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Temporal-scale spectral variability analysis of water quality parameters to realize seasonal behaviour of a tropical river system - River Cauvery, India

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Abstract: *This paper describes the Time series analysis of river water quality with emphasis on variation in parameters as evidenced by statistical approach and mathematical models. The extensive study enabled to differentiate and realize the behaviour of river and catchment's changes induced by human activities. The Time series analysis evaluation indicated trivial variation and movement in the water quality as reflected by the changes in the catchment characteristics. Although the observed trends showed an insignificant human contribution to basin hydrology and river water chemistry, noticeable human activities and unsustainable practices steadily contributed to change in water quality from the existing long term spectral signatures to short term spectral signatures. It is inferred that short term spectral signature exhibited on temporal scale by a monitoring program of this kind reflects an insalubrious river system and long term gradual changes in spectrum is an indication of healthy system. Monitoring and analyses of these decisive changes in water quality parameters over a period could be a powerful tool for assessing general river water quality and management plan.*

Key words: *Temporal-scale variability, Time series, Spectral function, River behaviour*
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Introduction

Mathematical models have been used extensively over the past fifty years to address water quality problems and are currently used to investigate and assess virtually every type of water resource problem (Friedman *et al.*, 1984). Today water quality model development is taking a new shape especially in the field of river basin management, river dynamics and river water quality. The innate reason is the chain of reactions occurring in the watershed due to increased human influence, leading to changes in the watershed characteristics (Karagul *et al.,* 2005). Gburek and Folmar (1999) reported a strong relationship between landuse type and the quantity and quality of water. Rivers running through various landuse activities are exposed to a combination of pollutants from point to non-point sources of various strengths (Samanta *et al.,* 2005). Monitoring a large river basin provides an outsized data for analysis and can be a source to develop new analytical tool for the river system. We have thought-out a temporal-scale variability function as an analytical tool, which utilizes time series analysis for the optimization of monitoring program and assessing seasonal behaviour of the river. This approach requires a continuous data set and cannot be applied to an irregularly sampled data set with some missing values (Draper and Smith, 1981; Smitha *et al.,* 2007; Shekhar *et al*., 2008). Linear multivariate methods are commonly applied to multivariate sets of physical and chemical data for deducing them to manageable subsets (Christophersen and Hooper, 1992; Mhamdi *et al.,* 1994). However, multivariate analysis for an array of data depends on the sampling procedure and the observed measurements needs to be equally spaced to obtain stable values (Castro *et al*., 1986). The Fourier analysis (Thomann, 1967) and the Box Jenkins time series analysis (Lohani and Wang, 1987) represent approaches for studying univariate time series. The Fourier method is more suitable for separating a long-term trend from periodic variations. However, this technique becomes less powerful if samples are not collected regularly (Chatfield, 1989). The Box-Jenkins methodology enables a description of the time series independent autocorrelation structure relying only on the time lag between two sampling dates. Further, this method deals with a time series measured at equal intervals of time.

The distribution of spectral bands and thorough statistical analysis for the recorded data sets help in decision making process for the selection of sampling frequency for the monitoring program. In their study on river Volga, Mexico Tushinsky (1981) indicated the seasonal structure of temporal water quality variations *viz.*, long-term harmonics (approximately 15 days period) and synoptic variation (5-7 days). Kumar and Mujumdar (1996) used discharge rate for spectral analysis of temporal distribution in the river Cauvery. The time series analysis also distinguishes clearly the seasonal variations of water quality parameters with respect to changes in pollution load and river dynamics (Nandan and Aher, 2005; Agarwal *et al.,* 2006; Hasan Goksel Ozdilek *et al*., 2007).

Materials and Methods

Study area: River Cauvery is one of the 14 major rivers of India flowing through four states. The river basin covering a total area of 87,900km^2 and is located between 10°17' and 13° 18' N and 75° 28' and 75° 52' E and flows from North-West to South-East before emptying into the Bay of Bengal. The drainage system of the river is of dendritic pattern involving eight major tributaries. Many of these tributaries carry catchment discharges generated by various human induced activities. Besides abstracting water for drinking purpose, agricultural usage is common.

The geology of the watershed is magmatic gneisses of grandioritic to tonalitic composition. These are hard and durable rocks of high load bearing capacity in unwithered state. Other than these, metamorphic and sedimentary rocks are also seen. The river has carved its path in the major lineament zones of the basin. Mainly three types of soil are found in the river basin, *viz.*, reddish brown with acidic to neutral pH (laterite soil); deep reddish brown with acidic and dark brown sandy loam soil having neutral to weakly alkaline properties.

Climate: The data on temperature, rainfall and relative humidity for the period 1999-2002 was obtained from Indian Metrological Department (IMD).

Temperature: The river basin is located in the tropical region; the temperature starts shooting up from spring equinox (March 21st) onwards. It is reflected as increase in temperature from March to May. As one progresses from west to east, a shift in the mean maximum daily temperature becomes evident. In the western part of the basin the mean maximum of 28.5°C is in March, whereas, in the eastern part mean maximum of 33.53°C prevails during April.

Rainfall: Cauvery basin receives major part of water through precipitation during the south-west monsoon (June-September). The delta part of basin receives considerable amount of precipitation during north-east monsoon (October -December). The intensity of rainfall is high in the Western part of the basin and reduces towards eastern part. The study area is located on the western part of the catchment that contribute to dilution of river water creating a balanced change in the concentration of water quality parameters. Nonetheless due to extreme dry spells throughout winter and summer, the concentration of water quality parameters give rise to elevated concentrations.

Relative humidity: Relative humidity is high in the western part of basin during south-west monsoon. In general it varies from 70 to 80% and about 90 to 95% at the extreme western end. On the eastern part, the relative humidity decreases to an average of 65%. The evaporation in general is higher in the eastern part than the western part.

Monitoring frequency and choice of sampling location: For the determination of long term water quality variations on a time scale and as a function of location, including the factors related with it, the sampling locations that represent relatively a large area with the same hydrological characteristics were selected. Schilperoot *et al*. (1982) opined that prescribed probability of detection and optimal frequency have to be assessed before sampling. The optimal frequency of monitoring was assessed based on the analysis of data from records besides short term monitoring by varying time from hours to fortnight.

The pivot monitoring station is located near Dasanapura (Kollegal), Central Water Commission Gauging Station, which is the last gauging station within the Karnataka state boundary. At this station, monitoring of water quality was considered for a stretch of about 10 km by dividing the sampling station into six sub-stations (JW, KDO, KSW, HDO, 4HSW and 6HSW) at an interval of around 1 to 2 km between stations. The water quality data was collected for two years, from records for 1997 and 1998. The water quality measurements were carried out from 1999 to 2002 on bi-monthly and monthly basis to collect expansive data to ascertain seasonal variations.

The composite sampling was carried out at each sub sampling stations and at various depths to have a representative sample (ISO 5667-1, 1980, 1990, 1991). Samples were analysed for the physico-chemical parameters using the standard method of APHA (2005). Conveniently, the parameters are grouped into conservative and non – conservative parameters. *In-situ* analysis for parameters like pH, Temperature and Dissolved oxygen was performed. Samples for the analysis of remaining parameters were transported to laboratory in an icebox, maintained at 3°C (± 3°C). A laboratory analysis was carried out by following the standard methods (Andrew *et al.*, 1995).

Seasonal and long term variations: Time-series analysis with component models or autoregressive models is widely used for trend analyses and forecasting purposes of water quality constituents (Bhangu and Whitfield, 1997; Jian and Yu, 1998; Worrall and Burt, 1999). To investigate the relationship between water quality variables statistical procedures like correlation analysis (Grum *et al.,* 1997; Vervier *et al.,* 1999) used. Seasonal variations and long-term trends of water quality variables were determined based on monthly data and by applying additive component models.

The seasonal component was modelled by a linear combination of sine and cosine functions with period 12. To describe the stochastic component autoregressive processes of order one proved to be appropriate. To assess the presence of trends in the time series, the estimated coefficients of a quadratic trend function in the component model used. When the coefficients of both linear and the quadratic term in the trend function were not significant at 5% level, the hypothesis of existence of a trend was rejected.

The data collected on narrow time scale indicated insignificant variations in the concentration of conservative and non – conservative parameters, which leads to specify the sampling frequency and analysis on wide range time scale from month to month. The whole length of realization was six years. To identify shifts in the overall level of seasonal variation of the water quality parameters during the study period, time series plots of monthly water quality data was analysed.

Results and Discussion

The outcome of the present spectral analysis is discussed here for some of the water quality parameters. Temperature showed a characteristic increase during summer with highest mean value of 31°C and mean minimum temperature of 26°C (Fig. 1). The temperature stagnation occurred in the mid summer with an average temperature ranging between 24 and 27°C (SD + 0.05). Also a sharp drop in the mid summer and an increase towards late summer was noticed with former dipping from 30.5 to 24.5°C caused by short periods of cold spell and latter increased to 30°C following dissipation of land temperature in to water. Also, removal of vegetation probably allowed more direct sunlight to reach the surface thereby increasing the surface temperature (Roy *et al.*, 1972). As monsoon approached, a drop in temperature in late summer to 24.5°C was noticed. During early monsoon a slight increase was observed and variation was maintained between 25 and 27.5°C, caused by the early shower runoffs that removed heat from the land surface of the basin. Onset of monsoon in the basin significantly reduced the temperature to half of the mean maximum temperature of summer. An increase in temperature during late monsoon is evident from the graph which is because, the retreating showers again washed off heat from the surface (intermittent showers). A short stagnation of temperature is seen at this juncture at around 27°C. A gradual decrease was noticed towards early winter from 29 to 23.5°C. During mid winter temperature showed narrow range of fluctuation between 23.5 and 24.5°C.

Spectral function variability of pH showed a minor variation for summer and winter seasons. In these seasons, the variation ranged between 8.0 and 8.6 (Fig. 2). This range is an indication of pH stagnation for the two dry seasons and it occurred during mid winter and extended up to mid summer. A wide fluctuation was apparent from late summer to whole of monsoon season. The pH ranged between 6.9 and 8.8, which is an indication of influx of overland flow into the riverine system. A steady increase during early monsoon and a gradual decrease in late monsoon was notable wherein former increased from 7 to a maximum of 8.8 and latter showed a decrease from 8.2 to 6.9.

Conductivity and pH are indicative parameters of the hydrological changes in the basin as well other activities. Conductivity showed fluctuation during wet season due to intermittent rain which was observed immediately after winter accompanied by the conductivity values ranging between 33 and 59 μmhos cm^{-1} (SD + 1.76) (Fig. 3). An increase during mid monsoon and decrease during post monsoon is evident from the spectral graphs. Similar trends were also observed by Bhangu and Whitefield (1997). The dry seasons indicated an insignificant variation along the entire length of the temporal scale. A quick decrease towards winter followed stagnation between 30 and 36 μmhos cm^{-1} and it is a clear indication of temperature dependency of the parameters; increase in temperature increases conductivity visa versa. The same stagnation phenomenon extended into summer, wherein the values assorted between 19 and 46 μmhos cm^{-1}. A slight fluctuation in conductivity was observed while approaching towards monsoon.

Chloride showed a wide range of fluctuations for all the seasons and ranged between 20.3 and 70.9 mg l^{-1} (SD + 1.98) (Fig. 4). The chloride fluctuation was minimal during early summer, post monsoon and early winter. The other parts of the seasons exhibited higher concentration of 35 and 70.9 mg l^{-1}. A slow increase from early monsoon towards mid monsoon followed a decreasing trend at the end of monsoon. The monsoon values ranged from 30 to 50 μmhos cm^{-1}. A sharp drop at the intersection of each season is also evident from the graph. It is inferred that the chloride ions flushed into the river during monsoon from agricultural and domestic activities. The spectral characteristic of sodium showed negligible variations during summer and winter wherein former showed a varied range of 19.6 to 37.3 mg l^{-1} (SD + 1.01) and latter showed variations between 19.6 and 38 mg l^{-1} (Fig. 5). Tsirkunov *et al*. (1992) reported maximum concentration of major ions during summer or winter low flows. The concentration of sodium ranged between 14.48 and 38 mg l^{-1}. It is observed that the unsustainable agricultural practices in the catchment, mainly excessive use of river water for irrigation contribute to washing of all the residual fertilizers and salts to the down stream.

The spectral characteristic of calcium for various seasons exhibited slight vitiations. The concentration during monsoon was comparatively lower than the other two seasons. It varied between 17.67 and 37.0 mg l^{-1} (SD + 0.1) (Fig. 6). Both summer and winter witnessed higher concentrations, varying from 13.2 to 37.0 mg l^{-1}. A distinct narrow fluctuation during early summer was also evident. The stagnation observed in the early monsoon, showed fluctuation between 18.7 and 20.3 mg l^{-1}. A gradual increase in the concentration while approaching winter took the maximum concentration to 41.98 mg l^{-1}. Magnesium exhibited a trend similar to calcium. The summer and winter concentrations ranged from 5.6 to 18.33 mg l^{-1} and 3.66 to 18.6 mg l^{-1} respectively (SD + 0.12) (Fig. 7). An increase during late summer extended to the whole length of monsoon. The concentration increased from 5.6 to 18.33 mg l^{-1}, but the curve dropped in the mid monsoon.

A wide range of fluctuation was showed by potassium during monsoon with values between 0.88 and 3.7 mg l^{-1} (SD + 0.134) (Fig. 8). A narrow and steady increase during winter followed stagnation at a maximum of 3.22 mg l^{-1}. A slight decrease during late summer towards monsoon was also noticed. It is obvious from the spectral graph that both summer and winter exhibited almost similar trends of concentration variation for conservative parameters.

Dissolved (DO) and biochemical oxygen demand (BOD) are the two parameters selected from the non-conservative category for temporal variability function. The spectral function of dissolved oxygen in the present study reflected that DO concentration is inversely proportional to temperature, pressure and salinity. Changes in DO can be represented by two components which have specific behavioural patterns: Daily minimum values close to saturation that is relatively predictable from the water temperature, and reflect the hydrological regime and seasonal photosynthetic activity of phytoplankton (Moatar *et al.,* 1999). The DO content varied between 5.9 and 10.0 mg l^{-1} (SD + 2.56) (Fig. 9). During early monsoon values varied between 5.9 and 7.0 mg l^{-1}, followed by a steady increase between 7.0 and 8.0 mg l^{-1}. Further, a peak in the mid monsoon took DO content to 10.0 mg l^{-1}. As the temperature decreased from the post monsoon to just before summer an increase DO of 6.9 to 10.3 mg l^{-1} was evident. Dissolved oxygen showed stagnation between post monsoon and mid winter attributed by a range of 7.8 and 8.1 mg l^{-1}. A raise in the DO content after stagnation during late winter to 9.8 mg l^{-1} was also realized followed by a decrease towards summer.

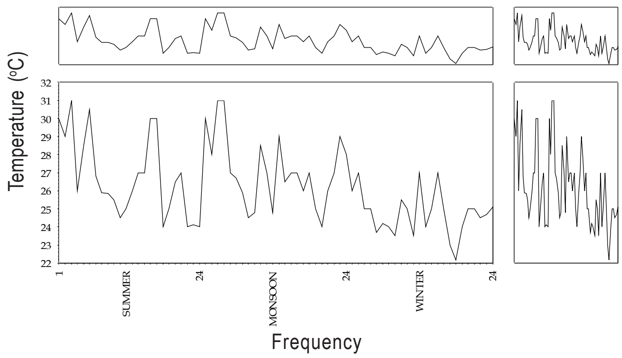

Fig. 1: Time series plot for temporal variation of temperature

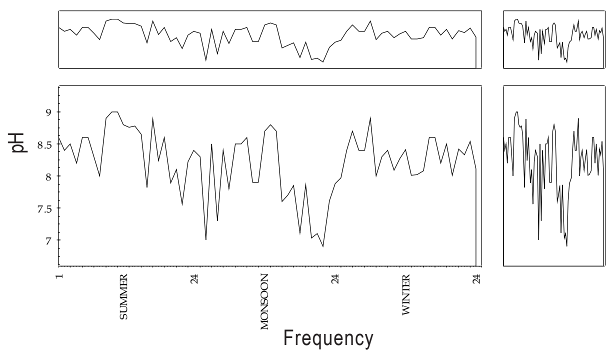

Fig. 2: Time series plot for temporal variation of pH

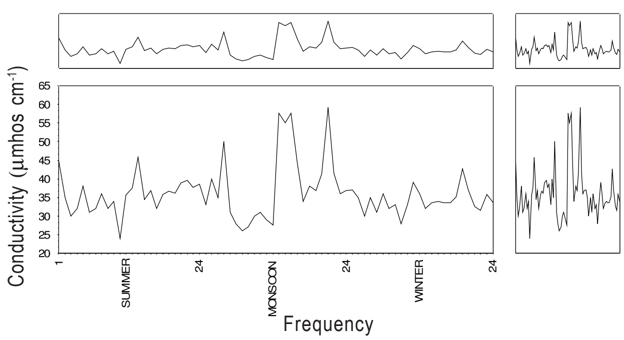

Fig. 3: Time series plot for temporal variation of conductivity

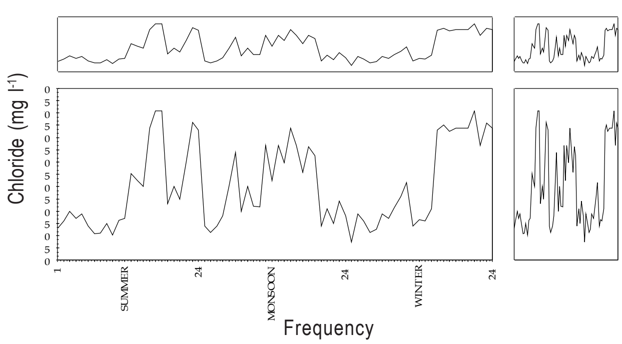

Fig. 4: Time series plot for temporal variation of chloride

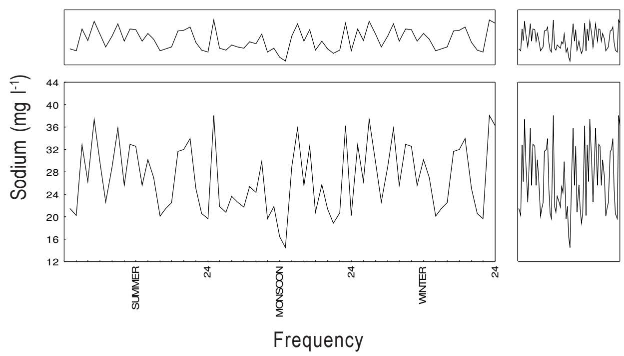

Fig. 5: Time series plot for temporal variation of sodium

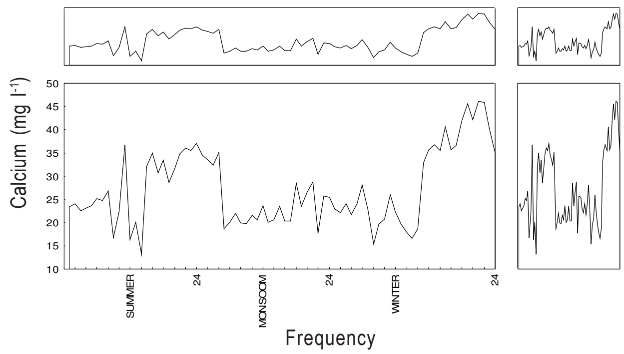

Fig. 6: Time series plot for temporal variation of calcium

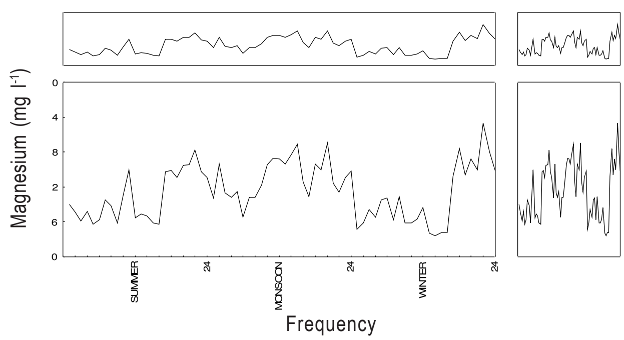

Fig. 7: Time series plot for temporal variation of magnesium

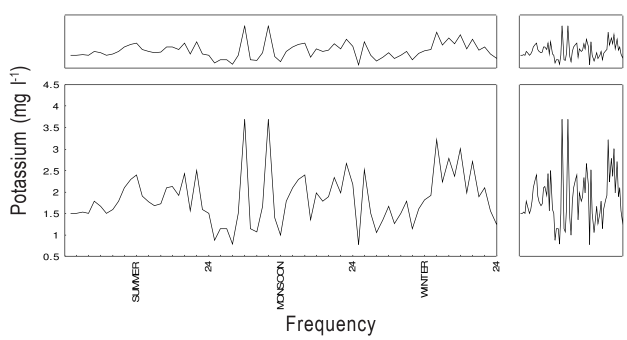

Fig. 8: Time series plot for temporal variation of potassium

The spectral function of BOD for various seasons conferred that spectrum is solid during early monsoon. The concentration varied from 1.1 to 2.7 mg l^{-1} (SD + 0.056) (Fig. 10). However, post monsoon showed decreasing trend from 7.2 to 0.9 mg l^{-1}. Characteristic stagnation between late monsoon and mid winter was also evident. The monsoon stagnation is observed to be between 0.7 and 0.9 mg l^{-1} with an increase during late winter to 2.8 mg l^{-1}. The summer season showed stagnation during early monsoon while increasing trend was distinct during mid and late summer. The BOD ranged from 0.9 to 1.5 mg l^{-1} and 1.2 to 2.3 mg l^{-1} for early

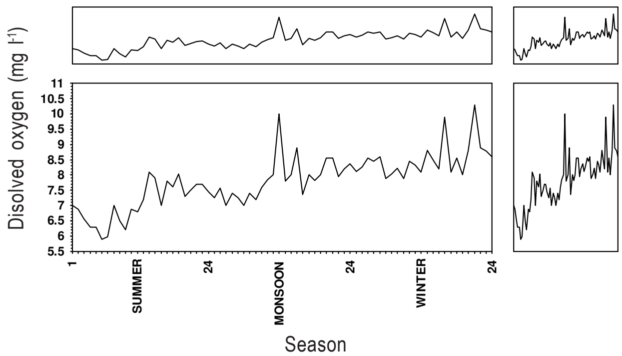

Fig. 9: Time series plot for temporal variation of dissolved oxygen (DO) demand

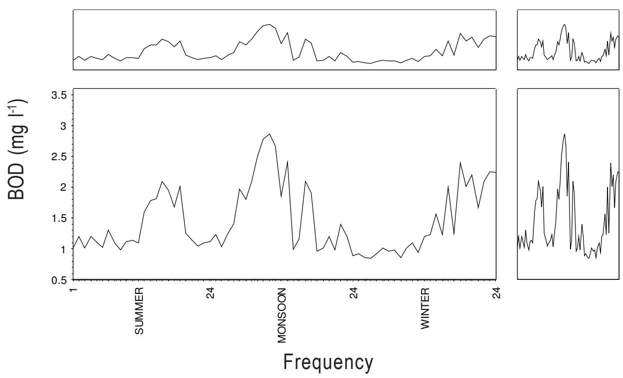

Fig. 10: Time series plot for temporal variation of biochemical oxygen demand (BOD)

and late summer respectively. The increasing trend during late summer is most possibly due to accumulation of algal matter and hydrophytes at low water level accompanied by sluggish flow as opined by Eartherall *et al.* (2000).

River Cauvery therefore showed a typical seasonal behaviour in terms of clear temporal water quality variability. The river is still showing some buoyancy to the swelling human activities in the catchment. The analysis also reflected that activities in the basin are inconsequential for short term fluctuations. However, the study showed a trend towards short term fluctuation from the existing long term fluctuations of water quality. This short term water quality fluctuation is an indicator of human pressure on the catchment. This is substantiated by the spectral demarcation for each of the season for various parameters used. A perpetuation towards short term fluctuations is well reasoned by unsustainable agricultural practices, blanket use of fertilizers and pesticides, discharges from domestic activities and over abstraction of river water in the catchment. The water chemistry of rivers and streams is a result of the hydrologic processes that are active in the watershed and these seasonal processes contribute to variation in water quality (Bhangu and Whitfield, 1997; Melina *et al.*, 2005).

To resolve further the occurrence of any shifts in the overall levels of the water quality over a period of 3 years were scrutinized. These plots suggested no movement in the data for any of the water quality parameters. Box and Jenkins (1976) time series analysis was used to develop a stochastic model to predict the future values of the water quality parameters. Most of the water quality parameters showed seasonal patterns, with slow decays to zero; as a result, lag 12 differencing was applied.

The analysis suggests that there is currently no shift in water quality and, rather the human pressure is perpetuating water quality variation from long term to short term, which means increased human activities up on the catchment. The existing trend in the river necessitates more than three consecutive seasons to show significant variations (Melina *et al.*, 2005) (excluding accident spills). The River basin is large and it is possible that any shift in water quality occurring due to point source and non-point sources on smaller scale are easily masked in the system, which is an indication of prolonging capacity to assimilate minor contributions from the human activities (Mathivanan *et al.,* 2007). The masked pollutant concentration can be identified on time scale by applying this methodology to water quality data of various parameters. System analysis then follows the development and application of statistical models to forecast criteria for water quality management. In the present study, a temporal scale spectral analysis is attempted; however, combination of spatial scale and temporal-scale analysis make the approach more robust for catchment modelling process. Limited number of models can be used to sufficiently model water quality parameters for many other tributaries of the basin and then, it will be possible to extend such models on a spatial basis. This extension will allow us to predict water quality in the basin with minimum data. There is a general consensus that catchment scale is the most appropriate spatial tool for environmental management analysis (Mainstone and Schofield, 1996; Novotny, 1999). Greiner (1999) discussed the main challenges of integrated catchment management and advocated a multidisciplinary approach to capture the complex system characteristics of land and water management in the catchment context.

In conclusion, some important features should be emphasized: a study can include several applications of models of increasing complexity. Each intermediate model gives indications to be used to verify the next more sophisticated model. A simpler model helps to delineate boundary conditions of more complex one. The prevailing duration (season) of high concentration and low concentration phases in the riverine system can be identified by a thorough examination of spectral distribution which effectively improves the optimization of monitoring programme and hence the outcome of the study has an imperative implication on the monitoring plan, river management and watershed management.

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