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Integrated analysis of water quality parameters for cost-effective faecal pollution management in river catchments

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ABSTRACT

In many parts of the world, microbial contamination of surface waters used for drinking, recreation, and shellfishery remains a pervasive risk to human health, especially in Less Economically Developed Countries (LEDC). However, the capacity to provide effective management strategies to break the waterborne route to human infection is often thwarted by our inability to identify the source of microbial contamination. Microbial Source Tracking (MST) has potential to improve water quality management in complex river catchments that are either routinely, or intermittently contaminated by faecal material from one or more sources, by attributing faecal loads to their human or non-human sources, and thereby supporting more rational approaches to microbial risk assessment. The River Ouse catchment in southeast England (U.K.) was used as a model with which to investigate the integration and application of a novel and simple MST approach to monitor microbial water quality over one calendar year, thereby encompassing a range of meteorological conditions. A key objective of the work was to develop simple low-cost protocols that could be easily replicated. Bacteriophages (viruses) capable of infecting a human specific strain of *Bacteroides* GB-124, and their correlation with presumptive *Escherichia coli*, were used to distinguish sources of faecal pollution. The results reported here suggest that in this river catchment the principal source of faecal pollution in most instances was non-human in origin. During storm events, presumptive *E. coli* and presumptive intestinal enterococci levels were 1.1–1.2 logs higher than during dry weather conditions, and levels of the faecal indicator organisms (FIOs) were closely associated with increased turbidity levels (presumptive *E. coli* and turbidity, $r = 0.43$). Spatio-temporal variation in microbial water quality parameters was accounted for by three principal components (67.6%). Cluster Analysis, reduced the fourteen monitoring sites to six representative 'sentinel' sites. The correlation coefficient between presumptive *E. coli* and phages of *Bacteroides* GB-124 was very small ($r = 0.05$) whilst that between turbidity and suspended solids was high ($r = 0.62$). Variations in climate, animal and anthropogenic interferences were all, either directly or indirectly, related to faecal contamination. The findings show the importance of meteorological conditions, such as storm events, on microbial water quality, and suggest that any future increases in the frequency of storm events (associated with climate change) are likely to result in a greater incidence of FIO/pathogen loads. This low-cost approach could help to predict spatio-temporal 'hotspots' of elevated waterborne disease risk. The work also represents an important step towards integrating novel MST tools into river catchment modelling.

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1. Introduction

More than a billion people have no access to safe drinking water, and over 2 million die each year from water-related diarrhoea. Diarrhoeal disease is one of the leading causes of morbidity and mortality in Less Economically Developed Countries (LEDC) (Unicef and Who, 2009). In LEDC, surface waters are highly vulnerable to anthropogenic faecal pollution resulting from rapid population growth (Godfrey et al., 2006). Such faecal contamination potentially has profound and severe implications for public health, particularly in small communities in LEDC, where surface waters are often a source of drinking and bathing water (Pedley and Howard, 1997). However, it is not just human populations in LEDC that are at risk from poor microbial water quality.

Rising demands on water resources raise concerns about longer-term sustainable provision of safe drinking water in many More Economically Developed Countries (MEDC). Intensive agriculture and large-scale construction of roads and settlements have led to a sharp rise in the contribution of non-point sources (NPS) by increasing the volume of run-off during rain events (Servais et al., 2007). In addition, the impact of both point sources (PS) and NPS of pollution may be exacerbated by the possible effects of climate change through more frequent flooding (Moore et al., 1997).

According to Domingo et al. (2007), waterborne human infectious diseases associated with faeces from humans and animals are becoming a greater concern globally, and they place an enormous burden on the human population of many countries. Efforts to reduce waterborne disease rates are taking place against a backdrop of the Millennium Development Goals (MDG) (UN, 2009), which aim to reduce by half the proportion of people without sustainable access to safe drinking water by 2015.

To protect and manage surface water quality in EU Member States, the revised Bathing Water Directive (2006/7/EC) and the Water Framework Directive (WFD) (2000/60/EC) have been established. The WFD requires all EU Member States to manage both PS and NPS of pollution, so as to achieve 'good ecological status and quality' in their watercourses by 2015 (EU, 2000).

Whilst faecal indicator organisms (FIOs) have long been used to identify faecal contamination, they do not distinguish sources of contamination. Their use may therefore underestimate potential risks to human health, as human faecal material may constitute a greater risk of disease because of the presence of human specific pathogens (Sinclair, 2009). However, the implementation of effective, simple, low-cost Microbial Source Tracking (MST) techniques within river catchments may significantly improve water quality by enhancing public health protection in a proactive and preventative manner. MST may provide a useful framework for differentiating sources of faecal contamination, and could support rational source protection strategies (Cotruvo, 2004).

For example, in the U.S., MST may assist environmental managers to comply with Total Maximum Daily Load regulations required by the U.S. Environmental Protection Agency. In Europe, its most obvious current application is in developing 'bathing water profiles' required under the revised EU bathing water Directive (EU, 2006). At a global level, MST is likely to prove an important tool for the development and implementation of Water Safety Plans (WSP), as prescribed by the WHO (2008). The aim of WSP is to ensure the consistent safety and acceptability of a drinking water supply, through the use of comprehensive risk assessment and risk management approaches. Identifying potential spatio-temporal faecal 'hotspots' within a river catchment using appropriate MST methods within a well-designed monitoring programme, would support a 'multiple-barrier approach' to source water evaluation, selection and protection.

Managing faecal pollution can be especially challenging for many LEDC because public resources can be inadequate, and reliable information about the extent, sources, risks and severity of faecal pollution may be limited at best (Jenkins et al., 2009). Therefore, simple procedures and tools that might potentially be applied in LEDC are urgently needed to assess the microbiological quality of water as a health protection measure.

Therefore, the overall aim of this study was to combine the use of traditional water quality parameters with novel MST tools in an attempt to develop low-cost protocols for microbial water quality monitoring and risk assessment under various meteorological conditions. The specific objectives of the study were to: 1) evaluate the potential usefulness of a previously isolated *Bacteroides* strain GB-124 as a marker for identifying and quantifying human sources of faecal contamination; 2) suggest a protocol for gathering and analysing relevant data in order to develop rational and effective low-cost techniques and mitigation approaches; 3) identify appropriate chemo-physical parameters that might provide simple and low-cost alternatives to FIO enumeration; and 4) suggest a protocol for identifying spatio-temporal 'hotspots' of faecal contamination in river catchments.

2. Materials and methods

2.1. The River Ouse catchment

The River Ouse catchment in southeast England was selected for this study because of its proximity to our laboratory facilities, and because of the ready availability of information on land-use and local pollution issues. The River Ouse contains 273 km of main river-channel, and drains 396 km^2 of land to its tidal limit. The catchment is predominantly rural, with only 7% of the land classed as 'urban' (Environment Agency, 2006). Agriculture is the principal land-use by area, but this potential source of faecal pollution is supplemented by over twenty municipal wastewater treatment works (WWTW) discharging partially treated wastewaters into the river system (Ebdon et al., 2007).

2.2. River water sampling

A total of 350 1-L grab samples of river water were collected at least biweekly from fourteen monitoring sites (Table 1, Fig. 1) over the period October 2007 to September 2008. These sites included locations impacted by recognised PS and/or NPS of faecal pollution (both human and non-human). Samples were taken manually by clamping 1000 ml sterile polyethylene bottles (Sterilin®, UK) to an extendible sampling pole. All