Statistical analysis of water policies, air quality and climate in Isfahan

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Abstract. *In recent years the upstream water of Zayandeh river has been increasingly diverted to agricultural and industrial usage. As a consequence, downstream Zayandeh river, whose bed passes through the city of Isfahan, is suffering from a drought during many months per year. In this paper, we consider the impact of this intervention on air quality and climate variables at Isfahan city level. To do this, climate impact is assessed with short term intervention analysis while, for air quality, we extend to the multivariate recently proposed for impact assessment of environmental policies at city level on single pollutants.*

Keywords. *Spatio-temporal modelling; Intervention analysis; D-STEM software; EM algorithm.*

1 Introduction

Water flow regimes are known to have a great influence on anthropic activity and climate. It is then important to assess how much changes in river regimes may affect air quality at a city level, especially in semi arid regions. This is the case of Zayandeh River, which is the largest river in the central plateau of Iran and, in the past, showed a significant flow all year long between the spring in the Zagros Mountains and the end in Gavkhouni swamp after 400 km. Zayandeh River crosses the city of Isfahan, which is a major cultural and economic center of Iran, and has a secular heritage of water management engineering and rules.

Recent years faced extreme use of water from the river related to violation of existing water-rights, drought, traditional irrigation as well as rapid increase in the population and the foundation of many industrial plants, as observed e.g. by Allahdadian and Khoshakhlagh (2013). As a consequence, the water flow in downstream section of Zayandeh River steadily decreased and the related closure of the floodgate of the Zayandeh dam resulted in exhausting the riverbed for many consecutive months each year. Drought caused big problems not only for agriculture, historical heritage, city parks, identity and psychology of citizens but also tourism, local climate and air quality, to mention few. In time series analysis, intervention analysis is known after the celebrated paper of Box and Tiao (1975). See also e.g. Hipel and McLeod (2005). In river networks water quality monitoring, Clement et al. (2006) considered a spatio-temporal model based on directed acyclic graphs.

In this paper, we consider the impact on air quality and climate variables at city level. To do this, climate impact is assessed with short term intervention analysis while, for air quality, we extend to the multivariate case the approach of Fassò (2013) used for spatio-temporal impact assessment at city level of single pollutants. In order to understand air quality and climate in Isfahan, in the next section, we introduce the data of the local air quality monitoring network and in the subsequent section 3, we introduce the multivariate spatio-temporal impact model used for the analysis.

2 Data

Data considered here are related to the Farsi calendar years 1389-1391corresponding to 21/03/2010-20/03/2012. The meteorological variables cover temperature, dew point, pressure, wind and precipitation and are measured at Isfahan Station that has latitude 32° 37" *N*, longitude 51° 40" *E* and elevation 1550 *m* and is considered representative of meteorology in the area of Zayandeh River. Data for air quality include daily average concentration of ozone, nitrogen oxides, particulate matters, sulphur dioxide, carbon monoxide. These data are collected from ten stations in Isfahan, years 2004-2012. However, as often happens with environmental monitoring, not all pollutants are observed in all stations and not all stations begin in the same year. Hence the need for D-STEM approach which covers heterotopic networks with structural missing data. Moreover, the data for Zayandeh River include the indication about days for which the gate is open or closed.

3 Methods

We consider here a multivariate model for assessing the impact on air quality of an environmental rule in a geographic region $\mathcal{D}$, which extends the univariate approach of Fassò (2013). To see this, the observed $p-$dimensional pollutant concentration vector at coordinates $s \in \mathcal{D}$ and time $t = 1, 2, ..., n$, is denoted by $y(s,t)$, and assumed to satisfy the equation

$$y(s,t) = \alpha(s,t) + \beta(t)x(s,t) + \zeta(s,t). \tag{1}$$

In this model, the $p-$dimensional quantity $\alpha(s,t)$ represents the expected spatio-temporal impact of the environmental intervention occurring at time t^* and $\alpha(s,t) = 0$ for $t < t^*$. In general terms α is a suitable spatio-temporal process and the impact of an environmental policy can be assessed by the expected impact on pollution concentrations over region $\mathcal{D}$ and time horizon M, which is given by

$$\Delta = \frac{1}{M} \sum_{t=t^*}^{t^*+M-1} \int_{\mathcal{D}} E(\alpha(s,t))\, p(s,t)\, ds.$$

The weighting function $p(s,t)$ may be used for averaging, e.g. $p(s,t) = |\mathcal{D}|^{-1}$, or, for risk assessment, we may use population distribution which usually is static $p(s,t) = p(s)$. If $\Delta > 0$ component wise, then the impact is negative and we have an increase in pollutant concentrations. The simplest model for reduction assessment, is given by a scalar deterministic impact

$$\alpha(s,t) = \alpha,$$

which assumes constant impact over time and space after intervention. At an intermediate complexity level, we may use $\alpha(s,t)$ which gives a seasonal reduction map, appropriate for assessing a localized permanent quasi stationary impact.

In equation (1), confounders may be covered by a linear confounder model component $\beta x(t)$ or, more generally, by a time varying linear component $\beta(t)x(t)$, where $\beta(t)$ is a deterministic varying coefficient vector or a stochastic process. For example, Finazzi and Fassò (2011) use Markovian dynamics for $\beta(t)$. Moreover, the spatio-temporal error $\zeta(s,t)$ allows for spatial and temporal correlation, see e.g. Bruno et al. (2009). In this paper, in the light of limited spatial information available, we use a simple latent process with three components which is a modification of Fassò and Finazzi (2011) and extends the univariate model of Cameletti et al. (2011), namely

$$\zeta(s,t) = \omega(s,t) + \varepsilon(s,t),$$

where

$$\omega(s,t) = A\omega(s,t-1) + \eta(s,t)$$

is a stable Gaussian Markovian process, with eigenvalues of A smaller than 1. The innovations η are a purely spatial component given by iid time replicates of a $p-$dimensional zero mean Gaussian spatial random field characterized by a Linear Coregionalization Model (LCM) so that the spatial correlation matrix function has the following form:

$$E\left(\eta(s,t)\eta(s',t')'\right) = I(t=t')\,\sigma_\eta^2 R_\eta \rho(|s-s'|)$$

where R_η a $p \times p$ valid correlation matrix and $\rho(|s-s'|)$ is a valid spatial correlation function. Finally $\varepsilon(s,t)$ is a $p-$dimensional Gaussian measurement error iid over time and space, with variance covariance matrix $\Sigma_\varepsilon = diag\left(\sigma_1^2, ..., \sigma_p^2\right)$.

This model will be estimated on above introduced historical data using a modification of D-STEM software, which is discussed in Finazzi and Fassò (2014).

References

[1] Allahdadian L, Khoshakhlagh R, (2013) Economic Water Reallocation in the Zayande River Basin (Iran) Among Different Uses via Designed Software. *International Journal of Academic Research in Economics and Management Sciences*. **2**(6): 1-19.

[2] Box GEP, Tiao GC (1975) Intervention Analysis with Applications to Economic and Environmental Problems. *Journal of American Statistical Association*. **70**(349): 70–79.

[3] Bruno F, Guttorp P, Sampson PD, Cocchi D (2009) A simple non-separable, non-stationary spatio-temporal model for ozone. *Environmental and Ecological Statistics*. **16**: 515–529.

[4] Cameletti M, Ignaccolo R, Bande S (2011) Comparing spatio-temporal models for particulate matter in Piemonte, *Environmetrics*. **22**(8): 985–996.

[5] Clement L, Thas O, Vanrolleghem PA, Ottoy JP (2006) Spatio-temporal statistical models for river monitoring networks. *Water Science & Technology*. **53**(1): 9–15.

[6] Fassò A (2013) Statistical assessment of air quality interventions. Stochastic Environmental Research and Risk Assessment. **27**(7): 1651–1660.

[7] Fassò A, Finazzi F (2011) Maximum likelihood estimation of the dynamic coregionalization model with heterotopic data. *Environmetrics*. **22**(6): 735–748.

[8] Finazzi F, Fassò A. (2014) D-STEM: a software for the analysis and mapping of environmental space-time variables. Journal of Statistical Software. Accepted.

[9] Finazzi F, Scott ME , Fassò A (2013) A model based framework for air quality indices and population risk evaluation. With an application to the analysis of Scottish air quality data. *Journal of the Royal Statistical Society, series C*. **62**(2): 287–308.

[10] Hipel KW, McLeod AI (2005) *Time Series Modelling of Water Resources and Environmental Systems*. Â© 2005 Hipel & McLeod. http://www.stats.uwo.ca/faculty/aim/1994Book/.