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Livestock ownership and microbial contamination of drinking-water: Evidence from nationally representative household surveys in Ghana, Nepal and Bangladesh

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ABSTRACT

Background: Current priorities for diarrhoeal disease prevention include use of sanitation and safe water. There have been few attempts to quantify the importance of animal faeces in drinking-water contamination, despite the presence of potentially water-borne zoonotic pathogens in animal faeces.

Objectives: This study aimed to quantify the relationship between livestock ownership and point-of-consumption drinking-water contamination.

Methods: Data from nationally representative household surveys in Nepal, Bangladesh, and Ghana, each with associated water quality assessments, were used. Multinomial regression adjusting for confounders was applied to assess the relationship between livestock ownership and the level of drinking-water contamination with *E. coli*.

Results: Ownership of five or more large livestock (e.g. cattle) was significantly associated with drinking-water contamination in Ghana (RRR = 7.9, 95% CI = 1.6 to 38.9 for medium levels of contamination with 1–31cfu/100 ml; RRR = 5.2, 95% CI = 1.1–24.5 for high levels of contamination with > 31cfu/100 ml) and Bangladesh (RRR = 2.4, 95% CI = 1.3–4.5 for medium levels of contamination; non-significant for high levels of contamination). Ownership of eight or more poultry (chickens, guinea fowl, ducks or turkeys) was associated with drinking-water contamination in Bangladesh (RRR = 1.5, 95% CI = 1.1–2.0 for medium levels of contamination, non-significant for high levels of contamination).

Conclusions: These results suggest that livestock ownership is a significant risk factor for the contamination of drinking-water at the point of consumption. This indicates that addressing human sanitation without consideration of faecal contamination from livestock sources will not be sufficient to prevent drinking-water contamination.

1. Introduction

Building on the Millennium Development Goals, the Sustainable Development Goals (SDGs), which were adopted in September 2015, include a focus on safe water and sanitation (United Nations General Assembly, 2015). SDG 6 aims to "ensure availability and sustainable management of water and sanitation for all", with proposed monitoring of the percentage of the population using safely managed drinking-water services (Sustainable Development Solutions Network, 2015). These are defined as a basic drinking-water source (piped water; boreholes or tubewells; protected dug wells; protected springs and rainwater) which is located on household premises and available when needed. Such services should also be free of faecal and priority chemical (identified nationally, but globally fluoride and arsenic) contamination and/or regulated by a competent authority (World Health Organization, 2015). The use of contaminated drinking-water (along with inadequate sanitation and hygiene) is a key contributing factor in diarrhoeal disease, particularly in low and middle-income settings (Prüss-Ustün et al., 2014). Current priorities with regard to sanitation focus primarily on the management of human faecal matter, and largely

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ignore the management of faecal matter from domestic animals, despite their contribution, as a group, of 85% of global animal faecal waste (Dufour et al., 2012).

In 2015, an estimated 844 million people globally were not using a basic source of drinking-water, and 159 million people were relying on untreated surface water, which is highly susceptible to contamination (World Health Organization and UNICEF, 2017). While 89% of the global population were using improved water sources (defined as those specifically designed to avoid contamination from outside) in 2012, water from these sources is also frequently found to be contaminated, or to become contaminated during storage within the home, with a recent systematic review indicating that many improved sources contained faecal indicator bacteria at levels above World Health Organization guideline values (Bain et al., 2014). Globally, the population using unimproved water sources, or improved water sources with faecal contamination in 2012 was estimated to be 1.9 billion (Bain et al., 2014).

Overall, diarrhoeal disease accounted for 1.4 million deaths in 2010, including 17.4% of deaths in children aged 28 days to 1 year, and 11.9% of deaths in children aged 1–4 years. Diarrhoeal disease is the 4th leading cause for years of life lost globally (Lozano et al., 2012). Of these deaths, 502,000 have been attributed to inadequate drinking-water and 280,000 to inadequate sanitation (Prüss-Ustün et al., 2014). In addition to diarrhoeal disease, inadequate drinking-water, sanitation and hygiene has complex impacts on undernutrition, growth stunting and environmental enteropathy, with subsequent life-long consequences, although these effects are difficult to quantify due to a lack of data (Clasen et al., 2014).

Microbial testing for faecal indicator bacteria (e.g. thermotolerant coliforms or *Escherichia coli*) is recommended to detect faecal contamination. The indicator bacteria groups used to detect faecal contamination are common to humans, livestock and many wildlife species. Thus, detection of faecal indicator bacteria may indicate contamination by human faeces, animal faeces or both (Mackay and Oxford, 1954; Meays et al., 2004). There are a number of potentially water-borne zoonotic pathogens which can be detrimental to human health, such as *Salmonella* spp, *E. coli* 0157:H7, *Campylobacter* and *Cryptosporidium parvum* (Cotruvo et al., 2004; Dufour et al., 2012). Several studies have detected significant positive correlations between domestic livestock and poultry contact and diarrhoeal disease in humans (Conan et al., 2017; El-Tras et al., 2015; Kaur et al., 2017; Zambrano et al., 2014). However, there have been few attempts to quantify the importance of animal faeces in the contamination of drinking-water. Those studies which have been conducted indicate that domestic animals contribute significant levels of faecal contamination to water sources (Daniels et al., 2015; Schriewer et al., 2015). The risks to human health posed by animal faeces are not well understood, however, and it is often assumed that due to the species-specific nature of many pathogens, contamination by animal faeces presents less risk than that by human faeces (Dufour et al., 2012). A better understanding of human versus animal sourced water contamination patterns, and the subsequent implications for human health, is required to enable effective and efficient interventions.

The present study aims to assess the potential influence of ownership of livestock, including poultry, on drinking-water contamination. We used three unique, nationally representative household surveys with associated water quality modules from Ghana, Bangladesh and Nepal, to address this aim. When analysis was undertaken, these were the only countries available with published micro-data from household surveys that included a water quality module. The statistical correlation between ownership of domestic animals and the presence of faecal indicator bacteria in water samples at the point of consumption was assessed, after controlling for confounding factors.

2. Materials and methods

2.1. Data

Data from the Ghana Living Standards Survey Round 6 (GLSS 6), Bangladesh Multiple Indicator Cluster Survey 2012–2013 (MICS) and Nepal MICS 2014 were used. These were nationally representative household surveys, which recorded household characteristics including housing conditions and household agriculture, and were conducted from October 2012 to October 2013 (Ghana), December 2012 to April 2013 (Bangladesh) and January to June 2014 (Nepal). In terms of the seasons, in Ghana the survey was conducted over a full calendar year (in each region); and in Bangladesh and Nepal the surveys were conducted mainly during the dry season. Each of these studies used a two-stage cluster sampling design to provide estimates representative at the national, urban versus rural, and sub-national levels (region in Ghana, district in Bangladesh and ecological zone in Nepal). The data collection procedures were approved by the relevant institutional review board in each country.

Nested within these surveys were additional water quality modules, for which households were selected randomly from within each cluster (three households per cluster in Ghana, one per cluster in Bangladesh, and three per cluster in Nepal). Respondents were requested for “a glass of water which you would give a child to drink”. The water provided was tested for *E. coli* as an indicator of faecal contamination by incubating 100 ml of the sample on Compact Dry EC growth media plates (Nissui, Japan), after filtration through a 0.45 μm filter (Millipore Microfil). Incubation was carried out at ambient temperature for 24 h, after which *E. coli* colonies were enumerated and recorded as colony forming units (CFUs) per 100 ml of water. The water quality testing procedures used were the same in all three surveys. Out of the overall sample sizes of 16,772 households (Ghana); 55,120 households (Bangladesh), and 12,975 households (Nepal), 2972; 2592; and 1492 had associated information on water contamination at the point of consumption, respectively.

As identified in Wright et al. (2016), CFU counts in these datasets exhibited preferential recording of values ending in zero. Since ‘heaped’ values such as 10 and 100 fall at class intervals, this makes analysis using the WHO risk categories of 1–10, 11–100, and 100–1000 problematic (World Health Organization, 1997). Thus, *E. coli* CFU data were categorised into three groups representing no contamination (0 CFU/100 ml); medium contamination (1–31 CFU/100 ml) and high contamination (> 31 CFU/100 ml). These cut-offs were selected by pooling the data from the three countries, excluding observations with 0 CFU/100 ml, then selecting the median value to ensure approximately equal counts within each category and comparability of analyses between countries. Livestock ownership was the primary factor of interest: the surveys included information on ownership (and numbers owned for each livestock species) of draught animals (e.g. donkeys, horses or bullocks), cattle, yak, buffalo, sheep, goats, pigs, and poultry (not all countries included all livestock types). Aggregate livestock categories were created by summing the number of animals owned in groups of livestock species: (1) large livestock (cattle, draught animals, yak and buffalo); (2) small livestock (sheep, goats and pigs); and (3) poultry (chickens, guinea fowl, ducks and turkeys were aggregated where these were recorded separately).

Variables relating to several important confounding factors for the assessment of faecal contamination of water were created. The level of faecal contamination in water from different source types can vary widely, including between different improved water sources (Bain et al., 2014; Shields et al., 2015). Thus, the source of drinking-water was defined in the following categories: (1) piped to premises; (2) standpipe, tanker or neighbours tap; (3) tubewell or borehole; (4) protected well or spring; (5) unprotected well or spring; (6) surface water; (7) sachet or bottled water; or (8) rain water collection. To avoid very small cell counts for Bangladesh, categories (3) and (4) were