Impacts of Climate Change and Human Activities on Streamflow in the upper basin of the Yongding River, North China

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Abstract

Quantitative assessment of the effects of climate change and human activities on runoff is very important for regional sustainable water resources utilization. Determining abrupt changes in runoff could enhance identification of the main driving factors for the sudden changes. In this study, the double mass curves analysis combined with field investigation is used to determine abrupt changes in runoff in two sub-catchments of Upper Yongding River Basin(UYRB), while trend analysis via the traditional Mann–Kendall test for the period 1961–2017 is used to identify the basic trend of precipitation, temperature and potential evapotranspiration(E0). The results suggest an insignificant change in precipitation, a significant increase in temperature and a significant decline in E0 in both sub-catchments. For both of the sub-catchments, abrupt changes in runoff occurred in 1982 and 2003. Both Budyko's curve and double mass curves are used to evaluate the potential impacts of climate variability and human activities on mean annual streamflow. The results showed that, from the 1960s to the 1980s, runoff declined by 20.01% and 22.28% for Xiangshuibu and Shixiali, respectively; from the 1980s to the 2000s, runoff declined by 68.23% and 67.77% respectively. In the variation stage I (1983˜2003), human activities contributed 90.6% and 62.7% of the mean annual streamflow change in YRB and SRB, respectively. In the variation stage II(2004˜2017), human activities contributed 99.5% and 93.5% of the change in YRB and SRB, respectively. It is also noted that the first abrupt decline in runoff was actually at the beginning of China's land reform, when the land reform motivated farmers to productively manage their reallocated lands, agricultural water consumption therefore increased. The second abrupt change point occurred in 2003, when "Capital water resources planning" implemented including water conservation projects and irrigation district construction. In general, human activities, including soil and water conservation projects and water consumption, are found to be the dominant factors responsible for the significant decline in the annual streamflow in the UYRB over the last six decades.

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Highlights

1. This study fitted the "basin-specific α" in Yang River and Sanggan River through the annual observation data.

2. In this paper, we study the impact of climate change and human activities on runoff through Budyko type formula, Fu's equation.

3. This paper update about ten years data compare with previous studies; in addition, this study also obtained a large number of field investigation data, which further confirmed the research results.

Abstract : Quantitative assessment of the effects of climate change and human activities on runoff is very important for regional sustainable water resources utilization. Determining abrupt changes in runoff could enhance identification of the main driving factors for the sudden changes. In this study, the double mass curves analysis combined with field investigation is used to determine abrupt changes in runoff in two sub-catchments of Upper Yongding River Basin(UYRB), while trend analysis via the traditional Mann–Kendall test for the period 1961–2017 is used to identify the basic trend of precipitation, temperature and potential evapotranspiration(E_0). The results suggest an insignificant change in precipitation, a significant increase in temperature and a significant decline in E_0in both sub-catchments. For both of the sub-catchments, abrupt changes in runoff occurred in 1982 and 2003. Both Budyko's curve and double mass curves are used to evaluate the potential impacts of climate variability and human activities on mean annual streamflow. The results showed that, from the 1960s to the 1980s, runoff declined by 20.01% and 22.28% for Xiangshuibu and Shixiali, respectively; from the 1980s to the 2000s, runoff declined by 68.23% and 67.77% respectively. In the variation stage I (1983˜2003), human activities contributed 90.6% and 62.7% of the mean annual streamflow change in YRB and SRB, respectively. In the variation stage II(2004˜2017), human activities contributed 99.5% and 93.5% of the change in YRB and SRB, respectively. It is also noted that the first abrupt decline in runoff was actually at the beginning of China's land reform, when the land reform motivated farmers to productively manage their reallocated lands, agricultural water consumption therefore increased. The second abrupt change point occurred in 2003, when "Capital water resources planning" implemented including water conservation projects and irrigation district construction. In general, human activities, including soil and water conservation projects and water consumption, are found to be the dominant factors responsible for the significant decline in the annual streamflow in the UYRB over the last six decades.

Keywords : Streamflow; Climate variability; Human activities; Yongding River Basin; Budyko's curve

1. Introduction

Climate change and increasing human activities is significantly impacting the runoff on a global scale(Xia, 2002; Arnell, 2004; Huntington, 2006; Emad et al., 2018; Falcone et al., 2018). This has become one of the serious issues of scientific concern especially in semi-arid area (Ren et al, 2002; Wang et al., 2011). The runoff of many rivers in semi-arid area has exhibited a significantly decreasing trend that greatly threatens water security (Xia, 2004; Braga et al, 2013). Impact of climate change and human activities on runoff has been widely studied(Huang, 2018; Kenny et al, 2019). Many studies have shown that: in the semi-arid area, with the increase of temperature and the decrease of precipitation, runoff will decrease to a certain extent(Nurtaev, 2015; Wang, 2011).Xu (2012) studied the runoff changes of 296 typical watersheds in China in the past 50 years (1956-2005), and quantitatively evaluated the impact of climate change and underlying surface change. The results show that in the Haihe River Basin, the lower Yellow River Basin, the lower Songhua River Basin and the Liaohe River Basin, the underlying surface change is the main reason for the runoff change, while the runoff change in other basins is mainly affected by climate change.

Climate change affects the land hydrological cycle system through the changes of temperature, precipitation and evaporation, thus affecting the hydrological process (Nurtaev, 2015). The influence of human activities on hydrological process is mainly through land use/cover, soil and water conservation and water conservancy projects (Zhao G, 2014). Therefore, the research on the impact of climate change and human activities on hydrological process is of great scientific significance and application value for water resources planning, management and application under changing environment. How to distinguish the contribution rate of climate change and human activities to runoff change is the core issue in the study of hydrology (Liu et al., 2014; Huang et al., 2018).

In terms of the impact of climate change and human activities on runoff, experts have done a lot of research, and considerable attention has been paid to assessing the impacts of climate variability and human-induced land use changes on water resources (Hang et al., 2011; Ma et al., 2008; Milly et al., 2008; Mu et al., 2007; Tao et al., 2011; Zhai et al., 2010; Zhang et al., 2008; Zhang et al., 2011). Assessments of the impacts of climate change on river streamflow are usually performed using hydrological models or by analyzing the variation of hydro-climatic variables (Yao et al., 2011; Wada Y. et al., 2016). Hydrological models, such as the Variable Infiltration Capacity (VIC) model, the SLURP (Semi-distributed Land Use-based Runoff Processes) model, the Xinanjiang model, the HBV model and the Soil and Water Assessment Tool (SWAT), have been commonly applied to assess the impacts of climate change and human activities such as land use changes on streamflow under various scenarios (Pikounis et al, 2003; Fohrer et al., 2005; Choi et al., 2009; Mahmoud et al., 2015). Although hydrological models have clear physical mechanism, a large number of parameters cannot be obtained from field measurements. Additionally, hydrological modeling requires a large number of input data sets and is often seen as time consuming for model calibration and validation. Due to these limitations, new attempts assess the effect of climate variability and human activities have recently been made. In recent years, both the hydrological sensitivity method and a simple water balance model known as Budyko's curve have been widely applied to separate the effects of climate change and human activities on streamflow (Dooge et al., 1999; Milly and Dunne, 2002; Wang et al., 2013a; Zhang et al., 2008). Several analytical equations have been proposed baesd on the Budyko hypothesis (Yang et al., 2008b). In Budyko's original hypothesis, the Budyko curve was regarded as "universal" for all basins at long-term scale and the default Budyko curve method corresponds to a α value of 2.6 [Donohue et al., 2011]. Later on, "basin-specific" Budyko curves were proposed: each basin has a distinct Budyko-type relationship between precipitation (P), potential evaporation (E_0), and actual evaportranpiration (E_a) at annual scale. Consequently, a simple parameterization for α with information that is readily available will be a good basis for applying Fu's equation and the Budyko framework, which would be applied in this study.

The Yongding River Basin (YRB) has served as the "mother river of Beijing" over the past millennia and continues to play a critical role in the development of Beijing (Jinbo, 2012). However, over the last several decades, progress has been impeded by a continuous water shortage. The UYRB, located northwest of Beijing, is a very important sub-basin of the Hai River Basin (Figure 1) because it is the major source of water for the Guanting Reservoir, supplying water to Beijing. This study is focused on the upper areas of the YRB. With the rapid social and economic development that has occurred over the past several decades, water consumption has increased continuously and, consequently, the inflows to the Guanting Reservoir have continuously decreased. The water scarcity in the study area has become increasingly severe (Wang, 2004; Wang et al, 2010), the increase in the amount of water withdrawal from the river course is the direct cause why observed runoff decreases in the northern part of China (Ren et al, 2002). Xia et al (2014) presents the analytical derivation method based on Budyko hypothesis to separate the effects of climate change and human activities in Upper Yongding River Basin (UYRB). Results show that climate change is estimated to account for 10.5–12.6% of the reduction in annual runoff and human activities contribute to 87.4–89.5% of the runoff decline, indicating that human activities are the main driving factors for the reduction in runoff. Zeng et al (2013) studied the characteristics of water cycle and its response to climate change in YRB by SWAT model. The results indicate that the water resources in YRB will decrease in the early 21st century and increase in the middle of the 21st century and the water resources crisis will be further intensified. Mo et al (2018) studied the impact of climate change and human activities on the runoff of YRB by elastic coefficient method. The results show that the potential evapotranspiration of the basin presents an upward trend, while the rainfall and runoff show a decreasing trend; the abrupt change point of runoff sequence occurred in 1984, and the runoff change rate caused by climate change is 28%, while that caused by human activities is 72%. However, Zhang's (2013) results show that climate change is the dominant influence factor with a contribution of 65.4%.

In previous studies, many methods were used to determine the change point, and the results would be different due to the different length of time series. In addition, most of the studies focus on the period before 2010 (Xia, 2012; Ding, 2013; Xia, 2014; Mo, 2018). However, the runoff of Yongding River has declined rapidly in recent ten years, especially after the "Capital water resources planning". Thus, it is necessary to do further research on the hydrological law of the basin. In addition to the existing methods, this study also obtained a large number of field survey data, which makes the results more accurate and reliable.

Although a few studies have investigated the variability of streamflow in UYRB in response to climate changes and human activities to support future water resource management. The changing streamflow properties and their connection to natural and anthropogenic impacts in the UYRB have not been extensively analyzed, especially after the "Capital water resources planning" project launched by Chinese government in 2003. Furthermore, the scientific community still disagrees on the main factors affecting the regional water resources in the UYRB. The objectives of this study, therefore, are (1) to assess the spatial and temporal variation of streamflow, climatic variables in the UYRB and (2) to quantify the effects of climate variability and human activities on streamflow there.

2. Materials and Methods

2.1 Study area and data sources

The Upper Yongding River Basin (UYRB), one river system of Haihe river basin, is located in North China. It includes part of Shanxi, Inner Mongolia and Hebei Province, has a population of [?]9.13 million. In this study, the analyzed sub-catchments together have an area of [?]43000km^2 , stretching between longitudes 111˚58'–116^{deg}22'E and latitudes 38^{deg}50'–41^{deg}16'N. The area lies at an elevation of 479–2852m above mean sea level (Fig. 1).The predominant climate of study area is continental monsoon climate, belonging to semi-arid area, with cold and dry winters and hot and rainy summers. The annual distribution of runoff is very uneven, about 80% of which is concentrated in the flood season. The annual average precipitation of the basin is less than 450 mm, about 75% of which falls in the rainy months of June to September. Average annual temperatures in the catchment are between -1.6 and 12.5. Main land use/land cover types are farmland ([?]42%), grassland ([?]29%) and forest ([?]10%). The forests consist mainly of deciduous broad-leaved forests. Maize is the dominant cultivated crops in the single-crop rotation system in the study area. Rainfall often does not meet crop water demand hence irrigated lands have not only increased, but are increasingly reliant on groundwater pumping and river water diversion project. As irrigation significantly enhances harvests, it has therefore become an indispensable agronomic practice in the region. Hence as the largest water user, agricultural water demand has a significant impact on the scale of water deficit in the region.

Daily meteorological data of 23 stations from CMA (Fig. 1) in and around the UYRB during 1961–2017 were used, including mean daily temperature, precipitation, mean relative humidity, mean wind speed, and sunshine duration. Daily runoff data were collected for the same period from two hydrological gauge stations situated at the outlets of the sub-catchments. Runoff was monitored in rectangular weirs setup in accordance with ISO (International Standards Organization) standards for open-channel liquid flow measurement. The hydrological gauge stations include the, Xiangshuibu station (for 14,600 km^2 area of Yanghe River sub-catchment), Shixiali station (for 23300 km^2 area of Sanggan River sub-catchment). The daily runoff data constitute direct flow measurements from the respective stations (Table 1). The DEM data with a resolution of 30m was from ASTER GDEM.

[Figure 1 here]

[Table 1 here]

2.2 Methods

2.2.1 Trend detection

This study applies the non-parametric Mann–Kendall test to detect trends in the hydro-climatic time series (Kendall, 1975; Mann, 1945). The method has been commonly used to examine trends in hydro-meteorological time series such as streamflow, precipitation and temperature in various regions throughout the world (Mu et al., 2007; Novotny and Stefan, 2007). For the given time series X(x_1, x_2, ..., x_n), the statistic S is defined as:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sgn(x_i - x_j) \text{where sgn}\,(x_j - x_i) = \{$$

$$\begin{matrix} 1 & x_j > x_i \\ 0 & x_j = x_i \quad (1) \\ -1 & x_j < x_i \end{matrix}$$

Mann (1945) and Kendall (1975) addressed that the statistic S is approximately normally distributed. Its variance is calculated as:

$$\text{var}\,(S) = \frac{n(n-1)(2n+5)}{18} \quad (2)$$

The standardized statistic is:

$$Z = \{$$

$$\begin{matrix} \frac{S-1}{\sqrt{\text{var}(S)}} & S > 0 & \\ 0 & S = 0 & (3) \\ \frac{S-1}{\sqrt{\text{var}(S)}} & S < 0 & \end{matrix}$$

A positive values of Z indicates an upward trend, while a negative Z indicates a downward trend. The null hypothesis of no trend is rejected if |Z| > 1.96 at 5% significance level. The effects of the serial correlation on the MK test were eliminated by using the Trend-Free pre-whitening procedure (Yue and Wang, 2004).According to the calculated autocorrelation coefficients at lag-1 for each annual time series, the hydro-climatic series are time-independent.

2.2.2 Change point detection

The method of runoff double cumulative curve and field survey data are used to study the abrupt point. The double mass curve is used to check the consistency of many kinds of hydrometeorological data by plotting the graph. The variables is a fixed ratio. Breaks in the double-mass curve of such variables are caused by changes in the relation between the variables (Searcy and Hardison, 1960). Double mass curve is a simple method, computed as follows.

Let the observed variable values X_i and Y_j, the cumulative amount calculated:

$X_i' = \sum_{j=1}^{i} X_j$ (4)

${Y'}_i = \sum_{j=1}^{i} Y_j$ (5)

Where, X_i represents rainfall, and Y_j is the runoff. The slope of the curve changes are abrupt changes points. In order to accurately determine the mutation time, we also refer to the field survey data, so that the determination of abrupt change points has a solid practical basis.

2.2.3 Separating the impact of climate change and human activity on streamflow

To quantitatively analyze the effects of climate variability and human activities on streamflow, both the water balance based Budyko model (1974) and a double mass curves method were applied to the hydro-climatic series during the two periods identified by the double mass curves combined with field investigation. The water balance in a catchment scale can be quantified as:

$Q = P - E_a - S$ (6)

Where P is the precipitation (mm), E_a is the actual evapotranspiration (mm), Q is the runoff depth (mm), and ΔS is the changes in the catchment water storage (mm), which is assumed to be zero over a long period. Following an assumption similar to that made by Budyko (1974), the actual evapotranspiration can be estimated as (Fu, 1981):

E_a=PF( ) (7)

F(φ)=1+φ-(1+ $^{\alpha}$)$^{1/\alpha}$ (8)

Where $\varphi = E_0/P$, E_0 is potential evapotranspiration which was calculated using the Penman–Monteith equation following the procedure outlined in FAO-56 (Allen et al., 1998). α is a model parameter estimated using long-term averaged data. As one form of the Budyko framework, Fu's equation has been widely used to model long-term basin-scale water balance. A detailed description of the values is available in Zhang et al. (2001).

A change in the observed mean annual streamflow $\Delta R_{\mathrm{total}}$may result from climate variability $\Delta R_{\mathrm{clima}}$ or from human activities $\Delta Q_{\mathrm{human}}$

R_{total}=$R_{\mathrm{clima}} + R_{\mathrm{human}}$ (9)

To assess the effects of climate change and human activities, we divided the streamflow records for each catchment that has undergone significant changes in qualities such as land use, dams, afforestation or deforestation into two periods. The first period represents the baseline, when no significant human activities occurred, while the second represents the changed period and is associated with significant human activities. Thus, a change in the average annual streamflow is calculated as:

$Q = Q_2 - Q_1$(10)

Where Q denotes the change in average annual streamflow and Q_1 andQ_2 are the average annual streamflow during the baseline period and changed period, respectively.

Precipitation and E_0 are the primary climatic variables determining the annual water balance (Zhang et al., 2004). Variations in these variables could lead to changes in the annual streamflow. The relationship between these variables can be estimated as:

$R_{\mathrm{climate}} = \frac{\partial R}{\partial P} P + \frac{\partial R}{\partial \mathrm{ET}_0} E_0$(11)

where ΔP and ΔE_0 are the changes in precipitation and E_0, respectively. Consequently, the impact of climate change on streamflow can be quantified as:

$\frac{\partial R}{\partial P} = P^{\alpha-1}(E_0^{\alpha} + P^{\alpha})^{\frac{1}{\alpha}-1}$(12)

$\frac{\partial R}{\partial \mathrm{ET}_0}$=$E_0^{\alpha-1}(E_0^{\alpha} + P^{\alpha})^{\frac{1}{\alpha}-1} - 1$(13)

In contrast, the runoff double mass curve(DMC) is a statistical method that does not consider the physical hydrological processes that were also established between streamflow and precipitation within the two periods (the changing period and the reference period). The DMC equation between annual streamflow (R_{ref}) and basin-averaged annual precipitation (P_{ref}) in the reference period can be expressed as follows:

$\Sigma R = k\Sigma P + b$ (14)

Thus, the impact of human activities and climate change on streamflow can be quantified as:

δ_{hi}=R_{2m}-R_{2c} (15)

δ_{ci}=R_{2c}-R_{1m} (16)

Q_g=(δ_{hi} or δ_{ci})/R_d (17)

Where, δ_{hi} 和 δ_{ci} is runoff depth caused by human activities and climate change respectively (mm), Q_g represents the contribution rate(%) of human activities and climate change to runoff reduction. R_{2m}represent measured values in variation period, R_{2c}represent calculated values in variation period, R_{1m}represent measured values in baseline period.

Results

4.1 Δετερμινατιον οφ τηε παραμετερ α ιν Φυ΄ς εχυατιον

The parameter α represents the integrated effects of catchment attributes (such as climate, vegetation cover, soil properties, and catchment topography) and human activities on P partitioning (Zhang et al., 2001; Zhou et al., 2015). That is to say, the curve shape parameter α controls how much of the available water will be evaporated given the available energy. α can be estimated by minimizing the difference between water-balance-based E_a (P-Q) and simulated E_a with Fu's equation. The parameter α obtained through this method is also called the "basin-specific α" (Li et al., 2013). In this study, the parameter α was fitted through the annual observation data (Fig 2). A larger α indicates less water yield capacity for a basin given sufficient energy. Obviously, the water yield capacity of Yang River is larger than Sanggan River. For both sub-catchments, all annual dryness indices(Φ=ET_0/P) is greater than one, means that the limiting factor to evapotranspiration is energy supply.

[Figure 2 here]

4.2 Spatiotemporal variation characteristics of meteorological variables

Fig.3 shows spatiotemporal variation characteristics in precipitation (P) and potential evapotranspiration (ET_0), estimated by the M-K test and Kriging interpolation method. Average annual precipitation for the sub-catchments is 319.4–554.1 mm and precipitation in the UYRB is relatively stable. As shown in Fig 3a, the annual precipitation showed an upward trend at 13 stations and a downward trend at 9 stations, but not significant, with Z value 0.154 ˜ 1.167 and -1.074 ˜-0.027, respectively. Fig 3a also shows that there is a slight increase in precipitation in the Sanggan River basin (SRB). Comparing with the background topography, we find that the precipitation increases with the elevation. At the same time, we analyzed the trend of temperature, and the results showed that temperature at most stations increased by 0.09–0.52 per decade. These changes in temperature duration are not shown in this work. Fig 3b shows that the annual average E_0 values ranged from 701.5 to 1111.5mm/yr and the E_0 of UYRB has a negative trend at 18 stations, with decreases from -0.18 mm/yr to -2.04 mm/yr over the study period. From the perspective of spatial distribution, the northern part of the study area presents a higher E_0 value, while the southern part is relatively low. This phenomenon is consistent with the global evaporation paradox, which may be caused by several climatic variables. The measured data witnessed a significant reduction in wind speed, which maybe cause the decline of E_0 value. The data of wind are not shown in this work.

[Figure 3 here]

4.3 Trend analysis of annual streamflow

In this study, annual streamflows at two stations (Fig. 4) are analyzed to assess the trend in this basin during the period 1961–2017. The linear regression analysis shows significant declines in annual runoff trend for Yang river and Sanggan river (not show in this work). The estimated rates of change are –0.74, –0.80mm/yr for Shixiali and Xiangshuibu, respectively, from 1961 to 2017. From the 1960s to the 1980s, runoff declined by 20.01% and 22.28% for Xiangshuibu and Shixiali, respectively. From the 1980s to the 2000s, runoff declined by 68.23% and 67.77%. As Fig. 3 shows, the runoff decreased rapidly around 2003, with precipitation had no significant trend. It is worth noting that the runoff of YRB and SRB decrease rapidly after 2003.

[Figure 4 here]

4.4 Change point analysis of annual streamflow

The method of double mass curve was applied to examine abrupt changes in annual streamflow at two sub-catchment of the upstream area of the Yongding River Basin (Fig. 5). According to the change of the slope of the curve, the first abrupt changes of these two basins most likely occurred in the early 1980s; this pattern can be largely attributed to the operation of the China's land reform that gave responsibility to farmers to productively manage the reallocated lands. The land reform policy was successful because it motivated farmers to increase agricultural production. Increased agricultural activity then results in increased agricultural water use. The second abrupt changes in annual streamflow occurred intensively between 2000 and 2005, which likely predominantly resulted from the "Capital water resources planning", when including large scale soil and water conservations practices and irrigation district construction. In general, 1978–1985 is the period with abrupt decline in runoff in the study area (Yang, 2009; zhang, 2013). To further prove this claim, we organized a two-week large-scale field survey in the upper Yongding River Basin. We found that it was in 1982 that the household contract responsibility system was implemented and the Capital water resources planning was mainly constructed in 2003. After the first point, the response of runoff to precipitation is continuously weakening. Accordingly, these breakpoints divide the study period for all the catchments into three periods: base period(1961-1982), variation stage I(1983-2003) and variation stage II(2004-2017).

[Figure 5 here]

4.5 Effects of climate variability and human activities on streamflow

Changes in streamflow for a given study area are affected by many factors that can be attributed to climate variability and human activity. The percentage change in average annual streamflow attributable to climatic variability and human activity are shown in Table 2. As shown in Table 2: the precipitation decreased by 4.46% and 6.37% in YRB and SRB during variation stage I (1983˜2003), recpectively, compare to the base period; the precipitation decreased by 1.53% and 0.71% in YRB and SRB during variation stage II (2004˜2017). In addition, the E_0 decreased by 3.71% and 1.35% in YRB and SRB during variation stage I ,respectively. The E_0 decreased by 1.98% in YRB and increased by 3.18 in SRB during variation stage II. The descriptions above reflect the climatic variables affecting runoff. the Streamflow at two sub-catchment is decreasing at extremely high rates especially the variation stage II, when the runoff of Yang River decreased by 87% and Sanggan River by 91% compare to the base period. Human activities are expected to account for more of this reduction in mean annual streamflow than the effects of climate change; this prediction is true at both sub-catchments. In the variation stage I, human activities contributed 90.6% and 62.7% of the mean annual streamflow change in YRB and SRB, respectively. In the variation stage II, human activities contributed 99.5% and 93.5% of the change in YRB and SRB, respectively, which is more affected by human activities than the first period of variation. In general, the contribution rate of human activities to the runoff of Yang River is higher than Sanggan River.

[Table 2 here]

5 Discussions

5.1. Estimation of climate and anthropogenic contributions by double mass curves

To further address the impacts of human activity on streamflow, double mass curves (DMCs) were plotted to show the correlation between cumulative annual streamflow and precipitation (Fig. 4). In general, the DMC was expected to be a straight line if streamflow was not influenced by human activities. The curves show the best fit between streamflow and precipitation (Zhang and Lu, 2009). Evident abrupt breakpoints can be identified in the DMCs, suggesting that the variations in hydrological processes were not only influenced by precipitation but also by human activities.

The relationships between runoff and precipitation are well represented by three straight lines with different slopes before and after the times of abrupt change. As shown in Fig. 4, the slopes of the regression lines are lower after the transition years than before for the DMCs , which suggests large reductions in streamflow in periods following the transition years. The DMCs method assessed the relative contributions of precipitation and human activity in the UYRB to changes in streamflow (Table 3). Generally, the contributions of human activities and variations in precipitation are, on the whole, consistent with the results from Budyko's curve, summarized in Table 2. Human activities played a dominant role in the reduction of streamflow for both catchments. However, the DMCs and Budyko's curve methods do not agree on the specific contribution fractions at all period in two sub-catchments. The variation stage I of YRB, for example, are more affected by human activities based on the Budyko's curve methods. However, the pattern of variation stage II is reversed. This discrepancy may be due to the different factors considered by the two methods, as the DMCs equation only considers precipitation. The first variation period has lower ET_0, which would cause higher climatic contributions for DMCs method ignoring the ET_0 variables relatively to the results of Budyko's curve method. Mo et al. (2018) found that the abrupt change point of runoff series occurred in 1984 and human activities were responsible for 72% of the total reduction in mean annual streamflow, while the remaining 13% was attributable to climate variability in the UYRB. This observation is on the whole consistent with our results, to a certain extent. However, our results do not completely agree with Hu et al. (2016). They found that climate variability were responsible for most of the total reduction in mean annual streamflow during 1980s 1990s. The discrepancies may be due to that the influence factors considered are different, because Hu et al. only considered the land use/cover change, ignoring the water for human consumption.

[Table 3 here]

5.2. Anthropogenic impacts on streamflow in the UYRB

In 1978, the land reform policy that returned responsibility for reallocated land to farmers was enacted. Since then, farmers have assumed absolute responsibility for productively managing their own lands (Gibson, 2020). As most of the activities occurred at different socio-economic and political conditions, relating the different socio-economic periods and the associated human activity with abrupt runoff changes could be helpful in determining the main driving factors of runoff decline (Gerstengarbe and Werner, 1999). The "Capital water resources planning" was started in 2002, and it was completed in 2003. The accumulated area of soil and water loss control in the study area is $1841 km^2$, and the engineering measures such as fish scale pit, horizontal ditch and check dam play an important role (Tan, 2004). In addition, forest and grass measures have been taken, and a large number of irrigation areas have been built (Wang, 2003). According to the field survey, flood irrigation is widely used in farmland near the upper reaches of Yang River and Sanggan River, up to 600 ~ 800m^3/mu/year, which greatly reduces the river discharge. It could therefore be deduced that human activity is the main driving factor of declining runoff in the study area. Beijing, the capital of china, began to carry out systematic management of YRB since 2019, which is to restore water conservation and ecological environment support functions. This study can provide valuable conclusions for the systematic planning of YRB.

5.3 Limitations of this study

In this study, there's no quantitative analysis on the various factors of climate and human activities that affect runoff, which is the main content of our work in the future. In addition, the mutation point detection has a certain degree subjectivity, which needs further study.

6 Conclusions

This study examines the spatial distribution and temporal variation of precipitation, ET_0, temperature and streamflow by using hydro-climatic series from the 1961 to 2017 in the UYRB. Impacts of climate variability and human activities were investigated using Budyko's curve, and potential causes for the streamflow changes were identified. The conclusion of our study can be summarized as follows.

A general decrease in the annual ET_0 and a rising temperature trend have been detected in the UYRB. The average annual streamflow shows a significant decrease at both sub-catchments. Abrupt changes in streamflow occurred in the 1982 and 2003, which may have resulted from the implementation of land reform policy and "Capital water resources planning".

Climate variability and human activities are two distinct contributors to the observed streamflow reduction. Consistent results were obtained from the Budyko's curve equation and double mass curves, although there's a slight discrepancy between the two methods caused by ET_0 variable. Generally, human activities accounted for more of the streamflow changes in the UYRB, which contributed at least 60% (or more) of the runoff decline. The adoption of the household contract responsibility system since 1982 altered the natural streamflow regimes and led to an abrupt reduction in streamflow. The overall results show that human activities, such as soil and water conservation projects, the construction of key water control projects and agricultural irrigation seem to be the major causes of the significant decline in the annual streamflow in the UYRB over the last four decades.

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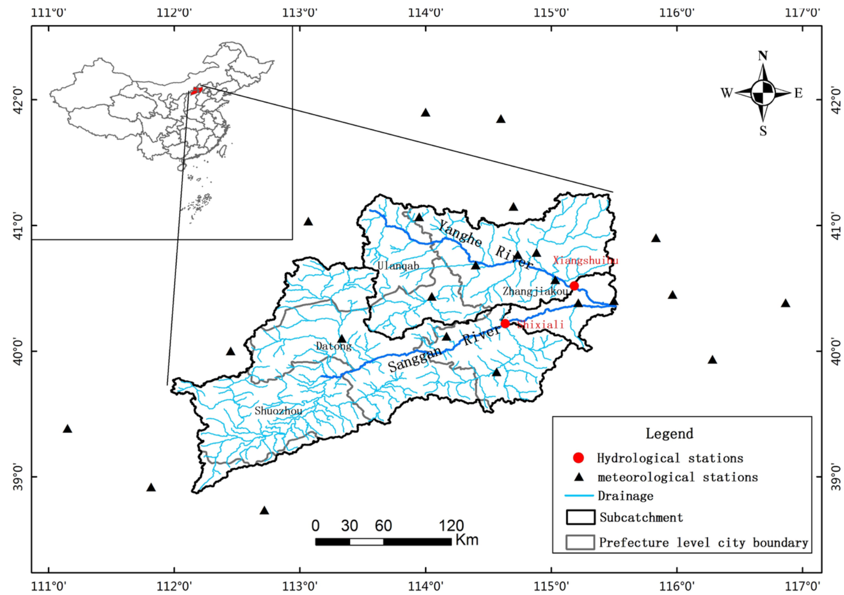
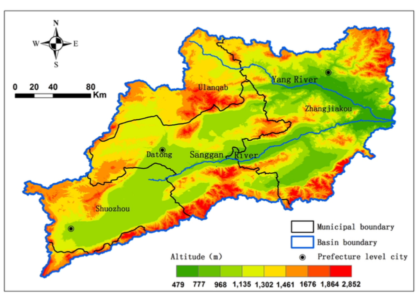
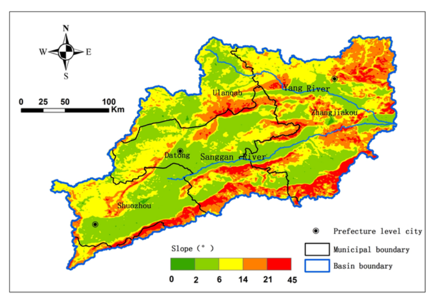
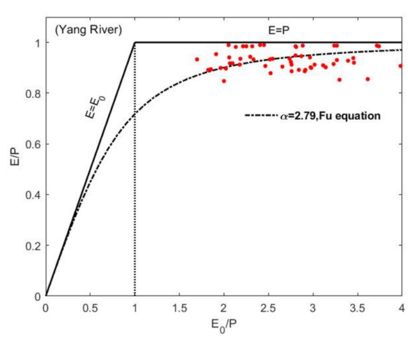
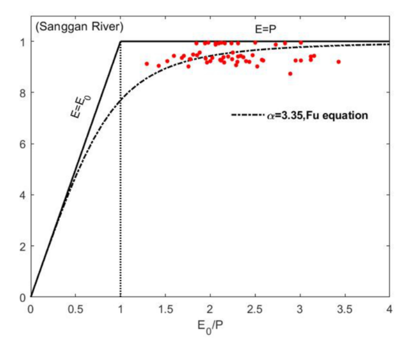
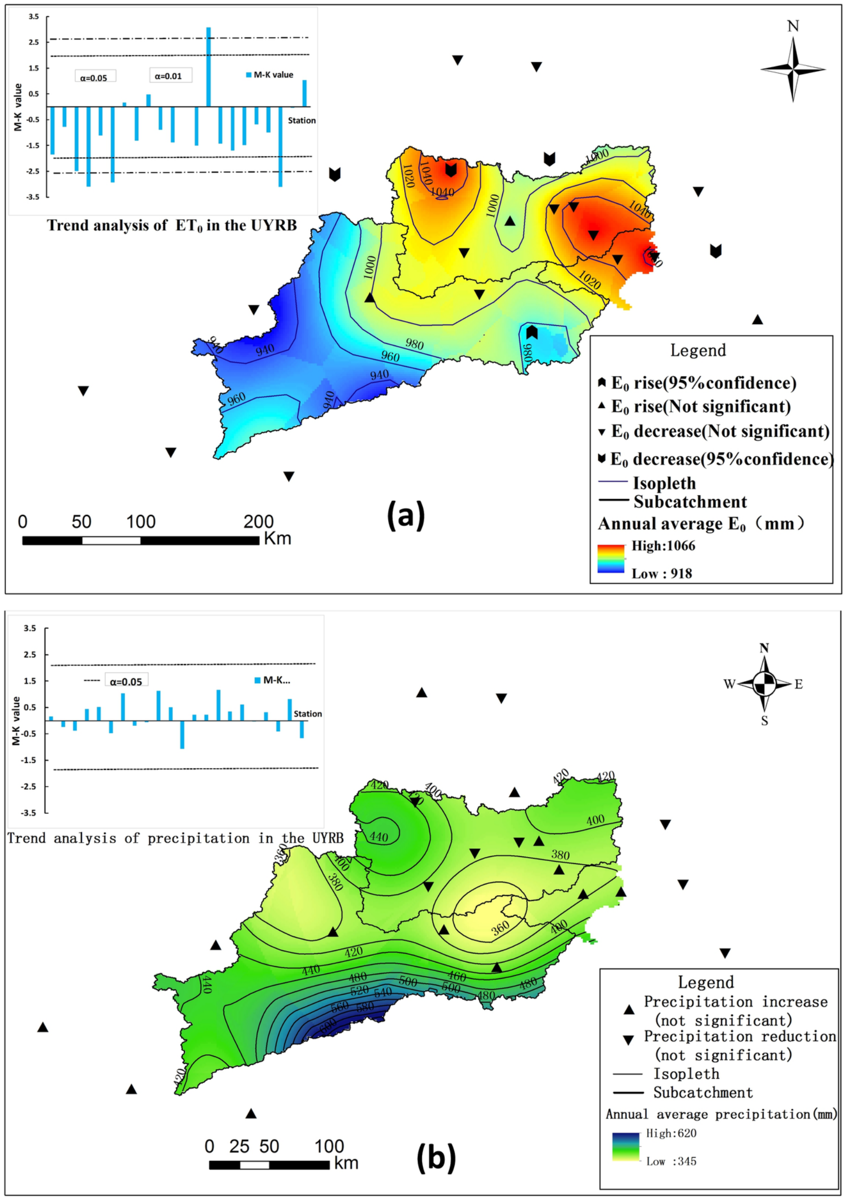




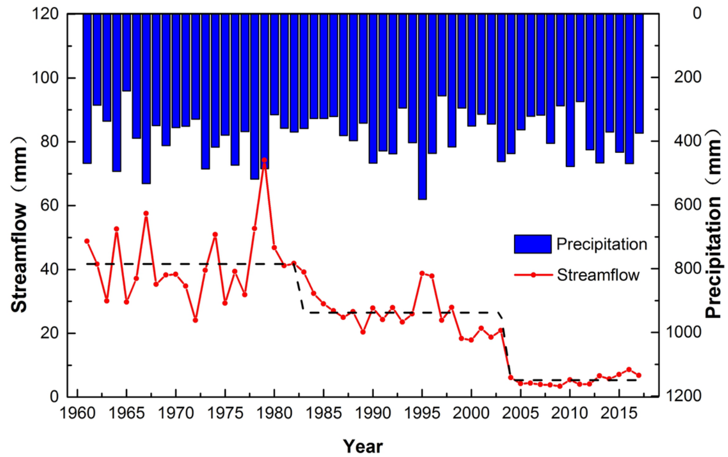




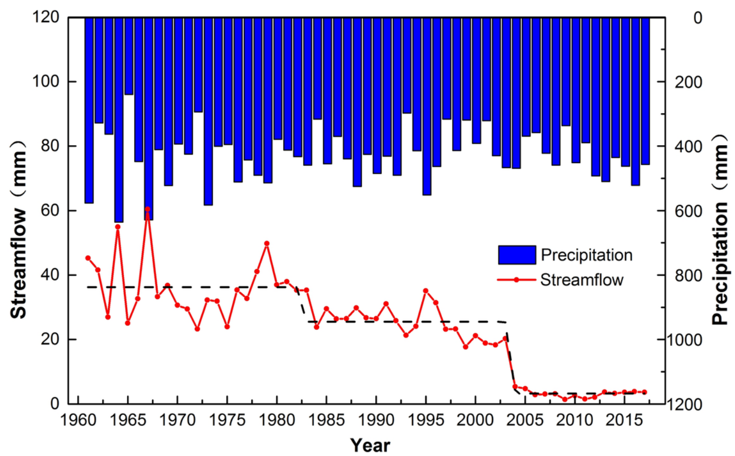




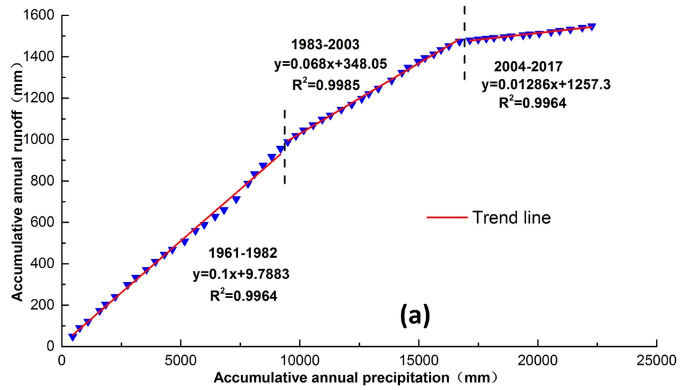
Trend analysis of ET0 in the UYRB
M-K value
Station
α=0.05
α=0.01
N
Legend
E0 rise(95%confidence)
E0 rise(Not significant)
E0 decrease(Not significant)
E0 decrease(95%confidence)
Isopleth
Subcatchment
Annual average E0（mm）
High:1066
Low : 918
0 50 100 200 Km
(a)
Trend analysis of precipitation in the UYRB
M-K value
α=0.05
Station
N
W
E
S
Legend
Precipitation increase (not significant)
Precipitation reduction (not significant)
Isopleth
Subcatchment
Annual average precipitation(mm)
High:620
Low :345
0 25 50 100 km
(b)

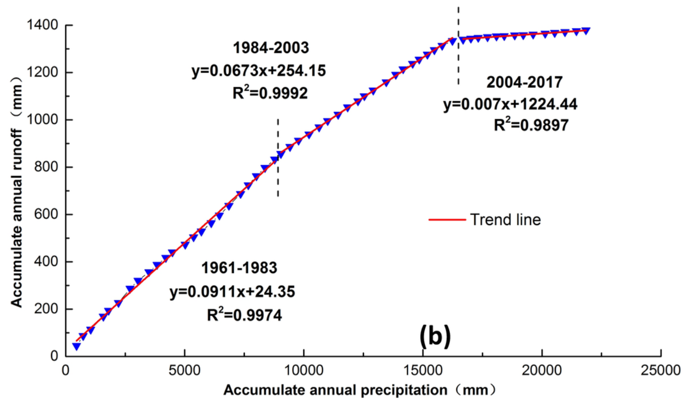


Streamflow（mm）
Precipitation（mm）
Year
Precipitation
Streamflow



Streamflow（mm）
Precipitation（mm）
Year
Precipitation
Streamflow





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