 30m as the standard, the regional distribution map of Hainan Plain and the platform can be extracted, as shown in Fig. 2(b). Using undulating height to characterize the effects of terrain characteristics on drought and flood disasters. Correcting the spatial distribution result of the precipitation Z index with undulating height data and dry land 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 area in spring, summer, autumn, winter and whole year of 1970-2019. Take a time scale every 5 years to calculate the drought and flood area 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. Calculating the frequency data of drought and flood occurrence at each grid point, take the frequency (p) greater than 0.2 as the dividing standard, and extracting the grid point with P>0.2 as drought (flood) prone areas (Yang et al. 2013b).

The set pair analysis method is used to divide the areas prone to alternate drought and flood (Zhao 1994). The classification results of the spring and summer drought and flood index Z index from 1970-2019 are divided into the following three levels. Grade I is used to express partial flood, severe flood and extreme flood. Class II is normal. Grade III indicates partial, severe and extreme drought. Using the set pair analysis formula to calculate the connection degree of the set, the formula is as follows:

$$U = \frac{S}{N} + i\frac{F}{N} + j\frac{P}{N} \quad (6)$$

Constructing a set (A, B), set A represents the spring drought and flood level set, and set B represents the summer drought and flood level set. Where U in the formula is the connectivity between set A and set B. S is the number of units, that is, the number of identical symbols in the set. F and P represent diversity and opposition, that is, the number of one level and two levels symbols, i and j refer to the diversity identification coefficient and the opposition identification coefficient, respectively. i is a differential identifier or coefficient. In the [-1, 1] interval, the value is valued in different situations, sometimes it is just as a differential mark. j is an opposite sex identifier or coefficient, which is generally -1 in the calculation, and sometimes it is only the role of the contrast tag. Because the lower the value of connection degree U_{A-B}, the more obvious the opposition is, and the greater the possibility of drought and flood alternation. Combined with frequencies of drought and flood alternating events. And the drought/flood grade standard of precipitation anomaly percentage was analyzed. Therefore, using 0.25 as the U value classification standard, extract the grid points with U<0.25 to obtain the alternate drought and flood prone areas in spring and summer (Yang et al. 2013a). The areas prone to alternating drought and flood in other seasons can also be obtained using the above method.

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 area in Hainan Province 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. Compared with the calculation results of the drought and flood area in Hainan Province from 1990 and 2018 (Fig. 3), the typical drought and flood years recorded are largely 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. However, because the recorded data refers to the area of drought and flood disaster, and the theoretical value refers to the area where drought and flood occur, 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 Province. Among them, Ding'an County, Wanning City, Wenchang City and other northeastern regions have higher drought frequency. In summer and autumn, the Changhua River Basin is prone to flood disasters. The research results of this article comparative conformity with them (Fig. 4), indicating that the research method is feasible.

3.2 Temporal Characteristics of Drought and Flood Area in Hainan

The spring, summer, autumn, winter seasons and the whole year of drought area and flood area in Hainan Province were counted. The average drought area and flood area in Hainan Province are 1074.40 km² and 2163.58 km² in the past 50 years, respectively. On the whole, the area of drought showed a decreasing trend, among which, the autumn drought area fluctuates. The flooding area is larger than the drought area, and the autumn flooding is more pronounced. Overall, the area of flood is increasing, and in recent years, winter flood disaster has been on the rise (Fig. 5). Based on the analysis of the special climatic conditions in Hainan Province, the flood season is from May to October, but September to October is autumn already. However, the unique geographical location of Hainan Province 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 area of drought decreased, and the area of flood increased. It is worth noting that the area of flood in winter has increased trend in recent years, which makes the drought disasters in Hainan Province have a slight alleviation trend.

3.3 Drought and flood prone areas of Hainan Island

Figure 6 shows the distribution of drought-prone areas in spring, summer, autumn, winter four seasons 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. It can be seen that there are fewer drought-prone areas in Baisha city, Qiongzhong city and Wuzhishan City.

The flood areas are about 6325.10 km², mainly distributed in the eastern coastal areas. Except for the central region, the distribution of flood-prone areas in autumn in the whole province is relatively even. The area of the flood-prone area in autumn is about 10480.12km^2, which is significantly larger than other months. It can be learned that autumn is the season of high flood, mainly because of the strong influence of tropical cyclones in autumn, leading to increase precipitation. The probability of flood in winter is relatively small, and they are mostly concentrated in the eastern and northern regions of Hainan Island.

3.4 Areas prone to alternate drought and flood

Figure 8 shows the distribution of drought and flood alternate prone areas between all seasons in Hainan Island. It can be found that the area of alternating drought and flood prone areas in spring with summer, summer with autumn and autumn with winter is 15.66 km², 13.12 km² and 38.78 km². Its area is relatively small, but the distribution is more concentrated, among which, summer and autumn drought and flood alternate prone areas are concentrated in Chengmai County and Tunchang County. Due to alternating seasonal drought and flood, it will be difficult to allocate water resources effectively. Moreover, it will also have a negative impact on the growth of crops. Therefore, we should strengthen the risk management of drought and flood alternate areas, and properly handle it. In Hainan Province, continuous drought often appears in winter and spring. In addition, the distribution of flood prone areas is less in winter and spring. The U value of the connection degree between winter and spring is greater than 0.25, thus there is no distribution of winter and spring drought and flood alternate prone areas.

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 types of land cover mean different evaporation rates, and changes in land cover are related to the reduction of runoff (Delgado et al. 2010). The urbanization process will cause drastic changes in the underlying surface conditions, such as land use and land cover types, which will affect the flood characteristic of the basin (Tian et al. 2018). Therefore, climate and land cover changes are in response to the temporal and spatial evolution of water resources. For drought analysis, this paper selects dry land from land use data. Considering the influence of the underlying surface, the flood analysis is carried out by selecting a plain platform that conforms to the topographical characteristics of Hainan Island. Based on the above-mentioned 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 spatio-temporal distribution characteristics can be obtained.

4.1 The area with and without underlying surface correction was compared

Calculating the area of drought and flood and alternating drought-flood areas that have not been corrected by the underlying surface. Fig. 9 can be obtained by comparing the area before and after the revision. The overall trend is relatively similar and obvious before and after the revision. The area of drought and flood areas that have not been corrected by underlying surface in the four seasons and throughout the year is much larger than the area of drought and flood prone areas after the underlying surface has been corrected. The areas of drought and flood throughout the year that have not been corrected for the underlying surface are 21946.86 km^2 and 18379.92 km^2, respectively. Compared with the areas of the revised drought and flood prone area of the underlying surface (2754.38 km^2 and 6325.14 km^2), the difference is about 8 times and 3 times respectively. During the comparison of the area before and after the correction, the multiples of the area contrast of drought and flood in the four seasons were 7 times and 3 times respectively. For drought, in four seasons, the ratio of the area that is not carried out and the underlying surface correction is 6.21, 8.72, 7.89, 7.27, 7.97 times respectively. For flood, in the four seasons, the area ratio before and after the underlying surface correction is 3.72, 3.26, 2.99, 2.51, 2.91 times. The reason is that it has not been able to locate the prone area after interpolation and correction of precipitation index. The delineated area is far beyond its prone area, 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 get after using the underlying surface to modify is the area of drought and flood prone areas. In order to prove the theoretical data is in line with the actual situation. Taking the agricultural area affected by drought and flood in Hainan Province recorded in the *China Flood and Drought Disaster Bulletin* (report) as a reference. Theoretically, the areas with extreme drought and extreme flood are more prone to agricultural drought and flood. Therefore, the area of extreme drought and extreme flood corrected by the underlying surface was compared with the recorded data (Fig. 10). First of all, since 2008, the theoretical drought-prone areas have been relatively close to the actual area of drought areas. In the years when the values are quite different, the change trend of the actual and theoretical value is 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 Hainan's climate pattern and the distribution pattern of drought and flood

Due to the difference in dry humidity caused by the distribution of sea and land, the dry humidity zonality in which the climate changes regularly with dry humidity occurs. At the same time, the climate is affected by factors such as terrain undulation, slope direction and underlying surface conditions. According to the classification of *Chinese National Geography* website, the geographical climate of Hainan Island can be divided into five major climate zones. Northern semi-humid zones, eastern coastal humid zone, central mountain humid zone, western semi-arid and southern semi-arid semi-humid zone. On the whole, the humid area in the east and the semi-humid area in the north are more consistent with the area where the flood prone areas are located. But 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. 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-prone areas 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-prone areas and flood-prone areas are rarely distribution in the central mountainous regions.

In summary, the difference between Hainan's climate pattern and the distribution of prone areas was 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 plains and terraces only account for 23.6%. (2) There are two major river basins which Changhua River and Zhubi River in the Changjiang Li Autonomous County. However, its annual average precipitation is much lower than the province's average precipitation, and the seasonal contradiction between water supply and demand and regional differentiation are obvious. The distribution of drought occasional area in the coastal area in the region is obvious. 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.

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 dynamic changes caused by them. The phenomenon of flooding caused by flood 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 dry land and plain platform 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 area. Therefore, with reference to the drought and flood prone areas divided in Fig. 6 and Fig. 7, 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.

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 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. 5 and Table 2, it can be seen that drought and flood show the opposite change trend. The two have a better mutual relief effect in the same prone area. (1) Therefore, for drought-prone areas in the above-mentioned 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. So as 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 City, Wenchang city and Wanning city 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.

Table 2
Drought and flood area and Kendall statistics of Hainan Island in four seasons and all year round

Season	The drought area /km²	Kendall value	The flood area /km²	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

5. Conclusion

(1) Over the past 50 years, the average drought and flood areas in Hainan Province were 1074.40 km² and 2163.58 km² respectively, with the most serious drought and flood in autumn. The drought area showed a downward trend throughout the year, while the flood area 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. Seasonal drought-flood alternating prone areas are less distributed, and there is no winter-spring drought-flood alternating prone area. The areas of alternating drought and flood prone areas in spring and summer, summer and autumn, and

autumn and winter are 15.66 km^2, 13.12 km^2 and 38.78 km^2, respectively. They are concentrated in the north-central region of Hainan Province.

(3) The overall trend of changes in the areas prone to drought and flood and alternate drought and flood prone areas after correction of the underlying surface is more consistent with the uncorrected regions, and the change trends are more obvious. Regardless of whether it is a prone area or an alternate prone area, the area after correction is smaller than the area before correction. Compare the area of drought and flood prone areas after the underlying surface is revised with the recorded agricultural area affected by drought and flood disasters. The areas of extreme drought in recent year are closely to the recorded value. The area of extreme flood was 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 area are relatively close to Hainan Island Climate Pattern. In Danzhou City, Changjiang Li Autonomous Region and Central Mountainous Areas showed a significant feature of the underlying surface. 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.

Declarations

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Data Availability: The datasets generated during and analysed during the current study are not publicly available due to sign relevant confidentiality agreements but are available from the corresponding author on reasonable request.

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Tables

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 area and Kendall statistics of Hainan Island in four seasons and all year round

Season	The drought area /km²	Kendall value	The flood area /km²	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

Figures

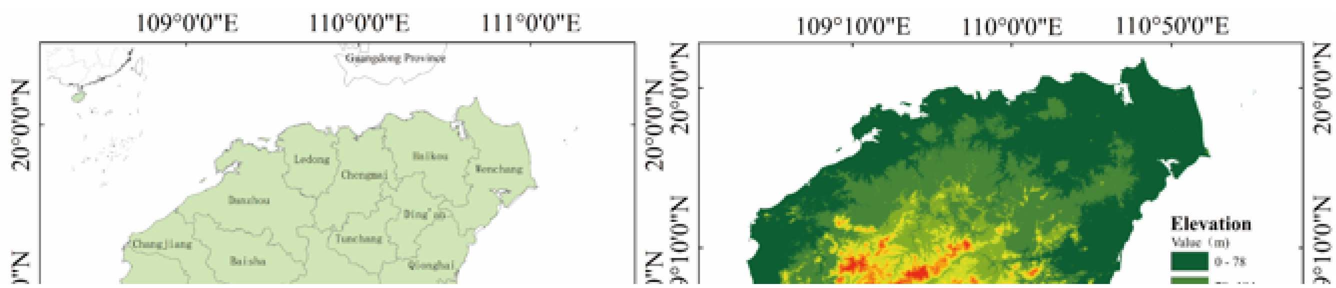

Figure 1

Regional Overview of Hainan Island

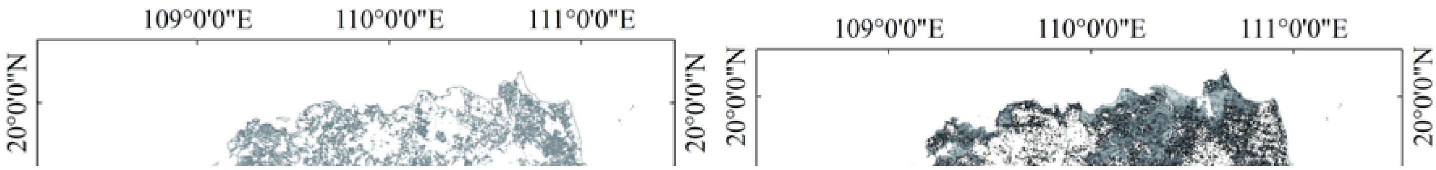

Figure 2

Distribution of Dry land and plain platform in Hainan Island

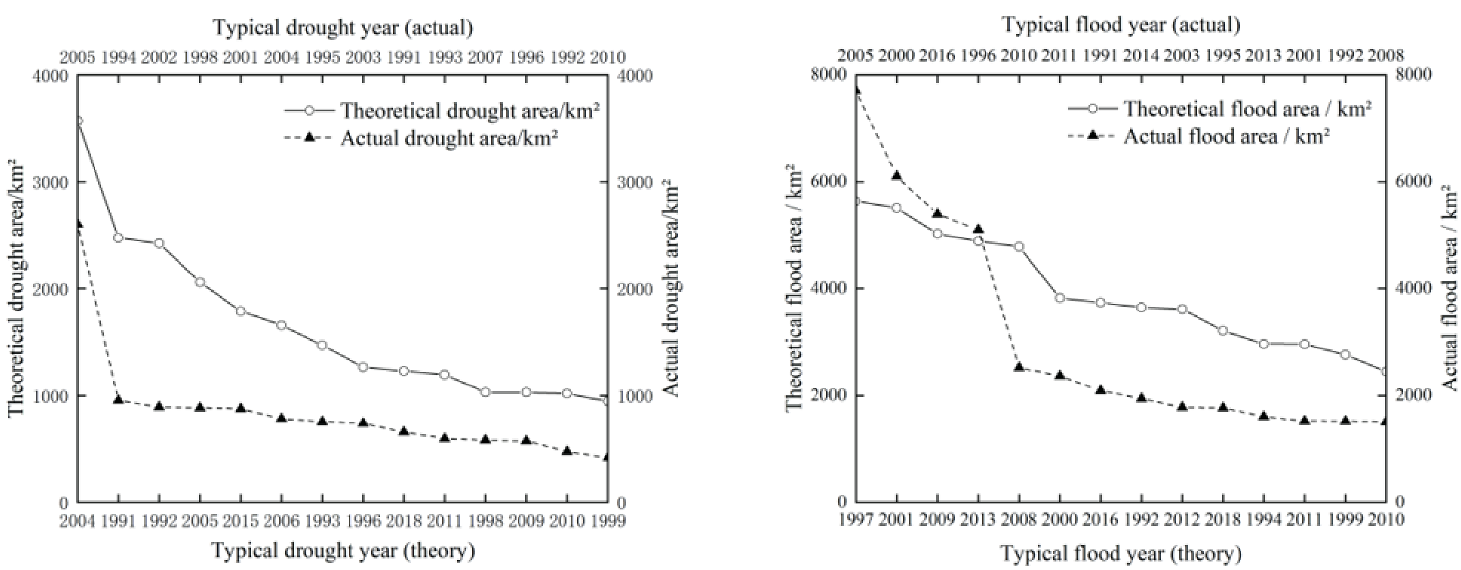

Figure 3

Actual disaster area and theoretical drought and flood area in Hainan Island

Figure 4

Actual and theoretical flood and drought disaster prone areas in Hainan Island

Figure 5

(a) Drought area change and Kendall statistics

(b) Flood area change and Kendall statistics

Time series of drought and flood areas in various seasons in Hainan Island

Figure 6

Distribution of drought-prone areas in Hainan Island

Figure 7

Distribution of flood prone areas in Hainan Island

Figure 8

Alternate prone area of drought and flood in Hainan Island

Figure 9

Comparison of the areas of drought and flood area without correction of underlying surface and the areas of prone area after correction

Figure 10

Comparison of the area of extreme drought/flood area after correction of the underlying surface and the actual agricultural disaster area