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Hydrology and Earth System Sciences Discussions

Interactive comment on "The causes of flow regime shifts in the semi-arid Hailiutu River, Northwest China" *by* Z. Yang et al.

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We appreciate very much the critical review and constructive suggestions which are useful for the improvement of the manuscript. Below, we address the comments point by point.

Major issue 1:

We agree that we have to clarify the discussion of the temperature impact in the revised manuscript. Since the temperature during winter season is below zero, evaporation is assumed to be negligible in the study catchment. Therefore, average temperature in growing season (from Aril to October; summer half-year) was used for the detection of

relevant temperature changes. We will also use the average temperature in growing season for regression analysis in the revisions.

The change point detection methods indentified an increase of average growing-season temperature since 1997. This temperature increase could have an impact on the decrease of river flows since the actual evaporation was expected to increase with a higher temperature. On the contrary, river flow has increased since 2001. The main cause was the significant decrease of crop area with the implementation of the policy to return farmland to forest and grassland that started in 1999. In the study catchment, crop area in large parts returned to nature, which are desert bushes. Actual evaporation from desert bushes is much smaller than from irrigated cropland under a higher temperature. The decrease of net water use because of large decrease in crop area had much larger impact on the river flow than a possible increase of actual evaporation from desert bushes under higher temperature. This explains why river flows have increased in spite of the temperature increase.

From correlation coefficient matrix of Table 6, it can be seen that the correlation coefficient between river discharge and crop area (-0.71) is much larger than those of precipitation (0.42) or temperature (-0.35). The regression coefficient for temperature in the regression equation is larger than those of crop area and precipitation due to the difference in scales of data. We have used the average temperature during the growing season for the regression analysis. The correlation coefficient between discharge and average temperature during the growing season remained lowest. When discharge, precipitation, crop area and average temperature during growing season are normalized (minus mean and divided by standard deviation), the regression equation becomes:

$Q=0.070145\ P - 0.69773\ Acrop - 0.35120\ T$

It shows again that crop area has the largest regression coefficient. With an increase of crop area or temperature, river discharge decreases since the actual evaporation increases with the increased temperature or crop area.

Major issue 2:

We stated "no correlation between the climatic variables and flow regime shifts was found in this catchment" in line 20 on page 6009. This statement is not precise and it will be changed to "the flow regime shifts were not likely caused by climatic changes".

Of course, the actual evapotranspiration is different from pan evaporation that can serve as a proxy for potential evaporation. It would be good to analyze the change of actual evapotranspiration and its impact on flow regime change. However, there are no historical data sets to estimate actual evapotranspiration, i.e. radiation data nor other climate data (humidity, wind speed) and soil moisture measurements (could be simulated with a continuous water balance model). Furthermore, detailed observations on land management (planting/harvest dates etc.) to convert evaporation estimates to crop evaporation rates are also missing.

However, we agree that both temperature and crop area have effects on actual evaporation. An increase of temperature and/or crop area should be positively correlated with actual evaporation, therefore reduce river discharge. These relationships are shown in Figure 7 and confirmed by regression analysis. However, crop area has a larger effect compared to the temperature as shown by both correlation coefficient and regression coefficient in the reply to the issue 1 (see above).

Land cover change is related to crop area change in the study area. In the river valley, it is the change between maize and nursery garden for trees. Trees (especially young, fast growing trees) may consume more water, but the area is limited. In the upper part of the catchment, it is the change between maize and desert bushes. Desert bushes (not irrigated) consume much less water compared to irrigated maize. We can conclude that with a large decrease of crop area since 1999 (Figure 7), actual evaporation was decreased resulting in an increase of river discharge. Although temperature increased in the same period, but the increase of actual evaporation by the tempera-

ture increase was much less than the reduction of actual evaporation by the crop area decrease.

The changes of crop area are presented in Figure 6f and change points were detected in 1971, 1990 and 1999. A clear description will be provided in the revised text in terms of percentage of changes.

Minor comment 1:

We will do a more thorough literature study and add more references.

Minor comment 2:

We will correct this typo.

Minor comment 3:

Geographically, the study catchment is a part of the Maowusu semi-desert. But the catchment is mainly occupied by xeric shrubland. We will add a land cover map (based on remote sensing images) and indicate percentage of areas covered by cropland, shrubland and other land covers.

The air temperature of 8.1 °C refers to the long-term annual average of daily mean temperature from 1961 to 2006. We will change this sentence in the revised manuscript. We will also change to “southeast monsoon”.

Minor comment 4:

We will describe these time series used in flow regime shift detection in the revised manuscript. The time series of characteristic parameters were derived from the daily river discharge series. Annual mean discharge is the average of daily discharges in each year, which is used to analyze changes in mean flows. Annual maximum discharge is the maximum daily discharge in each year, which is used to analyze the changes in peak flows. Annual mean monthly minimum discharge is the average of minimum daily flow of 12 months in every year, and is used to analyze changes in low flows. Annual mean monthly standard deviation is the average of standard deviations of daily discharges in very month, and is used to analyze the variation in monthly mean flows.

A new table with details of climate and hydrological stations has prepared and will be added to the revised paper. Minor comment 5:

We will rephrase this sentence. We will add a land cover map and indicate percentage of areas covered by cropland, shrubland and others.

Minor comment 6:

We will rephrase the paragraph and describe more clearly as follow.

Fig. 3 is a graphic presentation of Table 2. There are four characteristic time series. Table 2 lists the change points detected by three methods for every characteristic series. Fig. 3 contains the characteristic series (solid line curve) together with their step trends (dotted lines) of annual mean discharge (a), annual maximum discharge (b), mean monthly minimum discharge (c) and annual mean of monthly standard deviation (d). Every change point in Table 2 corresponds to a point of increase or decrease of step trends in Fig. 3. A change point is accepted only, if more than two methods detected the same point. Furthermore, in order to verify this change point, the Student t test in difference in two means was used to ascertain that the mean in the sub-set before the change point and the mean in the sub-set after the change point are statistically significantly different.

Minor comment 7:

We will make these corrections.

Minor comment 8:

We will modify the text accordingly. Hu et al., (2011a) analyzed trends in temperature and rainfall extremes from 16 meteorological stations in the Yellow River source region.

They found no significant changes in annual total rainfall for most of the stations in the Yellow River source region except in the upper part of the region.

Minor comment 9:

We will clarify this issue in the revised manuscript.

The temperatures are very low (< 0 °C) and evaporation is very low in winter season. The growing season starts from April and ends in October. The temperature in the growing season has a direct impact on evaporation. An increase of average temperature in growing season was detected in 1997, which might have impact on the increase of actual evaporation.

On long-term average, less than 8

Minor comment 10:

We will change the sentence to "Four major shifts in the flow regime have been detected in 1968, 1986, 1992 and 2001."

Minor comment 11:

We will explain more clearly that the policy of return farmland to forest and grass land means to covert cropland to xeric brushland in the study area. The brushland is not irrigated and evaporates less than irrigated cropland. This seems to be the main reason for the streamflow increases from 2001 onwards.

Minor comment 12:

Yes, this is still an expert guess. We suspect that the shift of winter peak flow one month earlier is most likely due to the irrigation return flow in the river valley. But there are no data to prove it is the case. We will clarify this in the text and add a sentence to investigate this hypothesis in future research.

Minor comment 13:

Yes, we will add the land surface elevation in Fig. 1.

Minor comment 14:

The y-axis in Fig. 5 will be adjusted.

Minor comment 15:

A mistake was made by inserting a wrong figure in the manuscript. The correct figure is shown below.

Figure 6. Annual precipitation (a), heavy precipitation (>10mm/d) (b), number of days of heavy precipitation (c), annual mean temperature (°C) from April to October (d) at meteorological stations from 1961 to 2006. Annual pan evaporation (e) and annual crop area (f) in Yuyang district from 1957 to 2007, the dotted lines are the means of the data in different periods.

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	Q(mm/a)	P (mm/a)	CA (km$^{2)}$	T (^{0}C)
Q(mm/a)	1.00			
P (mm/a)	0.42	1.00		
CA (km$^{2)}$	-0.71	-0.40	1.00	
T (^{0}C)	-0.31	-0.11	-0.09	1.00

Fig. 1. Table 6. Correlation matrix of river discharge, precipitation, crop area, and temperature in growing season.

Type	Name	Elevation m(a.m.s.l)	Data information
Hydrological station	Hanjiamao	1037	daily discharge from 1957 to 2007, daily river stage (1958~1960、1963~1966、1979~1981、1991~1997、2000)
Meteorological stations	Hanjiamao	1037	daily rainfall in 1961-1963; 1970-2007
	Henan	1247	monthly rainfall and pan evaporation 1985-2004;
	Wushenqi	1302	monthly rainfall and pan evaporation 1985-2008;
	Hengshan	1036	daily rainfall, relative humid, wind speed, air temperature 1961-2006
	Yulin	1082	daily rainfall, relative humid, wind speed, air temperature 1961-2006

Fig. 2. Table 3. List of available data in the research catchment.

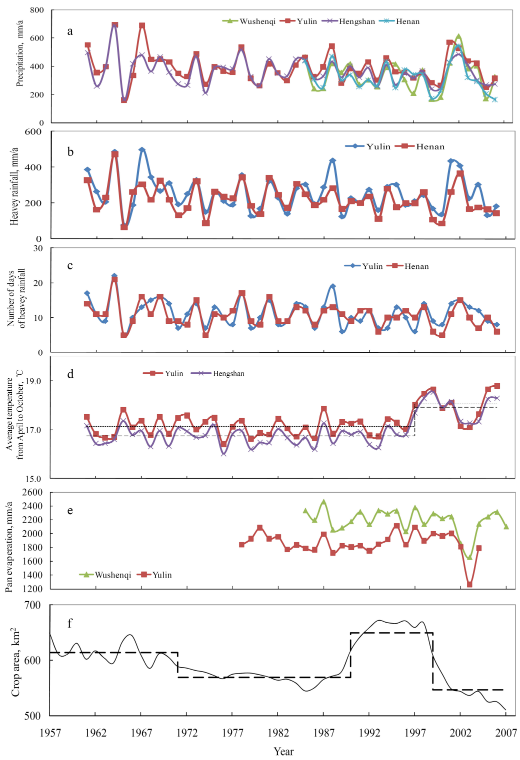

Fig. 3. The caption is too long to be uploaded in the system, please find the caption of the figure in the above text.