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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Research Article

Keywords: drought and flood, spatial and temporal distribution, underlying surface correction, Hainan province

Posted Date: October 18th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-821627/v1

Abstract

Most studies of temporal and spatial distribution characteristics of 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, land use dataset, etc, the precipitation Z index is used to evaluate the drought and flood levels in Hainan province. The analysis results were revised by underlying surface data to evaluate the spatiotemporal characteristics of the drought and flood area in Hainan province. The drought-prone areas and flood prone areas in Hainan province 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 Province, 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 20.43 times larger than that after revision. The flood prone areas before revision are 8.50 times larger than that after revision. The alternating drought and flood areas before underlying surface revision in spring and summer are 17.50 times larger than that after revision. Similarly, it is 48.64 times in summer and autumn, and 17.62 times in autumn and winter. Finally, combining climate and underlying surface factors, suggestions are put forward for drought and flood prevention.

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 hydrologic 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.

There are many methods 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.

It is necessary to compare and analyze different drought and flood indexes to carry out subregional research. 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 Yanhu 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, 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 are analyzed(Shi et al., 2020). There are many analyses of drought and flood disasters in China, however, most studies on drought and flood has 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., 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 province is the only island 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 99 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. 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).

2.4 Correction of underlying surface

The study considered the influence of the underlying cushion on regional drought and flood disasters(Yang et al., 2013). 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. The division of dry lands 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 is 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).

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

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. 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. 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:

$$U = \frac{S}{N} + i\frac{F}{N} + j\frac{P}{N} \quad (1)$$

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. The i value is 0 and the j value is -1. 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. 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. The areas prone to alternating droughts and floods 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 area of drought and flood disasters 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 more 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 "China Meteorological Disasters: 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 Province

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. 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 dry land decreased, and the area of floods 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 Province

Figure 6 shows the distribution of drought-prone areas in spring, summer, autumn, winter four seasons and the whole year in Hainan Province. As a whole, the drought-prone areas throughout the year are distributed in the northeast of Hainan Province, 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 Province. 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 floods, 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 Province.

3.4 Areas prone to alternate droughts and floods

Figure 8 shows the distribution of drought and flood alternate prone areas between all seasons in Hainan Province. 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, 13.12km² 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. Thus, the temporal and spatial distribution characteristics of drought and flood can be obtained more accurately.

4.1 The area with or 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. Figure 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 21946.86km^2 and 18379.78km^2, respectively. Compared with the areas of the revised drought and flood prone area of the underlying surface (1074.40km^2 and 2163.58km^2), the difference is about 20.43 times and 8.50 times respectively. Except for the drought and flood prone areas, the alternate drought and flood prone areas are narrow and small in size, and the area are quite different. The areas of alternating drought and flooding in spring and summer, summer and autumn and autumn and winter without modification of the underlying surface are 273.88, 638.20 and 683.43 km^2, respectively. The difference with the corrected area is about 17.50, 48.64 and 17.62 times respectively. 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” 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”, 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 supply and demand and regional differentiation are obvious. (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 floods 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 province 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 km^2 and 2163.58 km^2 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 km^2 and 6325.10 km^2. 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

Acknowledgement: The research is financially supported by the National Natural Science Foundation of China (Grant No.52069006, 51569009□51979043), the project from Natural science foundation of Hainan (Grant No.419MS019).

Author contributions statement

Changqing Ye designed the content and ideas of the research. Yi Zou and Dan Li calculated the data and analysed the results. Youwen Lin provided data resources. Yanhu He and Lirong Zhu revised and improved the quality of the research. All authors reviewed the manuscript.

References

1. Bao L, Yu Z, Men M, Englen V (2004) 1:250 000 Study on Soil and Terrain Database and Index System. Transactions of the Chinese Society of Agricultural Engineering 20: 259-263.
2. Delgado J, Llorens P, Nord G, Calder I R, Gallart F (2010) Modelling the hydrological response of a Mediterranean medium-sized headwater basin subject to land cover change: The Cardener River basin (NE Spain). Journal of Hydrology 383: 125-134. https://doi.org/10.1016/j.jhydrol.2009.07.024.
3. Dodson J, Li J, Lu F, Zhang W, Yan H, Cao S (2019) A Late Pleistocene and Holocene vegetation and environmental record from Shuangchi Maar, Hainan Province, South China. Palaeogeography, Palaeoclimatology, Palaeoecology 523: 89-96. https://doi.org/10.1016/j.palaeo.2019.03.026.
4. Fang X, Zou J, Wu Y, Zhang Y, Zhao Y, Zhang H (2021) Evaluation of the sustainable development of an island "Blue Economy": A case study of Hainan, China. Sustainable Cities and Society 66: 102662. https://doi.org/10.1016/j.scs.2020.102662.
5. Firoz A B M, Nauditt A, Fink M, Ribbe L (2018) Quantifying human impacts on hydrological drought using a combined modelling approach in a tropical river basin in central Vietnam. Hydrology and Earth System Sciences 22: 547-565. https://doi.org/10.5194/hess-22-547-2018.
6. He Yanhu, Chen Xiaohong, Kairong L, Xiaoqing W (2014) Characteristic of the Spatio-temporal Distribution of Droughts and Floods in the Dongjiang Basin in Recent 50 Years. Scientia Geographica Sinica 34: 1391-1398. https://doi.org/10.13249/j.cnki.sgs.2014.11.011.
7. Held I M, Soden B J (2006) Robust Responses of the Hydrological Cycle to Global Warming. JOURNAL OF CLIMATE 19: 5686-5699. https://doi.org/10.1175/JCLI3990.1.
8. Hu B, Cui R, Li J, Wei H, Zhao J, Bai F, Song W, Ding X (2013) Occurrence and distribution of heavy metals in surface sediments of the Changhua River Estuary and adjacent shelf (Hainan Island). Mar Pollut Bull 76: 400-405. https://doi.org/10.1016/j.marpolbul.2013.08.020.
9. Huntington T G (2006) Evidence for intensification of the global water cycle: Review and synthesis. Journal of Hydrology 319: 83-95. https://doi.org/10.1016/j.jhydrol.2005.07.003.
10. Kvočka D, Falconer R A, Bray M (2016) Flood hazard assessment for extreme flood events. Natural Hazards 84: 1569-1599. https://doi.org/10.1007/s11069-016-2501-z.
11. Li X, Ye X (2015) Spatiotemporal Characteristics of Dry-Wet Abrupt Transition Based on Precipitation in Poyang Lake Basin, China. Water 7: 1943-1958. https://doi.org/10.3390/w7051943.
12. Ling M, Han H, Wei X, Lv C (2021) Temporal and spatial distributions of precipitation on the Huang-Huai-Hai Plain during 1960–2019, China. Journal of Water and Climate Change. https://doi.org/10.2166/wcc.2021.313.
13. Lu Y, Bi S, Liu A, al. e (2018) Analysis on the Spatio-temporal Characteristics of Drought and Flood Disasters in the Pearl □iver Basin During 1644□1911 years. Resources and Environment in the Yangtze River Basin 27: 2867-2877.
14. Mahmoudi P, Rigi A, Miri Kamak M (2019) Evaluating the sensitivity of precipitation-based drought indices to different lengths of record. Journal of Hydrology 579:

124181. https://doi.org/10.1016/j.jhydrol.2019.124181.

15. Min X, Wang X, Yang C, al. e (2017) Spatio-temporal changes of floods and droughts at Huang-Huai-Hai region in last 500 years. Journal of Water Resources and Water Engineering 28: 66-71.
16. Modarres R, Sarhadi A, Burn D H (2016) Changes of extreme drought and flood events in Iran. Global and Planetary Change 144: 67-81. https://doi.org/10.1016/j.gloplacha.2016.07.008.
17. Shahabfar A, Eitzinger J (2013) Spatio-Temporal Analysis of Droughts in Semi-Arid Regions by Using Meteorological Drought Indices. Atmosphere 4: 94-112. https://doi.org/10.3390/atmos4020094.
18. Shao W, Kam J (2020) Retrospective and prospective evaluations of drought and flood. Sci Total Environ 748: 141155. https://doi.org/10.1016/j.scitotenv.2020.141155.
19. Shao X, Liu J, Xu Y (2001) Determination of drought-flood index and its temporal and spatial distribution characteristics in Hebei Province. Journal of Natural Disasters 10: 133-136.
20. Shi J, Cui L, Tian Z (2020) Spatial and temporal distribution and trend in flood and drought disasters in East China. Environ Res 185: 109406. https://doi.org/10.1016/j.envres.2020.109406.
21. Sun R, Wu Z, Chen B, Yang C, Qi D, Lan G, Fraedrich K (2020) Effects of land-use change on eco-environmental quality in Hainan Island, China. Ecological Indicators 109: 105777. https://doi.org/10.1016/j.ecolind.2019.105777.
22. Tan H, Li Q, Zhang H, Wu C, Zhao S, Deng X, Li Y (2020) Pesticide residues in agricultural topsoil from the Hainan tropical riverside basin: Determination, distribution, and relationships with planting patterns and surface water. Sci Total Environ 722: 137856. https://doi.org/10.1016/j.scitotenv.2020.137856.
23. Tian C, Huang D, Ma H (2018) Influence of the Change of Underlying Surface on Watershed Flood Characteristics. Yellow River 40: 16-27.
24. Wang X, Sun C, Cao Y (2017) Spatio-Temporal Characteristics of Drought and Flood in Heilongjiang Province Based on the Revised Z Index. Hydroelectric energy science 35: 1-4.
25. Wang Y, Liu J, Li R, Suo X, Lu E (2020a) Precipitation forecast of the Wujiang River Basin based on artificial bee colony algorithm and backpropagation neural network. Alexandria Engineering Journal 59: 1473-1483. https://doi.org/10.1016/j.aej.2020.04.035.
26. Wang Y F, Liang L S, Jing J L, Luo F L, Wang A N (2020b) Characteristic of Drought and Flood in the Dian-Qian-Gui Karst Areas Based on Trmm-Z Index. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-3/W10: 917-924. https://doi.org/10.5194/isprs-archives-XLII-3-W10-917-2020.
27. Xing Z, Yan D, Weng B, Yong Y (2014) The Impact of Underlying Surface Changes on the Extreme Hydrological Events and the Comprehensive Countermeasure Framework. Journal of Catastrophology 29: 188-193.
28. Xu S, Dong X, Li Z, Zhang C, WU P (2015) Impact of meteorological disasters on agricultural production and farmers' income in Hainan province. Energy and Environment: 187-192.

29. Yamamoto K, Sayama T, Apip (2021) Impact of climate change on flood inundation in a tropical river basin in Indonesia. Progress in Earth and Planetary Science 8: 5. https://doi.org/10.1186/s40645-020-00386-4.
30. Yang Z, Yuan Z, Yan D, Yu Y, Weng B (2013) Temporal and spatial distribution and combination characteristics of drought and flood in Huanghuaihai basin. Progress in water science 24: 617-625. https://doi.org/10.14042/j.cnki.32.1309.2013.05.014.
31. Zhang L, Huo Z, Zhang L, Huang D (2017) Integrated risk assessment of major meteorological disasters with paprika pepper in Hainan province. Journal of tropical meteorology 3: 334-345. https://doi.org/10.16555/j.1006-8775.2017.03.010.
32. Zhang P, Ruan H, Dai P, Zhao L, Zhang J (2020) Spatiotemporal river flux and composition of nutrients affecting adjacent coastal water quality in Hainan Island, China. Journal of Hydrology 591: 125293. https://doi.org/10.1016/j.jhydrol.2020.125293.
33. Zhang Q, Gu X, Singh V P, Kong D, Chen X (2015) Spatiotemporal behavior of floods and droughts and their impacts on agriculture in China. Global and Planetary Change 131: 63-72. https://doi.org/10.1016/j.gloplacha.2015.05.007.
34. Zhao K (1994) Set pair analysis and its preliminary application. Nature Exploration 13: 67-72.

Figures

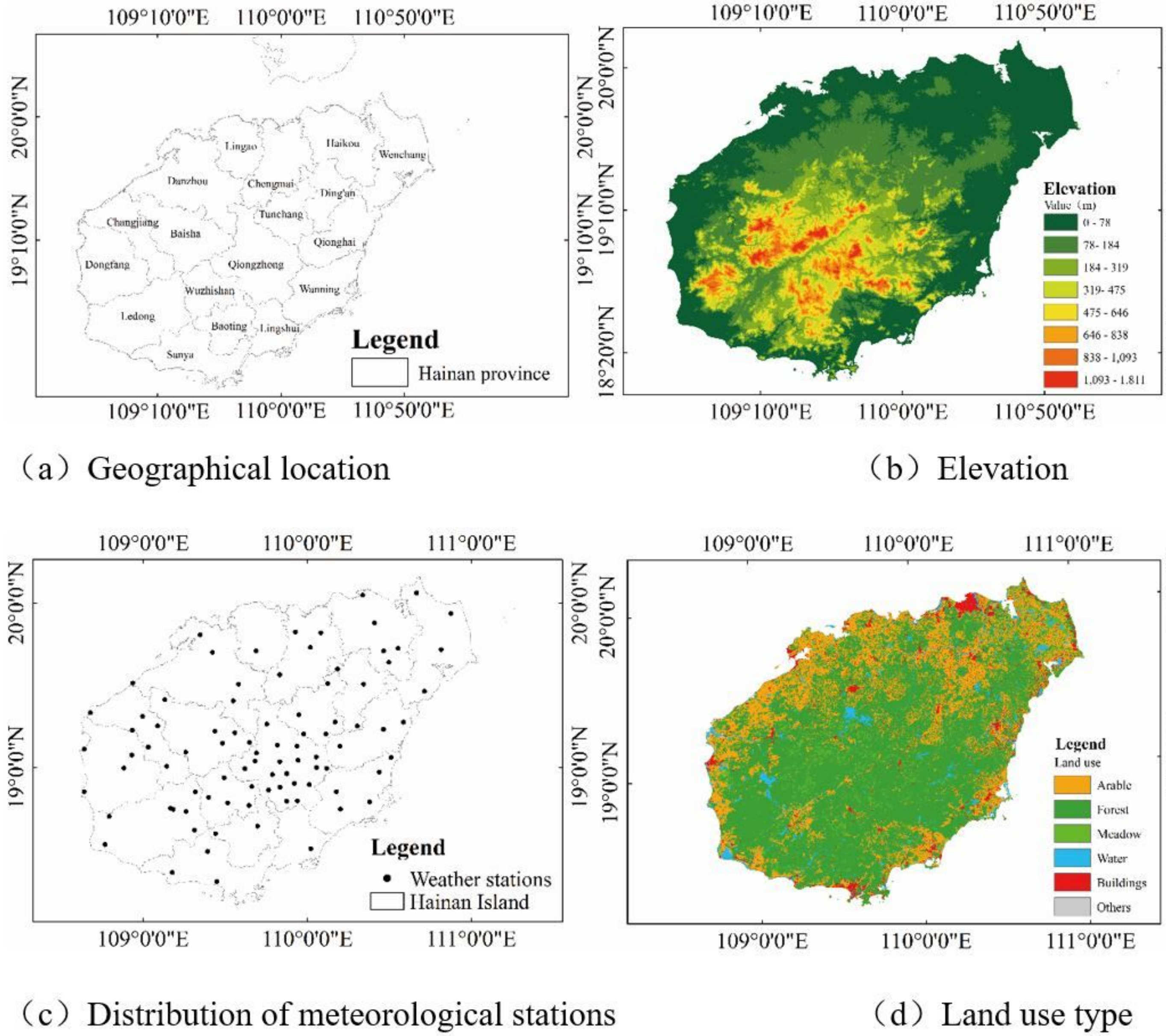

Figure 1

Regional Overview of Hainan Province

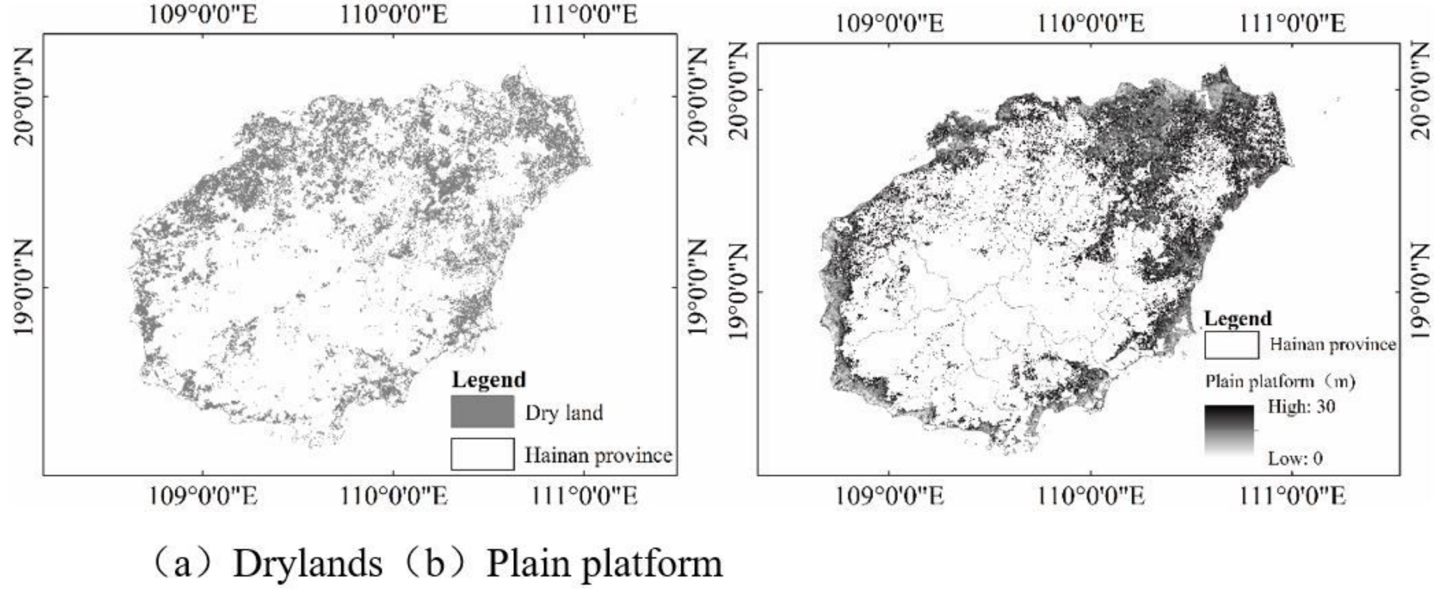

Figure 2

Distribution of Drylands and plain platform in Hainan Province

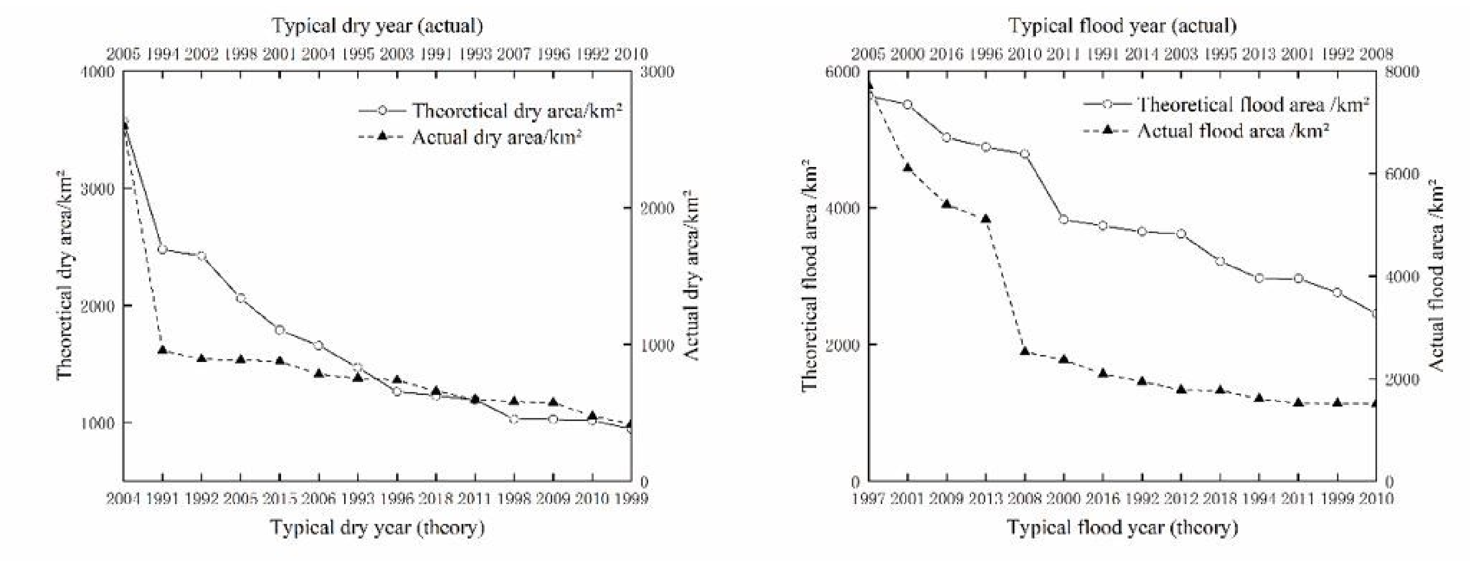

Figure 3

Actual Disaster Area and Theoretical Drought and Flood Area in Hainan Province

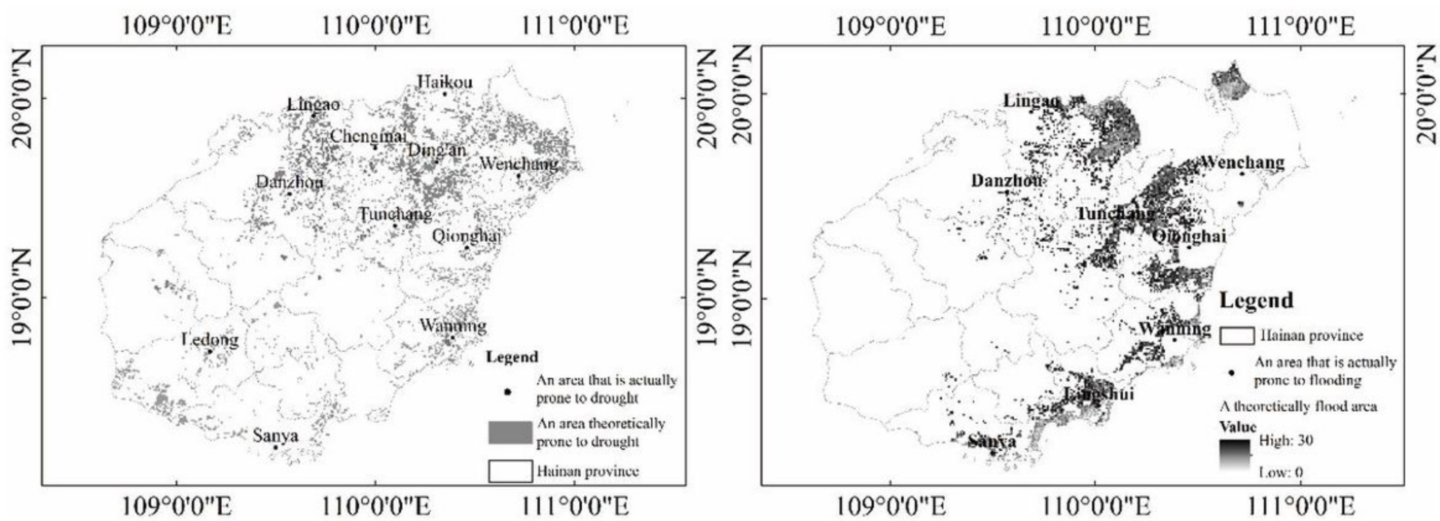

Figure 4

Actual and theoretical flood and drought disaster prone areas in Hainan

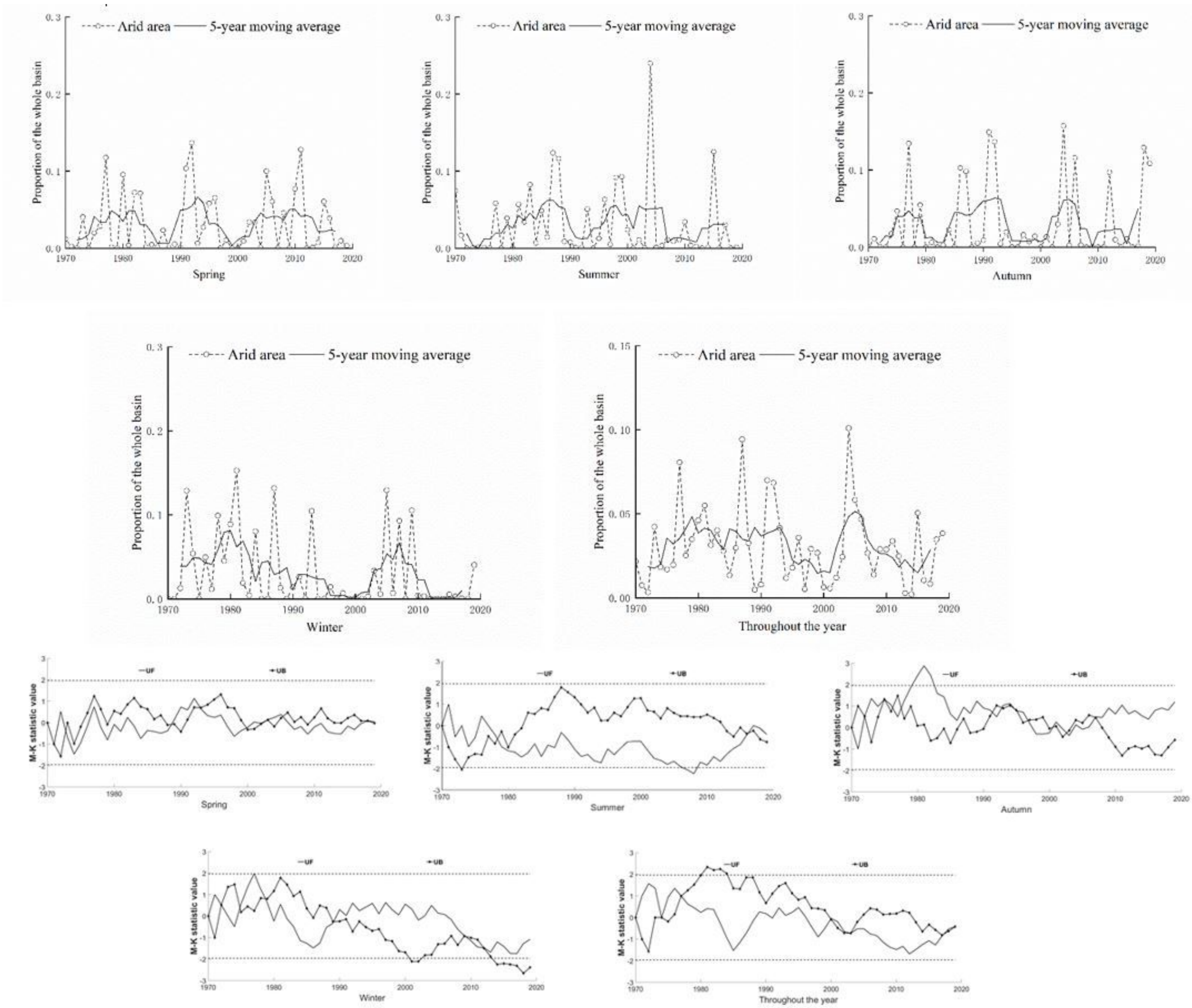

Figure 5

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

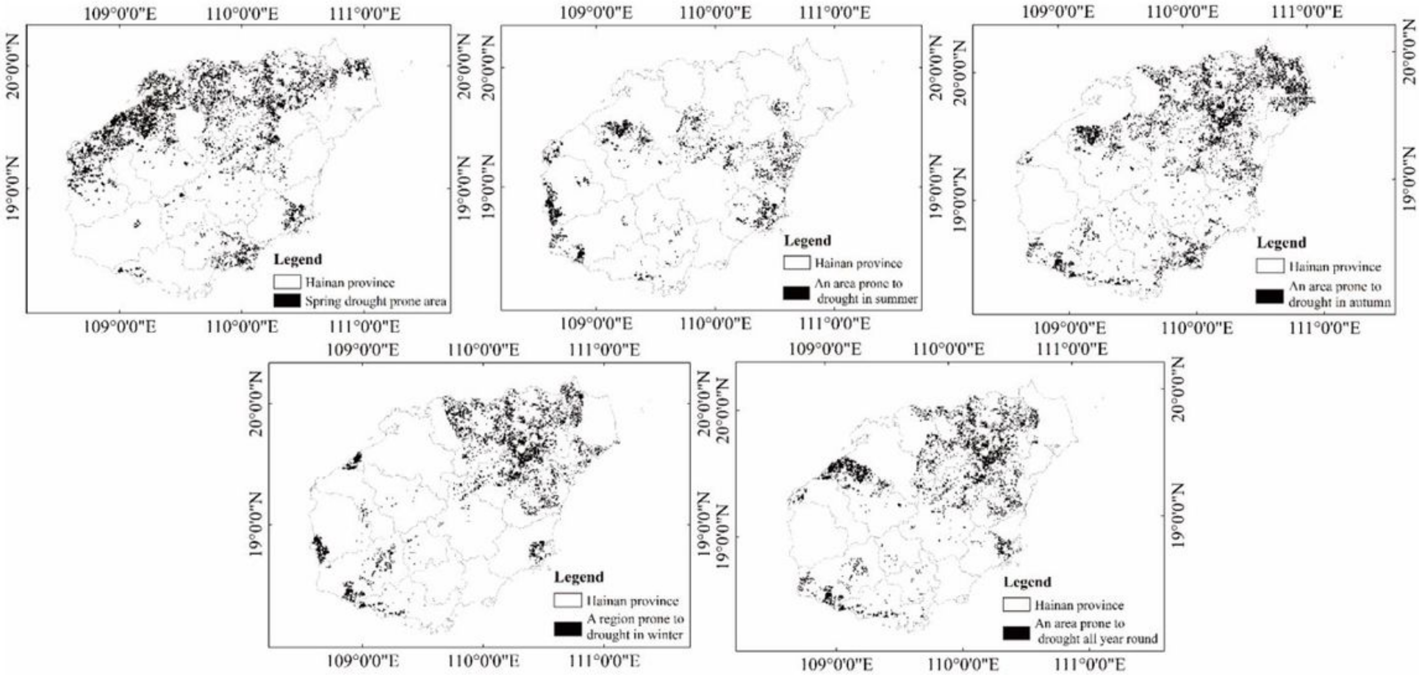

Figure 6

Distribution of drought-prone areas in Hainan Province

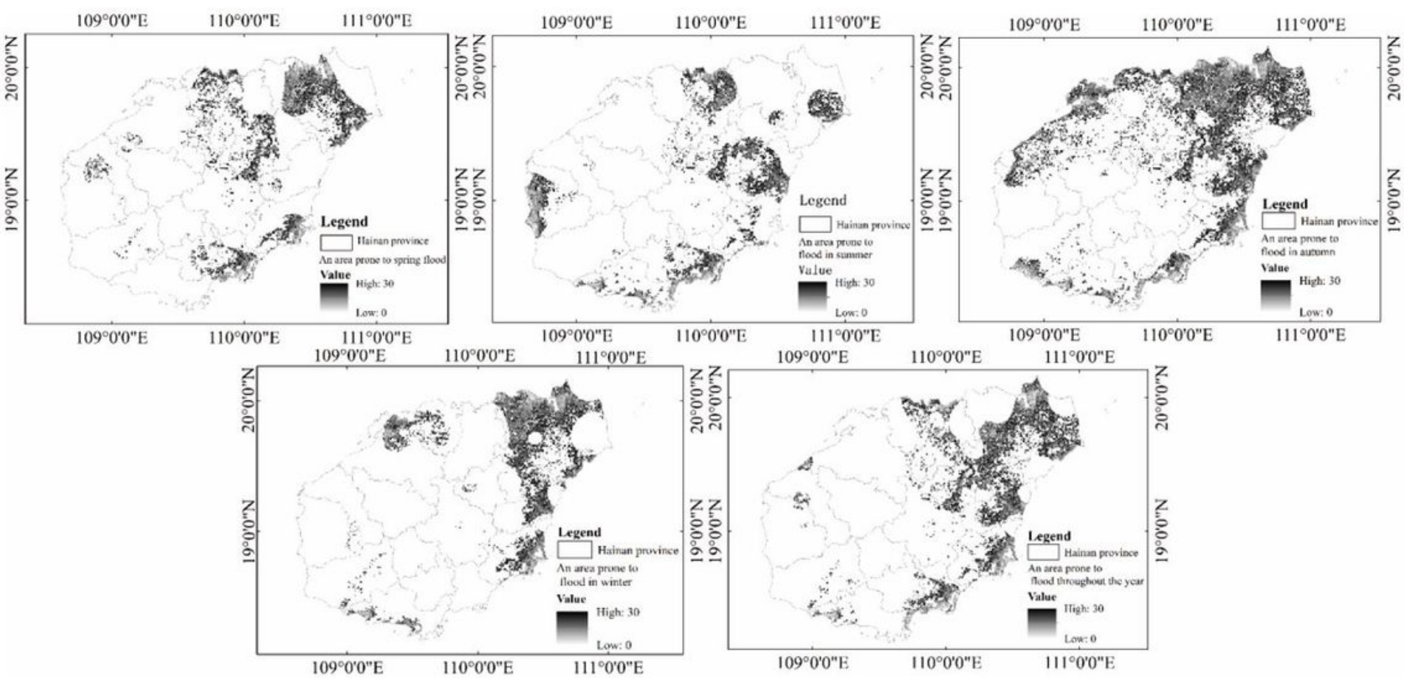

Figure 7

Distribution of flood prone areas in Hainan Province

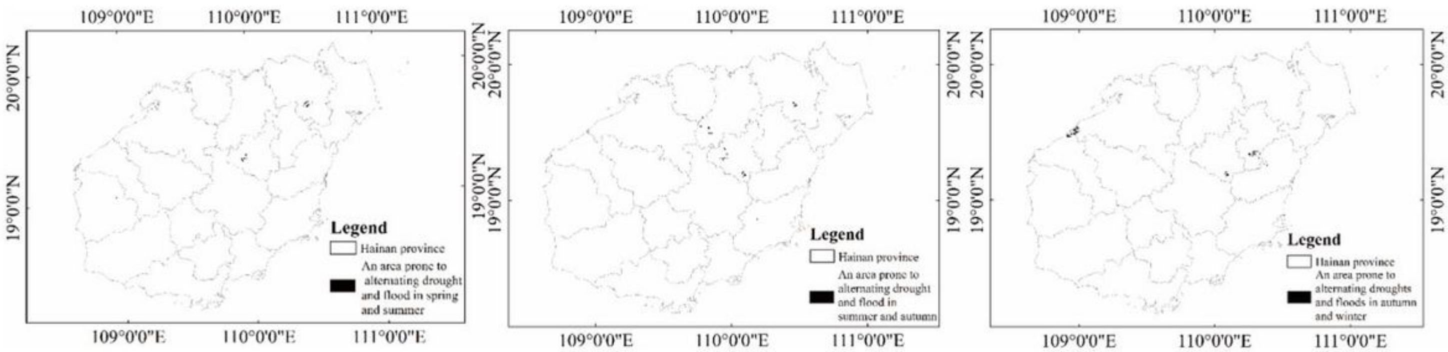

Figure 8

Alternate prone area of drought and flood in Hainan Province

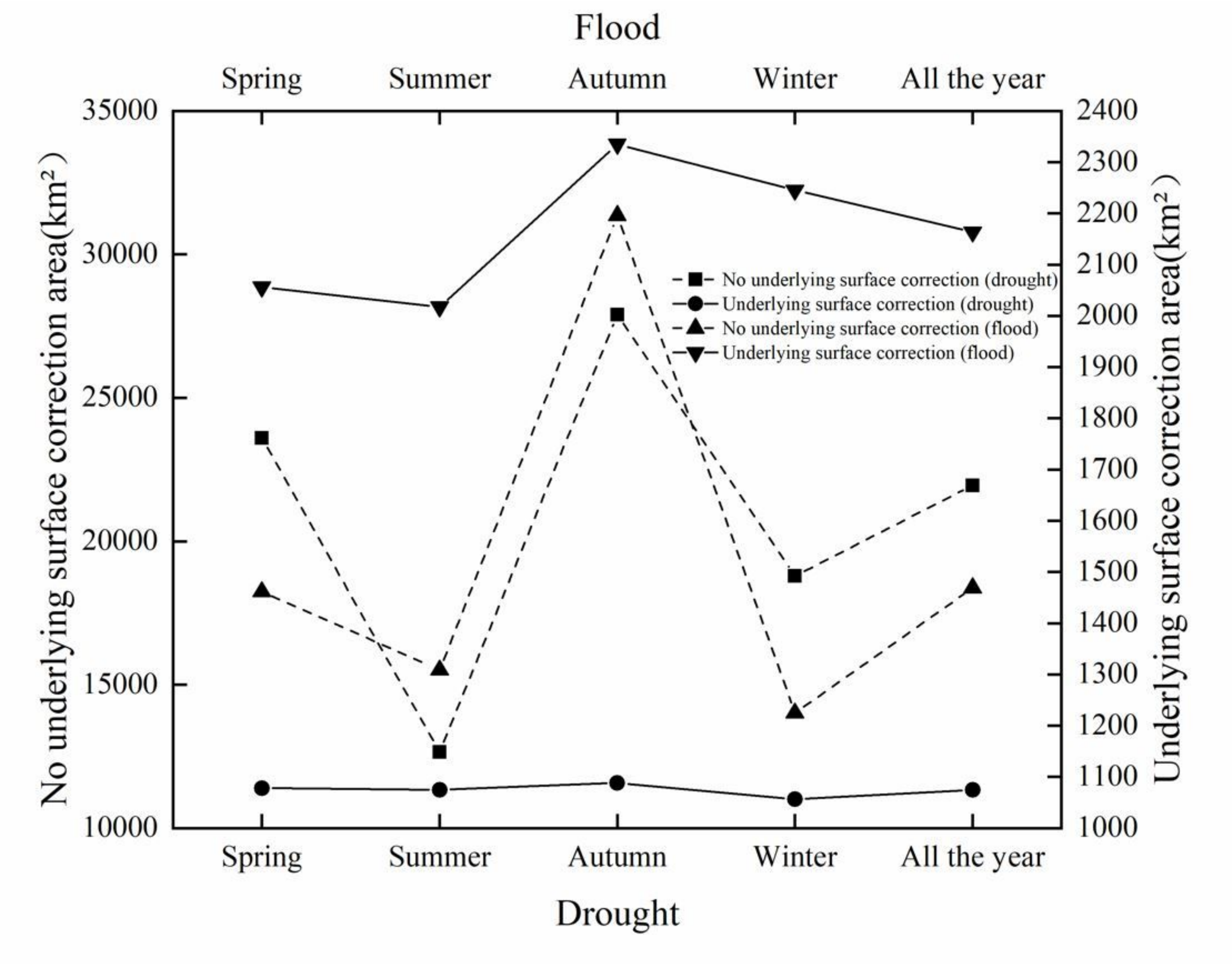

Figure 9

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

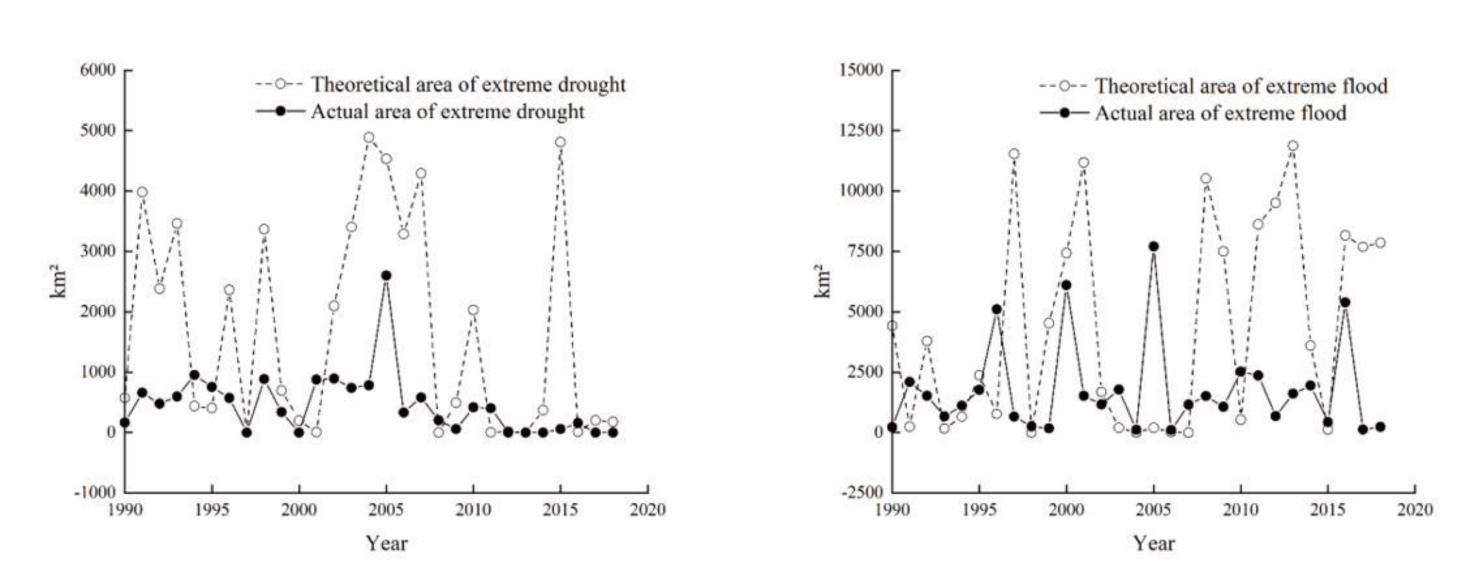

Figure 10

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