Response of Natural Runoff to Recent Climatic Changes in the Yellow River Basin, China

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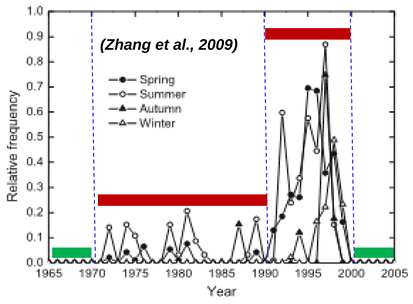
Summary

China's Yellow River has been running dry in its lower reaches since 1972 due to regional climatic changes and the increase of human water use. The river drying-up, indicated by the frequency of zero-flow days at the river mouth, started to occur in the 1970s, peaked in the 1990s, however, ended in the 2000s. Besides some engineering measures taken to maintain ecological flow, recovery of natural runoff responding to recent climatic changes may have also contributed to the reduction of drying-up. In this study, we used a hydrological model, the Soil Water Assessment Tool (SWAT), and climate elasticity of runoff to assess the impact of climatic changes on the natural runoff above Huayuankou station of the Yellow River. The results show that the natural runoff in the recent period (2003-2011) is about 5% above the mean runoff in the historical period of 1960-1990 while the precipitation in the recent period is 1% below that in the historical period. The analysis of runoff elasticity further suggests that the larger than expected runoff recovery is related to decline of wind speed and net radiation.

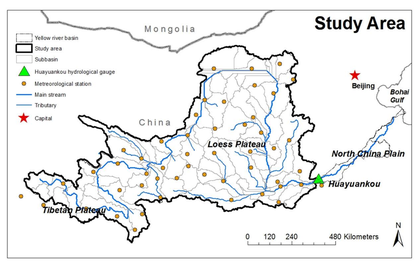
1 Background



The frequency of the drying-up phenomenon increased rapidly in the 1990s, however, the drying-up phenomenon seemed to disappear in the 2000s (Zhang et al. 2009). The frequent drying-up phenomenon in the 1990s was attributed to intensified human activities and climatic changes. Climatic change is the dominant cause of river flow reduction above the Huayuankou station, accounting for three quarter of annual streamflow changes (Tang et al. 2008). Recent climatic change in the river basin may be an important factor and will be discussed in this paper.

We compared the analytical estimates with the results from hydrological model, the Soil Water Assessment Tool (SWAT), and investigated the possible climatic factors contributed to recent runoff change and the disappearing drying-up phenomenon.

2 Study Area and Data



Data	Source	Resolution
DEM	http://datamirror.csdb.cn/admin/datademMain.jsp	1km*1km
Soil map	ISSCAS	1:4,000,000
Soil data	http://www.soil.csdb.cn	
Land use	(Liu et al., 2003)	1km*1km
Meteorological data	CMA	Daily (1957-2009)
Runoff data	YRCC	Monthly (1956-2000)

The study area is the catchment area above the Huayuankou station with an area approximating 97% of the total area of the Yellow River basin. The study area is largely in the semi-arid and arid regions where the annual mean precipitation ranges from 300 to 700 mm.

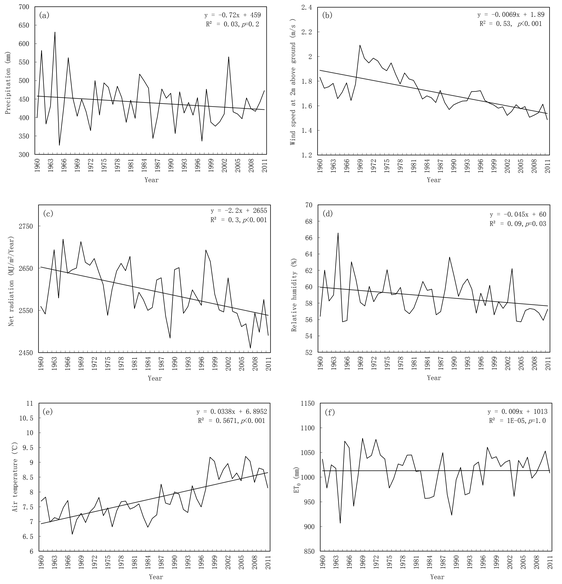
3 Method

The historical period of 1960-1990 was used as the baseline period. The past period of 1991-2002 was the low flow period and the recent period of 2003-2011 was the recovery period of the observed river flow. The relative changes of the climatic and hydrological variables to the baseline period were computed for the past low flow and recent recovery periods, respectively.

The SWAT model was set up to reproduce the natural streamflow at the Huayuankou station. The catchment area above the station was divided into 76 sub-basins, ranging from 32 to 40,194 km^2 . The model ran at yearly time step during the period of 1955-2011.

The climate elasticity of runoff (ε) was used to attribute the changes in natural runoff to changes in different climatic variables for the past low flow and recent recovery periods. The runoff elasticities to precipitation (P), net radiation (R_n), mean air temperature (T), wind speed (U_2), and relative humidity (RH) were derived using the annual mean climatic variables in the baseline period of 1960-1990 following the derivation described in Yang and Yang (2011). The derived annual runoff was compared with the SWAT simulated runoff and the naturalized streamflow from CMA during the overlap periods.

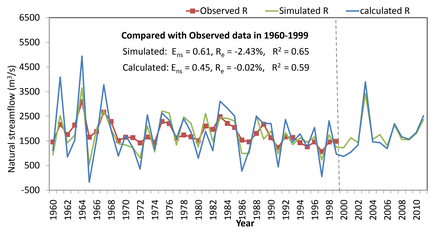
4 Results & Discussion



	P (mm)	R_n (MJ m^{-2} a^{-1})	T (℃)	U_2(m/s)	RH (%)	ET_0 (mm)
1960-1990	450	2617	7.38	1.79	59.31	1011
1991-2002	409	2597	8.21	1.64	58.65	1018
2003-2011	444	2521	8.64	1.56	57.27	1017
Change (1991-2002)	-9%	-0.7%	0.83	-8.5%	-1%	0.69%
Change (2003-2011)	-1%	-3.6%	1.25	-13%	-3%	0.59%

The above figure shows the changes in the climatic variables and potential evaporation during the period of 1960-2011 in the study area.

The above table shows annual mean value of climatic variables and potential evaporation in three periods, respectively and the relative changes to the baseline period.



	Observed ($m s^{-2}$)	SWAT Simulated ($m s^{-2}$)	Derived from elasticities ($m s^{-2}$)
1960-1990	1899	1846	1899
1991-2002		1407	1327
2003-2011		1939	1974
Change (1991-2002)		-23.8 %	-30.1 %
Change (2003-2011)		5.0 %	3.9 %

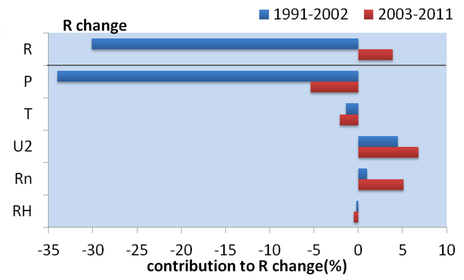
The above figure shows comparing annual natural runoff derived from the runoff elasticities and estimates from SWAT model with observed naturalized streamflow at Huayuankou station. The evaluation indices were calculated based on the data in 1960-1999.

The above table shows changes in natural runoff between the periods of 1991-2002 and 2003-2011 and the baseline period of 1960-1990.

		P	Rn	T	U2	RH
	Runoff elasticities(ε)	3.8	-1.4	-1.8	-0.55	0.16
1991-2002	change	-9%	-0.7%	0.83℃	-8.5%	-1%
2003-2011	Change	-1%	-3.6%	1.25℃	-13%	-3%

The above table shows estimated runoff elasticities, changes in the climatic variables to the baseline period (1960-1990).

The right figure shows separated contributions of the climatic variables to runoff change.



5 Conclusion

Our results show that the natural runoff in the recent period (2003-2011) is about 5% above the mean runoff in the historical period of 1960-1990 while the precipitation in the recent period is 1% below that in the historical period. The analysis of runoff elasticity further suggests that the larger than expected runoff recovery is related to decline of wind speed and net radiation.

References

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