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Analysing the Variability of Streamflow and Suspended Sediment Concentration Using Time Dependent Intrinsic Correlation

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Abstract

Understanding the association between streamflow and sediment concentration time series may help to improve the modeling efforts of sediment transport processes in natural channels. This paper proposes an alternative approach to find such associations in multiple time scales based on Time Dependent Intrinsic Correlation (TDIC) method. The method is applied to the monthly streamflow and TSS concentration data from Kallada river in Kerala state, India, for the period 1980-2007. In this method, first both the streamflow and Total Suspended Sediment (TSS) concentration data are decomposed to different oscillatory modes called Intrinsic Mode Functions (IMFs) of specific periodicity. In the running correlation analysis procedure namely TDIC, the sliding window is adaptively fixed based on instantaneous periods obtained by the Hilbert transform of the obtained IMFs. TDIC analysis showed a strong long range positive association between streamflow and TSS concentration at intra annual to annual modes, which depict the influence of hydrologic dynamics in sediment transport processes at these time scales. For the inter annual modes of IMF3 and IMF4, the association is primarily positive, but there are alterations in the nature of association between the two for shorter time spells, particularly for time series segments of length less than 60 months. For low frequency inter annual mode IMF5, there exists a strong long range negative association between streamflow and TSS concentration, which depicted the influence of human interventions on the hydrologic variability of Kallada river at upstream regions of the gauging station.

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Keywords: *Correlation; Hilbert Huang Transform*; *Multiscale*; *Sediment; Streamflow; TDIC*

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1. Introduction

Semi-arid rivers experiencing pronounced wet and dry seasons often display high variability in the sediment-streamflow relationship [1, 2]. Streamflow and sediment load relationships are influenced by external factors like climate forcing and internal factors like human activities, catchment characteristics etc., and their influence varies with time scales. Larger temporal scale corresponds to a slower variation of the physical quantity in time (such as the bed elevation changes) while smaller time scale corresponds to rapid variations (such as variations of flow). Such information on multiple temporal scales may lead to a singularly perturbed behaviour and used to justify the decoupled sediment transport models [3]. Few studies have investigated association between sediment load and streamflow in multiple time scales [4, 5]. Zhang et al. [4] analysed monthly streamflow and sediment load records of Datong station in Yangtze river using scanning *t*-test, *F*-*t*est and coherency analysis. Zhang et al. [5] applied similar techniques to analyse the streamflow and sediment load from 9 hydrological stations of Pearl river and possible implications were discussed. Similar studies were helpful in understanding the stable and unstable properties of hydrological processes at different time scales, to identify the possible causes and implications of construction of storage reservoirs etc. To identify such multiple time scale of variability and for subsequent interpretations spectral analysis procedures are helpful.
The traditional Fourier transform based spectral analysis method may be inappropriate in the case of existence of multiple time scales of variability. Moreover, the Fourier analysis is suited well only for linear and stationary time series, which is often rare to identify such properties in the hydrological time series. Therefore, it is more appropriate to perform the spectral analysis of sediment concentration and associated streamflow in a multiscale framework. Wavelets are alternative spectral analysis tools which are suitable for analyzing stationary time series, but not well suited to analyse time series of nonlinear characteristics. Also, their capabilities are often constrained by the selection of appropriate mother wavelet function and selection of appropriate levels of decomposition. As an alternative to wavelets, a fully data adaptive multiscale decomposition method namely Empirical Mode Decomposition (EMD) was proposed by Huang et al. [6] to get orthogonal modes namely Intrinsic Mode Functions (IMFs) and its use in conjunction with the Hilbert transform contributed an attractive spectral analysis tool namely Hilbert-Huang Transform (HHT) to analyse nonlinear and non-stationary time series data. The potential of HHT and its variants attracted many researchers and it is gaining popularity for the analysis of hydrologic time series [7-13].
Kuai and Tsai [11] applied the HHT for identification of varying time scale in sediment transport process by gathering both bed load and suspended sediment concentration data. They found the multiple scales involved in sediment transport process, succession of time scales by comparison of HHT spectra of streamflow and sediment data and noticed that the dominant time scale is time varying in characteristics. But they didn't attempt to quantitatively ascertain the link between streamflow and suspended sediment concentration. Also, as the time series of hydrologic variables are controlled by different physical processes (each have specific time scale of variability), it is more appropriate to investigate the links between streamflow and suspended sediment concentration in a multiscale framework, for which an efficient multiscale running correlation analysis technique may be helpful.

Most of the scale dependent correlation methods proposed earlier involves the estimation of correlation coefficient of the data subsets, by fixing suitable sliding window size [14, 15]. But the selection of appropriate window size is a challenging problem while applying such techniques and a data adaptive selection of window size (scale) is a solution to this problem. Chen et al. [16] proposed a method for determining scale dependent correlation between two time series, namely Time Dependent Intrinsic Correlation (TDIC) in which the window size is fixed adaptively (based on instantaneous frequency computed by HHT), keeping the stationary property of the data within the window. Huang and Schmitt [17] applied TDIC analysis to investigate the association between dissolved oxygen and temperature time series in marine environment. Ismail et al. [18] applied the technique to analyse the linkage between temperature time series from different locations of Indian Ocean. This technique is yet to be applied to investigate the multiscale correlation between two non-stationary hydrologic time series.

In the following sections, first brief description of EMD and the algorithm of TDIC analysis are presented. Then, a brief description of the study area and details of dataset used are presented; the results and discussion are presented thereafter.