Article

Climate Change and Its Influence on the Karst Groundwater Recharge in the Jinci Spring Region, Northern China

Zhenxing Jia [1,2], Hongfei Zang [3], Xiuqing Zheng [1,*] and Yongxin Xu [1,4]

[1] College of Water Resources Science and Engineering, Taiyuan University of Technology, Taiyuan 030024, China; jzhx2000@126.com (Z.J.); xuyongxin@tyut.edu.cn (Y.X.)

[2] Shanxi Institute of Water Resources, Taiyuan 030001, China

[3] School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou 450046, China; zhf6344@126.com

[4] Department of Earth Sciences, University of the Western Cape, Cape Town 7535, South Africa; yxu@uwc.ac.za

* Correspondence: zhengxiuqing6818@126.com; Tel.: +86-351-6018455

Abstract: Due to climate change and human activities over the last fifty years, the spring flow volume of karst groundwater has sharply diminished in China. Climate change is one of the critical factors that initiates a series of karst hydrogeologic and water ecological environmental problems, because the precipitation shows a decreasing trend while the temperature shows an increasing trend. The Jinci Spring is one of the largest, most famous springs in northern China. This study employed data from the Taiyuan Meteorological Station and ten precipitation stations in and around the Jinci Spring region as well as the runoff data gathered from two hydrological monitoring stations during 1960–2012. The sliding average method and the Mann-Kendall test were used to analyze the variation tendency of precipitation, temperature, and land evaporation in this area. Finally, the following were calculated: the varying pattern of the karst groundwater recharge amount and the response of the recharge amount to precipitation, land evaporation, and river runoff by quantitative analysis. The results indicated that the precipitation and land evaporation amount decreased at first and then subsequently increased. Likewise, the variation trend of the karst groundwater recharge amount in the spring region was roughly consistent with the precipitation variation pattern. In contrast, the temperature displayed an increasing trend. The climate change resulted in a reduction of the karst groundwater recharge amount, and it had the greatest influence in the 1990s, which caused the karst groundwater recharge amount to decrease 26.75 mm as compared to that of the 1960s (about 39.68% lower than that of the 1960s). The Jinci Spring had zero flow during this period. The reduction in precipitation was one of main factors that caused the cutoff of the Jinci Spring.

Keywords: karst groundwater; climate change; trend test; abrupt change test

1. Introduction

The karst groundwater in the Jinci Spring region is endowed with rich groundwater resources, stabilized dynamic state, and good water quality. Additionally, it has become the water supply source for urban water supply and industrial water. Due to both climate change and human activity, the Jinci Spring has been cutoff, and the karst groundwater level in the spring source area has declined, which has greatly influenced the urban water supply security and water ecological environment. This was a notable event marking a water environment degradation in Taiyuan over the last 50 years. The recharge of karst groundwater in the Jinci Spring region is primarily affected by local climate change; thus,

the influence of climate change on the recharge of groundwater in the spring region has particular significance to the optimization of utilization, the implementation of scientific scheduling, and the management of regional water resources. In general, water management is a strong key to use water resources in a correct way [1].

Since the 21st century, countries in Europe and America have begun to research the quantitative calculation methods of groundwater recharge on different temporal-spatial scales [2,3]. The water balance model includes surface runoff as well as groundwater recharge, and it also takes into consideration the influence of climate change and human activities on groundwater recharge, while simultaneously researching the influence of climate change on water resources [4,5]. Doveri, M. et al. utilized water isotopes as environmental tracers for the conceptual understanding of groundwater flow [6]. Cervi, F. et al. studied 12 springs from the northern Apennines of Italy by means of a comprehensive hydrogeological investigation to unravel recharge processes taking place in a highly fractured slab of flysch rock hosting the corresponding aquifers [7]. At present, the development of a groundwater recharge model and a sensitivity analysis of groundwater to climate change are still in the research and exploration stages in China [8]. Based on precipitation data obtained from over 600 precipitation stations and the annual average temperature data obtained for over 100 meteorological stations in northern China, Weitai Wang et al. analyzed the change tendency and the change relationship among the sunspot quantity, the precipitation, and climate change as well as estimated the influence of climate change on regional karst groundwater recharge in 2012 [9].

There has been considerable research focused on the Jinci Spring; however, much of the study has been concentrated on analyzing the cause of the spring flow exhaustion, analyzing the influence of human activities on the spring flow, and analyzing the conditions of the Jinci Spring reflow [10,11]. In contrast, there has been considerably less research conducted on the influence of climate change on karst groundwater recharge in the spring region [12]. For example, only Qinghai Guo et al. analyzed the guiding significance of the spring flow process in the context of climate change [13].

In this paper, the sliding average method and the Mann-Kendall test method have been adopted to analyze the annual variations of climatic factors [14], such as precipitation, temperature, and land evaporation [15,16]. The purpose of this study is to reveal the influence of atmospheric precipitation and Fenhe River leakage on karst groundwater recharge in the spring region and to provide a scientific basis for the reasonable exploitation and utilization of karst groundwater resources in the spring region and the establishment of karst groundwater management and protection policies [17,18].

2. Research Area Overview

The Jinci Spring is located 25 km southwest of Taiyuan, Shanxi Province, and it is one of the largest karst springs in northern China. The spring region is 2030 km^2 (Figure 1). The formation of the Jinci Spring was primarily a result of the karst groundwater of Taiyuan Xishan becoming blocked by the stratum of quaternary aquitard on the eastern side of the Taiyuan-Jiaocheng fault zone when there was basin movement. As a result, it overflowed through the ground and formed the spring. It is a classic piedmont fault overflow spring.

The Jinci Spring region has a typical temperate semi-arid continental monsoon climate, and it is typically characterized by droughts and windy conditions, a high precipitation concentration, intensive evaporation, four distinct seasons, a large temperature difference between day and night, and a short frost-free season. The multi-year (1960–2012) average precipitation of this region was 457.8 mm. The inter-annual, annual, and geographical distributions are extremely uneven. The precipitation of the highest flow year is over three times greater than that of the lowest flow year, and 60% of the annual precipitation is concentrated in the flood season, which extends from June to September. The multi-year average evaporation amount in this region is 1871.8 mm (an observed value of 20 cm from an observation vessel), and the multi-year average temperature is 10 °C.
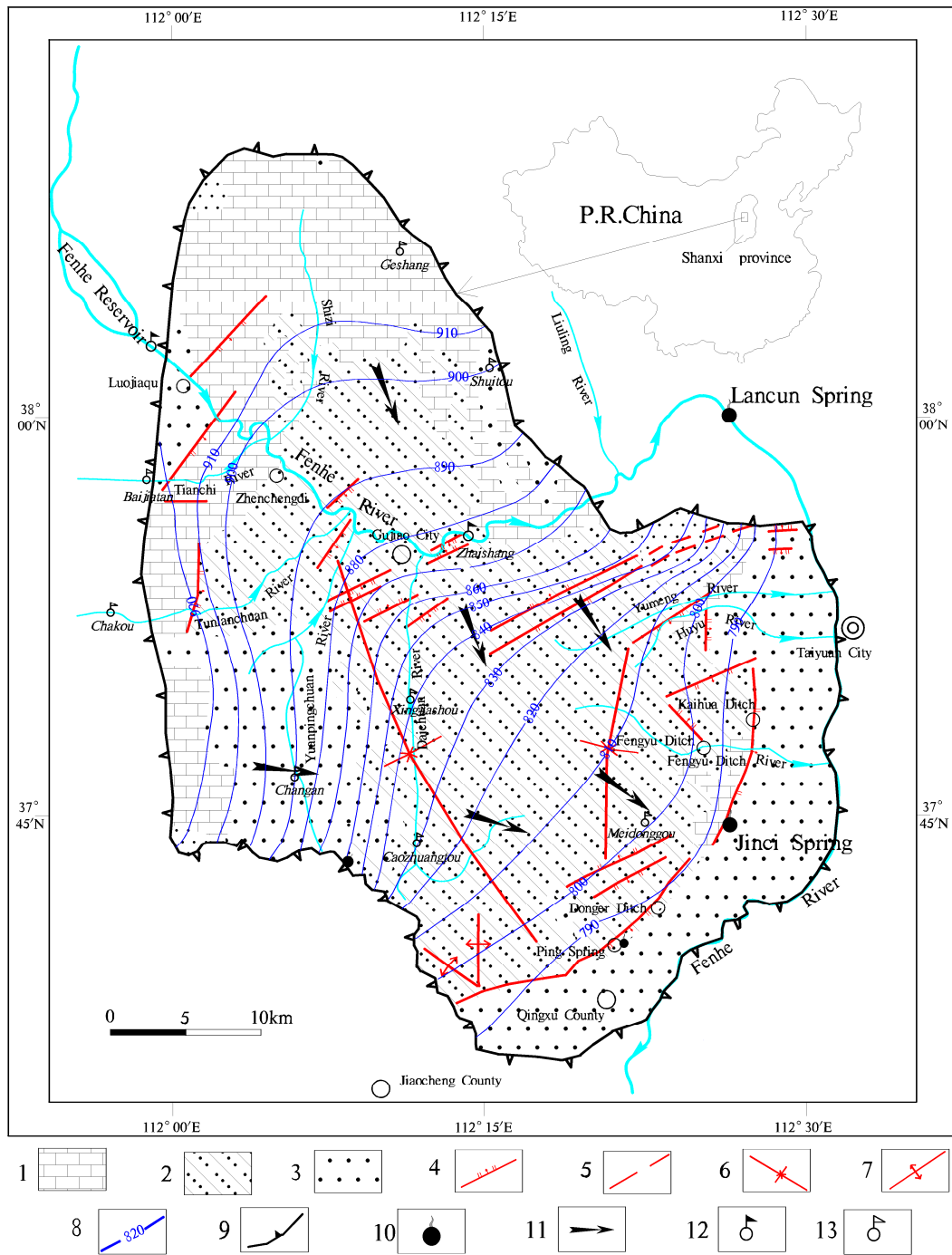
Figure 1. Simplified hydrogeological map of the Jinci Spring region. 1. Cambrian and Ordovician carbonate rocks; 2. Carboniferous-Permian clastic rocks; 3. Quaternary loose sediments; 4. fault structure; 5. buried fault; 6. syncline structure; 7. anticline structure; 8. groundwater contour lines; 9. boundary of spring region; 10. spring; 11. groundwater flow direction; 12. hydrologic station; 13. precipitation station.

The Jinci Spring region is part of the Fenhe River system of the Yellow River basin. The river system within the area is relatively developed, and the Fenhe River is the largest river in the area; it runs through this area from west to east and then turns south after it reaches the mountainous outlet in Lancun. The Tianchi River, Shizi River, Tunlanchuan, Yuanpinchuan, Dachuanhe, Liulin River and others are the first-grade tributaries of the Fenhe River, but they are seasonal rivers.

The spring region is composed of two parts, mountain area and plain area. It is bound by the Taiyuan-Jiaocheng fault. The northwestern part of the fault is a middle-low mountain area, and the terrain is higher in the northwest than in the southeast. The area is about 1771 km^2, and the elevation is 900–1500 m. The eastern fault zone is a basin plain area, with an area of 259 km^2 and an elevation of 780–850 m. The mountainous area and the basin plain area connect directly with terrain change.

The main aquifer of the Jinci Spring karst groundwater is the limestone of the upper and lower Majiagou Formation and the Fengfeng Formation of middle Ordovician, and the secondary is the dolomite and dolomitic limestone of the lower Ordovician and Cambrian system. The recharge source of the spring karst groundwater system primarily originates from three sources: the first is the precipitation penetrating recharge in the carbonatite bare field to the north of the Fenhe River, which is the main recharge of the Jinci Spring; the second is the seepage recharge in the section of the carbonatite river that reaches Fenhe (the seepage reach of the Fenhe River in this spring mainly includes the Luojiaqu-Zhenchendi seepage section (the length is about 22 km), the Gujiao–Zhaishang seepage section (the length is about 5 km), and the Zhaishang–Shaoshi seepage section (the length is about 16 km)); and the third is the leaking recharge from the groundwater of the overlying formation.

The karst groundwater in the spring region migrates from northwest to southeast. The Malan syncline is located in the middle area of this spring region, which displays in the northwest~southeast direction and extends for 43 km. Because the Ordovician limestone is buried, the karst development is weak and has poor permeability in the synclinal axis. The region in the west Malan syncline and to the south of the Fenhe River is a stagnant zone, and the karst groundwater basin that is located on the east side of this syncline is in the strong runoff zone. In addition, a water-abundance zone with strong karstification and water conductivity runs along the Taiyuan-Jiaocheng fault zone.

Except for the natural discharge points at the Jinci Spring and the Ping Spring, the karst groundwater in this spring discharges a small amount of water into the Taiyuan Basin as subsurface flow. In addition, the exploitation of karst groundwater is another source of groundwater discharge [19].

The Jinci Spring flow has exhibited a reduction tendency year by year since the 1960s, especially in the late 1980s. It declined from 1.69 m^3/s in the 1960s to 1.13 m^3/s in the 1970s, to 0.46 m^3/s in the 1980s, and to 0.15 m^3/s in the 1990s. The Jinci Spring was cutoff on 30 April 1994. The groundwater level of the entire Jinci Spring sharply declined from 1994 to 2009. The water level at the spring vent of the Jinci Spring declined to its lowest point in history (774.94 m), which is 27.65 m lower than the elevation at the spring vent of the Jinci Spring (802.59 m). However, it has exhibited a rising tendency from 2010 to 2012 and has recovered from 777.54 m in 2010 to 788.21 m in 2012 (Table A1 and Figure 2).
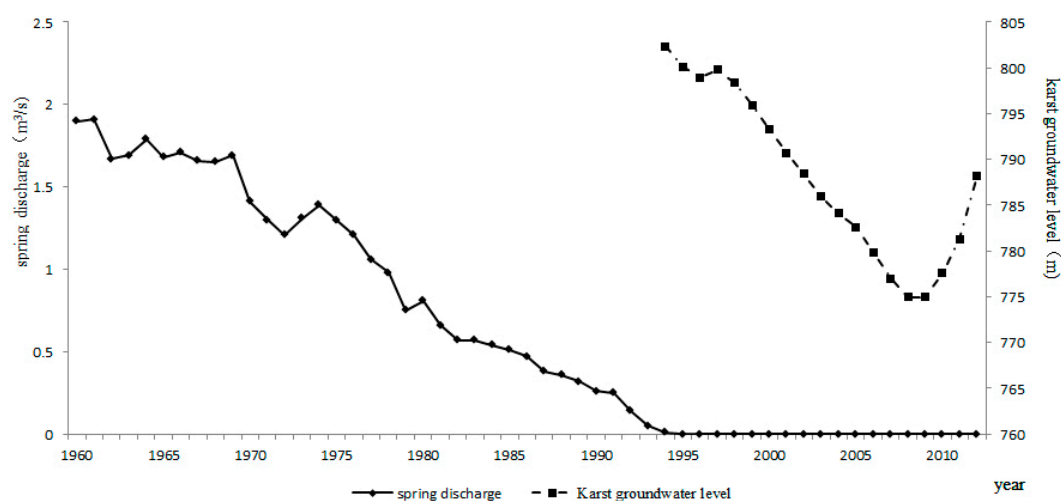

Figure 2. The change trend chart of Jinci Spring discharge and the karst groundwater level of the spring vent.

The average annual precipitation of the Jinci Spring region in the 1960s, 70s, 80s and 90s are 507.7 mm, 456.1 mm, 424.1 mm and 396.7 mm respectively, which shows a descending trend. According to the precipitation and discharge data of the 1960s and 1990s, the precipitation decreased by 21.9%, and the average spring flow decreased by 91.8%, from 1.735 m^3/s to 0.142 m^3/s. According to this result, precipitation is not the main factor of the spring flow attenuation. The average annual precipitation from 2000 to 2012 is 493.9 mm, which is 7.9% higher than that from 1960 to 2012 (458 mm). Therefore, the change of precipitation has a small contribution to the change of the karst water level in the Jinci Spring region. The reason why the spring dried up is mainly attributed to groundwater over-abstraction.

The main reasons for the rise of the groundwater level in recent years are as follows: first, by means of utilizing the Yellow River surface water, the local government closed part of the groundwater exploitation wells to reduce the amount of groundwater exploitation; second, the high water consumption enterprises in this region have been shut down or moved; third, the implementation of the Fenhe River resuming flow engineering has achieved continuous flow of the Fenhe River for many years, which increases the recharge of groundwater; fourth, through the implementation of regional ecological environment comprehensive management, vegetation coverage has been raised, and water resources are conserved. After taking the above measures, the karst groundwater level in the spring area has risen remarkably in recent years.

3. Research Method

3.1. Time-Series Test

To analyze climate change characteristics in this spring and the influence of climate on the karst groundwater recharge, the Mann-Kendall non-parametric test method was employed to conduct a trend analysis and abrupt change test [20].

3.1.1. Trend Test

The Mann-Kendall rank correlation test (referred to as the M-K trend test) is a non-parametric statistical test, which can accurately verify the sequence variation trend [21].

(1) The sample sequence $(x_1, x_2, \ldots, x_n)$ has no trend.

(2) The statistic is calculated, and the calculation formula is:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \tag{1}$$

(3) S is normal distribution, and its average value is 0. The variance is $Var(S) = n(n-1)(2n+5)/18$, and the calculation formula of the standard normal statistic is:

$$Z = \begin{cases} (S-1)/\sqrt{Var(S)} & S > 0 \\ 0 & S = 0 \\ (S+1)/\sqrt{Var(S)} & S < 0 \end{cases} \tag{2}$$

(4) After testing, if the statistic is $|Z| \geq Z_{1-\alpha/2}$, then the original hypothesis is refused, which means the sequence has an obvious rising or declining trend.

(5) The tilt rate (quantization of monotonous trend) is calculated, and the calculation formula is:

$$\beta = median\left[\frac{X_i - X_j}{i - j}\right], \forall j < i \tag{3}$$

where $1 < j < i < n$, and the median is the median function. When $\beta > 0$, the sequence exhibits a rising trend; when $\beta < 0$, the sequence exhibits a declining trend [22].

3.1.2. Abrupt Change Test

(1) The one time sequence is assumed to be $X_i = (x_1, x_2 \ldots, x_n)$, and a one-order sequence m_i is constructed to show the accumulative quantity of a sample when $x_i > x_j$ ($1 \leq j \leq i$). One statistic d_k is defined as:

$$d_k = \sum_{i=1}^{k} m_i, \ 2 \leq k \leq n \tag{4}$$

(2) Under the assumption that the original sequence is stochastic independence, the average value and variance of d_k are, respectively:

$$E(d_k) = k(k-1)/4 \tag{5}$$

$$\text{var}(d_k) = k(k-1)(2k+5)/72 \tag{6}$$

(3) d_k is standardized, and then:

$$u(d_k) = \frac{dk - E(d_k)}{\sqrt{\text{var}(d_k)}} \tag{7}$$

where $u(d_k)$ is a standard distribution, and its probability can be achieved through calculation or looking it up in a table. Assuming one significance level to be a_0, when $a_1 > a_0$, the original hypothesis is accepted; however, when $a_1 < a_0$, the original hypothesis is refused, which means that this sequence exhibits a strong rising or declining trend. All the $u(d_k)(1 \leq k \leq n)$ will chart a curve UF_k [23].

(4) The time sequence x_k is ranked in reverse and is then calculated according to formula (7), and at the mean time:

$$\begin{cases} UB_k = -UF_k \\ k' = n + 1 - k \end{cases} \quad (k, k' = 1, 2, \cdots, n) \tag{8}$$

The variation trend of sequence x_k can be further analyzed through analyzing the statistical series UF_k and UB_k, and the mutation time and area can be explicitly known. If $UF_k > 0$, then the sequence exhibits a rising trend, and if $UF_k < 0$, then the sequence exhibits a declining trend. If they are higher or lower than the critical lines, then the rising or declining trend is remarkable. If there is any point of intersection between the two curves of UF_k and UB_k, and the point of intersection is between critical lines, the time corresponding to the point of intersection is the mutation starting time [24].

3.2. Groundwater Recharge Amount Calculation

The main influencing factors of climate change on the karst groundwater recharge amount in the spring region are precipitation, land evaporation and river runoff [25]. The change of the groundwater recharge amount due to precipitation, land evaporation, and river runoff can be analyzed based on a quantitative calculation of karst groundwater recharge amount in the spring region. The water balance method is a general calculation method used for the hydrological cycle elements. This research uses the Fenhe Reservoir hydrologic station as the basin import and the Zhaishang hydrologic station as the basin export to determine the scope of the study area, which is 1587 km².

The length of the seepage zone in the Fenhe River from the Fenhe Reservoir to Zhaishang in the Jinci Spring is 27 km, and the length of the seepage zone in the Fenhe River from Zhaishang to Shaoshi is 16 km. The seepage zone from the Fenhe Reservoir to Zhaishang occupies 62.8% of the total seepage zone length. The exposed limestone area in this spring region is 391 km², which is mainly located to the north of this spring and to the north of the Fenhe River channel. The exposed limestone area in the basin controlled by the Zhaishang hydrologic station is 317 km², which occupies 81.1% of the total exposed area in this spring region. Thus, the research on the recharge of precipitation and the Fenhe River seepage of the zone from the Fenhe Reservoir to Zhaishang to the karst groundwater in the Jinci Spring region is highly important to the research on the karst groundwater recharge in the entire spring region.

The water balance in the basin from the Fenhe Reservoir to Zhaishang can be expressed as the following formula [26]:

$$Q_1 + P = Q_2 + E + R \tag{9}$$

where Q_1 is the observed runoff amount in the Fenhe Reservoir hydrologic station; P is the basin precipitation; Q_2 is the observed runoff amount in the Zhaishang hydrologic station; E is the land evaporation amount; and R is the recharge amount of precipitation and river channel seepage on the groundwater in this spring region.

4. Results and Discussion

The data used in this research includes meteorological data and runoff data from two hydrologic stations located at the Fenhe Reservoir and Zhaishang from 1960 to 2012; the station location map is shown in Figure 1.

4.1. Climate Change Characteristic Analysis

The precipitation infiltration recharge is the most important recharge source in the Jinci Spring, and its main means of recharge include the direct precipitation infiltration recharge of the exposed carbonatite area, the indirect precipitation infiltration recharge of the overlay area, and the seepage recharge of the surface runoff yield formed by the precipitation in the carbonatite river channel. The precipitation will be transformed in three ways after landing on the ground: to form surface runoff, to infiltrate underground and then form groundwater, and to land-evaporate via vegetation and ground surface. In these three ways, the slope surface has a short lag time that allows the precipitation to quickly import into the channel and flow away, and the land evaporation and underground infiltration demonstrate the reciprocal relationship under the transduction function of all kinds of energy, including water and vapor in an unsaturated zone. Additionally, the temperature controls the land evaporation capacity to some extent. Thus, the precipitation amount and the temperature have important influences on the infiltration of karst groundwater in this area.

4.1.1. Precipitation Variation

The precipitation data in the research uses the annual precipitation data from ten precipitation stations in the Jinci Spring region, and the areal precipitation in the spring region can be obtained through the Thiessen polygons method. The annual precipitation in the spring varies from 217.87 to 676.63 mm, and the multi-year average value is 457.85 mm. The precipitation in the spring region exhibits greater fluctuation at different times. For example, the 1960s and 1970s have a relatively larger fluctuation, the 1980s and 1990s have relatively less fluctuation, and the precipitation amount since 2000 is a significant increase as compared to the 1990s (Table A2 and Figure 3a). The most obvious precipitation decline took place during the 1990s, and it is 111 mm less than that in the 1960s (as shown in Table 1).
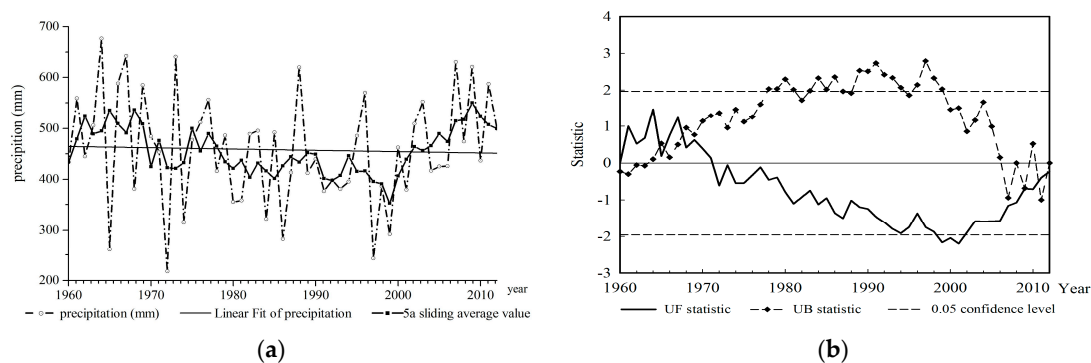

Figure 3. Annual precipitation variation trend and mutation analysis in the Jinci Spring region: (**a**) annual precipitation variation trend; (**b**) annual precipitation mutation analysis.

Table 1. Annual average precipitation, temperature, and evaporation for each time period in the Jinci Spring region: Statistical Table.

Time	1960s	1970s	1980s	1990s	2000–2012	Variation Degree between the 1960s and after 2000(%)
Average precipitation/mm	507.7	456.1	424.1	396.7	493.9	−2.73
Average temperature/°C	9.5	9.62	9.71	10.38	10.98	15.63
Average evaporation/mm	383.90	363.13	350.3	339.47	400.33	4.28
Average karst groundwater recharge/mm	67.40	63.47	65.98	40.66	59.53	−11.68

According to the sliding average method and the linear tendency estimate method, the number of years is 53, and by setting k = 5, the 5a sliding average value of the annual precipitation in the Jinci Spring region can be obtained, and the sliding curve can be charted (Figure 3a).

The following conclusions were made from the analysis. The 5a sliding average precipitation from 2007 to 2011 is the largest (549.87 mm), whereas the value from 1997 to 2001 is the lowest (352.77 mm). The annual precipitation in the Jinci Spring region generally exhibits an initial decrease and then subsequent increase trend. The variation amplitude of the precipitation in the Jinci Spring region shows volatility. The annual distribution is uneven. Additionally, the average precipitation is 457.85 mm, the maximum precipitation occurred in 1964 (676.63 mm), and the minimum occurred in 1972 (217.87 mm); their quantitative difference is 458.76 mm.

The statistic Z, β, and significance level of the annual precipitation in the Jinci Spring region can be obtained by the Mann-Kendall method to conduct a trend test, and the test results are, respectively, −0.22, −0.41, and 0.05. These results reveal that the precipitation test value Z of the study area is less than 0, but it does not pass the significance test level of 0.05, which means the precipitation in the Jinci Spring region from 1960 to 2012 generally shows a declining trend, and the multi-year average declining degree of precipitation is 0.41 mm/a [27].

According to the M-K abrupt change test result of the annual precipitation time variation (Figure 3b), the precipitation in the spring region before 1971 exhibited a rising trend, whereas a declining trend has been evident since 1972. It passes the 0.05 significance test ($U_{0.05}$ = 1.96). According to the intersecting point of the UF_k and UB_k curves, it can be determined that the mutation points of the annual precipitation existed in 1967 and 2009 in the Jinci Spring region [28].

4.1.2. Temperature Variation

The annual average temperature and the 5a sliding average temperature time sequence from 1960 to 2012 in the Jinci Spring region are shown in Figure 4a. According to Figure 4a, the two curves generally exhibit a rising trend over time.
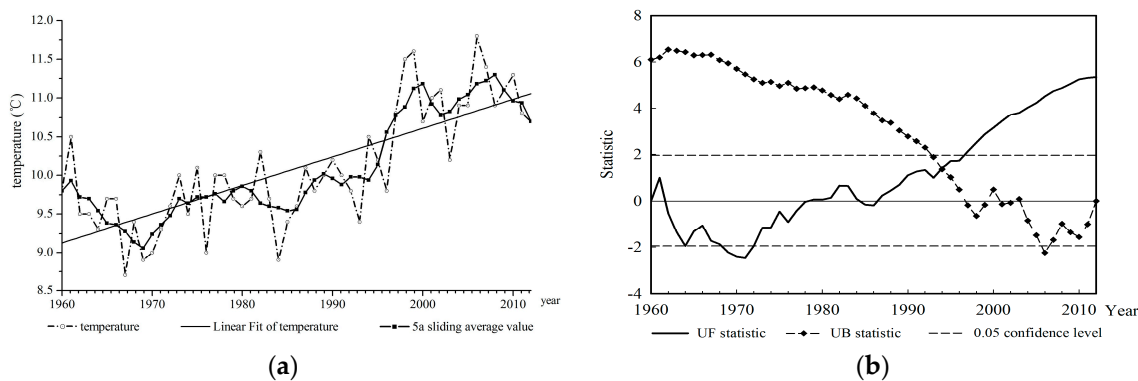
Figure 4. Annual average temperature variation trend and mutation analysis in the Jinci Spring region: (**a**) average temperature variation trend; (**b**) annual average temperature mutation analysis.

The annual average temperature in the Jinci Spring region varies from 8.7 to 11.8 °C, and the multi-year average value is 10.09 °C over the last fifty years. As for the annual average temperature, the highest occurred in 2006 (11.8 °C), and the lowest occurred in 1967 (8.7 °C). The average temperature the Jinci Spring region increased over time (as shown according to decade in Table 1). The difference between the 1960s, 1970s, and 1980s is not very large, but the average temperature in the 1990s increased sharply to 0.88 °C (about 9.3%) higher than that of the 1960s, and in the 2000s it was 1.48 °C (about 15.63%) higher than that of the 1960s. This conclusion is in accordance with the conclusion found in literature [29]. According to the statistical temperature data, the 5a sliding average temperature from 1967 to 1971 in the Jinci Spring region is the lowest (9.06 °C), and the value from 2006 to 2010 is the highest (11.8 °C); the difference between them is 2.74 °C.

The multi-year average temperature trend test result, as tested by the Mann-Kendall method, is shown in Table 2. It can be seen that the statistic |Z| of the multi-year average temperature in the Jinci Spring region is larger than $Z_{1-\alpha/2}$, which means that the temperature in the entire spring region refused the null hypothesis, and it has a monotonous trend with statistical meaning. The β value of the multi-year average temperature in the table is 0.04, which is larger than 0; it also indicates that the temperature has exhibited a rising trend in the Jinci Spring over the last five decades [30].

Table 2. The trend and abrupt change test of the annual average precipitation, temperature, land evaporation, and karst groundwater recharge.

Element	Multi-Year Average Value/mm	M–K Trend Test			Mutation Point (Year)
		Z	β	Trend	
Precipitation	457.85	−0.22	−0.41	Declining	1967, 2009
Temperature	10.09	6.10	0.04	Rising	1994
Land evaporation	369.29	0.41	0.15	Rising	1964, 2007
Karst groundwater recharge	59.37	−1.04	−0.25	Declining	1964, 2007

The M-K abrupt change test of the annual temperature time variation (Figure 4b) shows that the average temperature in the spring region from 1962 to 1978 exhibited a declining trend; however, the average temperature has been on a rising trend since 1979 (in addition to 1985 and 1986), and it is still rising today. This rising trend passes the 0.05 significance test ($U_{0.05}$ = 1.96), and the mutation occurred in 1994 (the intersection of the UF_k–UB_k curve in the figure).

4.1.3. Evaporation Variation

According to the annual precipitation and annual average temperature data from 1960 to 2012, the evaporation in the spring region is calculated based on the Turc land evaporation empirical formula [31]:

$$Q_z = P \div \sqrt{[0.9 + P^2 \div (300 + 25 \times T + 0.05 \times T^3)^2]} \qquad (10)$$

where Q_z is the land evaporation amount (mm), P is the precipitation (mm), and T is the temperature (°C).

Curves representing the annual evaporation and 5a sliding average evaporation time sequence in the spring region from 1960 to 2012 are shown in Figure 5a. The two curves generally show an initial decreasing and then subsequent increasing trend over time, which is similar to the precipitation variation trend (Figure 5a).

The annual land evaporation in the Jinci Spring region varies from 213.74 to 467.9 mm, and the multi-year average value is 369.29 mm. The lowest was 213.74 mm in 1972, and the highest was 467.9 mm in 2007; the difference between them is 254.15 mm.
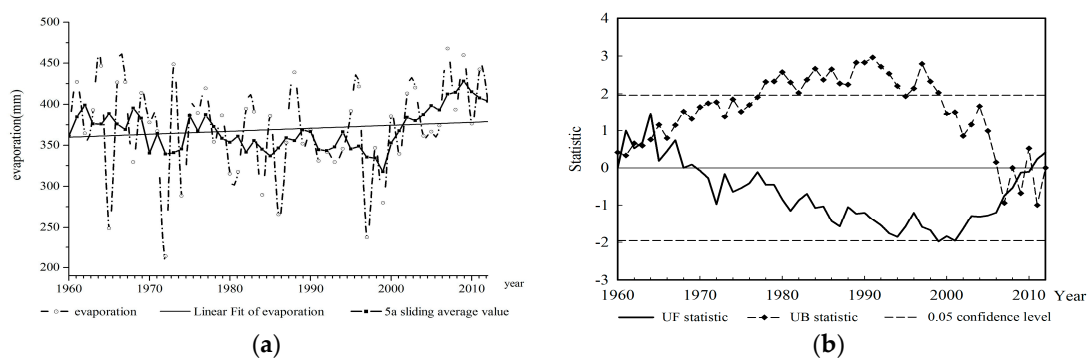
Figure 5. Annual evaporation variation trend and mutation analysis in the Jinci Spring region: (**a**) annual evaporation variation trend; (**b**) annual evaporation mutation analysis.

According to Table 1, the evaporation at each time period decreased first and then subsequently increased over time. As compared to the 1960s, the 1970s decreased 20.77 mm (about 5.4%), the 1980s decreased 33.6 mm (about 8.75%), the 1990s decreased 44.43 mm (about 11.57%), and 2000–2012 increased 16.43 mm (about 4.28%). As for the 5a sliding average evaporation, the value from 2007 to 2011 is the highest (428.01 mm), and the value from 1997 to 2001 is the lowest (317.85 mm); the difference between them is 110.15 mm.

The M-K mutation test of the annual land evaporation variation over time (Figure 5b) has shown that the land evaporation in the spring region from 1960 to 1969 exhibited a rising trend. From 1970 to 2010, it exhibited a declining trend, and 2011 and 2012 demonstrated a rising trend. According to the intersecting point of the UF_k and UB_k curves, it can be determined that the mutation existed in 1964 and 2007 [32].

4.2. Analysis of the Influence of Climate Change on Karst Groundwater Recharge in the Spring Region

The recharge amount of the Jinci Spring region from the precipitation and river channel seepage in the Fenhe Reservoir-Zhaishang zone can be obtained according to Formula (9).

The annual recharge amount in the Fenhe Reservoir-Zhaishang zone of the Jinci Spring region varies from 29.32 to 140.28 mm (about 11,500–54,900 thousand m^3), and the multi-year average value is 59.37 mm (about 23,200 thousand m^3).

The karst groundwater recharge amount in the study region has a larger fluctuation at different times. The 1960s, 1970s, and 1980s are relatively higher, whereas the 1990s is relatively lower, and since 2000 the recharge amount has slightly increased (Figure 6a). As compared to the 1960s, the recharge amount of the 1980s decreased 1.42 mm (about 2.11%), that of the 1990s decreased 26.75 mm (about 39.68%), and that of 2000–2012 decreased 8.07 mm (about 11.97%).

The curves of the annual recharge amount and 5a sliding average recharge amount time sequence in the study area from 1960 to 2012 are shown in Figure 6a. The following conclusions were drawn from the analysis. The highest 5a sliding average recharge amount was from 1973 to 1977 at 84.98 mm (converted into 33,200 thousand m^3), and the lowest value was from 1997 to 2001 at 37.96 mm (about 14,850 thousand m^3). Similar to the precipitation variation trend, the karst groundwater recharge amount in the spring region generally exhibited an initial declining and then subsequent increasing trend [33].

The Mann-Kendall method was used to conduct the trend test, and the test result shows that the statistic Z, β, and the significance level of the annual recharge amount in the study region are, respectively, −1.04, −0.25, and 0.05. The result reveals that the karst groundwater recharge amount test value Z of the study region is less than 0, which means that the karst groundwater recharge amount in the study region from 1960 to 2012 generally exhibits a declining trend. The M-K mutation test shows that the karst groundwater recharge amount exhibited a rising trend before 1967, and then a declining trend predominated; however, it has been rising once again since 2007. According to the

intersecting point of the UF_k and UB_k curves, it can be determined that the mutation existed in 1964 and 2007 (Figure 6b) [34].

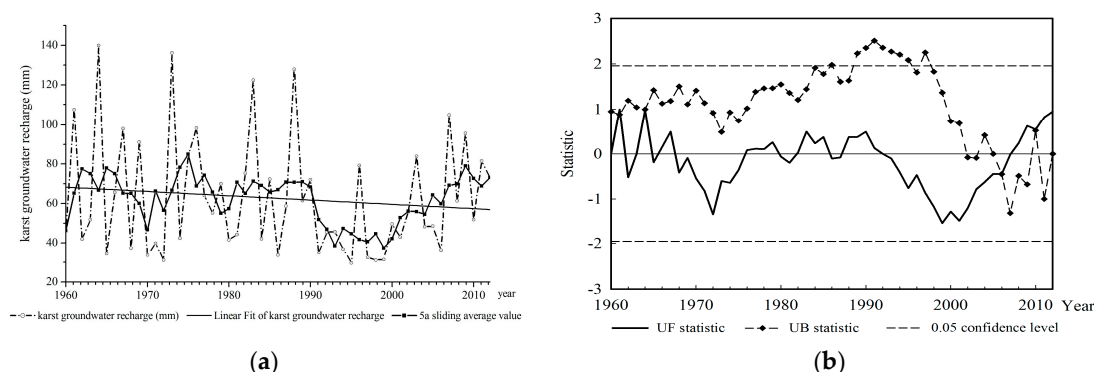(**a**)　　　　　　　　　　　　　　　　　　　　　(**b**)

Figure 6. Annual karst groundwater recharge amount variation trend and mutation analysis in the Fenhe Reservoir-Zhaishang zone of the Jinci Spring region: (**a**) annual karst groundwater recharge amount variation trend; (**b**) annual karst groundwater recharge amount variation trend mutation analysis.

5. Conclusions

This study employed the M-K non-parametric test method to analyze the variation trend and mutation characteristic of the annual precipitation, land evaporation, temperature, and karst groundwater recharge in the Jinci Spring region. The main conclusions are as follows:

(1)　By comparing the relationship between the change in precipitation and the discharge of the spring, the change in precipitation has a small contribution to the change in karst water level in the Jinci Spring region. The reason why the spring dried up is mainly attributed to groundwater over-abstraction.

(2)　A total of 53 years of statistics reveal that the annual precipitation of the Jinci Spring region generally follows an initial decreasing and then subsequent increasing trend, and the most obvious declining trend occurred in 1990s, which was 111 mm less than that of the 1960s. Likewise, the variation trend of land evaporation is similar to that of precipitation; however, the annual average temperature has maintained an increasing trend.

(3)　The variation process of the karst groundwater recharge in the Jinci Spring region is generally consistent with that of the precipitation. As compared to the climate of the 1960s, all the climate changes at the other time periods resulted in a reduction in the recharge amount. The climatic change had the strongest influence in the 1990s, which caused the karst groundwater recharge amount in the spring region to be reduced by 26.75 mm, about 39.68% lower than that of the 1960s. The reduction of precipitation is one of main reasons underlying the cutoff of the Jinci Spring.

(4)　The results of the Mann-Kendall abrupt change test revealed that the karst groundwater recharge amount in the Fenhe Reservoir-Zhaishang zone of the Jinci Spring region generally exhibits a declining tendency. The karst groundwater recharge amount exhibited a rising trend before 1967. After that, a declining trend took place; however, a rising trend has been occurring since 2007. The mutations existed in 1964 and 2007.

Author Contributions: All authors contributed to the design and development of this manuscript. Zhenxing Jia carried out the data analysis and prepared the first draft of the manuscript; Hongfei Zang collected part of meteorological data and contributed many ideas to the study; Xiuqing Zheng and Yongxin Xu provided important

advice on the concept of methodology and structuring of the manuscript, as well as edited the manuscript prior to submission and during revisions. All authors read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The data of spring discharge and karst groundwater levels.

Year	Spring Discharge (m³/s)	Karst Groundwater Level (m)
1960	1.9	
1961	1.91	
1962	1.67	
1963	1.69	
1964	1.79	
1965	1.68	
1966	1.71	
1967	1.66	
1968	1.65	
1969	1.69	
1970	1.41	
1971	1.3	
1972	1.21	
1973	1.31	
1974	1.39	
1975	1.3	
1976	1.21	
1977	1.06	
1978	0.98	
1979	0.75	
1980	0.81	
1981	0.66	
1982	0.57	
1983	0.57	
1984	0.54	
1985	0.51	
1986	0.47	
1987	0.38	
1988	0.36	
1989	0.32	
1990	0.26	
1991	0.25	
1992	0.14	
1993	0.05	
1994	0.01	802.32
1995	0	800.11
1996	0	798.97
1997	0	799.79
1998	0	798.37
1999	0	795.94
2000	0	793.3
2001	0	790.69
2002	0	788.42
2003	0	785.96
2004	0	784.07
2005	0	782.59
2006	0	779.86
2007	0	777
2008	0	774.94
2009	0	774.94
2010	0	777.54
2011	0	781.26
2012	0	788.21

Table A2. The data of precipitation, temperature and observed runoff amount.

Year	The Precipitation in the Jinci Spring Area (mm)	Average Temperature (°C)	The Observed Runoff Amount in the Fenhe Reservoir Hydrologic Station (m³/s)	The Observed Runoff Amount in the Zhaishang Hydrologic Station (m³/s)
1960	433.59	9.8	6.81	8.09
1961	558.89	10.5	6.98	8.2
1962	444.83	9.5	12.3	14.2
1963	506.34	9.5	10.6	13.7
1964	676.63	9.3	11.0	15.5
1965	260.63	9.7	19.9	19.3
1966	588.16	9.7	5.07	9.89
1967	642.10	8.7	27.2	33.1
1968	381.16	9.4	18.2	20.4
1969	584.83	8.9	14.3	18.3
1970	484.44	9	14.9	18.6
1971	453.94	9.3	8.54	10.9
1972	217.87	9.6	8.06	7.71
1973	641.07	10	5.55	8.38
1974	315.23	9.5	14.8	14
1975	477.61	10.1	5.34	5.68
1976	512.10	9	5.43	6.68
1977	555.91	10	9.95	13.6
1978	416.21	10	13.9	14.2
1979	486.16	9.7	13.6	15.1
1980	355.13	9.6	13.5	13.4
1981	358.19	9.7	6.97	6.78
1982	489.41	10.3	7.72	8.7
1983	495.87	9.7	8.65	7.79
1984	321.51	8.9	9.22	8.7
1985	492.36	9.4	4.89	6.62
1986	282.86	9.6	8.49	8.67
1987	413.17	10.1	3.78	3.84
1988	619.87	9.8	8.52	11.2
1989	412.33	10	9.54	9.48
1990	439.46	10.2	9.34	9.29
1991	376.33	10	8.43	8.95
1992	397.77	9.8	5.24	5.75
1993	381.11	9.4	7.73	8.02
1994	395.11	10.5	5.56	6.19
1995	485.76	10.2	12.5	15.7
1996	569.90	9.8	21.7	24.7
1997	243.46	10.8	9.21	8.87
1998	385.76	11.5	8.30	8.8
1999	292.43	11.6	7.35	7.41
2000	462.59	10.7	3.89	4.05
2001	379.63	11	3.8	4.09
2002	509.67	11.1	3.04	3.7
2003	551.73	10.2	5.46	5.77
2004	416.67	10.9	5.84	4.98
2005	425.05	10.9	4.02	3.32
2006	425.79	11.8	3.12	2.99
2007	630.25	11.4	2.36	2.67
2008	474.58	10.9	7.16	6.63
2009	621.03	11.1	6.13	7.07
2010	436.44	11.3	6.51	7.14
2011	587.04	10.8	7.37	8.52
2012	499.89	10.7	6.64	7.48

References

1. Tazioli, A.; Mattioli, A.; Nanni, T.; Vivalda, P.M. Natural Hazard Analysis in the Aspio Equipped Basin. In *Engineering Geology for Society and Territory–Volume 3: River Basins, Reservoir Sedimentation and Water Resources*; Springer International Publishing: Cham, Switzerland, 2015; pp. 431–435.

2. Goderniaux, P.; Brouyere, S.; Fowler, H.J.; Blenkinsop, S.; Therrien, R.; Orban, P.; Dassargues, A. Large scale surface-subsurface hydrological model to assess climate change impacts on groundwater reserves. *J. Hydrol.* **2009**, *373*, 122–138. [CrossRef]

3. Kundzewicz, Z.W.; Doll, P. Will groundwater ease freshwater stress under climate change. *Hydrol. Sci. J.* **2009**, *54*, 665–675. [CrossRef]

4. Liu, C.Z.; Xie, Z.H. Recent advances in research on sensitivity of groundwater to climatic changes. *J. China Hydrol.* **2007**, *27*, 1–6. (In Chinese).

5. Holman, I.P.; Tascone, D.; Hess, T.M. A comparison of stochastic and deterministic downscaling methods for modelling potential groundwater recharge under climate change in East Anglia, UK: Implications for groundwater resource management. *Hydrogeol. J.* **2009**, *17*, 1629–1641. [CrossRef]

6. Doveri, M.; Mussi, M. Water Isotopes as Environmental Tracers for Conceptual Understanding of Groundwater Flow: An Application for Fractured Aquifer Systems in the "Scansano-Magliano in Toscana" Area (Southern Tuscany, Italy). *Water* **2014**, *6*, 2255–2277. [CrossRef]

7. Cervi, F.; Corsini, A.; Doveri, M.; Mussi, M.; Ronchetti, F.; Tazioli, A. Characterizing the Recharge of Fractured Aquifers: A Case Study in a Flysch Rock Mass of theNorthern Apennines (Italy). In *Engineering Geology for Society and Territory—Volume 3: River Basins, Reservoir Sedimentation and Water Resources*; Springer International Publishing: Cham, Switzerland, 2015; pp. 563–567.

8. Jackson, C.R.; Meister, R.; Prudhomme, C. Modelling the effects of climate change and its uncertainty on UK Chalk groundwater resources from an ensemble of global climate model projections. *J. Hydrol.* **2011**, *399*, 12–28. [CrossRef]

9. Wang, W.T.; Liang, Y.P.; Wang, Z.H.; Zhao, C.H. Characteristics of climate change in northern China and its effect on groundwater in karst areas. *Hydrolgeol. Eng. Geol.* **2012**, *39*, 6–10. (In Chinese).

10. Huang, H.L. The relationship between the cutoff of Jinci Spring and the conservation of groundwater resource. *Coal. Geol. China* **2003**, *15*, 26–28. (In Chinese).

11. Long, Y.Q.; Li, W.; Li, Y.G. Tank model of Jinci karst groundwater system under the on the condition of simultaneous draining in minging. *Carsologica Sin.* **2011**, *30*, 27–33. (In Chinese).

12. Sun, C.Z.; Wang, J.S.; Lin, X.Y. Research on the Shanxi Jinci Spring's recovery after the use of water from the yellow river as municipal water supply. *Carsol. Sin.* **2001**, *20*, 11–16. (In Chinese).

13. Guo, Q.H.; Wang, Y.X.; Ma, T. The flow variation processes of large karstic spring in Shanxi in the recent 50 years and its guiding significance on global climatic change. *Sci. China. Ser. D* **2005**, *35*, 167–175. (In Chinese).

14. Green, T.R.; Taniguchi, M.; Kooi, H.; Gurdak, J.J.; Allen, D.M.; Hiscock, K.M.; Treidel, H.; Aureli, A. Beneath the surface of global change: Impacts of climate change on groundwater. *J. Hydrol.* **2011**, *405*, 532–560. [CrossRef]

15. Bloomfield, J.P.; Williams, R.J.; Gooddy, D.C.; Cape, J.N.; Guha, P. Impacts of climate change on the fate and behaviour of pesticides in surface and groundwater—A UK perspective. *Sci. Total Environ.* **2006**, *369*, 163–177. [CrossRef] [PubMed]

16. Ali, R.; McFarlane, D.; Varma, S.; Dawes, W.; Emelyanova, I.; Hodgson, G.; Charles, S. Potential climate change impacts on groundwater resources of south–western Australia. *J. Hydrol.* **2012**, *475*, 456–472. [CrossRef]

17. Barron, O.; Froend, R.; Hodgson, G.; Ali, R.; Dawes, W.; Davies, P.; McFarlane, D. Projected risks to groundwater–dependent terrestrial vegetation caused by changing climate and groundwater abstraction in the Central Perth Basin, Western Australia. *Hydrol. Process.* **2014**, *28*, 5513–5529. [CrossRef]

18. Waibel, M.S.; Gannett, M.W.; Chang, H.; Hulbe, C.L. Spatial variability of the response to climate change in regional groundwater systems—Examples from simulations in the Deschutes Basin, Oregon. *J. Hydrol.* **2013**, *486*, 187–201. [CrossRef]

19. Yadav, R.; Tripathi, S.K.; Pranuthi, G.; Dubey, S.K. Trend analysis by Mann–Kendall test for precipitation and temperature for thirteen districts of Uttarakhand. *J. Agrometeorol.* **2014**, *16*, 164–171.

20. Hamed, K.H. Trend detection in hydrologic data: The Mann–Kendall trend test under the scaling hypothesis. *J. Hydrol.* **2008**, *349*, 350–363. [CrossRef]

21. Lacombe, G.; McCartney, M.; Forkuor, G. Drying climate in Ghana over the period 1960–2005: Evidence from the resampling–based Mann–Kendall test at local and regional levels. *Hydrol. Sci. J.* **2012**, *57*, 1594–1609. [CrossRef]

22. Keilholz, P.; Disse, M.; Halik, U. Effects of Land Use and Climate Change on Groundwater and Ecosystems at the Middle Reaches of the Tarim River Using the MIKE SHE Integrated Hydrological Model. *Water* **2015**, *7*, 3040–3056. [CrossRef]

23. Liu, Y.L.; Zhai, X.L.; Zheng, A.Q. Analysis of precipitation variation trend in Guanzhong Basin based on the Mann–Kendall. *Yellow River* **2012**, *34*, 28–30. (In Chinese).

24. Hamed, K.H. Exact Distribution of the Mann–Kendall Trend Statistic for Persistent Data. *J. Hydrol.* **2009**, *365*, 86–94. [CrossRef]

25. Gain, A.K.; Giupponi, C.; Renaud, F.G. Climate Change Adaptation and Vulnerability Assessment of Water Resources Systems in Developing Countries: A Generalized Framework and a Feasibility Study in Bangladesh. *Water* **2012**, *4*, 345–366. [CrossRef]

26. Fathelrahman, E.; Davies, A.; Davies, S.; Pritchett, J. Assessing Climate Change Impacts on Water Resources and Colorado Agriculture Using an Equilibrium Displacement Mathematical Programming Model. *Water* **2014**, *6*, 1745–1770. [CrossRef]

27. Baruffi, F.; Cisotto, A.; Cimolino, A.; Ferri, M.; Monego, M.; Norbiato, D.; Cappelletto, M.; Bisaglia, M.; Pretner, A.; Galli, A. Climate change impact assessment on Veneto and Friuli plain groundwater. Part I: An integrated modeling approach for hazard scenario construction. *Sci. Total. Environ.* **2012**, *440*, 154–166. [CrossRef] [PubMed]

28. Samper, J.; Li, Y.M.; Pisani, B. An evaluation of climate change impacts on groundwater flow in the Plana de La Galera and Tortosa alluvial aquifers (Spain). *Environ. Earth. Sci.* **2015**, *73*, 2595–2608. [CrossRef]

29. Tang, G.; Ding, Y.; Wang, S.; Ren, G.; Liu, H.; Zhang, L. Comparative analysis of the time series of surface air temperature over China for the last 100 years. *Adv. Clim. Chang. Res.* **2009**, *5*, 71–78. (In Chinese).

30. Pasini, S.; Torresan, S.; Rizzi, J.; Zabeo, A.; Critto, A.; Marcomini, A. Climate change impact assessment in Veneto and Friuli Plain groundwater. Part II: A spatially resolved regional risk assessment. *Sci. Total. Environ.* **2012**, *440*, 219–235. [CrossRef] [PubMed]

31. Turc, L. The water balance of soils—Relation between precipitation evaporation and flow. *Ann. Agron.* **1954**, *5*, 491–569.

32. Ribeiro, L.; Kretschmer, N.; Nascimento, J.; Buxo, A.; Rotting, T.; Soto, G.; Senoret, M.; Oyarzun, J.; Maturana, H.; Oyarzun, R. Evaluating piezometric trends using the Mann–Kendall test on the alluvial aquifers of the Elqui River basin, Chile. *Hydrol. Sci. J.* **2015**, *60*, 1840–1852. [CrossRef]

33. Stefanova, A.; Hesse, C.; Krysanova, V. Combined Impacts of Medium Term Socio–Economic Changes and Climate Change on Water Resources in a Managed Mediterranean Catchment. *Water* **2015**, *7*, 1538–1567. [CrossRef]

34. Ligaray, M.; Kim, H.; Sthiannopkao, S.; Lee, S.; Cho, K.H.; Kim, J.H. Assessment on Hydrologic Response by Climate Change in the Chao Phraya River Basin, Thailand. *Water* **2015**, *7*, 6892–6909. [CrossRef]