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IMPACTS OF CLIMATE FACTORS ON RUNOFF COEFFICIENTS IN THE SOURCE REGIONS OF THE YELLOW RIVER, CHINA

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In the 1990's, runoff at the Tangnaihai hydrologic station experienced a serious decrease which attracted considerable attention. Changes in temperature and rainfall would have an important impact on the availability of water resources. From the point of view of water cycling, runoff coefficients are important indices of water resources conditions in a particular catchment. The Kalinin baseflow separation technique is an improved method based on the characteristics of precipitation and streamflow baseflow. First baseflow is separated, then runoff coefficient(R/P), baseflow coefficient (Br/P) and direct flow coefficient (Dr/P) are estimated. Statistical analyses are applied to assess the impact of precipitation and temperature on runoff coefficients (including Dr/P, Br/P and R/P). Results show that in the source regions of the Yellow River, the mean baseflow coefficient is higher than that of direct runoff. Runoff coefficients are in direct proportion to precipitation and inverse proportion to temperature. The decrease of runoff coefficients in the 1990's are closely related to the decrease in precipitation and increase in temperature. In different subbasins of the source regions of the Yellow River, runoff coefficients responded differently to precipitation and temperature. In the area above the Jimai hydrologic station where temperature is very low, temperature is the main factor influencing the runoff coefficients; runoff coefficients are inversely proportional to temperature, and precipitation has nearly no impact on runoff coefficients. In the subbasin between the Jimai and Maqu hydrologic stations, Dr/P is mainly affected by precipitation while R/P and Br/P are both significantly influenced by precipitation and temperature. In the area between the Maqu and Tangnaihai hydrologic station all three runoff coefficients increased with the rise in annual precipitation, while the direct runoff coefficient is inversely proportional to temperature. In the source regions of the Yellow River with the increase of annual average temperature, the impacts of temperature on runoff coefficients become weak.

INTRODUCTION

Runoff is a renewable resource, and runoff regeneration processes can be described as the cycles that begin with precipitation, then runoff, runoff emptying to the sea, evaporation and vapor transported to continents and precipitation to runoff again. One of the key processes is the conversion of precipitation, P, to runoff, R. Runoff can be separated to direct runoff and baseflow according to the runoff response rate to precipitation. Baseflow generally is defined (Hall, 1968) as the part of river runoff that comes from groundwater storage and other delayed water releases. Runoff coefficients denote the conversion rate of precipitation to runoff. The runoff coefficient (R/P) can be correspondingly divided into a direct runoff (Dr) coefficient (Dr/P) and a baseflow (Br) coefficient (Br/P).

The runoff coefficient can be more than a simple index reflecting the relationship between precipitation and runoff, it may also be a comprehensive index to describe the environment of the regional hydrological cycle. Savenije (1996) used the runoff coefficient as a key to simulate moisture recycling, showed that the annual runoff coefficient is a very good indicator of the importance of recycling and the degree of recycling of moisture in a given area, and a good indicator for monitoring the change over time of the recycling of moisture in a catchment. ; Gottschalk and Weingartner (1998) use runoff coefficient to analyze the distribution of peak flow. Changming Liu and Hongxing Zheng (2004) investigated the impact of change of runoff coefficient on runoff. The conversion of precipitation to runoff is influenced by many factors and in different climate environments the effective factors may be different. Becciu and Paoletti (2000) found that the runoff coefficient shows characteristics typical of random variates.

The regions above the Tangnaihai hydrologic station on the Yellow River are the main runoff generation areas. They contribute more than 35% of the total runoff with 15.3% of the total area, and are less affected by human activities. In the 1990's, runoff at the Tangnaihai hydrologic station had a serious decrease which attracted considerable attention (Wang Genxu et al., 2003; Zhang Shifeng et al. 2004; Zheng and Liu, 2003; Liu and Zeng 2004). Qian Zhenghan et al. (2004) described and identified the no-flow event in the Yellow River. Based on the geologic and physiographic conditions, Wang Wenke et al. (2004) investigated the conversion relationships between the river and groundwater in the Yellow River drainage area. However, the above studies did not provide an in-depth analysis on conversion of precipitation to runoff, especially the impact of climate change in the source regions of the Yellow River.

The main objective of this research is to analyze the change of runoff coefficient and the impact of climate factors. In the next section a short description of the study area and data availability are introduced, and based on the characteristics of climate and streamflow, the third section deals with the improvement of the Kalinin baseflow separation technique. This provides the basis for further analysis in the following sections. The fourth section presents the results, and the impacts of climate factors on runoff coefficient are discussed.

STUDY AREA AND DATA SOURCES

The Yellow River originates from the Yueguzonglie basin in the northern part of the Bayankela Mountains in the Tibet highlands at 4,500 m, flows through nine provinces, with a total length of 5,464 km, has a basin area of 795,000 km^2 (including an isolated inflow area of 42,000 km^2) and finally empties into the Bohai sea. It is the second largest river in China. The total population within the river basin is 107 million, and the cultivated land is 12 million ha. The source regions of the

Yellow River referred to as the regions above the Tangnaihai hydrological station in the Yellow River basin, are located in the northeast part of the Qinghai-Tibet Plateau (Figure 1) which is between 3000 and 5000 m above sea level and is famous as Roof of the World with an area of 122,217 km^2. The elevation ranges from the peak of Alnima at 6282 m to the valley of the Tongde basin at 2,665 m with a fall of 3617 m and average elevation of 4000 m. A series of mountains stretch from the northwest to the southeast, with snow and glaciers on the peaks year round. The head waters area of the Yellow River and its tributaries, the Heihe River, and the Baihe River, are plateau districts with grassland, lakes and swamps. The channel length is 1553 Km and the river slope averages 1.1 ‰ within the study area. The rainfall is influenced by the climate of the Bay of Bengal and the Pacific with maximum average monthly rainfall in the summer, accounting for 75% to 90% of the annual total, and a minimum in the winter (Figure 2). Precipitation events are characterized by long duration, low intensity and large areal extent. Annual precipitation varies from 250 mm to 750 mm. The mean annual flow at the Tangnaihai hydrologic station is calculated at 649 m^3/s or 204.70×10^8 m^3/yr which is more than 35% of the total Yellow River flow. Snowmelt runoff is the dominant form of runoff during winter and spring, while runoff from rainfall is dominant during summer and fall. With the change of climate, surficial and subsurface conditions, and the development of the Chinese economy the runoff of the study area has experienced several wide fluctuations, and the annual runoff decreased drastically in the 1990's. The regions for this study are divided into four subbasins as control sections at the locations of the four hydrologic stations (Huangheyan, Jimai, Maqu, and Tangnaihai) (Figure 1).

Due to the low population and economic development level in the area, very few data collection points exist in the basin. Figure 1 presents and lists the locations of the hydrometeorological stations used in this study. The precipitation and temperature of each subbasin are computed using the arithmetical mean of the meteorological data of the subbasin.

METHODOLOGY

Pearson correlation coefficient

Pearson's correlation coefficient, which functions as a measure of similarity between variables, measures the strength and direction (decreasing or increasing, depending on the sign) of a linear relationship between two variables X and Y and can be defined as

$$r = \frac{\sum (X-\overline{X})(Y-\overline{Y})}{\sqrt{\sum (X-\overline{X})^2 (Y-\overline{Y})^2}} \tag{1}$$

where $\overline{X}$ and $\overline{Y}$ denote the means of the two variables. Let A and B be climate factors and runoff respectively in the sample. The row X denotes the value of the climate, while the row Y denotes the value of the runoff. If A and B are in relative agreement, then the value of r will be high, whose positive (negative) sign indicates linear increasing (decreasing). A nonparametric method is suggested to estimate the statistical significance of a computed correlation coefficient.

Baseflow separation

Baseflow separation has long been a topic of interest in hydrology (Hall, 1968; Tallaksen, 1995) since the baseflow recession curve itself contains valuable information about aquifer properties. Baseflow recession analyses are routinely used in low flow forecasting, water supply allocation,

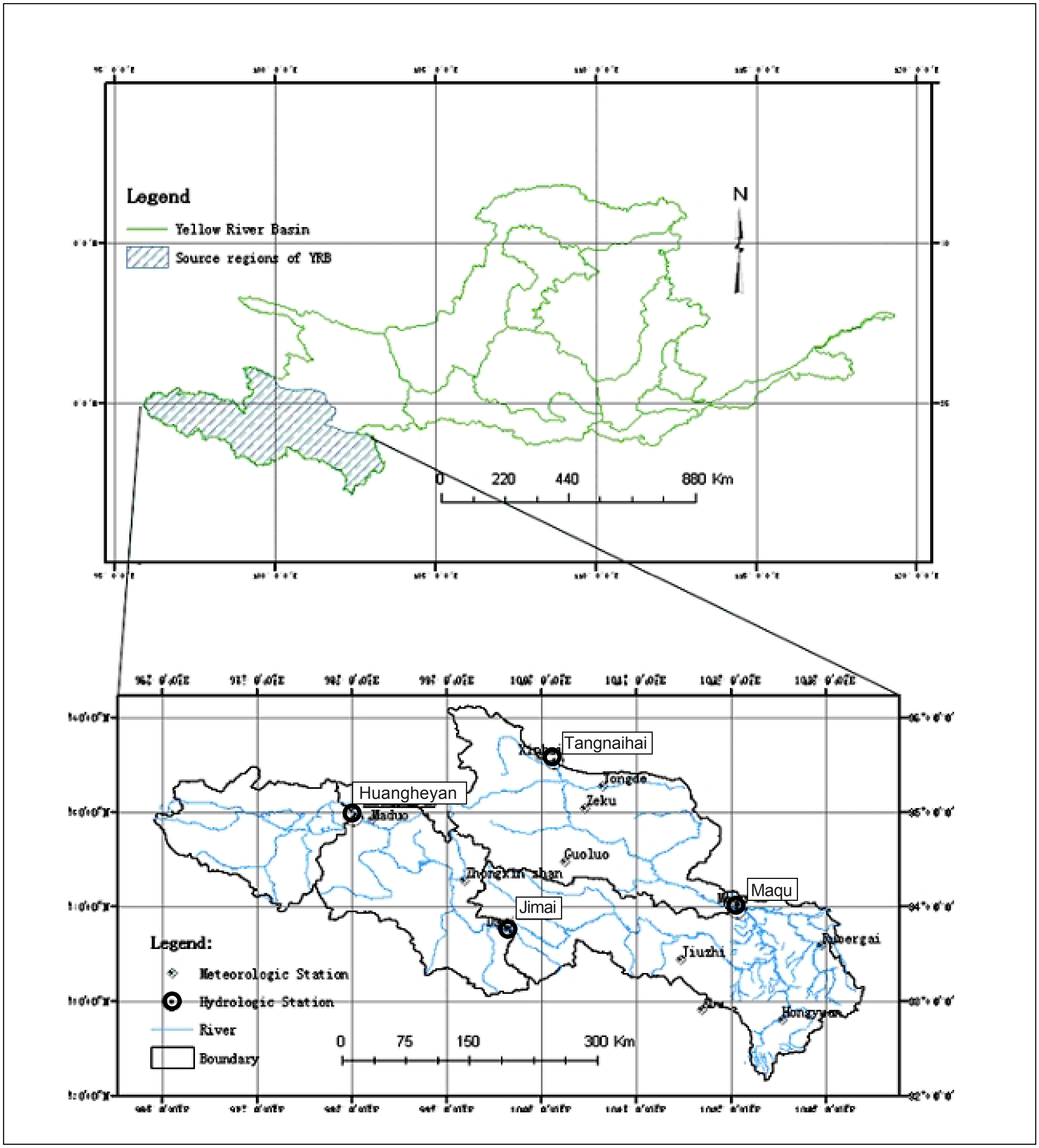

Figure 1. Location and rivernet of the study regions.

hydroelectric powerplant designs and in waste dilution schemes (Tallaksen, 1995). Also, baseflow separation from quick storm response is required for numerous widely used hydrological models (e.g. the HEC-1 flood hydrograph package by the US Army Corps of Engineers, and unit hydrograph techniques) and other water resource applications (Vogel and Kroll, 1996). There are a large number of existing techniques and a high level of subjectivity in separating baseflow contribution from total streamflow (Tallaksen, 1995). In this paper the Kalinin baseflow separation technique (Ding Zhili et al., 2003), based on water balance, is applied to separate the baseflow from streamflow with a daily time series. The Kalinin baseflow separation technique can be represented by:

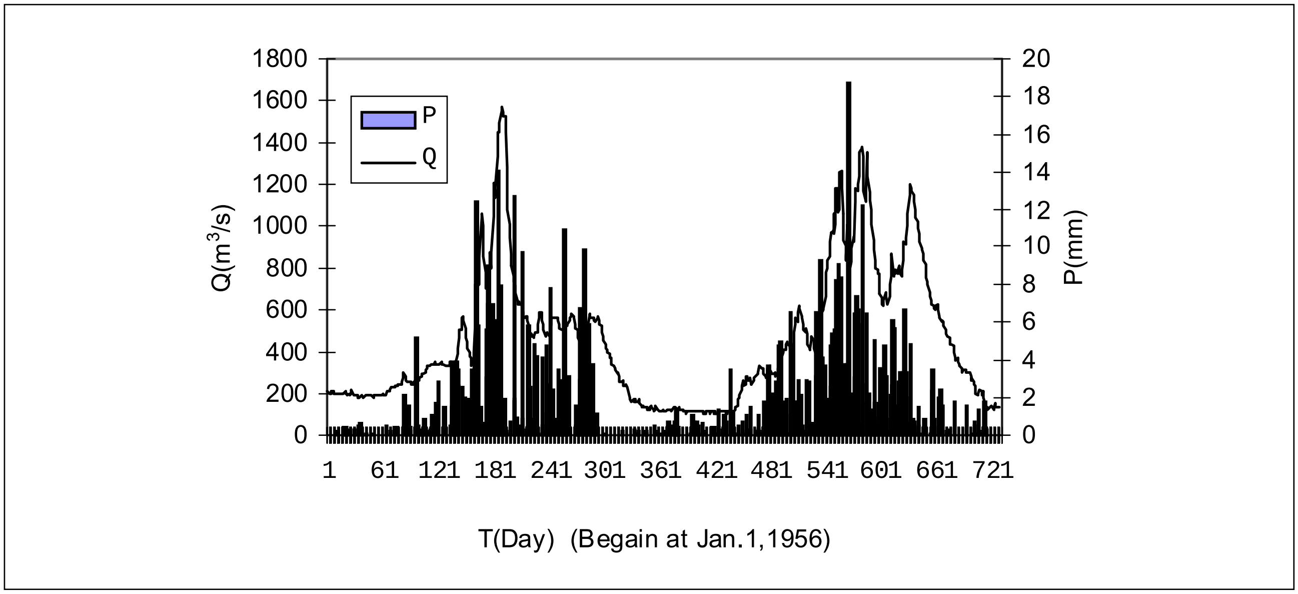

Figure 2. Mean precipitation and runoff of the study area from 1956 to 2000.

$$Q_b^n = \theta\overline{Q}_{n-1} + \lambda Q_b^{n-1} \tag{2}$$

where:

$$\begin{aligned} \theta &= \beta\alpha\Delta t \\ \lambda &= 1-(1+\beta)\alpha\Delta t \end{aligned} \tag{3}$$

$\overline{Q}_{n-1}$ is the average runoff at time step n-1 and n, Q_b^{n-1} is the baseflow at time n-1, α is the recession constant, and β is a coefficient determined by trial or experience, the value of which is around the ratio of annual baseflow to annual direct flow.

The Kalinin baseflow separation technique includes two parameters: recession constant α and ratio coefficient β. The recession constant is derived from the recession curve during time periods with no or low rain. The recession curve plots as a straight line on a semilogarithmic plot of *t* against log *Qt* and the recession constant is the absolute value of the slope coefficient. The recession constant is affected by precipitation, evaporation (Wittenberg and Sivapalan, 1999) and flow data errors. Figure 2 shows that precipitation is very low in winter in the study area, and in order to reduce errors two criteria should be satisfied when estimating recession constants: 1) the number of the days of the recession curve used to estimate recession constant should exceed 30 and 2) the Nash coefficient should be greater than 0.95 when a linear regression fit is applied to derive the slope rate (Figure 3). As shown in Figure 3 the recession constant is 0.0255.

The ratio coefficient β, determined empirically or by trial rather than theoretically, is based on the constituents of runoff of the study area. Through most of the dry season of the year, the streamflow discharge is composed entirely of baseflow. In a wet season, discharge is made up of baseflow and surface runoff, which represents the direct catchment response to rainfall events. Precipitation in the last two months is very low in the study regions (Figure 2). The following steps were proposed to separate baseflow:

1) Prepare input data one year at a time, including daily flow data, direct flow starting date (rising point in Figure 4) and the recession constant;

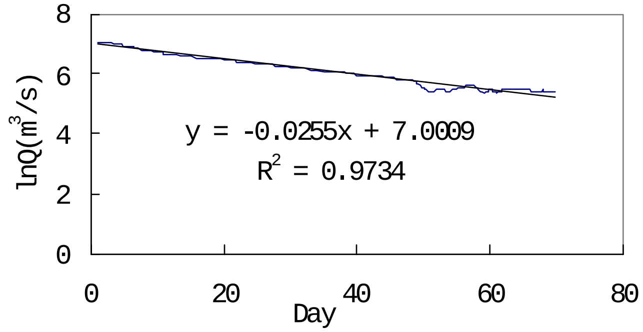

Figure 3. The computation of the runoff recession coefficient of Tangnaihai Hydrologic Station of the Year of 1958.

2) Initialize coefficient β with a range according to the constituents of the runoff component. Define an interval used to retrieve the coefficient β as an interval in the range from a low bound to a high bound. In this paper the coefficient β is initialized to the range of [0.5,4.0] and the interval of 0.01;

3) During time periods out of recession (namely the time periods from the rising point to the inflection point in Figure 4), use a ratio coefficient of β retrieved in step (2) once at a time, daily flow data, and the recession coefficient as input to Equation (2) to estimate the baseflow process. If the estimated baseflow process intersects with the streamflow process, discharge the ratio coefficient β, or else store it.

4) In the recession period (the periods after the inflection point in Figure 4) using the ratio coefficient achieved in step (3) once at a time, daily flow data and recession coefficient as input to Equation (2) to optimize the final ratio coefficient β. The least square sum, $\sum_{i=1}^{n}(Q^{i}{}_{observ} - Q^{i}{}_{compute})^{2}$, is used as the optimization criterion. Where $Q^{i}{}_{observ}$ is the observed streamflow and $Q^{i}{}_{compute}$ is the estimated baseflow at time step i in recession periods.

5) Separate baseflow from streamflow by applying Equation (2) to the whole year with daily runoff, the β coefficient derived in step (4), the recession constant and the direct flow begin date - the rising point as shown in Figure 4.

6) Repeat the steps (1) to (5) to separate baseflow from streamflow of the next year up to the final year.

These improvements reduced the required input parameters and the only input parameter is the recession constant. The estimated baseflow process is more objective depending on the shape of the hydrograph.

RESULT AND ANALYSIS

The runoff coefficients of the source regions

Annual average precipitation is 630.17×10^{8} m^3, runoff of 203.8×10^{8} m^3 , R/P of 0.320, Dr/P of 0.112 and Br/P of 0.209 during the time periods of 1956 to 2000 in the source regions of Yellow River (Table 1). The baseflow coefficient is greater than that of direct flow. The correlation coefficients of P against R/P and Dr/P are 0.463 and 0.452 respectively which are relatively

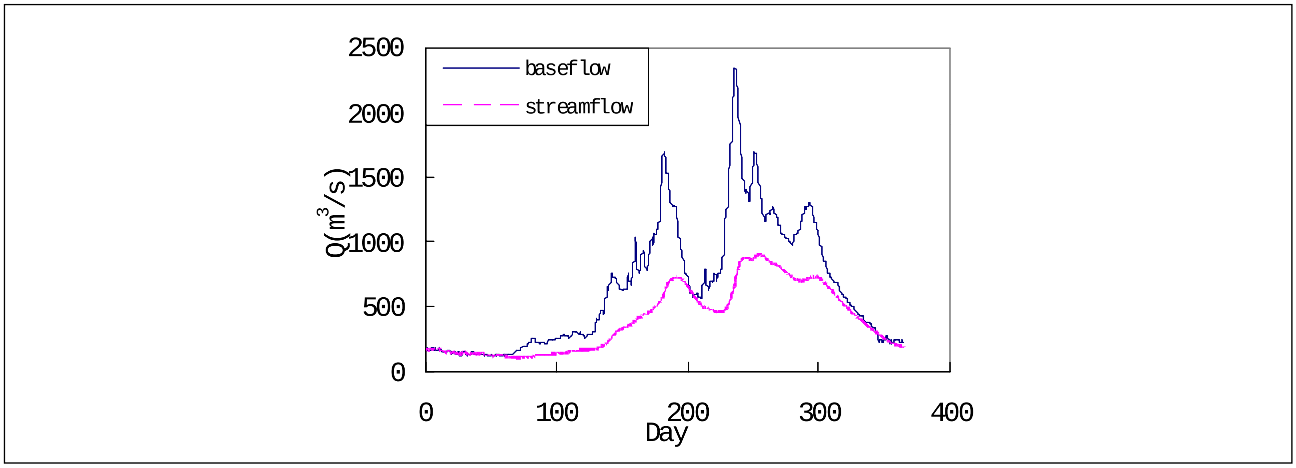

Figure 4. The runoff component separation of Tangnaihai hydrologic station of the year of 1958

Table 1. Runoff coefficients of the source regions of the Yellow River.

Year	$P\times10^8m^3$	Average T°C	R $\times10^8m^3$	R/P	Dr/P	Br/P
1956-1970	606.08	-0.97	196.91	0.322	0.112	0.210
1971-1980	649.30	-0.61	208.50	0.317	0.108	0.209
1981-1990	681.80	-0.40	238.67	0.346	0.128	0.218
1991-2000	642.80	0.11	174.70	0.272	0.089	0.183
1956-1990	629.57	-0.70	212.15	0.334	0.117	0.216
1956-2000	630.17	-0.52	203.81	0.320	0.112	0.209

significant at a level of 0.01. The correlation coefficient of 5 years moving average of precipitation against Br/P is 0.311. Although it is low, the correlation is relatively significant at a level of 0.05. Thus we could conclude that precipitation has significant impact on R/P and Dr/P on an annual time scale while the impact of precipitation on Br/P can be seen on a multi-year time scale in the study area.

Regression lines are fitted between annual average temperatures against time t (Figure 5). The correlation coefficient of the regression line is 0.83, which is significant and shows a significant increase in temperature. The correlation coefficients of T against R/P and Dr/P are -0.329 and -0.311 respectively and they pass the test of significance at the 0.05 level. The correlation coefficient of 3 years moving average of T against Br/P is -0.350. Although the value is low, the correlation is relatively significant at a level of 0.05. The temperature has negative effects on R/P, Dr/P and Br/P.

In the analysis we can see that R/P and Dr/P are influenced both by temperature and precipitation but the influence of precipitation is significant on an annual time scale. Br/P is affected both by temperature and precipitation but only at a multi-year scale can the influences be displayed. It responds more quickly to temperature than to precipitation.

In the 1990’s annual average precipitation was greater than that of 1956-2000 and annual average temperature greater than any other time periods listed in Table 2 while R/P, Dr/P and Br/P are the lowest among the time periods (Table 2). Table 2 also shows that the temperature rise rate is 0.2°C/10yr before 1990 and 0.51°C/10yr in the 1990’s. Partial correlation analysis of T against Dr/P is applied using precipitation as a control factor. The coefficient is -0.76 which is significant at a level of 0.02. The rapid rising of temperature in the 1990’s has a noticeable impact on Dr/P.

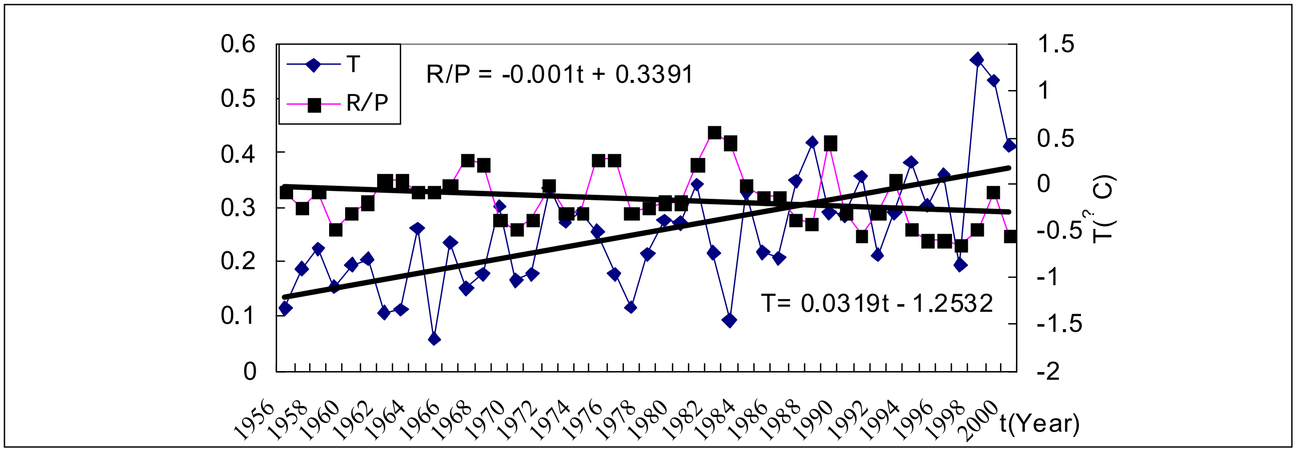

Figure 5. The annual temperatures runoff coefficients of the source regions of the Yellow River.

Frozen soil is another important factor. The annual average temperature of the study regions is -0.52 °C and the mean elevation is about 4000 m. There are widely distributed permafrost and seasonal frozen soils. Since the 1950's annual temperature shows an pronounced increasing tendency (Figure 5). The increasing rate of annual average temperature was 0.2°C/10yr during time periods of 1950-1990 while it reached 0.51°C/10yr in the 1990's. With the rising of temperature the frozen soil will melt. Research has indicated the thickness of permafrost will decrease 3-5 m with a temperature rise rate of 0.2-0.3°C/yr (Wang Shaoling, 1991). Thus we can conclude that in the 1990's the frozen soil thawed at a rate of 3-5m/10yr more than before. Frozen soil can prevent precipitation from infiltrating to deeper soil and keep the groundwater table up. If the elevation lower bound of the frozen soil is 4150 m, there are 31500 km^2 covered with frozen soil. With the melting of the frozen soil the soils will be filled with liquid water so runoff should decrease more than 8-12mm/yr in the 1990's compared to the time periods of 1950-1990. The characteristic of a precipitation of low intensity and long duration is favorable for infiltration so that the direct runoff decreases. The shallow soil moisture will decrease in dry conditions because the groundwater table moves downward, thus decreasing the baseflow. Frozen soil may disappear in some places with the continuous melt of frozen soil, and the groundwater table will move downwards. This will cause a deterioration of the basin's eco-environment with adverse impact on agricultural activities.

RUNOFF COEFFICIENTS OF SUBBASINS

Baseflow was separated from streamflow at the Tangnaihai, Maqu, Jimai and Huangheyan hydrologic stations with daily flow data, then the separated daily series were accumulated to annual series. The baseflow, direct flow and total runoff of the subbasins between two hydrologic stations (Figure 1) are computed using the annual series. The precipitation and temperature are calculated from the meteorological station in each subbasin. The head regions have the least runoff with mean coefficient of 0.097 and the subbasin between Maqu and Tangnaihai has the largest of 0.455 (Table 2).

Head regions of the Yellow River

Head regions of Yellow River are the area above the Huangheyan hydrologic station of the Yellow River with an area of 20930 km^2. The area is very cold and arid with annual average temperature of -3.89 °C and precipitation of 65.5×10^8 m^3. The mean R/P, Dr/P, Br/P are 0.097, 0.039 and 0.058 respectively which show the runoff regeneration ability is very weak. In Table 2

Table 2 Runoff coefficients of subbasin of the source regions of the Yellow river

Subbasin	Area (Km^2)	Year periods	P $\times 10^8 m^3$	Mean T°C	Runoff $\times 10^8 m^3$	R/P	Dr/P	Br/P
Head regions	20930	1956?1990	64.395	-4.03	7.361	0.113	0.046	0.067
		1991?2000	69.477	-3.38	3.919	0.055	0.020	0.035
		1956?2000	65.524	-3.89	6.405	0.097	0.039	0.058
Huangheyang -Jimai	25479	1959?1990	97.135	-3.88	35.633	0.368	0.155	0.213
		1991?2000	93.990	-3.56	28.670	0.304	0.128	0.176
		1956?2000	96.311	-3.80	33.611	0.349	0.147	0.202
Jimai-Maqu	40580	1960?1990	273.058	-0.25	108.214	0.394	0.139	0.255
		1991?2000	249.742	1.36	88.536	0.359	0.123	0.236
		1956?2000	267.371	0.15	103.673	0.395	0.139	0.256
Maqu-Tangnaihai	35228	1960?1990	149.075	0.45	63.455	0.484	0.152	0.333
		1991?2000	124.574	0.76	48.108	0.367	0.089	0.280
		1956?2000	143.099	0.53	59.712	0.455	0.136	0.320

we can see in the 1990's the annual average precipitation exceeds that of 1956 to 2000 while the runoff decreased seriously with decreasing rates of total runoff of 39%, direct runoff of 37% and baseflow of 45%.

The annual average precipitation shows an increasing tendency (Figure 6). The correlation coefficients of P against R/P, Dr/P and Br/P are very low and do not pass the test of significance even at the level of 0.05. It shows that the impact of precipitation on the runoff coefficients is low on an annual time scale. Correlation coefficients of P against R/P, Dr/P and Br/P for a moving average of 5 years could pass the test of significance at the level of 0.05, except that of P against Dr/P. The results show that in the head regions of the Yellow River annual precipitation can influence runoff coefficients except for the direct runoff coefficient, but the response rate is relatively slow.

Annual average temperature shows an increasing tendency (Figure 7). A regression line is fitted for annual average temperature. Although the points are scattered, the correlations are relatively significant at a level of 0.05. Correlation coefficients of T against runoff coefficients are calculated using a moving average of 2 to 5 years. Results show that the correlation coefficient of T against Dr/P is relatively significant at a level of 0.01 when the time interval is 2 years and the correlation coefficient of T against R/P is relatively significant at a level of 0.05 when the time interval is 3 years. The correlation coefficient of T against Br/P does not pass the test of significance when the time interval is 5 years. These analyses show that in the head regions of the Yellow River impacts of temperature on Br/P, Dr/P and R/P are different, with no impact on Br/P, relatively significant impact on R/P and significant impact on Dr/P for short time periods.

Subbasin between Huangheyan and Jimai

Table 2 shows this subbasin is relatively cold and arid with an average annual temperature of -3.80°C and annual average precipitation of 96.3×10^8 m^3. The runoff coefficient is high with annual average R/P of 0.349, Br/P of 0.202 and Dr/P of 0.147. Runoff, precipitation, R/P, Dr/P and Br/P decreased in the 1990's.

The correlation coefficients of precipitation and temperature against runoff coefficients (including R/P, Dr/P and Br/P) do not pass the test of significance at the level of 0.05. Correlation coefficients are calculated using moving averages of 2, 3 and 4 years. The correlation coefficients

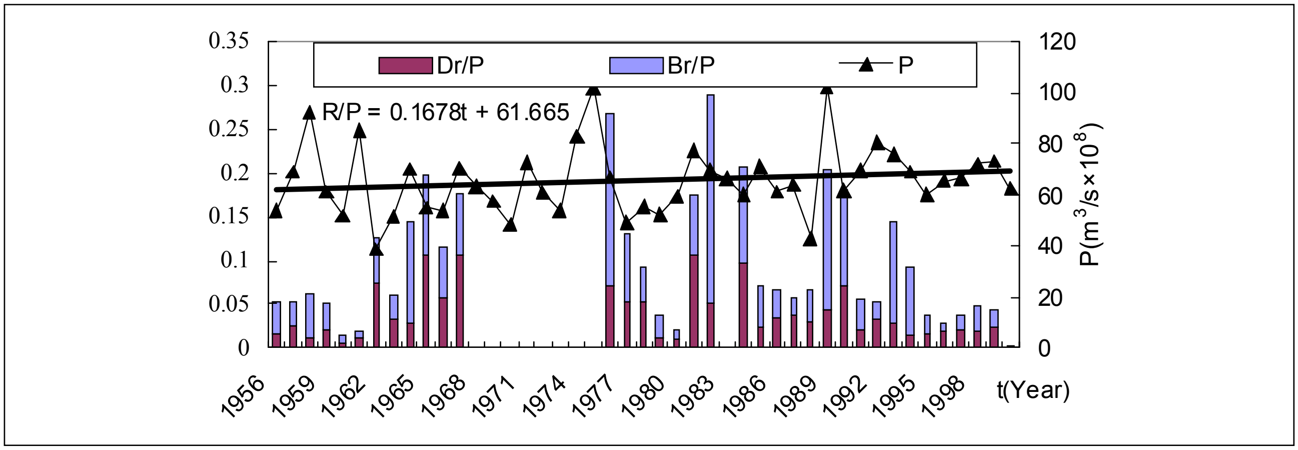

Figure 6. Annual precipitation and runoff coefficients of the head regions of the Yellow River.

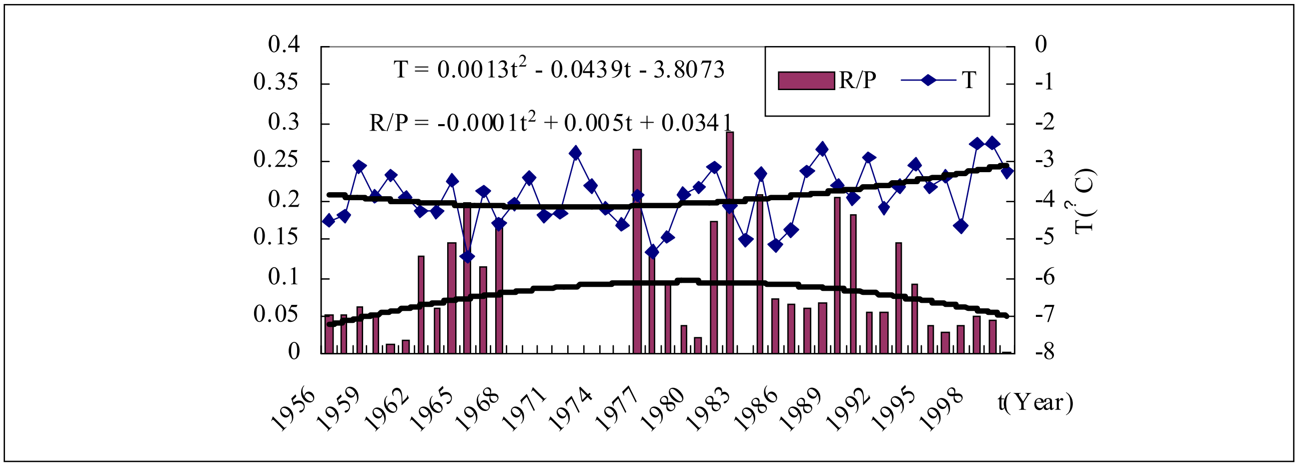

Figure 7. The annual temperature and runoff coefficients of the head regions of the Yellow River.

with a moving average of 4 years of P against Dr/P is 0.379 which could pass the test of significance at the level of 0.05, and correlation coefficients of T against R/P and Br/P are -0.504 and -0.577 respectively which are significant at a level of 0.01. Hence we can conclude that in the short term Dr/P is affected by precipitation, R/P and Br/P is influenced by temperature. As to the extent of influence, the impact of temperature on R/P and Br/P are more pronounced than that of precipitation on Dr/P. The decrease of R/P, Dr/P and Br/P in 1990's can easily be explained by the decrease of precipitation and increase of temperature in this time period.

Subbasin between Jimai and Maqu

This subbasin is characterized by abundant precipitation, with annual average precipitation of 267.3×10^8 m^3, and correspondingly the annual average runoff is relatively high at 103.7×10^8 m^3, which is more than 50% of the source regions of the Yellow River. The annual average temperature is 0.15°C. The runoff coefficient is relatively high with an annual average of R/P of 0.395, Br/P of 0.256 and Dr/P of 0.139. The total runoff, precipitation, R/P, Dr/P and Br/P decrease seriously in the 1990's while temperature is higher than ever.

Annual precipitation shows a decreasing tendency during the periods of 1956 to 2000 (Figure 8) while in the same periods the annual average temperature shows a significant increase with a correlation coefficient of 0.792 (Figure 9). Correlation coefficients of temperature and precipitation against R/P, Dr/P and Br/P are relatively low on an annual time scale, when the correlation coefficients are calculated using a moving average of 2 years. All these correlation

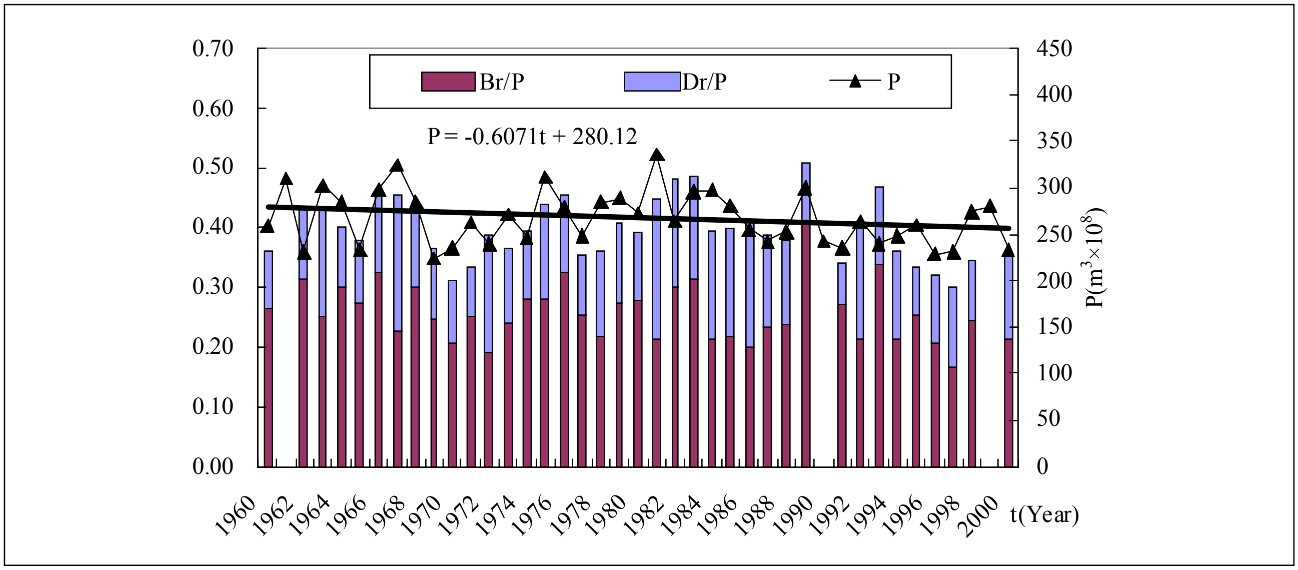

Figure 8. The annual precipitation and runoff coefficients of the area between Jimai and Maqu hydrologic station.

coefficients are relatively high and they pass the test of significance at the level of 0.01, except for T against Dr/P of -0.203, which does not pass the test of significance at a level of 0.05. These results show that in this subbasin Dr/P is mainly influenced by precipitation, and R/P and Br/P are both impacted by precipitation and temperature. Dr/P, R/P and Br/P are in direct proportion to precipitation while R/P and Br/P are inversely related to temperature. Using these results we can easy explain the significant decrease in runoff coefficient in 1990's with the rising of temperature and the decrease of precipitation.

Subbasin between Maqu and Tangnaihai

The hydrologic characteristics of this region from Table 2 are an annual average precipitation of 143.1×10^8 m^3, annual average temperature of 0.53°C, annual average runoff of 59.7×10^8 m^3, average R/P of 0.455, average Br/P of 0.320 and average Dr/P of 0.136. Total runoff, precipitation, R/P, Dr/P and Br/P experienced a serious decrease in the 1990's while temperature is higher than the average.

The maximum R/P is 0.833 in 1967 and the Dr/P is almost zero in 1960, 1978, 1988, 1996 and

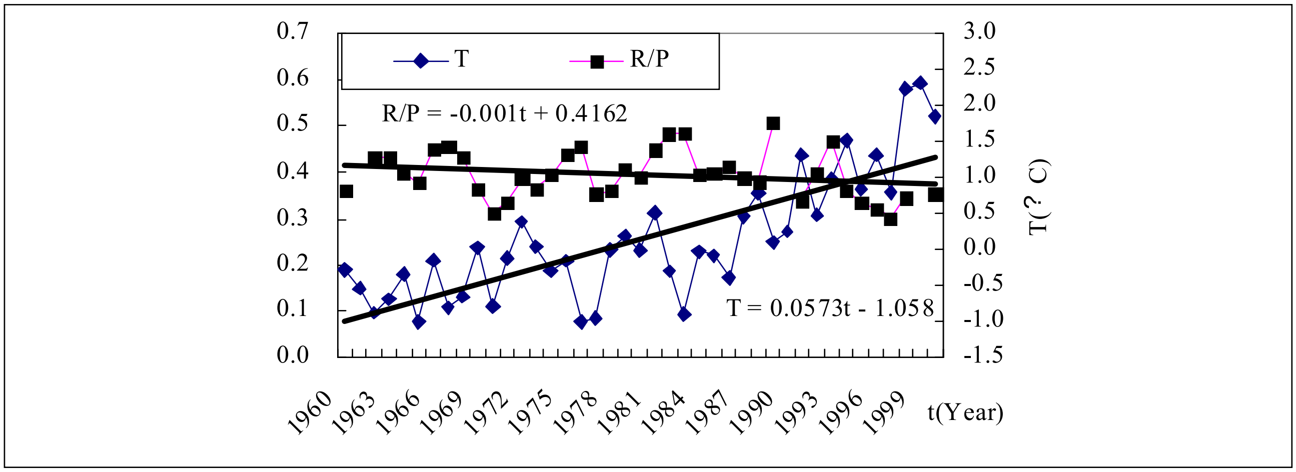

Figure 9. The annual temperature and runoff coefficients of the subbasin between Jimai and Maqu hydrologic station.

2000. Precipitation shows a decreasing tendency in this region (Figure 10). Precipitation is plotted against R/P and Br/P and regression lines are fitted for the two groups. Although the points are scattered, the correlations are relatively significant at level of 0.01 (Figure 11). The correlation coefficient of P against Dr/P is 0.416, which is relatively significant at a level of 0.01. These results show that precipitation has a direct impact on the R/P, Br/P and Dr/P on a time scale of 1 year in this subbasin.

Temperature shows an increasing tendency with the correlation coefficient of 0.499 significant at a level of 0.01 (Figure 12). The correlation coefficient of annual temperature against R/P, Dr/P and Br/P does not pass the test of significance even at the level of 0.05. Correlation coefficients are calculated using a moving average of 2 years. A test of significance is carried out only for the coefficient of T against Dr/P of -0.367 which can pass the test of significance at the level of 0.02.

RESULTS

Runoff coefficients of the source regions of the Yellow River are analyzed for the time period 1956 to 2000. Results show that in these regions the baseflow coefficient is higher than that of direct flow, and in the 1990's the runoff coefficients decreased significantly. In the study area

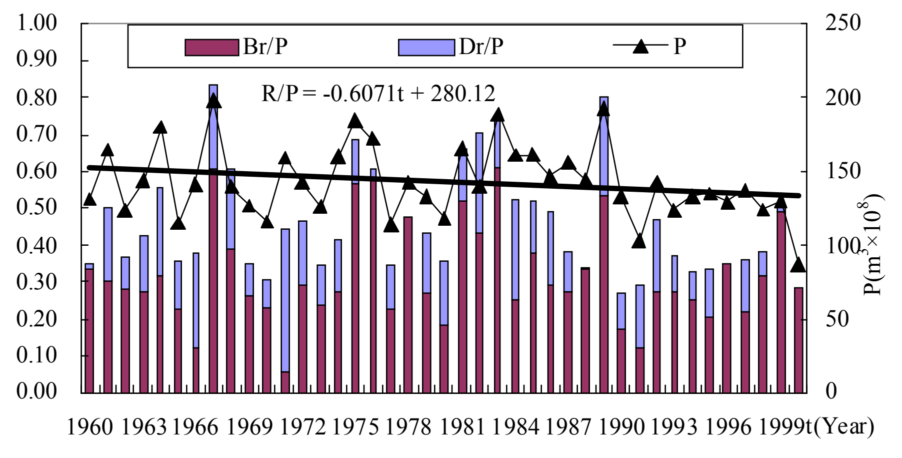

Figure 10. The annual precipitation and runoff coefficients of the subbasin between Maqu and Tangnaihai hydrologic station.

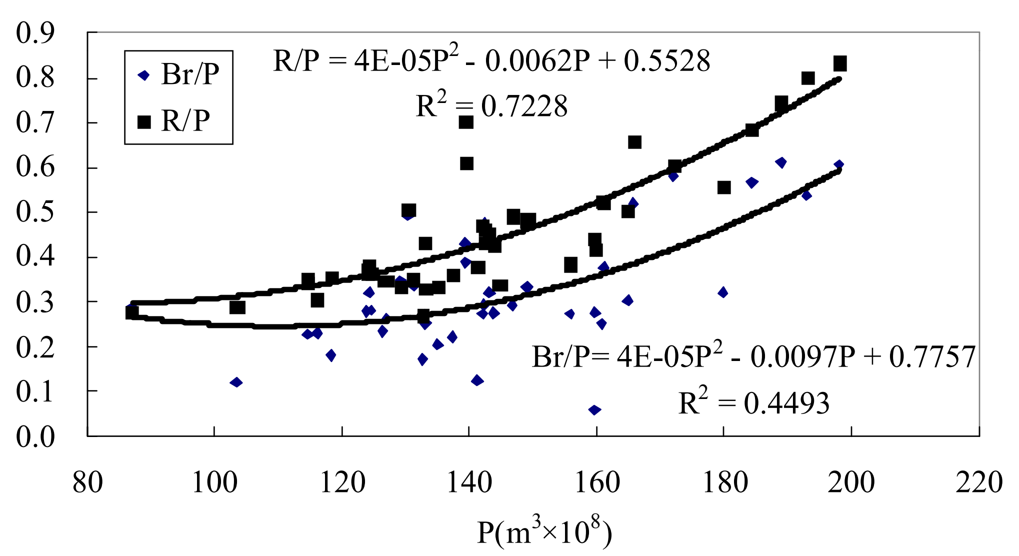

Figure 11. The plots of annual runoff coefficients against precipitation.

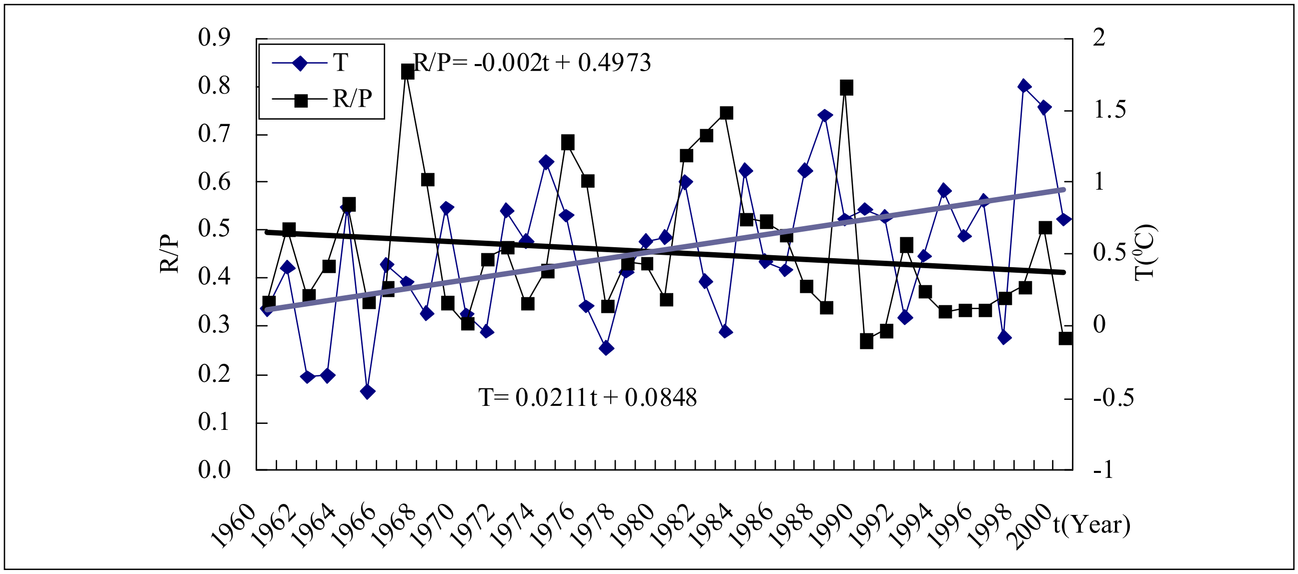

Figure 12. The annual temperature and runoff coefficient of the subbasin between Maqu and Tangnaihai hydrologic station.

runoff coefficients are in direct proportion to precipitation and inversely related to temperature. In the 1990's the decrease of runoff coefficients can be attributed to the increase of temperature and decrease of precipitation. The impacts of climate factors on runoff coefficients in different subbasins are different. In the regions above the Jimai hydrologic station where it is cold and arid with annual mean temperature of -3.80°C, temperature is the main factor affecting runoff coefficients and the impact of precipitation is insignificant. In the subbasin between the Jimai and Maqu hydrologic stations, Dr/P is mainly affected by precipitation, and R/P, Br/P is affected both by temperature and precipitation. In the subbasin between the Maqu and Tangnaihai hydrologic stations, Dr/P is mainly influenced both by temperature and precipitation and Br/P and R/P are mainly affected by precipitation. The low precipitation intensity is favorable for the precipitation to infiltrate, so the direct runoff decreases and the shallow soil moisture decreases in arid conditions with the increase of annual temperature. At the same time, the frozen soil may disappear with a continuous frozen soil melting and the groundwater table will move downwards which will have an adverse impact on the eco-environment of the basin and agricultural activities.

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