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Effect of Land-Use Change and Artificial Recharge on the Groundwater in an Arid Inland River Basin

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Abstract The spatial-temporal variability of groundwater in an inland basin is very sensitive to human activity. This study focused on groundwater changes in the Alagan area within the Tarim Basin, China, with the aim of analyzing the effects of land-use change and artificial recharge on the response characteristics of groundwater. The distributed hydrological model MIKE SHE was introduced for modeling the influence of land use and artificial recharge on groundwater. Based on the runoff variation of this area, we selected three periods to simulate and analyze the response of groundwater. The results of land-use change indicated that there were significant changes from 1980 to 2000. The changed region accounted for 11.93 % of the total area, and the low coverage grasslands showed the greatest reduction. The simulation of hydrological processes before artificial recharge showed that the groundwater depths differed greatly with land-use types. Response analysis of groundwater to artificial recharge showed that the regions in which groundwater decreased were mainly distributed in grassland and bare land. Moreover, spatial autocorrelation coefficients indicated positive spatial autocorrelation of groundwater depths, but these began to reverse in 2010. Overall, land use and artificial recharge have a great influence on the time and spatial distribution of groundwater. Artificial recharge has played a positive role in improving groundwater conditions, but did not change the decreasing trend in time and space. The adaptation of environment to the decrease of groundwater presents as degradation. Groundwater conditions could be improved to some extent by the artificial recharge, but its change seems to be an irreversible process. Overall, this response study provides insight into estimations for exploration of water resources in arid areas.

Keywords Groundwater recharge · Land use · Hydrological model · Inland river basins

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1 Introduction

In arid inland river basins, water recharge and consumption often occurs in different areas. As a result, groundwater in the lower reaches is more sensitive to climate change and human activities than that in the upper reaches. Groundwater in oases plays an important role in economic development and the ecological environment; therefore, it is important to investigate the dynamics of groundwater in such areas.

The impact of climate change on water resources is obvious on long temporal scales (Barron et al. 2013; Diaz-Ramirez et al. 2012; van der Molen et al. 2006). However, human activity has a greater effect on such resources at spatial and short temporal scales. Land use, one of the main representatives of human activity and primary driving factors of hydrological changes, can affect interception, infiltration capacity and surface evaporation (Sun et al. 2012). Accordingly, the influence of hydrological processes has generated a great deal of attention recently. With the development of the economy and society, great changes have occurred in the types of land use (Drummond et al. 2012) that have enabled water resources to be widely distributed. Such changes can improve or worsen water resources within a region (Garmendia et al. 2012). Many studies have investigated the effects of land use on water resources worldwide (Gallart and Llorens 2004; Mugabe et al. 2011); however, studies regarding their effects on groundwater change are still not sufficient in arid and semi-arid areas.

The intensity of human disturbance on water resources, especially groundwater in arid inland river basin, has resulted in continual degradation of the ecological environment (Oren et al. 2004). Artificial recharge is an effective method to resolve the problem of depletion of groundwater resources and ecological deterioration (Ghayoumian et al. 2007; Johnson et al. 1999). Artificial recharge of groundwater is the process of physically adding water to an aquifer. This method has been widely applied in many fields, including urban water supply (Karlsen et al. 2012), field irrigation (Pi and Wang 2006), pollution control (Kuster et al. 2010), environmental conservation (Nöjd et al. 2009), and oil exploitation (Harris et al. 1988). Identification of methods to recharge aquifers quantitatively and effectively is still an area of focus.

Hydrological models are effective tools for hydrological prediction and understanding hydrological processes (Kim et al. 2012; Martin-Carrasco et al. 2012; Zhang et al. 1996). A distributed hydrological model, forced by high spatial and temporal resolution rainfall measurements, would be very useful to simulate the effects of land use on groundwater change at all strategic locations within a hydrographic network (Andersen et al. 2002). Many applications to investigate the effects of climate change on water resources have been developed (Brath et al. 2004; Li et al. 2012). Among these, modeling the effect of land-use change on water processes is still insufficient. In the past years, statistical analysis has been adopted more than hydrological models (Van De Griend and Seyhan 1984; Zhao et al. 2012). Analyzing the hydrological effects of land use and climate change based on the distributed hydrological model is currently receiving a great deal of attention.

The lower reach of the Tarim River, located in an extremely arid region of China, is the subject of a great deal of hydrological and ecological research (Xu et al. 2004). There was little or no flow in the river in the 1990s owing to surface water scarcity, which led to decreased groundwater, plant death and desertification.

This study was conducted to analyze the effect of land-use change and artificial recharge on groundwater in an inland river basin. The main objectives of the study were as follows: (1) simulate the effect of land-use change on groundwater recharge using a spatially distributed hydrological model, MIKE-SHE; (2) simulate the effect of artificial recharge on groundwater recharge; (3) analyze the characteristics of groundwater changes and their relationships to land use and artificial recharge in the lower reach of the Tarim River.

2 Materials and Methods

2.1 Description of the Study Area

The study area, the Alagan watershed in the lower reach of the Tarim River, is located at the southeastern margin of the Taklimakan desert and covers a surface area of about 2,049 km^2 between latitudes 40°4′ and 40°37′N and longitudes 87°45′ and 88°29′E (Fig. 1). The climate in this area is extremely dry and rainfall is rare. The average annual precipitation is 20–70 mm, the average annual temperature is 10.9 °C and the mean annual potential evaporation is 2,000–3,000 mm. The area consists of an alluvial plain and a transition zone to wind-accumulated dunes. The soil is predominantly silt loam, fine sand, and sandy loam. The thickness of phreatic aquifer is about 20–40 m. The groundwater depth in most locations is greater than 10 m. The permeability coefficient is 1–5 m/d. The landforms in the area are characterized by low relief between elevations of 818 and 893 m. Zero flow appeared in the 1990s. From then on artificial recharge from Daxihaizi reservoir became the main source of discharge (Tursun et al. 2007). The starting point of Alagan section is apart from Daxihaizi reservoir 188 km. The average flow within the artificial recharge periods was 9.9 m^3/s (www.mwr.gov.cn/ztbd/tlmhjdh/20040404).

2.2 Description of the Hydrological Model

The physically-based distributed modeling system, MIKE SHE/MIKE 11, was selected to model the effects of land-use change and artificial recharge on groundwater in the inland

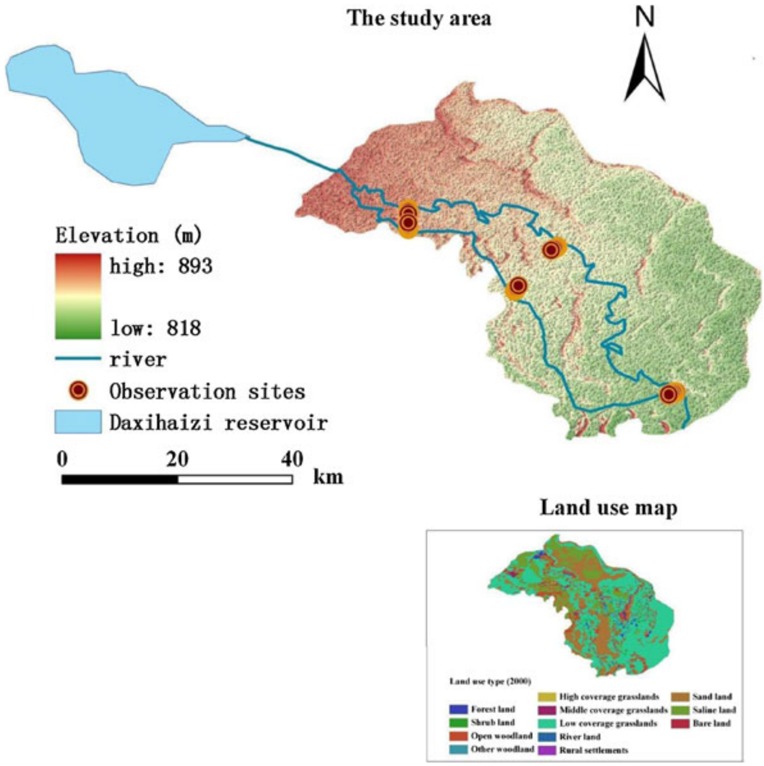

Fig. 1 Study area of the Alagan watershed in Xinjiang, China

river basin. The models of groundwater, surface water, recharge and evapotranspiration were integrated in MIKE SHE. This model has been applied to conjunctive use of surface water and groundwater, environmental river flows, land use and climate change, and groundwater remediation (Demetriou and Punthakey 1998; Sahoo et al. 2006). Accordingly, it can be used to analyze the effects of land-use change and artificial recharge on groundwater. The MIKE SHE 2007 version was selected for this study. A full description of MIKE SHE can be found in previous publications (Thompson et al. 2004).

In MIKE SHE, the watershed of interest is divided by a grid that represents hydrological response units. Each cell in the grid has physical properties of the watershed that are defined by the overlaying topography, soil data and land-use maps in a geographical information system (GIS)(Liu et al. 2007). This processing method could represent the properties of land uses and/or soils better, which may have a significant effect on hydrology.

MIKE 11 is a modelling system for rivers and channels (Panda et al. 2010). Through coupling of the MIKE-SHE implementation for the watershed with the MIKE 11 model of the river network in that watershed, the bi-directional interaction between the watershed hydrological processes and the river hydrodynamics can be accounted for. This enables investigation of the groundwater regimes and interactions with the artificial recharge and vegetation along flooded areas in the arid watershed being studied (Liu et al. 2007). In the coupled modeling system, data exchange between the two models is realized through a shared storage space (Thompson et al. 2004).

Unlike other hydrologic models, MIKE SHE/MIKE 11 includes equations and factors that allow the user to model land-use changes (Liu et al. 2007). For example, calculation of ET considers variations in radiation-use efficiency and transpiration due to changes in land use. MIKE SHE allows for the input of a dynamic land-use map and leaf area indexes (Vázquez 2003). Water exchange between the two models occurs via evapotranspiration, infiltration, overland runoff, and exchange between the stream and aquifer. Using source/sink terms of the Saint Venant continuous equations in MIKE 11 enables flow from MIKE SHE to be exchanged with MIKE 11. Coupling MIKE SHE and MIKE 11 can accurately describe the dynamic process of interaction between stream water and groundwater (Fig. 2).

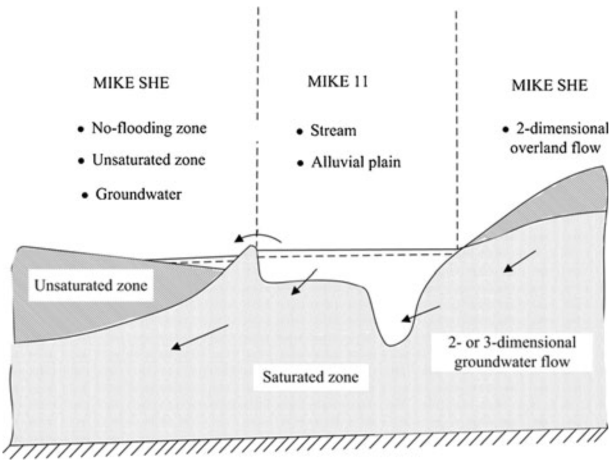

Fig. 2 Coupling structure of MIKE 11 and MIKE SHE (Liu et al. 2007)

2.3 Spatial Autocorrelation

Moran's I and Geary's C are the common methods used for testing spatial autocorrelation. These values are determined as follows (Zhang et al. 2008):

$$I = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m} w_{ij}\left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\left[\sum_{i=1}^{m}\sum_{j=1}^{m} w_{ij}\right]\left[\sum_{i=1}^{m}\frac{\left(X_i - \overline{X}\right)^2}{m}\right]} \tag{1}$$

$$C = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m} w_{ij}\left(X_i - X_j\right)^2}{\sum_{i=1}^{m}\sum_{j=1}^{m} w_{ij}\frac{2\left(X_i - \overline{X}\right)^2}{m-1}} \tag{2}$$

where m is the number of spatial units indexed by the ordinal i (i=1,2,…,m) and j(j=1,2,…,m); X_i is the attribute value of the i^{th} region; $\overline{X}$ is the mean of X, $\overline{X} = \sum_{i=1}^{m}\frac{X_i}{m}$; w_{ij} is a matrix of spatial weights. Generally, W is defined using an adjacency standard. When the ith region is correlated with the j^{th} region, W_{ij} is equal to 1, otherwise it is equal to 0. X_i is the groundwater amplitude.

Moran's I is a measure of spatial autocorrelation in statistics. Negative (positive) values indicate negative (positive) spatial autocorrelation. Values range from −1 (indicating perfect dispersion) to + 1 (indicating perfect correlation). A zero value indicates a random spatial pattern. Geary's C is inversely related to Moran's I, but not identical. The value of Geary's C lies between 0 and 2. A value of 1 indicates no spatial autocorrelation, while values lower than 1 demonstrate increasing positive spatial autocorrelation and values higher than 1 illustrate increasing negative spatial autocorrelation. Moran's I is a measure of global spatial autocorrelation, while Geary's C is more sensitive to local spatial autocorrelation (Zhang and Lin 2007).

2.4 Data Collection and Analysis

The purpose of this study was to compare changes in groundwater in areas with different land use and to test groundwater recharge during the artificial recharge period. The study periods selected were Jan 1–Dec 31, 1980, Jan 1–Dec 31, 2000 and Jun 20–Nov 16, 2010. We obtained daily temperature, precipitation, solar radiation and evaporation data for the modeling periods from the Xinjiang Autonomous Region Climate Center. Stream flows in the conveyance period and groundwater level data were obtained from the Tarim River Basin Administrative Bureau. Land-use types and Leaf Area Index (LAI) data were calculated based on Landsat thematic mapper data (TM) and China-Brazil Earth Resources Satellites (CBERS) data for the corresponding periods. Stream profile properties, such as cross-section area and storage width, were obtained from Digital Elevation Model data (DEM). The size of the grid cells for the model of the Alagan sub-watershed was 100 m×100 m.

2.5 Model Calibration and Performance Assessment

The primary task in this study was to obtain the spatial distribution of groundwater according to the observed data. The information did not need to be further predicted for this study; therefore, we calibrated the parameters for the three periods described above.

To statistically evaluate model performance, a standard performance metric, the Nash–Sutcliffe model efficiency coefficient was used (Nash and Sutcliffe 1970):

$$E = 1 - \frac{\sum_{j=1}^{n} (O-P)^2}{\sum_{j=1}^{n} \left(O-\overline{O}\right)^2} \tag{3}$$

where O and $\overline{O}$ are the observed groundwater level and the mean observed groundwater level, respectively, and P is the simulated groundwater level. If the simulation equals the mean observed water table, then E=0. When all the simulations equal their corresponding observations, then E=1.

The percentage difference between the total measured and simulated groundwater level (%) (D_v) can help determine how far a quantity varies from the value considered to be true. In this study, the accuracy between the simulated groundwater level and the observed data was determined using the following formula (Hines et al. 1986):

$$D_v = \frac{V_R - V'_R}{V_R} \cdot 100 \tag{4}$$

where V_R is the observed groundwater level and V'_R is simulated groundwater level. The nearer to zero D_v is, the higher the precision of the simulation is.

3 Results and Discussion

3.1 Model Calibration and Performance Assessment

The final values of the calibration parameters in Table 1 are consistent with the values proposed in previous studies conducted within arid and semi-arid areas (Christine et al. 2006; Zhao et al. 2005). Figure 3 shows a comparison of the simulated and measured daily stream flow at the outlet of the watershed for the calibration period (Jan 1–Jun 30, 2000) and test period (Jul 1–Dec 31, 2000). The visual comparison indicates that the model performance is satisfactory.

Table 1 Calibrated parameter values

Model parameter	Calibrated value Jan 1–Jun 30, 2000
C_{int}	0.33
C_1	0.31
C_2	0.16
C_3	20
K_x (m·s^{-1})	1.5×10^{-6}
K_z (m·s^{-1})	5.5×10^{-7}

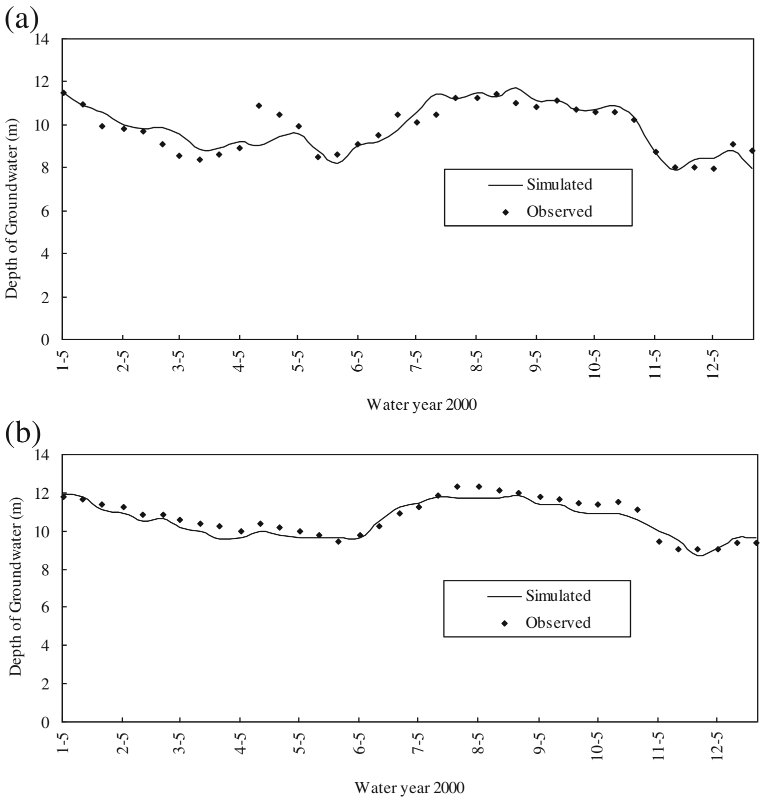

Fig. 3 Observed and simulated depth of groundwater at Alagan section. **a** The depth of groundwater at the point of 200 m away from the river bank. **b** The depth of groundwater at the point of 300 m away from the river bank

C_{int} is the interception coefficient and the empirical parameters C_1 and C_2 control the distribution of actual evapotranspiration between transpiration and soil evaporation, while C_3 influences the value of the moisture content function. The values of vertical saturated hydraulic conductivity (K_z) and horizontal saturated hydraulic conductivity (K_x) are given in Table 1, and these values are the final calibration parameters values.

The results of the model performance evaluation are listed in Table 2.

Values of E ranged from 0.68 to 0.72 (Table 2) for the groundwater depths during the two periods. The performance (E and D_v) was somewhat better than that reported by Merz and Blöschl (2004). These findings indicate that the model is acceptable for conducting a simulation of the Alagan sub-watershed.

Table 2 Estimation of uncertainties in the modeling periods

Period	E_{150}	D_{v150}	E_{200}	D_{v200}
Calibration period (Jan 1–Jun 30, 2000)	0.67	5.59	0.77	2.74
Test period (Jul 1–Dec 31, 2000)	0.79	3.46	0.81	2.48

The subscripts 150 and 200 represent the distance of the point away from the river bank

We calculated prediction errors for daily data over the two periods. Approximately 75 % of the observed water table values fell within the 5 % and 95 % uncertainty bounds based on regression of simulated versus observed values. When compared with the previous studies, the accuracy of the model predictions is considered to be acceptable (McMichael et al. 2006).

3.2 Response of Groundwater to Land Use

The inflection point of zero flow in the Alagan river basin appeared in the 1990s (Tu et al. 2007). To analyze the influence of land use on the groundwater, the groundwater distribution in 1980 and 2000 was modeled. The appearance time of zero flow was between the two periods. A great contrast of land use could reflect a difference in groundwater recharge. First, land-use changes between 1980 and 2000 were compared based on the classification of remote sensing data. The groundwater distribution was then modeled for the 2 years. Finally, their relationships and response characteristics were analyzed.

3.2.1 Variations in Land Use

To compare changes in land use between 1980 and 2000, we extracted the land-use information of the study region from TM data and calculated the transition matrix of land use (Table 3).

As shown in Table 3, there were eight land-use types in 1980, forest land, shrub land, open forest land, middle coverage grasslands, low coverage grasslands, rural settlements, sand land and saline land. Three new land-use types, high coverage grasslands, river land and bare land, appeared in 2000. Some land-use types changed significantly from 1980 to 2000. Although both increases and decreases were observed, most land-use types decreased. Reasons for changes in land use included water conveyance, because zero flow often occurs in this region. Wind erosion more easily causes channel deformation under these conditions.

Low coverage grasslands showed the greatest decrease among land types. Most of these areas were transformed into forest land, sand land and saline land, which accounted for 114.09 km^2, 29.62 km^2 and 20.23 km^2 in 2000, respectively. The greatest conversion was that of middle coverage grasslands, for which 64.54 % of the area changed. This was followed by the change in forest land, which was 19.88 %. These findings indicate that the ecological degradation rate is much greater than the improvement rate.

The variation in spatial distribution of land use also was analyzed using GIS (Fig. 4).

As shown in Fig. 4, areas for which there were changes in land use are widely distributed, but mainly located around rivers and in low-lying areas. The total changed area was about 11.93 %. These findings indicate that there is some relationship between land use and groundwater level. However, further analysis is necessary to investigate this phenomenon.

3.2.2 Response Characteristics of Groundwater to Land Use

As described above, land use in 1980 and 2000 differed greatly. To analyze the characteristics of groundwater response to land use, changes in groundwater were compared based on the simulation in this period.

The simulation results showed that the annual groundwater depths fluctuated obviously during the two periods. The maximum value of groundwater depth was 6.51 m in 1980 and

Table 3 The transition matrix of land use from 1980 to 2000 (%)

Land type (1980) 2000	Forest land	Shrub land	Open forest land	Middle coverage grasslands	Low coverage grasslands	Rural settlements	Sand land	Saline land
Forest land	80.12	4.92	3.71	11.33	1.73	0	0.3	0.29
Shrub land	2.86	90.16	1.62	9.85	1.34	0	0	0.02
Open woodland	5.42	0	81.98	31.03	6.83	0	1.55	0.49
Other woodland	0	0	0	0	0.01	0	0	0
High coverage grasslands	0	0	0.02	0	0.01	0	0	0.34
Middle coverage grasslands	0	0	0	35.47	0.38	0	0	0.08
Low coverage grasslands	8.28	4.92	9.31	12.32	85.30	0	2.17	3.08
River land	0	0	0.78	0	0.06	0	0	0.55
Rural settlements	0	0	0	0	0	100	0	0
Sand land	0	0	1.67	0	2.58	0	95.75	1.06
Saline land	3.31	0	0.9	0	1.76	0	0.23	93.66
Bare land	0	0	0	0	0	0	0	0.43

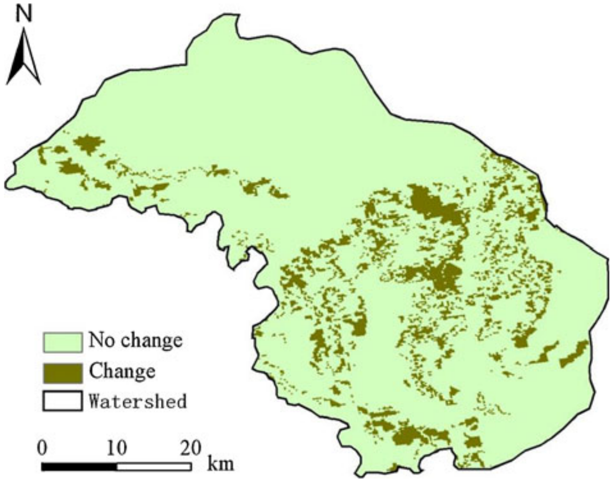

Fig. 4 Spatial variation in distribution of land use

9.05 m in 2000, while the minimum values were 6.37 m and 6.45 m. The average groundwater fluctuation in the whole area was 0.14 m and 2.60 m between 1980 and 2000, but was only 0.06 m in the region of no-land-use change. These findings indicate that groundwater in the study area tends to become unstable.

The groundwater depth map and land-use map were overlaid using GIS to analyze the effects of land-use types on groundwater fluctuation, after which a spatial statistical analysis was made. The results are listed in Table 4.

As shown in Table 4, groundwater depths vary greatly with land-use types. Overall, groundwater depths in most regions are likely to be decreasing. The land-use types showing groundwater increases are forest land, shrub land and woodland, which were mainly transformed from grassland and sand land in 1980. Conversely, the regions showing decreasing groundwater are the grassland and sand that were transformed from other land-use types. These findings indicate that groundwater has a positive effect on vegetation, and that environmental degradation is associated with decreasing groundwater.

3.3 Response of Groundwater to Artificial Recharge

As the groundwater level has decreased, ecological deterioration in the lower reaches of the Tarim River has become very serious. Indeed, groundwater level has an important influence on economic development and oasis stability. Artificial recharge has gradually become the main method to solve this problem. Water management departments have demanded that not less than 3.5×10^{8} m^{3} be released annually since 2000 (Tu et al. 2007). Water transmission is carried once or twice every year. There is little or no flow in the river when water transmission is over, so observation data shows the effect of artificial recharge on the study area. The aquifer is recharged through the artificial flood in this period. It is necessary to study the effects of artificial recharge on groundwater for ecological protection. In this study, the eleventh release of water in 2010 was selected to test this effect.

Table 4 The average fluctuation depth of groundwater (1980–2000)

Land type (1980) 2000	Forest land (m)	Shrub land (m)	Open forest land (m)	Middle coverage grasslands (m)	Low coverage grasslands (m)	Rural settlements (m)	Sand land (m)	Saline land (m)
Forest land (m)	−1.59	−2.91	−1.98	3.46	2.03	–	2.79	−1.63
Shrub land (m)	−0.7	−1.03	−1.41	3.53	2.74	–	–	–
Open woodland (m)	−0.82	–	−1.16	5.12	2.96	–	2.88	−1.9
Other woodland (m)	–	–	–	–	2.73	–	–	–
High coverage grasslands (m)	–	–	–	–	−0.01	–	–	−3.06
Middle coverage grasslands (m)	–	–	–	−1.67	−2.98	–	–	−7.77
Low coverage grasslands (m)	−6.52	−6.29	−6.96	−1.35	−3.07	–	−2.37	−7.25
River land	–	–	−1.5	–	2.4	–	–	−1.78
Rural settlements (m)	–	–	–	–	–	−2.97	–	–
Sand land (m)	−8.05	–	−6.34	–	−4.22	–	−3.34	−7.17
Saline land (m)	−1.31	–	−0.97	–	3.07	–	1.5	−1.21
Bare land (m)	–	–	−2.86	–	–	–	–	−1.21

3.3.1 Effect of Releasing Water on Groundwater Recharge

To analyze the variation of groundwater recharge during the release of water, the change process of groundwater from Jun 20 to Nov 16, 2010 was analyzed. The groundwater fluctuation before and after the release of water is listed in Fig. 5.

Figure 5 indicates that the response of groundwater to water transmission differs with land-use types. The groundwater level among four land-use types increased, while it declined for eight land-use types. The declined region is mainly distributed in grassland and bare land. The lowest value appeared in low coverage grasslands, where it decreased by 82.21 cm. A lesser decrease of 48.53 cm was observed for bare land. Conversely, areas in which groundwater level rose were primarily located in rural settlements and sand land, which showed increases of 25.62 cm and 37.70 cm, respectively. The average groundwater level showed a downward trend with a 39.27 cm decrease. Groundwater recharge may vary spatially owing to differences in the vegetation and soil properties in the study area. Grassland is the largest land-use type, occupying 52.28 % of the total area. Grassland is more sensitive to water consumption than other land-use types during short-term water supply. Adequate water supply causes the evapotranspiration rate to rise gradually.If the supply rate is greater than the recharge rate, the groundwater level would decrease further. Moreover, the sand land area accounts for 18.66 % of the total area; therefore, its great infiltration rate could cause more groundwater recharge during the water transmission.

3.3.2 The Spatial Characteristics of Groundwater Recharge During Water Transmission

To estimate the impact of water transmission on the spatial distribution of groundwater level, the groundwater level maps for Jun 19 and Nov 16, 2010 were overlaid using GIS. The average changes in groundwater level during the two periods were then measured (Fig. 6).

The results indicate that groundwater recharge has decreased in most places. The area with groundwater decrease accounts for 74.52 %, and the others are about 25.48 %. Moreover, the groundwater level of nearly every point has changed, which caused the groundwater resources system to become more uneven.

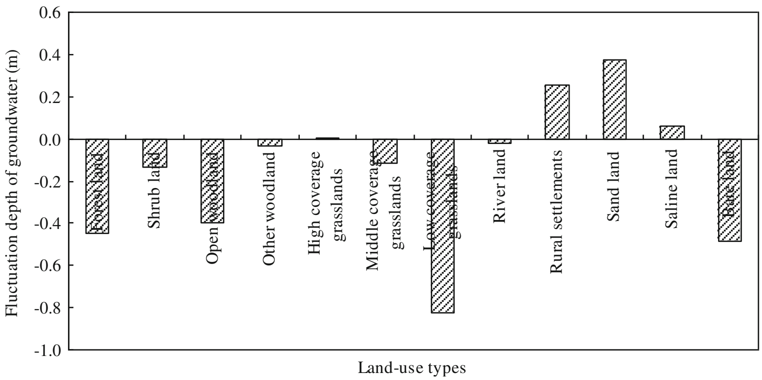

Fig. 5 Change in groundwater for areas of different land use during water transmission (2010)

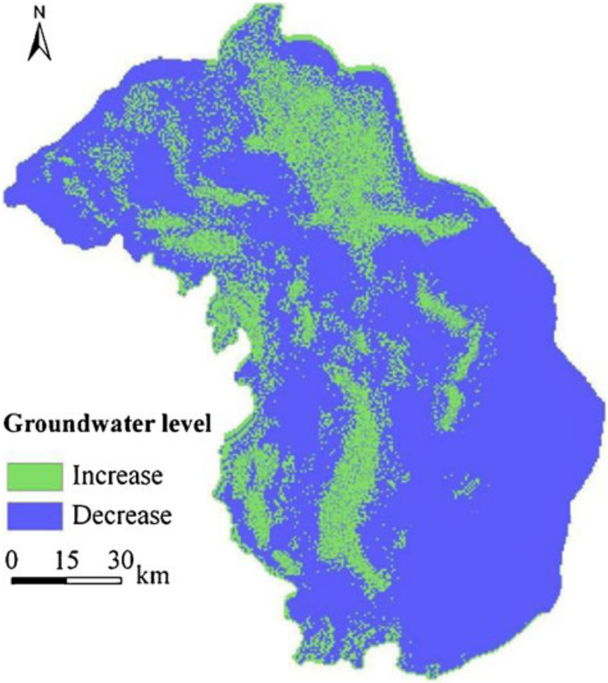

Fig. 6 Variation in spatial distribution of groundwater during water transmission

3.4 The Time-Spatial Characteristics of Groundwater Change

We compared the range and mean of groundwater fluctuation in different periods to investigate the evolution characteristics of groundwater level. Spatial autocorrelation coefficients, Moran's *I* and Geary's *C*, were also introduced to analyze the spatial characteristics of groundwater change. The computed results are listed in Table 5.

As shown in Table 5, the groundwater level showed a decreasing trend from 1980 to 2000, and the mean values decreased as the range fluctuated. The reduction in the amplitude of groundwater levels decreased slightly during the period of water transmission in 2010.

The spatial autocorrelation coefficients Moran's *I* values are near 1, while the Geary's *C* values are near 0 before 2000, indicating that groundwater depth has positive spatial autocorrelation.

Table 5 The statistics of groundwater change

Periods	Change type	Area ratio (%)	Fluctuation range (mm)	Mean (mm)	Moran's *I*	Geary's *C*
1980	Decrease	88.24	0–39.8	−10.6	0.7028	0.2987
	Increase	11.76	−18.1–0	1.9		
2000	Decrease	88.38	0-75.9	−15.6	0.7054	0.2961
	Increase	11.62	−23.9–0	2.6		
2010	Decrease	74.52	0–2,360.3	−20.6	0.1368	0.8663
	Increase	25.48	−2,529.7–0	23.5		

These values were reversed in 2010, indicating weak spatial autocorrelation of groundwater depth. This change was likely because water transmission caused the groundwater recharge to be uneven in space and prevent the groundwater level from returning to equilibrium rapidly.

The temporal-spatial characteristics of groundwater change indicate that the groundwater level is still decreasing. Water transmission has improved groundwater level, but cannot change the decreasing trend in time or space.

4 Conclusion

The groundwater resources system is off balance in the study area. Some land-use types have changed significantly in the last 30 years. The low coverage grasslands have showed the greatest reduction, primarily being converted into forest land, sand land and saline land. The changed region, accounting for 11.93 % of the total area, is mainly distributed near the river and in low-lying areas.

Simulation results show that the variation range of groundwater tends to become unstable. The maximum values in 1980 and 2000 were 6.51 m and 9.05 m, while the minimum values were 6.37 m and 6.45 m respectively. The groundwater depths also differ greatly with land-use types, although most regions show decreasing groundwater depth. The land-use types for which groundwater increased are those that were transformed from grassland and sand land in 1980, while those transformed from grassland and sand show decreasing groundwater levels. Decreasing groundwater is a primary reason for environmental degradation.

The response of groundwater to artificial recharge differs with land-use types. Regions with decreasing groundwater are primarily located in grassland and bare land. Specifically, the lowest value appeared in the low coverage grasslands, where it decreased by 82.21 cm, while bare land showed a decrease of 48.53 cm. Conversely, areas that showed increasing levels were primarily located in rural settlements and sand land, which showed increases of 25.62 cm and 37.70 cm, respectively. The average groundwater level showed a 39.27 cm decrease. Grassland is more sensitive to water consumption than the other land-use types during short-term water supply. Sand land has a large infiltration rate, which could cause more groundwater recharge during water transmission.

Water transmission played a positive role that improves groundwater conditions, but did not overcome the overall decreasing trend in time and space. Groundwater recharge has decreased in most places (74.52 % of the total area).

Spatial autocorrelation coefficients indicate that groundwater depth shows positive spatial autocorrelation. However, the coefficient reversed in 2010, which indicates that spatial autocorrelation of groundwater depth has become weak. This is likely because water transmission has caused groundwater recharge to become uneven in space.

The MIKE 11/MIKE SHE model has been applied extensively, and the performance of the model has been assessed using the coefficient of efficiency E. This coefficient is greater than 0.75, and approximately 85 % of the observed runoff values were within the 5 and 95 % uncertainty bounds of the regression of simulated versus observed runoff. These findings demonstrate that the model is acceptable for the simulation of rainfall runoff in the study area.

This study describes an efficient method for analysis of the impact of land-use change and artificial recharge on the groundwater. The results presented herein are important for understanding the hydrological cycle in arid inland river basin.

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