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Spatiotemporal Characteristics of Drought and Wet Events and Their Impacts on Agriculture in the Yellow River Basin

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Abstract: Droughts and floods have proven to be threats to food security worldwide. This research used the standardized precipitation index (SPI) to examine the spatiotemporal characteristics of drought and wet events from 1961 to 2020 in the Yellow River basin (YRB). Grain yield data were combined to assess how drought and wet frequency have affected the agricultural system. The occurrence frequency of drought was greater than that of wetness in time, drought frequency decreased, and wetness increased. Spatially, the frequency of drought in all provinces except Shanxi was higher than that of wetness. The grain yield per unit area of the YRB was generally highest in Shandong province and lowest in Gansu province. The grain yield per unit area have shown a significant growth trend in the nine provinces of the YRB since 1961. Drought had a negative effect on the grain yield per unit area in each province, while wetness had a positive effect on the grain yield per unit area in all provinces except Shandong. In general, the influence of drought on grain yield per unit area decreased, while the influence of wetness on grain yield per unit area increased. The results indicate that human activities are effective against preventing and controlling drought and wet disasters and can provide a reference for other parts of the world.

Keywords: drought; wet; standardized precipitation index; agriculture; Yellow River basin

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1. Introduction

In recent years, severe droughts and floods have occurred on all continents worldwide. Some scholars have assessed the impact of global change on flood and drought risk in Europe and proposed that the frequency of floods has increased in northern and north-eastern Europe, while the frequency of droughts has increased significantly in southern and south-eastern Europe [1,2]. Kourgialas et al. [3] assessed the impact of climate change on drought or flood in the region based on the standardized precipitation index (SPI) in northwestern Crete in Greece from 1960 to 2019, pointing out that there have been frequent droughts and floods in the region in recent decades. The authors also predicted that drought would become more frequent in the coming decades. Likewise, floods and droughts pose management challenges and risks to ecosystems in western Canada, and these challenges and risks are expected to intensify in a warmer climate [4]. Ekwezuo et al. [5] analyzed the regional characteristics of meteorological drought and flood in West Africa and found that the severity of drought in the region showed a decreasing trend, while the severity of floods increased; however, droughts and floods have always been the biggest threats to food production and security in West Africa. Scholars have evaluated the frequency of drought/flood severity in the Luvuvhu River basin, Limpopo Province, South Africa, and found that the frequency of moderate to severe drought increased from south to north, with most of the basin affected by severe drought, sloping to the northeast of the basin, and the northwestern parts of the basin experienced a high frequency of severely wet to extremely wet conditions [6].

Research has shown that meteorological drought in the Yellow River basin (YRB) has been increasing, and its distribution is expanding [7–9], while drought has shown a decreasing trend on both seasonal and annual scales [10]. At the seasonal scale, the frequency of drought in spring and summer was greater than that in autumn and winter [9,11], and the drought severity in spring and winter was higher than that in summer and autumn [12]. On the spatial scale, the drought degree in the northwest was higher than that in the southwest, and agriculture in northeast, northwest and north China was most affected by drought [13,14]. The YRB is one of the areas in China with the most frequent drought and flood disasters, especially drought disasters, and the drought-affected area is expanding each year [15,16]. In recent years, the drought in the upper and middle reaches of the YRB has intensified, while the drought in the lower reaches has eased [17]. Flood disasters in this basin have also been increasing overall, with "slight flood, but serious disaster" and heavy losses occurring occasionally [18]. There have been frequent floods in the middle and lower reaches of the Yellow River [19,20]. However, the possibility of flooding in the future is likely to be reduced [18].

Drought and flood disasters occur frequently on all continents worldwide, and the resulting food security problems have attracted increasing international attention. McCarthy et al. [21] analyzed the impact of drought and flood on crop production in Malawi and found that crop production was severely affected by flood and drought, with an average loss between 32 and 48 percent; however, bean intercropping can provide protection against flood and drought, while green belts can provide protection against floods. Scholars assessed the flood and drought problems affecting rice cultivation in the Mun River basin in Thailand and pointed out that floods and droughts in Thailand had adverse effects on rice cultivation in this region [22]. Venkatappa et al. [23] analyzed the impact of drought and floods on farmland and yields in southeast Asia and found that dryland crops in Thailand, Cambodia, and Myanmar were strongly affected by drought, while Indonesia, the Philippines, and Malaysia were more affected by floods during the same period. In China, both in time and in space, the impact of drought on crops is significantly greater than that of floods, and the impact of floods and droughts on agriculture is generally declining [13]. However, agricultural production losses caused by floods and droughts in most areas of China have significantly increased [24]. For example, the agricultural area affected by drought and flood disasters in northeastern China has increased, and the main disaster type has been drought [25]. There were some areas where the impact of floods on agriculture was greater than that of drought, such as in the middle and lower reaches of the Yangtze River [26]. Overall, the effects of drought and flood disasters on agriculture vary with zone and period. In the irrigated regions of arid areas, there was a positive correlation between flood and grain production, while in other arid areas, there was no obvious relationship between the two [27]. The impact of drought on grain production in northeastern China was more serious from May to July [28]. Before 2004, China's droughts and floods had a significant impact on food production, but afterwards, the extent of agricultural disasters was significantly reduced [29].

The YRB is a vast area. Due to the influence of various factors, such as terrain and altitude, the characteristics of drought and wetness in different provinces and regions are different, and the characteristics of agricultural production affected by drought and wetness also differ, but the relevant research is still incomplete. For example, most of the previous studies examined only the impact of drought on agriculture, ignoring the impact of wetness on agriculture, and considered only the impact of climate change on agricultural production in the YRB; in contrast, they did not discuss the changing trend of this impact. On the basis of previous studies, this paper not only discusses the impact of drought and wetness on agriculture but also discusses the changing trend of this effect, as this information can be used to predict the impact of drought and wetness on various provinces and regions in the future. Specifically, the research addressed the following four questions: (1) What are the annual and seasonal characteristics of drought and wet events in the nine provinces of the YRB on temporal and spatial scales; (2) what is the spatiotemporal distribution of crop yield; (3) how do different degrees of drought and wet events affect agriculture; and (4) what is the change trend of the impact?

The significance of this study is to provide guidance for the prevention and control of drought and wet disasters in the YRB and the adjustment of agricultural planting structures in various provinces. This research is of great significance for reducing food production losses and promoting high-quality development of the YRB.

2. Materials and Methods

2.1. Study Area

The Yellow River, with a total length of 5464 km, known as China's "mother river", originates from the Bayan Kara Mountains, flowing through nine provinces and regions, including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong, and the river empties into Bo Bay in Shandong Province [9,16]. The nine provinces in the Yellow River Basin are located between 95°53′~126°04′ E and 32°10′~ 53°23′ N, spanning the three-step landform in China. The basin includes many topographic units, such as the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, Central Shaanxi Plain, North China Plain, and Shandong Hills, and the basin topography is characterized by being high in the west and low in the east, high in the north and low in the south [14] (Figure 1). The YRB is located in the westerly zone of atmospheric circulation, and most of the basin is located in arid and semiarid regions. Precipitation decreases from southeast to northwest, with an annual average of 476 mm, and it is mostly concentrated in summer. The overall distribution of temperature gradually decreases from south to north and from east to west, and the annual average temperature is between −4°C and 14°C [18]. The cultivated land area of the nine provinces in the YRB is vast, accounting for 18.81% of the total area of the whole region, and the cultivated area is concentrated in the middle and southeast of the region. Henan, Shandong, Inner Mongolia, and Sichuan Provinces are the provinces in the basin with large grain outputs in China, and the main grain crops are wheat and rice.

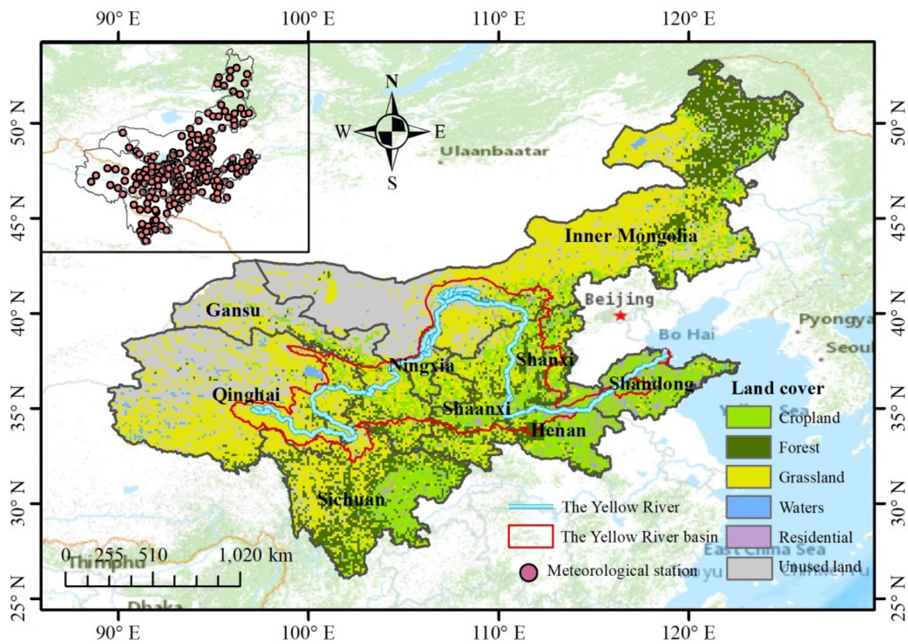

Figure 1. Meteorological stations and land use distribution map in the nine provinces of the Yellow River basin.

2.2. Materials

2.2.1. Precipitation Data

All the data related to grain yield use in the provinces are presented as statistical units. To ensure the consistency of the data, the precipitation data used in this paper were expanded to the nine provinces in the YRB. The precipitation data for the nine provinces in the YRB from 1961 to 2020 came from the "Daily Value Data Set of Surface Climate Data in China (V3.0)" of the National Meteorological Information Center (http://data.cma.cn accessed on 24 June 2021), which has a total of 227 meteorological stations. After removing the meteorological stations with missing data, 190 meteorological stations were selected. The daily value data were processed based on the site into monthly value data.

2.2.2. Grain Production Related Data

The data related to grain output for each province in the Yellow River region used in this study were derived from the State Statistics Bureau (https://data.stats.gov.cn accessed on 12 August 2021). The data included grain yield per unit area (1961–2018), effective irrigation area (1978–2019), and fertilizer application amount (1979–2019). The grain crops in the grain yield data used in this study included cereals, beans, and tubers, and the cereals were further divided into rice, wheat, and maize.

2.3. Methods

2.3.1. Standardized Precipitation Index (SPI)

The standardized precipitation index (SPI) is simple to calculate and requires only precipitation data [30]. The SPI is widely used to monitor drought and wetness [31,32]. The SPI of different scales can reflect the level of drought and wetness at different time scales [33,34]. For example, the one-month scale SPI (SPI1) is based on the precipitation of the previous month, while the three-month SPI (SPI3) considers the rainfall of the previous three months and can characterize agricultural drought and wetness. The twelve-month scale SPI (SPI12) can characterize long-term drought and wetness by considering the precipitation of the previous 12 months. In this paper, SPI3 and SPI12 were used to analyze the characteristics of drought and wetness in the nine provinces of the YRB on a seasonal scale and annual scale, respectively.

The SPI was calculated by the visual SPI calculation program developed by the American National Drought Mitigation Center, which was recognized by the International Meteorological Organization (https://drought.unl.edu/monitoring/SPI/SPIProgram.aspx accessed on 20 June 2021). The monthly SPI based on the site was averaged by province, which was taken as the monthly SPI of the province. According to previous studies [23,30,32], the SPI values were divided into different degrees of drought and wetness (Table 1).

Table 1. Standardized Precipitation Index (SPI) drought and wetness degrees classification.

SPI Value	Grades of Drought and Wetness
$SPI \leq -2$	Extreme drought
$-2 < SPI \leq -1.5$	Heavy drought
$-1.5 < SPI \leq -1$	Moderate drought
$-1 < SPI \leq -0.5$	Light drought
$-0.5 < SPI \leq 0.5$	Normal
$0.5 < SPI \leq 1$	Light wetness
$1 < SPI \leq 1.5$	Moderate wetness
$1.5 < SPI \leq 2$	Heavy wetness
$SPI > 2$	Extreme wetness

2.3.2. Univariate Regression Trend Analysis

Univariate regression trend analysis is a regression analysis method used for a group of variables changing with time, and it can be used to predict the changing trend of a variable. The calculation formula is as follows:

$$S = \frac{n \times \sum_{i=1}^{n} (i \times A_i) - \sum_{i=1}^{n} i \times \sum_{i=1}^{n} A_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \quad (1)$$

where S is the trend; n represents the total number of years; i represents the time ordinals; and A_i represents the corresponding value in time i. When S > 0, the data show an increasing trend in n years; when S = 0, the data series does not change in n years; when S < 0, the data series shows a decreasing trend in n years. In this paper, this method was used to analyze the temporal variation trend of the drought and wet characteristics of the nine provinces in the YRB from 1961 to 2020.

2.3.3. Partial Correlation Analysis

Partial correlation analysis, also known as net correlation analysis, mainly analyses the linear correlation degree between two variables under the control of other related variables and is committed to eliminating the transfer effect of correlation between other variables. When the number of control variables is 1, the partial correlation coefficient is the first-order partial correlation coefficient. When the number of control variables is 2, the partial correlation coefficient is the second-order correlation coefficient (controlling multiple variables and so on). When the number of control variables is 0, the partial correlation coefficient is called the zero-order partial correlation coefficient, which is the bivariate correlation coefficient.

2.3.4. Grey Correlation Analysis

Grey correlation analysis is a method used to measure the degree of correlation between two factors according to the development trend between them [35]. This method can overcome the deficiency of mathematical statistics in analyzing meteorological disaster statistical data to a certain extent, and the grey correlation curve can be obtained to visualize the relationship between the two factors. The closer the curve is, the greater the correlation degree is and vice versa.

3. Results

3.1. Spatiotemporal Characteristics of Drought and Wetness

3.1.1. Intra-Annual Distribution

Based on SPI3, the frequencies of different degrees of drought and wet events in spring, summer, autumn, and winter in the nine provinces of the YRB from 1961 to 2020 were calculated (Figure 2). The spring seasons of 1962, 1979, 1984, 1985, 1986, 1995, 2000, and 2001 were all dry seasons, and the frequency of drought was high. Drought was the most serious in the spring of 1962, and it had a frequency of 81.47%, among which the frequency of extreme drought was 3.70%. The spring seasons of 1964, 1967, 1990, 1991, and 1998 were the wet seasons, with a high frequency of wetness. In the spring of 1990, the frequency of wetness was 88.88%, among which the frequency of extreme wetness was 14.81%. Overall, the frequencies of drought and wetness in spring in the nine provinces of the YRB were consistent, but the frequency of drought was decreasing (S = −0.0374), while the frequency of wetness was increasing (S = 0.0321) (Table 2).

In the past 60 years, there were no extreme drought and wet events in the nine provinces of the YRB in summer. Only the summer seasons of 1965, 1968, 1969, 1997, and 2001 were dry seasons, and the frequency of drought was greater than 50%. Drought was the most serious in the summer of 2001, and it had a frequency of 66.66%, in which the frequency of heavy drought was 3.70%. The summer seasons of 1964, 1984, 1998, 2012, 2013, and 2018 were wet seasons, and the frequency of wetness was higher. The summer of 2018 was the most serious wet season, with a frequency of 62.96%, and the frequency of heavy wet seasons was 3.70%. Overall, the frequency of summer wetness in the nine provinces of the YRB was greater than that of drought, and the frequency of drought showed a downwards trend (S = 0.0589), while the frequency of wetness showed an increasing trend (S = 0.0544) (Table 2).

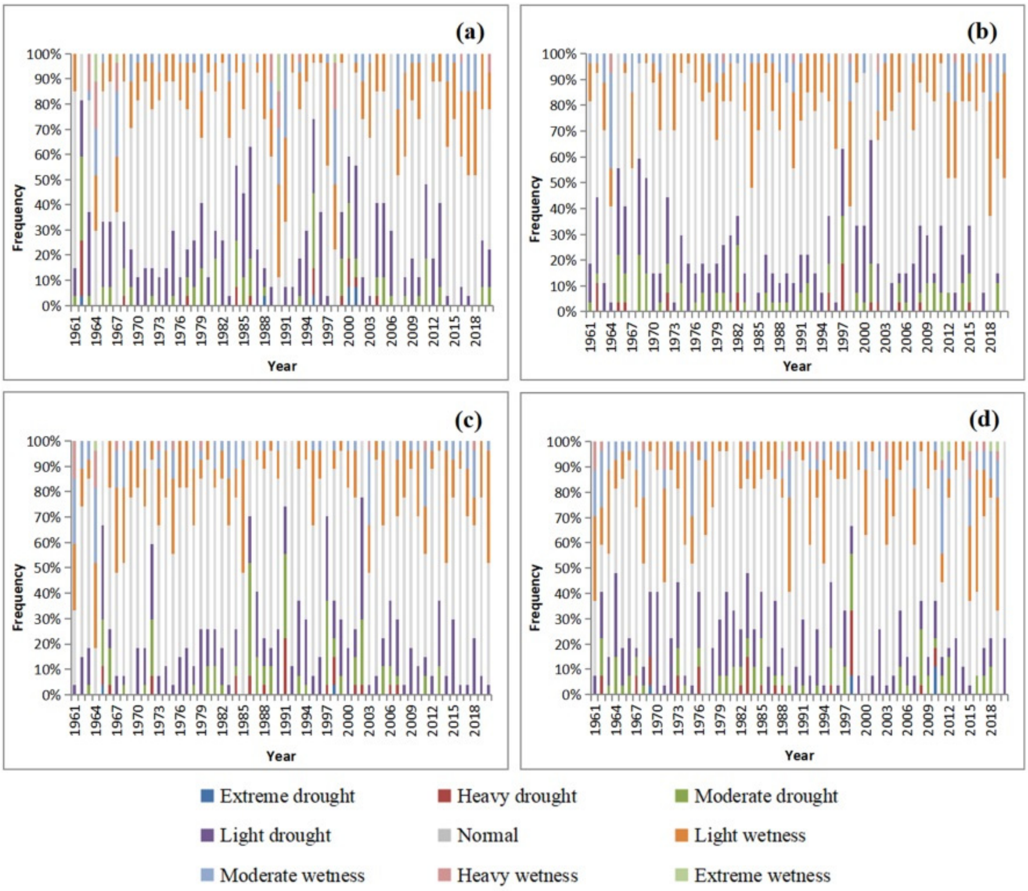

Figure 2. Frequency of different degrees of drought and wet events in spring (**a**), summer (**b**), autumn (**c**), and winter (**d**) in nine provinces of the Yellow River basin from 1961 to 2020.

The autumn seasons of 1965, 1972, 1986, 1991, 1997, and 2002 were dry seasons, and the frequency of drought was relatively high. The drought in autumn of 2002 was the most serious, with a frequency of 77.78%, among which the frequency of severe drought was 3.70%. In 1961, 1964, 1967, 1968, 1985, 2003, 2011, and 2014, the frequency of autumn wetness was relatively high. In the autumn of 1964, the frequency of wetness even reached 81.48%, among which the frequency of extreme wetness was 3.70%. Overall, the frequency of wetness in autumn in the nine provinces of the YRB was greater than that of drought, the frequencies of drought and wetness both showed a downwards trend, and the trend of wetness (S = −0.0412) was higher than that of drought (S = −0.0013) (Table 2).

The winter seasons of 1964, 1973, 1983, and 1998 were dry seasons, and the frequency of drought was relatively high. The drought in the winter of 1998 was the most serious, with a frequency of 66.67%, among which the frequency of extreme drought was 7.41%. In 1961, 1963, 1968, 1971, 1989, 2011, 2015, 2016, and 2019, the frequency of winter wetness was relatively high. In the winter of 2019, the frequency of wetness reached 66.67%, among which the frequency of extreme wetness was 3.70%. Overall, the frequency of winter wetness in the nine provinces of the YRB was greater than that of drought, and the frequencies of drought and wetness both showed a downwards trend, with drought having a decreasing trend (S = −0.0580) that was higher than that of wetness (S = −0.0008) (Table 2).

Generally, from 1961 to 2020, the nine provinces of the YRB experienced drought most often in spring, followed by autumn and finally summer. Wetness most frequently occurred in winter, followed by spring and finally summer. The frequency of wetness in summer, autumn, and winter was slightly higher than that of drought, though the frequency of drought and wetness in spring was the same. The drought frequency in spring, summer, autumn, and winter all showed a downwards trend, while the wetness frequency showed a downwards trend in autumn and winter and an upwards trend in spring and summer. However, the number of droughts in the nine provinces of the YRB overall showed a downwards trend, while the number of wet events showed an upwards trend (drought: S = −0.0766, and wetness: S = −0.0661) (Table 2).

Table 2. Trends of drought and wet events in the nine provinces of the Yellow River basin from 1961 to 2020.

		Spring	Summer	Autumn	Winter	Year
Gansu	Drought	−0.0071	−0.0075	−0.0024	−0.0153	−0.0368
	Wetness	0.0059	0.0086	−0.0111	0.0032	0.0256
Qinghai	Drought	−0.0153	−0.0176	−0.0056	−0.0153	−0.0775
	Wetness	0.0284	0.0210	0.0103	0.0103	0.0971
Inner Mongolia	Drought	−0.0116	−0.0037	0.0041	−0.0080	0.0372
	Wetness	0.0089	0.0104	0.0044	0.0182	0.0326
Shanxi	Drought	−0.0048	−0.0021	−0.0047	0.0010	−0.0011
	Wetness	−0.0058	−0.0065	−0.0117	−0.0061	−0.0457
Ningxia	Drought	0.0045	−0.0137	−0.0096	−0.0090	−0.0396
	Wetness	0.0029	0.0051	−0.0112	−0.0025	0.0100
Shaanxi	Drought	0.0092	−0.0045	0.0007	0.0000	−0.0028
	Wetness	−0.0067	0.0035	−0.0060	−0.0047	−0.0171
Shandong	Drought	−0.0020	0.0021	0.0059	−0.0008	0.0088
	Wetness	−0.0074	−0.0069	−0.0046	−0.0056	−0.0645
Sichuan	Drought	−0.0153	−0.0075	0.0057	0.0001	0.0216
	Wetness	0.0099	0.0131	−0.0056	−0.0062	0.0243
Henan	Drought	0.0048	−0.0044	0.0046	−0.0108	0.0136
	Wetness	−0.0040	0.0062	−0.0057	−0.0073	0.0039
Whole	Drought	−0.0374	−0.0589	−0.0013	−0.0580	−0.0766
	Wetness	0.0321	0.0544	−0.0412	−0.0008	0.0661

3.1.2. Annual Distribution

Due to the diversity of climate change, the characteristics of drought and wetness are different in different years. Based on SPI12, the frequency of different drought and wetness grades in the nine provinces of the YRB from 1961 to 2020 was calculated (Figure 3). The frequencies of drought and wetness in different years were obviously different. In 1966, 1973, 1981, 2000, and 2001, drought was dominant, and the frequency of drought was higher than that of wetness and normal conditions. Drought was particularly serious in 1966 and 2000, with the drought frequency reaching 60.19%, while extreme drought occurred in 1966, and the frequency of light drought in 2000 was 45.37%. In 1961, 1964, 2018, 2019, and 2020, the frequency of wetness was higher than that of drought and normal conditions. In 2018, wetness conditions were the most serious, with a frequency of 58.33%. The remaining years were normal, and the frequency of normal conditions was highest in 2016, reaching 84.26%. Generally, the frequency of drought in the nine provinces of the YRB was greater than that of wetness, but the frequency of drought was decreasing, while the frequency of wetness was increasing (Table 2).

3.2. Spatial Characteristics of Drought and Wetness

3.2.1. Spatial Characteristics on a Seasonal Scale

The seasonal climate characteristics in the nine provinces of the YRB were significantly different, and the spatial distribution of seasonal precipitation was uneven. Based on SPI3, we calculated the frequency of drought and wetness in different seasons in the nine provinces over the past 60 years (Figure 4). The grades of drought and wetness in the nine provinces and regions were mainly normal. In spring, the frequencies of drought and wetness were the highest in Shandong, with values of 28.33% and 28.89%, respectively, while in Inner Mongolia, they were the lowest, with values of 14.44% and 16.11%, respectively. In summer, Ningxia had the highest frequency of drought and wetness (31.11% and 28.89%), while Sichuan had the lowest frequency of drought and wetness (10.56% and 11.11%). In addition, there was no extreme drought or wetness in any province or region. In autumn, the frequency of drought was highest in Shaanxi Province (27.22%), Sichuan had the lowest frequency of drought and wetness (16.11% and 12.78%), and Shandong and Henan had the highest frequency of wetness (27.78%). In winter, the frequency of drought was highest in Shanxi (26.11%) and lowest in Inner Mongolia (16.11%), while the frequency of wetness was highest in Henan (30.56%) and lowest in Sichuan (16.67%). In summary, Gansu was prone to drought in summer; Qinghai was prone to wetness in summer; Sichuan and Inner Mongolia had less drought and wetness in the four seasons; Shanxi was prone to drought in winter; and Ningxia was prone to drought in summer and winter and to wetness in spring, summer, and autumn. Drought frequently occurred in spring and autumn in Shaanxi. Shandong was prone to drought in spring, but it was prone to wetness in spring, autumn, and winter. Henan was prone to drought in spring and autumn but had frequent wetness in spring, autumn, and winter.

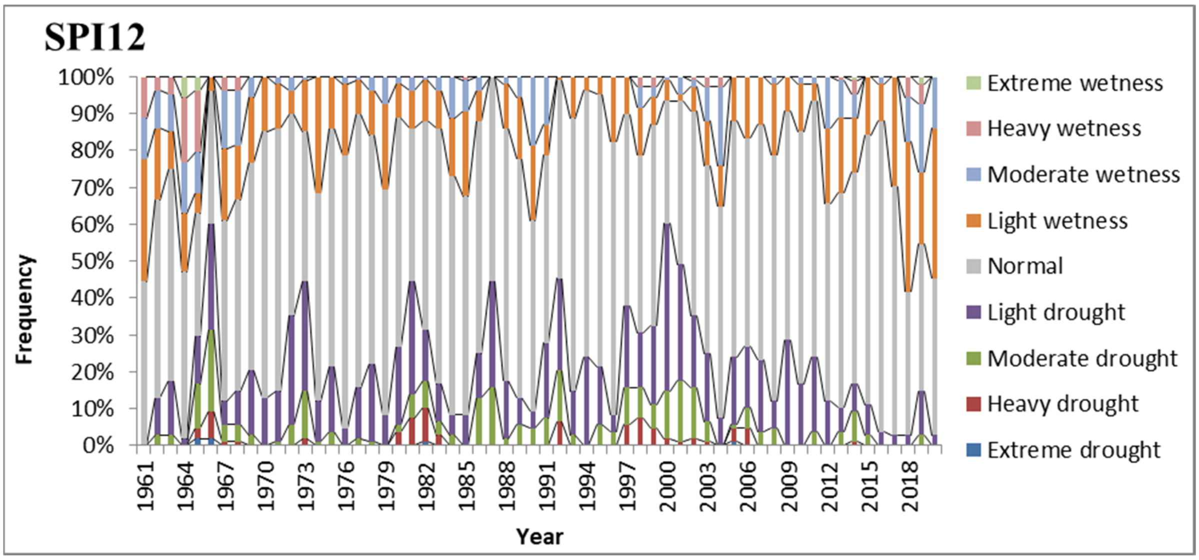

Figure 3. Frequency of different degrees of drought and wetness in the nine provinces and regions of the Yellow River basin from 1961 to 2020.

In the past 60 years, the occurrence trends of drought and wetness in different seasons in different provinces and regions were quite different (Table 2). In spring, only Ningxia, Shaanxi, and Henan Provinces showed an increasing trend among the nine provinces, while the other provinces showed a decreasing trend. The frequency of wetness in Shanxi, Shaanxi, Shandong, and Henan decreased, while that in the other provinces increased. In summer, drought increased in Shandong, while it decreased in the other provinces. Wet conditions decreased in Shanxi and Shandong, while wet conditions increased in the other provinces. In autumn, drought in Gansu, Qinghai, Shanxi, and Ningxia showed a decreasing trend, while the other provinces had an increasing trend. Wet conditions increased in Qinghai and Inner Mongolia, while they decreased in other provinces and regions. In winter, drought increased in Shanxi and Sichuan, and in Shaanxi, it remained basically unchanged, while that in the other provinces and regions decreased. Wet conditions increased in Gansu, Qinghai, and Inner Mongolia but decreased in the other provinces.

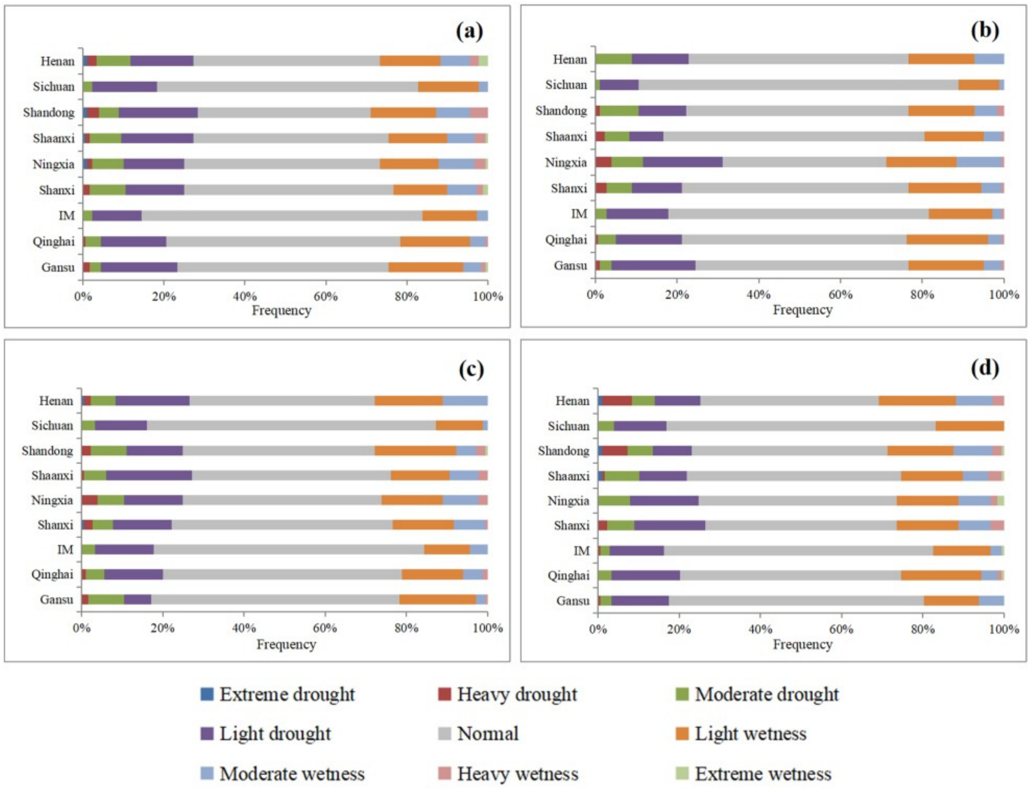

Figure 4. Characteristics of drought and wetness in spring (**a**), summer (**b**), autumn (**c**), and winter (**d**) in the Yellow River basin.

3.2.2. Spatial Characteristics on an Annual Scale

The nine provinces and regions of the YRB had significant differences in climatic characteristics, and the spatial distribution of interannual precipitation was uneven. Therefore, based on SPI12, the frequency of different drought and wet characteristics in the nine provinces and regions over the past 60 years was calculated (Figure 5). As seen from the figure, in the past 60 years, the frequency of drought events in all provinces except Shanxi was higher than that of wet events, but overall, all provinces and regions were mainly normal, though Sichuan had the highest drought frequency (74.89%) and Ningxia the lowest drought frequency (43.02%). Shanxi had the highest frequency of extreme drought (0.56%), followed by Ningxia (0.28%). The frequency of extreme drought in other provinces was 0. Shandong had the highest frequency of extreme wetness (1.13%), Qinghai and Ningxia had the same frequency of extreme wetness (0.28%), Shaanxi had only one extreme wet event, and the other provinces and regions had no extreme wet events. There was no extreme drought, heavy drought, extreme wetness, or heavy wetness in Sichuan. Table 2 shows that the drought in Inner Mongolia, Shandong, Sichuan, and Henan Provinces increased overall, while the wetness in Gansu, Qinghai, Inner Mongolia, Ningxia, Sichuan, and Henan Provinces increased overall. However, the change trends of the drought and wet grades in different provinces and regions were different (Figure 6). For example, heavy drought and light wetness in Gansu Province increased, while moderate drought, light drought, and moderate wetness decreased. All drought grades decreased in Qinghai, and wetness showed an increasing trend except for heavy wetness. Drought and wetness at all grades in Inner Mongolia increased. In Shanxi, extreme drought and heavy drought decreased, moderate drought and light drought increased, and all grades of wetness decreased.

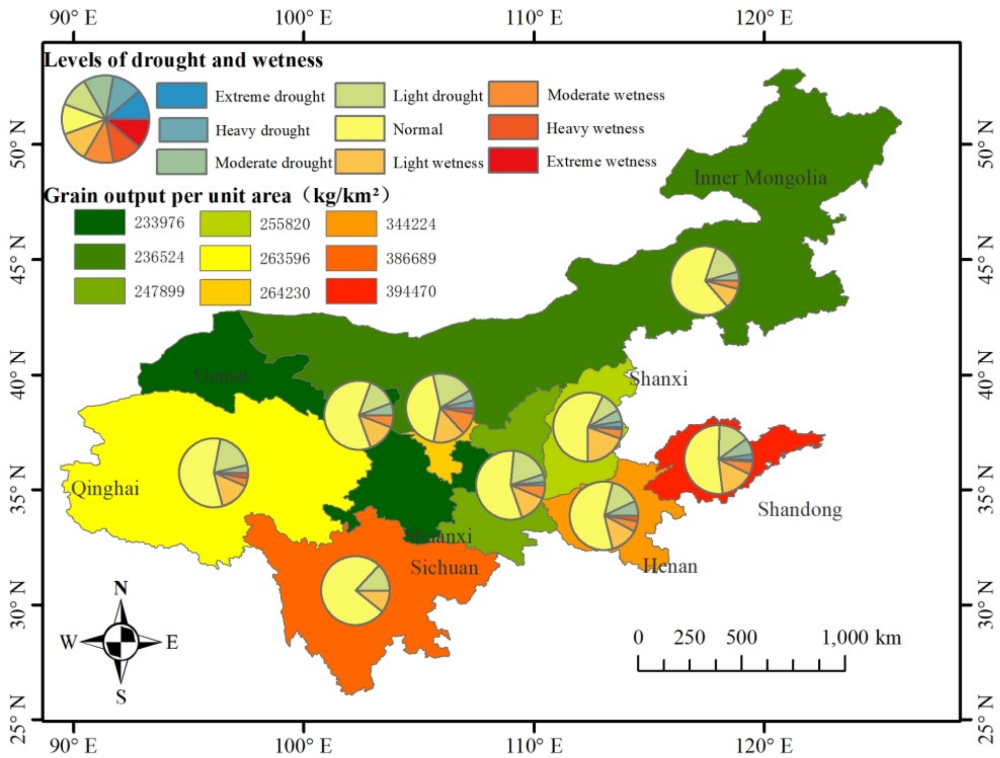

Figure 5. Spatial distribution of drought and wet degrees and grain output per unit area in the Yellow River basin from 1961 to 2020.

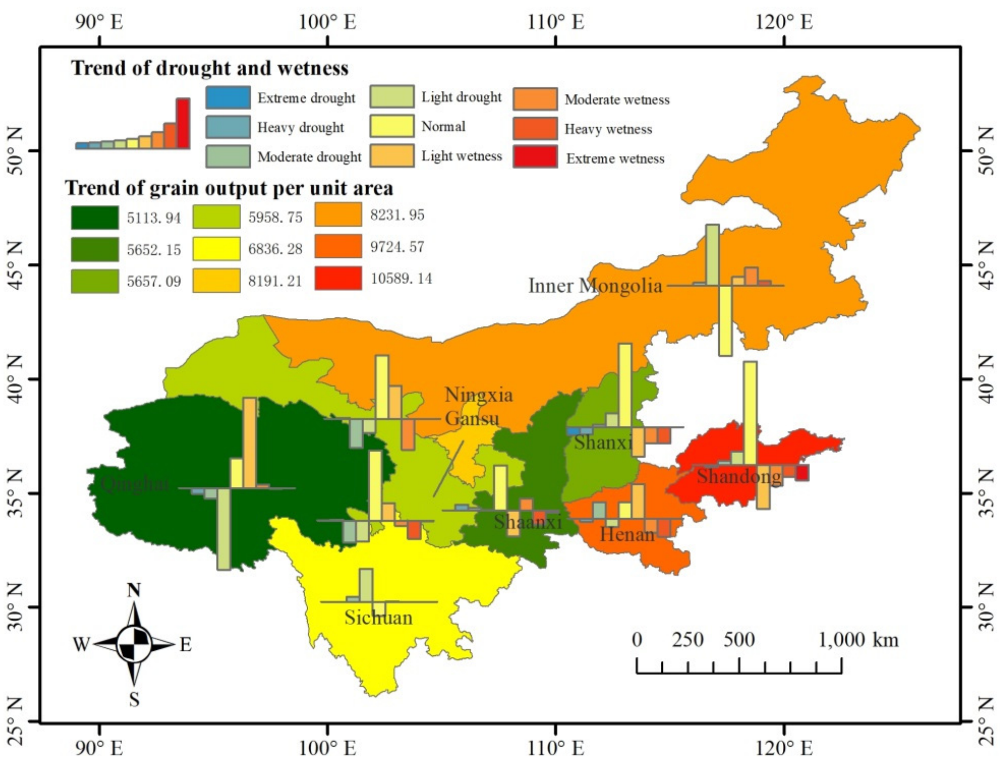

Figure 6. Spatial distribution of drought and wetness degree trends and grain yield per unit area trends in various provinces and regions of the Yellow River basin.

3.3. Influence of Drought and Wetness on Grain Yield in the Yellow River Basin

3.3.1. Temporal and Spatial Distribution Characteristics of Grain Yield per Unit Area

Spatially, the grain yield per unit area of the nine provinces in the YRB were generally highest in Shandong (394470 kg/km^2) and lowest in Gansu (233976 kg/km^2) (Figure 5). Over time, the grain yield per unit area in every province of the YRB showed a significant increasing trend ($p < 0.01$) since 1961, among which Shandong had the highest increasing trend and Qinghai had the lowest increasing trend (Figure 6). The average annual growth rate of grain yield per unit area in each province was 3%.

3.3.2. Influence of Drought and Wet Events on Grain Yield per Unit Area

Based on SPI12 and the grain yield per unit area data, we analyzed the effects of drought and wetness on grain yield per unit area in the YRB on the annual scale. Because grain yield was affected not only by drought and wet disasters but also by cultivated land area, sown area, fertilizer application amount, effective irrigation area, and other factors, the grain yield per unit area was selected to eliminate the influence of cultivated land area and sown area on grain yield. Using the fertilizer application amount and effective irrigation area as control variables, partial correlation analysis was carried out between drought frequency and grain yield in each province. Using the amount of chemical fertilizer as the control variable, partial correlation analysis was performed between the frequency of wetness and the per unit area yield of grain in each province (Table 3). To ensure the consistency of the data, 1979–2018 was selected as the analysis period by integrating various data time ranges.

There were obvious regional effects of drought and wetness on grain yield per unit area (Table 3). During the study period, drought and grain yield per unit area were negatively correlated in all provinces, among which Inner Mongolia, Shanxi, and Shaanxi had the higher partial correlation coefficients and passed the significance test at the 0.01 level. With the exception of Shandong, there was a positive correlation between wetness and grain yield per unit area, among which Shanxi, Ningxia, and Gansu had the highest partial correlation and passed the significance test at the 0.01 level. However, in Shandong, Henan, and Qinghai Provinces, there was little correlation between drought and wetness and grain yield per unit area. For each province, the partial correlation between wet and grain output per unit area in Gansu, Qinghai, and Ningxia was higher than that in drought, but the other provinces showed the opposite trend. Generally, drought had a great influence on grain yield per unit area, and all grades of drought were negatively correlated with grain yield per unit area. Wetness had little influence on grain production per unit area, and most wetness grades were positively correlated with grain yield per unit area.

The effects of different drought and wet grades on grain output per unit area in different provinces and regions were also different (Table 3). During the study period, heavy drought had the greatest impact on grain yield per unit area in Shandong (R = −0.401, $p < 0.05$); moderate drought, light drought, and light wet all had the greatest influence on grain yield per unit area in Shanxi (R = −0.411, −0.613 and 0.603, $p < 0.01$); medium wetness had the greatest influence on grain yield per unit area in Gansu (R = 0.411, $p < 0.01$); and heavy wetness had the greatest impact on grain yield per unit area in Henan (R = −0.383, $p < 0.05$). In Gansu, Inner Mongolia, Shanxi, Shaanxi, and Sichuan, light drought had the greatest impact on grain yield per unit area (R = −0.427, −0.594, −0.613, −0.539, and −0.342). In Qinghai, moderate drought had the greatest influence on grain yield per unit area (R = −0.310). In Ningxia and Henan Provinces, light wetness had the greatest impact on grain yield per unit area (R = 0.414 and 0.389). In Shandong Province, heavy drought had the greatest impact on grain yield per unit area (R = −0.401).

Table 3. Partial correlation coefficient between drought and wetness frequency and grain yield per unit area in the Yellow River basin from 1979 to 2018.

		Gansu	Qinghai	Inner Mongolia	Shanxi	Ningxia	Shaanxi	Shandong	Sichuan	Henan
Drought	R	−0.377 *	−0.176	−0.622 **	−0.606 **	−0.349 *	−0.520 **	−0.279	−0.373 *	−0.253
	P	0.020	0.290	0.000	0.000	0.032	0.001	0.090	0.021	0.125
Wetness	R	0.447 **	0.193	0.179	0.596 **	0.488 **	0.365 *	−0.054	0.222	0.252
	P	0.004	0.239	0.276	0.000	0.002	0.022	0.743	0.175	0.121
Extreme drought	R	/	/	/	/	−0.100	/	/	/	/
	P	/	/	/	/	0.550	/	/	/	/
Heavy drought	R	−0.085	/	/	0.056	−0.157	0.071	−0.401 *	/	0.177
	P	0.614	/	/	0.737	0.348	0.673	0.013	/	0.287
Moderate drought	R	0.033	−0.310	−0.253	−0.411 **	−0.298	−0.186	−0.178	−0.238	−0.184
	P	0.844	0.059	0.125	0.010	0.069	0.264	0.286	0.151	0.270
Light drought	R	−0.427 **	−0.081	−0.594 **	−0.613 **	−0.299	−0.539 **	−0.109	−0.342 *	−0.267
	P	0.007	0.627	0.000	0.000	0.068	0.000	0.514	0.035	0.105
Normal	R	0.072	0.044	0.184	0.050	−0.098	0.213	0.146	0.179	0.004
	P	0.666	0.794	0.268	0.765	0.560	0.200	0.382	0.282	0.983
Light wetness	R	0.369 *	0.218	−0.010	0.603 **	0.414 **	0.366 *	−0.147	0.222	0.389 *
	P	0.021	0.183	0.951	0.000	0.009	0.022	0.372	0.175	0.014
Moderate wetness	R	0.411 **	−0.004	0.286	0.231	0.325 *	0.195	0.066	/	0.082
	P	0.005	0.979	0.077	0.157	0.043	0.234	0.692	/	0.618
Heavy wetness	R	/	0.061	/	/	0.238	/	/	/	−0.383 *
	P	/	0.711	/	/	0.144	/	/	/	0.016
Extreme wetness	R	/	/	/	/	0.250	/	/	/	/
	P	/	/	/	/	0.125	/	/	/	/

Note: R refers to partial correlation coefficient; P refers to the significance test. * Significant correlation at 0.05 levels (bilateral). ** Significant correlation at 0.01 levels (bilateral) "/"refers to the grade of drought or wetness has not occurred

3.3.3. Grey Correlation Analysis of Grain Yield per Unit Area and Related Factors

Partial correlation analysis could not sufficiently explain the impact of drought and wet disasters on grain yield per unit area. To improve persuasiveness, based on the statistical data on drought and wet frequency, grain yield per unit area, effective irrigation area, and fertilizer application amount of SPI12 from 1979 to 2018, the grey correlation degree between grain yield per unit area and each of the above factors in the nine provinces was calculated, and the grey correlation degree table (Table 4) was obtained.

Table 4. Grey correlation degree between grain yield per unit area and related influencing factors in Yellow River basin from 1979 to 2018.

		Gansu	Qinghai	Inner Mongolia	Shanxi	Ningxia	Shaanxi	Shandong	Sichuan	Henan
Effective irrigation	D	0.9496	0.9629	0.9576	0.9355	0.9542	0.9271	0.9390	0.9363	0.9412
	Rank	1	1	1	1	1	1	2	2	1
Fertilizer application	D	0.9126	0.9505	0.8667	0.9076	0.8591	0.8878	0.9408	0.9556	0.8431
	Rank	2	2	2	2	2	2	1	1	2
Drought	D	0.6743	0.6944	0.7170	0.6544	0.6320	0.6966	0.7055	0.6722	0.5964
	Rank	5	5	4	5	5	4	4	5	4
Normal	D	0.8739	0.8562	0.8036	0.8401	0.7641	0.8707	0.8411	0.8922	0.7782
	Rank	3	3	3	3	3	3	3	3	3
Wetness	D	0.7036	0.7179	0.6816	0.6614	0.6328	0.6739	0.7015	0.6856	0.5924
	Rank	4	4	5	4	4	5	5	4	5

Note: D refers to the grey correlation degree; Rank represents the serial number of association degree.

By comparing the grey correlation degree between grades of drought and wetness and grain yield per unit area in different provinces and regions, we found that the correlation between drought and grain yield per unit area was highest in Inner Mongolia, and the correlation between wetness and grain yield per unit area was highest in Qinghai, Gansu, and Shandong. The correlation between drought and grain yield per unit area was higher in Inner Mongolia, Shaanxi, Shandong, and Henan Provinces than that under wet conditions. The conclusion of grey correlation analysis was roughly the same as that of the partial correlation analysis, verifying the credibility of the conclusion.

Overall, the effective irrigation area and chemical fertilizer application rate had a great influence on grain yield per unit area, and the effect of drought and wetness on grain yield per unit area was relatively small. According to the ranking of the correlation degree between grain yield per unit area and various factors, the correlation degree between the chemical fertilizer application rate and grain per unit yield was the highest in Shandong and Sichuan Provinces, and it was followed by the effective irrigation area. The correlation degree between the effective irrigation area and grain yield per unit area in other provinces was the highest, followed by the amount of chemical fertilizer (Table 4). The correlation degree between grain yield per unit area and wetness was lowest in Inner Mongolia, Shaanxi, Shandong, and Henan Provinces, and it was followed by drought. The correlation degree between grain yield per unit area and drought was lowest in the other five provinces and regions, followed by wetness (Table 4).

3.3.4. Grey Correlation Trend between Grain Yield per Unit Area and Related Factors

In 1999, China began to implement the ecological construction project of converting farmland into forest or grassland. Considering the impact of this measure on agriculture, the above research period was divided into two stages (1979–1998 and 1999–2018). Based on the above two periods, the grey correlation degree between grain output per unit area and the related factors in the nine provinces was separately calculated, and the change trend of grey correlation degree was assessed (Tables 5 and 6).

Table 5. Grey correlation degree between grain yield per unit area and related influencing factors in Yellow River basin from 1979 to 1998.

		Gansu	Qinghai	Inner Mongolia	Shanxi	Ningxia	Shaanxi	Shandong	Sichuan	Henan
Effective irrigation	D	0.9510	0.9721	0.9668	0.9226	0.9359	0.9542	0.9138	0.9567	0.9390
	Rank	1	1	1	1	1	1	1	1	1
Fertilizer application	D	0.9024	0.9460	0.9305	0.8408	0.8529	0.8448	0.9066	0.9328	0.8392
	Rank	2	2	2	2	2	3	2	2	2
Drought	D	0.7466	0.7024	0.7129	0.5978	0.6718	0.7160	0.6907	0.6784	0.6250
	Rank	4	4	5	4	4	4	4	4	4
Normal	D	0.8895	0.8721	0.9131	0.8069	0.7861	0.8550	0.7922	0.8880	0.8298
	Rank	3	3	3	3	3	2	3	3	3
Wetness	D	0.7060	0.6525	0.7622	0.5734	0.6133	0.6289	0.6323	0.6696	0.5686
	Rank	5	5	4	5	5	5	5	5	5

Note: D refers to the grey correlation degree; Rank represents the serial number of association degree.

Table 6. Grey correlation degree between grain yield per unit area and related influencing factors in Yellow River basin from 1999 to 2018.

		Gansu	Qinghai	Inner Mongolia	Shanxi	Ningxia	Shaanxi	Shandong	Sichuan	Henan
Effective irrigation	D	0.9715	0.9665	0.9707	0.9650	0.9590	0.9393	0.9762	0.9897	0.9711
	Rank	2	2	1	2	2	2	2	1	1
Fertilizer application	D	0.9790	0.9730	0.9457	0.9657	0.9636	0.9469	0.9772	0.9817	0.9516
	Rank	1	1	2	1	1	1	1	2	2
Drought	D	0.6573	0.7515	0.8086	0.6391	0.6036	0.6496	0.6408	0.6860	0.6027
	Rank	5	5	4	5	5	4	5	5	5
Normal	D	0.8906	0.8859	0.8406	0.8605	0.7948	0.8494	0.8196	0.9065	0.7810
	Rank	3	3	3	3	3	3	3	3	3
Wetness	D	0.7203	0.8177	0.6989	0.6787	0.6109	0.6296	0.6611	0.7299	0.6362
	Rank	4	4	5	4	4	5	4	4	4

Note: D refers to the grey correlation degree; Rank represents the serial number of association degree.

In general, in the second stage (1999–2018), compared with the first stage (1979–1998), the influence of the effective irrigation area on grain yield per unit area decreased, and the influence of chemical fertilizer application on grain yield per unit area increased; furthermore, the influence of drought on grain yield per unit area decreased, while the influence of wetness on grain yield per unit area increased.

Combining Tables 2, 3, 5 and 6, we found that drought and wetness in different provinces and regions had different change trends in the past 40 years, their effects on grain output per unit area in different provinces and regions could be divided into positive and negative effects, and the change trend of influence was also different. The drought in the central and western regions of the YRB, such as in Gansu, Qinghai, and Ningxia, showed an overall decreasing trend, which had a negative impact on grain production per unit area, and its influence also showed a downwards trend. However, the wetness in this area showed an increasing trend, which had a positive impact on grain production per unit area, and the influence was increasing. In the northern part of the YRB, such as in Inner Mongolia, drought and wetness showed an increasing trend overall, in which drought had a negative impact on grain production per unit area, and its influence showed an upwards trend. Wetness had a positive impact on grain production per unit area, but its influence showed a downwards trend. In the eastern part of the YRB, such as in Shandong Province, drought showed an overall increasing trend, which had a negative impact on grain production per unit area, but its influence showed a downwards trend. The wetness in this area showed a decreasing trend, which had a negative impact on grain production per unit area, and its influence was increasing.

4. Discussions

Previous studies have found (Table 7) that legumes are more resistant to drought and floods [21], dryland crops are severely affected by drought and floods [23], and non-irrigated crops are more sensitive than irrigated crops to drought. For example, soybean and maize are most sensitive to drought [36], drought reduces maize yields [37], and rice is also severely affected by drought and floods [22]. Drought lasted longer at high altitudes [37]. This paper did not consider the influence of terrain and altitude on drought and wetness and did not discuss the response mechanism of different food crops to different levels of drought and wetness. This represents one inadequate feature of this research and will be improved in future research.

Affected by various factors, such as topography and climate, different regions have different drought and flood characteristics (Table 7). For example, flooding is the most frequent natural disaster affecting Thailand [22], while the most frequent disaster in the YRB is drought [15,16]. Drought frequency is decreasing in the northern Wadi Cheliff Basin and increasing in the southern [38]. The drought in southwestern Zambia is significantly worse, and the drought in northeastern Zambia has been significantly alleviated [39]. Drought has intensified on the North Island of New Zealand, and the rainy season has weakened [40]. The severity of drought in western Apulia has shown an upwards trend, and the eastern region has shown a downwards trend [41]. In this paper, we found that drought events were more common than wet events in the YRB overall, which was consistent with previous conclusions, but the conclusions regarding the overall trend of drought and wetness and the characteristics of drought and floods in different seasons were somewhat different from those of previous studies [13]. For example, some scholars found that drought showed an increasing trend [7–9], but this paper found that drought showed a decreasing trend, which is consistent with the conclusions of Wang [10]. Predecessors found that the frequency of drought in spring and summer was higher than that in autumn and winter [9,11,42,43]. However, this paper found that the frequency of drought in spring and autumn was greater and that in summer was the lowest, which may be related to the difference in the drought index used. The conclusion that the wetness in the YRB has tended to be aggravated is consistent with that of previous studies [18].

Table 7. Research status and important conclusions of drought or flood and their impact on agriculture.

Literature	Study Area	Method/Index	Important Conclusions
[21]	Malawi	household-level data	Crop production outcomes were severely hit by both floods and droughts, with average losses ranging between 32 and 48%. Legume intercropping provided protection against both floods and droughts, while green belts provided protection against floods.
[22]	Mun River Basin in Thailand	SWAT and HEC-RAS	Thailand suffers from periodic floods in the rainy season and droughts in the dry season. Flood is the most frequent natural disaster that has affected Thailand. Drought and flood have adverse effects on rice planting in this region.
[23]	Southeast Asia	PDSI	Rainfed crops were severely affected by droughts and floods. In The past 40 years, the number of droughts and floods has increased. Future climate change may lead to more serious droughts and floods in the region.
[36]	the United States	SPI and SPEI	Among all crops, soybean and corn grain are most sensitive to drought. Non-irrigated crops are more sensitive to droughts than the irrigated crops, particularly in severe drought conditions.
[37]	Veracruz, Mexico	SPI	Between 1980 and 2018, drought intensified, with nearly 50% of the region experiencing drought. The drought reduced the yield of corn. Droughts are more persistent at higher elevations.

Table 7. *Cont.*

Literature	Study Area	Method/Index	Important Conclusions
[38]	The Wadi Cheliff Basin	SPI	The Cheliff Basin is at risk for extreme wet events as well as dry events. The drought frequency shows a downward trend in the northern part of the basin and an upward trend in the southern region.
[39]	Zambia, South Africa	SPI	Compared with the northern region, the drought felt in the southern region is more severe. The drought has obviously increased in the southwest and decreased in the northeast. Both annual and seasonal droughts have increased.
[40]	New Zealand	SPI	In the North Island, SPI showed an overall downward trend, indicating that the drought intensified and the rain period weakened.
[41]	Apulia, Italian	SPI and RDI	The drought severity in the western part of Apulia shows an upward trend, while that in the eastern region shows a downward trend.
[44]	China	Statistic	Drought and flood adversely affect crop production. Drought, however, is affecting a larger cropland area than flood.
[45]	the Modder River basin, South Africa	PDSI	The most severe drought episodes occurred during the period 1992–1995. The number of extreme and moderate drought events showed significant increasing trends during the five decades.
[46]	Poland	SPI	The frequency of meteorological droughts in the studied period amounts to 30.0%. No significant increase in the frequency and intensity of meteorological droughts over time was observed.
[47]	Global	SPI	Yield loss risk tends to grow faster when experiencing a shift in drought severity from moderate to severe than that from extreme to the exceptional category. Temperature plays an important role in determining drought impacts, through reducing or amplifying drought-driven yield loss risk.
This Paper	the Yellow River basin	SPI	The occurrence frequency of drought was greater than that of wetness in time, drought frequency decreased, and wetness increased. Spatially, the frequency of drought in all provinces except Shanxi was higher than that of wetness. The grain yield per unit area of the YRB was generally highest in Shandong and lowest in Gansu. The influence of drought on grain yield per unit area decreased, while the influence of wetness on grain yield per unit area increased.

According to Figure 5 and Table 3, the frequency of drought in Gansu, Qinghai, and Ningxia Provinces is higher than that of wetness, but the impact of wetness on grain yield per unit area is higher than that of drought. The reason for this is that the development of irrigated agriculture in the above three provinces and regions has established complete drought prevention and control facilities, which have reduced the impact of drought on grain production, while lighter wetness events have a greater beneficial impact on grain production, which is consistent with the conclusion of Chen [48]. Extreme wetness can lead to flooding and greater damage to agriculture, but overall, drought affects larger areas of farmland than do floods [44].

The results of the correlation analysis between drought and wetness and grain yield per unit area showed that drought had a weak influence on Henan and Shandong, which indicated that the measures to address drought in these two agricultural provinces are relatively mature. Combined with Figures 5 and 6, it can be seen that the drought in Inner Mongolia has increased in the past 60 years, and Shanxi had the highest frequency of extreme drought, which would have a negative impact on the grain output per unit area of the two provinces. Under the influence of human activities, the impact of drought and wetness on grain production per unit area will be weakened; however, the impact of wetness on grain production will change from a negative to a positive impact, which will alleviate the overall drought disaster situation in these provinces and regions and have a positive impact on food production, such as in Gansu, Shanxi, and Ningxia. However, there are many extreme wetness events in Shandong, which have a negative impact on grain production per unit area.

With the rapid development of science and technology in China, the level of agricultural modernization has improved, and a series of measures, such as building water conservancies, flood storage irrigation, irrigation from the Yellow River, and the cultivation of drought-resistant improved varieties, have enhanced the adaptability of food crops to drought, but the enhancement of evapotranspiration caused by global warming has made the drought intensity and yield loss of food crops still higher than the previous values under the same precipitation conditions. Additionally, the effective utilization of water has enhanced the beneficial impact on grain output, but the different planting structures in different regions cause wetness to have different impacts. The provinces and regions should adjust the agricultural planting structure according to the characteristics of drought and wetness in the different regions and according to the local conditions. It is also necessary to make overall planning in all provinces, regions and units, build reservoirs in the rainy season, and take water for irrigation in the dry season to reduce the adverse impact of drought on agriculture and make full use of the positive impact of wetness on agriculture.

5. Conclusions

This paper analyzed the spatiotemporal distribution of drought/wet events in the YRB and the impact of drought/wetness on grain yield per unit area based on the SPI of the YRB from 1961 to 2020. This information was combined with the data on grain yield per unit area, effective irrigation area, and fertilizer application amount to draw the following conclusions.

On the seasonal scale, the YRB experienced the most drought events in spring. The most frequent occurrence of wetness occurred in winter. The frequency of drought in the four seasons showed a downwards trend, and the wetness showed a decreasing trend in autumn and winter and an increasing trend in spring and summer. On the annual scale, the frequency of drought in the YRB was greater than that of wetness, but the frequency of drought was decreasing, while that of wetness was increasing. On the spatial and seasonal scales, the drought and wet characteristics of each province were different. For example, Gansu was prone to drought in summer; Qinghai was prone to wetness in summer; Shanxi was prone to drought in winter; and Henan was prone to drought in spring and autumn but was wet in spring, autumn, and winter. On the spatial annual scale, the frequency of drought was higher than that of wetness in all provinces except Shanxi in the last 60 years. However, generally speaking, all provinces and regions were normal. Drought should an overall increasing trend in Inner Mongolia, Shandong, Sichuan, and Henan Provinces, while wetness showed an overall increasing trend in Gansu, Qinghai, Inner Mongolia, Ningxia, Sichuan, and Henan Provinces.

The grain yield per unit area of the nine provinces in the YRB was highest in Shandong and lowest in Gansu. Since 1961, the grain yield per unit area of each province in the YRB has shown a significant growth trend ($p < 0.01$). There was a negative correlation between drought and grain yield per unit area in each province. With the exception of Shandong, there was a positive correlation between wet and grain yield per unit area. Light drought had the greatest impact on grain output per unit area in Gansu, Inner Mongolia, Shanxi, Shaanxi, and Sichuan Provinces. Moderate drought had the greatest influence on the grain output per unit area in Qinghai. Light wetness had the greatest impact on grain yield per unit area in Ningxia and Henan Provinces. Heavy drought had the greatest impact on the grain output per unit area in Shandong. The negative impact of drought on grain production per unit area in Inner Mongolia showed an upwards trend, but it was declining in other provinces. The negative impact of wet disasters on grain output per unit area in Shandong showed a downwards trend. The positive impact of wetness on grain production in Inner Mongolia showed a downwards trend, while other provinces showed an upwards trend.

The above conclusion can provide guidance for the prevention and control of drought and wet disasters in the YRB and the adjustment of agricultural planting structures in various provinces. This research is of great significance for reducing food production losses and promoting high-quality development of the YRB. In the future, the frequency of drought and wetness in the YRB may continue to decrease and increase, respectively. Based on the above research, it is suggested that the government increase investment in scientific research while building reservoirs, support agricultural colleges and universities in selecting good crop varieties and improving irrigation techniques in terms of policies and funds, and publicize and popularize fine varieties and advanced technologies to farmers in a timely manner.

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