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An empirical investigation of climate and land-use effects on water quantity and quality in two urbanising catchments in the southern United Kingdom

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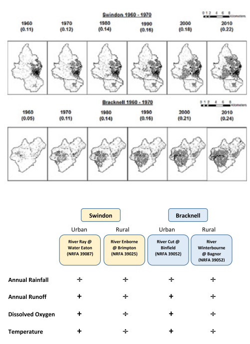
HIGHLIGHTS

- No evidence was found of trend in annual or seasonal precipitation in any of the four study catchments
- Upward trend in annual and seasonal runoff in urban catchments, but not in non-urban catchments
- Upward trend in the diss. oxygen and temperature in urban catchments, but not in the rural catchments
- Change in diss. oxygen and temperature in the urban catchments was not driven by climate variables.

GRAPHICAL ABSTRACT



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ABSTRACT

Using historical data of climate, land-use, hydrology and water quality from four catchments located in the south of England, this study identifies the impact of climate and land-use change on selected water quantity and water quality indicators. The study utilises a paired catchment approach, with two catchments that have experienced a high degree of urbanisation over the past five decades and two nearby, hydrologically similar, but undeveloped catchments. Multivariate regression models were used to assess the influence of rainfall and urbanisation on runoff (annual and seasonal), dissolved oxygen levels and temperature. Results indicate: (i) no trend in annual or seasonal rainfall totals, (ii) upward trend in runoff totals in the two urban catchments but not in the rural catchments, (iii) upward trend in dissolved oxygen and temperature in the urban catchments, but not in the rural catchments, and (iv) changes in temperature and dissolved oxygen in the urban catchments are not driven by climatic variables.

1. Introduction

A combination of changes in seasonal rainfall patterns and increased evapotranspiration as a result of raised temperatures, will result in changes in the United Kingdom with respect to future river flows,

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river water temperature and river water quality (Watts et al., 2015). To achieve sustainable utilisation of water resources, these pressures have to be balanced against the needs of a growing population and attendant pressures on land management. The population of the United Kingdom is projected to increase from 62.3 M in 2010 to 72.3 M by 2035 (ONS, 2011). The majority of this 16% growth is forecast for England and is likely to change the size and internal structure of urban areas. Such expansion and densification of urban areas is shown to have adverse impacts on the downstream aquatic environment downstream of the urban areas due to both changes in water quality and alterations of the natural flow regimes (Shuster et al., 2005). Detection of temporal changes in water quantity and quality provide the scientific basis for providing early warning signs of a potentially deteriorating aquatic environment and attribution of trends in long-term series of observations to concurrent changes in climate and development pressures provides the evidence basis for decision-makers to steer towards more effective policy interventions (Burt et al., 2008). However, the confounding influence of multiple stressors and the general lack of reliable and systematic long-term data makes this a challenging scientific task (Hering et al., 2015).

Reviewing the available literature, it appears that studies assessing the effect of urbanisation on water quantity have mainly adopted a modelling based approach (Cuo et al., 2008; Haase, 2009; Chu et al., 2013, Miller et al., 2014 among many others) and mostly agree that urbanisation will increase both peak flow and annual runoff volumes. Relatively fewer studies have attempted to detect and attribute urbanisation effects through use of long-term observed records of river flows and coincidental urban development. In the US, Rose and Peters (2001) analysed historical streamflow data and found statistically significant differences between streamflow in an urbanised Atlanta watershed and six other less developed watershed. This study found that peak flows are between 30% to more than 100% greater in the urbanised area than in other streams. In contrast, Steinschneider et al. (2013) reported little or no relationship between annual runoff coefficients and urbanisation in 19 catchments located in North East USA. In a study of observed flood events from catchments in the United Kingdom, Kjeldsen et al. (2013) found that urbanisation tend to reduce lag-time and increase runoff volumes, resulting in higher peak flow values, with the lag-time reduction being the most important process. Lerner (2002) discusses the sources of groundwater recharge in urban areas, including complications caused by contributions from the leaking water supply systems and imported water from outside the catchment.

There is extensive evidence from spatial surveys to make a positive link between metrics of urban land cover and water quality parameters in terms of nutrients (N, P, C), dissolved oxygen (DO) and suspended sediment (Chang, 2008). However it is important to understand how development patterns in specific watersheds affect water quality (Fu et al., 2009). Aside from a concentrated source of biological oxygen demand (BOD), warmer waters originating from urban areas will lower the oxygen carrying capacity of urban rivers and accelerate processes of chemical degradation threatening fish survival. Comprehensive data on the impacts of urbanisation are available in the largest cities in the world and these have been the subject of overarching review (Duh et al., 2008). Yet such an approach rather than confirm the negative impacts of urbanisation reveals inconsistent trends in BOD and DO between one major city and another, highlighting confounding influences most notably that growth stimulates resilience by prompting technological improvements (e.g. increased efficiency of wastewater treatment). Pinpointing the effects of urban growth on water quality at a small scale can be realistically quantified using scenario modelling but for interpretative purposes this approach has the restrictions of site-specific conditions. Studies have considered combined sewer systems and identified for example relationships between changes in spill volume (an indicator of population growth) and incidence/duration of undesirable DO conditions (Lau et al., 2002), yet much recent urban development is founded on separate storm and foul sewer systems. Therefore alongside deterministic modelling studies an empirical approach is very valuable and is the subject of this study on two growing towns largely characterised by separate sewer systems in which flood events have been mitigated against at the planning stage by the construction of balancing ponds. Although moderated by site-specific factors combined and separate sewer systems can have very different impacts on receiving water quality (Brombach et al., 2005). Whilst a move to separate systems will likely increase the overall storm water volume and pollutant load it should be beneficial as much of the organic matter reaching receiving waters will be of lower concentration and less biodegradable and therefore less likely to lower oxygen levels (Thorndahl et al., 2015).

The detection and attribution of effects of urbanisation on water quantity and quality has been hampered by the lack-of concurrent and consistent long-term historical records of relevant datasets on urban extent and associated indicators of urban development such as impervious cover. However, the recent development of a method to map the spatial–temporal development of urban areas by Miller and Grebby (2014) that does not rely upon limited remote sensing imagery but instead utilises historical maps from the UK Ordnance Survey provides a new opportunity for attribution of long term changes in water quantity and quality. The objective of this study is to utilise the method developed by Miller and Grebby (2014) to map long term change in urban cover to attribute observed trends in river water quantity and quality to urbanisation and climate variability.

Using a statistical approach the present study aims to detect and attribute stressors affecting the changes of river flow and water quality in the study sites. In selected catchments within the Thames basin (South England) for the period 1960–2010, use will be made of historic rainfall data coupled with the new information on spatio-temporal urban development to attribute the impact of climate and land-use change on both water quality and quantity. Daily rainfall, runoff and water quality data will be collated, but will be aggregated to annual and seasonal (winter, summer) metrics for the purposes of statistical analysis. The results will then compared to those from similar analyses conducted using data from two rural control catchments chosen on the basis of proximity and similar size. By considering water temperature and DO, key direct indicators of the health of waterbodies as well as other important indicators of nutrient enrichment (soluble reactive phosphorus (SRP)), we will investigate whether the confounding conclusions regarding impacts of urban growth drawn at the scale of mega-cities (Duh et al., 2008) are reflected in smaller areas where the process of detection and attribution is more tractable. The following research questions will be addressed:

- Can statistically significant trends be detected in rainfall, river flow and selected water quality data obtained from two urban catchments?
- How does the observed trend in the urban catchments compare with the trend found in data from two nearby and similar sized, but rural, catchments?
- Is urbanisation the main cause of the changes in river flow and water quality in urban catchments?

2. Study sites

The experimental approach adopted in this study required identification of two medium-sized catchments where a significant transformation from rural to urban land-cover has taken place, and coincide with the availability of good-quality long-term hydrological data covering the same time period. For each of the two urban catchments a nearby and hydrologically similar, but undeveloped rural, catchments, also with a long and high quality hydrological records, should be available. Finally, for each of the four study sites, good quality long-term records of comparable water quality measurements should also be available. Based on these criteria two sets of paired urban and rural catchments