Research Article

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Spatiotemporal variation in groundwater level within the Manas River Basin, Northwest China: Relative impacts of natural and human factors

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Abstract: The Manas River Basin (MRB), Northwest China, is an arid basin dependent on irrigation for agriculture, and human activities are believed to be the primary factor affecting the groundwater level fluctuations in this basin. Such fluctuations can have a significant adverse impact on the social economy, agricultural development, and natural environment of that region. This raises concerns regarding the sustainability of groundwater use. In this study, we used ArcGIS spatial interpolation and contrast coefficient variance analysis to analyse groundwater level, land-use change, and water resource consumption patterns from 2012 to 2019 in the plains of the MRB. The aim was to determine the main factors influencing the groundwater level and to provide a scientific basis for the rational development, utilisation, and management of water resources in this area. During the study period, the groundwater level decreased, increased, and then fluctuated with a gradually slowing downward trend; the decline ranged from −17.82 to −11.67 m during 2012–2019. Within a given year, groundwater levels declined from March/April to August/September, then rose from August/September to March/April, within a range of 0.29–19.05 m. Primary factors influencing the groundwater level included human activities (e.g., changes in land use, river regulation, irrigation, and groundwater exploitation) and natural causes (e.g., climate and weather anomalies). Human activities were the primary factors affecting groundwater level, especially land-use change and water resource consumption. These results provide a theoretical basis for the rational exploitation of groundwater and the optimisation of water resource management in this region.

Keywords: groundwater level, influence factor, contrast coefficient, Manas River Basin

1 Introduction

Groundwater is an essential and valuable resource, especially in areas where water demand is high but supply is low [1]. Widespread availability and accessibility of groundwater make it a primary resource in many water-scare areas. Groundwater drawdown is a special type of hydrogeological phenomenon that impacts the groundwater body. This complex phenomenon may have a significant adverse impact on the social economy, agricultural development, and natural environment of the region. As such, the influencing factors of this phenomenon have been the focus of several studies. In the arid area of Northwest China, human activities are believed to be the primary factor affecting the fluctuations in the groundwater level. Rising demand created by population and industrial and economic growth has continuously increased groundwater use and led to overexploitation, causing a series of environmental problems such as excessive declines in groundwater level, land subsidence, and deteriorating water quality [2].

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Groundwater, the largest storage component in the hydrological system, interacts with rivers, lakes, soil, snow, ice, and other terrestrial components such as plant water [3,4]. These water components are the primary recharge sources of groundwater. The relationship and exploitation mode of groundwater can be determined using data on groundwater level and exploitation along with precipitation time series in hydrological years. The results show that the response of groundwater level to groundwater exploitation is faster than that of rainfall. Soil permeability, land-use conditions, topography, precipitation, and snowmelt duration influence groundwater recharge with different degrees of spatiotemporal variation [5]. For example, decreasing paddy field area may lead to declining groundwater recharge and level [6]. Recent research has focused on evaluating the economic value of groundwater resources and formulating a sustainable development strategy to meet current and future water demand within the framework of social development and environmental protection [7]. Groundwater exploitation changes the underground flow path and surface soil water content within the depression funnel created by withdrawal, reducing the age of the groundwater in an aquifer [8]. Evapotranspiration and rainfall deficits are primary contributors to meteorological drought as they directly cause groundwater shortages. However, overexploitation remains the primary reason for declining groundwater levels [9].

If groundwater decreases below a critical level, the resulting deficit can produce a series of adverse effects [10,11]. Comparisons of geochemical processes in different groundwater systems show that these are closely related to the circulation depth [12]. Surficial recharge and discharge areas determined by topography, soil characteristics, and vegetation cover can characterise the effectiveness of groundwater flow systems [13]. The flow process of groundwater affects its chemical composition (Groundwater can dissolve a part of the rock composition). As one of the key sources of drinking water, human health is closely related to the quality of groundwater. Human influences such as overexploitation, animal husbandry, and agriculture can have complex impacts on groundwater systems including altering recharge and discharge conditions as well as reduced groundwater level [12]. Determining the flow system of an aquifer can help in evaluating the groundwater age. For example, groundwater in the lower reaches of a basin tends to be younger in local water systems with shallow circulation depth, but older in regional flow systems with deeper circulation depth [14]. Groundwater exploitation can cause a strong downward hydraulic gradient, resulting in the leakage and recharge of shallow high total dissolved solids and other high concentration groundwater components to deep semi-fine-grained aquifers, causing water quality to deteriorate [15].

Problems are closely related to human activities and concerns; their resolution requires the determination of rational groundwater use strategies by studying spatiotemporal variations in and influencing factors of groundwater level. In this study, we used the coefficient of variance and ArcGIS spatial interpolation to analyse changes in groundwater level, land use, and water resource consumption in the MRB to determine primary influence factors while providing a theoretical basis and technical support for the rational utilisation of groundwater in this region.

2 Materials and methods

2.1 Study area

The MRB is located in the hinterland of the Eurasian continent, on the edge of the Gurbantungut Desert, the largest fixed and semi-fixed desert in China (84°55′E–86°59′E, 43°4′N–45°20′N). It has a dry climate with the characteristics of intense evaporation and scarce precipitation. Hydrologically, it is a closed basin in which water resources originate from year-round snow cover in high-altitude mountains to the south [16]. Therefore, water in the Manas River is mainly derived from precipitation and meltwater released from the glacial ice of the Tianshan Mountains [17]. Water is transported north by intermittent small rivers that support numerous oases in the lower-gradient basin, and finally, dissipate in the desert (Figure 1). This part of arid Northwest China has a typical temperate continental climate, with a drought index (ratio of annual evaporation capacity to annual precipitation, $r = E_0/P$) of 4–10, annual precipitation range of 115–200 mm, annual evaporation range of 1,500–2,100 mm, and annual temperature range of 11.1–13.6°C. In the densely populated Shihezi city and Manas County, groundwater exploitation is large and concentrated, reaching 127.6 million m^3 per year. The basin's natural ecological environment is fragile, and both surface and groundwater change frequently, with each influencing the other [18–20].

Distribution of water resources is a critical factor that determines the agricultural and economic development of an area. Groundwater is an important index for measuring the ecological and environmental conditions of a particular area [21]. Previous studies conducted in the MRB have mainly focused on water resource regulation

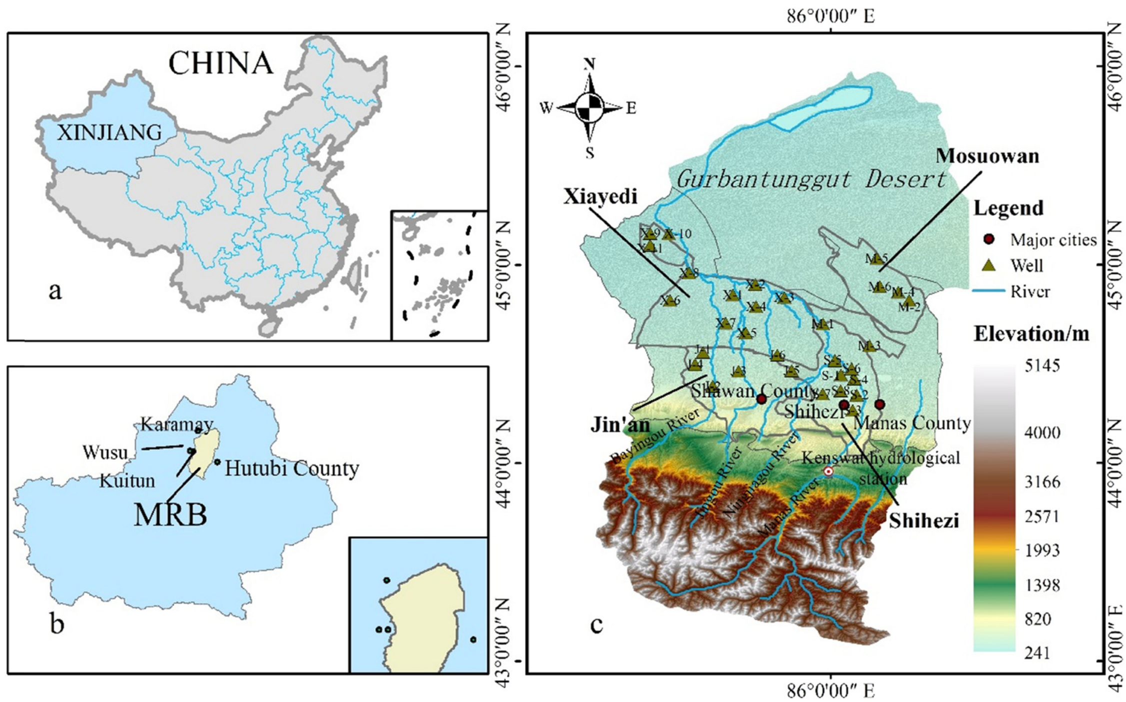

Figure 1: (a) Location of Xinjiang in Northwest China; (b) location of the Manas River Basin (MRB) in Xinjiang; (c) locations of monitoring wells in the MRB.

using methods such as development of a decision-support system for surface water allocation [22]. Analyses of water usage and structural changes in water consumption have enabled short-term water demand prediction with the use of the support vector machine regression method and have led to the development of a water demand model [23]. The influence of different water-saving irrigation conditions on the water cycle has been investigated under various scenarios, providing a theoretical basis for strengthening the ecological, economic, and social development of the MRB [24,25]. Substantial attention has also been paid to hydrogeochemistry and environmental isotopes, which has revealed groundwater mixing between aquifers and helps in the determination of groundwater recharge sources [26]. Recently, large quantities of groundwater were extracted in the MRB owing to ongoing agricultural and urban development. This has resulted in a reduced groundwater level, which in turn has inhibited and degraded natural vegetation growth on the edge of the desert.

2.2 Data sources

We studied four irrigation districts (Xiayedi, Mosuowan, Jin'an, and Shihezi) in the plain regions of the MRB from 2012 to 2019, using groundwater data from 30 wells monitored by the Shihezi Water Conservancy Bureau of the Xinjiang Uygur Autonomous Region (Figure 1). These data included well location (longitude and latitude), surface elevation, water level, and groundwater depth. The standard monitoring method is to place a water-level pipe in the well and use a water-level gauge (well depth gauge, WL500, Beijing Daimaike Technology Co., Ltd., China) for measurement.

We collected remotely sensed land-use data from 2012 to 2019 and cultivated land area statistics from 2012 to 2019 from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC; http://www.resdc.cn) [27]. Landsat-enhanced thematic mapper remote sensing images were used to interpret land-use data in 2012, and Landsat 8 remote sensing images were used to update these data from 2013 to 2019. Water consumption data were collected from previous research [28–33], including total water resource utilisation, groundwater utilisation, and surface water utilisation in the MRB from 2012 to 2019.

2.3 Methods

Contrast coefficient variance analysis was used to reveal the spatial variation characteristics of groundwater level.

The influencing factors were studied using factor analysis and multiple linear regression analysis in the SPSS software, taking into account the natural causes and human activities. We used the ENVI software to interpret the remote sensing image map and ArcGIS to analyse land-use change characteristics. The spatial distribution characteristics of groundwater were also analysed using ArcGIS spatial interpolation to explore dynamic change characteristics and influencing factors.

2.3.1 Measurement of surface elevation, groundwater level, and depth to the water table

The altimeter (barometer, thermometer, and compass) has four functions in determining surface elevation. The altimeter specifications were as follows: 68 mm (diameter) × 85 mm (length) + 67 mm (Compass length); measuring range: 0–5,000 m (height); height accuracy: ± 30 m; temperature: ± 2°C (−20 to 50°C). A groundwater level monitoring system was used to determine the groundwater level, a standard monitoring method was used to place a water-level pipe in the well, and a water-level gauge (well depth gauge, WL500, Beijing Daimaike Technology Co., Ltd., China) was used for groundwater level measurement. The depth to the water table can be indicated as follows:

$$h = H - Y \tag{1}$$

where h is the depth to the water table, H is surface elevation, and Y is groundwater level.

2.3.2 ArcGIS spatial interpolation

The interpolation method utilises the Inverse Distance Weight (IDW) method in ArcGIS to estimate the pixel value by taking the average of the sample data points in the neighbourhood of each pixel to be processed. The closer the point is to the pixel's centre to be estimated, the greater is its influence or weight in the averaging process. The IDW method mainly depends on inverse distance power. This power parameter can control the influence of known points on the interpolation based on the distance from the output point, and its value is 2. It is an accurate method and combines the advantages of Tyson polygon's adjacent point method and trend analysis's gradient method.

2.3.3 Contrast coefficient variance analysis

The contrast coefficient, a form of variable volatility evaluation index, assesses differences between sample values and sample mean values, reflecting the degree of abnormality for a given sample. This requires the calculation of the contrast coefficient value for each variable [34]:

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2 \tag{2}$$

where n is the number of samples, X_i is the sample value, and $\bar{X}$ is the sample mean value. The contrast coefficient X_i is calculated as:

$$\mathrm{V} = V_i/\bar{V} \tag{3}$$

where V_i is the sample value and $\bar{V}$ is the sample mean value.

2.3.4 Factor analysis and multiple linear regression analysis

The factor analysis and regression analysis modules of SPSS25 software were used to analyse factors influencing the dynamic changes in the groundwater level in the MRB. The former used the principal component method to extract common factors, while the latter used multiple linear regression analysis with a specific linear regression model to fit the data of dependent and independent variables while obtaining a regression equation by determining model parameters [35]. We selected climatic factors (annual rainfall X_1, annual average temperature X_2, and annual evaporation X_3) and four human activity factors (cultivated land area X_4, water resource utilisation amount X_5, groundwater use amount X_6, and surface water use amount X_7) to quantitatively verify and analyse influences on groundwater level in the MRB plain. The mathematical model is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \varepsilon \tag{4}$$

with the regression equation as follows:

$$E(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p \tag{5}$$

where Y and $E(y)$ are dependent variables (or, response variables), β_p is the coefficient of the index variable, X_p is an indicator variable, and ε is a random error.

3 Results and analysis

3.1 Dynamic changes in groundwater level

3.1.1 Interannual variations in groundwater level

In Figure 2, 2012 is the reference year, and the groundwater level is the difference between other years and 2012.

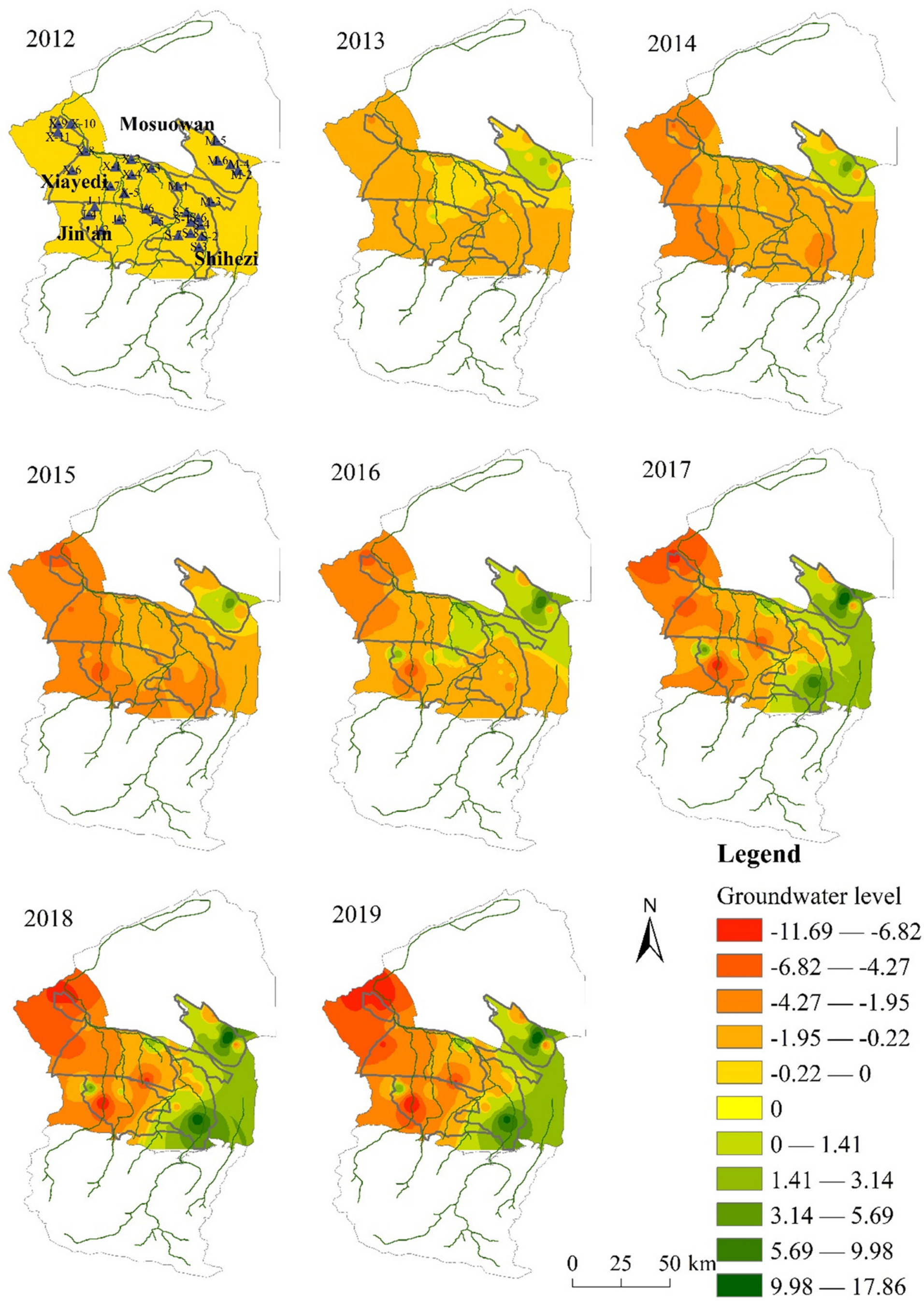

Figure 2: Spatial distribution of groundwater level changes from 2012 to 2019.

The higher the groundwater level, the higher the positive value and the smaller the negative value. From 2012 to 2019, the groundwater level was consistently higher in the south and east than in the north and west. Temporally, this could be divided into three multi-year stages: declining, rising, and fluctuating and declining with a gradually slowing downward trend (Figure 2). The water level in the Jin'an and Shihezi irrigation districts was higher than that in the Xiayedi and Mosuowan irrigation districts.

In Xiayedi, the water level fluctuated and declined from 2012 to 2015, increased from 2015 to 2016, then decreased again from 2016 to 2019 with the decreasing trend slowing down; the overall decline was 1.19% from 2012 to 2019. In Jin'an, the water level fluctuated from 2012 to 2015, increased from 2015 to 2016, then gradually decreased from 2016 to 2019; the overall decline was 0.68% from 2012 to 2019. In Mosuowan, the water level decreased from 2012 to 2015, increased from 2015 to 2016, then decreased from 2016 to 2019; the overall decline was 0.35% from 2012 to 2019. However, in well M-4, the water level rose each year with a total increase of 5.68%. In Shihezi, the water level gradually decreased from 2012 to 2015, increased from 2015 to 2018, and then decreased from 2018 to 2019; the overall increase was 0.43%. From 2012 to 2015, Shihezi had the slowest water-level drop, the longest water-level growth time, and the largest growth rate.

3.1.2 Monthly variations in groundwater level

Figure 3 shows the groundwater levels calculated as monthly average values of different wells from 2012 to 2019 with reference to sea level. Monthly variations in groundwater level could be divided into three stages: fluctuating and rising, gradually decreasing, and rising. During the study period, in Xiayedi, the groundwater level rose in a fluctuating manner from January to April, decreased from April to August, then increased from August to December, with an overall decline of 0.208% over the year (Table 1). In Jin'an, the groundwater level rose from January to March, decreased gradually from March to August, and then rose from August to December. The overall decline was 0.436% over the year. In Mosuowan, the groundwater level rose in a fluctuating manner from January to April, decreased gradually from April to September, then rose from September to December; the overall increase was 0.052% over the year. In Shihezi, the groundwater level rose steadily from January to March, gradually decreased from March to July, then rose from July to December; the overall decline was 0.059% over the year. However, the groundwater in some wells in this area fluctuated from January to April, gradually decreased from April to July, and rose from July to December, with an overall increase of 0.296%. Overall, the groundwater level in the four irrigation districts declines as agricultural water consumption increases during the growing season, but rises gradually during the offseason.

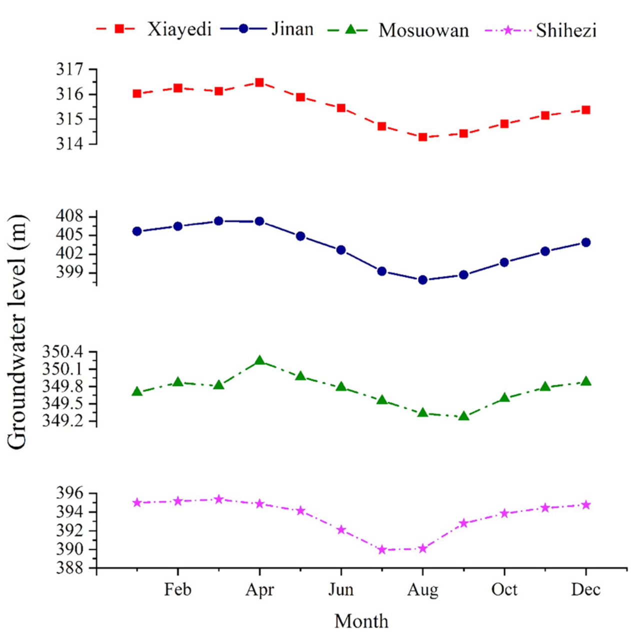

Figure 3: Monthly groundwater levels in the four irrigation districts from 2012 to 2019.

3.1.3 Long-term changes in groundwater level

Groundwater level decline from 2012 to 2019 ranged from 0.06 to 17.86 m (Figure 4). Mosuowan experienced the greatest changes (0.06 to −17.82 m), followed by Xiayedi (0.2 to −11.69 m), Shihezi (0.29 to −12.57 m), and Jin'an (0.77 to −10.31 m). The water-level changes were worse in the east than in the west. Annual groundwater level change in Xiayedi ranged from 0.29 to 4.44 m except for well X-9 (7.78 m), while that in Jin'an ranged from 3.62 to 7.3 m except for wells J-4 and J-5 (19.05 and 17.41 m, respectively), that in Mosuowan ranged from 0.47 to 5.28 m, and that in Shihezi ranged from 0.82 to 5.64 m, except for wells S-6 and S-7 (12.76 and 9.56 m, respectively). The high values presented in Figure 4 are primarily distributed in the edge of Xiayedi, the edge of Mosuowan, Shihezi city and Manas County of Shihezi,

Table 1: Annual variation of groundwater level in the four irrigation districts

Month	Xiayedi	Jinan	Mosuowan	Shihezi
Jan.	**316.032**	**405.662**	**349.696**	**394.989**
Feb.	316.255	406.488	349.867	395.151
Mar.	316.127	407.334	349.811	395.331
Apr.	316.477	407.293	350.240	394.858
May	315.891	404.897	349.967	394.122
Jun.	315.459	402.664	349.783	392.103
Jul.	314.718	399.280	349.554	389.950
Aug.	314.280	397.878	349.332	390.095
Sept.	314.417	398.691	349.274	392.786
Oct.	314.815	400.689	349.591	393.846
Nov.	315.151	402.451	349.783	394.433
Dec.	315.374	403.895	349.877	394.756
Variation (%)	0.208	0.436	0.052	0.059

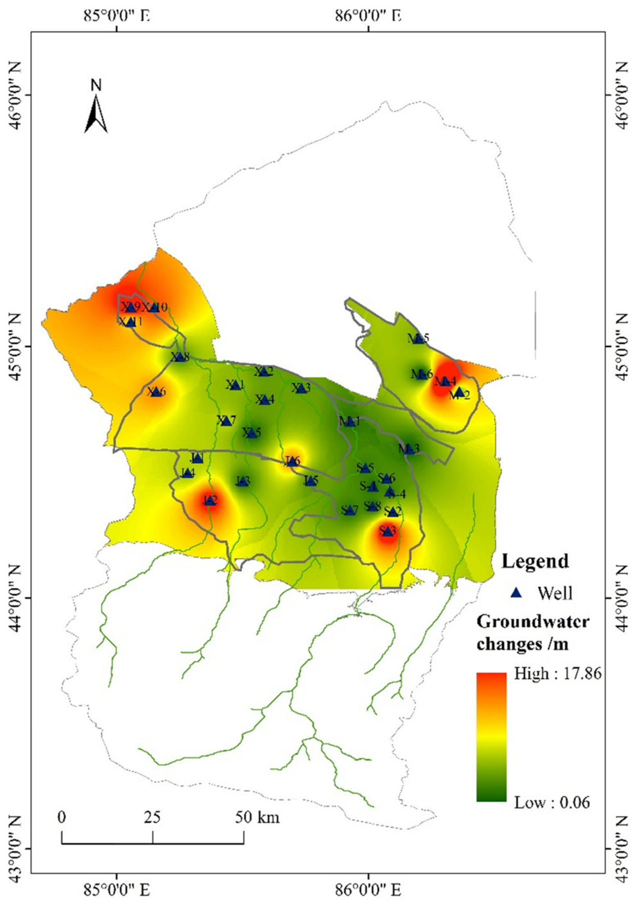

Figure 4: Changes in groundwater level from 2012 to 2019.

and Shawan County of Jin'an. The groundwater level of Xiayedi and Mosuowan near the desert changes greatly due to water shortage. Because of more and frequent water use, the groundwater level changes more frequently in the counties and cities where the population is concentrated than in other places.

3.1.4 Contrast coefficients

The contrast coefficient values of the groundwater level were all expanded by 10^5 times for clearer analysis and ranged from 0.01 to 44.97 (Table 2). The contrast coefficient values range in Xiayedi, Jin'an, Mosuowan, and Shihezi was 0.05–18.77, 0.16–9.02, 0.01–44.97, and 0.04–26.68, respectively. The fluctuation range was the smallest in Jin'an and largest in Mosuowan. Several zones showed apparent concentric increases in value toward their centres (Figure 5); the three largest circular areas in Shihezi, Mosuowan, and Xiayedi had maximum contrast coefficient variances of 26.68, 44.97, and 18.77, respectively. Overall, the amplitude of fluctuation was substantially greater in the east and northwest than that in the southwest. This is because Jin'an and Shihezi irrigation districts are close to the mountainous areas, while Xiayedi and Mosuowan irrigation districts are close to the Gurbantonggut desert. Therefore, compared with Xiayedi and Mosuowan irrigation districts, Jin'an and Shihezi irrigation districts have sufficient water resources, better water supply, and smaller variance of contrast coefficient. Shihezi is more densely populated than Jin'an, and therefore, has a larger contrast coefficient variance owing to the shortage of water. The Manasi river passes through Xiayedi and therefore has more water than Mosuowan; therefore, the contrast coefficient variance is smaller than Mosuowan. This is also the main reason why the high values presented in Figure 5 are primarily distributed in the edge of Xiayedi, the edge of Mosuowan, and Shihezi city and Manas County of Shihezi.

Table 2: Contrast coefficients of groundwater level ($\times 10^5$ for clarity)

Irrigation district	Well	Contrast coefficient	Irrigation district	Well	Contrast coefficient
Xiayedi	X-1	0.79	Mosuowan	M-1	0.15
	X-2	0.58			
	X-3	0.45		M-2	0.72
	X-4	0.28		M-3	0.04
	X-5	0.05		M-4	44.97
	X-6	5.73		M-5	0.61
	X-7	1.59		M-6	0.01
	X-8	0.43			
	X-9	18.77	Shihezi	S-1	0.04
	X-10	8.72		S-2	3.59
	X-11	3.21		S-3	26.68
Jinan	J-1	1.05		S-4	2.70
	J-2	6.39		S-5	0.10
	J-3	0.16		S-6	0.29
	J-4	3.45		S-7	0.41
	J-5	0.75		S-8	0.14
	J-6	9.02			

3.2 Changes in land use

The classification of land types was based on China's multi-period land-use/land cover remote sensing monitoring data classification system. From 2010 to 2019, cultivated land area increased by 483.53 km^2 (6.22%). Woodland area decreased by 5.25 km^2 (10.18%), primarily owing to the transformation of forest land into cultivated land (Figure 6). Grassland area decreased by 482.46 km^2 (5.64%) owing to transformation into cultivated land, water, urban, rural, industrial, mining, residential land,

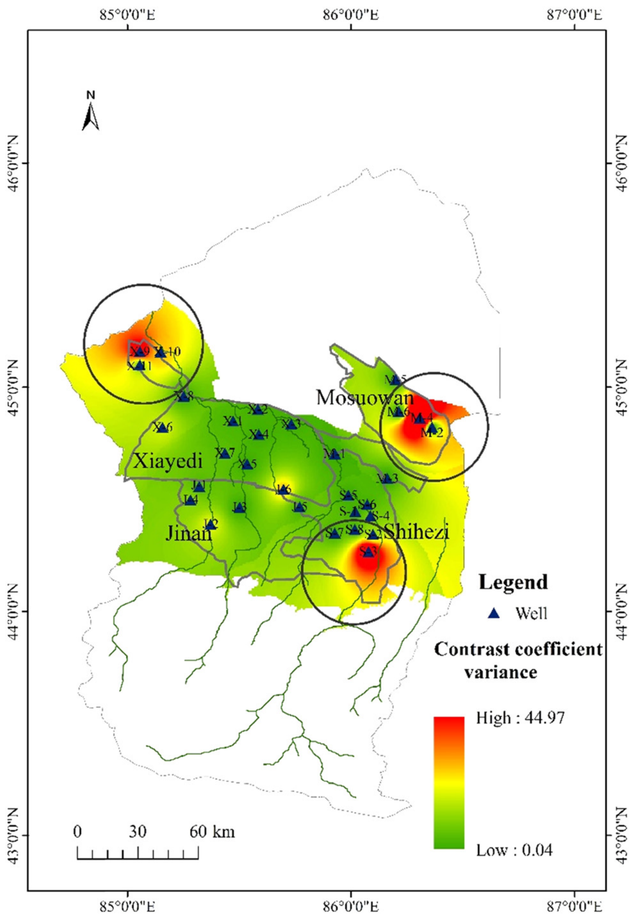

Figure 5: Spatial distribution of contrast coefficient variance of groundwater level.

and unused land. Water area decreased by 19.85 km^2 (8.51%) owing to transformation into grassland and cultivated land. Urban, rural, industrial, mining, and residential land increased by 66.12 km^2 (16.74%), mostly converted from cultivated land and unused land. Unused land area decreased by 42.10 km^2 (0.67%), mainly owing to the increase in cultivated land and urban, rural, industrial, mining, and residential land area, as well as smaller increases in water and grassland area. Overall, cultivated land and urban, rural, industrial, mining, and residential land increased significantly, with area under cultivation showing the most significant expansion. This increase in the cultivated land area explains the increase in agricultural irrigation water consumption. Woodland, grassland, water, and unused land areas decreased significantly; the first two led to lower vegetation coverage, allowing surface water to evaporate more quickly, further reducing surface water resources.

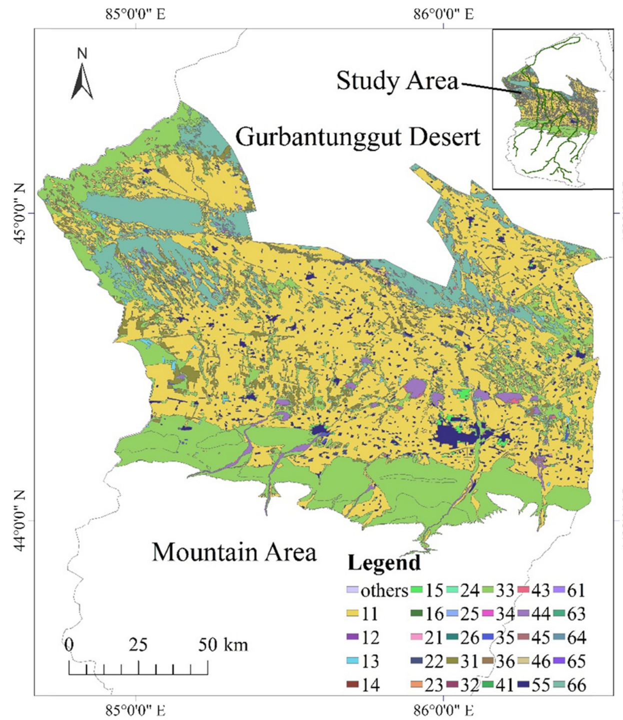

Figure 6: Changes in land use in the study area from 2010 to 2019. The first digit marks the 2010 land type and the second digit marks the 2019 land type (1, cultivated land; 2, woodland; 3, grassland; 4, water; 5, urban, rural, industrial, mining, and residential land; and 6, unused land).

3.3 Changes in water consumption

Surface water use declined from 2012 to 2014 and fluctuated and declined from 2014 to 2016 (Figure 7). After 2016, it increased and then stabilised. Groundwater use increased from 2012 to 2013, then fluctuated but trended downward until 2017, after which it stabilised. Total water resource use did not change much from 2012 to 2013. It fluctuated and declined from 2013 to 2017, after which it rose and then stabilised. The variation of groundwater consumption is negatively correlated with the groundwater level.

3.4 Verification and analysis of factors influencing groundwater level

Changes in groundwater level are the combined result of natural factors and human activities. Correlation analysis tools in the SPSS25 software were used to calculate the correlation coefficients for groundwater level Y and various influencing factors (Figure 8). The annual average groundwater level had a significant negative correlation with cultivated land area, water resource utilisation, and groundwater utilisation (−0.79, −0.65, and −0.68, respectively). The correlations between groundwater level and both water resource utilisation and groundwater use were also significant, indicating that increasing water resource utilisation and groundwater use led to declining groundwater level. There was also a significant correlation between cultivated land area and water resource utilisation (−0.85), indicating that greater cultivated land area led to increased water resource utilisation and subsequent groundwater level changes. Moreover, different degrees of correlation among the driving factors affected the change in the groundwater level. There were significant correlations between X_7 (surface water use amount) and X_4 (cultivated land area), as well as between Y (groundwater level) and X_4 (cultivated land area), and X_5 (water resource utilisation) and X_6 (groundwater use amount), indicating multicollinearity between the factors.

Principal component analysis was used to extract components further and reduce data overlap. The eigenvalues of the first three principal components were >1 and the cumulative contribution rate was 92.538% (Table 3), indicating that most information from the original seven driving factors was included. Therefore, we extracted these

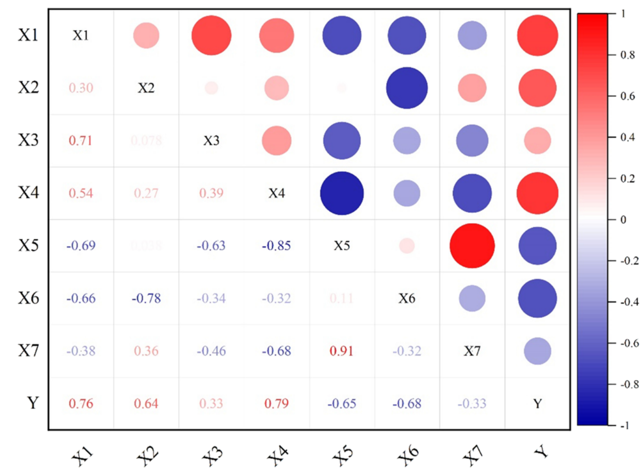

Figure 8: Correlation coefficient matrix of all influence factors.

components and calculated the corresponding eigenvectors (Table 4). In Table 3, the major constituents, 1 to 8, are the eight common factors that were extracted. These factors are as follows: annual rainfall, annual average temperature, annual evaporation, cultivated land area, water resource utilisation amount, groundwater use amount, and surface water use amount, represented as X_1 to X_7 in Table 4.

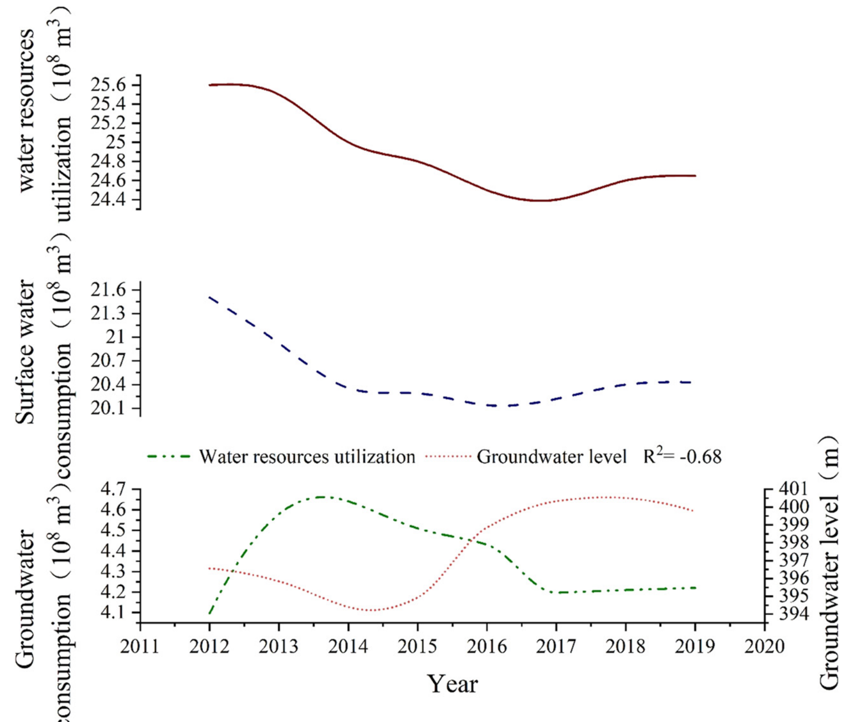

Figure 7: Water resource patterns in the study area over time.

Table 3: Eigenvalues and principal component contribution rates

Major constituent	Characteristic value	Contribution rate (%)	Cumulative contribution rate (%)	Main eigenvalues	Variance extraction rate (%)	Cumulative variance extraction rate (%)
1	3.989	49.863	49.863	3.989	49.863	49.863
2	2.054	25.673	75.536	2.054	25.673	75.536
3	1.387	17.343	92.879	1.387	17.343	92.879
4	0.498	6.2311	99.11			
5	0.049	0.6181	99.728			
6	0.020	0.247	99.975			
7	0.002	0.0252	100			
8	-5×10^{-17}	-6×10^{-16}	100			

For Z_1 and Z_3, the coefficients of cultivated land area, water resource utilisation, groundwater use, and surface water use were large, while those for Z_2 were small; therefore, Z_1 and Z_3 can be regarded as human factors and Z_2 as natural factors. Thus:

$$Y = 313.874 - 0.378Z_1 + 0.340Z_2 + 0.781Z_3 \tag{6}$$

After this calculation, the correlation coefficient R of the regression equation was 0.952, the determination coefficient R^2 was 0.907, the F test value was 12.978, and the significance probability $P = 0.016 < 0.05$, indicating that the regression effect of the equation was good. The coefficient of the equation was assessed using a t-test, showing that the significance of Z_1 was $P = 0.033 < 0.05$ and that of Z_3 was $P = 0.022 < 0.05$, indicating that human factors had a significant impact on groundwater level. The significance of Z_2 was $P = 0.023 < 0.05$, indicating that climate factors had a certain impact on the groundwater level; however, the correlation was not significant according to the correlation analysis. Based on the principles of regression analysis, natural factors have little influence on the groundwater level; therefore, natural factors were eliminated to obtain the final regression equation:

$$Y = 313.874 - 0.378Z_1 + 0.781Z_3 \tag{7}$$

Based on our results, we concluded that human activities are the main factors affecting groundwater level change in the MRB; while climate factors have had an impact, they do not play a leading role.

4 Discussion

From 2012 to 2019, there are three trends in the intra- and interannual variations of groundwater level in MRB. Interannual changes are as follows: declining, rising, and fluctuating and declining with a gradually slowing downward trend. Annual changes include: fluctuating and rising, gradually decreasing, and rising. Some studies have shown that the groundwater depth of the MRB continued to decline from 1998 to 2010 and that annual changes increase, decrease, and then gradually increased; this differs from the results of this study [36,37]. The main reason for the differences may be the implementation of water-saving irrigation measures for large areas of the MRB in recent years; the strict control of water resources has reduced groundwater exploitation. After the implementation of water-saving irrigation measures, the groundwater level will rise. However, since 2012, groundwater exploitation has increased (Figure 9). For regions with rice planting, the annual variation of groundwater level is contrary to contradict the results obtained in the present study. This mainly reflects the unique geographical environment of arid

Table 4: Principal component eigenvalue load matrix

Major constituent	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Z_1	−0.011	−0.142	0.060	0.203	−0.255	0.125	−0.296
Z_2	0.416	0.365	0.363	−0.074	−0.028	−0.039	−0.011
Z_3	−0.071	0.049	−0.136	0.142	0.101	−0.532	0.320

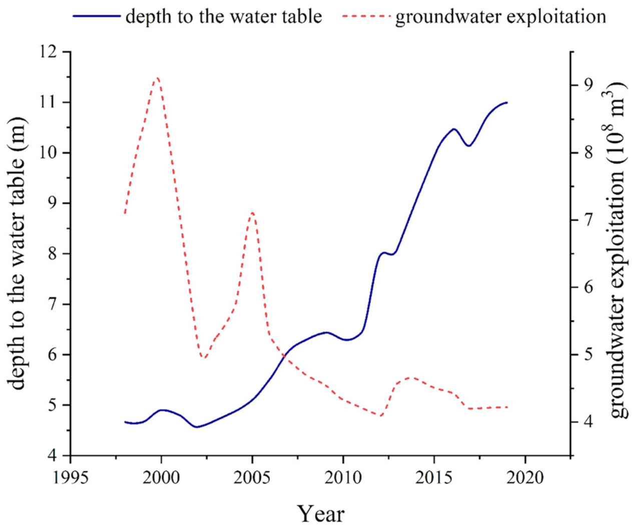

Figure 9: Changes in groundwater exploitation and depth to water table from 1998 to 2019.

areas of Northwest China, which is not suited to rice cultivation. In the study area, the water level decreases during the irrigation period and increases in the non-irrigation period [5].

Some studies have shown that increasing groundwater irrigation from shallow aquifers is the main reason behind the declining groundwater level, with groundwater exploitation the main reason for changes in the water level, which is consistent with the results of this study [9,15,38]. Other studies showed that from 1998 to 2010, a large amount of irrigation and pumping in the MRB was the main factor affecting groundwater depth. In contrast to the present study, evaporation was previously determined as the second important factor affecting fluctuations in groundwater level [36,37]. The absence of phreatic water evaporation is due to the continuous decline of the groundwater level since 1998 (i.e., the groundwater depth is increasing). When the buried depth is greater than 6 m, the phreatic water evaporation value is 0 (Figure 9). This shows that human activities constitute the main factor affecting the fluctuations in the groundwater level in the arid area of Northwest China.

It is of great significance to study the dynamic change law of groundwater level and its influence factors in the MRB to alleviate groundwater overdraft problems and promote the rational development and protection of groundwater. This study provides theoretical guidance for the coordinated development of groundwater utilisation and ecological environment in arid areas of Northwest China. However, our conclusions cannot completely solve the severe problems facing groundwater resources in arid areas. Owing to the comprehensive effects of various complex factors, such as development and utilisation, rainfall infiltration, and the water cycle, our results have certain limitations, and further study is needed. In the northwest inland arid area, the shortage of water resources is an important factor restricting the local development. We suggest that the groundwater exploitation should be strictly controlled and that the groundwater exploitation scheme should be optimised without affecting the economic development of the local basin, to ensure both the quantity and quality of water are desirable. Because the quality of groundwater, as a source of drinking water, is closely related to people's health, health risk assessment of potential toxic elements in the drinking water of parks (Limpopo National Park, Gaza Province, Southern Mozambique) has been conducted and various scholars have analysed the impact of the quality of groundwater on human health [39]. Mariachiara Cashetto analysed the factors affecting the health of a river ecosystem by investigating the human alteration of groundwater–surface water interactions[40]. In addition, the threshold of groundwater resources development and utilisation should be revised to ensure the sustainability of local water resources. Gradually, a policy of returning farmland to forest should be implemented, limiting the scale of cultivated land and reducing water consumption by agricultural irrigation [41]. Since groundwater and surface water in arid areas of Northwest China come from the same source and transform each other, we must make comprehensive utilisation and formulate a unified and reasonable water use planning scheme [42]. Relevant staff should continuously enhance their awareness of water resources protection, and for areas with excessive utilisation and development, they should adopt a policy to reduce unreasonable development [43].

5 Conclusion

(1) From 2012 to 2019, groundwater levels in the MRB showed decreasing, increasing, and then slowly decreasing trends in most areas. Groundwater levels were higher in the south and east than in the north and west. The Jin'an and Shihezi irrigation districts had higher water levels than the Xiayedi and Mosuowan irrigation districts.

(2) In most parts of the study area, water levels decrease from March/April to August/September, then rise from August/September to March/April. This pattern is closely related to agricultural water consumption (primarily irrigation), which increases sharply during the growing season (when groundwater level begins

to decline) and falls during the offseason (when groundwater level rises).

(3) Both human activities and natural processes influence the groundwater level in the study area, although the former is dominant. Changes in land use and water consumption are the most influential, statistically related to increases in cultivated land area and water resource utilisation.

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