The influence of change of land-use type on hydrological cycle

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Abstract. Change of land-use pattern causes the change of underlying surface environment in the basin, thus influencing the source and sink of hydrological cycle in the study area and to greatly affect the groundwater level. In order to study the relationship between underlying surface change and groundwater level, this paper quantitatively analyzed the remote sensing images of the Hailiutu River basin acquired in different periods and collected long-series groundwater monitoring data, and this paper drew a groundwater level change map by calculating the transfer matrix of different land-use types. On this basis, this paper analyzed the groundwater level and influential factors for the transfer amount of different land-use types. Results showed that the change in groundwater level was mainly influenced by the underlying surface change. The land-use types exhibited strong tempo-spatial transformation. Where there was a drastic change of land-use type, there was a sharp change in groundwater level, indicating that the change of land-use type greatly influenced the underlying surface and was positively correlated with the spatial distribution of groundwater level.

1. Introduction
The Hailiutu River basin is located in the central Ordos Basin and in an inland arid and semi-arid region, and it spans two national energy and chemical bases in Inner Mongolia and Shaanxi. The groundwater is the main water supply source for industry and agriculture in the study area[1-2]. With the enhancement of development of the national energy bases in recent years, the industrial land use and farmland exploitation have changed the original land-use pattern, and the change in vegetation coverage has affected such hydrological cycle processes as recharge, runoff and drainage of groundwater, and further influenced the distribution of groundwater flow field in the study area. Groundwater is an important safeguard for water supply in the inland arid and semi-arid region, Northwest China, so study on the influence of underlying surface change on groundwater is of great significance for planning of national land and resources, rational allocation of water resources, and protection of ecological environment in the study area.
Some scholars from China had ever explored the influence of underlying surface change on groundwater resources, groundwater quality and groundwater recharge[3-4]. Some ones studied the relationship between underlying surface change and groundwater level[5-7]. However, most of the research results were obtained in karst areas, oasis areas or loess plateau areas, and few research efforts on the influence of underlying surface change on groundwater were made in the vast typical arid areas with vulnerable ecological environment in Northwest China.

In this paper, with the Hailiutu River basin in Ordos Basin with relatively vulnerable ecological environment as the study area, we comprehensively analyzed the land-use types, underlying surface change, and change in groundwater level using such analysis methods as remote sensing interpretation, and field verification, and revealed that human activities reformed the hydrological underlying surface, thus to influence the whole hydrological cycle and the groundwater level. The research results are of guiding significance for achieving rational exploitation and utilization of groundwater resources in typical areas with vulnerable ecological environment.

2. Overview of the study area
The Hailiutu River basin (108°38′18″ – 109°18′50″E, 38°02′18″ – 38°50′51″N) is located in the Inner Mongolia-Shaanxi boundary, belongs to Ordos, Inner Mongolia and Yulin, Shaanxi, and has a total area of ~2,600 km². Since the Mesozoic, the Hailiutu River basin has formed a basin characteristic of overlapped upper and lower water-bearing formation complexes with stable distribution and layered structure.

The study area has a temperate continental monsoon climate, with annual precipitation being 334–364.7 mm, mean annual evaporation reaching 1,883.48–2,186 mm, and summer precipitation (from July to September) accounting for 65%–70% of whole year precipitation, so this is typical arid and semi-arid grassland climate and environment characterized by little precipitation, strong evaporation, and large temperature difference, etc. [8-9]. The main land-use types include farmland, grassland, transportation land, and urban construction land, etc. The main soil types include aeolian sandy soil, meadow soil, and chestnut soil. The main groundwater types in the study area include pore phreatic water and pore confined water, the groundwater level has small burial depth and the groundwater runoff flows slowly. The discharge types primarily include evapotranspiration and artificial exploitation. With the exploitation of energy bases and the constant development of agricultural requisition-compensation balance, the groundwater exploitation amount has increased gradually, the natural dynamic balance of groundwater has been destroyed, and there have been prominent water resource problems occurring[10-11].

3. Study methods
3.1. Data collection and processing
In this paper, the image data obtained in 2000 and 2014, with spatial resolution of 30 m × 30 m, were selected from the data source, i.e., Landsat8 TM remote sending images of the study area. The land-use patches were delimited according to the China national standard GB/T21010-2007 Current Land Use Classification and the land management industry standard of the people's Republic of China TD/T1010-1999 Regulations for Land Use Dynamic Monitoring by Remote Sensing. The land-use types in the study area in different periods were extracted from a 1:50000 topographic map with the current land use situations in the study area being taken into consideration, and the land-use types in the Hailiutu River basin were divided into seven categories, namely, forest land, farmland, grassland, water area, transportation land, and urban and rural residential land & industrial and mining land.

The shallow groundwater level data for the study area were from the mean annual data obtained in near 48 evenly-distributed groundwater observation wells (Fig. 1) in 2000 and 2014, and the variation characteristics and spatial distribution of groundwater level were obtained based on the above data using the geostatistical analysis method.
3.2. Analysis methods

3.2.1. Land-use transfer matrix
The transfer amounts of land-use type in different periods were obtained by superposing the land-use type maps for different periods. A dynamic model of land-use type conversion was needed to express the conversion process between different land-use types\textsuperscript{[12]}, and the calculation equation is

$$C_{(i\times j)}=10A_{(i\times j)}^k+A_{(i\times j)}^{(k+1)}$$

where, $C_{(i\times j)}$ is the map of changes of land-use type from period $k$ to period $k+1$; $A_{(i\times j)}^k$ is the map of land-use types in period $k$; $A_{(i\times j)}^{(k+1)}$ is the map of land-use types in period $k+1$; and $i$ and $j$ denote different land-use types, respectively. The land-use transfer matrix was visualized using GIS software, to characterize the features of conversion between different land-use types.

3.2.2. Analysis of spatial variation of groundwater flow field
Geostatistics can describe the spatial variation laws of natural environment and disclose the spatial heterogeneity and pattern of natural environment, and the most commonly-used geostatistical analysis method is the semivariogram model analysis method.

Under one-dimensional condition, when the spatial point $x$ changes only on the one-dimensional $x$ axis, half of the variance of the difference between the values of regionalized variable $Z(x)$ at points $x$ and $x+h$, i.e., $Z(x)$ and $Z(x+h)$, is called the semivariogram of regionalized variable $Z(x)$. According to the definition, the following is obtained

$$r(h)=1/2 \ E [Z(x)-Z(x+h)]^2$$

where, $r(h)$ is the variogram; $h$ is the range; and $E[Z(x)-Z(x+h)]$ denotes the mathematical expectation of sample variance at a sampling interval of $h$. Nugget/sill ($C_0/(C_0+C)$) can interpret the variation characteristics among samples. If this ratio is less than 25\%, it means that the spatial correlation of regionalized variables is strong. When this ratio is in the range from 25\% to 75\%, it means that the regionalized variables are moderately correlated. When this ratio is more than 75\%, it means that the spatial correlation of regionalized variables is weak\textsuperscript{[13-14]}. 

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Fig. 1 Schematic map of geographic location of the study area and locations of observation wells
4. Results and analysis

4.1. Analysis of tempo-spatial change of land-use and cover in the Hailiutu River basin in recent 15 years

Based on the interpretation and field verification of the remote sensing image data, we drew maps of land-use types for 2000 and 2014 (Fig. 2), conducted statistical analysis of the changes in area of main land-use types in the Hailiutu River basin, and calculated the transfer matrix.

Fig. 2 Maps of land-use types for 2000 and 2014 ((a) 2000; (b) 2014)
1. Transportation land; 2. Other land; 3. Urban and rural residential land & industrial and mining land; 4. Forest land; 5. Water area; 6. Farmland; 7. Grassland

As can be discerned from Fig. 2, the land-use types have evident spatial change in the study area from 2000 to 2014. The percentage of forest land area is the highest, and the areas of farmland, and urban and rural residential land & industrial and mining land exhibit increasing trends in the south. In the northwest, the areas of shoal land and grassland patches decrease significantly. In the east, the area of other land decreases and that of grassland increases a little. Afterwards, the land-use transfer matrix from 2000 to 2014 (Tables 1 and 2) was calculated based on Eq. (1) using GIS software.

The results in Tables 1 and 2 indicate that the conversion between different land-use types occurred frequently. The grassland area in 2014 was 75.2 km$^2$ less than in 2000, and the area of other land in 2014 was 21.16 km$^2$ less than in 2000. The decreased land was mainly converted into forest land, urban and rural residential land & industrial and mining land, and transportation land, and these three land-use types increased by 49.9, 23.35, and 22.13 km$^2$ respectively. It can be seen from the changes from 2000 to 2014 that the grassland area in the study area have always been in a descending trend and the decreasing amplitude in recent years have increased. The areas of transportation land and urban and rural residential land & industrial and mining land have increased constantly, in particular, they have multiplied in recent four years. Other land, including sand, has decreased somewhat, and the area of forest land has increased evidently in recent years.

As can be seen from the preliminary investigation results of underlying surface, the artificial disturbances in the study area, including industrial and mining construction, and grazing, are the main driving factors for the change of land-use type in the area. The ecological environment in the study area varied with the structural change of land-use type. As can be discerned from the map of land-use
types for 2000, there were herbaceous swamp wetlands distributed in the study area in 2000, but the herbaceous swamp had degraded in 2005. It can be seen from the face water areas in the study area, coupled with the annual precipitation change, that the study area is tending to aridity. In addition to development of vegetation type towards drought resistance, the vegetation in the study area is undoubtedly an important choice for groundwater utilization.

Table 1. Land-use transfer matrix from 2000 to 2014 (km²)

| Land-use type in 2014 | Land-use type in 2014 |
|----------------------|----------------------|
|                      | Transportation land  | Other land | Urban & industrial land | Forest land | Water area | Farmland | Grassland |
| Grassland            | 0.27                 | 130.65     | 0.74                   | 64.53       | 0.30       | 33.14     | 953.31    |
| Other land           | 0.00                 | 551.49     | 0.18                   | 14.28       | 0.22       | 1.20      | 129.28    |
| Forest land          | 0.02                 | 16.70      | 0.41                   | 132.89      | 0.08       | 9.59      | 108.48    |
| Farmland             | 0.00                 | 1.41       | 0.75                   | 3.67        | 0.03       | 84.98     | 41.07     |
| Water area           | 0.00                 | 0.36       | 0.07                   | 0.04        | 2.52       | 0.09      | 0.70      |
| Urban & industrial land | 0.00               | 9.11       | 7.65                   | 6.58        | 0.00       | 1.26      | 7.41      |
| Transportation land  | 0.12                 | 4.88       | 1.18                   | 2.72        | 0.01       | 0.38      | 10.81     |

Note: The rows denote the land-use types in 2014, and the columns denote the land-use types in 2000

Table 2. Changes in area of land-use type from 2000 to 2014 (km²)

|          | Farmland | Forest land | Grassland | Transportation land | Urban & industrial land | Water area | Other land |
|----------|----------|-------------|-----------|--------------------|-------------------------|------------|------------|
| 2000     | 146.09   | 249.11      | 1394.46   | 0.27               | 12.27                   | 3.78       | 798.11     |
| 2014     | 146.52   | 299.02      | 1319.23   | 22.40              | 35.61                   | 4.20       | 776.95     |
| Change amount | 0.43   | 49.91       | -75.23    | 22.13              | 23.35                   | 0.42       | -21.16     |

4.2. Change characteristics of groundwater flow field in the Hailiutu River basin

The spatial heterogeneity was mainly caused by two aspects, i.e., spatial structure, and random factors. In respect of spatial structure, the groundwater flow field was influenced by such natural factors as aquifer structure, vadose zone, topographic features, and meteorological phenomena, and by random factors including such human activities as agricultural reclamation, planting habits, irrigation methods, and water diversion and drainage works. These factors drove the spatial correlation of groundwater flow field in a joint manner but on different scales.

In this paper, semivariogram modeling, prediction and verification of shallow groundwater level data were carried out using the Geostatistical analysis module of the Arcgis10.0 software based on geostatistical methods, and an optimal semivariogram fitting model was determined for the groundwater level in 2000 and 2014 (Fig. 3). The relevant parameters of the semivariogram model are shown in Table 3.

Table 3 Semivariogram of groundwater level and parameters thereof

| Year | Theoretical model | C0 | C0+C | CO/(C0+C) | Range | R2  |
|------|------------------|----|------|-----------|-------|-----|
| 2000 | Gaussian model   | 0.16| 0.182| 0.0572    | 35.2  | 0.958|
| 2014 | Gaussian model   | 0.11| 0.23 | 0.3692    | 29.23 | 0.976|
As can be discerned from Table 3 and Fig. 3, the change in nugget of groundwater level decreased from 0.12 in 2000 to 0.104 in 2014, the nugget/sill increased from 5.84% in 2000 to 37.14% in 2014, and the R2 values were 0.962, and 0.972, respectively. In respect of fitting accuracy, the fitting degree is high, so the selection of the concept model and related parameters was rational. Analysis of spatial correlation degree of regionalized variable showed that the nugget/sill in 2000 was less than 22.1%, indicating that this variable had relatively strong spatial correlation. In 2014, the nugget/sill was between 22% and 69%, and the nugget increased, indicating that the spatial correlation degree was high in 2000 and decreased in 2014. In other words, the random influential factors were enhanced, indicating that the change in groundwater level was primarily affected by the source and sink. From 2000 to 2014, the range decreased and the maximum distance of spatial autocorrelation decreased, indicating that the scope of influence of random variables lessened. Therefore, the influences of random factors, including human activities, underlying surface, and source and sink, on groundwater level changed dramatically on small and medium scales, and the spatial continuity of groundwater resources weakened. The spatial distribution of groundwater level in the study area was obtained based on the parameters of the semivariogram, coupled with the Kringing interpolation method in geostatistics (Fig. 4).

It can be discerned from Fig. 4 that the overall change trend of spatial distribution of groundwater level in the study area was as follows: during 2000–2014, the burial depth of groundwater level in the Hailiutu River basin universally exhibited an increasing trend, with groundwater level rising in local zones, and the burial depth of groundwater level increased evidently in the south and the groundwater level declined evidently from west to east in the middle of the study area.
4.3. Influence of underlying surface change on spatial change in groundwater level

In order to more clearly determine the relationship between underlying surface change and groundwater level, the distribution of change in groundwater level was obtained by subtracting each GIS interpolated groundwater level value in 2014 from the corresponding value in 2000 (Fig. 5).

Fig. 5 Change amplitude of groundwater level in the Hailiutu River basin from 2000 to 2014

As can be discerned from Fig. 5, the groundwater level exhibited a declining trend in the west, north and east of the study area, with maximum decline amplitude of ~7.5 m. The groundwater level exhibited a rising trend in the south of the study area, with maximum rise amplitude of ~5.2 m.

It can be discerned from Fig. 6 that the distribution of different land-use types in the Hailiutu River basin varied with the burial depth of groundwater level. The grassland dominated by shrubberies including Artemisia ordosica, and Artemisia desertorum Spreng. Syst. Veg., was mainly distributed in the zones with burial depth of groundwater level ranging from 0 to 4 m. Other land-use type
dominated by desert was primarily distributed in the zones with larger burial depth of groundwater level, mostly 4–10 m. There were semi-fixed sand dunes with sparse vegetation and only a few plants of Agriophyllum squarrosum (L.) Moq., widely distributed in the zones with burial depth of groundwater level of near 10 m in the northwest of the study area. The forest land was distributed in the zones with burial depth of groundwater level of generally 5 m or more, greater than in the zones with shrubbery, (as shown in Fig. 6). There were mainly grassland and farmland distributed in the zones with burial depth of groundwater level of 0–1 m, rich land-use types distributed in the zones with burial depth of groundwater level of 1–4 m, and relatively single land-use type in the zones with burial depth of groundwater level of more than 10 m, which was primarily sandland/desert, or even bare land (as shown in Table 4).

Fig. 6 Spatial distribution of land-use types at different burial depths of groundwater level (in grids)

Table 4. Spatial distribution of land-use types at different burial depths of groundwater level (in grids)

| Land-use type/ burial depth of groundwater level | 0-1m | 1-2m | 2-3m | 3-4m | 4-5m | 5-8m | 8-10m | >10m |
|-----------------------------------------------|------|------|------|------|------|------|------|------|
| Grassland                                     | 2733 | 20769| 18650| 306597| 205120| 188607| 282312| 86142 |
| Other land                                    | 151  | 139220| 143899| 79009 | 210023| 124039| 134784| 31922 |
| Forest land                                   | 0    | 44684 | 18853 | 18871 | 36427 | 71210 | 62156 | 79951 |
| Farmland                                      | 91   | 8560  | 12531 | 41707 | 33337 | 39481 | 16581 | 10706 |
| Urban and mining land                         | 0    | 0    | 2941  | 534   | 166   | 12    | 1014  | 0     |
| Transportation land                           | 0    | 0    | 706   | 896   | 10040 | 9182  | 16657 | 13403 |
| Water area                                    | 0    | 2648  | 1444  | 2280  | 2886  | 1875  | 1303  | 341   |

5. Conclusions

(1) The change of land-use type in the Hailiutu River basin from 2000 to 2014 was mainly characterized by evident degradation of wetland and significant increase in area of forest land, urban and rural residential land & industrial and mining land, and transportation land.

(2) Such artificial factors in the study area as industrial and mining construction, and grazing, played a determining role in the change in groundwater level, resulting in the highest spatial correlation and the decreased correlation distance, in other words, the groundwater level variable changed on small and medium scales so that the spatial continuity of groundwater resources weakened.
(3) The more dramatic the change of land-use type in a zone, the more evident the change in groundwater level in the zone, indicating that the change in groundwater level exhibited positive correlation with the change of land-use type, and the change in groundwater level would become a driving factor for the change in land-use type in turn.

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References
[1] Wang X Y, Yin L H, Dai Z B, et al. Studies on Surface Evapotranspiration in the Hailiutu River in Ordos Basin [J]. Northwestern Geology, 2014, 47(1): 244-248. (in Chinese)
[2] Li Chengze, Wang Jinrong. Dynamics Mechanism of Deep-Earth Water Cycling and Its Research Progress [J]. Northwestern Geology, 2018, 51(2). (in Chinese)
[3] Mo H W, Ren Z Y, Xie H X. Land Use Dynamics and Ecological Effect Change in Farming-pastoral Area—Taking Yuyang District as an Example [J]. Arid Land Geology, 2005, 28(3): 352-356. (in Chinese)
[4] Sajikumar N, Remya R S. Impact of land cover and land use change on runoff characteristics [J]. Journal of Environmental Management, 2015, 161: 460-468.
[5] Goderniaux P, Brouyère S, Wildemeersch S, et al. Uncertainty of climate change impact on groundwater reserves – Application to a chalk aquifer [J]. Journal of Hydrology, 2015, 528: 108-121.
[6] Zhang B, Ding W H, Meng B. Analysis of Groundwater Hydrological Effects of Land Use in Arid Regions—Taking the Middle Area of Heihe River as an Example [J]. Arid Land Geology, 2005, 28(6): 764-769. (in Chinese)
[7] Dong J Q, Chang L. Analysis on the Change and Influence of Runoff Characteristics of the Hailiutu River. Journal of Water Resources and Water Engineering, 2014, 25(1): 144-147. (in Chinese)
[8] Zhang X F, Zhang L H, Gu J, et al. Spatial and Temporal Variation Characteristics of Groundwater and Its Response to Land Use/Cover Change in Dunhuang Oasis [J]. Journal of Lanzhou University (Natural Sciences), 2014, 50(3): 311-317. (in Chinese)
[9] SUN Fangqiang 1, 2, YIN Lihe 1, 2, WANG Xiaoyong, et al. Determination of vertical infiltration recharge of groundwater in the thick unsaturated zone of Sangong River Basin, Xinjiang [J]. Geology in China, 2017.
[10] Zhang J, Yin L H, Ma H Y, et al. Simulation study on the effect of vegetation change on groundwater flow system [J]. Yellow River, 2018, 40(6): 72-76. (in Chinese)
[11] Xu W H, Yin L H, Jiao W H, et al. Impact of Environmental Factors on Sap Flow of Willows in the MuusSandland [J]. Hydrogeology & Engineering Geology, 2018, 45(02): 102-108+116. (in Chinese)
[12] Monnikhof R A H, Edelenbos J, Hoeven F V D, et al. The new underground planning map of the Netherlands: a feasibility study of the possibilities of the use of underground space [J]. Tunnelling & Underground Space Technology, 1999, 14(3): 341-347.
[13] Wang Y Q, Shao M A, Liu Z P. Spatial variability of soil moisture at a regional scale in the Loess Plateau [J]. Advances in Water Science, 2012, 23(3): 310-316.
[14] MA Zhiyuan, DANG Shusheng, ZHAI Meijing, et al. The Characteristics of Isotopes and Hydrogeochemistry for Geothermal Water in the Tangyu Town in Lantian County [J]. Northwestern Geology, 2017 (2). (in Chinese)