Modelling the risk of contamination to private water supplies in Scotland

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1. Introduction to Private Water Supplies (PWSs)

- In Scotland, drinking water is distributed to its population from either a public mains supply or from a private water supply (PWS)
- 3.6% of the Scottish population uses around 22,000 PWSs, predominantly in rural areas[1]
- The majority (89%) of these are small, non-commercial water supplies (Type B supplies) which are unregulated and not routinely tested[2], which are the focus of this study
- In the northern regions of Scotland, 12% of the population are reliant on these PWSs **(Fig. 1)**
- The quality of PWSs is variable, posing associated health risks such as waterborne illness

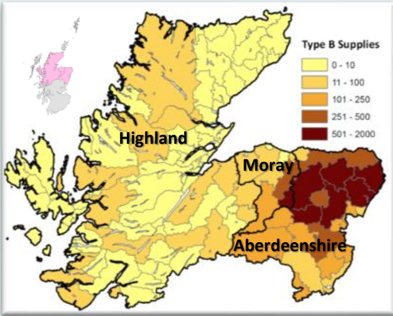

Figure 1: Numbers of Type B PWSs per postcode district in the study areas

2. Sources of Contamination

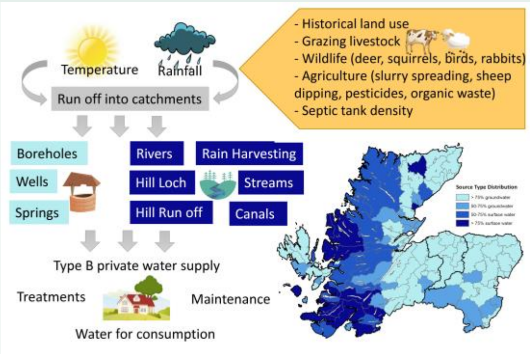

Figure 2: Processes and risk factors which can affect the vulnerability of a PWS to contamination

3. Impact of Livestock to Microbial Contamination

- The density of animals in the surrounding area of each private water supply is analysed for sheep and cattle, to estimate the risk from microbial contamination from these animals faecal matter
- Livestock density data ($\mu_{n,i}$) is given in a set of 2km by 2km grid points, with grid points having a distance d_n to a particular PWS **(Fig. 3)**
- A Gaussian Dispersal Kernel is used such that the probability of an animal impacting a water supply decreases with the distance to the PWS **(Fig. 4)**
- Each count $\mu_{n,i}$ is convolved with the Gaussian Dispersal Kernel $f(d_n)$ resulting in a Gaussian weighted distance animal density count $\lambda_{n,i}$

$$\lambda_{n,i} = \mu_{n,i} \times f(d_n)$$

This measures the effective number of animals which have the potential to impact the contamination of PWS

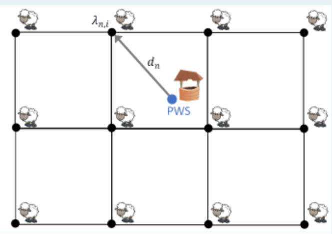

Figure 3: PWS location relative to 2km by 2km animal density grid points. d_n shows an example distance to one grid point containing $\lambda_{n,i}$ where n represents the n^{th} animal density grid point and i is the type of animal

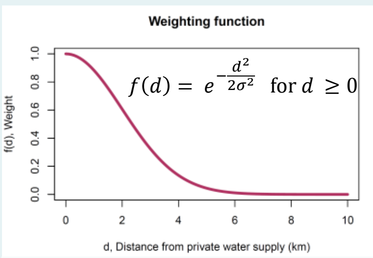

Figure 4: Gaussian Dispersal Kernel. Animals that are further away from the PWS have a lower probability of influencing the contamination of the supply.

4. Relation to *E. coli* Water Supply Fail Rates

- An estimate of the animal density in the area surrounding each PWS is given by $\rho_{pws,i} = \sum_{n=1}^{N} \lambda_{n,i}$
- This quantity will be used as a measure of the risk from microbiological contamination, i.e. the faecal matter produced from all animals
- PWSs with an *E. coli* water sampling test result in 2015 were analysed and the results were grouped into two categories:
  - PWSs with a **failed** water test detected the presence of >0 *E. coli* coliform forming units (CFU) in a 100ml potable water sample
  - PWSs with a **passed** water test had zero *E. coli* present
- 831 (4.7%) samples from all registered Type B supplies had conducted a water test in 2015 with the *E. coli* water test fail rate of 18.3% across the samples
- PWSs with a failed water test have more sheep in the surrounding area compared to the PWSs where the water test showed no presence of *E. coli* **(Figs. 5 and 6)**

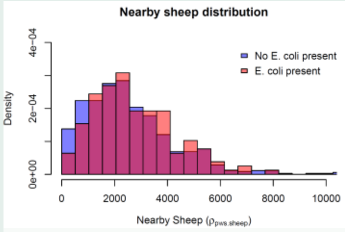

Figure 5: The PWSs with *E. coli* present tend to have a larger number of sheep in the surrounding area, indicated by the distribution being shifted to the right. The median values of $\rho_{\text{pws,sheep}}$ for water sample tests with and without *E. coli* present are 2416 and 2282 respectively. Areas where the two distributions overlap are shaded in purple.

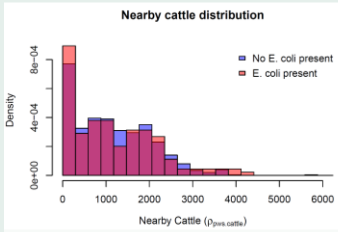

Figure 6: The median values of $\rho_{\text{pws,cattle}}$ are 1043 for water samples that passed an *E. coli* test and 1075 for samples that failed. This indicates that the number of nearby cattle is similar for the PWSs that failed and passed the *E. coli* water sample test. Areas where the two distributions overlap are shaded in purple.

- The seasonal variance in *E. coli* contamination of the water samples peaks during summer and is lowest during winter and spring **(Fig. 7)**

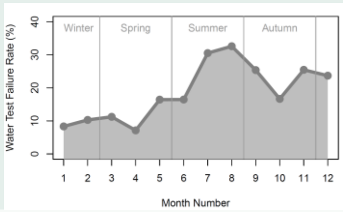

Figure 7: *E. coli* test failure rate for a 100ml potable water sample by month of year during 2015.

5. Conclusions and Future Work

- Of the livestock types that we investigated, sheep were the only animals to demonstrate a perceptible difference between the distributions of passed and failed water tests
- This model represents an initial development in what will be a continued effort to improve the prediction to microbial contamination to private water supplies across Scotland
- Future work will include a factor analysis of seasonal variation and take into account climatic variables and adverse weather events

References

[1] The Drinking Water Quality Regulator for Scotland. 2018. 'Drinking Water Quality in Scotland 2017: Private Water Supplies'

[2] Water Intended for Human Consumption (Private Supplies) (Scotland) Regulations 2017. 2017

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