



Paper 20 – Raphaëlle Roffo

Mapping risks of faecal contamination of shallow groundwater in Dakar, Senegal



Mapping risks of faecal contamination of shallow groundwater in Dakar, Senegal

An evaluation of culture-based methods and a real-time technique using tryptophan-like fluorescence

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Acknowledgements

- MSc Dissertation (MSc Geospatial Analysis, UCL, 2018)
Supervisor: Dr Richard Taylor
- Research was conducted under the AfriWatSan project, funded by The Royal Society (UK) and Department for International Development (DFID), and supported by the British Geological Survey (BGS), currently developing portable, UV-based fluorimeters for real-time screening of faecally contaminated drinking water in urban Africa.

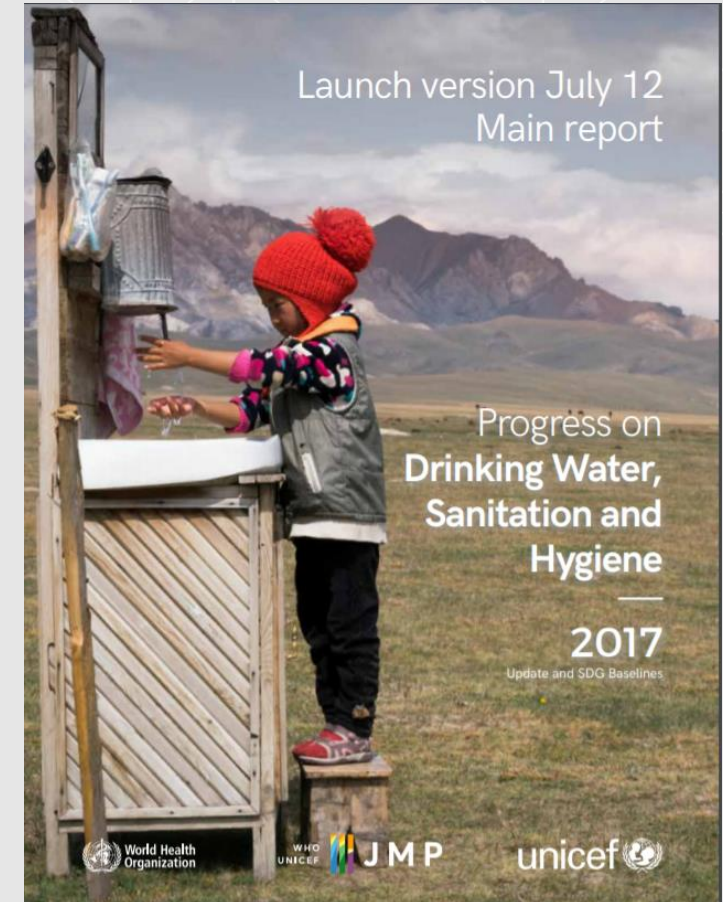
Motivation: Lack of Sanitation remains a leading cause of mortality in Sub-Saharan Africa

- Only 39% of the global population use safely managed sanitation infrastructure
- 1.8 billion people around the world still drink water that has been contaminated with faecal matter

In Sub-Saharan Africa alone:

- 72% of the population lack access to “at least basic” sanitation services
- 643,000 death from diarrhoeal diseases each year

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, 2017

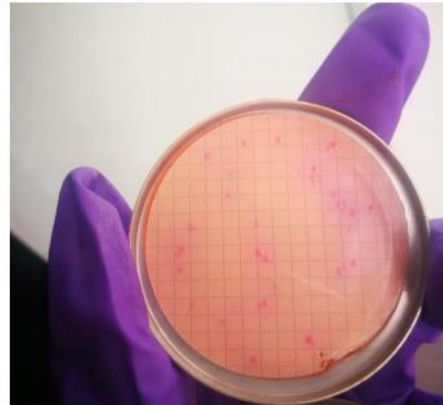


Tryptophan-like Fluorescence (TLF) as an alternative method for faecal matter detection

Thermotolerant Coliforms (TTC)
Culture-based method

+ **Very reliable**

– **Costly, requires logistics, reagent, expertise and time (18h incubation)**



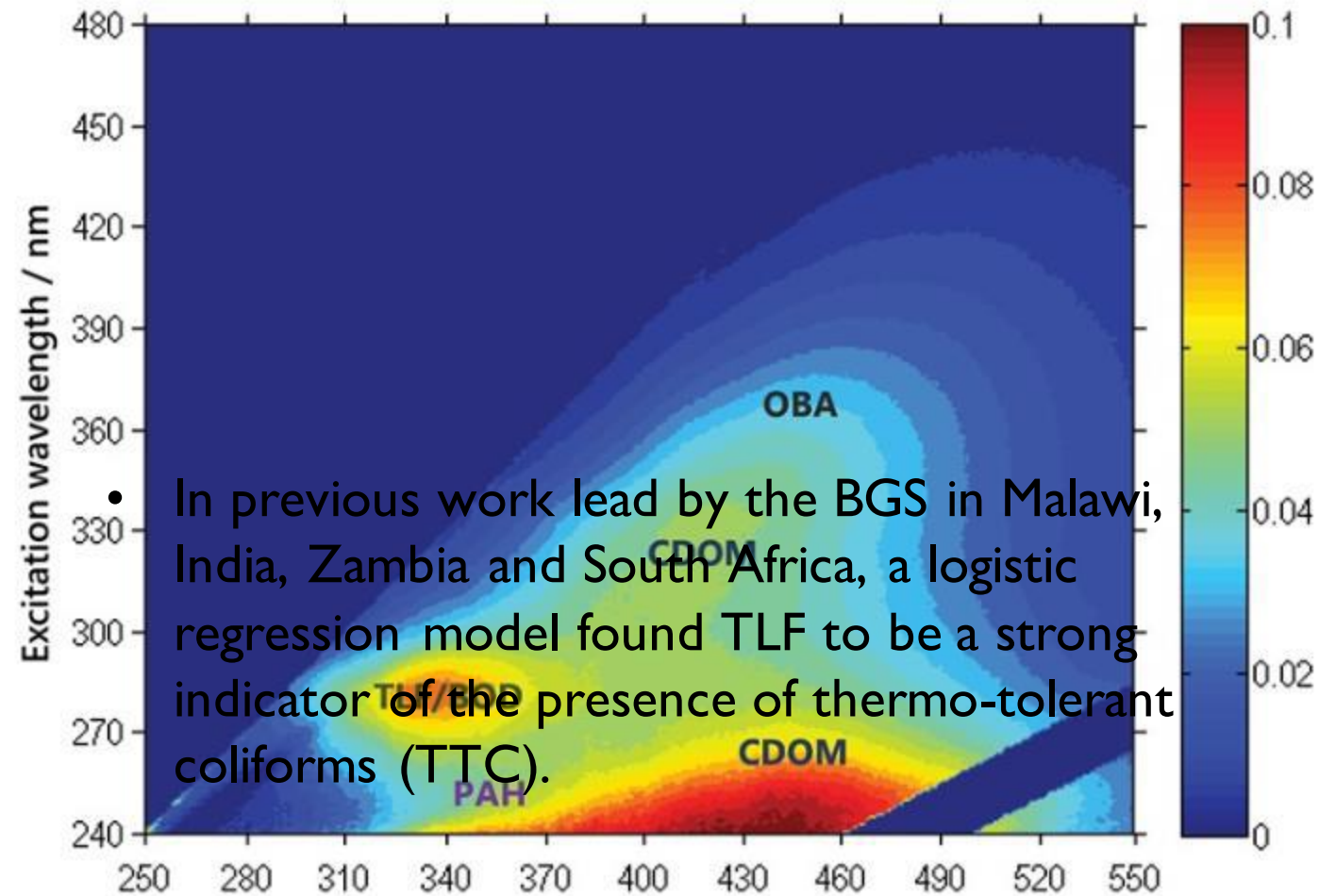
Tryptophan-like Fluorescence (TLF)
UV-fluorescence based method

+ **Real-time, portable and easy to use**

– **Early stages of the development, poorly understood mechanisms**



as an alternative method



- In previous work lead by the BGS in Malawi, India, Zambia and South Africa, a logistic regression model found TLF to be a strong indicator of the presence of thermo-tolerant coliforms (TTC).
- Portable fluorimeters measure concentration of organic dissolved matter at given wavelengths (280nm and 360nm).

Study area - the Thiaroye shallow aquifer, Dakar, Senegal

Legend

- Points Sampled
- Thiaroye aquifer

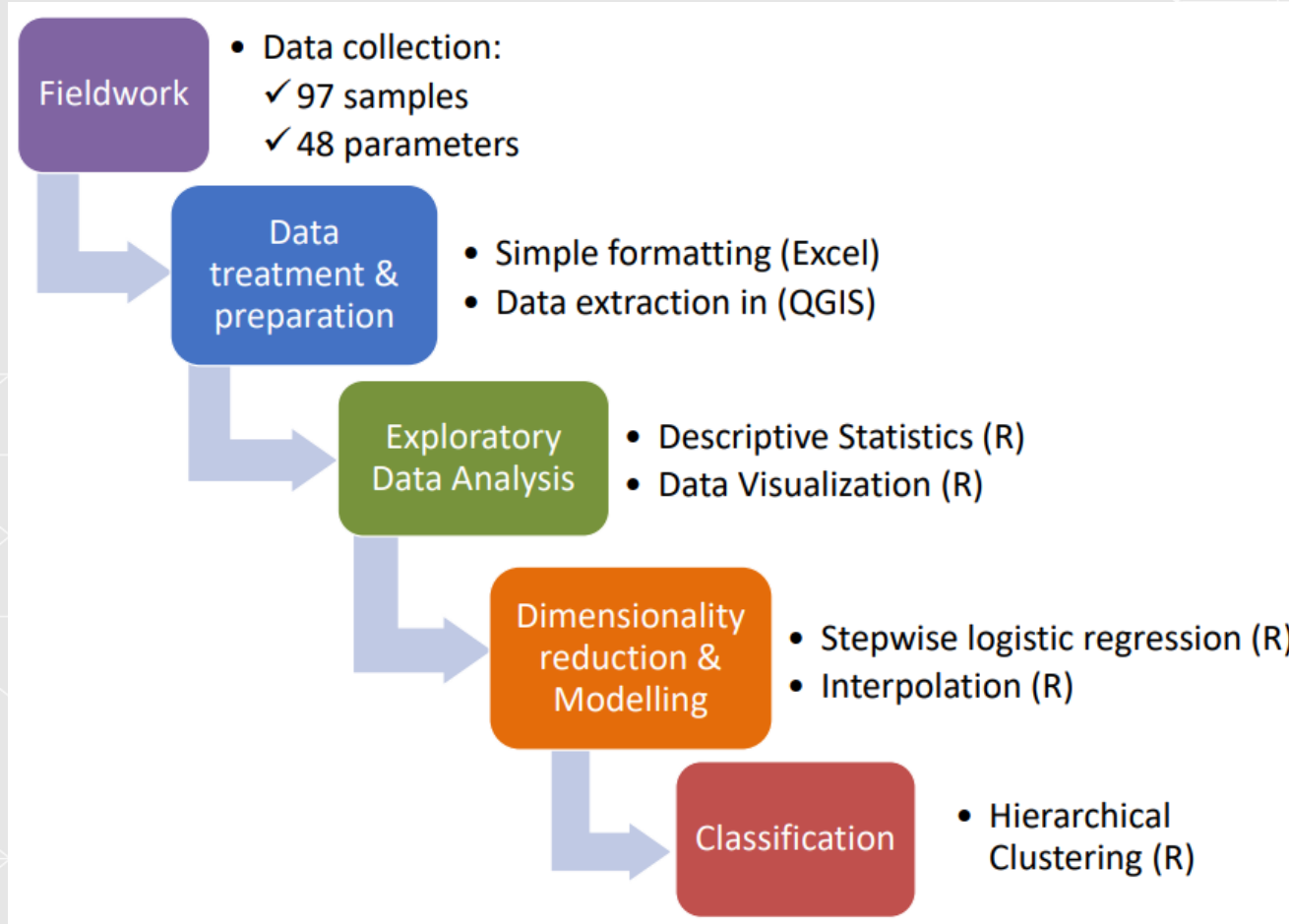




Research Aims

1. Explore Tryptophan-Like Fluorescence (TLF) robustness and reliability as a predictor of faecal contamination in a highly polluted and densely populated area.
2. Explore contamination of the Thiaroye aquifer in relation to other available environmental variables. Understand whether environmental factors and hydrochemical parameters can predict actual faecal contamination across the aquifer.

Methods



Data Collection:

97 samples across the Dakar region, 48 parameters



Handpump



Dug well



Piezometer



Borehole (with electric pump)

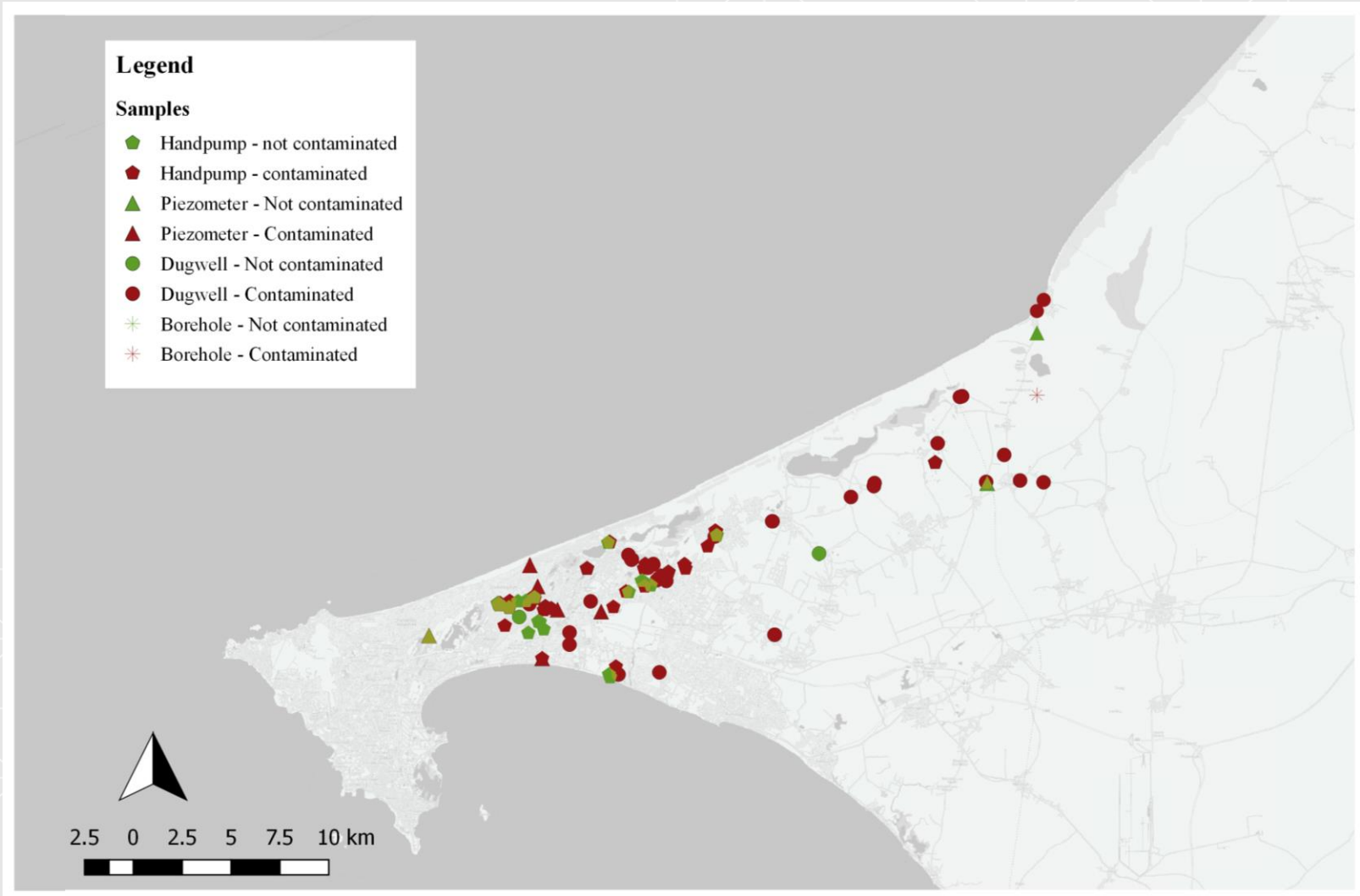


Data Collection:

97 samples across the Dakar region, 48 parameters

Variable	Variable Type	Data transformation if any	Role
<i>ID</i>	Ordinal	Removed for the analysis	Single identifier
<i>NAME_4</i>	String	Removed for the analysis in order not to work at aggregated level	Administrative Unit
<i>TTC</i>	Integer	Log10 Contamination (0 or 1)	Indicator organism for faecal contamination
<i>TLF</i>	Numeric	TLF concentration data in QSU extrapolated from the calibration trendline equation	Potential indicator of faecal contamination
<i>Type</i>	Categorical	Turned into numeric categories	Source type (handpump, dug well, etc.)
<i>Rain</i>	Binary	Ready to use	Separate points sampled before and after the rain
<i>x</i>	Numeric	Ready to use	Longitude
<i>y</i>	Numeric	Ready to use	Latitude
<i>PopDensity</i>	Numeric	Ready to use	Proxy for the discharge of faeces in groundwater
<i>Conductivity</i>	Numeric	Ready to use	Hydrochemical parameter.
<i>pH</i>	Numeric	Ready to use	Hydrochemical parameter
<i>Temperature</i>	Numeric	Ready to use	Hydrochemical parameter
<i>Salinity</i>	Numeric	Ready to use	Hydrochemical parameter
<i>Turbidity</i>	Numeric	Ready to use	Hydrochemical parameter
<i>FC</i>	Integer	Log10	Flow Cytometry data
<i>CDOM</i>	Numeric	Ready to use	Indicator of Dissolved particles, including carbon
<i>DistanceToCemetery</i>	Numeric	Extracted from Open Street Map	To assess influence of environmental factors
<i>DistanceToFarm</i>	Numeric	Extracted from Open Street Map	To assess influence of environmental factors
<i>DistanceToIndustry</i>	Numeric	Extracted from Open Street Map	To assess influence of environmental factors
<i>DistanceToLandfill</i>	Numeric	Extracted from Open Street Map	To assess influence of environmental factors
<i>DistanceToRoads</i>	Numeric	Extracted from Open Street Map	To assess influence of environmental factors
<i>Sanitation</i>	Binary	Extracted from sanitary risk form	Presence of sanitation facilities within 10m
<i>SepticTank</i>	Binary	Extracted from sanitary risk form	Presence of a septic tank within 10m
<i>SoakPit</i>	Binary	Extracted from sanitary risk form	Presence of a soak pit within 10m
<i>Latrines</i>	Binary	Extracted from sanitary risk form	Presence of latrines within 10m
<i>Cattle</i>	Binary	Extracted from sanitary risk form	Presence of cattle on the area
<i>Trash</i>	Binary	Extracted from sanitary risk form	Presence of trash or landfill
<i>Cultivation</i>	Binary	Extracted from sanitary risk form	Presence of agricultural activities
<i>Construction</i>	Binary	Extracted from sanitary risk form	Presence of construction works in the area
<i>Road</i>	Binary	Extracted from sanitary risk form	Presence of a road in the vicinity
<i>Petrol station</i>	Binary	Extracted from sanitary risk form	Presence of a petrol station in the vicinity
<i>Drainage channel</i>	Binary	Extracted from sanitary risk form	Is there a drainage channel?
<i>Fence</i>	Binary	Extracted from sanitary risk form	Is the source covered by a fence, when applicable?
<i>Apron area</i>	Binary	Extracted from sanitary risk form	Is there an apron area?
<i>Pump insanitary</i>	Binary	Extracted from sanitary risk form	Is the pump insanitary?
<i>CracksLoose</i>	Binary	Extracted from sanitary risk form	Is the pump cracked or loose at the base?
<i>TotalRisk</i>	Integer	Extracted from sanitary risk form	Sum of all risk indicators (/10)
<i>TLF_filtered</i>	Numeric	Missing data; used in a subset	TLF measured on filtered samples
<i>CDOM_filtered</i>	Numeric	Missing data; used in a subset	CDOM measured on filtered samples
<i>DOC</i>	Numeric	Missing data; used in a subset	Dissolved Organic Carbon
<i>Nitrates</i>	Numeric	Missing data; used in a subset	Nitrates
<i>Phosphates</i>	Numeric	Missing data; used in a subset	Phosphates
<i>Repeat</i>	Binary	Ready to use	Was this point sampled twice?
<i>Date</i>	Date	Removed for the analysis (irrelevant)	Date of sampling
<i>Time</i>	Time	Removed for the analysis (irrelevant)	Time of sampling

Exploratory Data Analysis



Exploratory Data Analysis

- TFL and TTC do not correlate

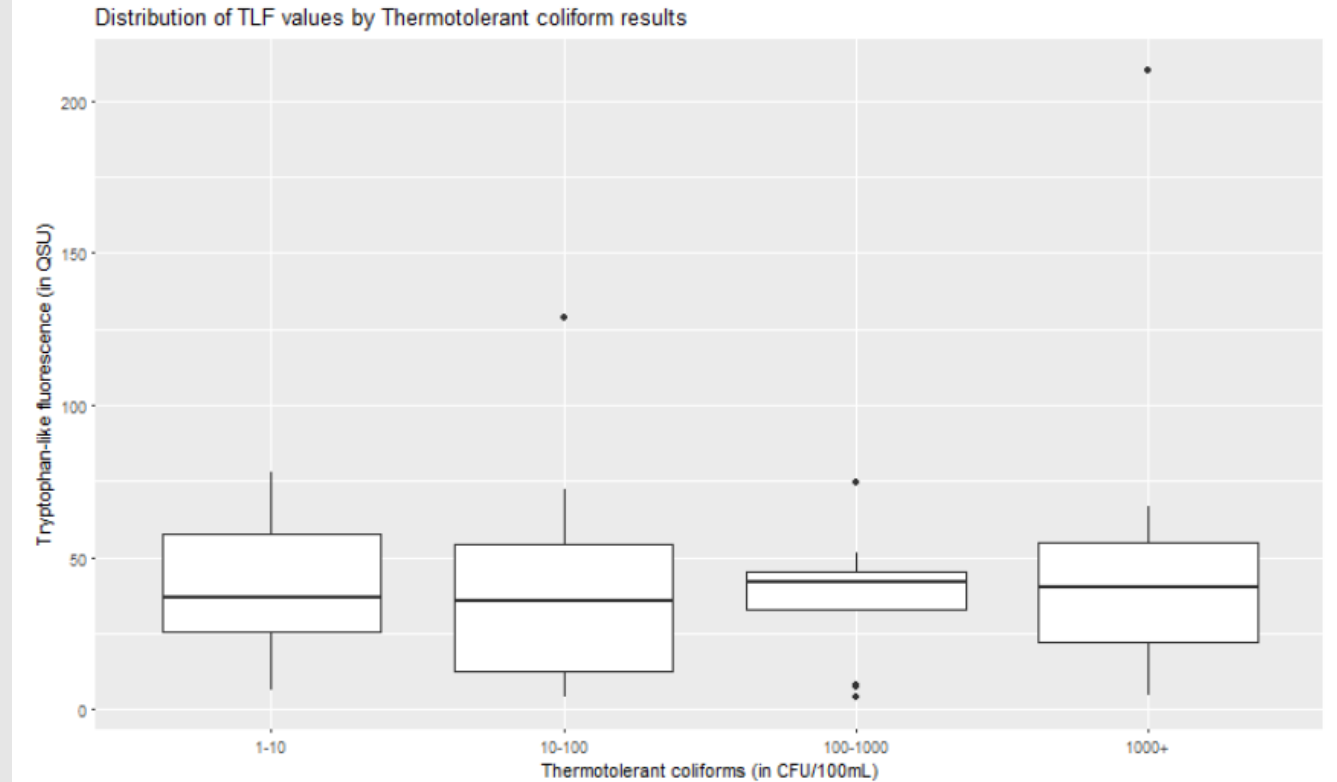
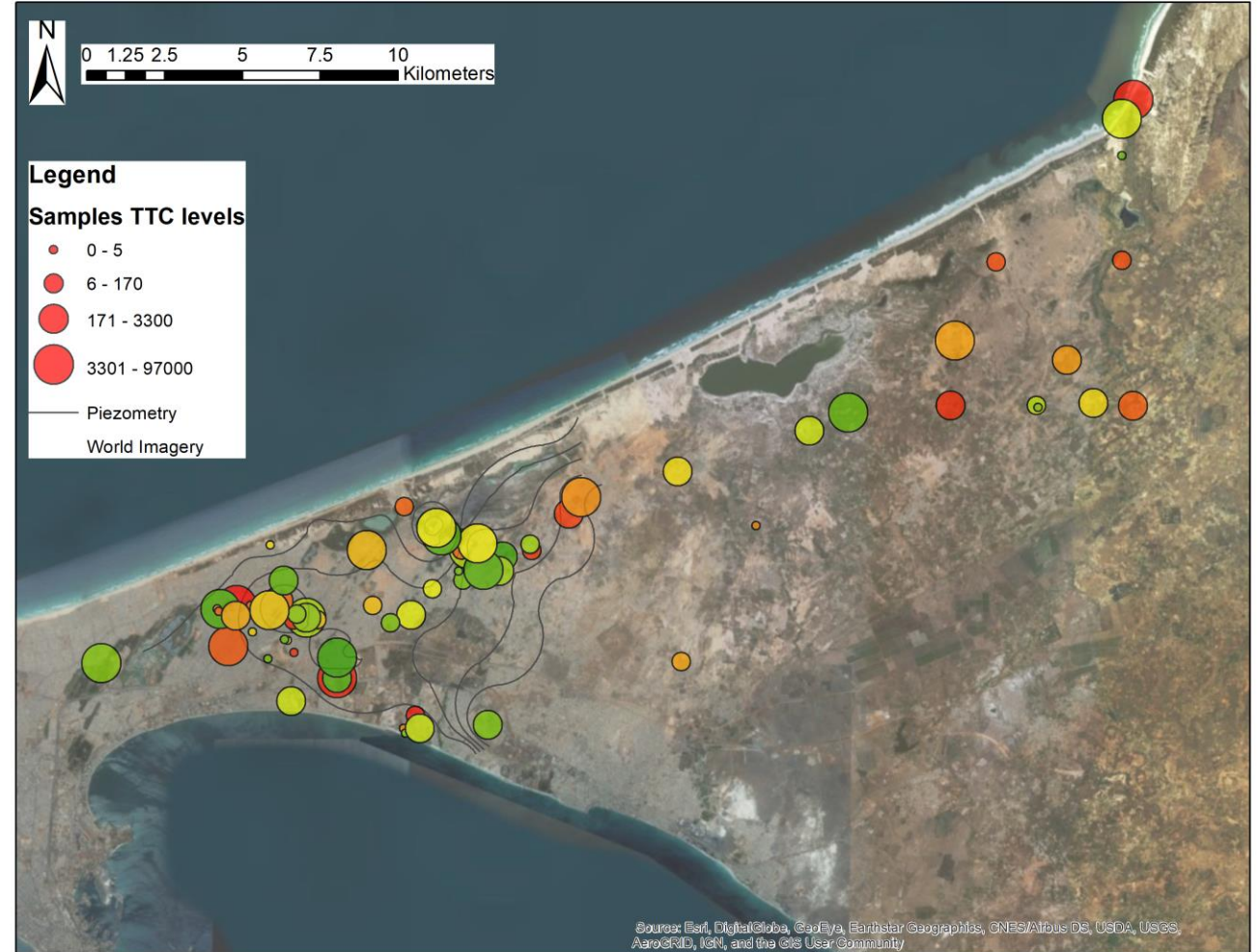


Figure 9: Boxplot of TLF by TTC count

Exploratory Data Analysis

- Colour: green = low TLF, red = high TLF
- If there were a strong relationship, we'd only observe small green bubbles of low actual contamination and low TLF, and large red bubbles of high actual contamination and high TLF



Working Hypothesis

After decades of pollution, the Thiaroye aquifer is very rich in nutrients and debris from past contamination. This may lead to high levels of dissolved organic matter, and potential interference with the real-time TLF readings. A combination of other parameters may be used as a proxy to model contamination across the aquifer.

Partial research questions

RQ1: Among the various hydrochemical and microbiological parameters collected, what are the main predictors of faecal contamination?

RQ2: Is the tryptophan-based, real-time detection method a significant variable when trying to model contamination of the Thiaroye aquifer?

RQ3: What is the predictive power of the tryptophan-based method? How do various environmental factors affect its reliability?

RQ4: What is the overall predictive power of a contamination model based on a selection of significant parameters?

RQ5: Does the faecal contamination demonstrate spatial patterns, and can it be classified?

RQ2: Is the tryptophan-based, real-time detection method a significant variable when trying to model contamination of the Thiaroye aquifer?

- No! Almost perfect absence of correlation:
TLF/TTC spearman rank $\rho = -0.01190626$

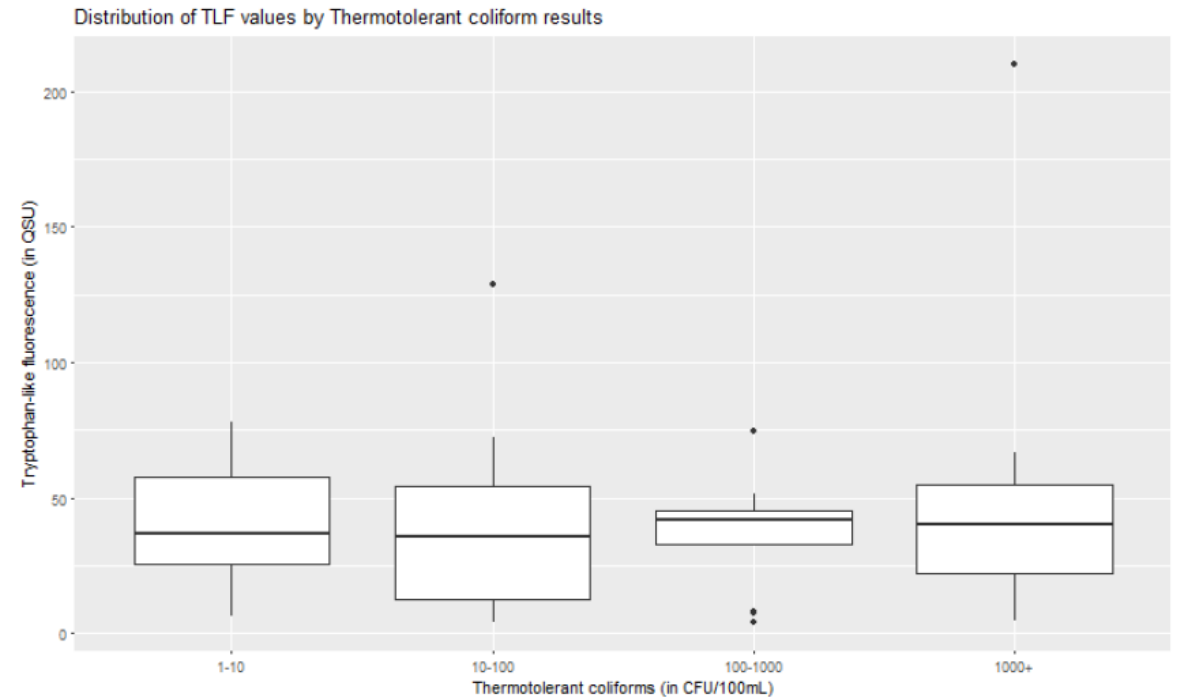
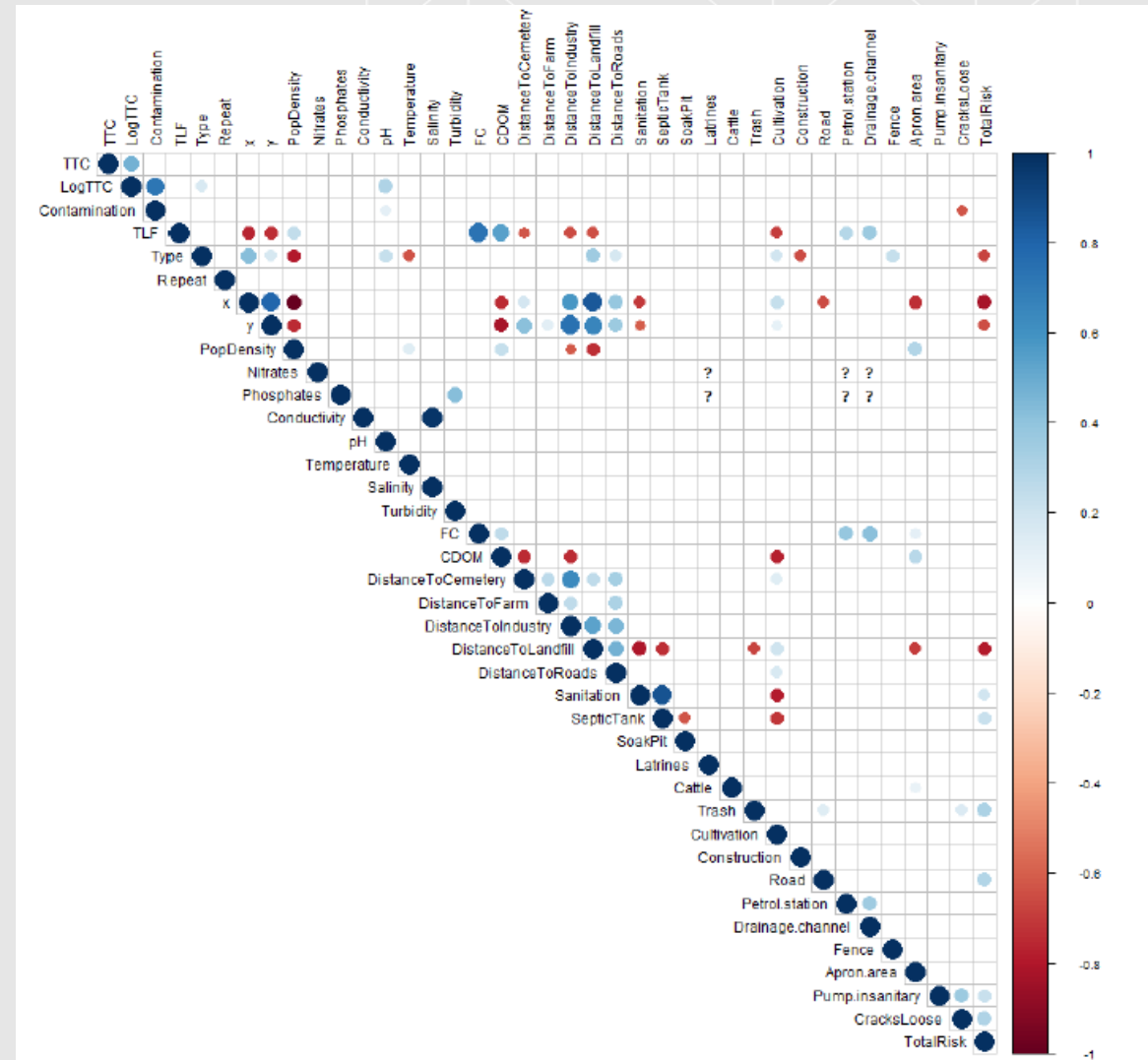


Figure 9: Boxplot of TLF by TTC count

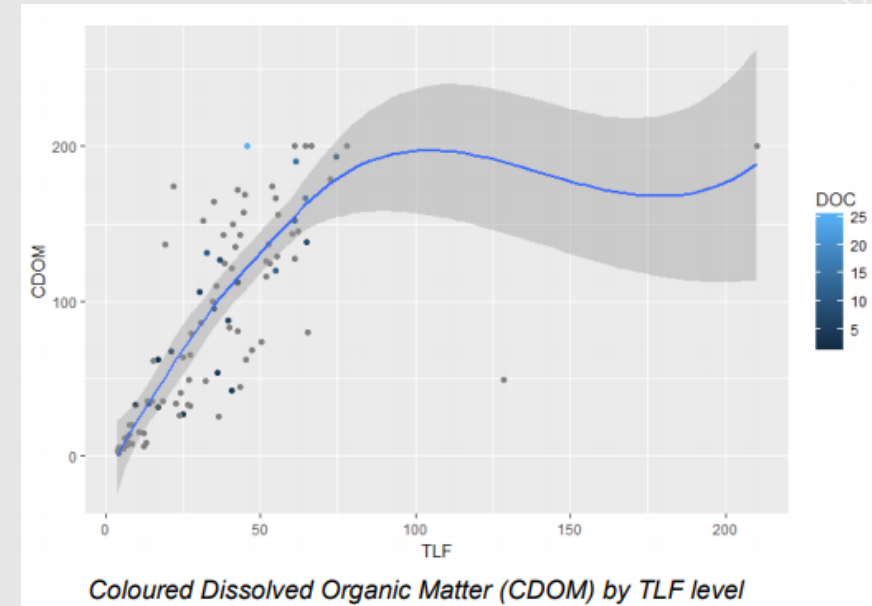
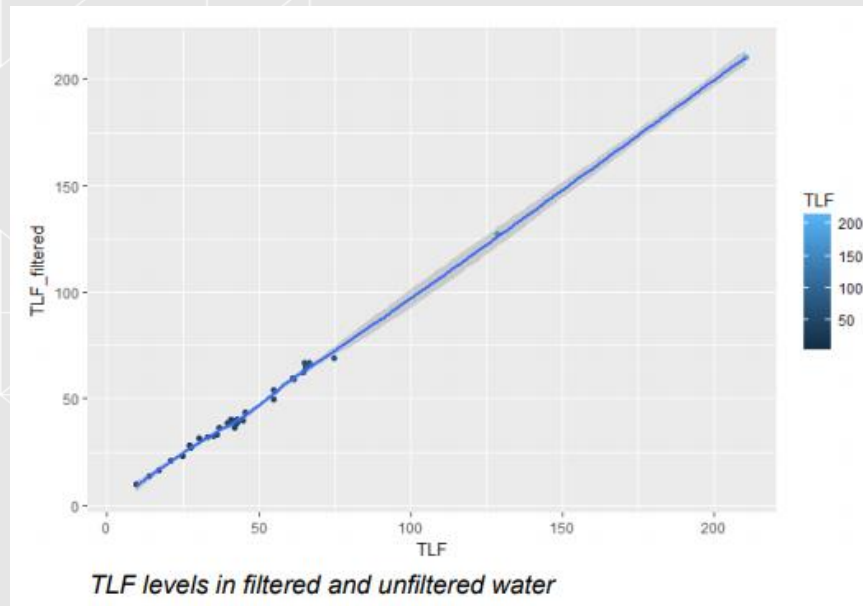
RQ I: Among the various hydrochemical and microbiological parameters collected, what are the main predictors of faecal contamination?

- Correlation Matrix
- Stepwise Logistic Regression, with 9 parameters retained as significant:
 - Latitude & longitude
 - Nearby presence of a septic tank / latrines
 - Nearby presence of a landfill
 - pH
 - Temperature
 - Turbidity
 - Flow cytometry count



RQ3: What is the predictive power of the tryptophan-based method? How do various environmental factors affect its reliability?

- TLF is strongly correlated with Flow Cytometry and Dissolved Organic Carbon
→ It appears that TLF is extra-cellular and the fluorometers are measuring debris of past pollution



RQ3: What is the predictive power of the tryptophan-based method? How do various environmental factors affect its reliability?

- TLF is negatively correlated to the presence of cultivation activities
- TLF levels are higher near cemeteries, industries and landfills

This could be due to specific compounds present around these facilities, but it is impossible to conclude with this dataset (further tests and controls would be needed).

RQ4: What is the overall predictive power of a contamination model based on a selection of significant parameters?

- Our logistic regression based on the 9 selected parameters correctly classifies unknown data as contaminated or not contaminated **72.22%** of the time.

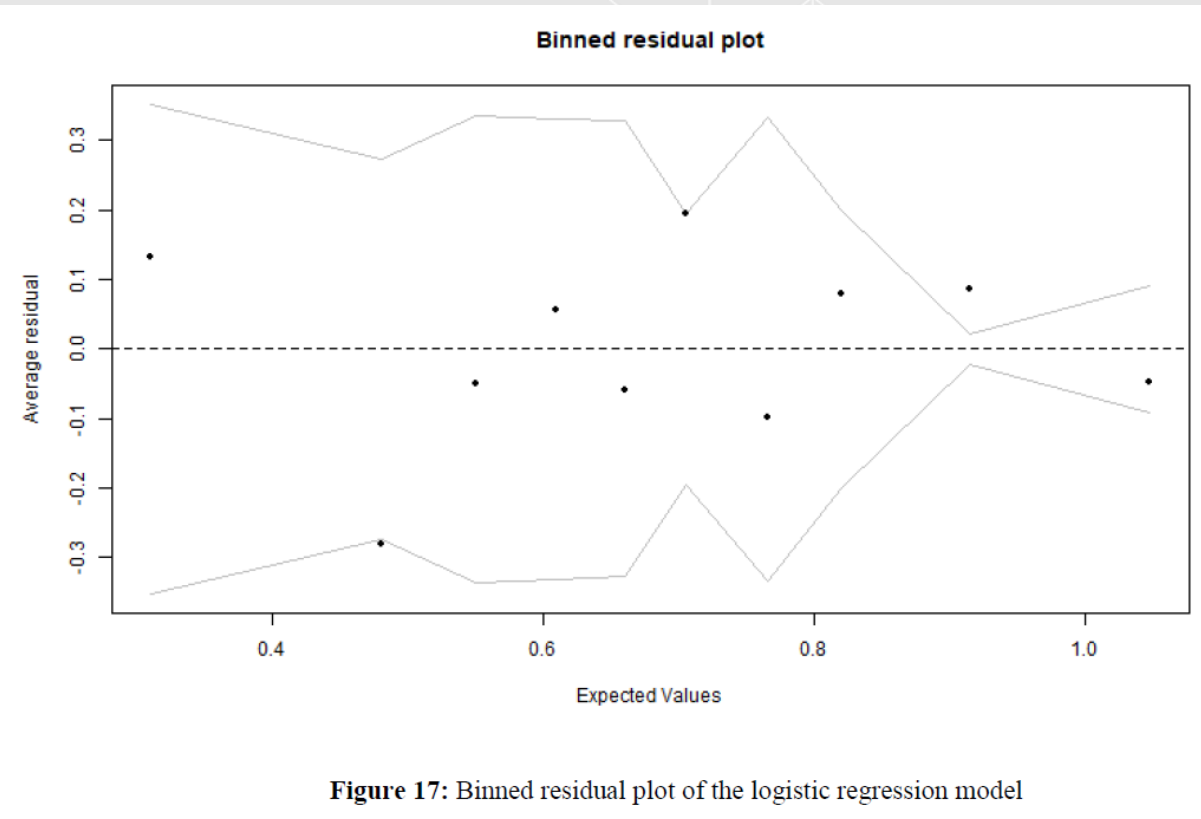
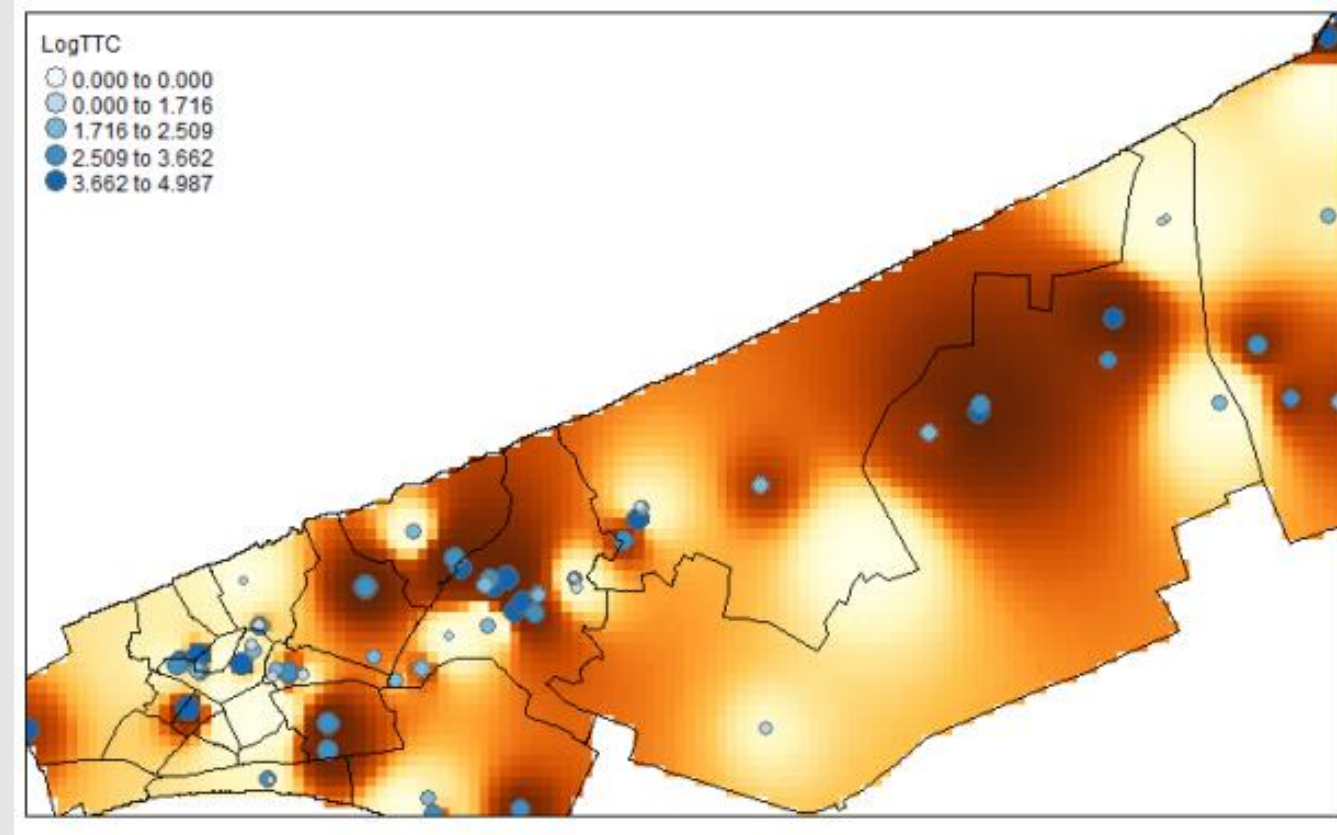


Figure 17: Binned residual plot of the logistic regression model

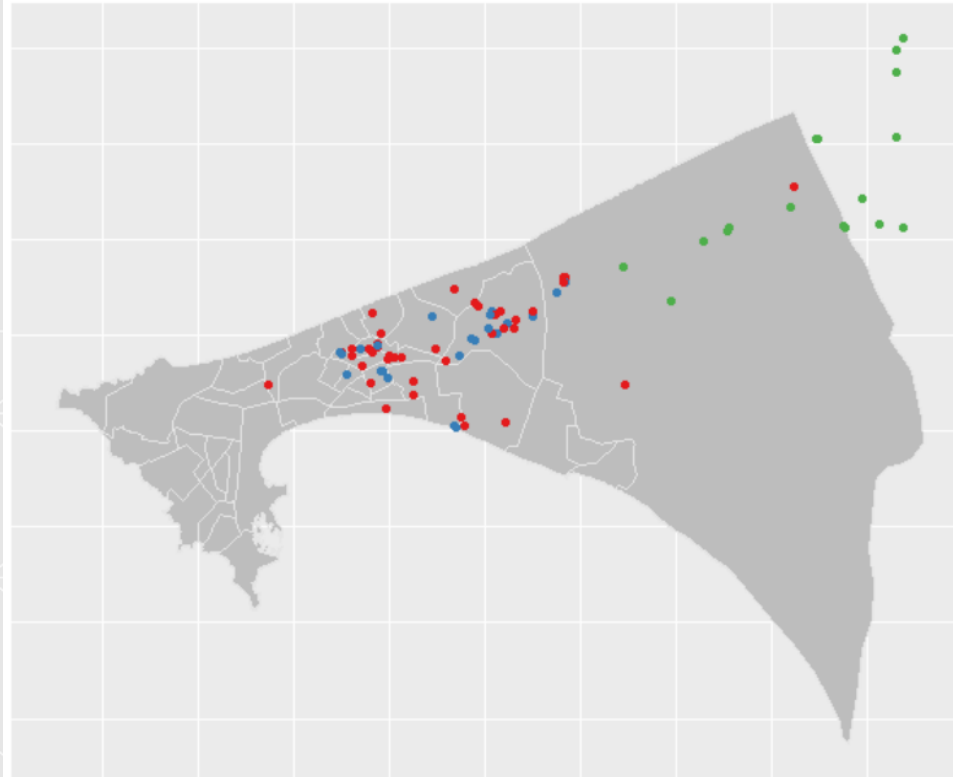
RQ5: Does faecal contamination demonstrate spatial patterns?

- Interpolation is not reliable in this case due to low degree of spatial autocorrelation in the contamination.



RQ5: Can faecal contamination be classified?

All Samples



cluster 1 2 3

Cluster 1: Peri-urban, handpumps, low TLF results and low TTC results but very high CDOM levels, sampled before the first rain.

Cluster 2: Peri-urban, hand pumps and dug wells, very high TTC levels and relatively high levels of TLF.

Cluster 3: Rural and agricultural, dug wells and piezometers, highly contaminated, very low population density

Discussion – Why this research matters

- Further our understanding of TLF
- Flag the limitations of TLF
- Skills exchange across the AfriWatSan network



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In-situ fluorescence spectroscopy indicates total bacterial abundance and dissolved organic carbon

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Highlights

- Total bacterial cells most related variable to tryptophan-like fluorescence (TLF)
- TLF and humic-like fluorescence strongly correlate with dissolved organic carbon.
- Thermotolerant coliforms are not strongly related to other variables.
- TLF and HLF relate to faecal contamination.

Next Steps

- Incorporate groundwater flows into groundwater pollution modelling
- Improve sampling scheme (very difficult!)
- With access to historical pollution and land use data, investigate links between historical loads of faecal bacteria and current TLF & CDOM rates



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Thank you for listening!

Q&A