Characteristics of the Lower Yellow River channel shrinkage and its discriminant parameters

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This paper analyzes the changing trends of the Lower Yellow River (LYR) transverse profile parameters and their aberrance points by the time series analysis method. Research results show that there has been a trend of changes in the LYR channel transverse profile parameters since the 1950s. The main river channel has a tendency of shrinkage year by year and the trend will be continued in the future. The main features of the LYR channel shrinkage are remarkable reductions of bankfull discharges and bankfull areas, corresponding decreases of bankfull widths, average bankfull water depths and maximal bankfull water depths, as well as increases of bankfull water levels and width-depth ratios accompanied. The discriminant parameters for threshold of the LYR main channel shrinkage were put forward. It indicates that the LYR main channel began to shrink in the 1970s and has entered into a serious phase of channel shrinkage since the 1990s. The incompatible index of discharged water-sediment processes of the Sanmenxia Reservoir was introduced, which revealed that there was a trend of increasing in the incompatibility between water flow and sediment load. Response relations between the LYR main channel shrinkage parameters and discharged water-sediment processes of the Sanmenxia Reservoir were founded, which indicate that the LYR main channel shrinkage can be mitigated and improved through the regulation of discharged water-sediment processes of the reservoir, especially through the regulation of water-sediment incompatible index. The LYR channel for water and sediment transportation can be restored and maintained.

Lower Yellow River, time series analysis, main river channel shrinkage, discriminant parameters of channel shrinkage, water-sediment incompatible index


1 Introduction

With the increasing influence of human activities and the climate changes, serious main river channel shrinkage has appeared in the Lower Yellow River (LYR) since the middle of the 1980s. The main channel has been filled up with sediment deposition seriously. The deposition ratio between beach and channel has changed from 7/3 in the 1950s to 3/7 in the 1990s, and the bankfull discharges have decreased from 7000–8000 m³/s in the 1950s to 3000–4000 m³/s in the beginning of the 1990s. In 2002 the bankfull discharges decreased to less than 2000 m³/s in some parts of channels, and there has been a trend of change in the transverse profile [1–5]. As the result, it intensifies the unfavourable condition of “secondary suspended river” and causes “little flood-large catastrophe” and some other new problems, which seriously limits the sustainable development of economy and society in the Yellow River basin. Previous studies on trends of channel shrinkage usually adopt some direct and descriptive methods like field data comparison, whereas, the aberrance points for trend analysis have not

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been applied yet. Based on the quantitative analysis of trends in the transverse profile parameters and aberrance points of the LYR, the discriminant parameters and criterion of channel shrinkage were put forward in this paper. Response relations between these parameters and discharged water-sediment processes of the Sanmenxia Reservoir were also founded. The effects of water and sediment process regulation on mitigating river channel shrinkage were also analyzed.

In this paper, trend analysis and aberrance points analysis approaches among the time series analysis methods were used in analyzing the LYR transverse profile parameters. Time series is formed by successive observational values of the same phenomenon in different time [6]. The transverse profile parameters of the LYR are all arrayed by time sequence, so time series analysis methods can be used. In the analysis, the Kendall’s Rank Correlation Method is adopted to analyze current changing trends, the R/S analysis method is used to analyze future changing trends, and the Orderly Cluster Analysis method is used to analyze aberrance points. The analysis data include bankfull discharges, bankfull areas, bankfull widths, average depths, maximal depths, bankfull water levels, width-depth ratios and some other parameters from Huayuankou, XiaoLangDi, Gaocun and Lijin gauging stations since 1951.

2 Trend analysis of changes of the LYR transverse profile parameters

2.1 Trend analysis on current changes of the transverse profile parameters of the LYR

2.1.1 Kendall’s Rank Correlation Method–Current trend analysis approach

Kendall’s Rank Correlation Method is a simple and effective non-parametric test method [7]. Whether there are significant trends in time series and what the trends direction is can be easily judged through data statistics.

For a time series \(\{x_1, x_2, \ldots, x_N\}\), \(P\) is the number of data that \(x_i < x_j\) appeared in all dual observational values \((x_i, x_j, i < j)\), and \(N\) is the length of the time series. If in the series \(x_1 < x_2 < \ldots < x_j < \ldots < x_N\), then there is an increasing trend in the series and \(P = (N-1) + (N-2) + \ldots + 1 = N(N-1)/2\). Otherwise if \(x_1 > x_2 > \ldots > x_j > \ldots > x_N\), there is a decreasing trend and \(P = 0\). For an absolutely random series, \(P \approx N(N-1)/4\). Kendall statistics \(\tau\) and standard variation \(M\) are defined as follows:

Kendall statistics: \[ \tau = \frac{4P}{N(N-1)} - 1; \] (1)

Standard variation: \[ M = \tau \cdot \sqrt{\frac{9N(N-1)}{2(2N+9)}}, \] (2)

\(M\) converges in the standard normal distribution rapidly when \(N\) increases.

Using hypothesis testing methods, the original assumption is that there is no trend in the time series. Given the significance level \(\alpha\), if \(|M| > M_{\alpha/2}\), the original assumption is accepted which means the trend is not significant, otherwise it is refused meaning the trend is significant.

2.1.2 Trend analysis on current changes of the LYR transverse profile parameters

Trend analyses on transverse profile parameters of the LYR gauging stations, such as bankfull discharges, bankfull areas, bankfull width, average water depth, maximal water depth, bankfull water level and width-depth ratios, were carried out with Kendall’s Rank Correlation Method. The data series of bankfull discharge used for the analysis were from the Huayuankou Gauging Station (1957, 1960–2003), Gaocun Gauging Station (1951–2003), Aishan Gauging Station (1954–1958, 1963–2003) and Lijin Gauging Station (1951–1959, 1965–2003). The data series of other transverse profile parameters are from the Huayuankou Gauging Station (1960–2003), Gaocun Gauging Station (1951–2003), Aishan Gauging Station (1968–2003) and Lijin Gauging Station (1968–2003).

Table 1 shows the calculating results of the Huayuankou Gauging Station with the Kendall’s Rank Correlation Method. It shows from the statistics table that \(M_{0.05/2} = 1.96\) and \(M_{0.01/2} = 2.576\). According to Table 1, it can be seen that \(|M| > M_{0.01/2}\) and \(P \rightarrow 0\) can be reached for all data series of bankfull discharge, bankfull areas, bankfull width and average water depth. It represents that these data series show a trend of significant decreasing. \(M_{0.05/2} < |M| < M_{0.01/2}\) and \(P \rightarrow 0\).

### Table 1 Examination of Kendall’s Rank Correlation of bankfull discharges and transverse profile parameters at Huayuankou Gauging Station

<table>
<thead>
<tr>
<th>Parameters</th>
<th>(N)</th>
<th>(P)</th>
<th>(N(N-1)/4)</th>
<th>(N(N-1)/2)</th>
<th>Statistics/(M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bankfull discharges</td>
<td>45</td>
<td>161</td>
<td>495</td>
<td>990</td>
<td>-6.4012</td>
</tr>
<tr>
<td>Bankfull areas</td>
<td>44</td>
<td>153</td>
<td>473</td>
<td>946</td>
<td>-6.3383</td>
</tr>
<tr>
<td>Bankfull widths</td>
<td>44</td>
<td>173</td>
<td>473</td>
<td>946</td>
<td>-5.9421</td>
</tr>
<tr>
<td>Average depths</td>
<td>44</td>
<td>214</td>
<td>473</td>
<td>946</td>
<td>-5.1300</td>
</tr>
<tr>
<td>Maximal depths</td>
<td>44</td>
<td>360</td>
<td>473</td>
<td>946</td>
<td>-2.2382</td>
</tr>
<tr>
<td>Bankfull water levels</td>
<td>44</td>
<td>493</td>
<td>473</td>
<td>946</td>
<td>0.3961</td>
</tr>
<tr>
<td>Width-depth ratios</td>
<td>44</td>
<td>470</td>
<td>473</td>
<td>946</td>
<td>-0.0594</td>
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