

Impact of environmental change on runoff in Hai River Catchment, North China: —
A case study of Ye River Basin

Yonghui Yang¹, Fei Tian^{1,2}, Shumin Han¹

Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road., Shijiazhuang 050021, China.

Graduate University of Chinese Academy of Sciences, Beijing 100039, China.

Abstract: In recent years, water resources in Haihe River Catchment have declined sharply and low runoff in the mountain areas has been identified as the main factor for dwindling water resources in the catchment. Yehe River Basin, a typical mountain watershed in the upstream of Haihe River Catchment was investigated in this study. Using measured stream flow and corresponding precipitation data for the period 1966 ~ 1999, runoff was analyzed on different time-scales. Runoff change in representative dry- and wet-years was also analyzed. Regression analysis was used to establish the correlation between runoff and precipitation at different time-scales. More importantly, however, a semi-quantitative analysis approach was adopted to quantify the impact of human activity and climate change on runoff. The respective impact of human activity and climate change on runoff was isolated. It was noted that runoff was not as driven by climate change as it was by human activity, which accounted for 79.22% of total runoff change, hence significantly influencing the distribution pattern and trend of runoff in the basin. In lieu of the research findings, we recommended further research on the trend of runoff and how it may affect human activity, land-use, socio-economic development and industrial and agricultural water use in the basin.

Keywords: Climate change, Human activity, Runoff, Yehe River Basin, Precipitation, Hai River Catchment.

1 Introduction

In recent decades, Haihe River Catchment has experienced high and growing water shortage due to climate change and human activity. It is reported that annual per capita water availability in the catchment is only 305 m³, less than 1/7th of China's average and 1/24th that of the world. Of the total river course of 10 000km, 4000km has become seasonal rivers as a result of over-exploitation, which has led to phenomenal shrinkage in the area coverage of wetlands, lakes and reservoirs in the last 30 years and an overall water shortage of about 8 billion cubic meters per year. With growing conflict in water use among the various stakeholders and limited water availability, water use has surpassed 90% of the basin exploitable water resource (Xia et al., 2002). Thus deep groundwater levels have been reported to be declining at 2.5

m/yr (Lv, 2003), leading to the development of huge groundwater drawdown funnels averaging 72,800 km², especially around the Bohai Sea – which accounts for about 52% of the spatial expanse in North China Plain (Zhang, 2006).

It has been widely acknowledged that decrease in runoff is highly influenced by human activity and climate change (Fraiture et al., 2007; Hejazi et al., 2007; Tanaka et al., 2006; Labat et al., 2004; Vortsmayr, 2000). Vortsmayr (2000) analyzed water resources from climate change, population growth and industrial development, and concluded that the effect of human activity on water availability outweighs that of climate change. Ren (2002) studied the impact of human activity on runoff in North China and concluded that, besides climate change, water development is more directly responsible for reduced runoff in the study area. Yuan et al. (2005) studied the impact of climate change on runoff in the Haihe River Catchment and concluded that runoff tends to decrease with time, but runoff increases under flooding. Yao et al. (2003) analyzed a time-space distribution of runoff in Chaobai River Basin and identified human activity to be the dominant over precipitation in determining runoff trend. Gao et al. (2002) analyzed the characteristics of annual inflow into Miyun reservoir and identified decreased inflow and human activity, e.g. high population growth and land use/land cover change as the main cause of the reservoir shrinkage.

Despite the unproportional focus of attention on runoff by the scientific community and policy/decision making bodies, the fundamental mechanisms of runoff still remain very poorly understood. Yehe River Basin, a subbasin of Hutuo River Basin in the upstream recharge zone of Haihe River Catchment, is roughly 6,420 km² in area. It is the source of water supply to the mega-city of Shijiazhuang, a city with a population of nearly 2.24 million. The South-to-North Water Transfer Project (the world's largest water reallocation engineering project designed to deliver water from Yangtze River in the south to the semi-arid north China) will deliver 0.73 billion m³ of water to the city by 2010, freeing-up water in the upstream of Haihe River Catchment for use in agricultural and eco-environmental sectors. Developing a sustainable balance between the transferred and local water resources is an urgent issue for water management in the region. In an effort to successfully address this issue, it is a necessary prerequisite to quantitatively isolate the effects of climate change and human activity on runoff in the basin (the source of water supply for Shijiazhuang City). Hence in this paper, a semi-quantitative analysis approach (Wang et al., 2006) was adopted to evaluate and quantify the respective contributions of human activity and climate change on the pattern and trend of runoff in the basin. The work is intended to profoundly contribute to the understanding of the relations between environmental change and water availability. It will also strengthen water awareness for the sustainable utilization and arrangement of the limited water

resources in the basin prior to (and possibly after) the delivery of water via the ambitious South-to-North Water Transfer Project.

2 Materials and method

2.1 Site description

Yehe River comprises of two major tributaries (Mian and Gantao Rivers), and originating from Shanxi Province. It is one of the most important subbasins in the upstream recharge zone of Haihe River Catchment in Hebei Province and covers an approximate area of 6,420 km² (Fig. 1). Yehe Riber Basin lies between longitudes 113.21 ~ 114.30°E and latitudes 37.23 ~ 38.28°N, and at an elevation of 160 ~ 1810m above mean sea level.

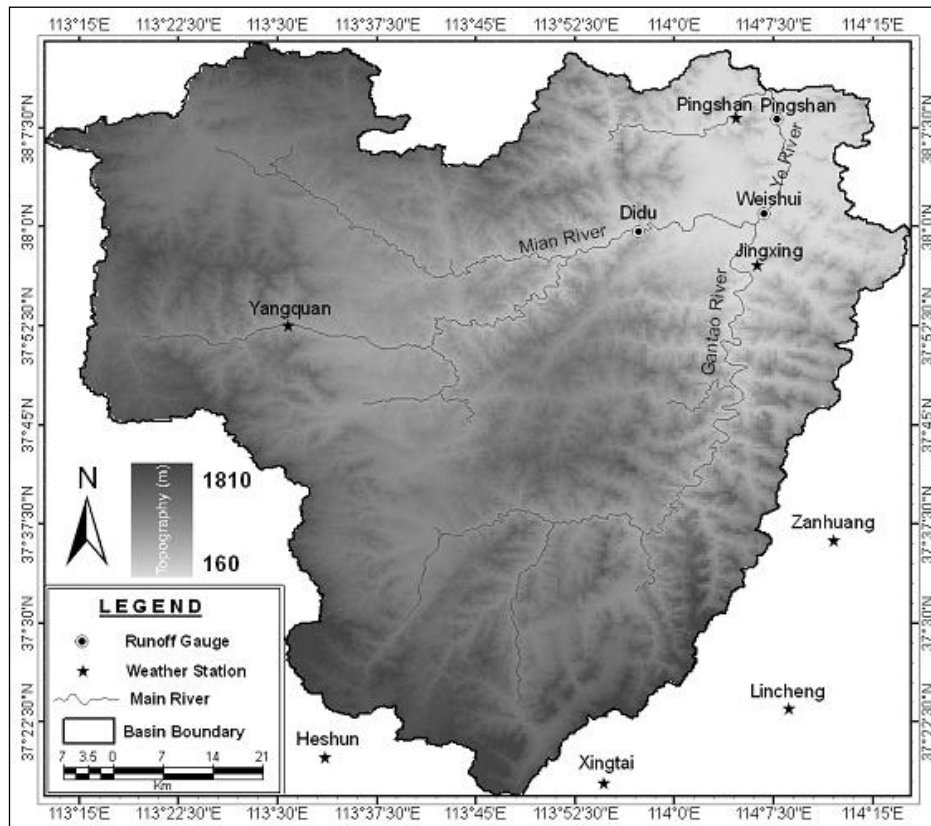


Fig. 1. Yehe River Basin showing drainage, elevation and the location of weather station and runoff gauge.

The climate is one of semi-arid with cold-dry winter and hot-rainy summer, and a mean annual precipitation of 505.81mm (which is highly variable both in space and time), 62.22% of which occurs in the summer/rainy months of July to September. The basin is largely composed of loess formation, of which loessial soil and brown earth constitute the main soil types. Gneiss is the predominant parent material, then shale and limestone. In the basin, major land use types are woodland, grassland and farmland. Woodland is mainly deciduous broad-leaved forest (e.g. *Quercus*) and

coniferous forest (e.g. *Pinus tabulaeformis* and *Platycladus orientalis*), and secondary forests from tree felling and logging comprise mainly of shrubs (e.g. *Vitex negundo* var. *heterophylla* and *Zizyphus jujuba* var. *spinosa*) and herbs (e.g. *Themeda triandra* var. *japonica* and *Bothriochloa ischaemum*). Winter-wheat and summer-maize are the main cultivated crops (under continuous crop rotation system) in the area.

2.2 Data collection and processing

Data used in the study were 34 years (1966 ~ 1999) of continuous daily precipitation from 8 weather stations (3 within the study area and 5 in the immediate environs) and daily flow data from Pingshan gauge station at the main outlet of the basin (Fig. 1). To get the daily precipitation of the basin, precipitation from the 8 weather stations was averaged on daily basis while the basin daily runoff was direct daily flow measurement at Pingshan gauge station, the main outlet of Yehe River Basin. Precipitation was monitored by manual Rain Gauge (the SM1 model manufactured by Shanghai Meteorological Instrument Factory Co., Ltd, China) and runoff monitored using a rectangular weir as established by ISO (International Standards Organization) for the measurement of liquid flow in open channels. In addition, a 90 m resolution NASA-DEM (National Aeronautics and Space Administration – Digital Elevation Model) was used to generate slope, river network and the basin boundary.

2.3 Detailed research procedure

The study covered a period of continuous observation data (1966 ~ 1999) that is sufficiently long enough for the analysis of long-term hydrological and climatic changes. Specifically, precipitation and human activity, the two driving factors of runoff were investigated for Yehe River Basin.

To assess the impact of human activity and climate change on runoff in the basin, three dry-years (1970, 1981 and 1993) and two wet-years (1976 and 1995) were selected. The rationale for the adoption of the above selection criteria was to compare runoff for similar precipitation events and for representative wet- and dry-years. Such comparison can enable us to easily and reliably isolate human and climate impact on runoff. The precipitation and runoff for the representative dry-years are 440.29mm and 15.32m³/s (1970), 439.21mm and 6.53m³/s (1981) and 433.91mm and 3.70m³/s (1993); and those for the representative wet-years are 651.94mm and 18.01m³/s (1976) and 643.63mm and 14.10m³/s (1995), respectively.

Through regression analysis, the relation between runoff, precipitation, human activity and climate change was established (for different time-scales), and human and

climatic effects on runoff isolated. In addition, the semi-quantitative analysis approach (Wang et al., 2006) was adopted to quantify the isolated human and climatic effect on runoff. For that purpose, the research period was again divided into two periods, based on the level of development of land and water resources in the basin. There is the pre-development period (1966 ~ 1979) – when land and water resources development was assumed to be minimal, hence insignificant perceived human effect on runoff. There is also the post-development period (1980 ~ 1999) – which was assumed to have witnessed a relatively extensive land and water resources development, hence a significant perceived human effect on runoff. Generally, the slope of runoff and precipitation curve is a reliable indicator of water use, which was exploited to determine human water use for the post-development period. From the correlation so developed between precipitation and runoff for the pre-development period, runoff for the post-development period, without human effect, was predicted using observed precipitation data. The difference between the predicted and measured runoff for the post-development period thus gave the quantitative measure human impact on runoff. Again assuming that precipitation was only influenced by climate change for the entire simulation period, predicted runoff for the post-development period was compared with observed runoff for the pre-development period, which gave the quantitative measure of the effect of climate change on runoff.

3 Results and Discussion

3.1 Long-term runoff and precipitation

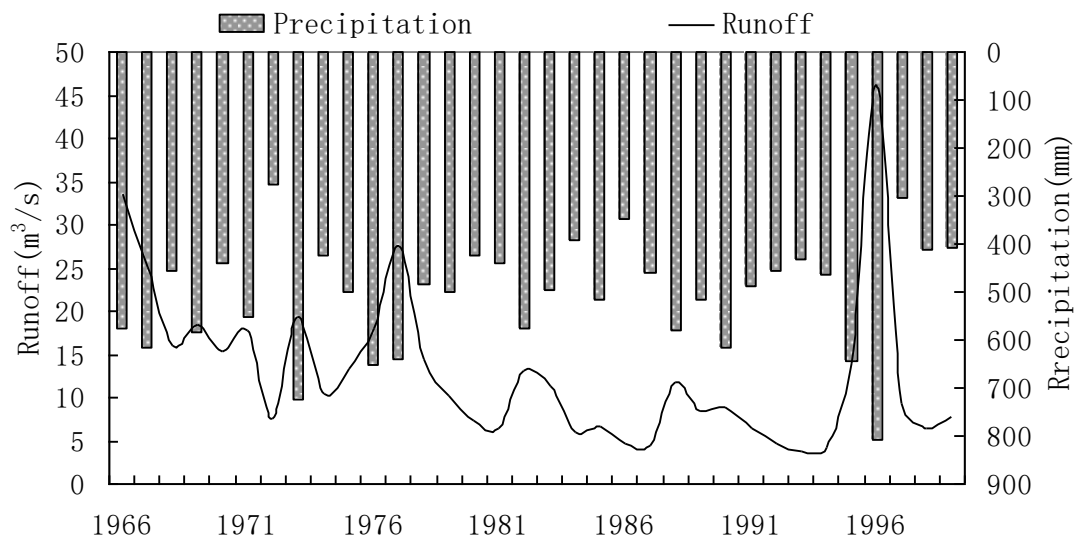


Fig. 2. Average annual runoff and precipitation in Yehe River Basin (1966 ~ 1999).

Fig. 2 illustrates the time-series of average annual runoff and precipitation in the basin. About 58.82% of the annual precipitation is below-average (i.e. below the long-term annual average precipitation of 505.81mm), while the remaining 41.18% is above-average, Furthermore, there is a longer (on the average of 3 ~ 4 years) and

frequent succession of below-average precipitation years, yielding low runoff. On the other hand, the succession (and on the average of only 1 ~ 2 years) of above-average precipitation years is quite low, yielding sporadic but high runoff.

It generally follows that runoff increases with increase in precipitation and decreases with decrease in precipitation. However, the rate of change of precipitation is not always equal to that of runoff. In Table 1, for instance, while precipitation dropped by 6.92% from the 1960s to '70s, runoff dropped by 33.72%; and when precipitation rose by 6.04% from the 1980s to '90s, runoff increased by 38.55%. The abrupt rise in runoff was due to extensive flooding in 1996, one of the wettest years of the century in the basin. In the devastating flood, with about 809.81mm precipitation and a peak flow of $1.3 \times 10^4 \text{m}^3/\text{s}$, average annual runoff rose above normal years by 6 orders of magnitude.

Table 1

Variation in stream flow and precipitation (1966 ~ 1999) in Ye River Basin.

Period	Appt.	Arof.	Period	Pvprof.		Pvppt.	
				Difference	%	Difference	%
1966 ~ 1969	557.79	23.27	70s-60s	-7.85	33.72	-38.60	6.92
1970 ~ 1979	519.19	15.42	80s-60s	-15.22	65.43	-83.38	14.95
1980 ~ 1989	474.40	8.04	80s-70s	-7.38	47.84	-44.78	8.63
1990 ~ 1999	503.06	11.14	90s-60s	-12.12	52.10	-54.73	9.81
—	—	—	90s-70s	-4.28	27.74	-16.13	3.11
—	—	—	90s-80s	3.10	38.55	28.65	6.04

Appt. = annual precipitation (mm), Arof. = annual runoff (m^3/s), Pvprof. = difference in runoff between periods (m^3/s), Pvppt. = precipitation difference between periods (mm). Note: negative value denotes a drop in runoff or precipitation.

Compared with the 1960s, runoff dropped by approximately 52.10% in the 1990s while precipitation declined by only 9.81% over the same period. The discrepancy between runoff and precipitation is more a function of water diversion and environmentally hostile human activity in the basin than climate change.

3.2 Runoff in representative wet- and dry-years

Fig. 3 and Fig. 4 are, respectively, average monthly precipitation and runoff for the representative dry-year and wet-year. In the dry-year scenario, there was less surface water and a significant decline in reservoir storage. In similar manner, from July to September, i.e. the wet months/rainy-season, average runoff in the wet-years (1976 and 1995) was respectively $42.29 \text{m}^3/\text{s}$ and $37.47 \text{m}^3/\text{s}$ with corresponding precipitation of 155.96mm and 146.93mm. Also from October to June, i.e. the dry months/non-rainy season, annual average runoff and precipitation were respectively

9.75m³/s and 6.32m³/s and 15.14mm and 17.30mm, runoff declined faster in non-rainy seasons than in rainy seasons, the same precipitation produce less runoff.

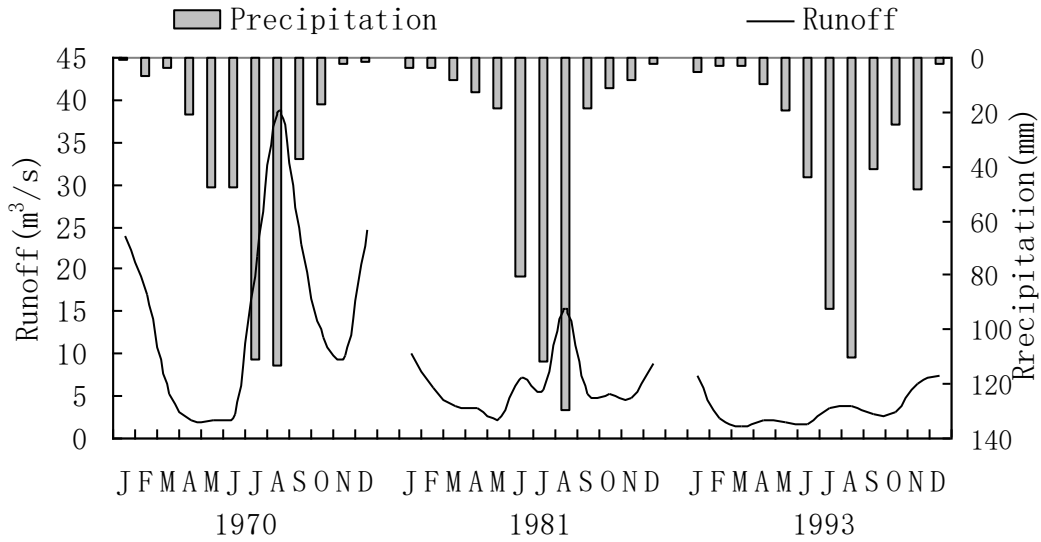


Fig. 3. Average monthly precipitation and runoff for the dry-year scenario (1970, 1981 and 1993).

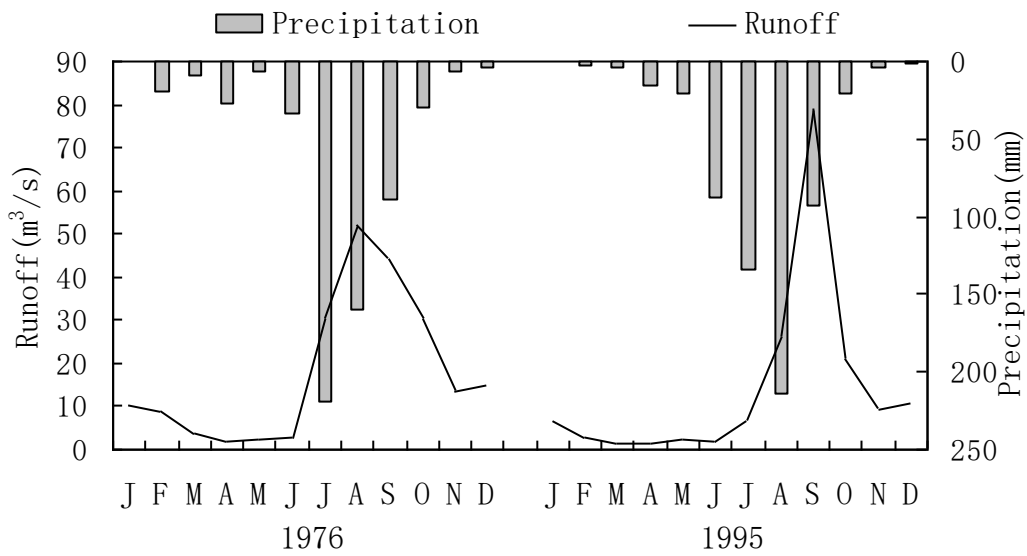


Fig. 4. Average monthly precipitation and runoff for the wet-year scenario (1976 and 1995).

Runoff for the representative wet-years indicates abundance of precipitation in wet rainy seasons, hence increased runoff. At the same time, water diversion for irrigation, industrial and domestic use is minimal during this period. It is the exact contrary in the dry-years and non-rainy seasons of wet-years (i.e. lower runoff with runoff time-series having sharp slopes). There was a general decline in water availability in years of low runoff after the 1980s which can be explained in terms of water use. With increasing water use after the 1980s, water diversion for crop irrigation, industrial (e.g. mining in the nearby province of Shanxi) and domestic use increased leading to drastic declines in runoff.

3.3 Pre- and post-development runoff characteristics

There is an increasing conflict between water supply and demand in China and the situation is predicted to worsen despite repeated efforts at addressing water shortage at county, provincial and national level. Fig. 5 shows the correlation between precipitation and runoff for 1966 ~ 1979 (pre-development period) and 1980 ~ 1999 (post-development period). The slope of the curve for the post-development period is steeper with less runoff, compared with the pre-development period. This can be attributed to a significant increase in human activity and subsequent (water resources) development since the 1980s.

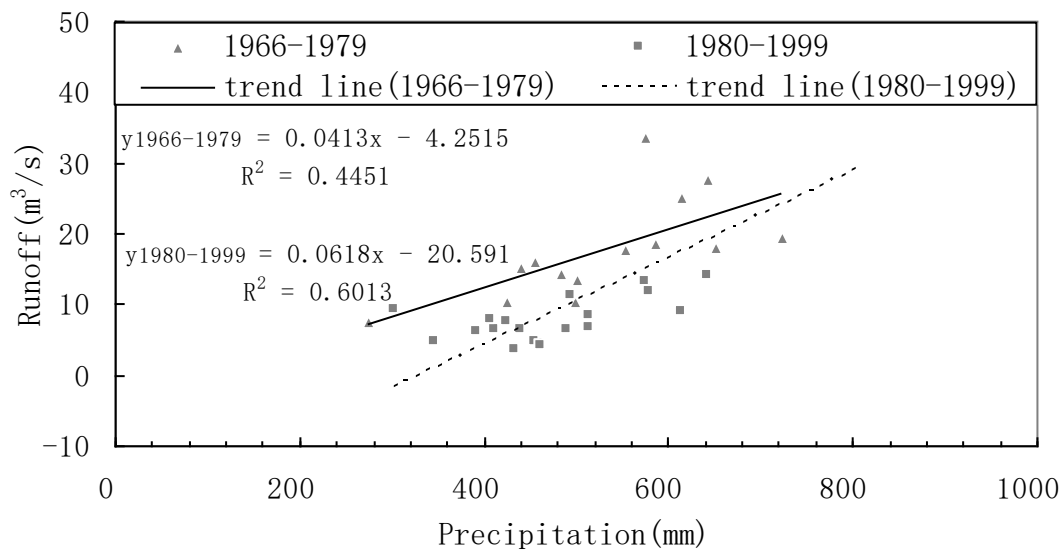


Fig. 5. Correlation plot of runoff and precipitation for the pre-development (1966 ~ 1979) and post-development (1980 ~ 1999) periods.

Guo et al. (2002) attributed the decrease in runoff to climate change, while our 34-year analysis reveals the contrary. The same precipitation produce less runoff, it then implies that climate change was merely an indicator than a cause of runoff decline, thus human activity can only be the main driving factor of declining runoff in the basin. In Fig. 5, the curve for 1980 ~ 1999 is below that for 1966 ~ 1979 with increasing gap towards 1999, which is a strong indication of steady decline in runoff after the 1980s, since precipitation for the two period were very similar. In years with 400mm of precipitation or less, surface water diversion or groundwater withdrawal increased. On the other hand, surface water diversion or groundwater withdrawal dropped in years with 600 mm of precipitation or more. Therefore, the gap between the regression curves could only be explained as the amount of water consumed in dry-years and dry months. After the 1980s, the basin entered a period of rapid economic, industrial and agricultural development as well as rapid urbanization, hence increased water consumption, especially surface water, the primary source of

surface runoff.

3.4 Impact of climate change and human activity on runoff

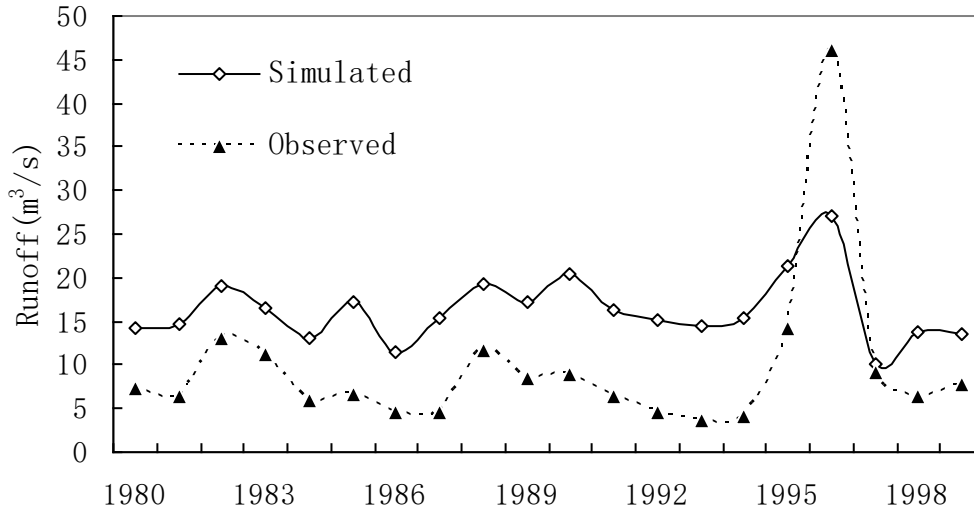


Fig. 6. Simulated and observed runoff in Ye River Basin for 1980 ~ 1999.

The correlations for precipitation and runoff in the pre-development period (the period for which runoff was assumed to be least affected by human activity) was used to predict runoff for the post-development period. By comparing the predicted runoff for post-development period with measured runoff for pre-development period, the impact of climate change on runoff was isolated. And the change in runoff unaccounted for by climate change was simply attributed to human activity. The regression equations used in the analysis are given in Table 2.

Table 2

Impact of climate change and human activity on runoff (1966 ~ 1999) in Yehe River Basin.

a	b	c	d	e	f	g
a	b	c	d = c-b	e = b-a	f = e/d	g = 1-f
55724.11	51340.61	30243.01	-21097.60	-4383.50	20.78	79.22

a = annual runoff (1966 ~ 1979), b = simulated annual runoff (1980 ~ 1999), c = measured annual runoff (1980 ~ 1999), d = runoff drop after 1980, e = climate change impact, f = climate impact ratio (%), g = human impact ratio (%)

Through semi-quantitative analysis of the observed data, the impact of human activity on runoff from the 1960s to 1990s was calculated to be 79.22%, while that of climate change was only 20.78%, implying that 79.22% of runoff drop was driven by human activity over the 34-year period. This again, is a strong indication that climate change has nominally influenced runoff while human activity has had a very significant impact on runoff. Fig. 6 shows the differences between simulated and observed annual runoff for 1980 ~ 1999 in Yehe River Basin, which have very similar (decreasing) trends, indicated the availability of the semi-quantitative method, but

with smaller observed than simulated runoff – except for the 1996 flood year; an indication the semi-quantitative analysis approach slightly over-predicts runoff for non-flood periods. The gap between the two curves widened after 1980, and the different value of y-axis in the same year was an indication of increased human activity in the basin.

4 Conclusion and recommendation

Through regression and semi-quantitative analyses, we have successfully quantified the relations between environmental change and runoff, and isolated the dominant factor (human activity) for runoff decrease in Yehe River Basin. Though climate change has been generally acknowledged to be a dominant factor for decreasing runoff, our 34-year (1966 ~ 1999) simulation results have shown that decreasing runoff from climate change was very minimal compared with that from human activity. Runoff decreased by 52.76% from the 1960s to '90s, and human activity alone accounted for some 79.22% of that decrease. Furthermore, observed annual and monthly mean stream flows for both the dry- and wet-year scenarios and regression analysis results for runoff and precipitation (at different time-scales) showed that climate change was not the principal factor for decreasing runoff in Yehe River Basin. Human activity e.g. population growth, socio-economic development, land use and irrigated agriculture, is a more important factor influencing the occurrence and distribution runoff.

In Yehe River Basin, water shortage remains a nagging constraint for sustainable socio-economic development and protection of the ecological environmental systems against catastrophic degradation. Thus, our research findings can serve as a relevant scientific base for policy/decision-makers, environmental scientists and land and water resources engineers in the planning and development of future strategies for sustainable management of the basin. This can be found particularly useful in the allocation of delivered water through the middle route of the South-to-North Water Transfer Project, or similar other projects in Haihe River Catchment. Despite our achievements in this research, however, we recommend that similar study be replicated for the other subbasins in Haihe River Catchment, given the strategic importance and level of water shortage in the region.

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