https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences
Open Access
Discussions

Effects of Urbanization on the water cycle in the Shiyang River Basin: Based on stable isotope method

Rui Li[a,b], Guofeng Zhu[a,b,*], Siyu Lu[a,b], Liyuan Sang[a,b], Gaojia Meng[a,b], Longhu Chen[a,b], Yinying Jiao[a,b], Qinqin Wang[a,b]

Affiliations:

[a] College of Geography and Environmental Science, Northwest Normal University, Lanzhou 730070, Gansu, China

[b] Shiyang River Ecological Environment Observation Station, Northwest Normal University, Lanzhou 730070, Gansu, China

** Corresponding author. Email: zhugf@nwnu.edu.cn.*

Abstract: The water cycle has been hampered by urban development and the changes it has made to natural surfaces, especially in arid regions with scarce water supplies. Urbanization has a significant hydrological impact because of the high water demands of urban populations and economic factors. We set up an observational system close to Wuwei City, which is situated in the Shiyang River Basin, to research the effects of urbanization on isotope dynamics within the basin. We sought to clarify any perceptible changes in isotopic patterns by the methodical collecting and analysis of water samples from various water sources. According to our research, landscape dams in urban areas have a substantial impact on the evaporation and penetration of surface water. We have also observed a weaker connection between precipitation, surface water, and groundwater in urban areas, as compared to non-urban regions. Also, our research has demonstrated that metropolitan areas have a quicker catchment cycle and a quicker conversion of rainfall to runoff. These results have important ramifications

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences Discussions
Open Access

for managing water resources and urban planning since they offer important insight into the hydrological dynamics of urban areas. In dry regions, where care must be made to the loss of water resources owing to landscape dam evaporation, the barrier impact of urbanization on water body connection is particularly severe.

Keywords: Urbanization; Water cycle; Stable isotopes; River Connectivity

1 Introduction

According to the "2020 Global Cities Report," urban areas are currently home to more than half of the worldwide people, which amounts to 56.2%. This pattern is expected to continue over the course of the next decade, culminating in an urbanization rate of 60.4% by the year 2030. In addition, the study forecasts that by the year 2050, approximately seventy percent of the world's population would reside in urban areas (United Nations, 2019; UN-Habitat, 2020; Chen et al., 2020). Unlike other regions, urban regions have a substantial influence on the hydrological system, resulting in significant consequences on water balance and the water cycle (Gillefalk and Tetzlaff et al., 2021). To meet the diverse household and industrial requirements in metropolitan areas, where the population is concentrated and water demands are high, a complex interplay between natural and manmade components of the water cycle is required. These components include both natural features such as streams and groundwater, as well as human-made systems like drinking water and drainage networks (Gessner et al., 2014). Urbanization has led to a dramatic increase in water consumption, significantly impacting groundwater quality (Cho et al., 2009), affecting the environment and water availability (Bhaskar et al., 2015). Rapid urbanization will

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

seriously pressure the structure, function and water quality degradation of watershed ecosystems (Grimm et al., 2008; Sun and Lockaby, 2012; Sun and Caldwell, 2015).

Urbanization's effects on watershed hydrology and the related processes have complex and varying consequences (Caldwell et al., 2012; Martin et al., 2017). In the past few decades, with the continuous acceleration of urbanization, human activities in urban areas have become more frequent, and the hydrological effects of urbanization have become more intense, attracting widespread attention worldwide (Salvadore and Bronders et al., 2015). The rise of impervious surfaces in urbanized regions increases the rate of urban water runoff, which raises the danger of urban floods (Wing et al., 2018). In addition, high-intensity human activities have led to increased discharge of domestic sewage and industrial wastewater, deteriorating water quality and ecological environment (Pickett et al., 2011). Hence, study into how human activities alter the features of river runoff and the water cycle within a basin is essential for the prudent use and sustainable development of water resources.

Isotopes that are stable of hydrogen and oxygen are very useful tools for investigating hydrological issues that are connected to surface water and groundwater sources (Gat, 1996, Tetzlaff et al., 2007, Šanda et al., 2017). Researchers have been conducting studies using stable isotopes as tracers over the course of the past few years in order to explore the impact that urbanization has had on the water cycle. Urbanization has the potential to trigger and intensify convective activity and warm-season rainfall in both urban areas and their surrounding regions (Burian and Shepherd, 2005). Researchers generally agree that urbanization reduces depressions

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences Discussions

on the underlying surface, weakens water permeability and increases runoff. At the same time, the lower roughness of the underlying surface shortens the confluence time (Oudin and Salavati et al., 2018; Guan and Sillanpää et al., 2016). Moreover, against the backdrop of swift urbanization, the swift proliferation of urban regions has resulted in a sharp surge in impermeable areas, alterations to regional microclimates, and the erection of a vast number of infrastructures (including overpasses, subways, and so on), all of which have significantly impacted the water cycle process in urban areas (Jacobson, 2011; Westra et al., 2014). The complex connection between the permeable and impermeable zones influences the surface confluence processes (Bruwier and Maravat et al., 2020). The construction of urban water conservation projects, such as rubber dams and pumping stations, also affects the confluence process of urban areas to a certain extent (Zhu et al., 2021). Limited long-term and continuous monitoring has hampered accurate depiction of urbanization's spatiotemporal effects on watershed hydrology. Furthermore, the scientific research till lacks sufficient research on arid regions that heavily depend on mountain river runoff for sustenance and development, highlighting a significant knowledge gap.

The Shiyang River (SYR) Basin, situated in the parched expanse of Northwest China, represents a classic case of an inland river system. The urban area of Wuwei City, where the river flows through, has a population of 1.46 million, and the annual runoff of the river is 517 million/m^3. Since 2017, a comprehensive observation system has been established in the SYR Basin, and stable isotope observations and hydrometeorological observations have been carried out on surface water, shallow

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

groundwater and rainfall. The following problems are proposed to be solved: (1) An examination of the mechanisms underlying evaporation and infiltration of surface water within urban aquatic ecosystems; (2) Assessing the effects of urbanization on water body connectivity through a comprehensive analysis; (3) The influence of urbanization on the precipitation-runoff process is analyzed. Isotopes are utilised in this study to examine the hydrological consequences of urbanization on a localized scale. This provides us with essential information on how to maintain and manage the water resources found in inland river basins, which is especially useful in light of the fact that the rate of urbanization is growing.

2 Systems, Data, and Methods of Observation

The SYR Basin is located in Gansu Province, China, to the east of the He-xi Corridor. Its coordinates are 101°22' ~ 104°16' E and 36°29' ~ 39°27' N. The SYR Basin is bounded to the west by the Wushaoling Mountain and to the north by the foothills of the Qilian Mountain (Zhu et al., 2019). The basin in question is situated within the continental temperate belt, characterized by a parched climate and diverse topography. Annual precipitation hovers within the range of 100 to 600 mm, while pan evaporation levels exhibit greater variability, ranging from 700 to 2600 mm annually. The majesty of the Qilian Mountains is where the SYR begins its journey, and the Qilian Mountains are the source of its eight main tributaries. The SYR is principally supported by the convergence of precipitation, snowmelt, and glacier runoff (Wei et al., 2013).

The Wuwei City is crossed by four important rivers, namely the Xiying, Zamu,

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Huangyang and Jinta, which cover a catchment area of 3986 km^2. As the principal water source for the entire region, the SYR Basin is one of the most highly utilized inland river basins in terms of water resource development and consumption worldwide. The dams in the SYR basin are predominantly situated in close proximity to the urbanized regions of Liangzhou District, located within Wuwei City. Liangzhou District, situated in the middle of the basin, boasts of a relatively high population density and a notable commercial concentration. At the turn of the millennium, Wuwei City only boasted a paltry five landscape dams positioned on its rivers. As of 2019, this figure has surged dramatically, with a staggering total of 51 urban landscape dams now gracing both urban and peri-urban areas of the city. These dams are primarily composed of man-made landscape waterfalls and rubber dams, fulfilling their core function of creating public landscape water bodies within the urban expanse. (Zhu et al ., 2021).

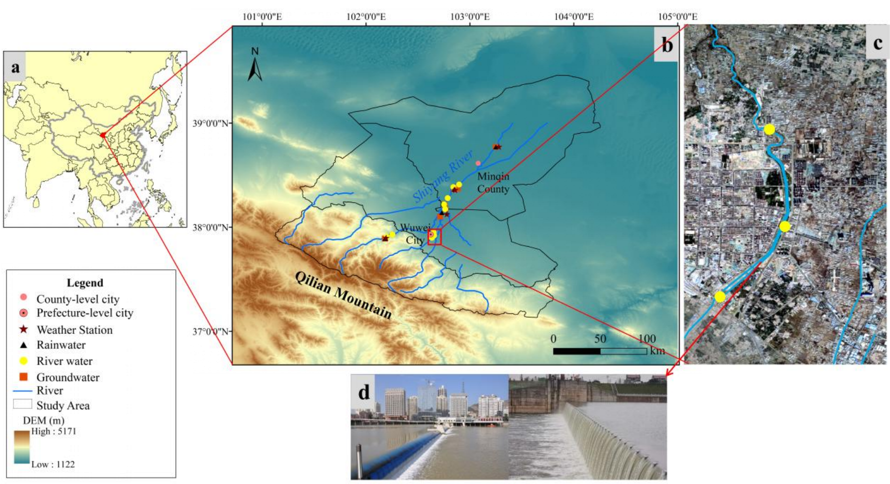

Figure 1 (a) The location of the study area, (b) Comprehensive observation system for the study area, (c) Urban surface water sampling points (from © Google Maps), (d)

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Common urban landscape dams in SYR Basin.

3 Sampling and data analysis

Continuous sampling in the SYR Basin was carried out from April 2017 to March 2020, different water bodies were sampled, and we collected a total of 943 samples from 24 sampling points (Table 1). The sampling location ought to be selected such that it is physically possible to go as close to the middle of the river as possible, with the goal of minimizing the impact of areas with standing water and sewage. Samples of groundwater bodies were obtained at 7 sampling stations around the basin. The automated weather station was used to measure meteorological factors such as temperature and relative humidity while collecting precipitation samples. Water samples were sealed in high-density polyethylene bottles to avoid evaporation and leakage during transit and storage, precipitation samples were collected using weather station standard rain gauges. These samples were then frozen and wrapped with plastic tape.

Table 1 Basic information on precipitation, surface water and groundwater sampling sites

Parameter	**Sampling Point**	**Number**	**Sampling period**	**Collection Channels**
Precipitation	P1, P2, P3, P4, P5,P6, P7,	387	Precipitation events	Rain tube collection
Surface Water	S1,S2,S3,S4,S5,S6, S7, S8, S9, S10	270	Monthly	Sampling in river water
Groundwater	G1、G2、G3、G4、G5、G6、G7	189	Monthly	Sampling from wells

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Analysis of the water samples is conducted through liquid water isotope analysis utilizing the DLT-100 (Los Gatos Research) in the Stable Isotope Laboratory at Northwest Normal University. Each water sample and isotope standard are injected six times in succession to assure reliable findings, with the first two injection values eliminated and the average of the last four injections used for final analysis, thereby avoiding any potential isotope analysis memory effect. The isotope measurements were denoted by the symbol "δ," which indicates the deviation in thousandths from the Vienna Standard Mean Ocean Water:

$$\delta_{\text{sample}}(‰) = [(\frac{R_s}{R_{v-smow}}) - 1] \times 1000 \qquad (1)$$

where R_s is the ratio of $^{18}O/^{16}O$ or $^{2}H/^{1}H$ in the collected sample, $Rv\text{-}smow$ is the ratio of $^{18}O/^{16}O$ or $^{2}H/^{1}H$ of the Vienna standard sample, and the analytical accuracy of δD and $\delta^{18}O$ is ±0.6‰ and ±0.2‰, respectively.

3 Analysis methods

3.1 Calculation and indication of deuterium excess (*d-excess*)

Dansgaard (1964) introduced the concept of deuterium excess (*d-excess*) as the difference in isotopic composition between global precipitation and the Vienna Standard Mean Ocean Water (V_{SMOW}) reference water, which corresponds to a value of 10‰. This parameter reflects the average isotopic composition of air masses associated with precipitation and is widely used to identify atmospheric source regions (Deng et al., 2016). *d-excess* was proposed by Dansgaard (Dansgaard, 1964) and is defined as:

$$d\text{-}excess = \delta D - 8\delta^{18}O \qquad (2)$$

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences Discussions
Open Access EGU

3.2 Calculation of evaporation loss of surface water

The loss of surface water through evaporation and the resulting fluctuations in water levels of rivers, lakes, and wetlands are key aspects of the terrestrial water cycle that merit significant attention (Gammons et al., 2006; Hamilton et al., 2005). Evaporation is the primary mechanism of water loss in the water cycle. For river water in dry regions and urban river water that flows slowly due to manmade constraints, evaporation cannot be ignored. Thus, it is vital to address the alteration of urban landscape dam water caused by non-equilibrium isotope fractionation during evaporation. The provided formula (3) can be used to estimate the rate of evaporative water loss from the body of water in question (Skrzypek et al., 2015):

$$f = 1 - \left[\frac{(\delta - \delta^{*})}{(\delta_0 - \delta^{*})} \right]^{\frac{1}{m}} \tag{3}$$

The variables in the equation are as follows: f represents the ratio of water lost to evaporation, δ denotes the measured values of the water body located in the urban dam area of Wuwei City, situated in the middle reaches of the SYR and δ_0 represents the initial value of the hydrogen and oxygen stable isotope of the water body. It is widely assumed that the point of intersection between the local meteoric water line (LMWL) and the local evaporation line (LEL) represents the average isotopic composition of the input water body within the basin (Gibson et al., 2005). In the current investigation, the intersection point marked by $\delta^{18}O$ = -7.24 and δD = -46.9 has been designated as the δ_0 value, while δ^* denotes the maximum isotope enrichment factor and m corresponds to the enrichment slope. The calculation of the above parameters in this paper is realized in Hydrocalculator software (Skrzypek et al., 2015) (http://hydrocalculator.gskrzypek.com). According to studies (Qian et al., 2007), it is more accurate to use δ^{18}O when calculating the evaporation loss ratio, so this study calculates the *f* value of SYR water using δ^{18}O value.

3.3 Periodic regression analysis and The mean residence time (MRT)

Precipitation and surface water samples were collected from a variety of locations across Slovenia, as well as from Belgrade, Serbia, for the Sava and Danube rivers. Seasonal fluctuations in δ^{18}O levels were analyzed using periodic regression analysis to determine how these levels changed over time. This method entailed fitting seasonal sine wave curves to annual δ^{18}O variations using least squares optimization (Rodgers et al., 2005):

$$\delta^{18}O = \delta^{18}O_{ave} + A\cdot\left[\cos(c\cdot t-\theta)\right] \tag{4}$$

The modelled $\delta^{18}O$ values and the mean weighted annual measured $\delta^{18}O_{ave}$ values were both utilized in the analysis of seasonal fluctuations in δ^{18}O levels. Additionally, the measured δ^{18}O annual amplitude (A), the radial frequency of annual fluctuations (c), and the time in days after the start of the sampling period (t) were also considered in this analysis. Furthermore, the phase lag or time of the annual peak δ^{18}O in radians (θ) was determined through this approach.

An exponential model was used for the purpose of estimating the mean residence time (MRT). This model operates on the presumption that precipitation inputs quickly mix with resident water. In order to do this, the following equation was used (Maloszewski et al., 1983; Rodgers et al., 2005):

$$MRT = c^{-1} \cdot \left[(A_{Z2} / A_{Z1})^{-2} - 1 \right]^{0.5} \tag{5}$$

The amplitude of precipitation (A_{Z1}), the amplitude of the surface water outputs (A_{Z2}), and the radial frequency of the annual fluctuation (c) as defined in Eq. (4) were taken into consideration to estimate the mean residence time (MRT).

4 Results

4.1 Spatiotemporal distribution of isotopes in different water bodies

The isotopes values of the surface water in the SYR Basin show a clear enrichment from upstream to downstream when viewed from space. It is worth noting that landscape dams and reservoirs in urban areas alter this pattern significantly, producing markedly higher isotopic compositions of surface water around such structures (Fig. 2). To be more specific, the surface water throughout the entire basin had average isotope values that were lower than those of the sampling points in the dams region, which had values that were greater. In addition, the dams slowed the flow of the river, which led to an increase in the amount of surface water that evaporated from the area around the dams, this resulted in isotope enrichment of the river water. Notably, these values exhibit spatial and temporal variability, with the largest δD and δ^{18}O values observed in river water, and the lowest in groundwater.

Table 2 Isotopic composition statistics of surface water in SYR Basin

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Sampling Point	$\delta^{18}O$			δD			*d-excess*		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
S1	-9.35	-9.86	-9.06	-57.16	-59.46	-52.47	17.2	12.33	23.91
S2	-9.22	-10.02	-8.78	-56.62	-63.85	-10.02	16.46	15.53	19.28
S3	-7.74	-9.03	-7.75	-49.84	-50.76	-46.66	15.42	13.59	19.48
S4	-7.29	-8.79	-7.65	-46.22	-53.29	-46.26	14.9	11.01	18.03
S5	-7.43	-9.11	-5.53	-48.84	-56.66	-40.62	14.29	14.21	29.72
S6	-9.54	-10.43	-8.29	-60.14	-75.43	-54.40	14.31	10.26	17.62
S7	-9.04	-9.54	-8.21	-54.23	-70.04	-48.03	16.54	12.81	21.16
S8	-9.15	-10.35	-8.64	-56.37	-63.35	-52.22	16.84	14.56	19.54
S9	-8.41	-9.70	-6.02	-53.95	-65.33	-45.54	13.33	12.31	19.50
S10	-8.18	-8.84	-6.58	-51.92	-58.05	-45.39	13.48	12.21	21.72

To be more specific, over the course of time, these values shift seasonally from spring to autumn (Table 2, Fig. 3). There was a range of values from -75.43‰ to -40.62‰ for the δD values of surface water, with an average of -53.53‰. The $\delta^{18}O$ values display a varied range, from -10.43‰ to -5.53‰, with an average of -8.54‰, whereas the *d-excess* values demonstrate variability ranging from 10.26‰ to 29.72‰, with 15.28‰ as the average value. A broad spectrum of δD values are observed during the summer season, ranging from -61.27‰ to -31.16‰, with an average -48.90‰. Meanwhile, $\delta^{18}O$ values fluctuate between -9.52‰ and -3.41‰, with an average -8.12‰. The phenomenon that was observed can be traced back primarily to the aftereffects of the Hongyashan Reservoir built downstream. Because the reservoir has such a large capacity for water retention, it causes significant amounts of river water to evaporate, which ultimately results in a discernible enrichment of the isotopic composition.

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences
Discussions

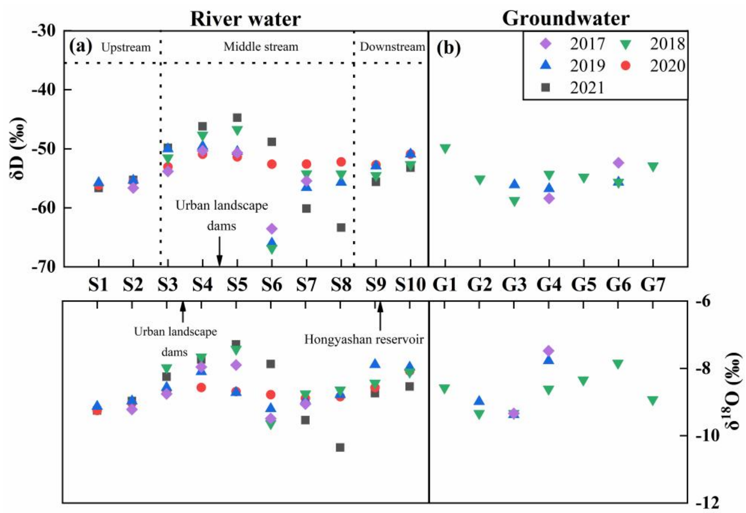

Figure 2 Longitudinal variation of δD and δ^{18}O in river water and groundwater in the SYR Basin.

4.2 The Relationship between δD and δ^{18}O values

As shown by the linear fitting equation $\delta D = 7.52\delta^{18}O+7.58$, there is a significant linear positive correlation (R^2 = 0.96) between δD and δ^{18}O in atmospheric precipitation in the SYR Basin (Fig. 3). It is clear that the slope (7.52) and intercept (7.58) of the local meteoric water line (LMWL) are smaller than the global geteoric water line (GMWL), which can be attributed to the basin's location in an inland arid region, where precipitation disturbances are less frequent and evaporative fractionation of precipitation is stronger. The majority of surface water and groundwater sampling points are located close to the local meteoric water line, which reveals that precipitation is the principal source of surface water replenishment according to the findings of an analysis of these two types of sample locations. The SYR Basin surface water samples that were collected exhibited a linear regression of

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences Discussions

δD=5.63δ^{18}O-6.11, which revealed a spatial variation in isotopic composition from upstream to downstream. Where the river water line (RWL) intercept and slope show a trend that is first decreasing and then increasing as one moves from upstream to downstream. This demonstrated the presence of significant isotopic differences in the water. Moreover, the groundwater samples analyzed in the study displayed a linear regression of δD=6.3δ^{18}O-2.15. The decrease in slope and intercept of the LMWL and GMWL in the SYR Basin is suggestive of significant evaporative enrichment of the surface water, with precipitation from the atmosphere serving as the primary source of recharge. This is supported by the fact that the LMWL and GMWL have decreased.

Isotopic analysis of groundwater samples reveals a range of δD and δ^{18}O values spanning from -50.7‰ to -71.9‰ and from -7.23‰ to -10.4‰, respectively. Such values provide insights into groundwater origin, recharge source, transit distance, and subsurface residence time, and facilitate the identification of potential changes in recharge patterns or contamination sources. In addition, the distribution of groundwater line (GWL) exhibits a striking similarity to that of river water line (RWL) and local meteoric water line (LMWL), as depicted in Fig. 3. This observation strongly suggests a replenishment relationship among these hydrological components.

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

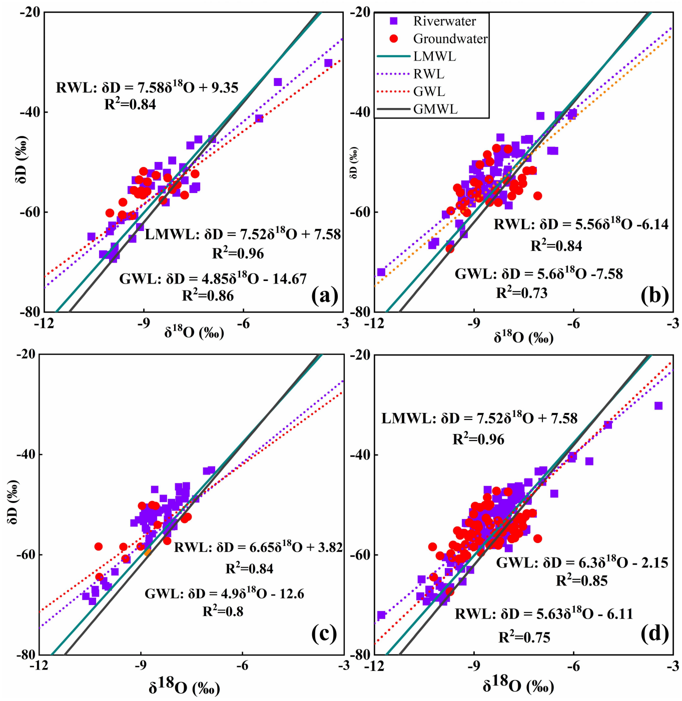

Figure 3 Relationship between δD and $\delta^{18}O$ in various water bodies in the SYR Basin during different seasons (a) Spring, (b) Summer, (c) Autumn, (d) The contrast between RWL, GWL, LMWL and GMWL throughout the sampling period

4.3 Temporal and spatial variation of surface water evaporation loss in the urban area of Wuwei

In addition to being an essential part of the hydrological cycle, evaporation is widely recognized as one of the most significant factors driving climate change in semi-arid regions and in telluric ecosystems (Gibson et al., 2002; Gibson and Edwards, 2002). An obviously spatial and temporal fluctuation can be seen in the amount of surface water that is lost to evaporation in the upper mountain area as well as the intermediate urban area of the SYR basin (Fig. 4). Analyzed from a time-varying

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences Discussions
Open Access

perspective, there is significant seasonal variation in surface water evaporation losses both in the upstream mountainous region and the midstream urban area of Wuwei, with the highest rates occurring during summer and the lowest during winter (Fig.4). Additionally, a spatial comparison reveals that surface water evaporation losses in the midstream urban area of Wuwei are significantly greater than those in the upstream mountainous area.

The discrepancy in evaporation losses between these regions can be attributed to the presence of numerous urban landscape dams located in the midstream of the SYR, which have altered the natural state of the river and created a semi-stagnant state of surface water. Meanwhile, the water bodies in the dams catchment area remain relatively stable, and their surface water recharge source primarily originates from the upstream river confluence. Furthermore, the flat and open topography of the area exacerbates water evaporation losses.

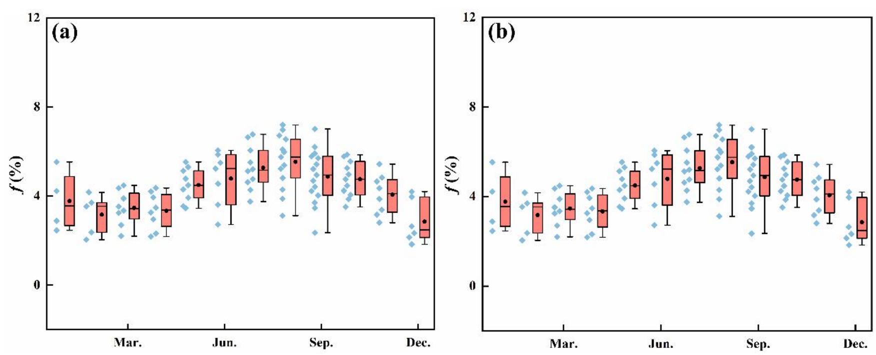

Figure 4 Evaporation losses from surface water in different areas of the SYR (a) Upper reaches mountainous area, (b) Middle reaches urban areas.

5 Discussion

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences
Open Access
EGU
Discussions

5.1 Effects of Urbanization on the Rainfall-Runoff Process

Fig. 5 depicts the regression model of rainfall events in the SYR Basin, represented by a sine wave, and the fitting of surface water δ^{18}O across the research season. The δ^{18}O levels of precipitation reported in the SYR Basin have an excellent regularity (R^2=0.46) and a seasonal patterns trend that effectively depicts the influence of the monsoon climate on the local environment. Seasonal variations are seen in the generally steady δ^{18}O and δ^{18}O values of the upstream water. These results indicate that the predominant component of the river water is the baseflow resulting from recent precipitation runoff. Throughout the duration of the study, the majority of the lowest δ^{18}O values in the 10 surface water sample points were recorded during the winter, whilst the highest values were recorded during the summer. These trends coincide with both the temporal variation of precipitation isotopes in the SYR Basin, indicating that precipitation input is the underlying cause of isotope changes in river water. Nevertheless, variations in the isotopes of river water differ in range across various regions within the SYR Basin, with significant variation in the degree of fit for the regression curve. The fitting degree of surface water in the upper and lower reaches is relatively low (R^2=0.37, R^2=0.28, R^2=0.23), implying limited seasonal isotopic variability in these regions. The midstream surface water exhibits a notably higher degree of conformity as compared to its upstream and downstream counterparts (R^2=0.38, R^2=0.48, R^2=0.32, R^2=0.78, R^2=0.54, R^2=0.48). Moreover, the isotopic composition of surface water throughout this area exhibits notable cyclic variations.

Possible reasons for the disparity in isotopic periodicity across various regions could be attributed to local water management systems, topographical characteristics, and urban development. In the upper SYR Basin, the primary source of surface water originates from alpine ice and snow melt, characterized by a comparatively stable isotopic composition with minimal seasonal fluctuations. In the midstream of the SYR Basin, the expansion of built-up and cultivated areas has led to a significant rise in surface runoff during the rainy season, causing surface water to exhibit a periodic trend comparable to that of precipitation. Moreover, the upstream operation of reservoirs and hydropower stations has resulted in a reduced river speed, increasing the proportion of rainfall in the runoff constituents as a result of the gradually increased extent of impermeable surfaces. Conversely, the relatively even topography of the midstream of the SYR Basin, as opposed to the higher altitude of the upstream, facilitates the formation of a larger catchment area and consequently, greater runoff formation in this region.

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

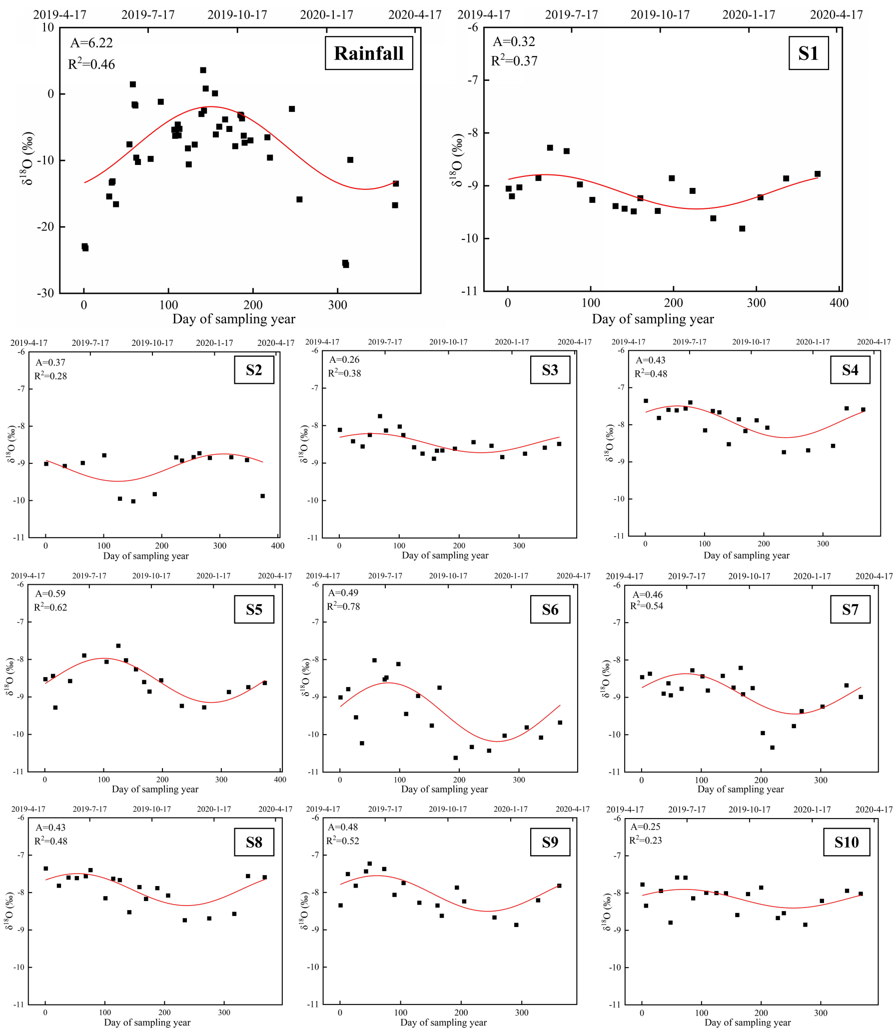

Figure 5 Fits the annual regression model of $\delta^{18}O$ in SYR Basin precipitation and river water (time: 2019/4/17—2020/4/23; S1-S10 are surface water sampling points).

Brooks et al. (2014) have discovered a significant adverse correlation between catchment areas and lake water residence time. In the SYR Basin, a gradual reduction in catchment area from the upstream to the midstream urban areas has been observed, leading to a progressive shortening of Mean Residence Time (MRT) of water (Fig. 6b). Urbanization and changes in topography could also account for the observed phenomenon. Rodgers et al. (2005) found that land cover plays a vital role in influencing Mean Residence Time (MRT) in a mesoscale watershed. Additionally, soil permeability displays a strong negative correlation with MRT, as reported by Rodgers et al. (2005). In the midstream of the SYR Basin, characterized by a higher level of urbanization, a substantial portion of the land is covered by impervious surfaces. This, in turn, expedites the conversion of precipitation into runoff, leading to a shorter Mean Residence Time (MRT) of water. Conversely, the downstream regions, with relatively lower urbanization levels and primarily used for agriculture, experience a slower conversion of precipitation to runoff, hence resulting in longer MRTs for water in these areas.

5.2 Effects of Water Conservancy Projects in Urban Areas on Isotope Dynamics

Recent studies have suggested that the development of dam-reservoir systems may result in river fragmentation and modifications in flow regimes in terms of their volume, frequency, and duration. Furthermore, chemical-containing nutrient migration, such as phosphorus, may occur during sediment movement, resulting in widespread eutrophication problems (Yang et al., 2007; Duan et al., 2019). As of 2019, a total of 51 urban landscape dams, primarily consisting of artificial landscape waterfalls and rubber dams, have been constructed in and around Wuwei city (Zhu et al., 2021). The presence of dams can lengthen the residence period of surface water, leading in the concentration of heavy isotopes in the water. This damping effect has been observed in numerous dammed rivers across the globe, including the Rio Grande in the southwestern United States (Vitvar et al., 2007) and the Orange River in

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences
Discussions

southern South Africa (Talma et al., 2012), as evidenced by isotopic tracers. In the metropolitan coast of Wuwei, a number of landscape dams have led to the accumulation of isotopic tracers in the surface water. The results indicate that the δD and δ^{18}O levels of the surface water at the outflow of Wuwei City are greater than those at the inflow. (Fig. 2). Moreover, the influence of evaporation on isotopic composition should not be overlooked, as it can lead to a decrease in *d-excess* values (Peng et al., 2012). Consistent with previous studies (Wang et al., 2019), we observed that the *d-excess* of influent water was higher than that of reservoir water. This observation further supports the accumulation of heavy H-O isotopes in the surface waters of the dam areas, as shown in Fig. 6a.

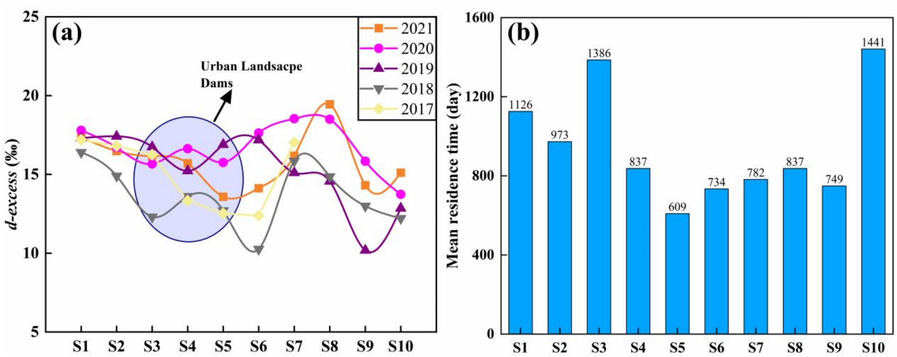

Figure 6 (a) The longitudinal variation of the surface water *d-excess* of the SYR, (b) The longitudinal variation of the surface water MRT of the SYR.

5.3 Effects of Urbanization on the Water Cycle of Watersheds

Alterations in the local microclimate have an effect on the processes of precipitation and evapotranspiration, and these changes have a significant impact on the water cycle in urban areas. The underlying surface conditions become even more

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

complicated as a result of urbanization, which then leads to intricate flow generation and confluence patterning. The infiltration process is hindered in urban areas due to urbanization, which further exacerbates the runoff generation mechanism. Urbanization significantly increases the surface's impermeability. A comprehensive study of rainfall-runoff responses using periodic regression uncovered a significant periodicity in the SYR Basin's river water across all of its regions. This periodicity was found in the SYR Basin's river water. The high level of urbanization in the midstream shortens the average residence time, also known as MRT, and increases the proportion of precipitation that is carried away as runoff.

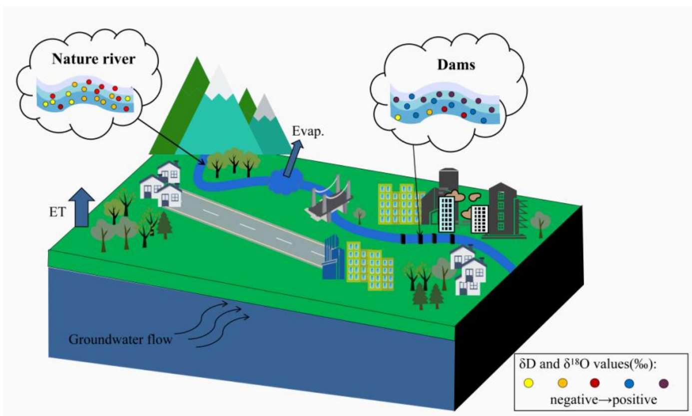

Figure 7 Schematic diagram of the effect of urbanization on river isotope dynamics.

Urbanization has had a profound and swift impact on the water environment of cities, often causing an array of water-related problems. The development of impermeable surfaces, such as parking areas, roofs, roads, and sidewalks, has ultimately results in a surge of runoff and an increase in the number of pathways by which pollutants are transported from the landscape to water bodies (Wilson and Weng, 2010). In the alternative, agricultural activities can also make a contribution to

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

the deterioration of water quality through the use of chemical fertilizers, pesticides, herbicides, and animal waste on farmland to fulfill the dietary demands of a growing population. This is done in an effort to keep up with the demand for food that is being generated by the growing population. These contaminants have the potential to make their way into nearby bodies of water, which, when combined with the direct and indirect effects of urbanization, can result in a deterioration of water quality (Yu et al., 2013). The SYR Basin is notable for its innovative water resource management and highest utilization rate in China. Within the basin, the Liangzhou District is of particular interest because it is an artificial oasis with a high population density and substantial water demands. Our research demonstrates that the residence time of water in urban areas is significantly shorter than in natural settings, resulting in accelerated river runoff. This may accelerate the river's eutrophication and increase salinity levels.

Implementing effective water resource management in the SYR Basin is essential for furthering the region's sustainable water and environmental development. This involves the formulation of water-use rules that reduce possible safety, environmental, and health problems and encourage the ecological expansion of the region. To guarantee the long-term viability of the region's water resources and ecology, governments and interested parties must prioritize the execution of these measures.

6 Conclusions

Based on the stable isotope data of different water bodies in the SYR Basin, this study examined the characteristics and impacting components of stable hydrogen and oxygen isotopes within water bodies. The results indicate that the surface water isotope values in the SYR basin show a gradual spatial enrichment from upstream to downstream, with the highest surface water isotope enrichment around the urban area of Wuwei. This is primarily due to the construction of a large number of landscape dams in the urban area, which slowed water flow and increased water evaporation. Moreover, urban landscape dams reduce the flow rate of urban rivers, resulting in the semi-blockage of surface water bodies. In urban areas, surface water evaporation losses are greater than in other natural river areas due to the flat and open terrain and increased water catchment area. Throughout the year, surface water evaporation loss in the Wuwei urban landscape dam area is greatest in the summer. The approach of periodic regression analysis was used to evaluate the differences in rainfall-runoff processes in various places, demonstrating that the periodicity of river water varies considerably across the basin. The projected average residence period of surface water falls gradually from the higher to middle portions of a river. The input of precipitation to river water increases steadily from upstream to downstream, illustrating the accelerated rainfall-runoff process caused by an increase in impervious surface area and urban drainage system. The metropolitan landscape's dams and big reservoirs have a significant impact on the local hydrological system and produce a considerable evaporation effect.

Acknowledgements

This research was financially supported by the National Natural Science Foundation of China (41971036, 41867030).

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Hydrology and Earth System Sciences
Discussions

Data availability Statement

The isotopic data that support the findings of this study are openly available in Zhu, Guofeng (2022), "Stable water isotope monitoring network of different water bodies in SYR Basin, a typical arid river in China", Mendeley Data, V1, doi: 10.17632/vhm44t74sy.1

Competing Interests

We undersigned declare that this manuscript entitled "Effects of Urbanization on the water cycle in the SYR Basin: Based on stable isotope method" is original, has not been published before and is not currently being considered for publication elsewhere.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Reference

Baker, A.: Land Use and Water Quality, in: Encyclopedia of Hydrological Sciences, edited by: Anderson, M. G. and McDonnell, J. J., John Wiley & Sons, Ltd, Chichester, UK, hsa195, https://doi.org/10.1002/0470848944.hsa195, 2005.

Bhaskar, A. S. and Welty, C.: Analysis of subsurface storage and streamflow generation in urban watersheds, Water Resour. Res., 51, 1493 – 1513, https://doi.org/10.1002/2014WR015607, 2015.

Brooks, J. R., Gibson, J. J., Birks, S. J., Weber, M. H., Rodecap, K. D., and Stoddard, J. L.: Stable isotope estimates of evaporation : inflow and water residence time for lakes across the United States as a tool for national lake water quality assessments, Limnol. Oceanogr., 59, 2150 – 2165, https://doi.org/10.4319/lo.2014.59.6.2150, 2014.

Bruwier, M., Maravat, C., Mustafa, A., Teller, J., Pirotton, M., Erpicum, S., Archambeau, P., and Dewals, B.: Influence of urban forms on surface flow in urban pluvial flooding, Journal of Hydrology, 582, 124493, https://doi.org/10.1016/j.jhydrol.2019.124493, 2020.

Burian, S. J. and Shepherd, J. M.: Effect of urbanization on the diurnal rainfall pattern in Houston, Hydrol. Process., 19, 1089 – 1103, https://doi.org/10.1002/hyp.5647, 2005.

Caldwell, P. V., Sun, G., McNulty, S. G., Cohen, E. C., and Moore Myers, J. A.: Impacts of impervious cover, water withdrawals, and climate change on river flows in the conterminous US, Hydrol. Earth Syst. Sci., 16, 2839 – 2857, https://doi.org/10.5194/hess-16-2839-2012, 2012.

Chen, G., Li, X., Liu, X., Chen, Y., Liang, X., Leng, J., Xu, X., Liao, W., Qiu, Y., Wu, Q., and Huang, K.: Global projections of future urban land expansion under shared socioeconomic pathways, Nat Commun, 11, 537, https://doi.org/10.1038/s41467-020-14386-x, 2020.

Cho, J., Barone, V. A., and Mostaghimi, S.: Simulation of land use impacts on groundwater levels and streamflow in a Virginia watershed, Agricultural Water Management, 96, 1 – 11, https://doi.org/10.1016/j.agwat.2008.07.005, 2009.

Dansgaard, W.: Stable isotopes in precipitation, Tellus, 16, 436 – 468, https://doi.org/10.1111/j.2153-3490.1964.tb00181.x, 1964.

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Deng, K., Yang, S., Lian, E., Li, C., Yang, C., and Wei, H.: Three Gorges Dam alters the Changjiang (Yangtze) river water cycle in the dry seasons: Evidence from H-O isotopes, Science of The Total Environment, 562, 89 – 97, https://doi.org/10.1016/j.scitotenv.2016.03.213, 2016.

Duan, W., Hanasaki, N., Shiogama, H., Chen, Y., Zou, S., Nover, D., Zhou, B., and Wang, Y.: Evaluation and Future Projection of Chinese Precipitation Extremes Using Large Ensemble High-Resolution Climate Simulations, Journal of Climate, 32, 2169 – 2183, https://doi.org/10.1175/JCLI-D-18-0465.1, 2019.

Flörke, M., Schneider, C., and McDonald, R. I.: Water competition between cities and agriculture driven by climate change and urban growth, Nat Sustain, 1, 51 – 58, https://doi.org/10.1038/s41893-017-0006-8, 2018.

Gammons, C. H., Poulson, S. R., Pellicori, D. A., Reed, P. J., Roesler, A. J., and Petrescu, E. M.: The hydrogen and oxygen isotopic composition of precipitation, evaporated mine water, and river water in Montana, USA, Journal of Hydrology, 328, 319 – 330, https://doi.org/10.1016/j.jhydrol.2005.12.005, 2006.

Gat, J. R.: OXYGEN AND HYDROGEN ISOTOPES IN THE HYDROLOGIC CYCLE, Annu. Rev. Earth Planet. Sci., 24, 225 – 262, https://doi.org/10.1146/annurev.earth.24.1.225, 1996.

Gessner, M. O., Hinkelmann, R., Nützmann, G., Jekel, M., Singer, G., Lewandowski, J., Nehls, T., and Barjenbruch, M.: Urban water interfaces, Journal of Hydrology, 514, 226 – 232, https://doi.org/10.1016/j.jhydrol.2014.04.021, 2014.

Gibson, J. J., Edwards, T. W. D., Birks, S. J., St Amour, N. A., Buhay, W. M., McEachern, P., Wolfe, B. B., and Peters, D. L.: Progress in isotope tracer hydrology in Canada, Hydrol. Process., 19, 303 – 327, https://doi.org/10.1002/hyp.5766, 2005.

Gibson, J. J. and Edwards, T. W. D.: Regional water balance trends and evaporation-transpiration partitioning from a stable isotope survey of lakes in northern Canada: REGIONAL WATER BALANCE USING STABLE ISOTOPES, Global Biogeochem. Cycles, 16, 10-1-10 – 14, https://doi.org/10.1029/2001GB001839, 2002.

Gibson, J. J., Prepas, E. E., and McEachern, P.: Quantitative comparison of lake throughflow, residency, and catchment runoff using stable isotopes: modelling and results from a regional survey of Boreal lakes, Journal of Hydrology, 2002.

Gillefalk, M., Tetzlaff, D., Hinkelmann, R., Kuhlemann, L.-M., Smith, A., Meier, F., Maneta, M. P., and Soulsby, C.: Quantifying the effects of urban green space on water partitioning and ages using an isotope-based ecohydrological model, Hydrol. Earth Syst. Sci., 25, 3635 – 3652, https://doi.org/10.5194/hess-25-3635-2021, 2021.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., and Briggs, J. M.: Global Change and the Ecology of Cities, Science, 319, 756 – 760, https://doi.org/10.1126/science.1150195, 2008.

Guan, M., Sillanpää, N., and Koivusalo, H.: Storm runoff response to rainfall pattern, magnitude and urbanization in a developing urban catchment: Storm Runoff

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Response to Rainfall Pattern, Magnitude and Urbanization, Hydrol. Process., n/a-n/a, https://doi.org/10.1002/hyp.10624, 2016.

Hamilton, S. K., Bunn, S. E., Thoms, M. C., and Marshall, J. C.: Persistence of aquatic refugia between flow pulses in a dryland river system(Cooper Creek, Australia), Limnol. Oceanogr., 50, 743 – 754, https://doi.org/10.4319/lo.2005.50.3.0743, 2005.

Jacobson, C. R.: Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review, Journal of Environmental Management, 92, 1438 – 1448, https://doi.org/10.1016/j.jenvman.2011.01.018, 2011.

Li, C., Wang, Y., Wu, X., Cao, H., Li, W., and Wu, T.: Reducing human activity promotes environmental restoration in arid and semi-arid regions: A case study in Northwest China, Science of The Total Environment, 768, 144525, https://doi.org/10.1016/j.scitotenv.2020.144525, 2021.

Małoszewski, P., Rauert, W., Stichler, W., and Herrmann, A.: Application of flow models in an alpine catchment area using tritium and deuterium data, Journal of Hydrology, 66, 319 – 330, https://doi.org/10.1016/0022-1694(83)90193-2, 1983.

Martin, K. L., Hwang, T., Vose, J. M., Coulston, J. W., Wear, D. N., Miles, B., and Band, L. E.: Watershed impacts of climate and land use changes depend on magnitude and land use context, Ecohydrology, 10, e1870, https://doi.org/10.1002/eco.1870, 2017.

Oudin, L., Salavati, B., Furusho-Percot, C., Ribstein, P., and Saadi, M.: Hydrological impacts of urbanization at the catchment scale, Journal of Hydrology, 559, 774 – 786, https://doi.org/10.1016/j.jhydrol.2018.02.064, 2018.

Peng, T.-R., Huang, C.-C., Wang, C.-H., Liu, T.-K., Lu, W.-C., and Chen, K.-Y.: Using oxygen, hydrogen, and tritium isotopes to assess pond water ’ s contribution to groundwater and local precipitation in the pediment tableland areas of northwestern Taiwan, Journal of Hydrology, 450 – 451, 105 – 116, https://doi.org/10.1016/j.jhydrol.2012.05.021, 2012.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E., Kaushal, S. S., Marshall, V., McGrath, B. P., Nilon, C. H., Pouyat, R. V., Szlavecz, K., Troy, A., and Warren, P.: Urban ecological systems: Scientific foundations and a decade of progress, Journal of Environmental Management, 92, 331 – 362, https://doi.org/10.1016/j.jenvman.2010.08.022, 2011.

Qian, H., Dou, Y., Li, X.J., Yang, B.C., and Zhao, Z.H.: Changes of $\delta^{18}O$ and δD along Dousitu River and its indication of river water evaporation. Hydrogeol. Eng. Geol. 34 (1), 107–112, https://doi.org/10.16030/j.cnki.issn.1000-3665.2007.01.024,2007.

Rodgers, P., Soulsby, C., Waldron, S., and Tetzlaff, D.: Using stable isotope tracers to assess hydrological flow paths, residence times and landscape influences in a nested mesoscale catchment, Hydrol. Earth Syst. Sci., 9, 139 – 155, https://doi.org/10.5194/hess-9-139-2005, 2005.

Salvadore, E., Bronders, J., and Batelaan, O.: Hydrological modelling of urbanized catchments: A review and future directions, Journal of Hydrology, 529, 62 – 81, https://doi.org/10.1016/j.jhydrol.2015.06.028, 2015.

Šanda, M., Sedlmaierová, P., Vitvar, T., Seidler, C., Kändler, M., Jankovec, J., Kulasová, A., and Paška, F.: Pre-event water contributions and streamwater residence times in different land use settings of the transboundary mesoscale Lužická Nisa catchment, Journal of Hydrology and Hydromechanics, 65, 154 – 164, https://doi.org/10.1515/johh-2017-0003, 2017.

Skrzypek, G., Mydłowski, A., Dogramaci, S., Hedley, P., Gibson, J. J., and Grierson, P. F.: Estimation of evaporative loss based on the stable isotope composition of water using Hydrocalculator, Journal of Hydrology, 523, 781 – 789, https://doi.org/10.1016/j.jhydrol.2015.02.010, 2015.

Sun, G., Caldwell, P. V., and McNulty, S. G.: Modelling the potential role of forest thinning in maintaining water supplies under a changing climate across the conterminous United States: Response of Water Yield to Forest Thinning and Climate Change, Hydrol. Process., 29, 5016 – 5030, https://doi.org/10.1002/hyp.10469, 2015.

Sun, G. and Lockaby, B. G.: Water Quantity and Quality at the Urban-Rural Interface, in: Urban-Rural Interfaces, edited by: Laband, D. N., Lockaby, B. G., and Zipperer, W. C., American Society of Agronomy, Soil Science Society of America, Crop Science Society of America, Inc., Madison, WI, USA, 29 – 48, https://doi.org/10.2136/2012.urban-rural.c3, 2012.

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

Talma, S, Woodborne, S. and Lorentz, S.: South African Contribution to the Rivers CRP, 2012.

Tetzlaff, D., Waldron, S., Brewer, M. J., and Soulsby, C.: Assessing nested hydrological and hydrochemical behaviour of a mesoscale catchment using continuous tracer data, Journal of Hydrology, 336, 430–443, https://doi.org/10.1016/j.jhydrol.2007.01.020, 2007.

UN-Habitat (Ed.): World cities report 2020 : the value of sustainable urbanization, UN-Habitat, Nairobi, Kenya, 377 pp., 2020.

United Nations Department of Economic and Social Affairs: World Urbanization Prospects 2018: Highlights, UN, https://doi.org/10.18356/6255ead2-en, 2019.

Vitvar, T., Aggarwal, P. K., and Herczeg, A. L.: Global network is launched to monitor isotopes in rivers, Eos Trans. AGU, 88, 325–326, https://doi.org/10.1029/2007EO330001, 2007.

Wang, B., Zhang, H., Liang, X., Li, X., and Wang, F.: Cumulative effects of cascade dams on river water cycle: Evidence from hydrogen and oxygen isotopes, Journal of Hydrology, 568, 604–610, https://doi.org/10.1016/j.jhydrol.2018.11.016, 2019.

Wei, W., Shi, P., Zhou, J., Feng, H., Wang, X., and Wang, X.: Environmental suitability evaluation for human settlements in an arid inland river basin: A case study of the Shiyang River Basin, J. Geogr. Sci., 23, 331–343, https://doi.org/10.1007/s11442-013-1013-y, 2013.

Westra, S., Fowler, H. J., Evans, J. P., Alexander, L. V., Berg, P., Johnson, F., Kendon, E. J., Lenderink, G., and Roberts, N. M.: Future changes to the intensity and frequency of short-duration extreme rainfall: FUTURE INTENSITY OF SUB-DAILY RAINFALL, Rev. Geophys., 52, 522 – 555, https://doi.org/10.1002/2014RG000464, 2014.

Wilson, C. and Weng, Q.: Assessing Surface Water Quality and Its Relation with Urban Land Cover Changes in the Lake Calumet Area, Greater Chicago, Environmental Management, 45, 1096 – 1111, https://doi.org/10.1007/s00267-010-9482-6, 2010.

Wing, O. E. J., Bates, P. D., Smith, A. M., Sampson, C. C., Johnson, K. A., Fargione, J., and Morefield, P.: Estimates of present and future flood risk in the conterminous United States, Environ. Res. Lett., 13, 034023, https://doi.org/10.1088/1748-9326/aaac65, 2018.

Yang, S. L., Zhang, J., and Xu, X. J.: Influence of the Three Gorges Dam on downstream delivery of sediment and its environmental implications, Yangtze River, Geophys. Res. Lett., 34, L10401, https://doi.org/10.1029/2007GL029472, 2007.

Yu, D., Shi, P., Liu, Y., and Xun, B.: Detecting land use-water quality relationships from the viewpoint of ecological restoration in an urban area, Ecological Engineering, 53, 205 – 216, https://doi.org/10.1016/j.ecoleng.2012.12.045, 2013.

Zhu, G., Guo, H., Qin, D., Pan, H., Zhang, Y., Jia, W., and Ma, X.: Contribution of recycled moisture to precipitation in the monsoon marginal zone: Estimate based

https://doi.org/10.5194/hess-2023-96
Preprint. Discussion started: 3 May 2023

on stable isotope data, Journal of Hydrology, 569, 423 – 435, https://doi.org/10.1016/j.jhydrol.2018.12.014, 2019.

Zhu, G., Sang, L., Zhang, Z., Sun, Z., Ma, H., Liu, Y., Zhao, K., Wang, L., and Guo, H.: Impact of landscape dams on river water cycle in urban and peri-urban areas in the Shiyang River Basin: Evidence obtained from hydrogen and oxygen isotopes, Journal of Hydrology, 602, 126779, https://doi.org/10.1016/j.jhydrol.2021.126779, 2021.