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Microbial risk assessment with the OAEL approach at water abstraction points in rural Kenya

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ABSTRACT

US-based models for recreational water quality were applied to characterize the potential health risk (PHR) of infection with gastroenteritis (GI) and highly credible gastroenteritis (HCGI) illnesses from single exposure at several water abstraction points (WAPs) along the Njoro River in rural Kenya. Ambient geometric mean densities of *Escherichia coli* (EC) and intestinal enterococci (IE) were generally high (2–4 log units of cfu/100 ml) and risk levels were grossly in excess of acceptable health risk (AHR) levels for bathing and drinking. PHR was 2–3 times higher with the Cabelli (IE) model (Equation (2)) compared to the US EPA (EC) model (Equation (1)). Risk levels varied among WAPs in concomitance to the spatial and seasonal variability of ambient EC and IE densities. With the Cabelli IE model, PHR of HCGI illness on single exposure to the dry weather 95th percentile IE density for bathing was 2.5% of the exposed population at Logoman compared to 5.2% at Turkana Flats, 4.9% at Kenyatta or Nessuit and 4.6%, 4.5% and 4.2% at Treetop, Segotik and Njoro Bridge, respectively. PHR was $\geqslant$5% on exposure to the wet weather 95th percentile IE density at all WAPs, excepting Treetop with 4.3%. Relative risk levels increased by at least 30 and 70 times for GI and HCGI illnesses, respectively, from drinking (250 ml) raw stream water, rising erratically in wet weather by >80% of the dry weather risk at Logoman, >30% at Njoro Bridge and Kenyatta and 10–15% at Segotik, Nessuit and Turkana Flats. By stipulating freshwater bathing water quality guidelines of 126 and 33 cfu/100 ml for EC and IE, respectively, US, EPA upholds maximum AHR levels at 0.7% and 1.9% for EC and IE, respectively. Hence, reducing current PHR levels at the WAPs to the US, EPA bathing AHR levels would require at least 2–4 log reductions of IE and EC densities with even further log reductions to achieve the WHO recommended drinking water AHR level of 0.1%. This would necessitate specialized treatment, in particular point-of-use treatment at the household level, as well as the implementation of comprehensive catchment management measures to protect the stream and the WAPs.

1. Introduction

Exposure to contaminated water has been associated with illnesses such as gastroenteritis and other infections of the skin, eyes, ears, nose and throat (Cabelli et al., 1982; Cabelli, 1983, 1989; Dufour, 1984). The threat of microbial pollution-related illnesses is predictable with quantitative microbial risk assessment (QMRA). In particular, QMRA can function as a valuable tool for risk identification and management in situations where epidemiological investigations may be lacking. With the Observed Adverse Effect Level (OAEL) approach, the level of faecal contamination is indicated by the presence of an indicator organism (Steyn et al., 2004). A negative health effect can be expected if the indicator is present and the level of risk increases with increase in the indicator density. The common bacteria indicators currently in use are total coliforms (TC), faecal coliforms (FC), faecal streptococci (FS), *Escherichia coli* (EC) and intestinal enterococci (IE). Most regulatory agencies are interested in EC and IE given that they correlate well with the rate of gastrointestinal (GI) illnesses in recreational waters. This correlation has been useful for the development of microbial water quality guidelines. Notably, the guidelines of the United States (US) Environmental Protection Agency for bathing water (US EPA, 1986) and the European Union (EU) New Bathing Water Directive (EU, 2006) were adopted on the basis of measured levels of faecal indicator bacteria in recreational waters. Similarly, regulatory institutions in many countries are aided by WHO water quality guidelines (WHO, 2001, 2003) that were developed on the same basic principle.

A guideline value stipulates a theoretical health safety limit that is often associated with the maximum acceptable health risk. It is usually the tolerable concentration of an indicator rather than the

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detectable harmful dose of infectious pathogens (Salas, 1986; Steyn et al., 2004). The choice of indicator over pathogen is largely due to methodological problems. A lot of time and resources may be needed to adequately detect any type of pathogen and because they are diverse and occur in low numbers in the environment, large errors and costs may be incurred in sampling and enumeration (Wade et al., 2006). Also, many pathogenic bacteria could be described as viable but non-culturable and the densities of most pathogens in environmental waters are unpredictable. As a result, bacteria indicators such as EC and IE are used during routine microbiological assessment. However, both indicators have been criticized for not being representative enough, especially, for viral and protozoan pathogens. Pathogens may be present where bacteria indicators are shown to be absent with substantial evidence that natural systems with no established faecal input may harbour some bacteria indicators. For example, IE has been associated with soil, insects, plants, aquatic organisms and other natural sources where faecal contamination is not expected (Anderson et al., 2005). Similarly, EC may occur in non-faecal environments and its persistence and potential to multiply in the environment has been demonstrated (Byappanahalli and Fujioka, 1998). Despite these limitations, tests for faecal indicator bacteria are customary for assessing the hygienic quality of environmental waters.

Given that a complete epidemiological investigation is normally expensive and time consuming, public health authorities and water quality managers are inclined to follow the OAEL approach, which is usually integrated into the routine water quality monitoring programme. OAEL requires testing the water for the presence of a preferential faecal indicator bacterium at the point of exposure, usually a recreational site or a water source. When the indicator bacterium is present in excess of referential water quality guidelines and the tolerable risk threshold is breached, a sanitary survey is executed to detect faecal sources (WHO, 2003). This may be undertaken in synchrony with ancillary water quality parameters such as suspended solids, turbidity and colour, in addition to chemical constituents like the Biochemical Oxygen Demand, oxygen concentration and ammonia or chloride levels to verify any external input that may be associated with faecal contamination. In spite of this, the OAEL approach is crammed with a variety of caveats besides the overt limitations of the common bacteria indicators that are often used. For instance, the popular one-dimensional linear relationship between bacteria density and illness risk does not directly account for viral or protozoan pathogens even though they are the leading etiological agents for acute GI illnesses (Cabelli, 1983; Wade et al., 2006). Because of this limitation, various pathogen-based dose–response models have been developed for drinking water and certain recreational waters (Gale, 2001; Benke and Hamilton, 2007). Yet many sources of uncertainty still exist. Besides computational problems such as the averaging procedure for microbial density, dose–response relationships are complicated by many extrinsic factors such as individual susceptibility, medical history of the exposed population or even secondary transmissions of GI illness, all of which could vary with region, race, age, culture, environment, economic status and diet (Salas, 1986).

Recent studies on the Njoro River (a predominantly rural stream in southwestern Kenya) have reported the deteriorating state of affairs with regard to changes in land use within the catchment. This is believed to have seriously affected stream flow and water quality, especially at the middle and lower reaches, where the stream is seriously polluted and flow is now intermittent (Kundu et al., 2004; Mokaya et al., 2004; Jenkins, 2008; Yillia et al., 2008a,b; Yillia and Kreuzinger, 2009). Despite the poor water quality status, many residents depend on the stream for their daily water needs as water supply in the riparian settlements is acutely inadequate (Yillia et al., 2008a). The stream is used constantly for a variety of functions including domestic needs, in particular, drinking, washing, cooking and bathing. It has been alleged that the reported cases of preventable water related diseases such as typhoid, diarrhoea and dysentery at public health institutions in the area account for over 50% of all illnesses. And it is thought that the prevalence of water related diseases among residents in the area is corollary to the use of polluted water from the stream even though an epidemiological study has not been previously undertaken to establish this link. As a prelude to that investigation, the research aspect of this study pursued the OAEL framework to characterize the potential health risk of infection with gastroenteritis (GI) and highly credible gastroenteritis (HCGI) illnesses that may be attributed to bathing or drinking contaminated water at several water abstraction points (WAPs) along the stream. In addition, the seasonal variability of risk levels at the WAPs with respect to acceptable referential threshold levels for bathing and drinking was assessed and the prospective efficacy of ancillary chemical water quality parameters to indicate potential health risk of GI and HCGI illnesses was examined.

2. Materials and methods

2.1. Description of the study area – Njoro River

Njoro River (60 km) drains a small predominantly rural catchment (280 km^2) in southwestern Kenya, approximately 160 km northwest of Nairobi (Fig. 1). It is a high altitude stream with its source at the eastern segment of Mau Hills (2700 m a.s.l) (Mathooko, 2001). The stream is very narrow and shallow, and follows a northward course at the upper reaches but at the middle reaches it turns northeast, followed by a southeast bend at the lower reaches where it is intermittent with usually no flow during dry spells (Yillia et al., 2008a). When flowing at full length, Njoro River drains into Lake Nakuru (1700 m a.s.l) at the floor of the Rift Valley (Shivoga, 2001). Its main tributary is the Little Shuru, which joins the main Njoro River flow in the lower segment of the Upper Njoro River Catchment (UNRC). Below the confluence, the stream flows through mostly poor rural communities that lack proper sanitation and adequate access to clean drinking water. The communities comprise Njokerio, Njoro Town, Ngatta and the suburbs of Nakuru Town. The entire stream is used extensively for a variety of activities including water abstraction, bathing, washing, religious baptism and livestock watering. These activities occur beside or within the stream channel even though most of them are concentrated especially at designated pools called water abstraction points (WAPs) at the moderate bed slopes of the middle and lower reaches (Yillia et al., 2008a).

2.2. Water abstraction points (WAPs) along Njoro River

The location of the main WAPs at the middle and upper reaches of the Njoro River is shown in Fig. 1. In the UNRC are Logoman, Segotik and Nessuit. During the study, the vicinity of Logoman consisted of grazing land in the open areas with exotic and natural trees in the forested area. At Segotik, a narrow riparian strip was evident along the stream but the nearby area was used for grazing and farming. On the Little Shuru is the WAP, Nessuit, which is the main WAP for Nessuit Village, a pastoral and farming community with approximately 2000 inhabitants. The other WAPs – Treetop, Turkana Flats, Njoro Bridge and Kenyatta – are located at the middle reaches. Treetop is 1 km downstream the confluence of the main Njoro River flow with the Little Shuru and close to the wet weather supplementary drinking water intake of Egerton University. The riparian vegetation at Treetop was vividly present even though the nearby area was under cultivation and grazing. In