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GIS-based research on climate suitable region of Loquat in Lishui, Zhejiang province of China

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Abstract

To develop a climatic suitability index and conduct the cultivation division of loquat in Lishui, Zhejiang province of China, we introduced the multi-indicator comprehensive risk assessment method to combine with the hazard factor model, necessary climatic elements during the growing season of loquat and geographic information elements. Results show that the annual active accumulated temperature (rainfall) over most Lishui is more than 4500 °C (1600mm). The two climatic factors above can well meet the needs of loquat growth. The frozen injury days over most Lishui during the young fruit period of loquat are more than 10.0 days, which are higher than those during the flowering period. The annual mean number of continuous overcast rain occurrences is less than 4.5. The climatic mean annual occurrence of persistent abnormal high temperature weather is less than 1. Overall, the most suitable area for the cultivation of loquat mainly located over the relatively flat areas such as river valleys and basins, especially the banks of the Oujiang River in Qingtian and Xiaoxi River valley in Jingning. The excellent combinations of light, heat and water with relatively few meteorological disasters just like frozen injury, continuous rain and high temperature provide a good climatic conditions of the high-quality of loquat planting.

1. Introduction

Loquat (Eriobotrya japonica Lindl.) is a subtropical evergreen fruit tree originated in south China (Lin et al 1999, Cai et al 2019), being considered as a delicious fruit in summer because of its varied advantages (Gupta et al 2020). As a native fruit in China (Lamis et al 2014), Loquat has different growth period relative to other fruit trees. Loquat usually blooms in autumn and winter, its young fruit is formed in the early spring and finally matures in spring and summer. So low temperature in winter and early spring is easy to cause frozen injury for flowers and young fruits of loquat (Zhang et al 2009). The frozen injury of loquat has a large impact on the loquat yield of the year, which largely limits the loquat economic cultivation (Huang et al 2000, Xie and Li 2006). Loquat has special ecological response and suitability under different ecological conditions (Shih 2007, Li et al 2011). Water requirements of loquat are different at different stages of growth. It is not resistant to flood (Wang 2003, Hong et al 2013) and drought (Zhou and Zhou 2003, Zhang et al 2004, Zheng 2005, Wang et al 2007).

The obvious mountain climatic conditions of Lishui endow the loquat resources with much potential developing and utilizing values. There is a long history of loquat cultivation in Lishui earlier than 1846. Lishui loquat was once well-known as the ‘Zhejiang Natural Loquat Gene Bank’. Recent researches on loquat planting mostly focus on the cultivation techniques (Yang et al 2018, Zhang 2018) and suitable meteorological conditions (Wang 2003). Agro-meteorological indicators (Huang 2012), ecological suitability (Liang and Wei 2004) of loquat were analyzed and evaluated in different ecological regions (Jiang et al 2010). There were also many studies on disastrous weather for loquat cultivation (Lu et al 2009, Qiu et al 2009, Yang et al 2012, Jiang et al 2015).

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GIS techniques (Valjarevi et al 2018, Jumaah et al 2019) and methodologies have been gradually applied to agriculture in recent years. Spatial distribution of suitability or characterization for agriculture have been calculated using GIS (Zhou et al 2016, Ramlan et al 2018, Bos et al 2020). Meanwhile, the cultivation suitability of loquat has been analyzed based on GIS. Loquat suitable areas and division evaluation model have been analyzed using GIS technology (Chen et al 2006, Zhang et al 2009, Liu et al 2018).

Based on the daily observation data from high-resolution automatic weather stations in Lishui and the topographical elements such as terrain slope, aspect and topographic position index (TPI), the distribution characteristics of climatic factors such as active accumulated temperature and precipitation during the loquat growth period are firstly revealed and indicated. Then combined with the topographic characteristics, the main
risk factors (low temperature, continuous rain and high temperature, etc.) are further analyzed to reveal the climate suitability regionalization of loquat cultivation based on GIS in Lishui. Main findings of current study may provides valuable reference for the cultivation of loquat in mountainous areas and scientific basis for the development of loquat industry.

2. Study area, data and methods

2.1. Study Area
Lishui located in the southwestern part of Zhejiang Province has the terrain characterized by ‘nine mountains with half water and half field’ (figure 1). It has a mid-subtropical monsoon climate featured by warm, humid, abundant heat and sufficient precipitation with four distinct seasons. The annual mean temperature is 16.9 ~ 18.4 °C and the annual rainfall is 1396 ~ 1741 mm in Lishui.

2.2. Data
The daily observation data, such as temperature and precipitation from 380 automatic weather stations in Lishui are used in current study. With the constant standardization of routine maintenance and data correction, the reliability of the data has been assured. The observation data with the horizontal resolution of ~7km and observation frequency of 5 min are quality controlled by Meteorological Data Operational System (MDOS) since 2013. Compared with the Tropical Rainfall Measuring Mission (TRMM) satellite data and NCEP/NCAR reanalysis, ERA-Interim and other reanalysis datasets (Zhang et al 2011, Mao and Wu 2012), the observation data from automatic weather station is higher at spatiotemporal resolution and more reliable. To ensure the integrity and accuracy of the data, the data at the stations with the missing rate >5% were removed, and the daily data from 239 stations (figure 2) during 2013 to 2020 were selected for analysis. The daily sunshine data was used to conduct analysis for the continuous rain. Since the regional automatic stations rarely have sunshine observation data and sunshine hours have changed little under local small-scale terrain, the Sunshine data from nine national basic stations was used to replace the Sunshine data of the regional automatic stations from the corresponding counties (cities). In addition, the terrain aspect, slope, and TPI data was derived from the SRTM90 dataset (Tang and Liu 2009) with the horizontal resolution of 90m (http://srtm.csi.cgiar.org/srtmdata/).

2.3. Method
To establish a geographic model of climatic elements in this study, we introduce the TPI which is a topographical parameter to describe the topographic position. The basic idea of TPI is that the position of a given point on the inclined surface is determined by the difference between the elevation of it and the mean elevation of a certain range around it together with its slope (Weiss 2001). Table 1 gives the definition of TPI classes by comparing the TPI at given cell with the standard deviation (STDV) of the terrain elevations over the cells around it within a predetermined radius. Topography of mountainous terrain in Lishui characterized by TPI exhibits obvious mountain micro-climate characteristics, which has a significant impact on the environmental factors of loquat cultivation such as temperature and precipitation.

According to Sun et al (2016), with the consideration of the special geographical environment and climatic characteristics in Lishui, the continuous rain is defined by:

1) The rainy process lasts for at least 5 days;
2) The precipitation amount ≥ 30 mm during a given continuous rainy process;
3) The daily mean sunshine hours ≤ 2 h during the continuous rainy process;

| Class          | Description | Breakpoints                        |
|----------------|-------------|------------------------------------|
| 1  | Ridge  | TPI > 1 STDV |
| 2  | Upper Slope  | 0.5 STDV < TPI ≤ 1 STDV             |
| 3  | Middle Slope  | −0.5 STDV < TPI < 0.5 STDV, Slope > 5° |
| 4  | Flat Slope  | −0.5 STDV < TPI < 0.5 STDV, Slope ≤ 5° |
| 5  | Lower Slope  | −1 STDV < TPI ≤ −0.5 STDV           |
| 6  | Valley  | TPI < −1.0 STDV                      |
4) The continuous rain is divided into three categories namely mild (5–7 d), moderate (8–10 d) and severe (≥11 d) in terms of the duration of the rainy process.

The fruit of loquat is easy to be wilting and sunburn if the temperature of loquat fruit surface easily rise and its water supply become insufficient under high temperature, drought and strong sunshine during the growth period. It basically occurs after 2-3 sunny and hot days. The stronger high temperature and sunshine, the more serious wilting and sunburn occur.

The annual mean meteorological elements such as temperature, precipitation, sunshine duration and so on from the 239 automatic weather stations in Lishui are only scattered point data. However, these data can not characterize the distribution of meteorological elements. So geographical estimation models are adopted to calculate the spatial distribution of meteorological elements, converting scattered point data into area data. The meteorological elements data are used as the dependent variables; considering the effects of terrain factors such as longitude (\( \varphi \)), latitude (\( \lambda \)) of altitude (\( h \)), aspect (\( \text{asp} \)), slope, and TPI as the independent variables, a geographical estimation model for the climate factors of a suitable index for loquat cultivation is established as follows:

\[
    f(\varphi, \lambda, h, \text{asp}, \text{slope}, \text{TPI}) = x_0 + x_1\varphi + x_2\lambda + x_3h + x_4\text{asp} + x_5\text{slope} + x_6\text{TPI}
\]  

(1)

\( f \) is the function of meteorological element geographic estimation, \( x_0-x_6 \) are coefficients calculated by multivariate stepwise regression and mathematical statistical methods (Wei 1985).

The impact of hazard factors on the loquat during growth period are mainly indicated by the intensity, duration and probability of meteorological disaster occurrences (Yang et al. 2015). Based on the intensity of each level of meteorological disasters and the probability of occurrence, combined with previous research results (Bao et al. 2012), the comprehensive risk index model (Yang et al. 2015) is established by the following equation:

\[
    P_i = \frac{n_i}{N} \times 100\%
\]

(2)

\[
    Q = \sum_{i=1}^{3} J_iP_i
\]

(3)

Where \( Q \) is the comprehensive climate risk distribution index, \( P_i \) is the probability of occurrence of meteorological disasters with different grades at a given station, \( n_i \) is the number of disasters for the \( i \) th level at a given station during 2013 to 2020, \( N \) is the year of observation data (\( N = 8 \) in this study). \( J_i \) is the intensity of the meteorological disaster at the \( i \) th level (occurrence percentage of the meteorological disaster) (Bao et al. 2012, Yang et al. 2015).

Yang et al. (2013) developed an integrated climatic index of low temperature injury evaluation of loquat by using the method of principal component analysis to comprehensively simplify four disaster-inducing factors including extreme minimum temperature, the total days with the daily mean temperature ≤3.0 °C, the maximum sustained days of low temperature injury ≤3.0 °C, and the accumulated temperature for ≤3.0 °C. Chen et al. (2012) constructed a risk evaluation index system for meteorological disasters of loquat based on the identification of the major disaster-causing factors affecting loquat growth and yield. Refer to the main conclusions above, the ‘Multi-indicator Comprehensive Risk Assessment Method’ which is similar with proofed methods just like RUSLE and MUSLE have been adopted to assess the climate suitability of loquat cultivation. The main processes are: (1) evaluation of meteorological indicators necessary for loquat cultivation in Lishui; (2) assessment of the major meteorological disaster-causing factors of loquat cultivation. (3) determining the weight of the evaluation index (including both meteorological indicators and hazard factor indicators); (4) classifying the risk index and making suitability regionalization based on GIS. This study comprehensively applied analytic hierarchy process (Wei et al. 2006, Li 2009) and entropy weight coefficient method (Xu 2001, Tang and Wang 2002) to determine the subjective and objective weights of risk assessment indicators. To fully reflect the importance of the evaluation indicators, subjective and objective weights given by decision-makers from each indicator are combined to finally determine the comprehensive weight of each indicator (Chen et al. 2014). Combined with the hazard factor model during the loquat growth period, a suitability index for the loquat cultivation (Yang et al. 2012) is established as follow:

\[
    S = \sum_{i=1}^{n} b_iA_i
\]

(4)

\( S \) is the climatic suitability index for the loquat cultivation, characterizing the suitability of loquat cultivation. Low \( S \) indicates high suitability. \( A_i \) is the normalized values of indicators, \( b_i \) is the coefficients for the \( i \)th indicator calculated by multi-indicator comprehensive risk assessment method based on comprehensive risk index model, \( n \) is the number of indicators.
3. Results

3.1. Key climatic factors during the loquat growth period

The yield and quality of loquat are critically affected by temperature and moisture because of the distinctive growth period of loquat. The agroclimatological indicators of temperature and moisture are mainly active accumulated temperature and precipitation. Based on the daily data from the 239 automatic weather stations in Lishui during 2013 to 2020 and the mathematical statistics and stepwise regression method, we have established geographical projection models on main climatic factors such as active accumulated temperature and precipitation during the loquat growth period. It can be seen from table 2 that the correlation coefficients between estimation of the statistic models and observation for the annual active accumulated temperature and precipitation are significant at the 1% level according to the F test. The two statistic models above can characterize the distribution characteristics of climatic factors in Lishui.

Table 2. Geographical estimation models of climatic elements for loquat cultivation.

| Climatic elements  | Geographical estimation models                                                                 | Correlation coefficients | F test value |
|--------------------|-------------------------------------------------------------------------------------------------|--------------------------|--------------|
| Annual active accumulated temperature | $AT = 16512.250 - 2.291h - 0.0033\lambda - 53.209p + 0.001\varphi + 0.000323h^2$ | 0.954                    | 470.729*     |
| Annual precipitation | $PR = 7027.866 + 0.390h - 0.00173\lambda + 0.253\varphi$ | 0.694                    | 72.541*      |

* Notes: denotes that it is significant at the 1% level.

3.1.1. Active accumulated temperature

Figure 3 gives the spatial distribution of climatic mean annual active accumulated temperature (AAT) with the daily air temperature $\geq 10^\circ C$ in Lishui over 2013–2020. The annual active accumulated temperature over most Lishui is more than 4500 $^\circ C$. The areas with the highest annual active accumulated temperature ($> 5500 ^\circ C$) concentrate in the area along the Oujiang River in Qingtian and Liandu urban regions to Bihu Plain, Songgu Plain, Yunhe and Longquan. The areas with the annual active accumulated temperature below 4500 $^\circ C$ are located over the middle and high altitude areas such as Fengyang Mountain, the junction of Suichang and Longquan, and eastern Jinyun. High-quality loquat needs the climatic environment with the annual active accumulated temperature ranging from 5000 $^\circ C$ to 6000 $^\circ C$ (Liang and Wei 2004). It is clear that the annual active accumulated temperature over the Oujiang River Basin in Qingtian, Liandu urban to Bihu Plain are very suitable for the high-quality loquat cultivation.
3.1.2. Water condition

The growth of loquat needs a moist environment with abundant rainfall. The climatic mean annual rainfall ranging from 1000 mm to 1500 mm or above is suitable for the loquat cultivation (Huang 2012). However, loquat needs different water condition at different growth stages. Spring continuous rain could cause fruit falling, fruit cracking, rotten fruit, etc., while certain water conditions are necessary for the growth of the fruits during the fruit maturation period.

Figure 4 shows the spatial distribution of climatic mean annual precipitation (AMP) in Lishui over 2013–2020.

Figure 5 shows the spatial distribution of climatic mean frozen injury days (FID) in the flowering period of loquat over Lishui during 2013–2020.

3.1.2. Water condition

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Figure 4 shows the spatial distribution of climatic mean annual precipitation in Lishui over 2013 to 2020. The annual precipitation in Lishui is more than 1600 mm over the entire Lishui, which can meet the
requirements of loquat cultivation. The precipitation generally weakens from south to north Lishui. And low-value areas are located in the northern Liandu, Songgu Plain, western Jinyun and Qingtian Oujiang River Basin. The most areas with abundant precipitation are situated in Qingyuan, southeast of Longquan and southwest of Jingning with the annual rainfall over 2200mm. Water requirements of loquat in different growth periods are different, especially the continuous rain has a great impact on the yield of loquat. Therefore, it is not enough to assess the suitability of rainfall alone. The analysis of hazard factors and continuous rain should be further studied.

3.2. Major hazard climatic factors for loquat

Although the annual active accumulated temperature and precipitation in Lishui can meet the needs of loquat cultivation, but uneven temporal distribution of temperature and precipitation would have a great impact on the loquat production.

Overall, frozen injury during the flowering and young fruiting periods as well as the continuous rain and high temperature (the daily maximal temperature is higher than 35 °C for more than 2 days) during the whole growth period are main disaster climatic factors for the loquat cultivation. In particular, the frozen injury is much more important and can be calculated according to the meteorological standard of ‘QX/T 281–2015’ (Cheng et al 2015).

3.2.1. Frozen injury

In the standard named ‘Grade of freezing injury to Chinese loquat’ (Cheng et al 2015), daily minimum temperature is used as an indicator of frozen injury. During the loquat flowering period, low temperature inhibits pollen grain germination (Zhang et al 2007). Figure 5 shows the spatial distribution of frozen injury occurrences in the flowering period (from mid-November to next early February). The frozen injury days <10.0d are widely distributed over most Lishui. The areas with the value below 10.0d mainly locate in Qingtian, Liandu, Yunhe, Songyang and Jingning. Only a few areas with the value above 10.0d distribute in the eastern part of Jinyun, the north-central part of Suichang to the junction of Songyang and Longquan, and the Fengyang Mountain to the Qingyuan Baishanzu area. These areas with more serious frozen injury mainly occur in the areas with the altitude above 1000m, such as Baima Mountain in Suichang, Dayang Mountain in Jinyun, Fengyang Mountain in Longquan and Fengyuan in Liandu.

The loquat young fruit period is from the preceding December to the following February. Continuous low temperature will cause browning of fruit seeds or pulp, which will affect or stunt normal growth of loquat fruit, leading to reduction or no harvest. Figure 6 shows the spatial distribution of climatic mean frozen injury days in the young fruit period. The annual lowest temperature over Lishui generally appears in January, the frozen
injury can easily happen in this month compared to the other months. Therefore, the number of frozen days is more in the young fruit period than in the flowering period, and the frozen days more than 10.0 d in the young fruit period can be noted over most Lishui. Meanwhile, the areas with the frozen days below 10.0d are concentrated in most Qingtian, Yunhe, especially in the southeastern part of Qingtian, where the frozen days are less than 5.0 days. The most serious frozen injury is mainly located over the relative higher altitude areas in the young fruit period. This is similar to that in the flowering period.
3.2.2. Continuous rain

The continuous rain during the flower period of loquat can cause fruit falling, fruit cracking, rotten fruit and other phenomena (Hong et al. 2013). Excessive precipitation in the fruit expansion period can affect the fruit quality; during the mature and picking periods, continuous rain can cause fruit falling and rotten fruit, etc. (Wang 2003). Figure 7 shows the spatial distribution of the occurrence of continuous rain during the loquat growth period (from preceding December to June). The mean occurrence of continuous rain over Lishui ranges from 3.3 to 7.5 times. The occurrence of continuous rain less than 4.5 times is only located over the regions from the Liandu urban area to northern Qingtian, southeast of Qingtian and the middle and east of Longquan with relatively low altitude. The occurrence of continuous rain in most Lishui is more than 4.5 times, especially in the Qingyuan Zhaibang and Jianggen, where the occurrence of continuous rain is more than 7.5 times.

3.2.3. Continuous high temperature

Loquat is not resistant to drought, especially due to drought caused by continuous high temperature (Zhou and Zhou 2003, Zheng 2005, Wang et al. 2007). Near the mature period, due to the high temperature, drought and strong sunshine, the fruit surface temperature is easy to rise; thus insufficient water supply of fruit can easily cause wilting and sunburn. The stronger high-temperature sunshine, the more severe wilting and sunburn occur (Zhang et al. 2004). Especially in the 7–15 days before harvesting, the maturity of loquat fruit is very easily affected by the Sunburn when the temperature is higher than 35 °C.

Figure 8 gives the occurrence of continuous high temperature during the loquat growth period in Lishui. It is clear that the mean annual occurrence of continuous high temperature in most Lishui is less than 1.0 times during the loquat growth period. Areas with the occurrence of continuous high temperature exceeding 1 times are mainly located over the middle and central Lishui. The occurrence of continuous high temperature exceeding 2 times is only situated in a very small areas (the central Qingtian and the central and western Jingning).

3.3. Suitability regionalization of loquat cultivation

The above assessments of the climatic disaster factors for loquat are only based on the single-point data from the automatic weather observation stations. However, the point data is hard to represent regional features. Therefore, we apply the method mentioned in section 3.1 to construct the geographical estimation models of three hazard factors (the frozen injury during the loquat flowering and young fruit periods, the continuous rain and continuous high temperature) in terms of their relations to the geographical information elements (longitude \( \varphi \), latitude \( \lambda \), elevation \( h \), slope \( s \), aspect \( asp \), \( tpi \)) (table 3). Combined with the GIS technology for geographical interpolation calculation, the site data is transferred to planar grid data to achieve spatially continuous distribution of disaster-causing climatic factors. It can be seen from table 3 that the frozen injury is closely related to TPI besides altitude and latitude; whereas the continuous rain is more closely related to the elevation.

Based on annual yield and disaster situation of loquat over these years on Lishui, according to the opinions of agricultural experts, the coefficients of the disaster factors have been determined. Suitability index for loquat cultivation \( S \) is calculated as follow (\( n = 4 \) in formula 3): \( S = 0.3\times A_1 + 0.3\times A_2 + 0.2\times A_3 + 0.2\times A_4 \) by using ‘multi-index comprehensive risk assessment method’. Where \( A_i \) is the normalized values of evaluation indicators in table 3. For example, \( A_1 \) is frozen injury index during flowering period, \( A_2 \) is the normalized values of \( A_1 \). The suitability index is combined with the key climatic factors such as active accumulated temperature and precipitation in the loquat growth period. The heat requirement of loquat is high during the whole growth period, generally the loquat can grow at the regions with the annual mean temperature more than 12 °C (Huang 2012). Therefore, the annual mean temperature of 12 °C is converted into the annual mean active accumulated temperature, and 4500 °C is considered as necessary annual active accumulated temperature for the normal growth of loquat to improve the suitability index for loquat cultivation. According to the relevant conclusions in Chen et al. (2014), adopting the opinions of senior loquat experts, the loquat cultivation suitability
in Lishui is divided into the most suitable (0–0.35), suitable (0.35–0.45), general (0.45–0.60) and unsuitable (0.6 or more) levels finally. As shown in figure 9, the suitable regions for the loquat cultivation in Lishui are large and most of them concentrate in the flat areas such as river valleys and basins. The most suitable areas (green) for the loquat cultivation are mainly located along the banks of the Oujiang River in Qingtian, Xiaoxi River valley in Jingning, and the central part of Liandu to Yunhe. In addition, the most suitable areas are also distributed in the Huangtan, Zhukou to Qingyuan County and Longquan District to Daoxiang Town. The suitable areas are mainly located in Jinyun and Suichang.

Table 4 shows the areas for loquat cultivation in different suitable grades. The most suitable grade area is about 7.12 km² over Lishui (accounting for 4.1% of the total area of Lishui), the suitable grade area is around 34.05 km² (19.7% of the total area of Lishui), and the general grade area is about 41.55 km² (24.1% of the total area of Lishui). Among them, Qingtian has the largest areas with the most suitable level, followed by Liandu and Longquan. Longquan has the largest areas at suitable level, followed by Qingtian and Liandu. In general, Qingtian has the largest areas (9.00 km²) with suitable and above level, followed by Longquan (7.86 km²) and Liandu (6.38 km²).

Table 4. Suitable areas for different grades of loquat cultivation in Lishui. (Units: km²).

| Counties   | Most suitable | Suitable | General | Unsuitable |
|------------|---------------|----------|---------|------------|
| Jinyun     | 0.00          | 1.40     | 6.06    | 7.46       |
| Longquan   | 0.86          | 6.99     | 6.25    | 16.35      |
| Qingyuan   | 0.59          | 3.08     | 2.22    | 13.08      |
| Jingning   | 0.54          | 3.40     | 3.49    | 11.97      |
| Yunhe      | 0.71          | 3.00     | 2.10    | 4.09       |
| Qingtian   | 2.64          | 6.35     | 6.32    | 9.46       |
| Suichang   | 0.02          | 1.38     | 7.28    | 16.69      |
| Songyang   | 0.26          | 3.56     | 3.73    | 6.47       |
| Liandu     | 1.49          | 4.89     | 4.10    | 4.46       |

Figure 9. Suitability regionalization of loquat in Lishui.
4. Discussion

Loquat is an important economic crop in Lishui. Current research on its climate suitability regionalization provides a guiding significance for the development of local agricultural economy and good reference value for the planting and development of other crops.

Zhang et al (2009) conducted the division of the loquat suitable areas by the annual lowest temperature combined with terrain slope. Chen et al (2006) used GIS to determine the regional distribution of loquat by minimum temperature estimation model combined with altitude, slope and aspect. Chen et al (2014) developed an integrated risk evaluation model of meteorological disasters and gave a fine risk division map with GIS technique. Liu et al (2018) further used the weighted index sum method to establish the division evaluation model and refined the division map of loquat planting. These studies above did not take into account the effects of microclimate and small terrain such as mountain three-dimensional climate, on the cultivation of loquat. The terrain of Lishui is complicated, and the geographical factors are obviously different within a small range. Microtopography further caused significant microclimate characteristics over Lishui. The number of auto weather stations is limited, and their observation data is difficult to describe the regional difference of microclimate. In this study, geographic estimation models of climatic elements and the impact of hazard factors during the growing season of loquat have been studied based on the observation and geographic information elements (i.e., terrain slope and topographic position index). Then a comprehensive risk index model of hazard factor is established based on the intensity, duration and probability of meteorological disaster occurrences. And the climatic suitability index of loquat cultivation was assessed by ‘multi-indicator comprehensive risk assessment method’ combined with the hazard factor model during the loquat growth period. Meanwhile, necessary active accumulated temperature and rainfall amount has been considered to improve the suitability index.

The aim of this paper is to reveal the spatial distribution of climate suitable region for loquat cultivation. Using climatic suitability index of loquat cultivation, we find that the most suitable areas distributed in lower latitudes, where the combinations of light, heat, water and their are much better than in other areas over Lishui, and there are relatively few meteorological disasters just like frozen injury, the continuous rain and high temperature etc. Lu et al (2009) pointed out that suitable and sub-suitable areas for loquat cultivation are mainly distributed in river valleys belong to relatively low altitudes. A comprehensive risk assessment (Chen et al 2014) indicates that the comprehensive risks above severe level are mainly distributed in mountainous areas with high altitudes. The mild risk areas are mainly distributed in low-altitude areas. The conclusion from the references above is suitable for loquat cultivation in Lishui. A good climatic conditions, coupled with fewer meteorological disasters, play a vital role in the formation of high-quality of loquat.

5. Conclusions

The suitability index for the loquat cultivation in Lishui has been built based on the climatic factors which are needed by loquat during its growth period and main risk factors (low temperature, continuous rain and high temperature, etc.). The climate suitability regionalization of loquat cultivation is further revealed. Main results are shown as follows:

The active accumulated temperature over most Lishui is more than 4500 °C. The areas with the highest active accumulated temperature (> 5500 °C) concentrate in the low altitude areas. The annual rainfall amount above 1600mm. As far as the basic climatic conditions are concerned, it is very suitable for the loquat cultivation with high-quality over Lishui.

The frozen days during the flowering period of loquat are less than 10.0d over Lishui. The frozen injury days are less in the flowering period than in the young fruit period. These areas with more serious frozen injury in the young fruit period and flowering period mainly occur in the areas with relative higher altitude above 1000 m.

The mean annual continuous rain occurrences range from 3.3 to 7.5 times. The occurrence of continuous rain less than 4.5 times is only located over the regions with relatively low altitude. The occurrences of continuous high temperature are less than 1.0 times in most Lishui.

The suitable regions for the loquat cultivation in Lishui are large (41.17 km², 23.8% of total area of Lishui), and most of them are mainly located in the flat areas such as river valleys and basins. The most suitable areas for the loquat cultivation are mainly located along the banks of the Oujiang River in Qingtian, Xiaoxi River valley in Jingning, the central part of Liandu to Yunhe. In addition, the most suitable areas are also distributed in the Huangtan, Zhukou to Qingyuan County and Longquan District to Daoxiang Town. The regions with suitable or higher level are mainly distributed along the banks of the Oujiang River in Qingtian (9.00 km²), followed by Longquan (7.86 km²) and Liandu (6.38 km²). Altitude has an import impact on loquat cultivation, meanwhile, the microclimatic factors also significantly affect the distribution of suitable areas.
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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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