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# The Effect of Vegetative Coverage and Altitude on the Vegetation Water Consumption in the Alpine Inland River Basin of the Northeastern Qinghai–Tibet Plateau

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**Abstract:** Estimating accurately the vegetation water consumption (VWC) in the Qinghai Lake Basin (QLB) is conducive to the effective utilization and management of water resources in the QLB, which is of great significance to the construction of a national park in the QLB. We used Geographic Information System (GIS) technology and remote sensing (RS) technology based on potential evapotranspiration data to calculate the VWC in the QLB from 2000 to 2020, and analyzed the influencing factors of the VWC in the QLB from 2000 to 2020. The results showed that (1) the average value of the VWC in the QLB varied from 242.96 mm to 287.99 mm, the average value of the VWC was 267.07 mm, and the average value of the total VWC was 79.05 $\times$ $10^8$ $m^3$ from 2000 to 2020. (2) In terms of spatial variation of the VWC, the VWC in the QLB did not increase significantly from 2000 to 2014, however, the VWC in the QLB showed a significant increase from 2015 to 2020. (3) As the altitude gradient increases, the VWC in the QLB from 2000 to 2020 showed a significant downward trend with the increase in altitude. When the altitude increases by 100 m, the value of the VWC decreases by 13.47 mm from 2000 to 2014 and 22.8 mm from 2015 to 2020, respectively. (4) Exploring the influencing factors of the VWC in the QLB from 2000 to 2020, the results showed that the VWC was mainly affected by the average annual precipitation and normalized difference vegetation index (NDVI) from 2000 to 2014. It was mainly affected by the combined effects of annual temperature, precipitation, and vegetation coverage from 2015 to 2020. The VWC was mainly affected by the average annual temperature, precipitation, and vegetation coverage along the altitude gradient from 2000 to 2014. It was mainly affected by the average annual temperature and vegetation coverage in the QLB from 2015 to 2020. Obviously, vegetation coverage was the most important factor affecting the VWC regardless of spatial or altitude gradient variations.

**Keywords:** Qinghai Lake Basin; vegetation water consumption; temporal and spatial trends; GIS

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## 1. Introduction

Water is the core of a healthy ecosystem [1] and profoundly affects the growth of plants and the material cycle of the ecosystem [1,2]. Water loss from vegetation is mainly through transpiration [3–5]. Evapotranspiration is an important part of the water cycle and a key ecological process that sustains vegetation water consumption [6–8]. At present, global climate change is becoming more and more intense, which profoundly affects all links of the global water cycle, and has a significant impact on the spatial and temporal distribution of global precipitation [9,10]. At the same time, global warming is increasing surface evaporation, which affects vegetation transpiration and its water consumption [11]. Therefore, studying the vegetation water consumption (VWC) under such a climate background is not only conducive to in-depth understanding of the impact of global climate change on vegetation evaporation but also conducive to providing data and theoretical support for the effective use and management of regional water resources.

At present, a large number of studies on ecological water consumption have been carried all over the word [12–14]. In recent years, the method of simulation calculation based remote sensing (RS) has been widely used. For example, Chimtengo et al. [12] used RS to calculate the ecological water demand, and Groeneveld et al. [13] used the model to calculate the vegetation evapotranspiration in arid areas. This study uses geographic information system (GIS) technology and RS technology to calculate the VWC, and quantitatively analyze the variations, trends and influencing factors of the VWC.

The Qinghai–Tibetan Plateau (QTP), called "the third pole of the earth and the water tower in Asia", is one of the most sensitive regions to external disturbances such as climate change in the world and is a critical region for ecological security [15–18], and is thus an ideal place to study the variations of the VWC. However, there are currently few reports on the VWC on the QTP, especially in the alpine inland river basin. How much water is consumed by vegetation on the QTP and what factors affect the VWC on the QTP are still unclear.

The Qinghai Lake Basin (QLB) is located in the northeastern part of the QTP. This region is a sensitive area for global climate change and a typical fragile ecosystem. This region has become one of the representative areas for the international scientific community to study many ecological and environmental issues on the QTP [19–23]. Predecessors have mainly focused on the VWC of farmland and some specific plant communities in the QLB. They used stable isotope technology to study the source of vegetation water and the characteristics of vegetation transpiration. Studies have mainly focused on the water use of vegetation in a specific type of ecosystem. However, how much water is consumed by vegetation in the entire QLB, what has the threshold of the VWC been over the years, and what are the main factors affecting the VWC in the QLB are still unclear. Therefore, the study of the VWC in the QLB has practical significance for revealing the variation characteristics of the VWC and its adaptation to climate change. This study focuses on revealing the spatial and elevational variations of the VWC in the QLB and clarifying the influencing factors of the VWC. The results can provide valuable information for the management of water resources and the construction of national parks in the QLB.

In this study, we investigated the temporal and spatial variation of the VWC and the influencing factors of the VWC in the QLB in period of from 2000 to 2020. This study's purpose is to: (1) identify the spatial and temporal variation of the VWC in the QLB, (2) quantify how altitude affects VWC in the QLB, and (3) investigate the influencing factors of the VWC to understand which influencing factors have the most significant impact on VWC. Therefore, this study explores the VWC in the QLB from 2000 to 2020 and provides theoretical support for the effective protection and management of water resources in the QLB.

## 2. Materials and Methods

### *2.1. The Study Area*

The Qinghai Lake Basin (QLB) is located in the northeastern part of the QTP (36°15′ to 38°20′ N, 97°50′ to 101°20′ E) (Figure 1). The area of the QLB is about $2.96 \times 10^4$ km$^2$, and the altitude varies from 3169 m to 5268 m. The terrain of the QLB is high in the northwest and low in the southeast [20,21]. In order to better study the VWC in the QLB, this study divided the QLB into 8 sub-basins to quantitatively calculate the water consumption of each sub-basin, so as to understand in detail the status of the VWC of each part of the QLB (Figure 2).

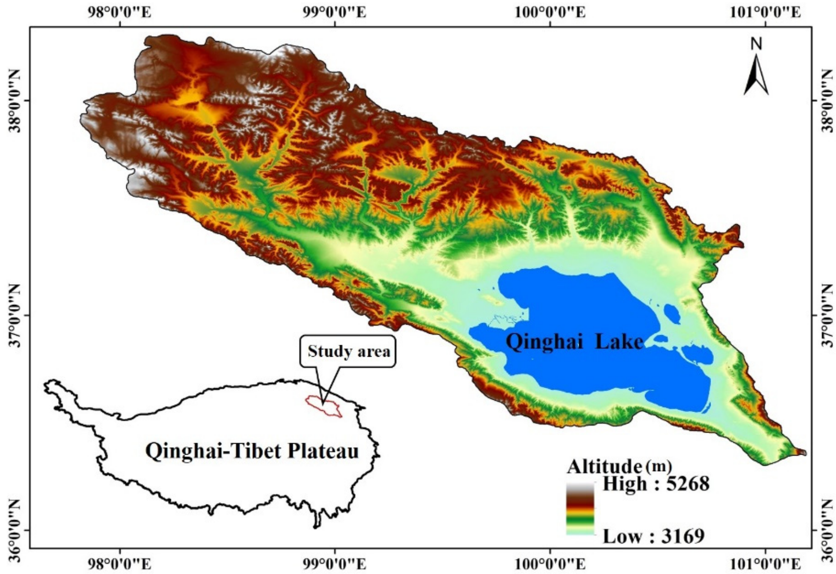


**Figure 1.** Location of the Qinghai Lake Basin.

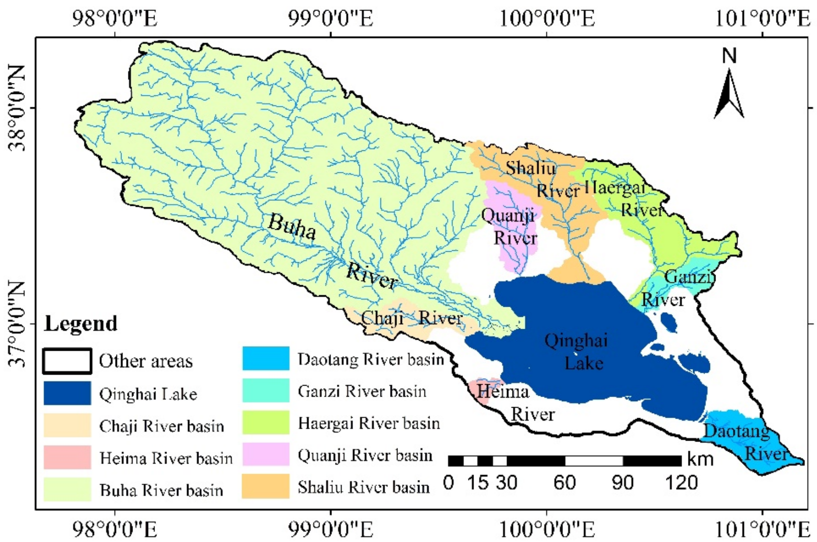


**Figure 2.** Distribution map of main river sub-basins in Qinghai Lake Basin.

## 2.2. Data Sources and Processing

The potential evapotranspiration data sets (PET) from 2000 to 2014 were obtained from the Numerical Terra Dynamic Simulation Group at the University of Montana (http://www.ntsg.umt.edu/ (accessed on 5 July 2021)). The PET data from 2015 to 2020 came from the National Earth System Science Data Center (http://www.geodata.cn/ (accessed on 14 July 2021)). The data of the temperature and precipitation from 2000 to 2014 were from the Resource Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/ (accessed on 18 July 2021)) and the data of the temperature and precipitation from 2015 to 2020 were from the National Earth System Science Data Center (http://www.geodata.cn/ (accessed on 20 July 2021)). The data of normalized difference vegetation index (NDVI) came from the Resource Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/ (accessed on 26 July 2021)). These data were first preprocessed by ArcGIS and ENVI software to remove invalid values, and then used ArcGIS software for data format conversion to unify the data coordinate system and resolution size, resampling the spatial resolution of the required data to 1 km × 1 km. This research also used ArcGIS 10.3 software (Redlands, CA, USA) for data calculation, resampling, and raster calculation.

### 2.3. Methods

#### 2.3.1. Calculation of Vegetation Water Consumption

Existing research shows that the product of vegetation coefficient and potential evapotranspiration is the calculation of vegetation water consumption [24]. The calculation formula is as follows [24]:

$$VWC = K_s \times K_c \times PET \tag{1}$$

where *VWC* represents the vegetation water consumption, *PET* represents the potential evapotranspiration, $K_c$ represents the vegetation coefficient, and $K_s$ represents the soil moisture limitation coefficient. The value of $K_s$ in this study was based on the empirical parameters of FAO [25]. According to the results of Choudhury et al. [26], $K_c$ can be replaced by the vegetation transpiration coefficient $T_c$. The calculation formula was as follows [26]:

$$K_c = T_c = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}}\right)^{\eta} \tag{2}$$

where *NDVI* represents the normalized difference vegetation index and the value of $\eta$ is determined by the relationship between vegetation evapotranspiration and vegetation index. Potential evapotranspiration was calculated using the P-M formula from 2000 to 2014 as follows [25]:

$$PET = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{3}$$

where $\Delta$ represents the slope of the curve between saturated vapor pressure and temperature, in kPa/°C; $R_n$ represents solar radiation, in MJ/(m$^2$·day); $G$ represents soil heat flux, in MJ/(m$^2$·day); $\gamma$ represents the psychrometric constant, in kPa/°C; $T$ represents the average temperature, in °C; $u_2$ represents the average wind speed at a height of 2 m, in m/s; $e_s$ represents saturated vapor pressure, in kPa; $e_a$ represents the actual vapor pressure, in kPa.

Potential evapotranspiration was calculated using the Hargreaves formula from 2015 to 2020 as follows [27–29]:

$$PET = 0.0023 \times S_0 \times (MaxT - MinT)^{0.5} \times (MeanT + 17.8) \tag{4}$$

where *MaxT* represents the monthly maximum temperature (°C), *MinT* represents the monthly minimum temperature (°C), *MeanT* represents the monthly mean temperature (°C), and $S_0$ represents the extra-terrestrial solar radiation (mm/month) at the top of the Earth's atmosphere on a horizontal surface [25,30]. $S_0$ can be calculated according to the solar constant, number of days in a year, latitude, and solar decimation [30]. The detailed calculation procedure has been described in Allen et al. [25] and Zhao et al. [31].

#### 2.3.2. Trend Analysis

This study applied least-squares regression to estimate the linear trends of the *VWC* in the QLB from 2000 to 2020. More details for this method can be found in Gang et al. [32]; the calculation formula was as follows [32]:

$$SLOPE = \frac{n \times \sum_{i=1}^{n} i \times j_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} j_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \tag{5}$$

where *SLOPE* represents the slope of the regression equation, $n$ represents the length of the time series; $j_i$ represents the *VWC* in $i$ year. If slope value > 0, it means the *VWC* increased; if slope value < 0, it indicates that the *VWC* was reduced.

2.3.3. Correlation Analysis

In correlation analysis, the correlation coefficient can truly reflect the correlation between the variables of $x$ and $y$, the calculation formula was as follows [18,33]:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \tag{6}$$

where $\overline{x}$ represents the average value of temperature, precipitation and $NDVI$, $\overline{y}$ represents the average value of the $VWC$, $i$ represents the annual number, for example, $i$ = 1, 2, ... 20, $n$ represents the series of the study period, and $x_i$ represents the temperature, precipitation and $NDVI$ in the year of $i$. $y_i$ represents the $VWC$ in the year of $i$. If $r > 0$, there was a positive correlation between the two, and if $r < 0$, there was a negative correlation between the two. The closer the absolute value was to 1, the stronger the correlation, and the closer its value was to 0, the weaker the correlation [18].

This research used the $t$-test to check the significance of the correlation coefficient, and its calculation formula was as follows:

$$T = \sqrt{n-2} \times \frac{r}{\sqrt{1-r^2}} \tag{7}$$

where $n$ represents the sample size (the period series is 2000 to 2020), $r$ represents the correlation coefficient. The significance level of the results of the $t$-test in this study was set to $\alpha = 0.05$.

## 3. Results

### *3.1. Change of Vegetation Water Consumption*

From 2000 to 2020, the average annual value of the VWC in the QLB fluctuated (Figure 3), and there was no obvious upward trend ($R^2 = 0.06$ $p > 0.05$). The average annual value of the VWC in the QLB varied from 242.96 mm to 287.99 mm from 2000 to 2020; the average value of the VWC was 267.07 mm (Figure 3). The maximum annual average value of the VWC in the Q LB was in 2013 at 287.99 mm (Figure 3). The minimum annual average value of the VWC in the QLB was in 2016 at 242.96 mm (Figure 3).

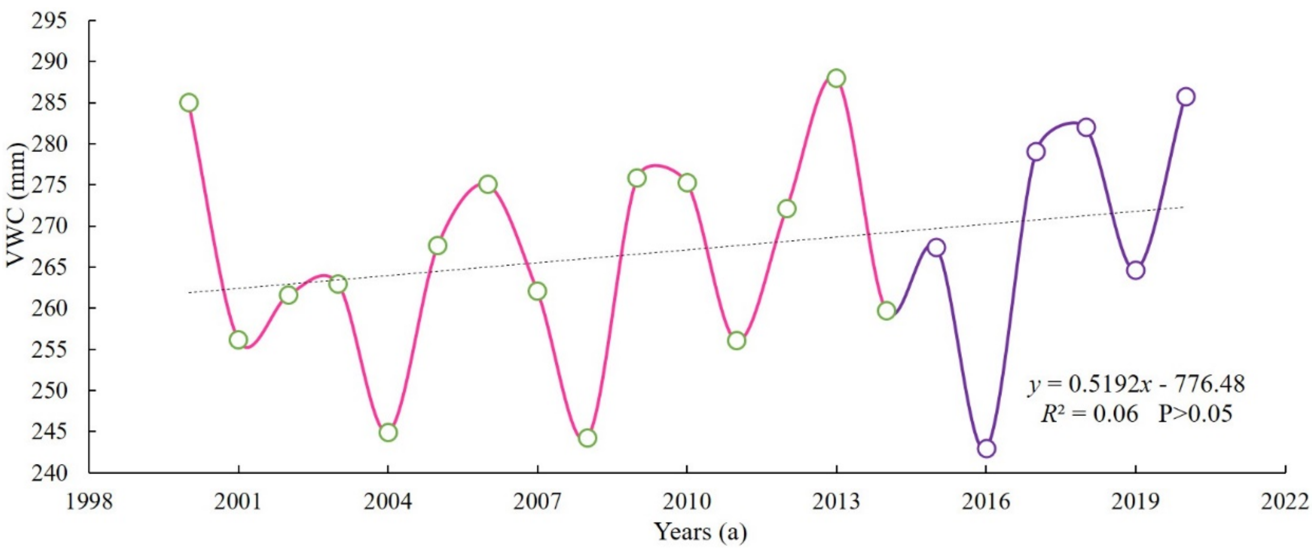


**Figure 3.** Change of the VWC in Qinghai Lake Basin from 2000 to 2020.

### *3.2. Spatial Characteristics and Changing Trends of the Vegetation Water Consumption*

The average value of the VWC in the QLB varied from 40.09 mm to 426.21 mm from 2000 to 2014 (Figure 4a). The areas with the largest value of the VWC were mainly distributed in the southern and central areas of the basin, and the areas with the smallest value of the VWC were mainly distributed in the northwest of the basin (Figure 4a). The spatial distribution of the VWC was patchy in the QLB from 2000 to 2014. From the west to the east of the basin, the VWC showed an increasing trend, and from the northwest to the southeast of the basin, it first increased and then decreased (Figure 4a). According to the calculation results of the trend change, the slope value of the VWC in the QLB varied from −8.93 to 10.99 from 2000 to 2014 (Figure 4b). The increasing area of the VWC in the QLB was mainly distributed in the northwest of the basin, which accounted for 55% of the basin area (Figure 4b). The reducing areas of the VWC were mainly distributed in the southern and northern regions of the basin, which accounted for 45% of the basin area (Figure 4b).

The average value of the VWC in the QLB varied from 10.49 mm to 482.62 mm from 2015 to 2020 (Figure 5a). The areas with the largest value of the VWC were mainly distributed in central areas of the basin, and the areas with the smallest value of the VWC were mainly distributed in the northwest of the basin (Figure 5a). Furthermore, the spatial distribution of the VWC was zonal in the QLB from 2015 to 2020. From the west to the east of the basin, the VWC showed an increasing trend (Figure 5a). According to the calculation results of the change trend, the slope value of the VWC in the QLB varied from −106.42 to 84.28 from 2015 to 2020 (Figure 5b). The reducing areas of the VWC were mainly distributed in the downstream area of the Buha River, and the VWC in most areas showed a significant increase (Figure 5b).

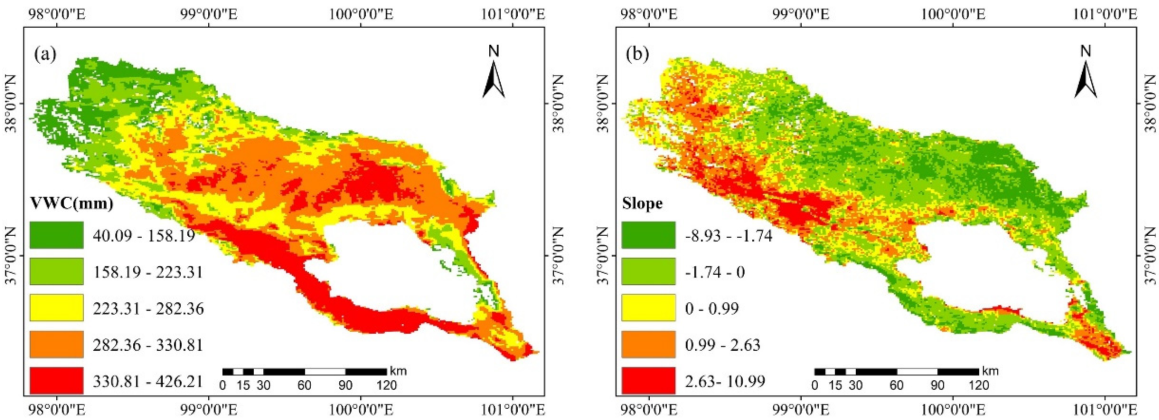


**Figure 4.** Spatial characteristics (**a**) and changing trends (**b**) of the VWC in the Qinghai Lake Basin from 2000 to 2014.

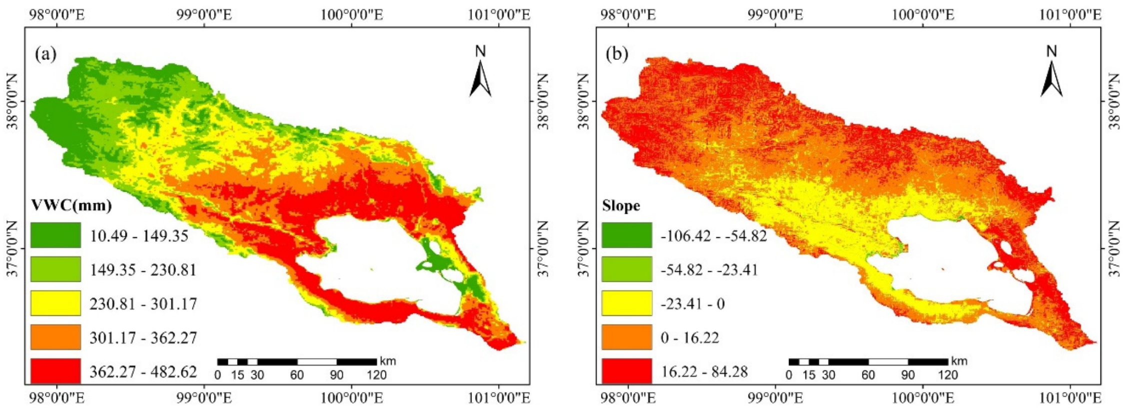


**Figure 5.** Spatial characteristics (**a**) and changing trends (**b**) of the VWC in the Qinghai Lake Basin from 2015 to 2020.

### 3.3. Analysis of Vegetation Water Consumption in Sub-Catchment

From 2000 to 2014, the value of the VWC in the various sub-basins of the QLB was the highest value in the Heima River basin and the lowest value in the Buha River basin. The value of the VWC was 352.78 mm and 241.64 mm, respectively (Figure 6a). However, the Ganzi River Basin had the highest value of the VWC in each sub-basin from 2015 to 2020, while the Buha River Basin of the value of the VWC was still the lowest, their values of the VWC were 371.77 mm and 232.62 mm, respectively (Figure 6a). The average value of the total VWC in the QLB from 2000 to 2014 was 78.65 × $10^8$ $m^3$ and the average value of the total VWC in the QLB from 2015 to 2020 was 80.01 × $10^8$ $m^3$.

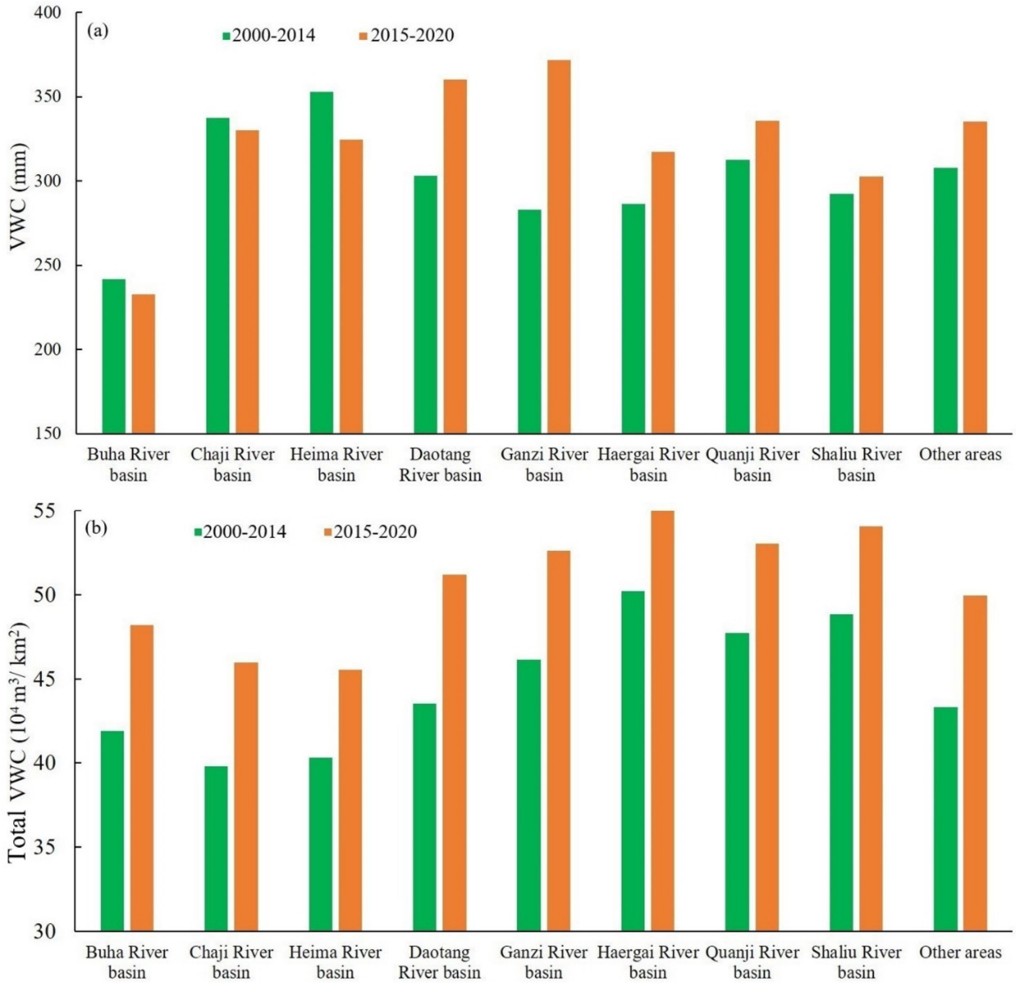


**Figure 6.** The VWC (**a**) and per unit area of the total VWC (**b**) in 8 sub-basins of the Qinghai Lake Basin from 2000 to 2020.

In order to further understand the VWC of each sub-basin, this study carried out the calculation and statistics of the total VWC per unit area (1 $km^2$) of each sub-basin (Figure 6b). The results showed that the highest value of the total VWC per unit area in each sub-basin was the Hargai River Basin, and the lowest value of the total VWC per unit area was the Quji River Basin from 2000 to 2014, their values of the total VWC per unit area were 50.22 × $10^4$ $m^3/km^2$ and 39.79 × $10^4$ $m^3/km^2$, respectively (Figure 6b). However, the value of the total VWC per unit area from 2015 to 2020 in most of the sub-catchment areas has increased significantly compared with 2000 to 2014. The value of the total VWC per unit area was the highest in the Hargai River Basin, and the value of the total VWC per unit area was the lowest in the Heima River Basin from 2015 to 2020, their values of the total VWC per unit area were 55.44 × $10^4$ $m^3/km^2$ and 45.54 × $10^4$ $m^3/km^2$, respectively (Figure 6b).

## 4. Discussion

### 4.1. Research Results of VWC and Analysis of Meteorological Influence Factors

This study used GIS and RS technology to calculate that the average value of the VWC was 267.07 mm in the QLB from 2000 to 2020. We compared the results of this study with the areas near the QLB, and the results showed that the VWC calculated in this study was basically consistent with the results of the Heihe River Basin and Tarim River Basin [34,35]. For the spatial variation of the VWC in the QLB, regarding the spatial variation of the VWC in the basin, we found that the high value area of the VWC from 2015 to 2020 moved to the south of the basin compared with 2000 to 2014. In terms of changing trends, most areas of the VWC in the basin showed a decrease in water consumption from 2000 to 2014, however, most areas of the VWC in the basin showed an increase in water consumption from 2015 to 2020. This may be related to changes in temperature and precipitation in the basin [6].

In order to reveal the influence of temperature and precipitation on the VWC in the basin from 2000 to 2020, this study performed a correlation analysis of temperature, precipitation and VWC. The results showed that the correlation coefficients of the temperature and precipitation and VWC were −0.29 to 0.58 and −0.85 to 0.85, respectively (Figure 7). Areas with a positive correlation between temperature and VWC were mainly distributed in the southern part of the basin, and areas with a negative correlation were mainly distributed in the northern part of the basin, which accounted for 53% and 47% of the basin area, respectively (Figure 7a). Areas with a positive correlation between precipitation and VWC were mainly distributed in the northwest of the basin, and areas with a negative correlation were mainly concentrated in the northern part of the basin, which accounted for 61% and 39% of the basin area, respectively (Figure 7b). The temperature had no significant effect on the VWC of the basin from 2000 to 2014, however, precipitation had a significant impact on the VWC in parts of the basin from 2000 to 2014 (Figure 7c,d).

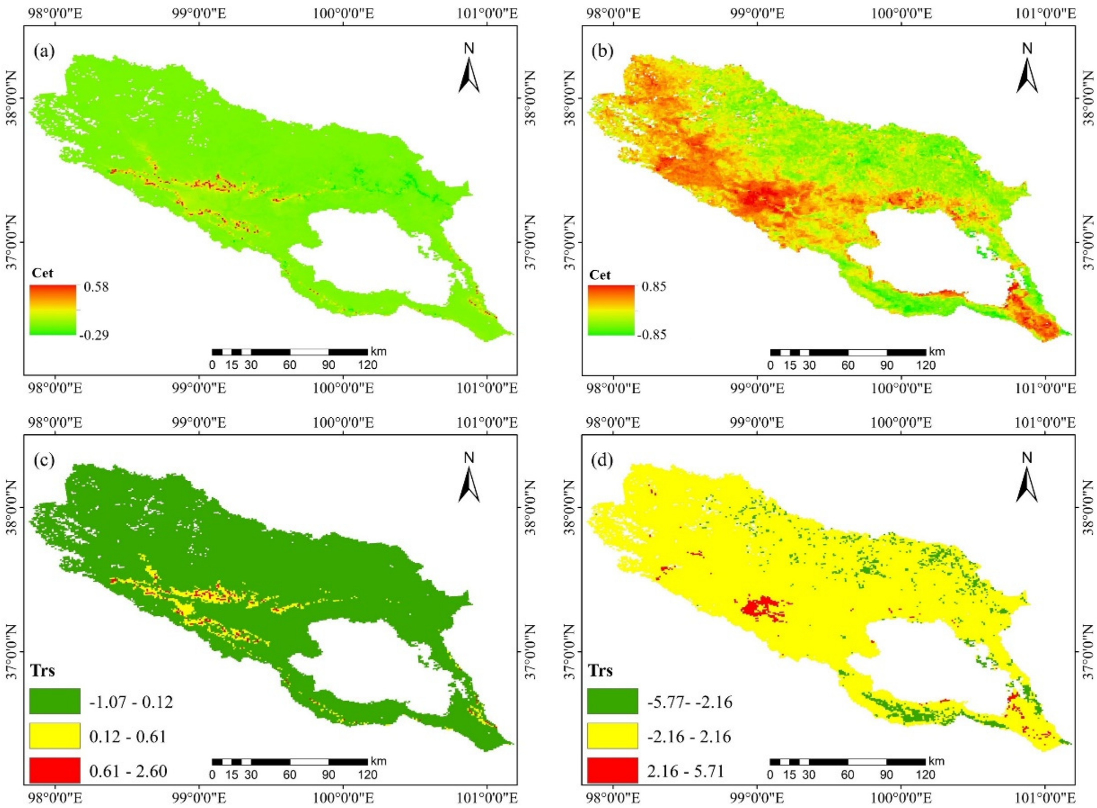


**Figure 7.** Spatial correlations of temperature (**a**), precipitation (**b**) with VWC and the *t*-test results in the Qinghai Lake Basin from 2000 to 2014. Figure (**c**) represents the *t*-test results of the correlation between temperature and VWC; figure (**d**) represents the *t*-test results of the correlation between precipitation and VWC. Cet and Trs represent correlation coefficient and the *t*-test results, respectively.

However, the VWC from 2015 to 2020 was significantly correlated with the average annual temperature and precipitation (Figure 8). The correlation analysis and *t*-test results showed that the annual average temperature and the VWC were spatially positively and significantly correlated ($\alpha < 0.05$), its area was mainly distributed near the Buha River (Figure 8a,c). The areas where the average annual precipitation had a significant correlation ($\alpha < 0.05$) with VWC were mainly concentrated in the Buha River Basin (Figure 8b,d).

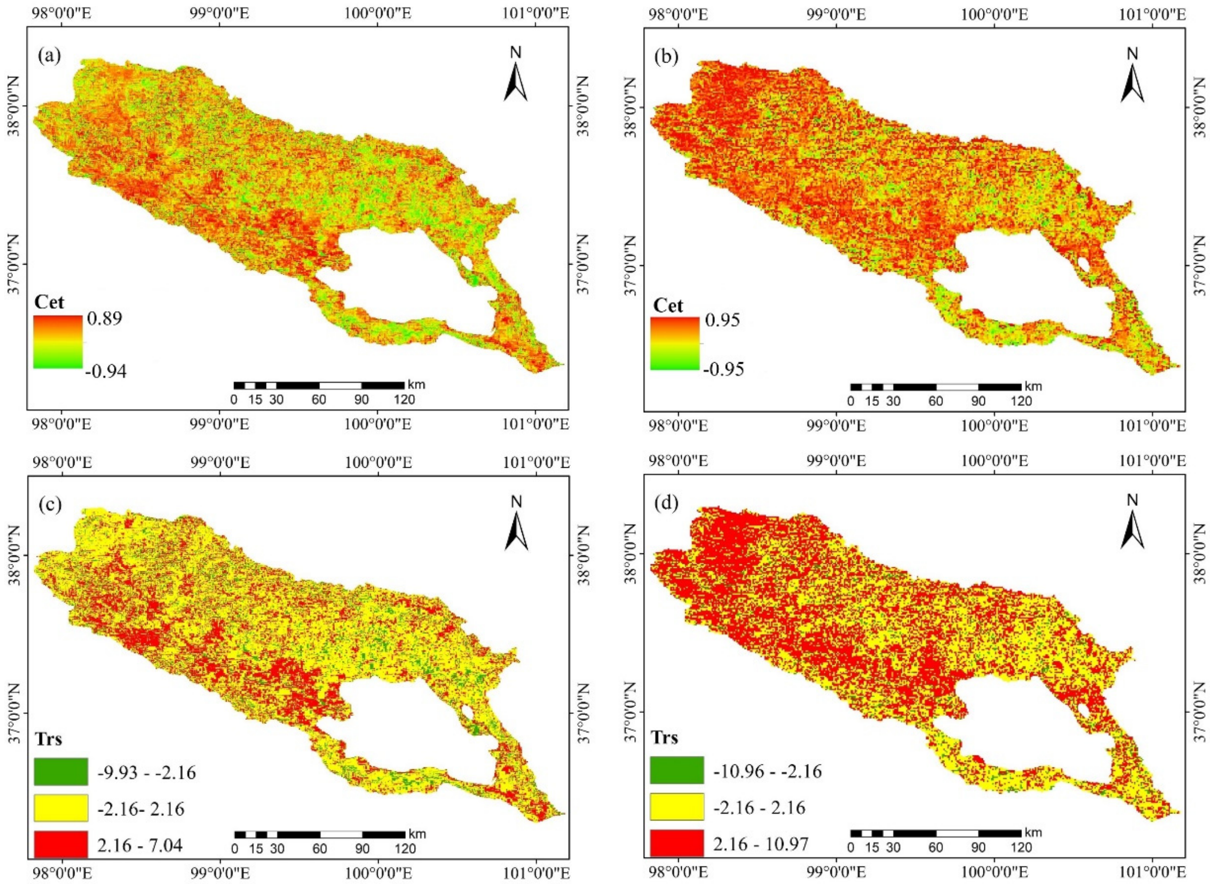


**Figure 8.** Spatial correlations of temperature (**a**), precipitation (**b**) with VWC and the *t*-test results in the Qinghai Lake Basin from 2015 to 2020. Figure (**c**) represents the *t*-test results of the correlation between temperature and VWC; figure (**d**) represents the *t*-test results of the correlation between precipitation and VWC. Cet and Trs represent correlation coefficient and *t*-test results, respectively.

The analysis of the relationship between VWC and temperature and precipitation showed that the impact of meteorological factors on VWC in the QLB has obvious spatial differences, which were related to the local climate differences in the QLB. In general, the impact of precipitation on VWC was greater than that of temperature. In particular, the VWC in the QLB in the past five years has been greatly affected by meteorological factors, which are related to the obvious warming and humidification trend in the climate in the QLB from 2015 to 2020.

### *4.2. Influence of Vegetation Coverage on Vegetation Water Consumption*

The above discussion showed that from 2000 to 2014 in the QLB, there was no significant correlation between VWC and temperature, and there were few areas where there was a significant correlation with precipitation, which may be related to changes in vegetation coverage [36]. In order to explore whether the effect of vegetation cover on VWC was significant, and since PET can reflect vegetation coverage, this study used NDVI for analysis and explored the correlation between the two (Figures 9 and 10). We found that the VWC from 2000 to 2014 and the NDVI were obviously related, and the coefficient varied from −0.47 to 0.99 (Figure 9a). Areas showing a positive correlation between VWC and NDVI were mainly distributed in the northwest of the basin, and areas showing a negative correlation were mainly distributed on the northern shore of Qinghai Lake, the positive and negative correlation regions accounted for 97.26% and 2.74% of the basin area, respectively (Figure 9a). Obviously, the spatial variation of VWC in the QLB from 2000 to 2014 was mainly affected by vegetation coverage.

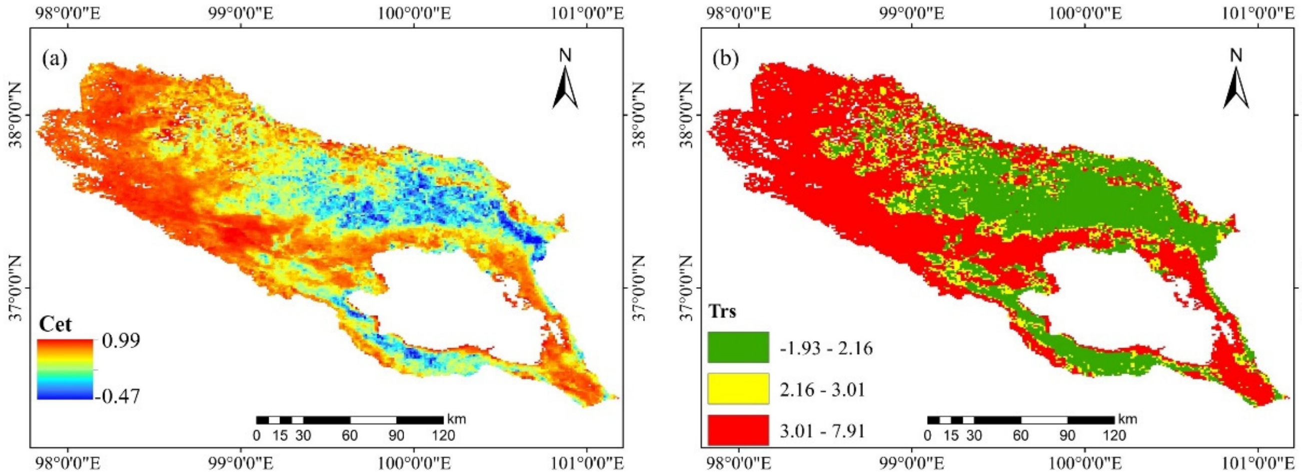


**Figure 9.** Spatial correlations of NDVI with VWC (**a**) and the *t*-test results (**b**) in the Qinghai Lake Basin from 2000 to 2014. Cet and Trs represent correlation coefficient and the *t*-test results, respectively.

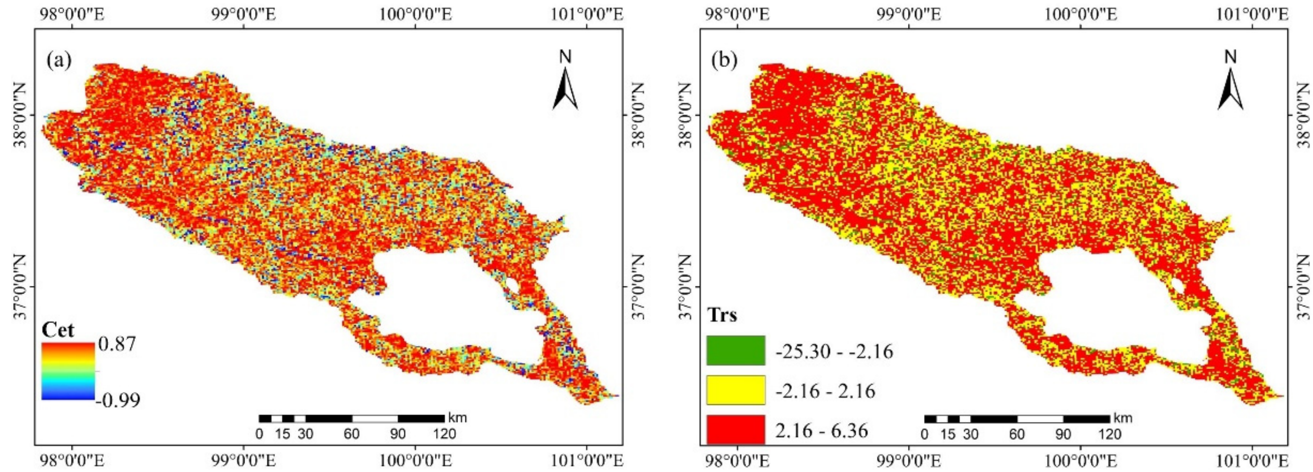


**Figure 10.** Spatial correlations of NDVI with VWC (**a**) and the *t*-test results (**b**) in the Qinghai Lake Basin from 2015 to 2020. Cet and Trs represent correlation coefficient and the *t*-test results, respectively.

At the same time, the VWC from 2015 to 2020 was consistent with the research results of the previous 15 years. The NDVI and VWC were mainly positively correlated (Figure 10). The *t*-test results showed that the NDVI and VWC were spatially positively correlated, areas showing a significant positive correlation ($\alpha < 0.05$) were distributed in most areas of basin (Figure 10). Through the above analysis, vegetation coverage was an important factor affecting the VWC.

There was a correlation between VWC and its own coverage. The correlation between VWC and vegetation coverage in the QLB showed that vegetation coverage has a significant spatial impact on VWC in the basin. This was more consistent with the results of related similar studies [36]. The higher the vegetation coverage, the greater the amount of the VWC in the watershed. Because the vegetation in the QLB was dominated by alpine grassland and meadows, the higher the grassland coverage, the higher the VWC, which is proportional to it.

*4.3. The Effect of Altitude on Vegetation Water Consumption*

Due to the large relative drop in the Qinghai Lake Basin, the elevation gradient changes significantly. Elevation is an important factor affecting the hydrothermal conditions of the watershed, affecting air temperature, precipitation, and vegetation growth [18,36]. As the altitude gradient increases, temperature and precipitation can change, and vegetation coverage can also change. The terrain of the QLB is relatively complex, with large elevation gradients from southeast to northwest, and the temperature, precipitation, and vegetation coverage are all different [18]. To this end, this study further analyzed the influence of altitude on VWC in the QLB from 2000 to 2020. The results showed that along the altitude gradient, the VWC, annual average temperature, and NDVI in the QLB from 2000 to 2014 showed a significant downward trend with the increase in altitude ($R^2$ = 0.8 $p < 0.01$; $R^2$ = 0.99 $p < 0.01$; $R^2$ = 0.81 $p < 0.01$) (Figure 11) (Table 1). However, the average annual precipitation showed a significant upward trend in altitude ($R^2$ = 0.99 $p < 0.01$). In addition, when the altitude increased by 100 m, the VWC was reduced by 13.47 mm, the average annual temperature was reduced by 0.72 °C, the NDVI was reduced by 0.03, and the average annual precipitation increased by 6.11 mm (Figure 11) (Table 1). Of course, the VWC in the QLB from 2015 to 2020 showed a similar trend along the altitude gradient. From 2015 to 2020, the VWC, annual average temperature, and NDVI in the QLB all showed a significant downward trend ($R^2$ = 0.96 $p < 0.01$; $R^2$ = 0.98 $p < 0.01$; $R^2$ = 0.83 $p < 0.01$) (Figure 12) (Table 1). However, the average annual precipitation has no obvious upward trend with altitude (Figure 12) (Table 1), which may be related to the difference in local precipitation.

In order to further analyze the influence of temperature, precipitation, and vegetation coverage changes on the VWC on the altitude gradient, the study conducted a correlation analysis on altitude gradient, and the results showed that the average annual temperature and NDVI from 2000 to 2014 were significantly positively correlated with VWC, and the average annual precipitation was significantly negatively correlated (Figure 13). Along the altitude gradient, if the annual average temperature and NDVI increase by 1 °C and 0.1, respectively, the VWC will increase by 17.65 mm and 38.5 mm, respectively. If average annual precipitation increases by 1 mm, the VWC will decrease by 2.1 mm (Figure 13). Similarly, there was a similar linear relationship from 2015 to 2020. The average annual temperature and vegetation coverage had a significant positive correlation with VWC, while the average annual precipitation had no obvious correlation with it (Figure 14). So, along the altitude gradient, if the annual average temperature and vegetation coverage increase by 1 °C and 0.1, respectively, the VWC will increase by 29.83 mm and 52.6 mm, respectively (Figure 14). Obviously, climatic factors and vegetation coverage factors had a significant impact on VWC on the altitude gradient. On the altitude gradient, the order of factors affecting VWC was that vegetation coverage > temperature > precipitation.

Based on the above analysis, the VWC in the QLB from 2000 to 2014 was mainly affected by the average annual precipitation and NDVI. The VWC in the basin from 2015 to 2020 was mainly due to the comprehensive influence of climatic factors and vegetation coverage factors. The discussion results of factors affecting VWC were basically consistent with the research results of Lin et al. [37] and Yuan et al. [38]. Lin et al. [37] and Yuan et al. [38] pointed out that wind speed and vapor pressure difference were the main influencing factors of potential evapotranspiration in the target study area. This was because the current warming and humidification of the QTP had led to an increase in precipitation, and the implementation of ecological process construction in ecologically degraded areas would increase vegetation coverage. The combined effect of these two factors would reduce wind speed and reduce vapor pressure, thereby reducing potential evapotranspiration in the area. However, with the increase of vegetation coverage, the VWC was significantly increased.

Through the above discussion, this study analyzed the effects of climate factors, vegetation coverage, and altitude on the VWC in the QLB, and obtained some qualitative and quantitative conclusions both in terms of space and altitude in the QLB. It reveals the spatial differentiation characteristics of VWC in the QLB, and clarifies its influencing factors. However, there are still some shortcomings. In terms of data sets, since the calculation results of this study were calculated based on two sets of data, this was an important deficiency of this study. Because of the different calculation methods between the two, there were certain differences in data calculations. However, by comparing the existing research results, it was found that the calculation results of the research have a certain degree of credibility. The inconsistency of potential evapotranspiration data may cause certain errors in the calculation results. In the future, it is necessary to use more accurate and high-resolution data sets to simulate and predict the past and future changes in VWC in the QLB.

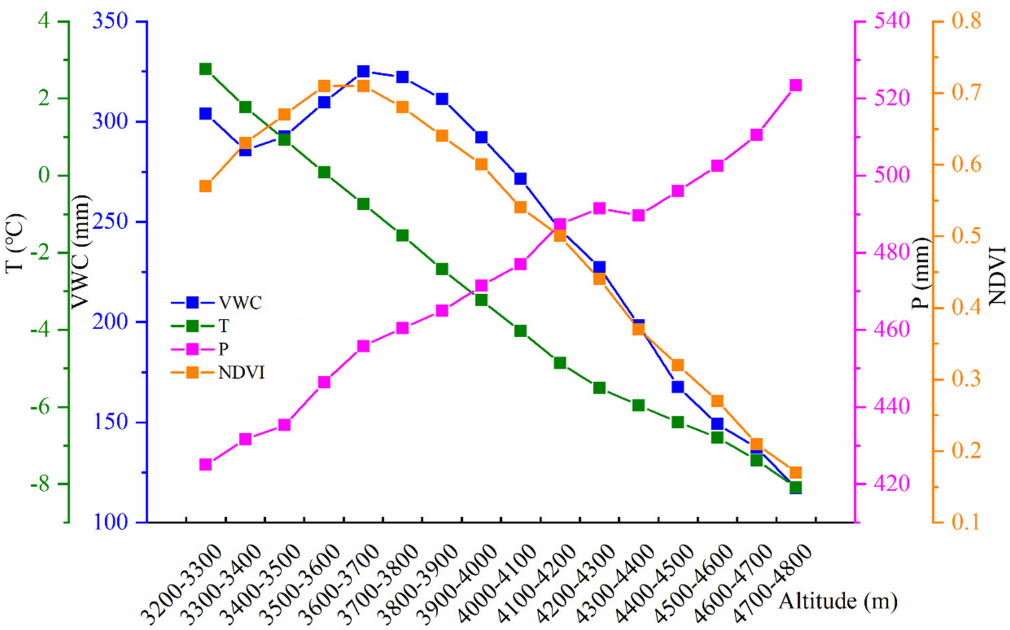


**Figure 11.** The VWC, annual average temperature, precipitation, and NDVI change along the altitude gradient in the Qinghai Lake Basin from 2000 to 2014.

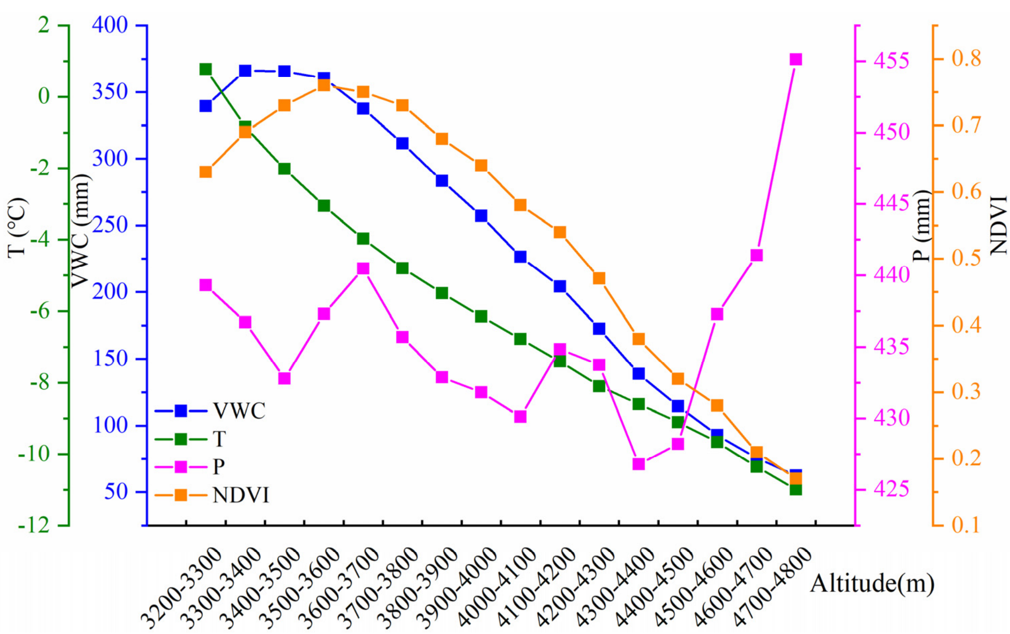


**Figure 12.** The VWC, annual average temperature, precipitation, and NDVI change along the altitude gradient in the Qinghai Lake Basin from 2015 to 2020.

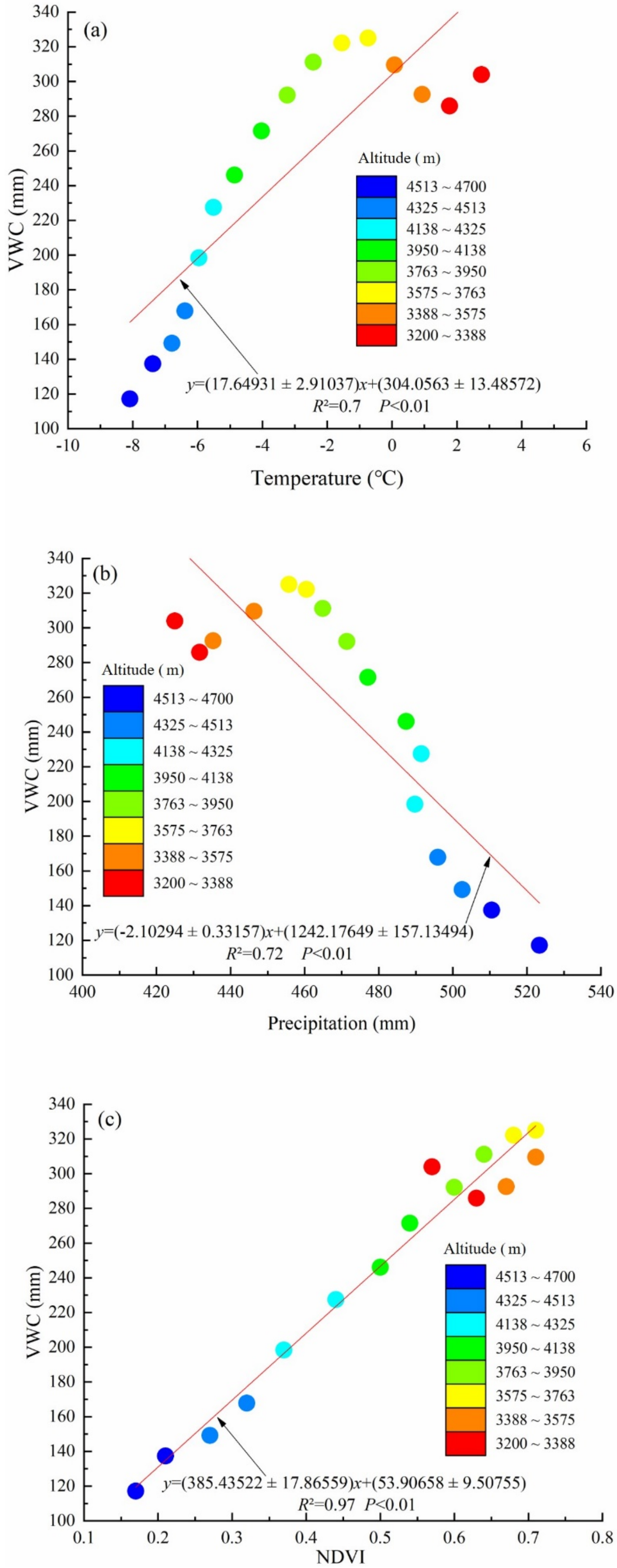


**Figure 13.** Linear relationships between annual average temperature (**a**), precipitation (**b**), NDVI (**c**), and VWC along the altitude gradient in the Qinghai Lake Basin from 2000 to 2014.

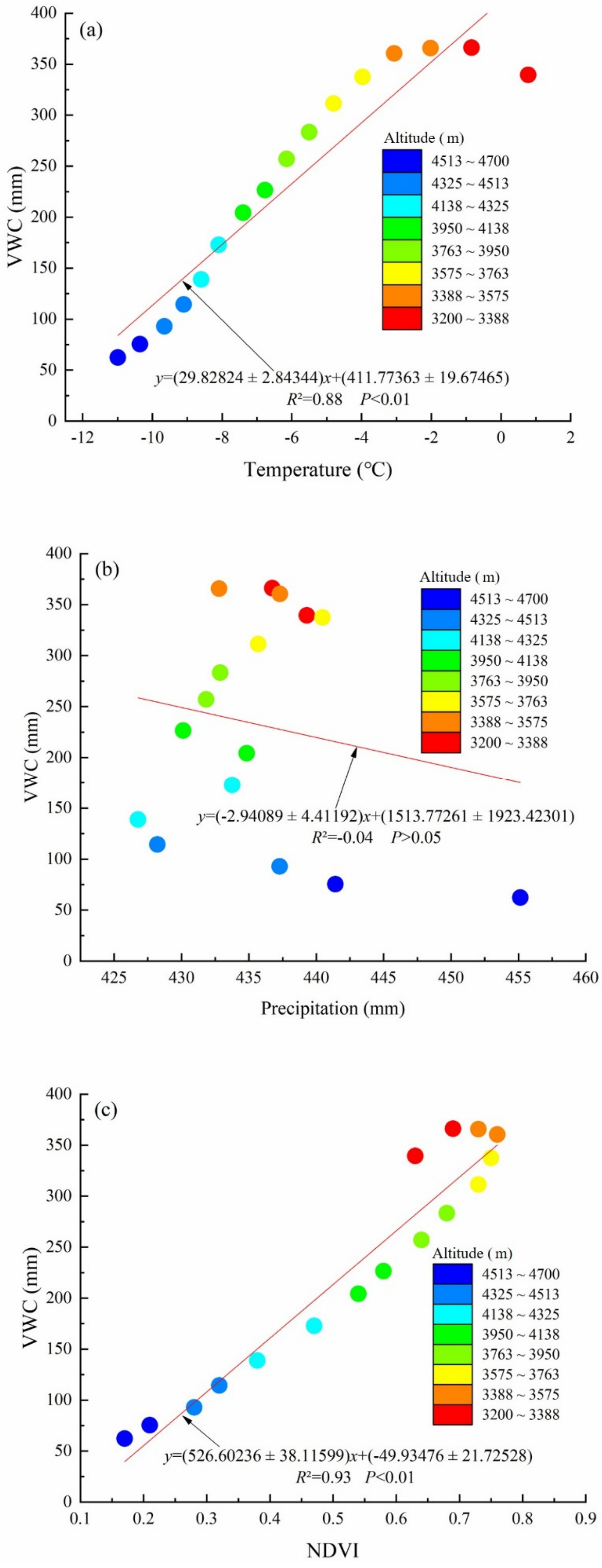


**Figure 14.** Linear relationships between annual average temperature (**a**), precipitation (**b**), NDVI (**c**), and VWC along the altitude gradient in the Qinghai Lake Basin from 2015 to 2020.

**Table 1.** Linear relationships between the VWC, annual average temperature, precipitation, NDVI, and altitude gradient.

| Year | Factor | Fitting Equation | Fitting Coefficient | Significant Test |
|---|---|---|---|---|
| 2000–2014 | Vegetation water consumption | y = −13.472x + 361.86 | 0.8 | $p < 0.01$ |
| | Average annual temperature | y = −0.7197x + 2.9045 | 0.99 | $p < 0.01$ |
| | Average annual precipitation | y = 6.1094x + 421.14 | 0.99 | $p < 0.01$ |
| | NDVI | y = −0.0345x + 0.7948 | 0.81 | $p < 0.01$ |
| 2015–2020 | Vegetation water consumption | y = −22.798x + 425.58 | 0.96 | $p < 0.01$ |
| | Average annual temperature | y = −0.7264x + 0.1405 | 0.98 | $p < 0.01$ |
| | Average annual precipitation | y = 0.2422x + 433.86 | 0.03 | $p > 0.05$ |
| | NDVI | y = −0.0389x + 0.8653 | 0.83 | $p < 0.01$ |

## 5. Conclusions

This study used GIS and RS technology to calculate the VWC in the QLB from 2000 to 2020 and analyzed the main influencing factors of the VWC. The conclusions showed that the average annual VWC in the QLB varied from 242.96 mm to 287.99 mm, the average VWC was 267.07 mm, and the average total VWC was $79.05 \times 10^8$ $m^3$ from 2000 to 2020. The VWC was mainly affected by the annual precipitation and NDVI from 2000 to 2014 in the space of the QLB, and it was mainly affected by the combined effects of annual temperature, precipitation, and vegetation coverage from 2015 to 2020. The VWC was mainly affected by the average annual temperature, precipitation, and vegetation coverage along the altitude gradient from 2000 to 2014, and it was mainly affected by the average annual temperature and vegetation coverage in the QLB from 2015 to 2020. Altitude not only affects changes in temperature, precipitation, and vegetation coverage, but also significantly affects the VWC in the QLB. Obviously, vegetation coverage and altitude affected the changes of the VWC in QLB from 2000 to 2020.

The conclusions of this study can provide data support and theoretical guidance for the effective management and utilization of water resources in the Qinghai Lake Basin. However, more factors affecting the VWC should be discussed, such as whether seasonal frozen soil and freezing and thawing processes affect the VWC in the Qinghai Lake Basin. The discussion of these influencing factors will be further analyzed in future research.

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