Aquavalens Project

"Protecting the health of Europeans by improving methods for the detection of pathogens in drinking water and water used in food preparation."

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Report on modelling of the impact of climate change on risk to European drinking water

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Authors: Natalia R Jones, Iain R Lake, Paul R Hunter

University of East Anglia, Norwich, UK

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Executive summary

Data on the pathogen load in raw water from four Drinking Water Treatment Plants was collected in Work Package 10. Here we report on analysis which was undertaken on pathogen load and related weather conditions, namely lagged daily rainfall and temperature. The findings show few pathogens were found. Only pathogens found in Spain were shown to be associated with rainfall and temperature. Due to the low numbers of samples and the lower number still of positive samples, it was not possible to examine associations with future climate scenarios.

Introduction

It is well recognised that climate is a factor in the spread of environmental pathogens (Baylis, 2017). Waterborne pathogens are sensitive to climate factors such as temperature and rainfall (McIntyre *et al.*, 2017, Eze *et al.*, 2014, Cann *et al.*, 2013) and recent studies have shown that waterborne diseases are likely to increase with the effects of climate change (Levy *et al.*, 2016, Bouzid, 2016). In order to assess the impact of climate change on pathogens it is necessary to examine the impact of current weather conditions on pathogens. This relationship can then be used to determine how a future climate may impact on pathogen load (Lake, 2017, Colón-González *et al.*, 2013).

Using data collected in Work Package 10 on the pathogen load in raw water from four Drinking Water Treatment Plants (DWTP) in the UK, Spain, Germany and Denmark, the relationship between pathogen load and associated weather conditions is examined. Where significant relationships exist the potential for modelling the impact of climate change on drinking water is explored.

Methodology

In Work Package 10 of the Aquavalens project, sampling was undertaken to determine the pathogens in the raw water of large water supplies in four locations (UK, Spain, Germany and Denmark). Detailed information on the sampling methods, locations of the DWTPs and the pathogens found can be found in Deliverables D10.1, D10.2 and D10.3. The source of the raw water varied for each DWTP, as shown in Table 1. In Spain and Germany the water was drawn directly from a river, while in the UK the water tested came from a reservoir and in Denmark the water source was Groundwater. In Work Package 14 these data on pathogen presence in raw water are analysed in relation to weather conditions, obtained from nearby weather stations.

Pathogen data

Pathogen levels in raw water were measured approximately once a month between July 2016 and July 2017 at most sites, although data collection did not occur every month at all sites. A total of 13 different pathogens could have been tested using the Aquavalens methods, however not all pathogens were tested for at each site. Table 1 shows the pathogens measured and the months data were collected at each site.

Table 1: Pathogens and months data collected across four European sites

Site	Water source	Pathogens measured	Data collected during months	
UK	Reservoir water (sourced from multiple rivers)	Norovirus GI Norovirus GII *E. coli* *C. jejuni* *Giardia spp.* *G. intestinalis* *Cryptosporidium spp.*	2016 July August September October November December	2017 January February March April May June July
Spain	Surface River water	Norovirus GI Norovirus GII Hepatitis A *E. coli* *Campylobacter spp.* *C. jejuni* *Salmonella spp.* *L. pneumophila* *P. aeruginosa* *G. intestinalis* *Cryptosporidium spp.* *T. gondii*	2016 August September October November December	2017 January March April May June July
Germany	Surface River water	Norovirus GI Norovirus GII *E. coli* *Campylobacter spp.* *C. jejuni* *Giardia spp.* *G. intestinalis* *Cryptosporidium spp.*	2016 July August September October November	2017 January^{+} February April May June July
Denmark	Groundwater	Norovirus GI	2016	2017

Norovirus GII	January
E. coli	February
Campylobacter spp.	March
C. jejuni	April
Giardia spp.	May
G. intestinalis	June
Cryptosporidium spp.	July
	August

[+] Two water samples were taken during this month

Weather data

For each raw water sampling location weather data was obtained from the UK *Met Office Integrated Data Archive System (MIDAS) Land and Marine Surface Stations Dataset* which can be accessed through NERCs British Atmospheric Data Centre (BADC), Centre for Environmental Data Analysis (CEDA) http://browse.ceda.ac.uk/browse/badc/ukmo-midas/data . This dataset includes worldwide weather stations. The weather station nearest to each DWTP with the most complete data for the time period was selected. This provided AM and PM maximum and minimum temperatures and a 24 hour precipitation measure. For the Spanish site it was only possible to obtain the AM minimum temperature and the PM maximum temperature from this weather station. Therefore a second station near the DWTP was used to obtain the AM maximum and PM minimum temperatures. This station is located on a nearby school and is part of a network of non-professional automatic weather stations. The data from this station was downloaded from eduMET (http://edumet.cat/edumet/meteo_2/index.php). Comparison of the AM minimum and PM maximum temperature values from the two sites showed the values were highly correlated (r=0.9).

Previous studies demonstrate that the association between rainfall and pathogen load may be lagged (Richardson *et al.*, 2009) due to the hydrological response of the catchment. Therefore for each site, alongside a measure of the previous days daily rainfall, a measure of the cumulative daily rainfall over the previous 28 and 7 days was calculated. Temperature has generally been shown to have a more immediate impact and thus the average temperature of the day prior to measurement was determined.

Analysis

For each DWTP site the pathogen loads were examined to determine those which were consistently found over the time period of data collection. For those pathogens which were detected in water on more than four occasions, relationships between the level of pathogen and the previous 1, 7 and 28 days daily rainfall and the previous days temperature were examined. In those case where pathogen occurrence was less frequent, variability was deemed too low to explore associations with weather. Table 2 shows which pathogens found in the four sites were examined.

Table 2: Pathogens analysed with weather

Site	Pathogens analysed
UK	*E. coli*
Spain	Norovirus GI
	Norovirus GII
	E. coli
	Campylobacter spp.
Germany	*E. coli*
Denmark	-

Graphs with trendlines were produced to visualise the relationships, and using STATA 14 both Pearson's r and Spearman's ρ were calculated. Based on these measures the relationship between the pathogen load and weather conditions were determined as having a strong association, some association and no association using the criteria in Table 3.

Table 3: Criteria for Strength of Association

	Pearson's r		Spearman's ρ
Strong association	>0.60 or <-0.60	AND	>0.60 or <-0.60
Some association	>0.30 or <-0.30	AND	>0.30 or <-0.30
No association	<=0.30 or >=-0.30	AND	<=0.30 or >=-0.30

Using a random effects censored regression model, with country as the random effect, *E. coli* presence (as the pathogen with the most consistent load across all countries) was modelled with the previous 28 days cumulative daily rainfall and the previous days temperature.

Results

Examination of the associations between pathogen load and the cumulative daily rainfall over the previous 7 days and the day prior to sampling found no relationships. Therefore these findings have not been reported here. The relationships between pathogen load and cumulative daily rainfall over the previous 28 days and the previous days temperature are reported here.

UK

At the UK site, *E. coli* was the only consistently found pathogen. There was no relationship between levels of *E. coli* at the UK site and either cumulative daily rainfall over the 28 days prior to the sample (Pearson's r = 0.01; Spearman's ρ = 0.31) (see Figure 1) or the previous days average temperature (Pearson's r = 0.13; Spearman's ρ = 0.12) (see Figure 2).

Figure 1: UK *E. coli* levels and previous 28 days cumulative daily rainfall

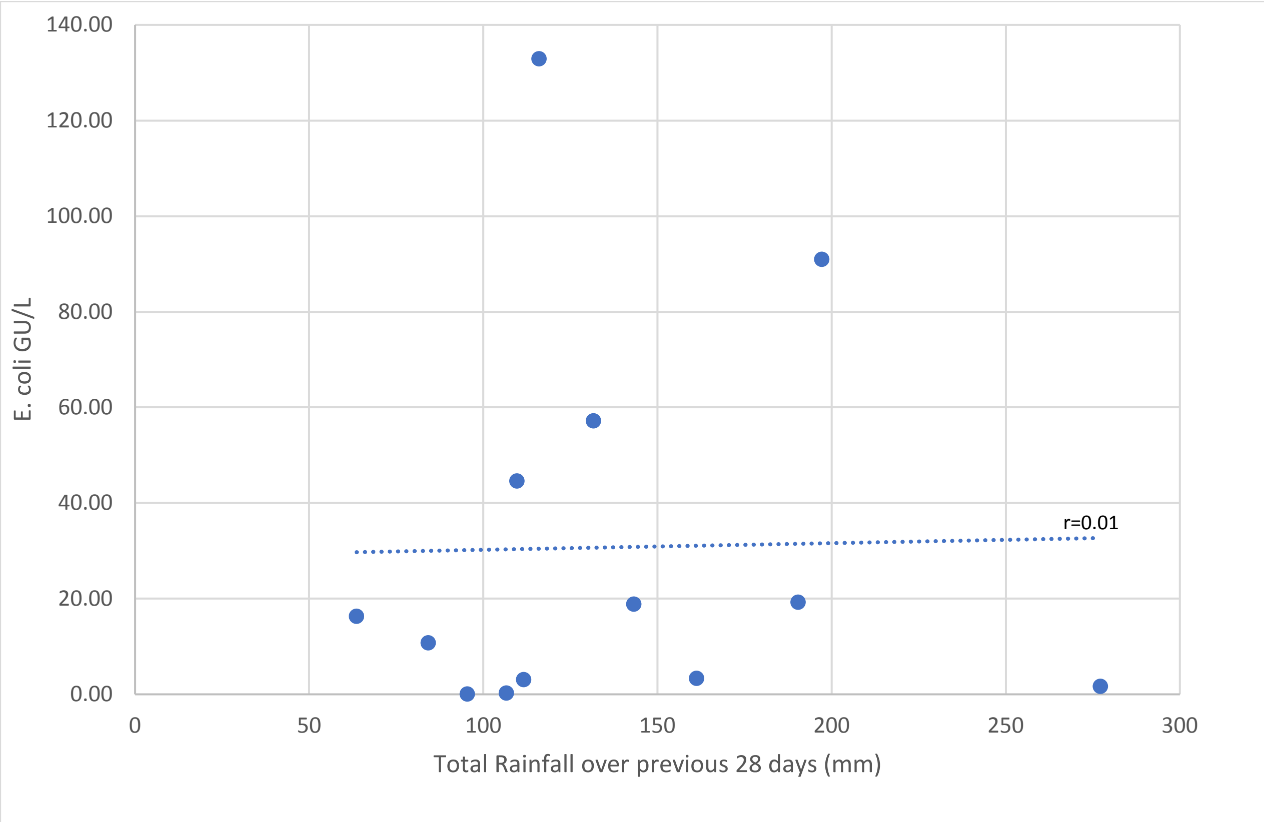
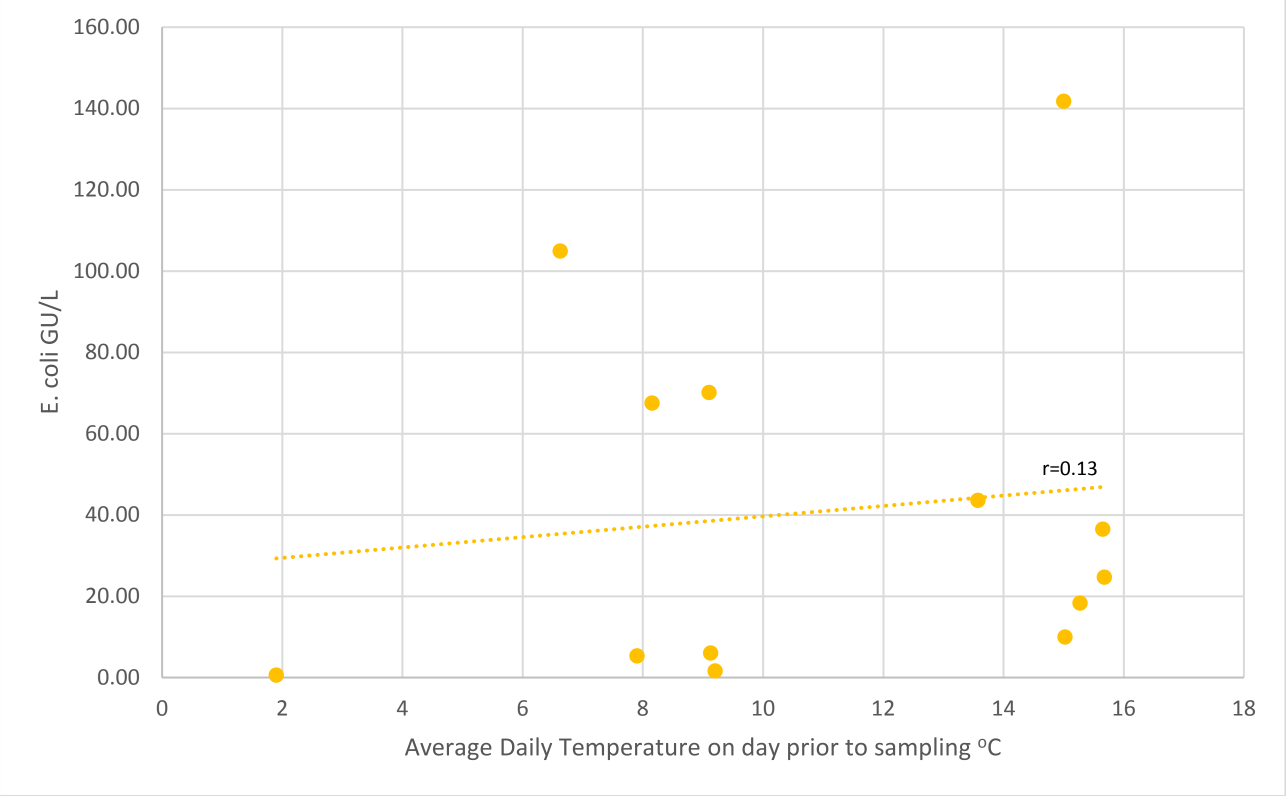


Figure 2: UK *E. coli* levels and previous day average temperature



Spain

In Spain four pathogens were consistently measured – *E. coli*, *Campylobacter* and Norovirus GI and GII. Figure 3 shows some evidence of a positive association between *E. coli* levels and 28 day cumulative daily rainfall, with higher levels occurring with more rain (Pearson's r = 0.45; Spearman's ρ = 0.35). There was strong evidence of a negative association between temperature and levels of *E. coli* (Pearson's r = -0.64; Spearman's ρ = -0.68), as shown in Figure 4.

Figure 3: Spanish *E. coli* levels and previous 28 days cumulative daily rainfall

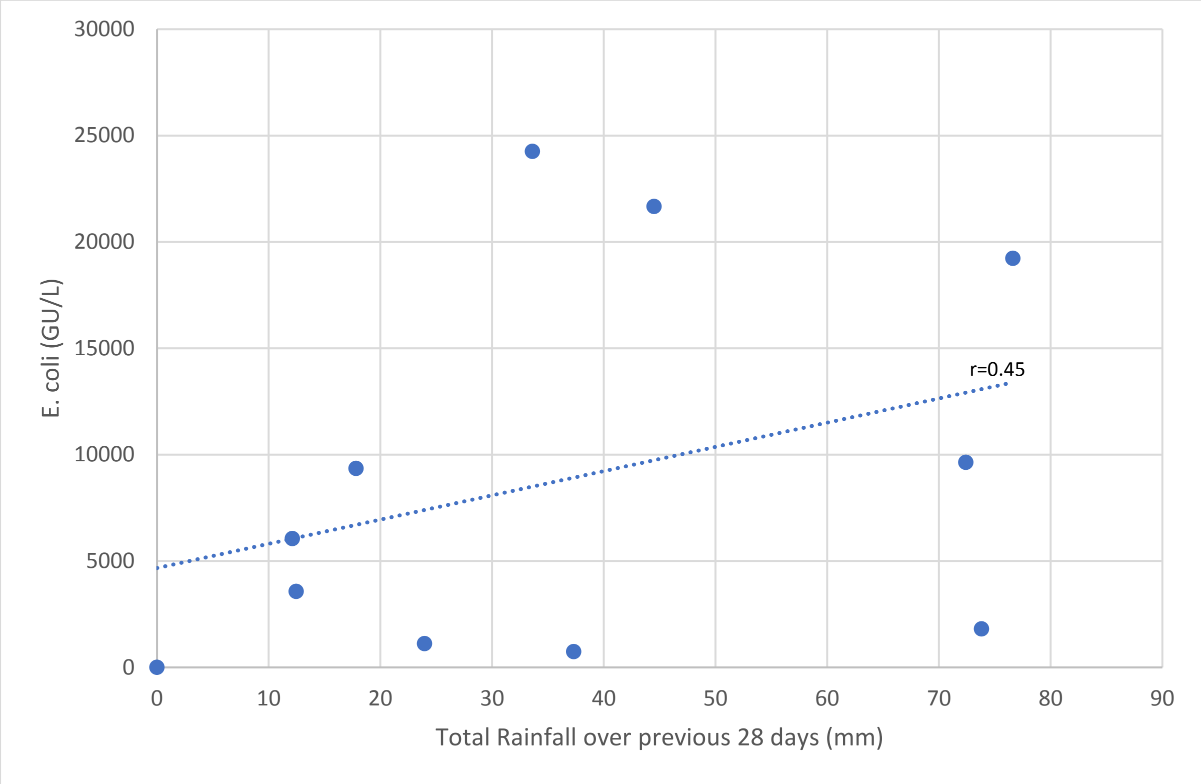


Figure 4: Spanish *E. coli* levels and previous days average temperature

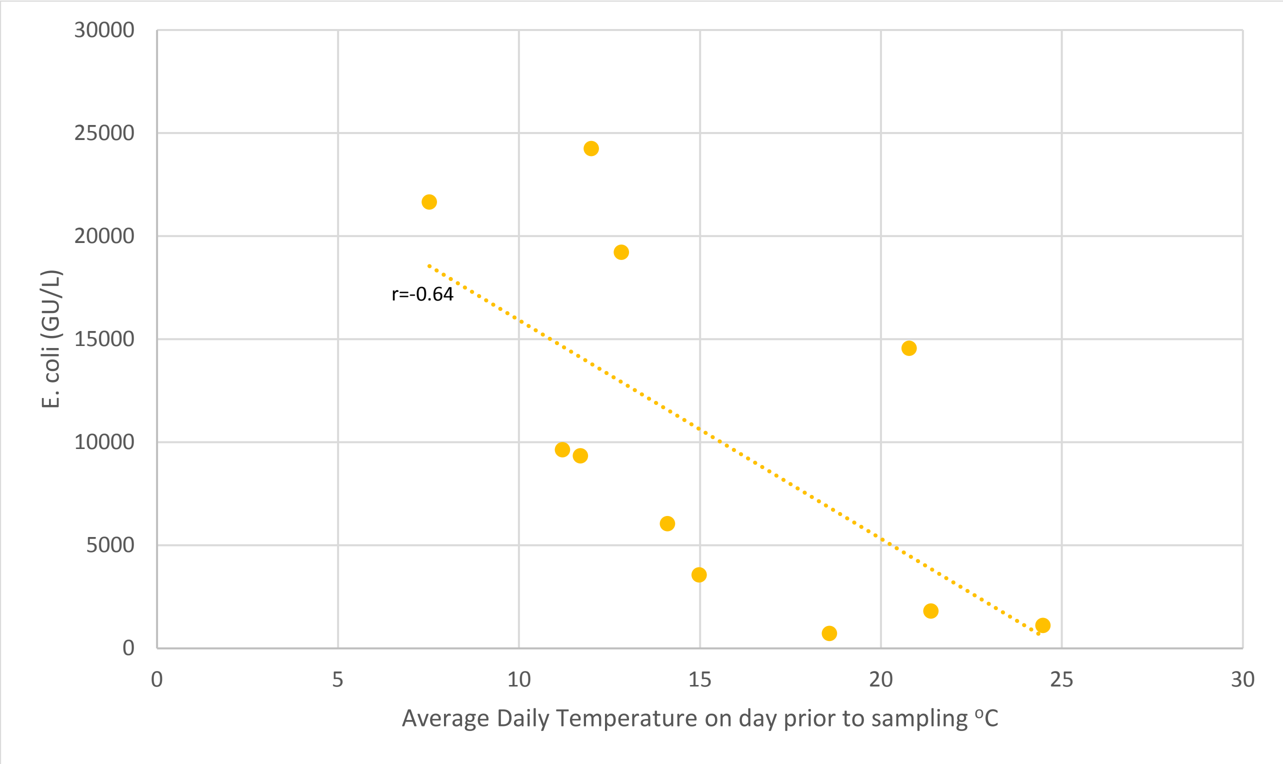


Figure 5 shows some positive association between the *Campylobacter* levels in Spain and higher levels of cumulative daily rainfall over the 28 days prior to sampling (Pearson's r = 0.59; Spearman's ρ = 0.35). However there was no association between levels of *Campylobacter* and previous days average temperature (Pearson's r = -0.19; Spearman's ρ = -0.10) (see Figure 6).

Figure 5: Spanish *Campylobacter* levels and previous 28 days cumulative daily rainfall

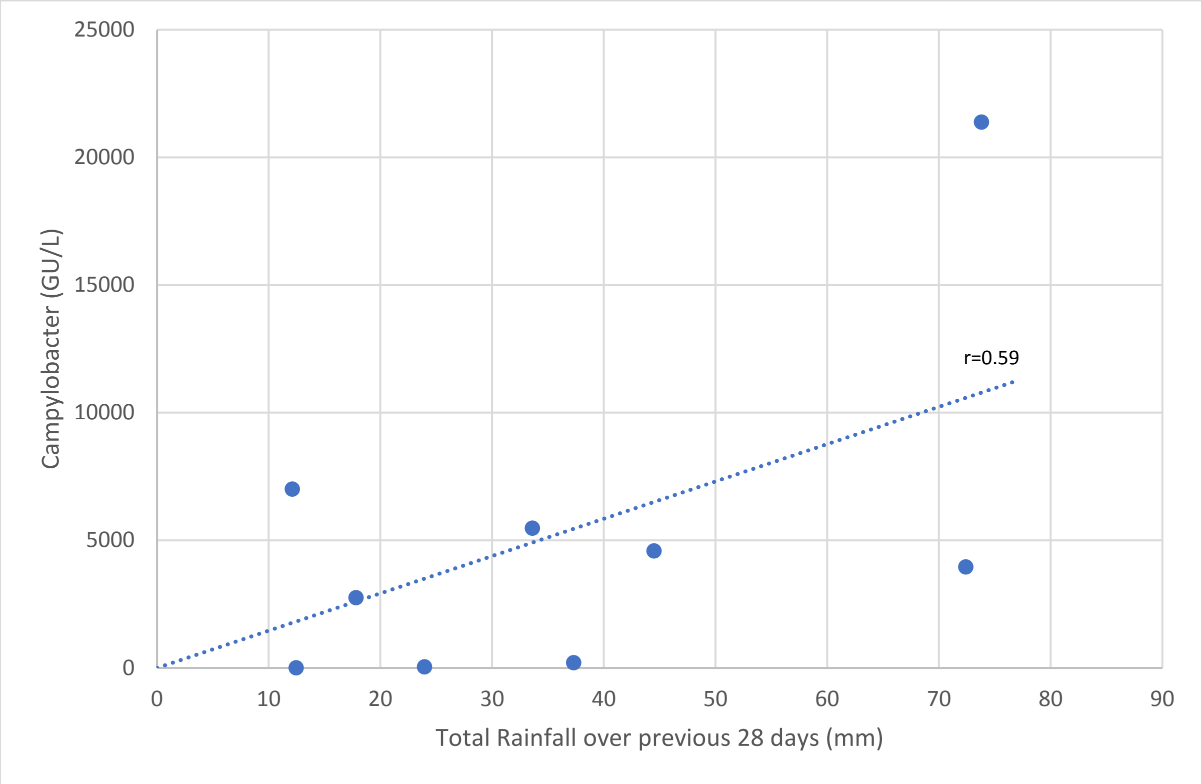
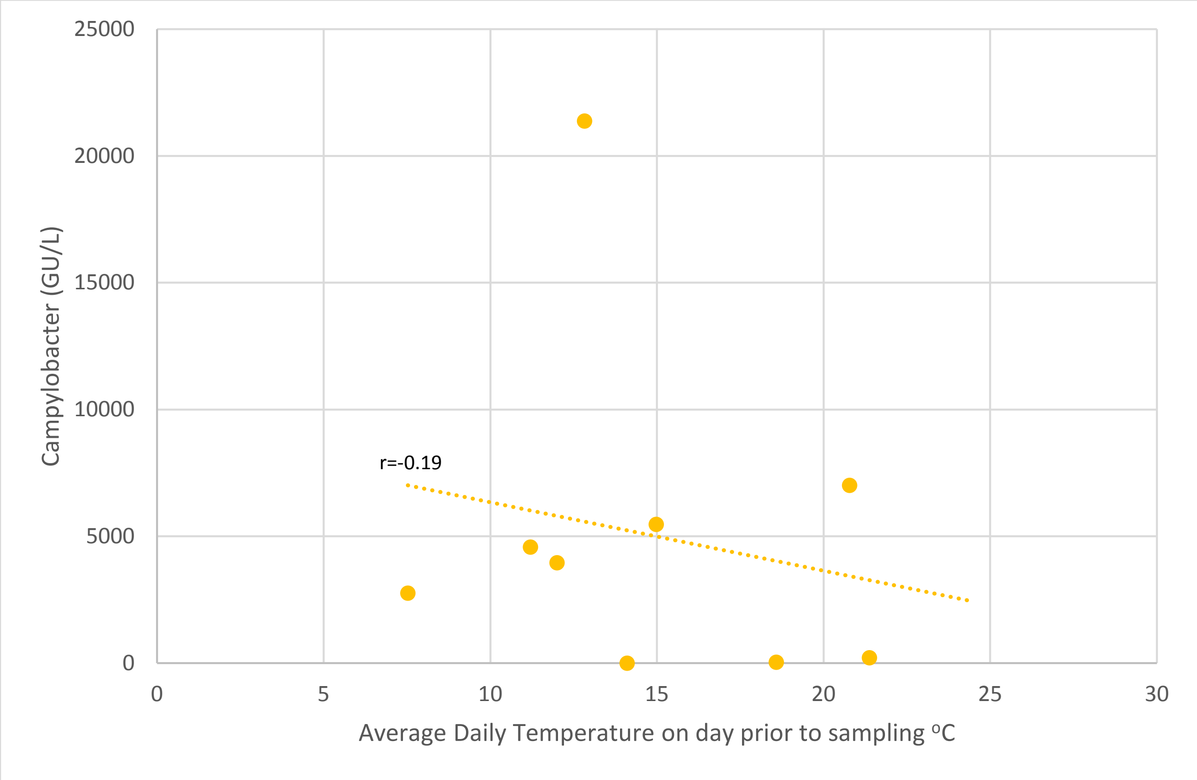


Figure 6: Spanish *Campylobacter* levels and previous days average temperature



Figures 7 and 8 show there is no association between Norovirus GI and previous 28 days cumulative daily rainfall (Pearson's r = 0.01; Spearman's ρ = -0.13) or previous days average temperture (Pearson's r = -0.35; Spearman's ρ = -0.11)

Figure 7: Spanish Norovirus GI levels and previous 28 days cumulative daily rainfall

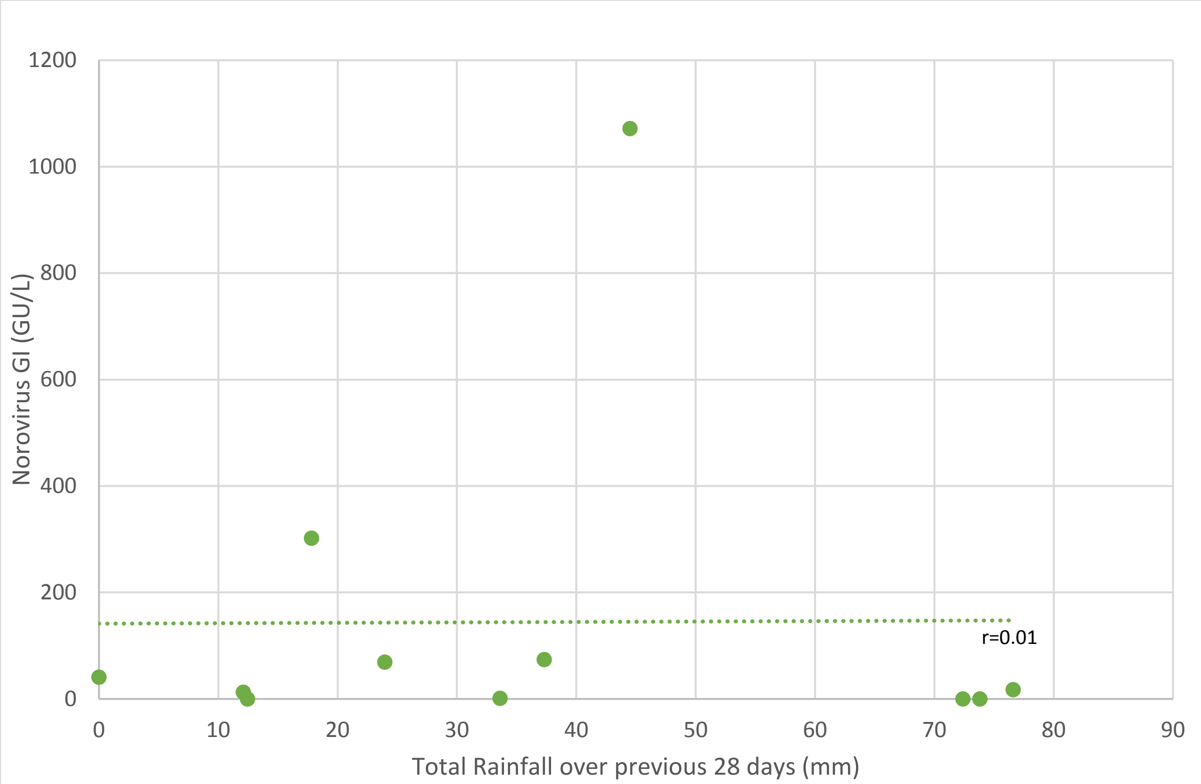
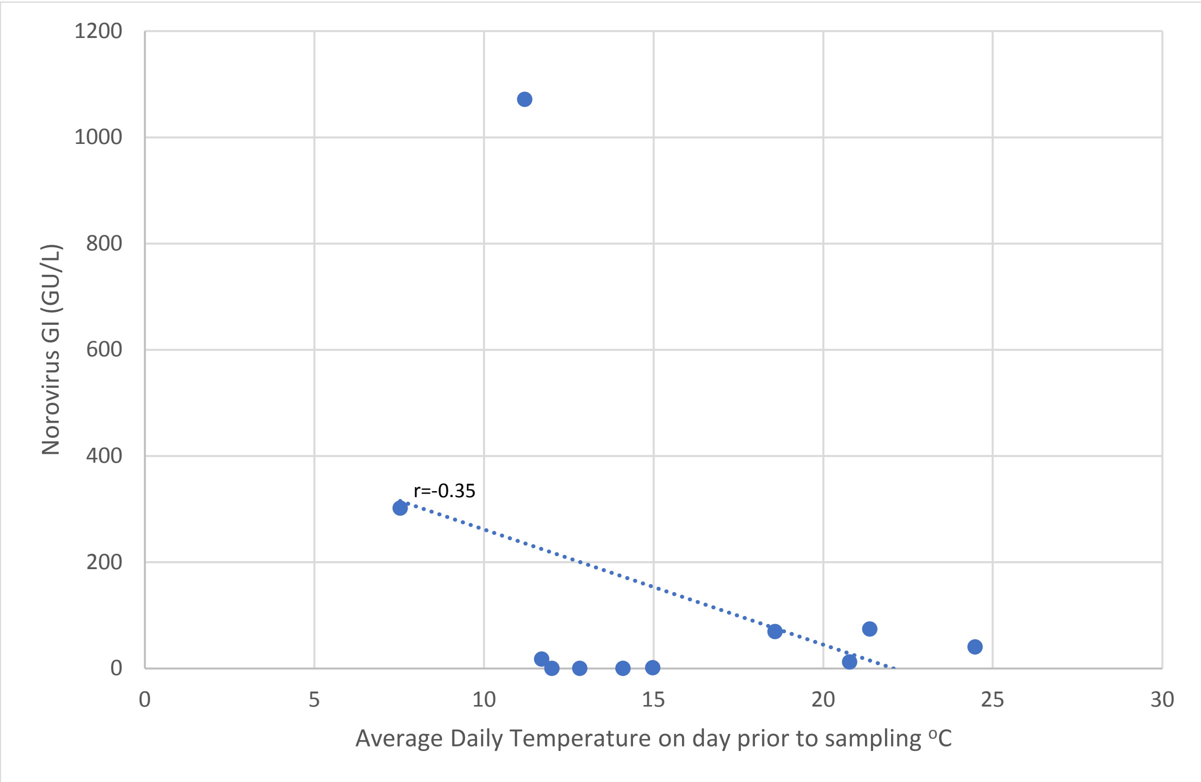


Figure 8: Spanish Norovirus GI levels and previous days average temperature



There was no relationship between the previous 28 days cumulative daily rainfall and Norovirus GII levels in Spain (Pearson's r = -0.14; Spearman's ρ = 0.03) (see Figure 9). However, as shown in Figure 10, there is evidence of some negative association between Norovirus GII and the previous day's average temperature (Pearson's r = -0.59; Spearman's ρ = -0.61).

Figure 9: Spanish Norovirus GII levels and previous 28 days cumulative daily rainfall

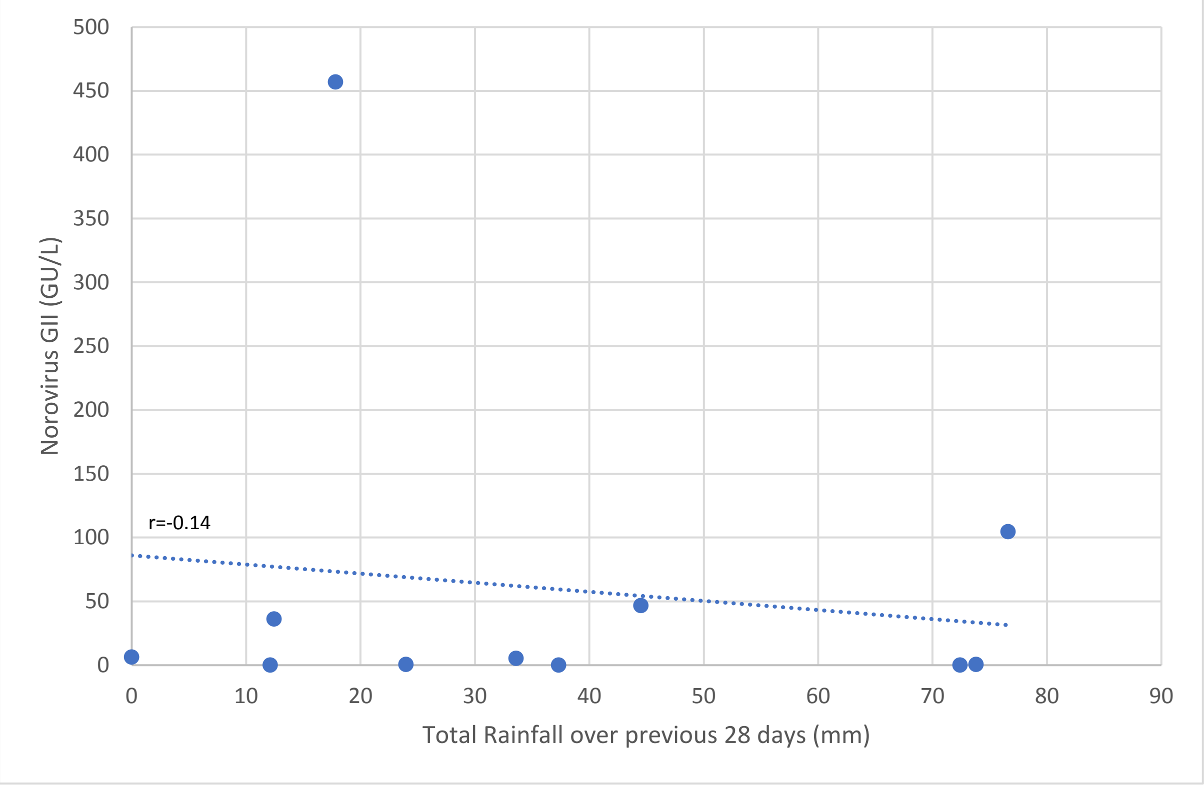
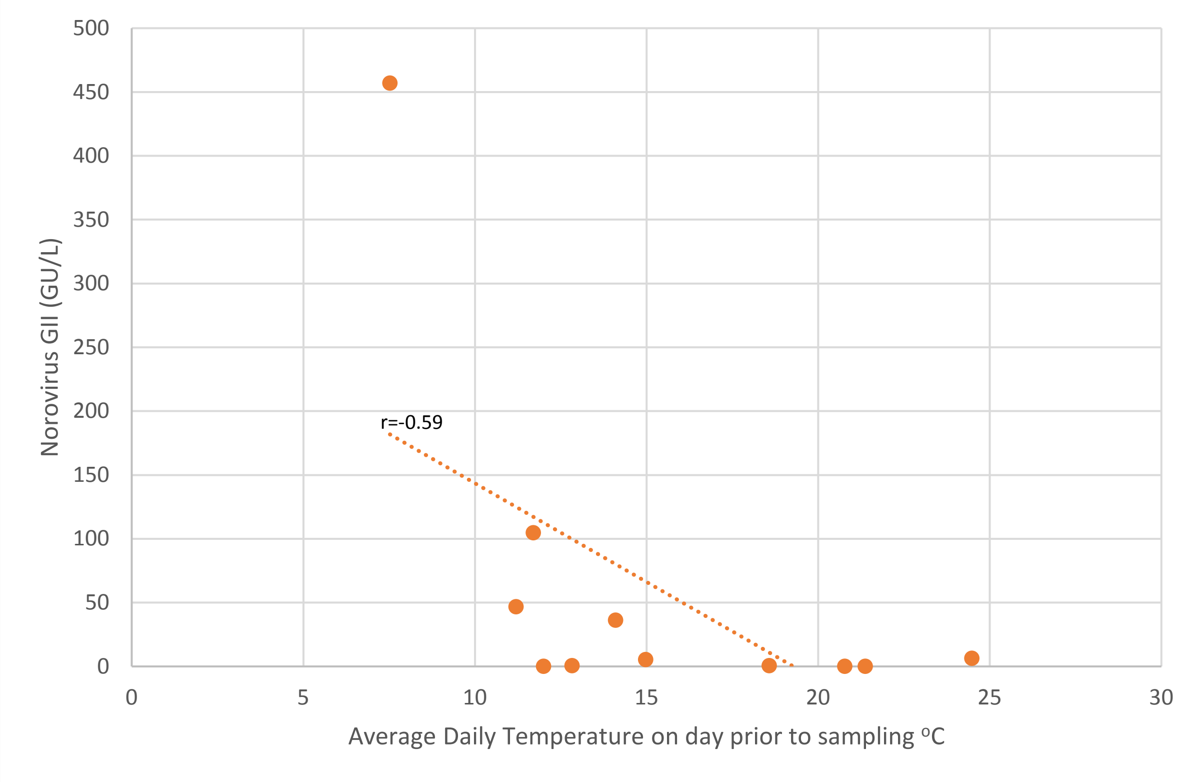


Figure 10: Spanish Norovirus GII levels and previous days average temperature



Germany

At the German site, the main pathogen observed was *E. coli*. Figure 11 shows there is no association between 28 day cumulative daily rainfall (Pearson's r = 0.47; Spearman's ρ = -0.00). Nor was there any association between the previous days average temperature and *E. coli* levels (Pearson's r = -0.38; Spearman's ρ = -0.08) (see Figure 12).

Figure 11: German *E. coli* levels and previous 28 days cumulative daily rainfall

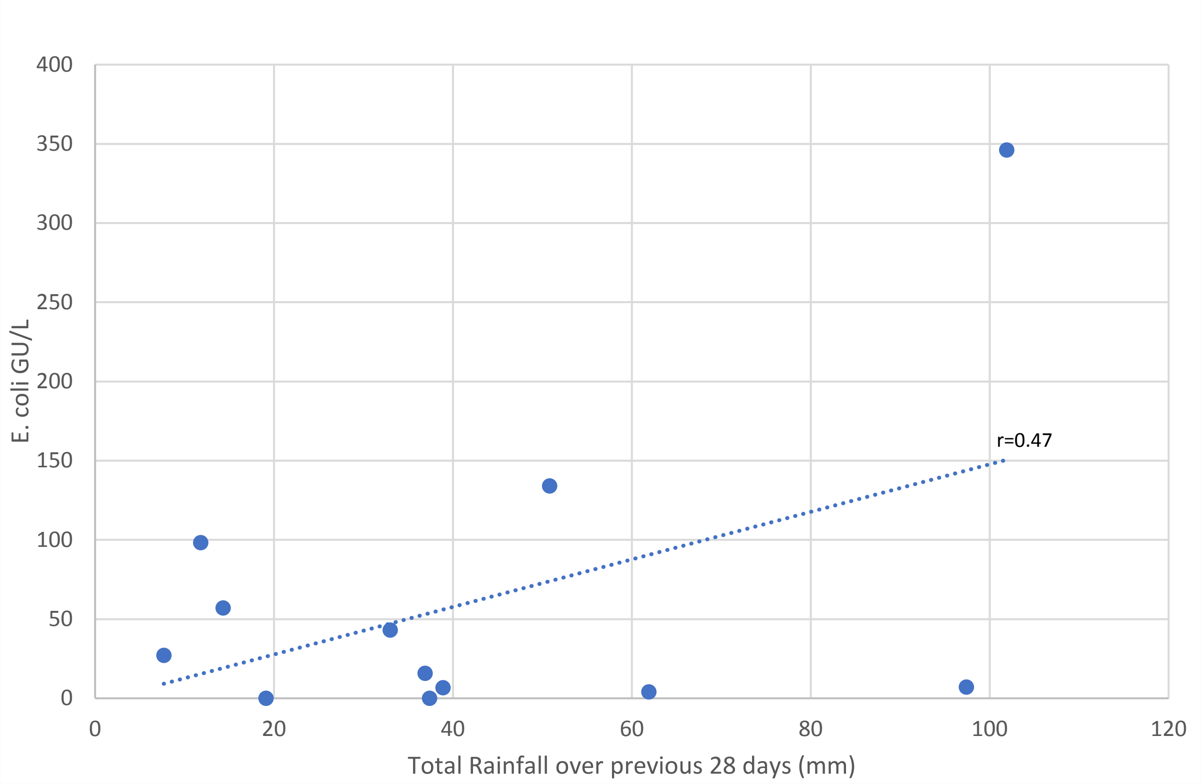
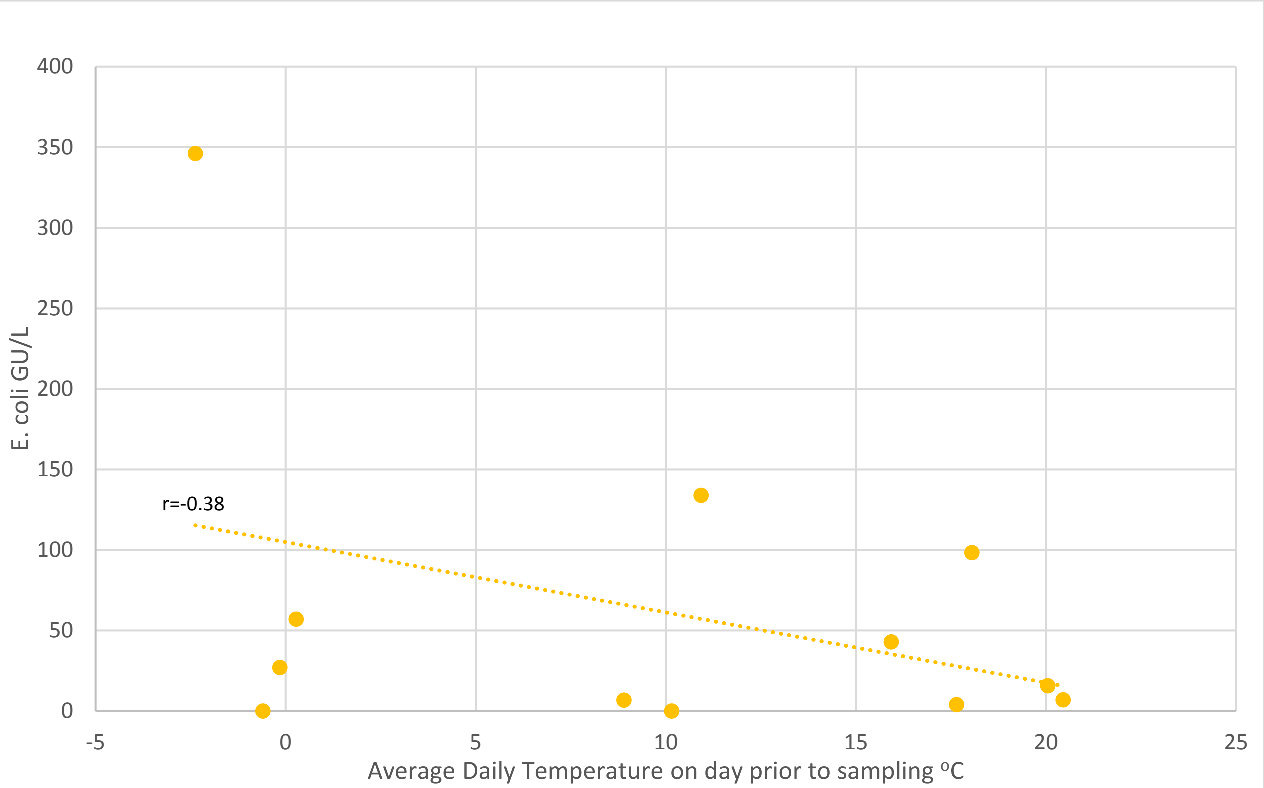


Figure 12: German *E. coli* levels and previous day average temperature



Denmark

There were no positive pathogen results found in Denmark. Therefore it was not possible to examine associations between pathogens and recent weather conditions.

Summary of associations

Table 4 gives a summary of the associations found between weather conditions and pathogen load. Associations were only found in Spain.

Table 4: Summary of associations between weather conditions and pathogen load

Country	Pathogen	Association with 28 days previous cumulative daily rainfall Association	Association with previous days average temperature Association
UK	*E. coli*	No	No
Spain	*E. coli*	Some positive	Strong negative
Spain	*Campylobacter*	Some positive	No
Spain	Norovirus GI	No	No
Spain	Norovirus GII	No	Some negative
Germany	*E. coli*	No	No

Modelling pathogen load and weather

E. coli was the only pathogen consistently found in more than one country (UK, Spain and Germany). A random effects censored regression model was run to determine the associations between *E. coli* load and weather conditions across all samples. Country was included as a random effect. A censored technique was adopted to account for limits of detection issues. The results are shown in Table 5. No significant associations with weather were found.

Table 5: A random effects censored regression model showing the influence of the previous 28 days average rainfall and the previous days average temperature

	Coefficient [95% CI]	Standard error	p
Cumulative daily rainfall in the 28 days prior (mm)	18.45 [-19.91 – 56.82]	19.57	0.346
Average air temperature for the day prior (°C)	-152.98 [-413.32 – 107.36]	132.83	0.249

Wald $\chi2$ = 2.11 ($p>\chi2$ <0.35)
Country included as random effect.

Conclusions

There were very few pathogens found in the raw water sampled for Aquavalens. No measureable pathogens were found in the Danish samples. The water supply in Denmark is groundwater and thus this is to be expected unless residence times in aquifers are low. Even if pathogens had been found in this source it would be unlikely that there would be a relationship between the weather conditions and pathogen load in groundwater.

E. coli was consistently found in the UK and Germany, however no significant relationships between *E. coli* load and rainfall and temperature were found in these countries. This may reflect the lower loads found in these samples (compared to Spain). In the UK it could also be related to the water source, which is a reservoir where water will have been held for a period of time, and therefore weather conditions may have less impact. This does not explain the results in Germany however, where the water supply is a large river.

The pathogen load found in Spain was much higher than that found in the UK and Germany. The total amount of *E. coli* found was higher and alongside this, *Campylobacter* and Norovirus GI and GII was also consistently found. Possibly as a result of the higher pathogen load, a relationship between rainfall and *E. coli* was found in Spain, with higher rainfall being associated with higher loads of *E. coli*, whilst lower temperatures were strongly associated with higher loads of *E. coli*. Following a similar pattern, higher loads of *Campylobacter* were found to be associated with more rainfall, while higher loads of Norovirus GII were associated with lower temperatures. These findings could indicate a greater threat of pathogens in raw water when the weather is cooler and damper in Spain. However, as this is based on a small number of samples, is not replicated in the other sites and no relationship was found in the statistical model it is not possible to extrapolate this further.

In this Work Package it was intended that analysis on the impact of Climate Change would be examined. However in order to do this a statistical relationship between pathogen load and weather conditions needs to be determined. As few relationships were found, it was not possible to examine any association with future climate scenarios.

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