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Short-Term Variability of Johor River Discharge Based On Wavelet Analysis

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Abstract. River discharge provides a direct measure of water quantity and availability of water for specific uses. It also provides the basis for understanding river basin processes and is essential for interpreting and understanding river flow characteristics. This study investigates the temporal variability of river discharge records of Johor River. Wavelet analysis of discharge records for 30 years was carried out to characterize the river flow variability. Our results indicate that Johor River discharge data shows a significant short-term variability of between 0.6 to 2.5 years.

Keywords: Wavelet Analysis, Variability, River Flow.
PACS: 02.30.-f

INTRODUCTION

River discharge is defined by the volume of water flowing past a given point during a given period of time. It is measured in cubic meter per second (m^3/s) and its records are in the form of time series data. In general, the discharge of a river is important because it provides a direct measure of water quantity and hence the availability of water for specific uses [1].

Johor river is the largest contributory river in the southern state of Peninsular Malaysia. Investigation on the characteristics and changing patterns in this river is necessary in order to assess the impact of water resource allocation and impacts of climate change as explained by [2]. However, human activities along or close to the Johor River basin may lead to some degree of changes in the natural background variability in its river discharge pattern. Most hydrological studies for Johor River focused in discovering their dependency and correlation to other hydrological factors [3,4]. However, this study aims to detect any changes in the discharge pattern based on a set of historical time series observations.

Based on a wavelet transform approach, this paper investigates the temporal variability of the Johor River discharge and identify the periods of unexpected change occurred in the river discharge time series which can be used for flood forecasting estimation run-off forecast for Johor River basin. The data, measured by an automatic water level recorder was obtained from the Department of Irrigation & Drainage Malaysia for a local station for a period of 30 consecutive years from January 1980 to December 2010.

DATA

Johor River is the main river of the Johor state in Peninsular Malaysia. The river is 122.7 km long with a catchment of 2,636 km^2 and flows in a roughly north-south direction. The temperature in the basin ranges from 21°C to 32°C. Also, the catchment receives an average annual precipitation of 2470 mm. The river and tributaries are important sources of water supply not only for the state of Johor but also for the neighboring country Singapore.

The river discharge data was observed from Johor River specifically in *Rantau Panjang* station. The data ranged for 30 years, from January 1980 to December 2010 in cubic meter per second (m^3/s). The geographical locations of the river flow's measurement sites can be referred to in Figure 1. The data was obtained from the Department of Irrigation & Drainage Malaysia and was measured daily from 8.00 am to 8.00 am the following day and the average was recorded using an Automatic Water Level Recorder. The daily average was observed at 35.26 m^3/s with a standard deviation of about 40 m^3/s. In order to assess Sungai Johor discharge variability, we consider the weekly average of the discharge data to form 1618 data points for analysis. We plot the discharge data series along with the

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sample autocorrelation function (ACF). The plot seems to indicate a non-stationary time series since it appears to decline over time and the sample ACF fail to die out rapidly.

(a) **(b)**

FIGURE 1. (a) The geographical location of Sungai Johor on the map of Peninsular Malayisa. (b) River discharge data taken from Rantau Panjang station (station ID: 1737451) situated along Sungai Johor .

METHODOLOGY

River discharge data series which has a non-stationary or transient behavior often consists of a variety of frequency phases that could vary in time thus highlighting localised signals. Wavelet transform is an approach that can provide information at these localised time by providing information at different scale in the series, thus identifying the variability in the time-series dataset. This technique is a decomposition of the original data signal based on time and frequency analysis in which the signals are analyzed separately. The transformation is carried out by comparing the waveforms of limited duration to the signal and calculating their correlation coefficient via an analyzing function called the wavelet. Such comparison involves comparing the signals to be shifted, compressed or stretched to the version of a specified wavelet (mother wavelet) several times. This process is repeated at different scales and position as described by the following equation:

$$W(s,\tau) = \int_{-\infty}^{\infty} f(t)\, \Psi^{*}{}_{s,\tau}(t)\, dt \qquad (1)$$

where $f(t)$ is the signal, split into a set of basis functions called wavelets. $\Psi^{*}{}_{s,\tau}(t)$ is the wavelet and (s,τ) are the scale and translation parameters respectively for the wavelet transform. For this analysis, we use the continuous form of complex wavelet function, Morlet as the mother wavelet. Complex functions are better compared to real functions since it could adjust better in tracking the oscillation behavior. In addition, Morlet generally has a higher frequency resolutions compared to other functions [5]. This is useful in detecting significant features in our non-intermittent tropical river discharge which typically does not vary considerably much throughout the year. Wavelet Morlet function is defined as:

$$\Psi(t) = \frac{1}{\sqrt[4]{\pi}}\left(e^{-i\omega_0 t} - e^{-\frac{\omega_0{}^2}{2}}\right) e^{-\frac{t^2}{2}} \qquad (2)$$

where ω_0 is the central frequency of the mother wavelet which determines the location of ω_0 in the frequency space. We have used Torrence and Compo interactive wavelet plot [6] for our analysis in order to demonstrate a better representation of the Johor river discharge data.

RESULTS AND DISCUSSION

Figure 2 (a) highlights the time series observations for weekly average Johor River discharge that shows strongest notable singularities (very high discharge) over the threshold of 200 m^3/s. This threshold as seen by the horizontal line refers to an alert condition of high river discharge level, based on the Department of Irrigation & Drainage Malaysia monitoring system for Rantau Panjang station. These high discharge events appear to occur during the weeks of the North–East Monsoon period which begins in November and ends in March as detailed out in Table 2. The maximum average appears to have occurred at week 840 of the 30 year weekly data with a discharge level of about 398 m^3/s. These strong singularities are also reflected in the wavelet power spectrum, which are statistically significant at a 90% confidence interval, in Figure 2 (b).

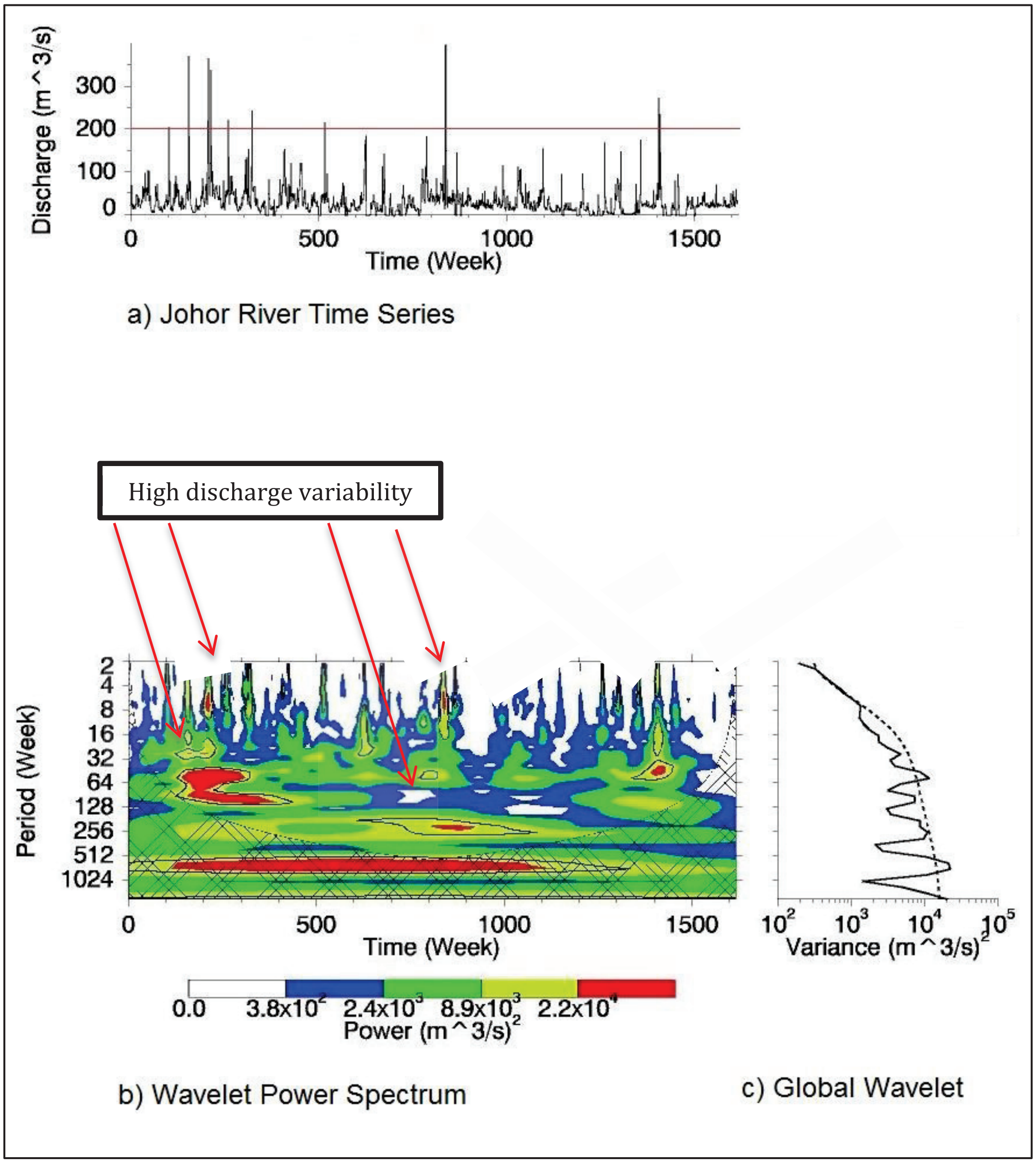

FIGURE 2. (a) Weekly average discharge (1980-2010) of Sungai Johor at Rantau Panjang station. The red line indicates a river discharge level of about 200 m^3/s which denotes the weekly maximum alert condition of daily river discharge level. (b) Wavelet power spectrum which indicates the wavelet domain on the y-axis and x-axis as the affected period and time respectively. (c) The Global Wavelet. The dotted line reflects the 90% confidence level.

TABLE 2. High level of discharge above the threshold of 200 m^3/s for the period of 1980-2010.

Week	Year	Months
156	1982	December
207	1983	December
209	1983 – 1984	Dec – Jan
324	1986	March
840	1996	Jan – Feb
1408	2006	December
1411	2007	January

In relation, Figure 2 (b) corresponds to the wavelet power spectrum which shows the periodic oscillation of the discharge level at different time scales during the last 30 years. The y-axis of the wavelet domain indicates the period (number of weeks) and the x-axis indicates the time. The density of the patterns of the wavelet power spectrum signifies the variability at a given frequency. The red coloured spectrum indicates strong significant discharge variabilities encircled by the overlain bold solid black line which signifies the 90% confidence interval. Note that red regions contained in the crosshatched area are considered negligible since it caters for errors at the beginning and end of a wavelet power spectrum. The dotted lines in the Global Wavelet in Figure 2(c) shows the 90% confidence interval dotted line. Dominant frequencies detected is considered significant at 90% confidence interval in the time series when the variance exceeds this dotted line and can be indicated from the horizontal patterns spanning that time interval.

The wavelet power spectrum in Figure 2(b) is shown with 90% confidence interval with the overlain bold solid black line, surrounding the red regions, with the exception of the crosshatched area. In general, Johor River demonstrates a sparse pattern in high variability discharge, mostly indicating moderate power across the band. This is expected for a large non-intermittent river like Johor river. The Global wavelet (Figure 2(c)) clearly shows three dominating frequencies between the period 32-128 weeks, 4-8 weeks and at 256 weeks. It also shows another local frequency at 32 weeks.

The most dominant frequency corresponds to a clear high variability discharge pattern between week 156 (end of year 1983) and ended prior to week 500 (midyear 1989) for the 32 to 128 week period. This variability period is roughly equivalent to 0.6 to 2-5 years. This event seemed to coincide with the construction of the first Johor reservoir which officially started in the year 1984. The other river discharge variability rate which are statistically significant at 90% confidence interval show shorter period patterns and appear to correspond to the high singularities shown in Table 2. These discharge variability could be due to climate conditions which would affect the variability of the river.

Based on the definition of short term variability (period of less than 540 weeks) and long term variability (period of more than 540 weeks) as used by [7], thus Johor river discharge variability indicated by the wavelet analysis appear to show short-term variability.

CONCLUSION

Wavelet analysis is presented here as a powerful tool for exploring the variability of non-stationary time series. This approach provides a quantitative measurement in gauging important features in the characterization of Johor river discharge based on temporal variability and frequency shifts in the overall flow. Our wavelet analysis results show that the Johor river discharge varied at different time scales in the 30 year period of the data, with a moderate power spectrum in the overall band. This is expected for a large non-intermittent river not unlike Johor river. However the wavelet results also showed instances in which the data exhibited several strong discharge variability between the years of 1980 to 2010. These highlighted time periods appear to be in-synch with the time of construction of Johor reservoir and the period of North-East monsoon. This indicates that such events do affect the variability of Johor river in the short run.

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REFERENCES

1. M. Meybeck, G. Friedrich, R. Thomas and D. Chapman. River. In : *Assessment of the Quality of the Aquatic Environnement Through Water, Biota and Sediment*. D. Chapman (ed), D. Chapman & Hall, London, pp. 239-316.
2. M. Franco-Villoria, M. Scott, T. Hoey and D. Fischbacher-Smith. Journal of Environmental Statistic. 2012, Volume 3 (Issue 6), 1-20.
3. M. R. Behera, C. Chun, S. Palani and P. Tkalich. Mar Pollut Bull. 2013 Dec 15;77(1-2):380-95.
4. A. H. Ahmed Suliman, (2010) Using HEC-RAS and qual2e to assess Johor River water quality. Masters thesis, Universiti Teknologi Malaysia, Faculty of Civil Engineering.
5. W.K. Ngui, M.S. Leong, L. M. Hee and A. H. Abdelrhman. Wavelet Analysis: Mother Wavelet Selection Methods. Applied Mechanics and Materials Vol.393 (2013) pp 953-958.
6. C. Torrence and G. P. Compo. Bulletin of the American Meteorological Society, 1998, Vol 79, 61–78.
7. D. C. Díaz and O. Siergieieva, Long term variability of Swedish river discharge as represented by EC-Earth in the past and future climates. Master Degree. Lunds University, 2012.