A Spatial Analysis of Giardiasis and Cryptosporidiosis in Relation to Public Water Supply Distribution in North West England

Colour figures in print not required

Keywords: Cryptosporidiosis, gastrointestinal disease, giardiasis, Public health, surveillance, Spatial analysis

Abstract

Giardia and Cryptosporidium are both waterborne parasites and leading causes of gastroenteritis. Although specimens from diarrhoeic patients are routinely examined for Cryptosporidium, they are often not examined for Giardia so many cases go undiagnosed. Since 2002, all faecal specimens in Central Lancashire have been tested for infection with Giardia and Cryptosporidium. The aim of this paper is to gain insight into the factors contributing to giardiasis and cryptosporidiosis, including evidence of transmission via drinking water. Our analysis found age to be an important factor for both conditions with a higher risk for young children and a second peak in risk of giardiasis in adults. There was a significantly higher risk of giardiasis for males and a higher risk of cryptosporidiosis for females. The geographical location was significant, showing an increased risk in the north. For one of the water treatment works studied, residence in an area with increased supply was a significant predictor for cryptosporidiosis but not giardiasis.

Introduction

Giardiasis and cryptosporidiosis are parasitic diseases caused by the protozoa *Giardia duodenalis* (also called *Giardia lamblia* or *Giardia intestinalis*) and Cryptosporidium respectively. They are leading causes of human gastroenteritis worldwide. Both are waterborne parasites with similar reservoirs and transmission routes. The principal risk factors for infection are foreign travel, contact with fresh water, countryside activities or person-to-person transmission (Kabore et al., 2010; Hunter et al., 2004). The protozoa are transmitted via human or animal faeces that has found its way into drinking water or food (Sopwith et al., 2005). Zoonotic transmission of Cryptosporidium is well established (Chalmers and Giles, 2010) and giardiasis has been associated with farm animal contact (Warburton et al., 1994). Waterborne outbreaks of giardiasis can occur (Nygård et al., 2006) and giardiasis has been associated with consumption of mains tap water in South West England (Stuart et al., 2003) and North West England (Minetti et al., 2015).

Giardiasis and cryptosporidiosis are both neglected conditions, due to a widely held view that they are predominately travel-acquired conditions (Minetti et al., 2015; Savioli et al., 2006). There are around 3,000 cases of giardiasis and between 3,000 and 5,000 cases of cryptosporidiosis annually in the UK (Public Health England, 2011a,b), although the true number is likely to be higher as many cases are undiagnosed. The Second Infectious Intestinal Disease study (IID2) estimated that there were 52,434 (95% CI: 15,022 to 183,020) cases of giardiasis and 43,834 (95% CI: 11,393 to 168,655) cases of cryptosporidiosis in the UK from April 2008 to August 2009 (Tam et al., 2012). Even the lower bounds of the IID2 estimates suggest that these conditions are largely unreported. Under-reporting occurs for a number of reasons: many people do not present to their GP when they experience symptoms and if they do, a faecal specimen is not always requested. Although faecal specimens are routinely examined for Cryptosporidium, laboratories often apply selective criteria to Giardia. Criteria vary but usually include travel abroad hence indigenous cases of giardiasis are often undiagnosed.

Since 2002, all faecal specimens in Central Lancashire from patients presenting with diarrhoea have been tested for infection with Giardia and Cryptosporidium. In 2002, the laboratory in Preston introduced an Enzyme Immunoassay (EIA) test, which is more sensitive than the standard test involving light microscopy of specimens. This has been associated with a trebling of diagnosed Giardia infections and an increased proportion of cases, especially in young/middle aged adults (Ellam et al., 2008). Since 2002, all specimens in Central Lancashire have been assessed by this laboratory, which gives a better impression of the true incidence of giardiasis and cryptosporidiosis.

Nearly all households in Central Lancashire receive a public water supply treated to remove both parasites; less than 1% of the population have a private water supply (Figure 2 of Drinking Water Inspectorate (2014)). Prior to 2000 removal of Cryptosporidium was incomplete and waterbourne outbreaks occurred (Sopwith et al., 2005; Smith et al., 2006). Water sources include rivers and reservoirs with a complex treatment and distribution system that ultimately supplies water to households in defined water zones.

The source of many cases of cryptosporidiosis and giardiasis in the UK is unknown. The aim of this paper therefore, is to gain insight into the factors contributing to, and the etiology of, giardiasis and cryptosporidiosis in Central Lancashire. This includes any potential relationship with water source, through an examination of the spatial distribution of cases in relation to the public water supply.

Methods

Data

The study region is Central Lancashire, North West England, an administrative district consisting of the Local Authorities (LAs) Chorley, South Ribble and Preston (Figure 1). The region has a total population of 333,949 and is ethnically predominantly white (93%) with 5% Asian or Asian British (Table 1). The main industries of employment are: wholesale and retail trade; repair of motor vehicles; manufacturing; health and social work; real estate, renting and business activities, with only 1% of the population employed in agriculture (Table 2) (Office for National Statistics ; General Register Office for Scotland ; Northern Ireland Statistics and Research Agency, 2005).

Information on giardiasis cases and cryptosporidiosis cases in 2003 to 2011 was obtained from surveillance data held by the Cumbria and Lancashire Health Protection Unit. For each case, the age, sex and postcode of the patient was recorded. Other individual level data, such as foreign travel, were unavailable.

Figure 1: Location of the study region(blue shaded area) within North West England . Red lines show the borders of the local authorities.

Source: Ministry of Housing, Communities & Local Government (2016); Map data: Geobasis-DE/BKG, Google

Controls were a random sample of all people registered with a GP in the study region. GP registrations were available for each year 2006 to 2011. From each year, four times the number of cases occurring in that year were randomly selected as controls. For the years 2003 to 2005, four times the number of cases occurring in each year were selected randomly from the GP registrations from 2006. Consequently we used separate control sets for giardiasis and cryptosporidiosis. As with the cases, the age, sex and postcode of each control was recorded.

The postcode for both cases and controls was linked to the Lower Super Output Area (LSOA - a unit of geography containing an average of 1500 people), and the English Indices of Deprivation 2007 (Department for Communities and Local Government, 2007) was used as an index of multiple deprivation (IMD) for each LSOA. This was included as deprivation is associated with poor health

(Pickett and Pearl, 2001; Haan et al., 1987; Sooman and Macintyre, 1995; Sloggett and Joshi, 1994; Eames et al., 1993; Sloggett and Joshi, 1998). The IMD is a single summary measure based on seven domains of deprivation: Income Deprivation; Employment Deprivation; Health Deprivation and Disability; Education, Skills and Training Deprivation; Barriers to Housing and Services; Crime; and Living Environment Deprivation.

Countryside activities are one of the principal risk factors for both giardiasis and cryptosporidiosis. As individual level information on behaviour was not available, the urban/rural classification was used as a proxy for countryside exposures. The urban/rural classification for each postcode was also established using census data. There are eight classifications, UR 1-8 (Office for National Statistics, 2001b). Classifications UR 1-4 refer to areas where the wider surrounding area is sparsely populated. Classifications UR 5-8 refer to areas where the wider surrounding area is less sparsely populated. The study area only has classifications UR 5-8: Urban (population over 10,000) (UR 5); Town and Fringe (UR 6); Village (UR 7); Hamlet and Isolated Dwellings (UR 8).

Data on the water zones in the study region and the water treatment works that supply them were obtained from the water company operating in the North West of England: United Utilities. The water sources were either rivers or reservoirs with a number of water treatment works and service reservoirs in the distribution chain. The smallest unit of defined water supply was the water zone. A water zone (WZ) is a geographical area, the boundaries of which can change over time. Each water zone may receive its water from one or more water treatment works (WTW) in various percentages. These percentages can also change over time. Each case and control was assigned to the relevant water zone based on their postcode and year. From this, the percentage of water supply from each water treatment works was found for each case and control.

Statistical analysis

We fit a generalized additive model using a binomial distribution with case/control indicator Y_i (cases = 1, controls = 0) for the ith individual as the response variable and adjust for age (A_i), sex (M, F), where G_{iM} indicates male, the interaction between age and sex, IMD (D_i), urban/rural indicator where U_{il} ($l = 5, 6, 7, 8$) indicates membership of the lth urban/rural category, percentage of water supply from the jth water treatment works (W_{ij}) and geographical location (E_i, N_i).

Age is known to have a non-linear relationship with both giardiasis and cryptosporidiosis and consequently was modelled using a cubic spline with knots at ages $c = 18$, 40 and 60. See Durrleman and Simon (1989) for more details on cubic splines. IMD and percentage of water received from each of the main water treatment works were included as linear terms. A main water treatment works is one which supplies a mean of greater than 1% of the total of an individual's supply. Geographical location was included using a penalised regression spline, providing a fitted surface showing any areas with an excess of cases after adjusting for the other factors.

	Frequency	**%**
Age		
0-4	18998	6
5-9	21452	6
10-14	22976	7
15-19	22000	7
20-24	20138	6
25-29	21974	7
30-44	75075	22
45-59	65394	20
60-74	43415	13
75+	22527	7
Sex		
Males	163709	49
Females	170240	51
Ethnicity		
White	310974	93
Mixed	2972	< 1
Asian or asian British	16701	5
Black or Black British	1629	< 1
Chinese	1198	< 1
Other	447	< 1
Missing	28	< 1

Table 1: Study region demographics

This model was applied separately to giardiasis and to cryptosporidiosis.

$$Y_i \sim \text{Bernoulli}(\mu_i)$$

$$logit(\mu_i) = \alpha + \beta_0 G_{iM} + \beta_1 A_i + \beta_2 A_i^2 + \beta_3 A_i^3 + \sum_{k=1}^{3} \gamma_k A_k^* + \left[\beta_4 A_i + \beta_5 A_i^2 + \beta_6 A_i^3 + \sum_{k=1}^{3} \delta_k A_k^*\right] G_{iM}$$
$$+ \beta_7 D_i + \sum_{l=6}^{8} \epsilon_l U_{il} + \sum_{j=1}^{6} \zeta_j W_{ij} + s(E_i, N_i)$$

$$A_k^* = \begin{cases} 0 & A < c_k \\ (A_i - c_k)^3 & A > c_k \end{cases} \tag{1}$$

Occupation	Frequency	%
Wholesale and retail trade, repair of motor vehicles	29454	19
Manufacturing	27016	17
Health and social work	17782	11
Real estate, renting and business activities	16478	11
Public administration and defence	12462	8
Education	12200	8
Construction	10396	7
Transport, storage and communication	9305	6
Hotels and catering	7126	5
Financial intermediation	4706	3
Agriculture, hunting and forestry	2265	1
Electricity, gas and water supply	963	1
Mining and quarrying	119	< 1
Fishing	22	< 1
Other	6425	4

Table 2: Industry of occupation for individuals in the study region

Inference

The model building process used forward selection: variables were added one-by-one starting with the most significant. A likelihood ratio (LR) test was conducted between the models with and without the variable being tested. If the LR test indicated the model was improved with the added variable, it was retained in the model. Interactions between age, sex and IMD were also tested. Once the final model was selected, the fitted values were fixed as an offset and a non-parametric smooth for geographical location was added to model residual spatial variation. P-values for UR, age and WTW were calculated using a LR between models including all levels of the factor, or related variables, compared to none.

Results

Descriptive Statistics

There were 723 giardiasis cases and 488 cryptosporidiosis cases during the study period (Table 3). We selected 2892 controls for giardiasis and 1952 controls for cryptosporidiosis, Approximately 50% of controls were male for both conditions. 58% of giardiasis cases were male compared to 46% of cryptosporidiosis cases. Our study population varied by urban rural status. 81% and

84% of giardiasis cases and controls respectively and 84% and 85% of cryptosporidiosis cases and controls respectively were classified as UR 5 (Urban, population over 10,000). In contrast, a greater percentage of cases for both conditions was classified as UR 8 (hamlet and isolated dwellings) than controls: 5% compared to 2% of giardiasis cases and controls respectively and 3% compared to 2% of cryptosporidiosis cases and controls respectively.

	Giardiasis		Cryptosporidiosis	
	Cases	Controls	Cases	Controls
Total number	723	2892	488	1952
Male n (%)	419 (57.95)	1460 (50.48)	226 (46.31)	996 (51.02)
UR5 n (%)	589 (81.47)	2439 (84.34)	408 (83.61)	1663 (85.19)
UR6 n (%)	58 (8.02)	267 (9.23)	39 (7.99)	161 (8.25)
UR7 n (%)	38 (5.26)	122 (4.22)	24 (4.92)	83 (4.25)
UR8 n (%)	38 (5.26)	64 (2.21)	17 (3.48)	45 (2.31)
Age Mean (SD) [range]	38.49 (20.70) [0, 92]	39.27 (22.39) [0, 99]	18.37 (18.29) [0, 82]	38.34 (22.64) [0, 100]
IMD Mean (SD) [range]	20.61 (16.59) [3.20, 75.04]	21.53 (15.90) [3.14, 75.04]	19.53 (14.83) [3.41, 67.54]	21.98 (16.66) [3.14, 75.04]

Table 3: Summary statistics for giardiasis and cryptosporidiosis

The mean ages of cases and controls for giardiasis were very similar at 38 (SD 21) and 39 (SD 22) respectively. However, the mean age of cases of cryptosporidiosis was markedly lower at 18 (SD 18) while the mean age of controls (38, SD 23) is similar to that of controls for giardiasis. Mean IMD was very similar for cases and controls of both conditions.

Water in the study region was mainly supplied by just one WTW: WTW6. Cases and controls in the study received an average of about 80% of their water from WTW6 (Table 4). The remaining percentage came from eight other WTW. The majority (95%) of individuals in both the giardiasis and cryptosporidiosis datasets received at least 95% of their water from one WTW. Six water treatment works (WTW 1-6) met our definition of a main water treatment plant (supplied more than 1% of the case or control's water) and were included in the analysis.

Fitted Models

There was a significant age-sex interaction for cryptosporidiosis (p-value 0.008). Figure 2b shows a non-linear relationship between age and odds of cryptosporidiosis. Though the relationship is different for males and females, both show higher numbers of cases in young children, and a steady decline with age. The odds of cryptosporidiosis is higher for adult females than males, except perhaps at around age 50, and is similar for both genders in children. The age-sex interaction was not significant for giardiasis (p-value 0.337). Sex was also not significant (p-value 0.099) but was significant in a model without the age-sex interaction (p-value 0.002). Age had a significant non-

	Giardiasis % Supply			Cryptosporidiosis % Supply		
WTW Code	All	Cases	Controls	All	Cases	Controls
WTW7	0.03	0.14	0.00	0.00	0.00	0.00
WTW8	0.11	0.00	0.14	0.04	0.00	0.05
WTW9	0.12	0.20	0.10	0.17	0.39	0.11
WTW1	1.41	1.57	1.36	1.65	1.19	1.77
WTW2	2.28	3.48	1.98	2.49	4.01	2.11
WTW3	3.84	2.75	4.11	3.84	4.30	3.72
WTW4	4.38	7.68	3.56	4.18	6.37	3.63
WTW5	6.65	7.62	6.41	6.11	5.45	6.28
WTW6	81.19	76.56	82.35	81.52	78.29	82.32

Table 4: Water treatment works codes and the mean percentage of total water they supply.

linear relationship with giardiasis (p-value < 0.001), but the pattern is different to that observed for cryptosporidiosis (Figure 2a). As with cryptosporidiosis, the odds of giardiasis is highest in ages 0-5, but there is another peak in adults at around ages 30-50. The odds of giardiasis is highest for males at all ages except among young children.

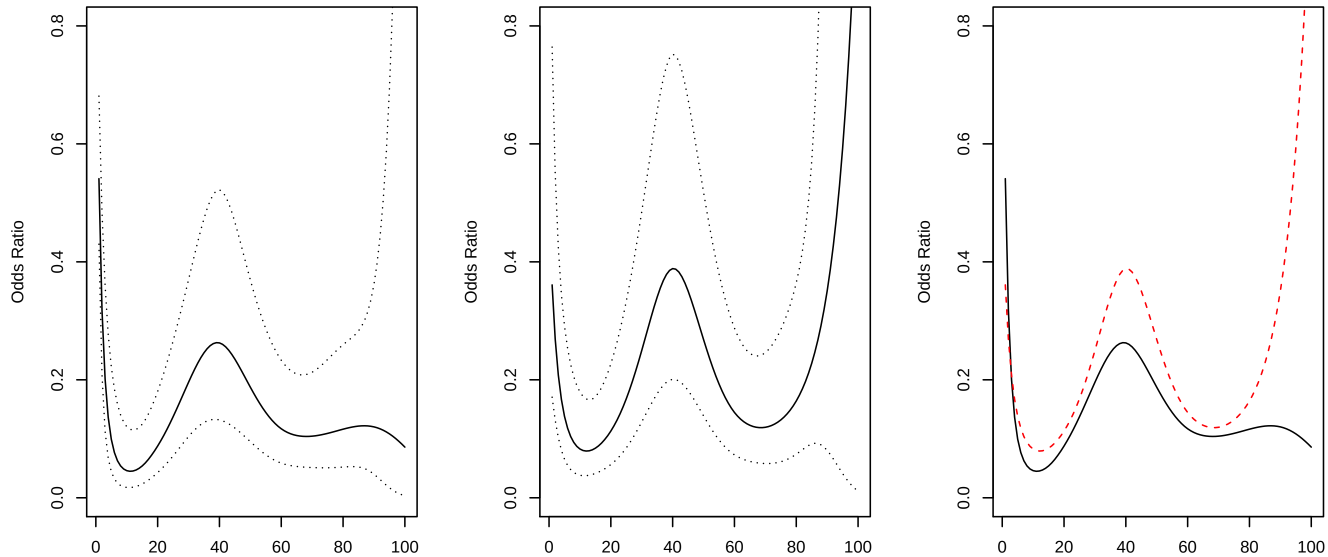
The effect of deprivation as measured by IMD was not significant for giardiasis (LR p-value 0.904 (Table 5)) but was significant for cryptosporidiosis (LR p-value 0.003), indicating a lower odds of contracting cryptosporidium in more deprived areas. The urban/rural indicator was significant for giardiasis (LR p-value 0.027), showing higher odds in rural areas compared to urban areas. The urban/rural indicator was not significant for cryptosporidiosis (LR p-value 0.624).

	Cryptosporidium		Giardia	
	Odds Ratio	P-value	Odds Ratio	P-value
IMD	0.989	0.003	1.000	0.904
UR6	1.064		0.957	
UR7	1.334		1.154	
UR8	1.294	0.624	2.012	0.027

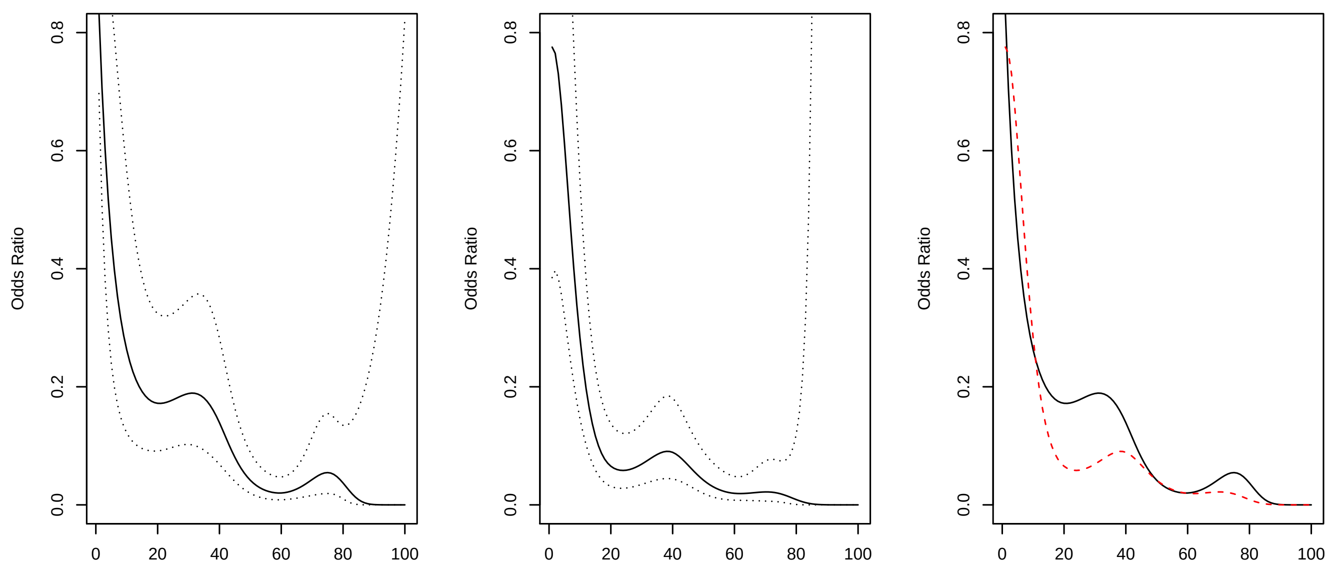
Table 5: Fitted odds ratios. Odds ratios for UR 6-8 are comparisons with UR 5. P-values for Urban/rural indicator refer to the significance of including all levels of the factors compared to none.

The smooth term for geographical location was highly significant (p-value 0.001) for giardiasis. The fitted surface for the region (Figure 3, left) shows an increase in the log-odds of giardiasis in the north of the region. The smooth term was also significant for cryptosporidiosis (p-value 0.004), and again shows an increase in the log-odds of cryptosporidiosis in the north of the region (Figure 3, right).

The inclusion of water treatment works was significant for cryptosporidiosis (LR p-value $<$ 0.001) and for giardiasis (LR p-value $<$ 0.001). There is an indication that there may be something different about WTW2 as its odds ratio is distinct from the others for cryptosporidiosis (Figure 4). An analysis of the contrast between the odds ratio for WTW2 and the average of the odds ratios for the other WTW does not indicate a significant difference for giardiasis (estimate 0.003 [-0.015, 0.020]) but does indicate a significant difference for cryptosporidiosis (estimate 0.041 [0.012, 0.071]).



(a) Giardiasis



(b) Cryptosporidiosis

Figure 2: Effect of age on the odds ratio (solid line) of giardiasis (a) and cryptosporidiosis (b), for females (left) and males (centre), with ±2 standard errors (dotted lines). A direct comparison of males (red, dashed line) and females (black, solid line) is shown on the right.

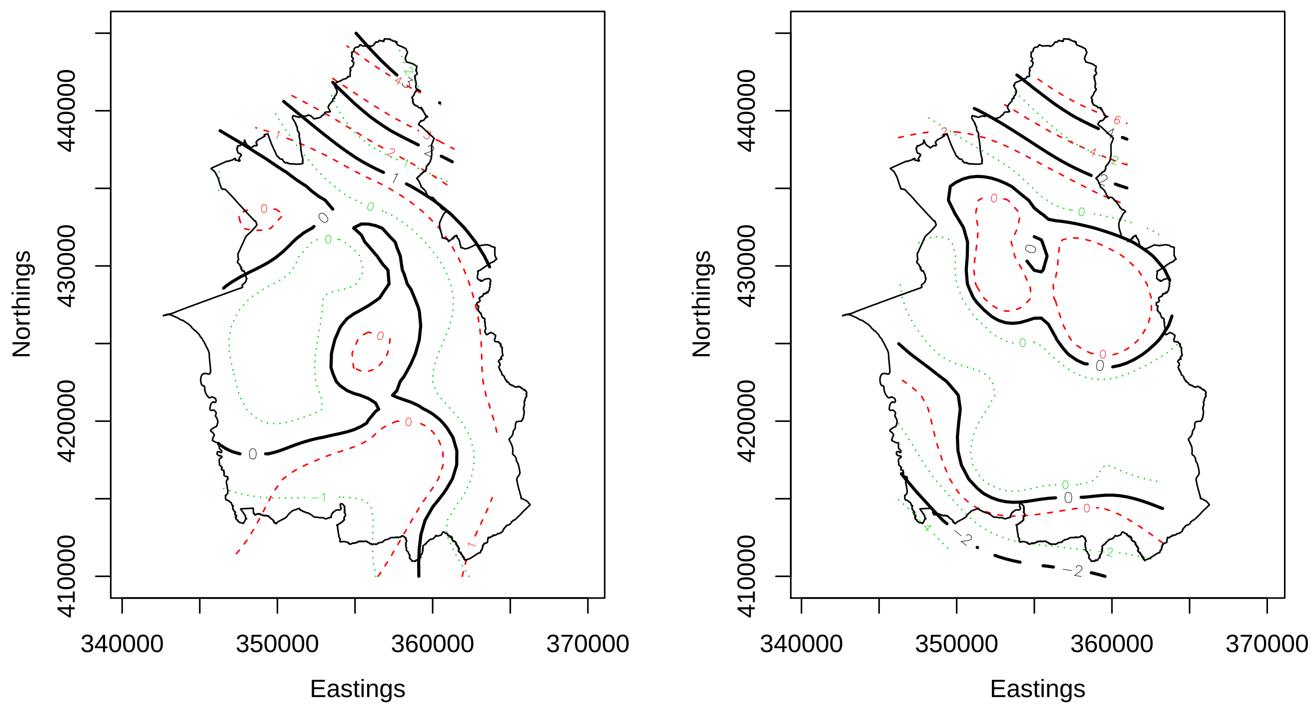


Figure 3: Residual spatial variation (solid line) in the log-odds of giardiasis (left) and cryptosporidiosis (right) after adjusting for other variables with +1SE (green dotted lines) and -1SE (red dashed lines).

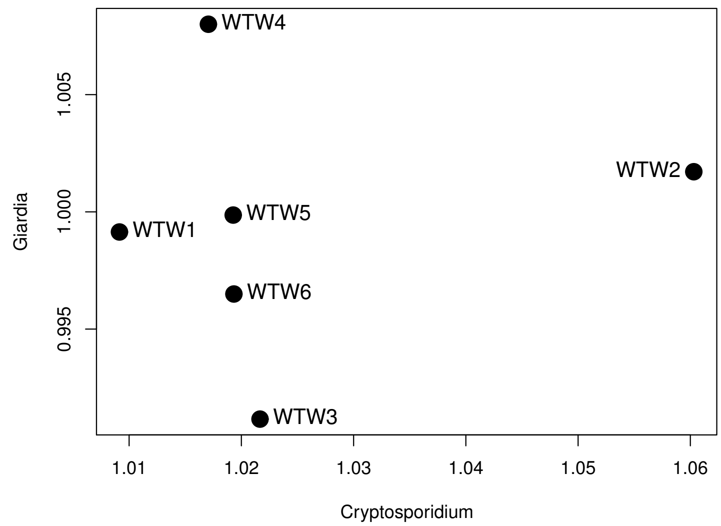


Figure 4: Odds ratios for each WTW for cryptosporidiosis plotted against odds ratios for giardiasis. There is an indication of a difference in odds ratio for cryptosporidiosis for WTW2 compared to the others. Labels give the codes for the WTW.

Discussion

Our analysis has found age to be an important factor for both cryptosporidiosis and giardiasis, with a higher risk of both conditions for young children and a second peak in risk of giardiasis in adults. Sex was also found to be significant with a higher risk of giardiasis for males and a higher risk of cryptosporidiosis for females. IMD was significant for cryptosporidiosis but not giardiasis, while the urban/rural indicator was significant for giardiasis but not cryptosporidiosis. The geographical location was significant for both giardiasis and cryptosporidiosis, showing an increased risk in the north for both. Water treatment works (WTW) was also significant for both giardiasis and cryptosporidiosis and WTW2 was significantly different to other WTW for cryptosporidiosis.

Since 2002, all specimens sent to the Preston laboratory have been tested for giardiasis and cryptosporidiosis using the sensitive Enzyme Immunoassay (EIA) test. This gives a more complete record of cases in our study region, and allows us to gain a better understanding of the true incidence of these two conditions. Despite the increased completeness of our data, there will still be some under-reporting of cases. People do not always present to their GP when they have symptoms and GPs do not always request specimens from them when they do present. It seems particularly likely that there is under-reporting in males, as males are less likely than females to present to their GP for any illness (Rowlands and Moser, 2002). However, we see no reason why the likelihood of presenting to the GP should vary spatially. In a separate paper (Reeve et al., 2014) we investigated the variation in specimen requests from GP practices and though there were differences in the rate of specimen requests between GP practices, there was no spatial correlation between the rates. The under-reporting of cases should therefore not materially affect our conclusions about the spatial distribution of giardiasis and cryptosporidiosis in the North West of England.

Asymptomatic cases will also contribute to the under-estimation of the prevalence of giardiasis and cryptosporidiosis in the study region. In a community-wide survey, Lopez et al. (1980) found that 76% of infections of Giardia were asymptomatic but there was no significant secondary, person-to-person spread. We do not expect that the proportion of symptomatic/asymptomatic cases should vary spatially, so lack of information on asymptomatic cases should not affect our conclusions regarding the existence and effect-size for factors that affect relative risk, but we cannot estimate absolute risk.

Our results are consistent with other research showing higher rates of both giardiasis and cryptosporidiosis in children and in adults aged 30-40 and higher rates of giardiasis in males (Naumova et al., 2000). However, Naumova (Naumova et al., 2000) also found higher rates of cryptosporidiosis in males, whereas we found higher rates for females.

Deprivation level was not found to be significantly associated with giardiasis risk. For cryptosporidiosis our results showed that lowered deprivation score was a significant predictor of disease. In prior work, increased deprivation is more commonly associated with higher disease risk (Public Health England, 2017), but our result is in keeping with a study of the risk of giardiasis and cryptosporidiosis in New Zealand, where lower cryptosporidiosis rates were found in areas of higher deprivation (Snel et al., 2009). That paper suggested that the finding may reflect poor access and use of primary health-care services by more deprived populations. While we have no means of testing this idea in our population, previous findings have shown that there is an association between deprivation and lack of engagement in primary healthcare, with people who miss GP appointments more likely to be from deprived areas (Ellis et al., 2017). This could result in an over-representation of diagnoses in the less deprived. We tried alternative models including different forms for the IMD summary (for example using quintiles) but results were unaffected.

The higher risk for both conditions found in the north of the study region suggests higher exposures in that area. It is a more rural area so contact with farm animals may be higher. However, other rural areas in the study region do not have the same increase in risk. As such, further investigation may be required into what the potential causes of that increased risk may be. One possible explanation is the use of private water supplies. Private water supplies are more common in rural areas and when supplying single households are not subject to the same stringent water quality regulations as public water supplies, therefore they may pose a greater risk. The Drinking Water Inspectorate (2013) report shows that most of the private water supplies in the Chorley and South Ribble Local Authorities are in the east. Unfortunately, information was not provided by the Preston Local Authority, which is situated in the north of the study region. Urban/rural status is adjusted for in the model, but it may be that this indicator does not fully account for the variation in rural areas.

The model estimates of the effect of WTW on the risk of giardiasis and cryptosporidiosis are difficult to interpret individually, since an increase in percentage supply from one WTW implies a decrease in percentage supply from another i.e. there is a linear dependency between WTW. The contrast analysis allows us to compare WTW2 to the other WTW and indicates a difference for WTW2 for cryptosporidiosis, but we cannot say why that difference might occur. It is possible that WTW is acting as a proxy for some other spatial exposure, for example travel abroad or use of a private water supply, and it is that exposure which causes a difference in risk, rather than WTW. WTW2 only supplies relatively low percentages of water, predominately to the north of the study region and one water zone in the south-east. It seems likely that the difference observed for WTW2 is linked to the issues already mentioned for the higher risk in the North. We also understand that active quality control procedures have identified no deterioration in Cryptosporidium-specific water quality in WTW2 over the period covered by this study (United Utilities, personal communication, 8th September 2014).

It is not possible to include all WTW in the model due to the linear dependency between the WTW. Consequently, we included the 'main' WTW, defined as those supplying a mean of at least 1% of an individual's total supply. We tried using other combinations of WTW but the results were not materially changed. This included adding WTW as a factor i.e. '1' for the WTW that supplies the majority of an individual's water and '0' for all other WTW. This also did not change the results materially. This may be because most individuals receive at least 95% of their water supply from a single WTW during a year.

Our exposure assessment would have been strengthened had we had data on tap water consumption patterns at home, and of other water and drinks, at an individual level. Our assessment also assumes that individuals were exposed to tap water at home, whereas people are likely to spend time away from home, commonly at work or at school. However, Villanueva et al. (2007) noted that adding tap water consumption at work did not add to an exposure model in terms of explaining variation in the exposure measured. Additionally, we only had limited data for some cases and none of the controls on other important exposures such as travel abroad or nature of work exposures, so we were not able to include them in the model. Further information on these exposures would provide more information on the behaviour of Giardia and Cryptosporidium. Ethnicity would also be useful information as it is linked to travel abroad.

Geographical location is partially confounded with WTW as the delivery of water from a WTW depends on geographical location. It is also partially confounded with IMD and urban/rural indicator. This may account for the non-significant result for IMD for giardiasis, and for urban/rural indicator for cryptosporidiosis.

There is a difference in risk between males and females for both conditions, though in different directions: males have a higher risk of giardiasis than females, and females have a higher risk of cryptosporidiosis than males. This could be due to different exposures, such as places of work or frequency of nappy changing. Biological differences between genders could also have an effect, such as differences in immune responses (Klein, 2004). The increased risk of giardiasis for males is particularly striking, given the likely under-reporting of cases in males.

The increased risk of both conditions for young children could be due to increased exposure or an under-developed immune system. Reporting bias is also likely to have an effect here, as young children are more likely to be presented and tested for infection than older children and adults. The second peak in risk for giardiasis around ages 30-50 could be explained by lifestyle-related exposures such as nappy changing or outdoor activities.

Using controls from 2006 for cases from 2003-2005 assumes that there has been no change in population distribution from 2003 to 2006, but allows us to use data from this extended period. We know that the population in the area has not changed radically over the study period: for 80% of Lower Super Output Areas (LSOAs) in the study area, population change has been less than 20% (19.69% for 80% of urban LSOAs, 17.40% for 80% of rural LSOAs) and for 80% of LSOAs the change in mean age has been less than 3.75 years (3.70 for 80% of urban LSOAs, 3.84 for 80% of rural LSOAs) between the 2001 and 2011 census (Office for National Statistics, 2001a, 2011). We repeated the analysis using data only from 2006-2011 and the results were not materially changed.

Giardiasis and cryptosporidiosis are neglected conditions in the UK, due to an assumed strong association with travel abroad. The source of infection for many indigenous cases is unknown. Consumption of mains tap water is considered an unlikely source of cryptosporidiosis and giardiasis in the study area and study period due to the water treatment process for both parasites which includes either UV inactivation, physical removal by either coagulation and filtration, or membrane filtration. It is important to remember that outbreaks of both giardiasis and cryptosporidiosis have been associated with drinking water supply (Sopwith et al., 2005; Nygård et al., 2006; Stuart et al., 2003; Minetti et al., 2015; Smith et al., 2006), though in England and Wales, there has been a decline in the number of outbreaks associated with public water supplies since 2000 (Smith et al., 2006).

Our comparison of the epidemiology and spatial distribution of these two waterborne parasites highlights important differences between them and adds to the knowledge of factors related to these two conditions in North West England.

Acknowledgements

We thank United Utilities for their helpful explanation of the water system and for the provision of the water data. We also thank Corrado Minetti, Department of Infection Biology, University of

Liverpool, for his contribution to the literature review.

Declaration of Interest

Financial Support

N. Reeve was funded by a studentship from the Medical Research Council.

Conflict of interest

None.

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