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Seemingly unrelated intervention time series models for effectiveness evaluation of large scale environmental remediation

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ABSTRACT

Large scale environmental remediation projects applied to sea water always involve large amount of capital investments. Rigorous effectiveness evaluations of such projects are, therefore, necessary and essential for policy review and future planning. This study aims at investigating effectiveness of environmental remediation using three different Seemingly Unrelated Regression (SUR) time series models with intervention effects, including Model (1) assuming no correlation within and across variables, Model (2) assuming no correlation across variable but allowing correlations within variable across different sites, and Model (3) allowing all possible correlations among variables (i.e., an unrestricted model). The results suggested that the unrestricted SUR model is the most reliable one, consistently having smallest variations of the estimated model parameters. We discussed our results with reference to marine water quality management in Hong Kong while bringing managerial issues into consideration.

1. Introduction

Large scale environmental remediation projects such as implementation of sewage master plans and building of waste and wastewater treatment facilities in urban cites often involve a vast amount of capital investments. It is, therefore, necessary and essential for policy makers and environmental authorities to rigorously evaluate the effectiveness of such large scale remediation projects using objective and unbiased statistical analysis. Using the Harbour Area Treatment Scheme (HATS) at Victoria Harbour of Hong Kong as an example, this study develops and introduces a modified Seemingly Unrelated Regression (SUR) time series model which can be efficiently applied to evaluate if such a large scale environmental remediation project successfully improves the marine water quality of the harbour.

In Hong Kong, Victoria Harbour is a harbour located between Hong Kong Island and Kowloon Peninsula (Fig. 1). Before the commencement of HATS in December 2001, Victoria Harbour received over a million tonne of untreated sewage on a daily basis which resulted in a serious pollution setback over the past. Indeed, HATS was one of the major water pollution control policies which aimed at improving the water quality in areas on both sides of Victoria Harbour. Construction work of Stage I of HATS was commenced in 1994. The HATS Stage I involved construction of a 23.6 km-long system of underground tunnels for transporting sewage from Kowloon, Tsing Yi, Kwai Chung, Tseung Kwan O and eastern Hong Kong Island to Stonecutters Island Sewage Treatment Works for the chemically-enhanced primary treatment (Fig. 1). The system collects 1.4 million tonnes of sewage each day, representing 75% of the sewage generated in the harbour area. After the chemically-enhanced primary treatment, the treated sewage effluent is then discharged through a submarine ocean outfall from southeast of Stone Cutters Island (Fig. 1). The overall construction cost for this project was about HK$8.2 billion (i.e., US$1 billion). The HATS Stage I was completed and commenced to operate in December 2001 and was able to remove 62–78% 5-day biochemical oxygen demand (BOD5) and 74–83% suspended solids from the influent. Readers may refer to the official website http://www.cleanharbour.gov.hk/ for obtaining more information about HATS.

Intervention analysis is a stochastic modelling technique to analyse the effects brought by intervention events such as implementation of laws, regulations or policies, to the mean level of a time series. Detailed description on the classical approach of intervention analysis can be found in Box and Jenkins (1976) and Wei (2006). This statistical method has been successfully applied on environmental data (e.g., Box and Tiao, 1975; Rao and Rao, 1983; Hipel et al., 1975). For instance, Yeung and Yung (1999) applied the intervention analysis to test the effect of two sewage screening plants on BOD5 levels in the Victoria Harbour of Hong Kong and its vicinity, and this work was carried out long before the commencement of HATS by the end of 2001.

However, the above classical approach of time series models with intervention effects considers only the autocorrelations (or called serial correlation in some literatures) of the same variable at the same station, which may not have made full use of the

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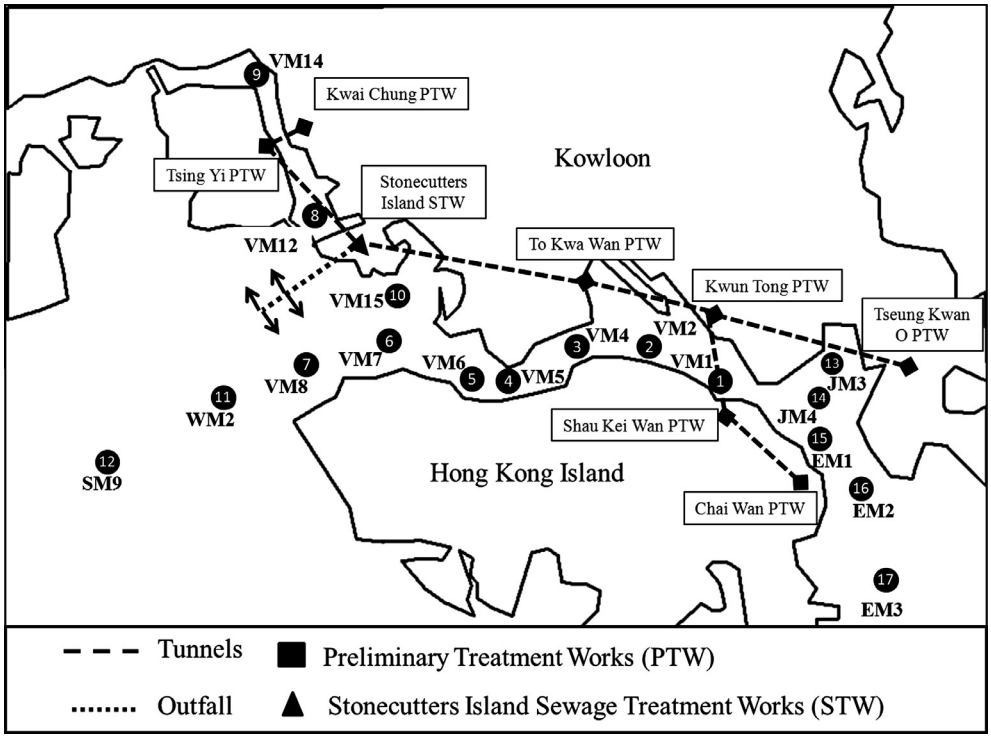

Fig. 1. Tunnels and outfall constructed during the first stage of HATS.

available information. Since the sampling stations are often near to each other and the water may flow from one station to another, it seems reasonable to consider also the correlation structure across different stations and also across different variables. Seemingly Unrelated Regression (SUR) model was first introduced by Zellner (1962, 1963) to assess the correlations among different time series equations. After that, SUR models have been applied to various fields. For example, Lenten and Moosa (2003) used SUR model into modelling temperature time series data. Some authors have proposed different estimates of parameters under SUR model and found that the estimates were more efficient than the ordinary least square estimates (e.g., Ma and Ye, 2010; Liu, 2002). Although it is successfully applied to econometrics data, SUR model is rarely, if any, used in water quality management.

The purpose of this study was to test whether the first stage of HATS is effective in improving the water quality along and nearby the Victoria Harbour using SUR time-series models with intervention effects. Three different SUR models were considered, including Model (1) assuming no correlation within and across variables, Model (2) assuming no correlation across variable but allowing correlations within variable across different sites, and Model (3) allowing all possible correlations among variables (i.e., unrestricted model). Based on the historical water quality monitoring data of dissolved oxygen, BOD5 and unionised ammonia which were collected by the Hong Kong Government between 1999 and 2010, the three SUR models were compared and evaluated. We discovered that the results were more precise when the correlation structures among different stations and variables were considered. Using the best SUR Model (3), we were able to verify if the water quality was significantly improved in Victoria Harbour and its vicinity areas.

2. Data and methodology

Historical marine water quality monitoring data were collected by Environmental Protection Department (EPD) of the Government of the Hong Kong Special Administrative Region, China. Sampling methods and analytical techniques used have been described and reported by EPD (HKEPD (2009)). The data used in this study are also available at the EPD's website on Marine Water Quality Reports: http://www.epd.gov.hk/epd/english/environmentinhk/water/marine_quality/mwq_report.html. The data are monthly data from January 1999 to December 2009 (a total of 132 data points for each chemical at each site). Three chemicals including Dissolved Oxygen (DO, in mg/L), 5-day Biochemical Oxygen Demand (BOD5, in mg/L, called BOD for convenience hereafter) and Unionised Ammonia (NH_3, in mg/L, called UA for convenience hereafter) from 17 sites (VM1-2, 4-8, 12, 14-15, WM2, SM9, JM3-4, and EM1-3, refer to Fig. 1) along Victoria Harbour at middle water depth were investigated. Generally speaking, higher level of DO and lower levels of BOD and UA indicate a better marine water quality. In this study, SUR models integrated with time series models and intervention analysis were used to examine the effect of the first stage of HATS on the marine water quality. All the computations were carried out using SAS® (version 9.2).

2.1. Data modifications

Few modifications were made on the dataset in order to make time series model usable:

- Time series models usually assume the data is equally spaced (Box and Jenkins, 1976). However, the sampling dates in our dataset vary from month to month and therefore the time intervals between observations are unequally spaced. The EXPAND procedure in SAS® is used to convert all the data points to the middle of each month under the cubic spline interpolation method.
- Outliers were removed and regarded as missing. Hence, all the missing values were imputed by cubic spline interpolation using the EXPAND procedure in SAS®.