Analysis and assessment of hydrological processes in the warm humid region of Liaoning Province: a case study

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Abstract Analysis and assessment of hydrological processes is a requirement in the assessment of water resources. This study covers eastern part of Liaoning Province which is a warm humid region of China. Through analysis of long-term meteorological and hydrological data and the state of human activities, the characteristics and variations of the hydrological processes, and relations between the hydrological regime and the main influences including those of climate and man's activities in the region are presented. After the main factors are analysed quantitatively, the impacts of human activities on the hydrology are enunciated. The greatest impact of human activities is on sediment yields of streams, the next greatest impact of human activities is on river runoff. The role of analysis and assessment of hydrological processes in assessment of water resources and basin management is presented.

INTRODUCTION
Liaoning Province, one of the economically developing provinces in China, is located in the southern part of northeast China. It is situated between longitudes 118°50’ and 125°46’E and latitudes 38°43’ and 43°29’N. The province basically consists of three regions: in the east it is mountainous and hilly, the central region is a plain, and in the west there are lower mountains and hills. The study area is in the east of the province, a warm humid region, its location is shown in Fig. 1. There are rich natural resources in the region that have been developed for many years. The north of the region is referred to as the east Liaoning mountainous zone. The south of the region is referred to as the East Liaoning Peninsula hilly zone, which has been listed as one of the latest important economic development zones in the province and the nation. One can be reasonably confident that economic development of the east of Liaoning Province will lead to economic and social development of the province, and even of the whole nation. It is believed that the analysis and assessment of hydrological processes in the region will be of great significance for water resources development and the economic development of the area.

GENERAL PHYSIOGRAPHICAL CHARACTERISTICS OF THE STUDY AREA
The south of the area faces two seas, the Bohai Sea in the west and the Yellow Sea in the south. There are many large rivers that cross the region, such as the River Liao
and its tributary the River Qing, the River Hun, the River Taizi, which flow into the Bohai Sea. The River Yalu and its tributary the River Ai flow into the Yellow Sea. There are also many medium and small rivers which flow directly into sea, such as the River Biliu and the River Dayang - into the Yellow Sea, and the River Xiongyao - into the Bohai Sea. The climate in the region is of the humid monsoon climate in the temperate zone, the continental climate is evident. A characteristic of the climate is that the highest rainfall and hottest temperature are in the same season. Mean annual temperature decreases gradually from the south to the north and varies between 4.6° and 10.2°C. Average annual precipitation in the region varies from 650 mm in the northwest of the region to 1200 mm in the southeast. The topography in the region is mountainous and hilly. The altitudes gradually decrease from the northeast to the southwest. The mountains consist mainly of two mountain-chains, the Changbai and Qianshan, that constitute the watershed divide between Rivers Liao, Hun, Taizi, Yalu, Dayang, Biliu and others. The native rocks in the east part of Liaoning basically consists of old metamorphic rocks and granites. There are carbonatite and fragmentary rocks of marine deposits of the Palaeozoic era distributed in most parts of the region. The major soil type is brown forest soil. The natural vegetation in the northeast mountainous area is a mix of coniferous forest and broad-leaf forest, and the forest in the rest of the region belongs to broad-leaf of a warm temperate zone. The average forest cover in the mountainous area of the east Liaoning region is over 45%. The average forest cover in the coast peninsula is about 28%.

There are some ten large reservoirs and a great many small ones which have been built in the east part of the province since new China was founded. They provide

Fig. 1 Location and river system of study area.
supplies of water, the former for both irrigation and industrial use, the latter only for irrigation. Although considerable work such as planting trees, building level terraces, planting grass and closing forests, in water and soil conservation has been done, and some positive results have been obtained, large areas with water and soil losses still exist in the region.

CHARACTERISTICS AND VARIATIONS OF HYDROLOGICAL PROCESSES

Hydrological processes of a natural catchment where there are no economic activities depend on natural factors. The hydrological processes can be referred to as natural hydrological processes. Generally speaking, precipitation has the smallest effect, but it is influenced by human activity. With the development of society and economy, the influences of human activities on hydrological processes including runoff and sediment yields are increasing. Nowadays hydrological processes such as runoff, sediment, in most of basins are the results of the combined effects of natural and human factors in the basins. There are many more-developed places and basins in warm humid regions of Liaoning Province, with increasingly fewer undeveloped places and basins where there is a little influence of human activity. In order to define the characteristics and variations of natural hydrological processes, precipitation, runoff and sediment stations of catchments where no influence of human activity exists were selected for analysis.

Characteristics and variation of annual precipitation

In the warm humid region of the province, the earliest precipitation observations began at three stations (Shenyang, Dalian and Dendong) around 1905. These longest data series, 86 years series for Shenyang and Dalian, and 83 years series for Dendong were used to analyse the characteristics and variation of precipitation. It can be seen from the annual precipitation variation graph at these three stations that precipitation differs from year to year, the ratio between maximum and minimum precipitation is around 3.0, wet years and drought years are alternatively changing every three to five years. To eliminate the influence of occasional factors, five-year moving average values of annual precipitation were calculated and are shown on Fig. 2. From the figure it can be seen that peak values of the five-year moving mean precipitation process and lower values are alternatively changing every 10-14 years. Looking at the average precipitation over several small basins (Caohe, Jianchan, Gengwangzhuong), the maximum of precipitation is about 2.5 times that of the minimum. From five-year moving mean graph of annual precipitation of three small basins, (Figs 3, 4 and 5) it can also be seen that peak values of moving mean of precipitation begin in 1964 and occur every 10-13 years, they have the same characteristics of annual precipitation as the three stations with long-term data series.

Characteristics and variation of annual flow

The flow data from small basin stations representative of the region with little or no human influence were used. Annual runoff also differs from year to year, and wet and
dry year alternate. Higher or lower annual runoff occurred in the same year as higher or lower annual precipitation. The highest annual runoff amount at Gengwangzhuong station in the upstream of River Qing was 292 million cubic metres, occurring in 1964. The lowest annual runoff of this station was 10.8 million cubic metres. The largest one is 27 times that of the lowest. The maximum of annual runoff at the Jianchan station upstream of the River Biliu was 850 million cubic metres, also occurring in 1964. The minimum at the station was 54.5 million cubic metres. The maximum is 15.6 times that of the minimum. The maximum annual runoff at Caohé station upstream of the River Ai was 1856 million cubic metres, again occurring in 1964. The minimum of yearly runoff of this station was 314 million cubic metres. The maximum is 5.9 times the minimum value. The ratios of extremes of yearly runoff increase from 6 times in the River Ai, where the highest annual average precipitation occurred, to 16 times in the south and 27 times in the north as annual average precipitation gradually decreases. It can be seen from above that variation of yearly runoff in this warm humid region is greater than that of annual precipitation. From five-year moving mean runoffs at these three stations (Figs 3, 4 and 5) it can be observed that five-year mean values of runoff of these stations all begin to reduce gradually from the highest peaks of 1964, then gradually increase, the second peaks occur in 1975, after that they decrease gradually, then increase again with the third peaks around 1987. It can be seen that peak and lower value of annual runoff are also alternatively changing about every 11 years.
Fig. 3 Five-year moving mean graph of hydrological elements in the Gengwangzhuong basin.

Fig. 4 Five-year moving mean graph of hydrological elements in the Jianchan basin.
Characteristics and variation of annual sediment yields

Analysis of annual sediment yields is based on same three stations, above. Annual sediment yields are alternately changing also, the peaks of annual sediment yields occurring basically in the same year as those of the peaks of annual runoff. But the year the lower points of yearly sediment yields occur differs from annual runoff because of influence of human activities. The ratios of the maximum to the minimum of annual sediment yields from these three stations are 543 for Jianchan, 549 for Caohe and 800 for Gengwangzhuong. The variation of annual sediment yields is far more severe than those of annual runoff. From five-year moving mean values of annual sediment yields for these stations (Figs 3, 4 and 5) it can be seen that the maximum moving mean of annual sediment yields occur in 1964, moving mean values reduce gradually after that. There is then an increase, there is then a period of higher mean values till 1975, then mean values decrease gradually, increase again, till 1985-1987 during which another peak of five year moving mean of annual sediment yields occurs. It can be seen that the variation of annual sediment yields is corresponding to that of annual runoff, higher mean values of sediment yields correspondingly occur approximately every 11 years.

It can be seen that the characteristics and annual variations of hydrological elements in this region are as follows: under the condition of no human influence, annual runoff and sediment yields change as annual precipitation changes, with the degree of variation of annual runoff and sediment yields corresponding to that of annual precipitation.

IMPACT OF CLIMATE ON HYDROLOGICAL PROCESSES

In order to analyse the impact of climate on hydrological processes, the hydrometeorological data from the Gengwangzhuong, Jianchan and Caohe basins, where no human influence exists were used. Climatic conditions can principally be represented by precipitation. Hydrological processes can be represented by runoff. The
analytical method of contrast of data series of precipitation and hydrological elements in the same basin has been adopted as the basic method for analysing the influence of climate condition on hydrological processes.

In the Gengwangzhuang basin, comparing five-year moving means of annual runoff with that of annual precipitation (see Fig. 3), it can be seen that the variation of the five-year moving mean runoff of series data for 31 years corresponds well to that of five-year moving mean precipitation. As noted before, maximums of runoff mean value and precipitation mean value occur in 1964. The second highest peak values for the two elements occur around 1975. The third peak values also basically occur around 1987. Both minimums occur in 1982, the second minimums occurring around 1971. From the five-year moving mean graph of annual precipitation and runoff for the Jianchan basin (Fig. 4), it can be found that the variation of the five-year moving mean runoff from 29 years data series also corresponds well to that of the five-year moving mean precipitation. Both maximums of precipitation mean value and runoff mean value occur in 1964. The second peak values of the two elements occur around 1975. The third peak values occur around 1987. From the five-year moving mean graphs of annual precipitation and runoff for the Caohe basin (Fig. 5), it can be seen that the variation of precipitation mean value and that of runoff mean value are similar. The first peak values of these two elements occur in 1964. The second peak values occur around 1974. The third peak values occur in 1987. The lowest values occur around 1980.

From fully corresponding variation of both annual precipitation and runoff of the three basins above, it can be seen that precipitation, representing climatic factors, has a long-term and wide ranging correspondence with the hydrological processes, alternate variations between peak and lower value of annual natural runoff resulting directly from alternate changes between peak and lower values of annual precipitation.

**IMPACT OF HUMAN ACTIVITIES ON HYDROLOGICAL PROCESSES**

For decades, a lot of hydraulic engineering, and water and soil conservation works have been built in the eastern part of Liaoning Province. There are also man's economic activities in river basins of the region. Hydrological processes have been greatly affected by these works and activities, the extent of their effects varying in different places. Annual runoff double mass curves for Shenyang station on the River Hun and station Liaoyang on the River Taizi (Fig. 6) show that human activities in the early fifties had little influence on runoff. From this figure, it can be seen that influences of human activities on runoff gradually grow as time goes on, and that human influence on Shenyang station before 1957 is only 5-7%, later in the fifties and sixties it is 19.5%, in the seventies it is 29.7%, in the eighties it is 27.6%, and human influence on runoff of Liaoyang station before 1959 is only 5%, in the sixties it is 6.2%, in the seventies it is 19.0%, in the eighties it is 22.9%, these show that influence of human activities on runoff before the end of the fifties is small. Why does the influence of human activities on runoff increase for Shenyang after the fifties and for Liaoyang after the early seventies? Because a large reservoir was completed on the River Hun in 1959, and two large reservoirs were completed on the River Taizi around 1970, the influence of water losses of reservoirs as well as influence of water
use in agriculture and industry is evident. Through analysis of the relation between precipitation and runoff in the upstream basin of the River Hun, where there is no influence of large reservoir, it was found that the coefficient of annual runoff corresponding to the same precipitation during last three decades has changed little. It was also found that influence of human activities, except large reservoirs, on annual runoff is small. From the five-year moving mean process of the annual natural runoff and measured sediment yields at Shenyang station on the River Hun (Fig. 7), it can be observed that in five-year mean runoffs that have the same 29 years series as sediment yields, moving mean values before 1964 are higher, reduce between 1975 and 1982 when the minimum occurs (at about 50% of the mean value before 1964).
There is then a gradual increase, the maximum of five-year mean values after 1986 accounting for 108% of five-year mean value before 1964. Though the variation process of the five-year mean of sediment yields is similar to that of annual runoff in general, the ratio of the minimum of five-year mean value till 1982 to that before 1964 is only 12% for sediment yields, less than 50% for runoff. At the same time, the extent of increase of the five-year mean values after 1986 of sediment yields differs from that of runoff: the maximum of increase of sediment yields only accounts for 41% of five-year mean value before 1964, far less than that of runoff. From the above it can be seen that the reduction of sediment is faster than that of annual runoff during the sixties and seventies, primarily as a result of a large reservoir being built upstream of the main stream of River Hun. The ratio of the minimum of the five-year mean of sediment yields to the moving mean before 1964 is about 40% smaller than that of runoff and the ratio of increase of moving mean of sediment yields after 1986 to moving mean before 1964 is 60-70% smaller than that of runoff. According to a survey of small basins in the upstream portion of the River Hun, this is the result of basin regulation and water and soil conservation works having been developed in most parts of the basin since 1980, and the effect of the large reservoir.

In most parts of the region, through comparison of runoff and sediment yield between eighties and sixties under the same moving mean of precipitation in the upstream regions, runoff in the later eighties is about 10% less than two decades before, sediment in the later eighties is less than nearly two decades before: River Ai 20%, River Biliu 30%, River Taizi 57%, due to closing of the forests since 1980. But
in a few basins it is different, e.g. from graph of ten-year moving means of precipitation, runoff and sediment for the Shalizhai station on the River Dayang (Fig. 8). It can be seen that the variations of ten-year moving mean of precipitation entirely corresponds to that of runoff. The extents of variation also correspond to each other. This indicates that the influence of human activities on runoff is not large. Although runoff and sediment possess corresponding tendencies of variation, the variation of sediment is more severe than that of runoff. In addition, there are two points to note in the variation of sediment yields: (a) The increase of the moving mean of sediment yields after its decrease happens (in 1982) is earlier than that of runoff (in 1985); (b) The increased value of the moving mean of runoff in the later eighties corresponds only to 82% of maximum value of moving mean of runoff in the sixties, while the mean value of sediment in the later eighties is greater than the maximum value of the moving mean of sediment, about 110% of the maximum. The reason for this, according to the survey, is because of forest denudation in the basin, vegetation has been destroyed since 1980, and terraces were damaged by flood. As a result, soil losses in the basin increased again.

CONCLUSION

Through the above analysis, wet and dry periods in annual precipitation and natural runoff have been shown to have a certain cyclical changes. Compared with sun spot activity, the cycling of annual precipitation and runoff is not as regular and evident; the average length of precipitation and natural runoff is about 12 years, which corresponds to the cycle length of sun spot numbers. The characteristics and variations of precipitation and natural runoff processes were analysed. It was observed that the influence of human activities has caused a small reduction in runoff, 6-12% in general. This may increase to 20-30% where the influence of large reservoirs and increasing water use in agriculture and industry exist. But influence of human activities on sediment yield is larger than runoff and more complicated, in most rivers of the region it is a 20-60% reduction. In a few rivers they have caused about 30% increase, mainly due to forest denudation. The analysis and assessment of water resources ought to consider restoration of such human influences.