Sustainability **2015**, *7*, 3086-3108; doi:10.3390/su7033086

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Scenario Analysis for Water Resources in Response to Land Use Change in the Middle and Upper Reaches of the Heihe River Basin

Zhihui Li [1,2,3], Xiangzheng Deng [1,3,*], Feng Wu [4] and Shaikh Shamim Hasan [1,2,5]

1. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; E-Mail: lizh.12b@igsnrr.ac.cn
2. University of Chinese Academy of Sciences, Beijing 100049, China
3. Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China
4. State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China; E-Mail: wufeng@igsnrr.ac.cn
5. Department of Agricultural Extension and Rural Development, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU); E-Mail: shinuextn120@yahoo.com

* Author to whom correspondence should be addressed; E-Mail: dengxz.ccap@gmail.com; Tel.: +86-10-6488-8980.

Academic Editor: Marc A. Rosen

Received: 29 November 2014 / Accepted: 9 March 2015 / Published: 13 March 2015

Abstract: Water availability is at the core of sustainable socioeconomic development and ecological conservation along with global climate and land use changes, especially in the areas that experience water problems. This study investigated the impacts of land use change on surface runoff and water yield with scenario-based land use change in the upper and middle reaches of the Heihe River Basin, the second largest inland river basin in the arid region of northwestern China. Firstly, three land use structure scenarios were established, with different water utilization ratio levels (low-level, middle-level and high-level water utilization ratios). Then the spatial pattern of land uses was simulated with the Dynamic of Land System (DLS). Thereafter, the simulated land use data were used as the input data to drive the Soil and Water Assessment Tool (SWAT) model, keeping other input data unchanged to isolate the land use change impacts on surface runoff and water yield. The results showed that the forestland and grassland will expand along with the increase in water utilization ratio. The quick-response surface runoff would decrease significantly due to forest and grassland expansion, which may cause an overall decreasing trend of the water yield. This indicated the unreasonable allocation of water resources may exert negative impacts on the water yield even if the water utilization ratio is increased; therefore, water resources should be reasonably allocated for different land use demand, which is critical for sustainable development. The results of this study will be informative to decision makers for sustainable water resource and land management when facing land use change and an increasing demand for water resources in the Heihe River Basin.

Keywords: surface runoff; water yield; land use change; scenario; DLS; SWAT; Heihe River Basin

1. Introduction

Water resources have become a critical element for socioeconomic development, especially in the arid and semi-arid regions. In many countries, along with rapid population growth and economic development, water resources are under severe pressure from human intervention, further triggering water scarcity issues. Water scarcity impedes development, provokes food shortages and conflicts that exerts adverse effects on human and ecosystem health; thus, water provision is an important ecosystem service, which is a key issue in the river basin management to reconcile water availability and demand [1].

The provision of water resources is closely related with the hydrological processes, while climate and land use/cover changes are considered as the two major factors that affect the hydrological processes in the basins [2–4]. On the one hand, the impacts of climate change on water availability have been identified in many areas [5–9]; on the other hand, land use change alters the hydrologic system and exerts impacts on water resources in arid regions at a wide range of temporal and spatial scales [10–13]. Better understanding of the impact mechanism of climate and land use/cover changes on hydrological processes is crucial for sustainable water resources management.

While climate change and land use/cover change interact with each other, it is important to apply consistent climate or land use conditions when trying to investigate the separate impacts of land use/cover change and climate change on the hydrological processes [14]. For example, Van Ty *et al.* [15] and Kim *et al.* [16] investigated the impacts of climate change and land use/cover change on hydrological processes, respectively, and their results showed that both climate change and land use/cover change have significant impacts on streamflow in the basins.

Besides, for long-term water resource planning and management, scenario analysis has become an efficient method to predict the responses of hydrological process to climate change and land use/cover change. For example, Menzel *et al.* designed two intermediate land use/cover change scenarios, with projected developments ranging between optimistic and pessimistic futures (with regard to social and economic conditions in the region) and climate conditions remaining unchanged, the simulation results showed both increases and decreases of water availability depended on the future pattern of natural and agricultural vegetation and the related dominance of hydrological processes [13].

The Heihe River Basin, which is located in a semi-arid region of northwest China, is facing serious water scarcity problems, which has become the major bottleneck of socioeconomic development and ecological security. The water resources management and land use patterns are intrinsically linked. On the one hand, water resource is the determinant factor that will affect the land use structure since different land use types have different water demand [17], land use/cover change in arid region is strongly restricted by water resources. For example, Li *et al.* found that after the implementation of the water allocation scheme in the Heihe River Basin between Gansu Province and Inner Mongolia in 2000, water use in the middle reach region was further limited, which significantly affected the land use structure changes in the middle reach region of the Heihe River Basin [18]. On the other hand, hydrological processes which decide the water provision will be affected by land use/cover changes. At a catchment level, forest cover and agricultural cultivation have significant impacts on the water resources and can affect the availability of water for other users. Land use management not only affects the quantity of water flowing but also is a key factor in managing pollution and influencing flood risk [19]. Taking the upper and middle reaches of the Heihe River Basin as the study area, and assuming that other conditions (e.g. climate conditions) will remain unchanged, this study aimed to investigate the changes in the hydrological processes under different land use scenarios based on the degrees of water constraints. Specifically, three land use scenarios were designed according to the improvement of the water utilization ratio. Under different scenarios, different water utilization ratios resulted in different amount of available water resources, which further led to different land use structure changes. Then we applied the land use structure data to simulate spatial land use patterns with the Dynamic Land use System (DLS) model. Furthermore, the surface runoff and water yield changes in response to the impacts of land use/cover change were simulated with the Soil and Water Assessment Tool (SWAT) model. The impact of land use/cover change on hydrological processes under different water constraint conditions were analyzed through comparing the simulated results of surface runoff and water yield under different scenarios. The results of this study will provide valuable information for future water and land management in the Heihe River Basin.

2. Data and Methodology

2.1. Study Area

The Heihe River Basin is the second largest inland river basin in China (Figure 1). There is a very arid climate in this basin, with the mean annual potential evaporation between 1453 mm and 2351 mm and the average annual precipitation between 200 mm to 500 mm. The major rivers in the study area are the mainstream of the Heihe River and its tributaries, the Liyuan and Daciyao rivers [12]. The water resource in this basin mainly originates from the Qilian Mountains and runs towards the Gobi desert, and there is severe shortage of water resources, which is associated with competition between economic development and ecological conservation [20].

The Heihe River Basin covers an area of approximately 130,000 km^2, which can be divided into three parts: the upper reach region, including most part of Qilian County of Qinghai Province and some parts of Su'nan County, where the supply of water mainly comes from the Qilian Mountains in the upper reach; the middle reach region, including Zhangye city (Zhangye district, Su'nan, Gaotai, Linze, Minle and Shandan county), Jiuquan and Jiayuguan cities, which is an irrigation agriculture economic zone; and the lower reach region, including parts of Jinta county, and Ejin Banner of Inner Mongolia Autonomous Region, which is mainly dominated by the desert animal husbandry. Among the three parts, the upper reach is the main source of water, while the middle reach region (especially Zhangye city) is the main water consumption area, and we selected the upper and middle reaches as the study area to detect the impacts of scenario-based land use/cover change on hydrological process.

Specifically, the study area is a highly developed irrigation agriculture zone in the Heihe River Basin, with an agricultural history of about 2000 years. The Heihe River water flowing out of the Qilian mountain valley is the only surface streamflow to Zhangye city. The Yingluoxia hydrological station at the mouth of the mountain valley monitors the water inflow rate and variations. After flowing through areas experiencing large-scale and complex surface-water–groundwater conversion, the Heihe River water flows out of the study area at the Zhengyixia hydrological station (Figure 1).

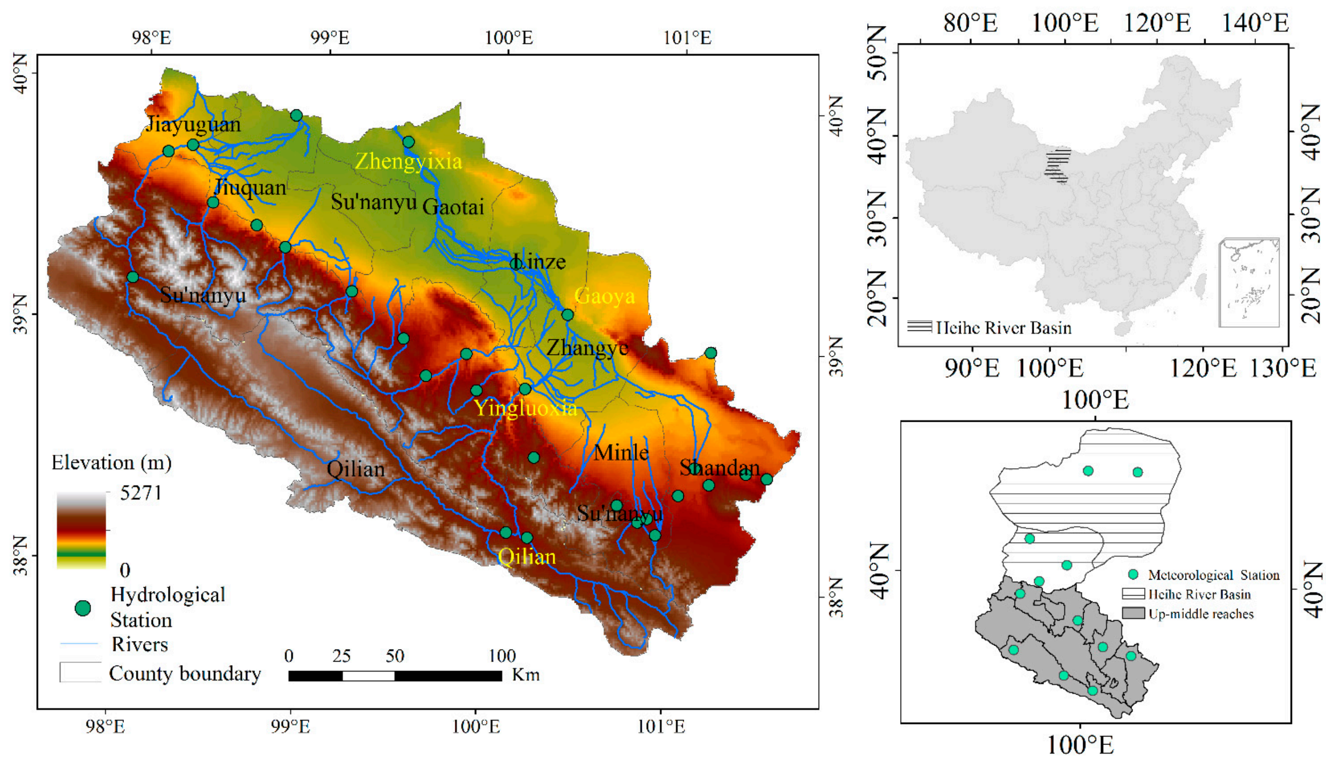


Figure 1. Geographic location of the upper and middle reach of the Heihe River Basin.

2.2. Data

2.2.1. Topographic and Soil Data

The topographic data include elevation, slope and aspect, flow direction and flow accumulation. The topographic data were obtained from a digital elevation model (DEM) of Shuttle Radar Topography Mission (SRTM) with a 90 m resolution [21]. The soil data mainly include soil texture, soil depth, and soil drainage attributes. The soil data with the resolution of 1km were derived from the Harmonized World Soil Database (HWSD) [22] provided by the Environmental and Ecological Science Data Center for West China (WestDC) (Table 1).

2.2.2. Hydrometeorological Data

To simulate the daily hydrological processes with the SWAT model, meteorological data are required, including daily precipitation, maximum and minimum air temperatures, solar radiation, wind speed, and relative humidity. In general, the historical daily meteorological observation data sets of the Heihe River Basin were collected from meteorological stations maintained by China Meteorological Administration (CMA) (Table 1). The meteorological data were obtained from 12 meteorological stations located within the Heihe River Basin (Figure 1), and the data were available during 1980–2010. In addition, the historical hydrological data for the SWAT model calibration and validation include the river flow data, discharge data of the hydrological stations, which were obtained from the People's Republic of China Hydrological Yearbook—Inland Rivers Hydrological Data. The hydrological data of the year 2007 were used for SWAT calibration, while the data of the year 2008 were used for SWAT validation (Table 1).

Table 1. Input data used in the Soil and Water Assessment Tool (SWAT) model of the study.

Data	Data sources	Information	Date/period	Description
Digital elevation models (DEM)	Shuttle Radar Topography Mission (SRTM) [23]	Raster, 90 m	2000	
Land use	Resources and Environment Scientific Data Center (RESDC), Chinese Academy of Sciences [24]	Raster, 1 km	2000, 2008	Including six land use types
Soil data	Environmental and Ecological Science Data Center for West China (WestDC) [25]	Raster, 1 km	1995	Parameters including saturation, texture and hydraulic condition, calculated using a Soil–Plant–Atmosphere–Water (SPAW) Field and Pond Hydrology model
Meteorological data	China Meteorological Administration (CMA) [26]	Daily	1980–2010	Daily temperature and precipitation data from the weather stations at Tuole, Yeniugou, Qilian, ShanDan, and Zhangye
Hydrological data	People's Republic of China Hydrological Yearbook— Inland Rivers Hydrological Data	Daily	2007, 2008	Discharge data, at hydrological stations Zhengyixia and Yingluoxia
Glacier	Environmental and Ecological Science Data Center for West China (WestDC) [27]	Raster, 1 km	2000	Attributes including width, length and depth

2.2.3. Land Use Data

The historical land use data with a resolution of 1km used in this study were derived from the database of the Resources and Environment Scientific Data Center, Chinese Academy of Sciences (Table 1). The land use data covers four periods: the late 1980s, mainly including the data from 1986 to 1989; the middle of 1990s, including the data from 1995 to 1996; the late 1990s, including the data from 1999 to 2000; and the late 2000s, including the data from 2005 to 2008. In the late 1990s the Chinese Academy of Sciences organized eight research institutions and about 100 scientists to conduct its second nationwide land cover and land use classification project. The research team developed the national land use databases by visual interpretation and digitalization based on remotely sensed digital images by the US Landsat TM/ETM satellite with a spatial resolution of 30 m. Further the interpretation of TM images and land-cover classifications were validated against extensive large-scale field surveys. After the ground truthing, the results showed that the average interpretation accuracy for land-cover classification were higher than 90% for each period [28–33]. The land use data used in this study were composed of six land use types, including cultivated land use, forest land, grassland, water area, built-up land and unused land. Land use properties were obtained directly from the SWAT model database, and the glacier data were obtained from WestDC [34,35] (Table 1). The land use data of the year 2008 were adopted for the accuracy assessment of the simulation with the DLS model.

2.3. Methodology

The DLS model and the SWAT model serve as our modeling approaches, brief descriptions of the two models are given below.

2.3.1. Land Use Scenarios

Facing water scarcity, it is of great significance to integrate water and land use management. In the Heihe River Basin, contradictions among water and land resources utilization, agricultural production, economic development and ecological construction will be an outstanding issue for a long period in the future. The water constrains will be the key factor of land use/cover changes in the basin. Especially, in the middle reach region, which is characterized by irrigation agriculture, the water supply is critical to the regional development. According to the "water-allocation-scheme" in the Heihe River Basin, the water amount for the middle reach will be strictly controlled to assure the supply of water for ecosystem conservation in the lower reach region. With this regard, it is urgent to improve the water utilization ratio in the middle reach, the water availability will be increased if the water utilization ratio were improved, which will significantly influence the land use pattern.

Particularly, Zhangye city covers about 90% of the middle reach, and more than 80% of artificial oasis, 92% of the population, 83% of GDP and 95% of the arable land concentrated in the Zhangye City [36,37]. The water resource in Zhangye city is the main constrain of the socioeconomic development. This study aims to detect how water resources constrain will affect the land use pattern, and further how land use/cover change will affect the hydrological process. According to the water amount from the upper reach of the Heihe River, Zhang *et al.* designed three scenarios of available water amount used in Zhangye city [38,39]. They are 18.0×10^8 m^3, 26.5×10^8 m^3 and 35.0×10^8 m^3, respectively, related to 68%, 100%, and 132% of water utilization ratio, with circulation and repeat utilization between surface water and groundwater taken into account within the study area. In each scenario, the water resources for ecological utilization are considered according to ecological environmental conditions and total amount of available water, designed as 2.636×10^8 m^3, 4.967×10^8 m^3 and

7.625×10^8 m^3 respectively. Further aiming to maximize the total socioeconomic utility of water resources, the changing trend of six land use types from 2001 to 2020 under three water resources constraint scenarios using linear programming were calculated, with the constraint conditions of water quantity, total land areas, total population and macro-scheme of regional development and ecological balances in Zhangye city.

In this study, taking the land use data of the year 2000 as baseline, we simulated the land use till the year of 2020 under the three land use structure change scenarios which correspond to three water utilization ratio (low-level water utilization ratio scenario (S1), middle-level water utilization ratio (S2) and high-level water utilization ratio (S3)).

2.3.2. DLS Model

The DLS model is a collection of programs that simulate the pattern changes in land uses by conducting scenario analysis of the area of land use/cover change [40]. The model analyzes causes of the dynamics of land use patterns, simulates the process of land use/cover change and assists land use planning and land management decisions. The DLS model can export a macroscopic pattern changes map of land uses at high spatial and temporal resolution by estimating the effects of changes in the spatial pattern of driving factors, formulating land use conversion rules and scenarios of land use change and simulating dynamic spatiotemporal processes of land use/cover change. The simulation process includes the analysis on driving mechanism, scenario design and spatial allocation of land cover, and the DLS model has been proved to be robust to simulate the land cover change at the pixel scale [41,42].

The analysis of the driving factors aims to estimate the statistical relationship between land use pattern successions and driving factors, which theoretically provides the response function for each land use types. All the driving factors are endowed with corresponding weights according to certain principles which can be assumed not to change during a short period, while the driving factors vary with time. In this study, after collinearity diagnosis, we selected 17 driving factors to conduct the logistical regression analysis, and got the relationships between the frequency of each land use type and the driving factors (Table 2). The results showed that the 17 driving factors can reasonably explain the spatial patterns of the six land use types. Specifically, the driving factors at the significant level and driving mechanisms were different for each land use types. For example, the change of cultivated land was significantly driven by 16 driving factors, while the changes in the water area and built-up land were significantly affected by less driving factors. For each land use type, we selected those specific significant driving factors for land use pattern simulation. Base on the driving mechanism, spatial disaggregation module in the DLS model can spatially explicitly convert the land demands into land use/cover change at various locations of the study area under different scenarios.

Table 2. Relationships between the frequency of each land use type and the driving factors base on logistical regression.

Driving factors	Cultivated land	Forest land	Grassland	Water area	Built-up land	Unused land
Slope	-2.95×10^{-3} ***	1.15×10^{-3} ***	-0.49×10^{-3} ***	-0.74×10^{-3} ***	-1.44×10^{-3} ***	0.20×10^{-3} ***
Aspect	-1.52×10^{-5} ***	0.22×10^{-5}	0.13×10^{-5}	-0.33×10^{-5}	-0.59×10^{-5}	0.22×10^{-5} **
Elevation	-2.54×10^{-3} ***	-0.47×10^{-3} ***	0.039×10^{-3}	-0.73×10^{-5} ***	-2.07×10^{-5} ***	1.29×10^{-5} ***
Rain	-1.32×10^{-3} ***	-0.93×10^{-3} ***	0.546×10^{-3} ***	-0.17×10^{-3}	0.59×10^{-3}	-0.88×10^{-3} ***
Sun radiation	-1.9×10^{-2} ***	-0.52×10^{-2} ***	0.15×10^{-2} ***	-0.69×10^{-2} ***	-0.28×10^{-2}	-0.24×10^{-2} ***
>0 °C accumulated temperature	-0.0426×10^{-4}	1.45×10^{-4} ***	1.48×10^{-4} ***	-2.007×10^{-4} ***	-0.93×10^{-4}	-1.72×10^{-4} ***
>10 °C accumulated temperature	-2.02×10^{-4} ***	-2.36×10^{-4} ***	-1.55×10^{-4} ***	1.40×10^{-4} ***	0.32×10^{-4}	2.88×10^{-4} ***
Soil_depth	−0.11 ***	0.07 ***	−0.027 ***	0.092 ***	−0.089	−0.0099 *
Soil_organic	−1.09 **	2.52 ***	0.42	−0.83	−3.08	−1.47 ***
Soil_ph	−0.72 ***	−0.25 ***	0.039	−0.20	−0.17	0.036
Population density	1.97×10^{-4} *	-9.45×10^{-4} ***	-1.4×10^{-4}	4.58×10^{-4}	0.50×10^{-4}	7.00×10^{-4} ***
GDP	2.74×10^{-3} ***	-8.30×10^{-3} ***	-7.66×10^{-3} ***	-4.52×10^{-3} ***	7.72×10^{-3} ***	-24.05×10^{-3} ***
Distance to express way	-5.60×10^{-2} ***	-1.80×10^{-2} ***	-0.66×10^{-2} ***	0.33×10^{-2}	-1.86×10^{-2} ***	1.20×10^{-2} ***
Distance to highway	1.2×10^{-2} ***	0.41×10^{-2} ***	-0.46×10^{-2} ***	0.38×10^{-2}	0.45×10^{-2}	0.69×10^{-2} ***
Distance to province way	-0.83×10^{-2} ***	-1.714×10^{-2} ***	-0.25×10^{-2} ***	-1.39×10^{-2} ***	0.52×10^{-2}	1.09×10^{-2} ***
Distance to water source	-0.73×10^{-2} ***	1.42×10^{-2} ***	1.35×10^{-2} ***	-1.06×10^{-2} ***	0.19×10^{-2}	-1.22×10^{-2} ***
Distance to province capital	-0.95×10^{-2} ***	-01.26×10^{-2} ***	0.55×10^{-2} ***	-0.15×10^{-2} ***	-1.42×10^{-2} ***	-0.59×10^{-2} ***
cons	71.36	4.73	−2.35	8.38	22.94	2.71

Note: t statistics in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

2.3.3. SWAT Model

Hydrological modeling was performed using the SWAT extension for ArcGIS mapping analysis software, called ArcSWAT [43]. The SWAT model is an agro-hydrological watershed-scale model developed by the United States Department of Agriculture (USDA), Agricultural Research Service [44]. It was a physically based and semi-distributed model that uses a GIS interface and readily available input data such as Digital Elevation Model (DEM), climate, soil and land-use data to predict the impacts of land management practices such as land use/cover changes, reservoir management, groundwater withdrawals, and water transfers on sediment, and agricultural chemical yields in complex watersheds with varying soils, land-use and management conditions over long periods of time [45,46]. The SWAT model has been widely applied in hydrologic modeling studies, water resources management, and water pollution problems [47]. For examples, Rahman *et al.* investigated the low flow response to the A2 (high economic growth, low technology development, high population growth) climate change scenario [48], Castillo *et al.* [5] applied the SWAT model to detect the individual and combined impacts of changes in land use and land cover and in precipitation patterns on hydrological processes, including streamflows and sediment transport, in a coastal Texas watershed. Wu *et al.* [49] In addition, analyzed the possible future water demand and water availability with the application of the CGE model and the SWAT model in the rapidly urbanized Heihe River Basin, Northwest China, based on different climate and land use change scenarios. SWAT is also applied to investigate the hydrologic and water quality responses to land use/cover changes, for example, Chiang *et al.* [50] assessed individual impacts of land use/cover change and pasture management on water quality, including sediment, N, and P losses, with the application of SWAT2009.

In this study, we aimed to simulate the response of hydrological processes to individual land use/cover changes using the SWAT model. Specifically, the input data for the SWAT model include elevation/slope, soil, LULC, precipitation, temperature, and streamflow (Table 1). The SWAT model was performed on a daily time step to predict the impacts of land use/cover change on water flow. In the SWAT model, a basin is divided into multiple sub-basins, which are then further divided into one or more hydrological response units (HRUs) on the basis of unique combinations of land use, soil and slope class. These HRUs are defined as homogeneous spatial units characterized by similar geo-morphological and hydrological properties [51]. To generate the HRUs, we used two slope classes (0%–25% and greater than 25%), and we also used a threshold of 25% for slope class and 38 soil type, that is, slope classes and soil types that covered more than 25% of a subbasin area would become their own HRU. Furthermore, we incorporated land use and land cover into the SWAT model to generate the HRUs, as the study selected multiple HRUs in a subbasin to simulate, the HRU threshold is determined by the threshold percentage of land use land cover over subbasin area (5%), and soil over land use area (10%). Finally, 113 sub basins and 1171 HRUs were generated in the upper and middle reaches of the Heihe River Basin. For each subbasin, a modified soil conservation service (SCS) curve number (CN) method, which integrates a slope factor, was applied to simulate the surface runoff [49].

3. Results and Discussions

In this study, three different land use change scenarios under low-level water utilization ratio scenario (S1), middle-level water utilization ratio (S2) and high-level water utilization ratio (S3) conditions were established to assess the impacts of the land use/cover change on hydrological processes.

3.1. Land Use/Cover Change Simulated with DLS for Each Scenario

3.1.1. Performance of the DLS Model

Land use change models have been widely used to analyze the possible land use dynamics, which helps to support land use management and relevant policy-making. For further scientific application of land use change models, results obtained with these models are often assessed by comparing the simulated and actual spatial land-use patterns. For this, one of the most commonly used methods for the agreement assessment is the Kappa coefficient of agreement [52–54]. As land-use datasets are categorical, Kappa can be used for accuracy assessment of the results of spatial simulation models [55]. In this study, the land use data of the year 2000 was used as the base data to simulate the land use data of the year 2008. Then the Kappa was applied to assess the agreement between the simulated and actual land use patterns of the year 2008 (Figure 2).

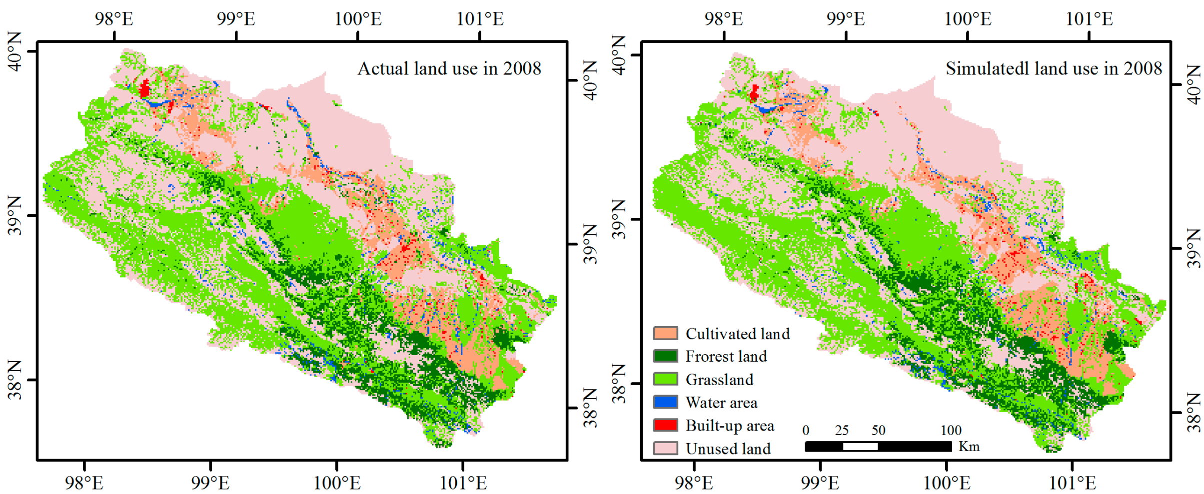


Figure 2. Comparison of the actual and simulated land use pattern in the upper and middle reaches of the Heihe River Basin, 2008.

Table 3 gives the contingency table from the comparison of the actual land use map (map A) with the simulated land use map (map B) of the year 2008, fields in the table indicated the fraction of cells that has a specific land use in map A and in map B. Based on Table 3, the agreement value and the Kappa value were calculated, the results shown in Table 4 indicated that the agreement between the actual and simulated land use pattern is 72.83%, and the corresponding Kappa is 0.605. According to the classification criterion based on Kappa coefficient [56], the Kappa value above 0.6 indicated that the agreement between the actual data and simulation results was good, and the DLS model was suitable for simulating the spatial pattern of land use in the upper and middle reaches of the Heihe River Basin.

Table 3. The contingency table of actual and simulated land use in 2008 (Unit: %).

Actual land use in 2008 (map A)	Simulated land use in 2008 (map B)						Total
	1	2	3	4	5	6	
1	8.3	0.0	1.2	0.3	0.7	1.1	11.6
2	0.2	5.9	2.8	0.1	0.0	0.8	9.8
3	1.4	2.6	25.2	0.4	0.1	5.2	34.8
4	0.3	0.0	0.4	0.3	0.0	0.5	1.7
5	0.6	0.0	0.0	0.0	0.2	0.1	0.9
6	1.1	1.3	5.2	0.5	0.1	33.0	41.2
Total	11.9	9.9	34.8	1.6	1.1	40.6	100

Table 4. Accuracy of DLS land use simulation results assessed with Kappa statistics.

Agreement	Expected Agreement	Kappa	Standard error	Z	Prob > Z
72.83%	31.25%	0.605	0.003	182.830	0.000

3.1.2. Simulated Land Uses

Grassland, forest lands, cultivated lands and unused lands are the four major land use types in the upper and middle reaches of the Heihe River Basin. Under the three water utilization ratio scenarios, the changing trend of the land uses are shown in Figure 3 and Table 5. It mainly shows that the increase of water utilization ratio will mitigate the decrease of cultivated land. The increase of forest land and grassland shows a positive relationship with the water utilization ratio. As to the built-up land, it will expand more significantly if the water resource is more strictly restricted. In other words, with lower water availability, to get the optimal utilization and maximum utility, water resources will be more diverted to built-up land. In addition, the unused land greatly decreases along with the increase of water utilization ratio.

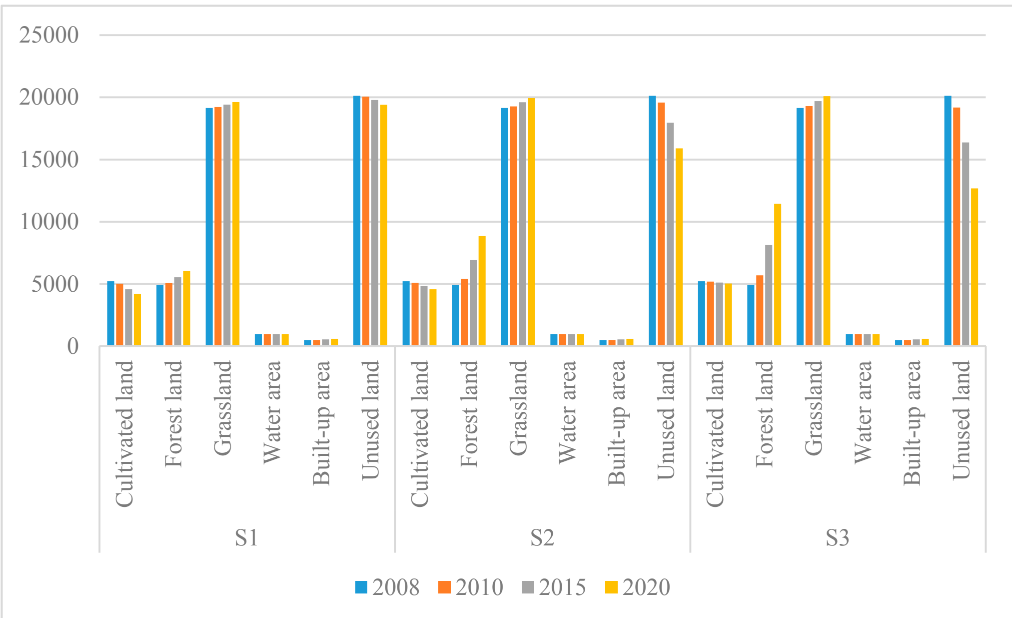


Figure 3. Land use structure changes under S1, S2 and S3 scenarios.

Table 5. Simulated areas of land use types under different scenarios (Unit: km^2).

Land use types	**2008**	**2020**					
		S1		**S2**		**S3**	
		Area	**Percent change (%)**	**Area**	**Percent change (%)**	**Area**	**Percent change (%)**
Cultivated land	5217	4413	−15.4	4807	−7.9	5217	0
Forest land	4894	6031	23.2	8807	80	11,420	133.3
Grassland	19,135	19,525	2	19,866	3.8	20,029	4.7
Water area	957	917	−4.2	923	−3.6	911	−4.8
Built-up land	500	601	20.2	588	17.6	573	14.6
Unused land	20113	19329	−3.9	15,825	−21.3	12,666	−37

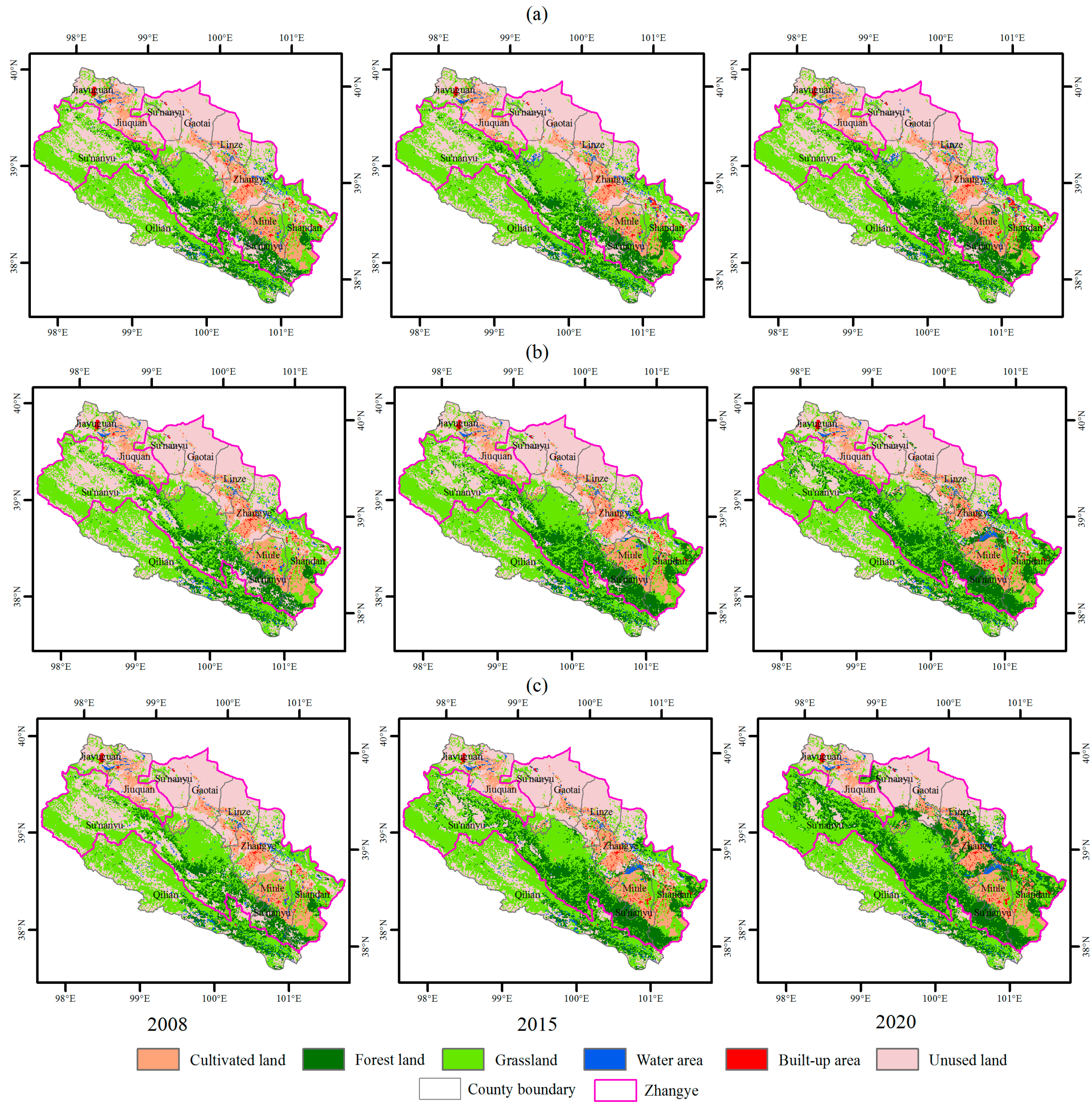


Figure 4. Simulate land use patterns under the (**a**) S1 scenario; (**b**) S2 scenario and (**c**) S3 scenario in the upper and middle reaches of the Heihe River Basin for the year 2008, 2015 and 2020.

Figure 4 shows the land use patterns under each scenario for 2008−2020, which was simulated with the DLS model based on logistic regression analyses in Table 2. During the simulation processes, the land use structure data of the whole Zhangye city was applied as the input data, and the development-restricted areas and other counties were taken as restricted region. The simulation results indicated that land use/cover change in the arid area is strongly constrained by water resources, especially for the forest lands. The land use/cover change during 2008–2020 were mainly dominated by substantial expansion of forestland, grassland, and the shrinkage of the cultivated land and unused land, which would exert significant impacts on water quantity in this basin.

3.2. SWAT Model Calibration and Validation

The purpose of the model calibration is to better parameterize a model to a given set of local conditions, thus to improve the simulation accuracy. Model validation is to check whether the model can predict flow for another range of time periods or conditions than those for which the model was calibrated. Many hydrological models contain parameters that cannot be determined directly from field measurements. To improve the SWAT model performance, model calibration and validation are used to adjust and validate such parameters to optimize the agreement between observed and simulated values [57,58]. In the SWAT model, the input parameters are process based and must be held within a realistic uncertainty range, and the first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given basin or subbasin [59]. The most sensitive parameters were identified in the calibration process with the built-in sensitivity analysis tool in SWAT [60]. The calibration of the SWAT model is time consuming, so in this study SWAT-CUP SUFI-2 (Sequential Uncertainly Fitting Ver. 2) was used to evaluate the SWAT model by performing calibration and uncertainly analysis. SUFI-2 is a semi-automated inverse modeling procedure for combined calibration-uncertainly analysis [61], based on which sensitive initial and default parameters related to hydrology varied simultaneously until an optimal solution was met. The most sensitive parameters with their best ranges and best-fitted values used for the SWAT model simulation are shown in Table 6. Finally, these best-fitted values were used to adjust the initial model inputs for the future simulation.

In this study, the SWAT model was calibrated for streamflow at the sub-basin level for the period 2005–2007 based on the daily observed streamflow from Yingluoxia hydrological station in the upper reach of the Heihe River Basin, where human activities are not intensive With the first two years (2005–2006) used as a warm-up period which were not considered in the calibration analysis, the data of year 2007 were actually applied to calibrate the model. Validation of the model was conducted using data of the year 2008. The model performance was evaluated using goodness-of-fit statistics such as the Nash and Sutcliffe model efficiency coefficient (E_{ns}) and the coefficient of determination (R^2) [62]. Figure 5 shows the calibration and validation results. During the calibration period, the Nash-Sutcliffe coefficient (E_{ns}) was 0.88 and the values of R^2 between the simulated and observed daily streamflows was 0.87. During the validation period, the E_{ns} was 0.87 and the value of R^2 was 0.89. The simulated streamflow was considered to be accurate for values of $E_{ns} > 0.75$ [63]. These results suggest that the calibrated model can accurately simulate the streamflow in the Heihe River Basin and confirm that the calibrated model with the set of optimized parameters can be used to examine the responses of hydrological processes to land use/cover change in the upper and middle reaches of the Heihe River Basin.

Table 6. List of calibration parameters and the optimized values.

Parameters	Descriptions	Ranges	Fitted Values
CN_2	SCS curve number	−20%~20%	+6.32%
Sol_k	Saturated hydrological conductivity	−20%~20%	+11.56%
Escno	Evaporation compensation factor	0~1.0	0.83
SFTMP	Snowfall temperature	−2.0~2.0 °C	0.9 °C
Sol_z	Depth from soil surface to bottom of layer	−20%~20%	+3.65%
Sol_Awc	Available soil water content	−20%~20%	−0.35%
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0~500 mm	306.5
ALPHA_BF	Baseflow alpha factor	0.00~1.00	0.07

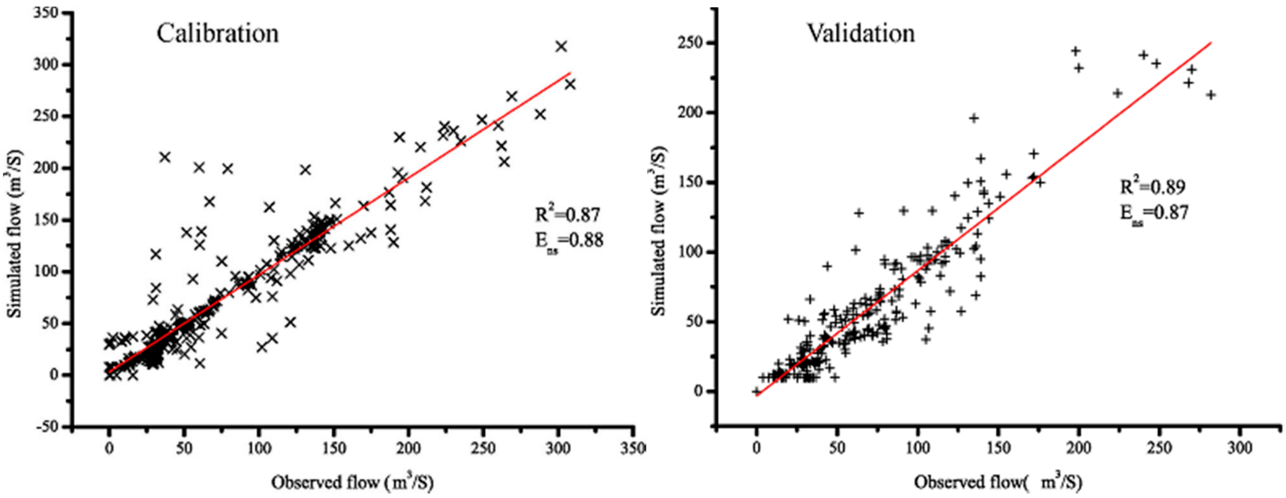


Figure 5. Scatter plot of observed and simulated flow for the calibration and validation periods.

3.3. Effects of Land-Use Changes on Hydrological Processes

The influence of land use/cover change on the hydrological processes is a key factor in the rational allocation of water resources in the study area. It has been widely reported that land use/cover change can affect the quantity of water resources. The data of Zhengyixia hydrological station located at the outlet of middle reach (Figure 1) were used to examine the impact of land use/cover changes on hydrological processes. We choose surface runoff and water yield to analyze the impacts of land use/cover change. The monthly average values of the surface runoff, water yield and precipitation were calculated (Figure 6). The results showed that the impacts of land use/cover change on the surface runoff and water yield varied with the precipitation and seasons, and the changing trend of surface runoff and water yield were similar to that of the precipitation.

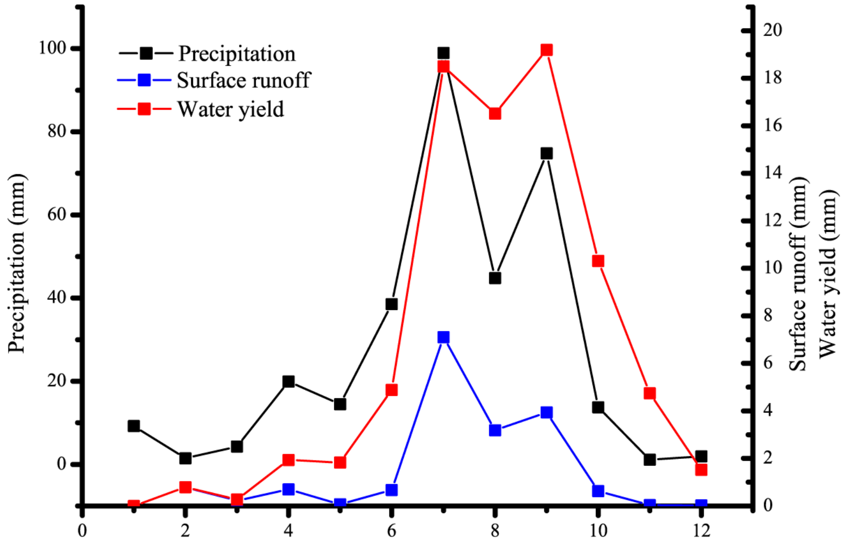
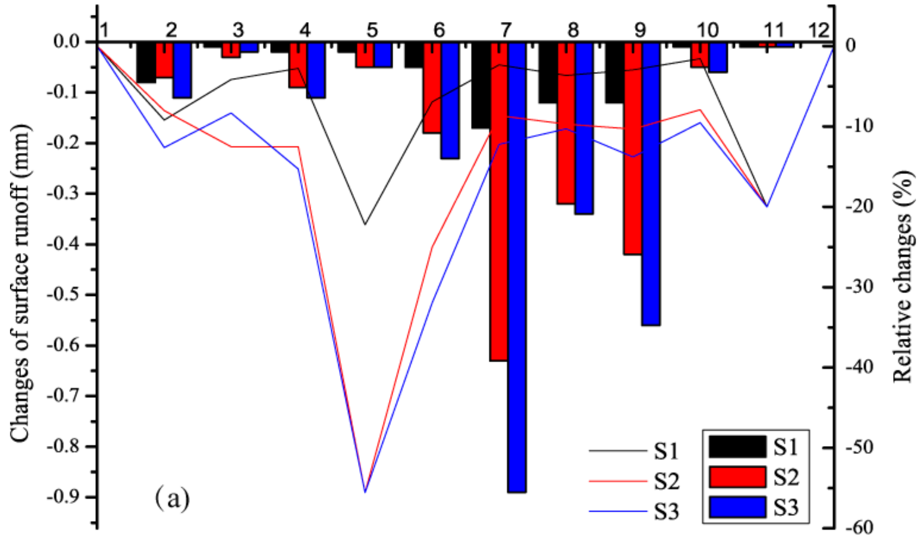


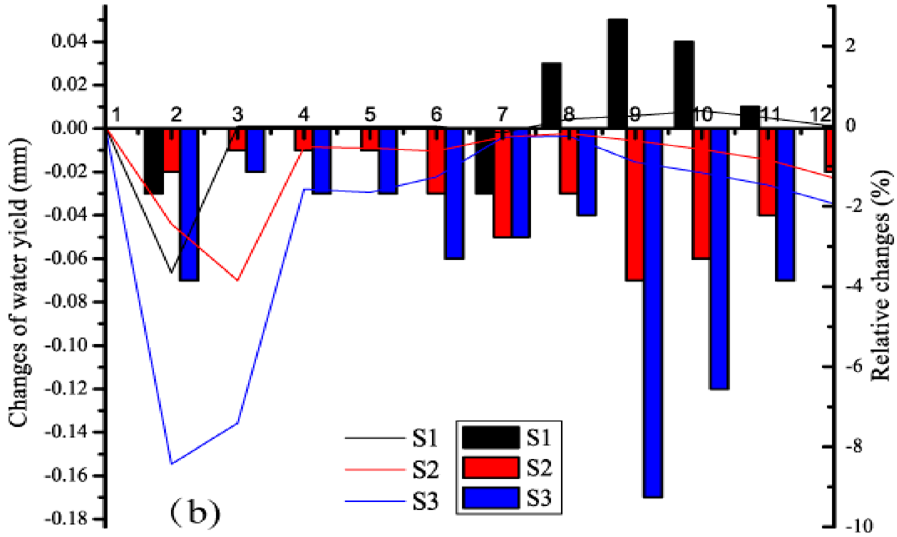
Figure 6. Multi-year averaged monthly precipitation, surface runoff and water yield in the upper and middle reaches of the Heihe River Basin.

The simulated surface runoff and water yield of the year 2020 under the three scenarios were compared to the corresponding values in the baseline year 2008. Figure 7 shows the changes in monthly surface runoff and water yield under different land use/cover change scenarios. Surface runoff is one of the major pathways contributing to the water yield. The monthly quick-response surface runoff showed a decreasing trend, with the relative changes ranging from −55.5% to −1.6% (Figure 7a) under the three scenarios. The water yield would increase in May and June, and decrease in all other months in scenarios S2 and S3, while the water yield will increase during August-November in scenario S1 (Figure 7b). The overall changing trend of the surface runoff is consistent with the water yield in scenarios S2 and S3, both revealing a decreasing trend due to land use/cover change.



(a)

Figure 7. *Cont.*



(b)

Figure 7. Changes in monthly surface runoff (**a**) and water yield (**b**) under S1, S2 and S3 scenarios for the year 2020 relative to 2008.

The major causes of the decrease in surface runoff are the expansions of forest land and grassland. There is broad agreement amongst researchers that the stream flow change is likely to be caused by different kinds of forestry activities, such as afforestation that may lead to lower runoff generation and reduction of water yield. Sahin and Hall analyzed empirical data from 145 sites around the world and found a decrease in annual runoff resulting from increase of scrub cover, and an increase in runoff for reduction of deciduous hardwood cover [64]. As it has been identified, the order of runoff rate of different land use types was as follows: Unused land > Cultivated land > Grassland > Forest land [65], Since in this study forest land and grassland land were mainly converted from unused land, which inevitably led to the reduction of surface runoff, and the more intensive forest land and grassland expansion are, the more the reduction and fluctuation of surface runoff are. As shown in Figure 7a, surface runoff reduced most significantly under the S3 scenario, especially in July, August and September, when the precipitation is much more intensive, the impacts of land use/cover change on the absolute runoff amount changes will be more significantly.

As to the water yield, the scenario S1, with less grassland and forest land expansion compared to scenarios S2 and S3, even if the surface runoff is decreasing, the water yield during August-November still shows an increasing trend. Different land use types have different characteristics of the soil water infiltration, the infiltration rate of forest land is larger than grassland and unused land [66]. As both surface runoff and base flow are the major two parts contributing to water yield, with unused land being converted to grassland and forest land, the infiltration will increase and further lead to the increase of base flow.. The impacts of vegetation coverage on the base flow is complex. On the one hand, infiltration rates increased strongly with the increase of vegetative coverage, leading to more generation of base flow [67]. On the other hand, vegetation evaporation and transpiration will consume a large amount of water, and vegetation coverage change will alter and improve the water storage capacity of soil, which is not conducive to supplement the base flow [68]. In addition, vegetation roots, especially the larger deep-rooted vegetation that increased absorption may make base flow absorbed by vegetation, and consequently the water yield declines [69]. The smaller the rainfall and rainfall intensity are, the greater the capacity of vegetation to intercept precipitation is. During July-October the rainfall is much larger than it is in other months, leading to a lower capacity of vegetation to intercept precipitation. Under S1 scenario, the vegetation coverage density is much lower than that under S2 and S3 scenario, resulting in less decrease of surface runoff and less absorption of vegetation, and the positive effect on base flow overwhelmed the negative effect on surface runoff, finally resulting in an increase in the water yield during August-November under S1 scenario (Figure 7b). While under the S2 and S3 scenario, with much higher vegetation coverage, the negative impacts on surface runoff overwhelmed the positive impacts on base flow, finally leading to the increase of water yield. In particular, during the winter season (October-December), the decrease of water yield is even larger than the decrease in surface runoff, which means that the base flow during the winter season has also been negatively affected by the forest and grassland expansion in the basin.

This study was carried out in the upper and middle reaches of the Heihe River Basin, which is a typical inland river basin in the semi-arid and arid region of China, the results of this study can provide information for water resource and land use management in the river basins that with the similar conditions, such as the catchment on the Loess Plateau [70] and the catchment in the semiarid zone on the southern High Plains, United States [71]. It is widely acknowledged that land use and climate are the two major factors directly affecting the hydrological processes, while in this study we only took the land use impacts into consideration. It is a particular challenge to distinguish the effects of land use/cover changes from that of concurrent climate variability [72]. Since the land use/cover change interacts with climate change, it is important to use land use/cover change scenarios that are consistent with the specific assumptions under climate change scenarios when aiming to investigate the combined impacts of land use and climate, and the further separation of their effects in order to detect the individual impacts of land use and climate changes on the hydrological processes is of great importance for land use planning and water resources management [14]. There are also some studies that investigated the combined impacts of land use and climate on water availability, and further separate the impacts through changing one factor and controlling others constant [15,70,73], the results of these studies showed that climate change was more significant than land use/cover change in determining the hydrological response in the basin. In the Heihe River Basin, several studies have also been conducted to investigate the impacts of land use and climate change, which also showed that the climate variability influenced the surface hydrology more significantly than the land use/cover change [70,74]. In this study, the land use/cover change scenarios were designed based on the water availability, if we also take the climate change into consideration, then the water availability for socioeconomic development and ecological conservation will accordingly change and further affect the land use patterns, also along with the changes in precipitation and temperature, the l impacts land use/cover change on the surface runoff and water yield may be totally offset by the impacts of climate changes as the climate variability plays an important role in the land use planning and water resources management. More studies should be conducted to quantify the extent to which land use/cover change and climate variability influence the hydrological processes with consistent water utilization rate, land use and climate scenarios in the future.

4. Conclusions

Water resources constraints are a critical factor affecting land use demand for socioeconomic development and ecological conservation, and further resulting land use/cover change, which will affect the water supply through influencing the hydrological processes. Understanding the interactions between water resources and land use change is crucial for sustainable water resource and land use management. This study first examined the possible land use/cover changes under different water utilization levels, with the higher water utilization ratio the more water available for socioeconomic development and ecological conservation, which can further ease the decreasing trend of cultivated land in the irrigation agriculture area and stimulate the expansion of forest land and grassland. Then based on the simulated land use data with unchanged climate conditions, we conducted quantitative analyses of the impacts of land use/cover change on the surface runoff and water yield in the upper and middle reaches of the Heihe River Basin for the year 2008–2020. The results indicated the surface runoff and water yield both changed when there was forest and grassland expansion. The impacts of land use/cover change on hydrological processes is complex, the surface runoff showed a decreasing trend along with the increasing expansion forest land and grassland under the three scenarios, while, the water yield generally showed a decreasing trend. Exceptionally, the water yield showed an increasing trend during August-November under S1 scenario, under which the expansion of forest land and grassland was much lower than that under S2 and S3 scenarios, and the decreasing trend in water yield under S3 scenario is much more significantly than that under the S1 and S2 scenario.

With the higher water utilization ratio and the aim to maximize the socioeconomic utility of water resources, the higher water availability would lead to the expansion of forest land and grassland, which will in return exert negative impacts on the water yield, resulting in less water availability. This indicates that even if the water utilization ratio increases, the unreasonable allocation of water resources may exert negative impacts on the water resource, and therefore it is very necessary to reasonably allocate the water resources for different land use demand. The water and land use planning should consider not only the current socioeconomic utility of water resources, but also the future possible response of hydrological processes to the land use/cover change, and it is essential to carry out integrated water and land use management and consider the responses of hydrological process to land use/cover change resulted from water and land use management. The long-term water resource planning should be flexible and adaptable to changes due to these responses. This study just takes the impacts of land use/cover changes into consideration, but the climate change and socio-economic production activities are also important factors of the water supply and water demand, there is still considerable potential to improve the integrated modeling and analyses of water resources in the Heihe River Basin and other basins with similar conditions.

Acknowledgments

The authors would like to acknowledge funding from the major research plan of the National Natural Science Foundation of China (Grant No. 91325302), the National Natural Science Funds of China for Distinguished Young Scholar (Grant No. 71225005).

Author Contributions

In this paper, Zhihui Li contributed to research design and organized research flow, data analysis and interpretation; Xiangzheng Deng contributed to the result analysis and interpretation; Feng Wu contributed to SWAT simulations in the case study; Shaikh Shamim Hasan contributed to the interpretation of the results. All the authors contributed to writing of the article.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Notter, B.; Hurni, H.; Wiesmann, U.; Abbaspour, K. Modelling water provision as an ecosystem service in a large east African River Basin. *Hydrol. Earth Syst. Sci.* **2011**, *8*, 7987–8033.
2. Praskievicz, S.; Chang, H. Impacts of climate change and urban development on water resources in the Tualatin River Basin, Oregon. *Ann. Assoc. Am. Geogr.* **2011**, *101*, 249–271.
3. Chang, H.; Franczyk, J. Climate change, land-use change, and floods: Toward an integrated assessment. *Geogr. Compass* **2008**, *2*, 1549–1579.
4. Al-Bakri, J.T.; Salahat, M.; Suleiman, A.; Suifan, M.; Hamdan, M.R.; Khresat, S.; Kandakji, T. Impact of climate and land use changes on water and food security in jordan: Implications for transcending "the tragedy of the commons". *Sustainability* **2013**, *5*, 724–748.
5. Castillo, C.R.; Güneralp, I.; Güneralp, B. Influence of changes in developed land and precipitation on hydrology of a coastal texas watershed. *Appl. Geogr.* **2014**, *47*, 154–167.
6. Chang, H.; Knight, C.G.; Staneva, M.P.; Kostov, D. Water resource impacts of climate change in southwestern Bulgaria. *GeoJournal* **2002**, *57*, 159–168.
7. Bangash, R.F.; Passuello, A.; Sanchez-Canales, M.; Terrado, M.; Lopez, A.; Elorza, F.J.; Ziv, G.; Acuna, V.; Schuhmacher, M. Ecosystem services in Mediterranean River Basin: Climate change impact on water provisioning and erosion control. *Sci. Total Environ.* **2013**, *458*, 246–255.
8. Christensen, N.S.; Wood, A.W.; Voisin, N.; Lettenmaier, D.P.; Palmer, R.N. The effects of climate change on the hydrology and water resources of the Colorado River Basin. *Clim. Chang.* **2004**, *62*, 337–363.
9. Wiltshire, A.J.; Kay, G.; Gornall, J.L.; Betts, R.A. The impact of climate, co2 and population on regional food and water resources in the 2050s. *Sustainability* **2013**, *5*, 2129–2151.
10. Güneralp, B.; Güneralp, İ.; Castillo, C.R.; Filippi, A.M. Land change in the mission-aransas coastal region, texas: Implications for coastal vulnerability and protected areas. *Sustainability* **2013**, *5*, 4247–4267.
11. Wagner, P.D.; Kumar, S.; Schneider, K. An assessment of land use change impacts on the water resources of the mula and mutha rivers catchment upstream of Pune, India. *Hydrol. Earth Syst. Sci.* **2013**, *17*, 2233–2246.
12. Nian, Y.; Li, X.; Zhou, J.; Hu, X. Impact of land use change on water resource allocation in the middle reaches of the Heihe River Basin in northwestern China. *J. Arid Land* **2014**, *6*, 273–286.

13. Menzel, L.; Koch, J.; Onigkeit, J.; Schaldach, R. Modelling the effects of land-use and land-cover change on water availability in the Jordan river region. *Adv. Geosci.* **2009**, *21*, 73–80.
14. U.S. Environment Protection Agency (EPA). Land-Use Scenarios: National-Scale Housing-Density Scenarios Consistent with Climate Change Storylines (Final Report). Available online: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203458#Download (accessed on 11 March 2015).
15. Van Ty, T.; Sunada, K.; Ichikawa, Y.; Oishi, S. Scenario-based impact assessment of land use/cover and climate changes on water resources and demand: A case study in the Srepok River Basin, Vietnam—Cambodia. *Water Resour. Manag.* **2012**, *26*, 1387–1407.
16. Kim, J.; Choi, J.; Choi, C.; Park, S. Impacts of changes in climate and land use/land cover under IPCC RCP scenarios on streamflow in the hoeya river basin, korea. *Sci. Total Environ.* **2013**, *452*, 181–195.
17. Deng, X.; Zhang, F.; Wang, Z.; Li, X.; Zhang, T. An extended input output table compiled for analyzing water demand and consumption at county level in China. *Sustainability* **2014**, *6*, 3301–3320.
18. Li, C.; Yu, F.; Liu, J.; Yan, D.; Zhou, T. Research on land use/cover change and its driving force in midstream of the heihe mainstream basin during the past 20 years. *J. Nat. Resour.* **2011**, *26*, 353–363.
19. Abbott, J. *Water Scarcity and Land Use Planning*; RICS: London, UK, 2011.
20. Ji, X.; Kang, E.; Chen, R.; Zhao, W.; Zhang, Z.; Jin, B. The impact of the development of water resources on environment in arid inland river basins of Hexi region, northwestern China. *Environ. Geol.* **2006**, *50*, 793–801.
21. Jarvis, A.; Reuter, H.I.; Nelson, A.; Guevara, E. Hole-filled srtm for the globe version 4. Available online: http://srtm.csi.cgiar.org (accessed on 11 March 2015).
22. Food and Agriculture Organization (FAO), Soil Reference and Information Centre ISRIC. Harmonized world soil database (version 1.1). Available online: http://www.fao.org/nr/land/soils/harmonized-world-soildatabase/en (accessed on 11 March 2015).
23. CGIAR-CSI, SRTM 90m Digital Elevation Data. Available online: http://srtm.csi.cgiar.org/ (accessed on 11 March 2015).
24. RESDC, Land Use Data. Available online: http://www.resdc.cn/data.aspx?DATAID=99 (accessed on 11 March 2015).
25. WESTDC, Soil Data. Available online: http://westdc.westgis.ac.cn/ (accessed on 11 March 2015).
26. CMA, Meteorological Data. Available online: http://www.cma.gov.cn (accessed on 11 March 2015).
27. WESTDC, Glacier Data. Available online: http://westdc.westgis.ac.cn/glacier (accessed on 11 March 2015).
28. Liu, J.; Liu, M.; Tian, H.; Zhuang, D.; Zhang, Z.; Zhang, W.; Tang, X.; Deng, X. Spatial and temporal patterns of China's cropland during 1990–2000: An analysis based on landsat TM data. *Remote Sens. Environ.* **2005**, *98*, 442–456.
29. Liu, J.; Kuang, W.; Zhang, Z.; Xu, X.; Qin, Y.; Ning, J.; Zhou, W.; Zhang, S.; Li, R.; Yan, C. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *J. Geogr. Sci.* **2014**, *24*, 195–210.
30. Deng, X.; Jiang, Q.; Su, H.; Wu, F. Trace forest conversions in northeast China with a 1-km area percentage data model. *J. Appl. Remote Sens.* **2010**, doi:10.1117/1.3491193.

31. Wu, F.; Zhan, J.; Yan, H.; Shi, C.; Huang, J. Land cover mapping based on multisource spatial data mining approach for climate simulation: A case study in the farming-pastoral ecotone of north China. *Adv. Meteorol.* **2013**, doi:10.1155/2013/520803.
32. Liu, J.; Zhang, Z.; Xu, X.; Kuang, W.; Zhou, W.; Zhang, S.; Li, R.; Yan, C.; Yu, D.; Wu, S. Spatial patterns and driving forces of land use change in China during the early 21st century. *J. Geogr. Sci.* **2010**, *20*, 483–494.
33. Liu, J.; Liu, M.; Zhuang, D.; Zhang, Z.; Deng, X. Study on spatial pattern of land-use change in china during 1995–2000. *Sci. China Series D Earth Sci.* **2003**, *46*, 373–384.
34. Guo, W.; Liu, S.; Yu, P.; Xu, J. Automatic extraction of ridgelines using on drainage boundaries and aspect difference. *Sci. Survey Mapp.* **2011**, *36*, 210–212.
35. Guo, W. China's first ice catalog revision dataset. Available online: http://westdc.westgis.ac.cn/data/5ba5f168-50e3-4ab6-95cc-e4e10cedc4c3 (accessed on11 March 2015).
36. Wang, Y.; Xiao, H.; Zou, S.; Li, C.; Ren, J.; Lu, M. Study and simulation on water resources regulation in Zhangye city based on CGE model. *J. Nat. Resour.* **2010**, *6*, 959–966. (In Chinese).
37. Shi, M.; Wang, L.; Wang, X. A study on changes and driving factors of agricultural water supply and demand in Zhangye after water reallocation of the Heihe River. *Resour. Sci.* **2011**, *33*, 1489–1497.
38. Zhang, H.; Zhang, B.; Zhao, C. Modelling the Future Variations of Land Use and Land Cover in the Middle Reaches of Heihe River, Northwestern China. In Proceedings of 2010 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Honolulu, HI, USA, 25–30 July 2010; pp. 883–886.
39. Zhang, H.; Zhang, B.; Verburg, P. The future variations of land use and land coverage in arid regions, modeled in three scenarios of water resources—A case study in Zhangye municipality in the Heihe River Basin. *J. Glaciol. Geocryol.* **2007**, *29*, 397–405.
40. Deng, X. *Modeling the Dynamics and Consequences of Land System Change*; Springer: Berlin, German, 2011.
41. Jiang, Q.; Ma, E.; Zhan, J.; Shi, N. Seasonal and interannual variation in energy balance in the semi-arid grassland area of China. *Adv. Meteorol.* **2014**, in press.
42. Deng, X.; Jiang, Q.; Zhan, J.; He, S.; Lin, Y. Simulation on the dynamics of forest area changes in northeast China. *J. Geogr. Sci.* **2010**, *20*, 495–509.
43. Winchell, M.; Srinivasan, R.; Di Luzio, M.; Arnold, J. *Arcswat 2.3. 4 Interface for Swat 2005: User's Guide*; Texas Agricultural Experiment Station and Agricultural Research Service-US Department of Agriculture: Temple, TX, USA, 2009.
44. Arnold, J.G.; Srinivasan, R.; Muttiah, R.S.; Williams, J.R. Large area hydrologic modeling and assessment part i: Model development. *J. Am. Water. Resour. A* **1998**, *34*, 73–89.
45. Arnold, J.; Kiniry, J.; Srinivasan, R.; Williams, J.; Haney, E.; Neitsch, S. Soil and Water Assessment Tool Input/Output File Documentation–version 2009. Available online: http://159.226.251.229/videoplayer/swat-io-2009.pdf?ich_u_r_i=f4aa3a866eee8bd77612868f3fc4f1ed&ich_s_t_a_r_t=0&ich_e_n_d=0&ich_k_e_y=1545038912750663042409&ich_t_y_p_e=1&ich_d_i_s_k_i_d=3&ich_u_n_i_t=1 (accessed on 12 March 2015).
46. Neitsch, S.; Arnold, J.; Kiniry, J.; Williams, J.; King, K. *Soil and Water Assessment Tool Theoretical Documentation*, *Version 2000*; Water Resource Institute: College Station, TX, USA, 2002.

47. Douglas-Mankin, K.; Srinivasan, R.; Arnold, J. Soil and water assessment tool (swat) model: Current developments and applications. *T. Asabe* **2010**, *53*, 1423–1431.
48. Rahman, M.; Bolisetti, T.; Balachandar, R. Effect of climate change on low-flow conditions in the ruscom river watershed, Ontario. *T. Asabe* **2010**, *53*, 1521–1532.
49. Wu, F.; Zhan, J.; Güneralp, İ. Present and future of urban water balance in the rapidly urbanizing Heihe River basin, northwest China. *Ecol. Model.* **2014**, in press.
50. Chiang, L.; Chaubey, I.; Gitau, M.W.; Arnold, J.G. Differentiating impacts of land use changes from pasture management in a ceap watershed using the swat model. *T. Asabe* **2010**, *53*, 1569–1584.
51. Flügel, W.A. Delineating hydrological response units by geographical information system analyses for regional hydrological modelling using PRMS/MMS in the drainage basin of the river Bröl, Germany. *Hydrol. Process.* **1995**, *9*, 423–436.
52. Cohen, J. A coefficient of agreement for nominal scales. *Educ. Psychol. Meas.* **1960**, *20*, 37–46.
53. Congalton, R.G. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sens. Environ.* **1991**, *37*, 35–46.
54. Monserud, R.A.; Leemans, R. Comparing global vegetation maps with the kappa statistic. *Ecol. Model.* **1992**, *62*, 275–293.
55. Hagen-Zanker, A.; Lajoie, G. Neutral models of landscape change as benchmarks in the assessment of model performance. *Landsc. Urban. Plan.* **2008**, *86*, 284–296.
56. Saraux, A.; Tobón, G.J.; Benhamou, M.; Devauchelle-Pensec, V.; Dougados, M.; Mariette, X.; Berenbaum, F.; Chiocchia, G.; Rat, A.C.; Schaeverbeke, T. Potential classification criteria for rheumatoid arthritis after two years: Results from a french multicenter cohort. *Arthritis Care Res.* **2013**, *65*, 1227–1234.
57. Tolson, B.A.; Shoemaker, C.A. Cannonsville reservoir watershed swat 2000 model development, calibration and validation. *J. Hydrol.* **2007**, *337*, 68–86.
58. Zhang, X.; Srinivasan, R.; Bosch, D. Calibration and uncertainty analysis of the swat model using genetic algorithms and bayesian model averaging. *J. Hydrol.* **2009**, *374*, 307–317.
59. Arnold, J.; Moriasi, D.; Gassman, P.; Abbaspour, K.; White, M.; Srinivasan, R.; Santhi, C.; Harmel, R.; van Griensven, A.; van Liew, M. Swat: Model use, calibration, and validation. *T. Asabe* **2012**, *55*, 1491–1508.
60. Neitsch, S.; Arnold, J.; Kiniry, J.E.A.; Srinivasan, R.; Williams, J. *Soil and Water Assessment Tool User's Manual Version 2000*; U.S. Department of Agriculture and Agricultural Research Service: Temple, TX, USA, 2001.
61. Abbaspour, K.C.; Yang, J.; Maximov, I.; Siber, R.; Bogner, K.; Mieleitner, J.; Zobrist, J.; Srinivasan, R. Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. *J. Hydrol.* **2007**, *333*, 413–430.
62. Nash, J.; Sutcliffe, J.V. River flow forecasting through conceptual models part I—A discussion of principles. *J. Hydrol.* **1970**, *10*, 282–290.
63. Motovilov, Y.G.; Gottschalk, L.; Engeland, K.; Rodhe, A. Validation of a distributed hydrological model against spatial observations. *Agr. Forest Meteorol.* **1999**, *98*, 257–277.
64. Huang, M.; Zhang, L.; Gallichand, J. Runoff responses to afforestation in a watershed of the Loess Plateau, China. *Hydrol. Process.* **2003**, *17*, 2599–2609.

65. Yin, R.; Rothstein, D.; Qi, J.; Liu, S. *Methodology for An Integrative Assessment of China's Ecological Restoration Programs*; Springer: Berlin, German, 2009.
66. Liu, Z.; Lang, N.; Wang, K. Infiltration Characteristics under Different Land Uses in Yuanmou Dry-Hot Valley Area. In *Proceedings of the 2nd International Conference on Green Communications and Networks 2012 (GCN 2012): Volume 1*; Yang, Y., Ma, M., Eds.; Springer: Berlin, Germany, 2013; Volume 223, pp. 567–572.
67. Loch, R. Effects of vegetation cover on runoff and erosion under simulated rain and overland flow on a rehabilitated site on the meandu mine, Tarong, Queensland. *Soil Res.* **2000**, *38*, 299–312.
68. Li, Y. Effects of forest on water circle on the Loess Plateau. *J. Nat. Resour.* **2000**, *16*, 427–432.
69. Walker, J.; Bullen, F.; Williams, B. Ecohydrological changes in the murray-darling basin. I. The number of trees cleared over two centuries. *J. Appl. Ecol.* **1993**, *30*, 265–273.
70. Li, Z.; Liu, W.; Zhang, X.; Zheng, F. Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *J. Hydrol.* **2009**, *377*, 35–42.
71. Scanlon, B.R.; Reedy, R.C.; Tachovsky, J.A. Semiarid unsaturated zone chloride profiles: Archives of past land use change impacts on water resources in the southern high plains, United States. *Water Resour. Res.* **2007**, *43*, W06423.
72. Lioubimtseva, E.; Cole, R.; Adams, J.; Kapustin, G. Impacts of climate and land-cover changes in arid lands of central Asia. *J. Arid. Environ.* **2005**, *62*, 285–308.
73. Guo, H.; Hu, Q.; Jiang, T. Annual and seasonal streamflow responses to climate and land-cover changes in the Poyang Lake Basin, China. *J. Hydrol.* **2008**, *355*, 106–122.
74. Wu, F.; Zhan, J.; Su, H.; Yan, H.; Ma, E. Scenario-based impact assessment of land use/cover and climate changes on watershed hydrology in Heihe River Basin of northwest China. *Adv. Meteorol.* **2014**, in press.