Relating complex network theory metrics with discolouration activity in water distribution networks

Greg Kyritsakas et al.

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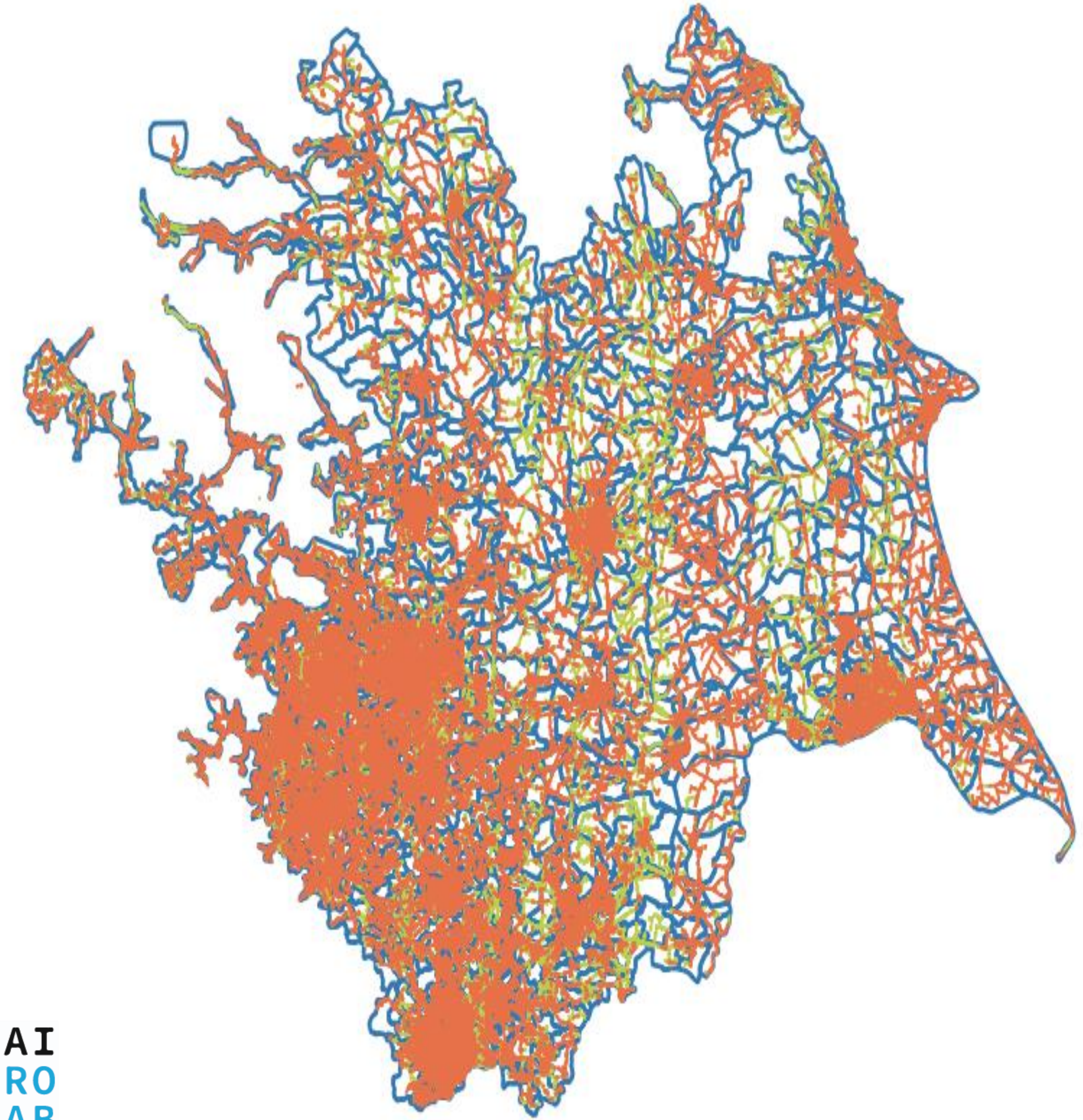
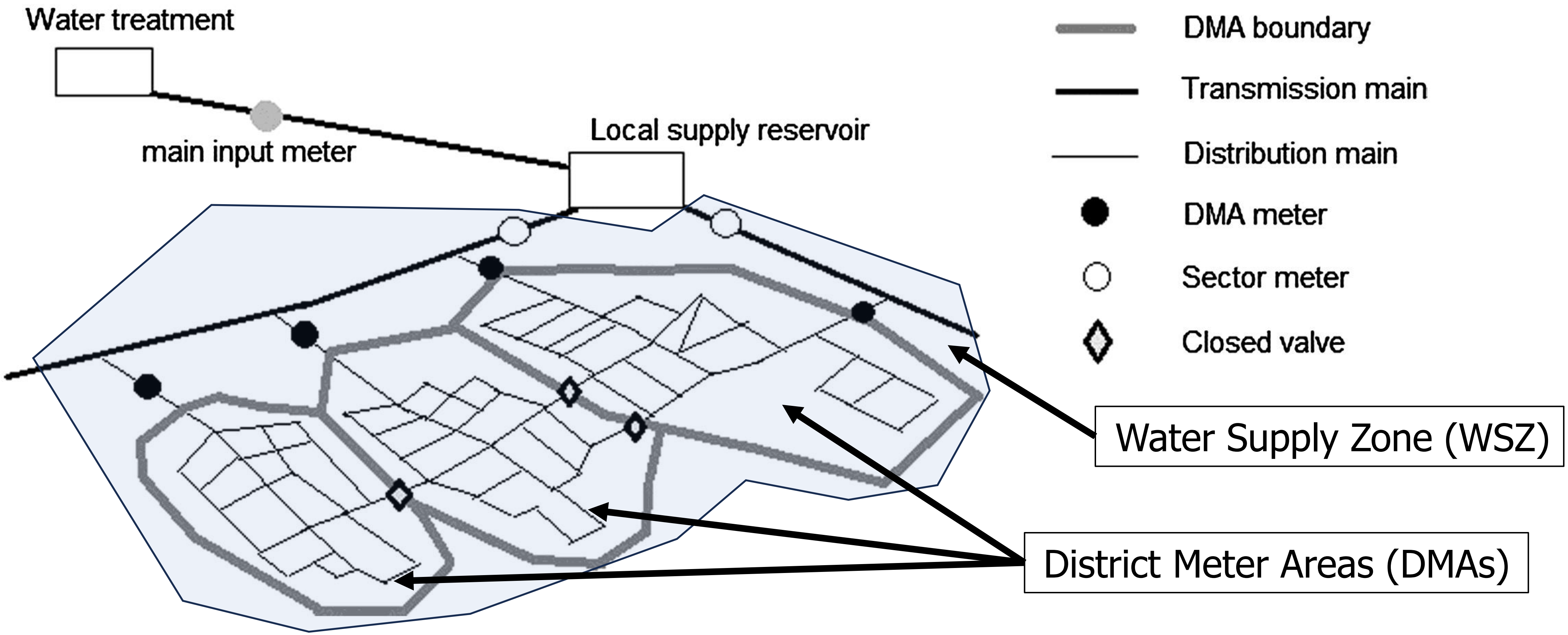


Overview

- Drinking water distribution networks management
- Drinking Water quality monitoring programs
- Discolouration of the drinking water
- Aim of research
- Methodology
- Results, Conclusions and Future Work

Water Distribution Networks (WDN) management



Source: Ferrari, G. et al.(2014). "Graph-Theoretic Approach and Sound Engineering Principles for Design of District Metered Areas." Journal of Water Resources Planning and Management, Volume 140,Issue 12.

Drinking water quality monitoring program

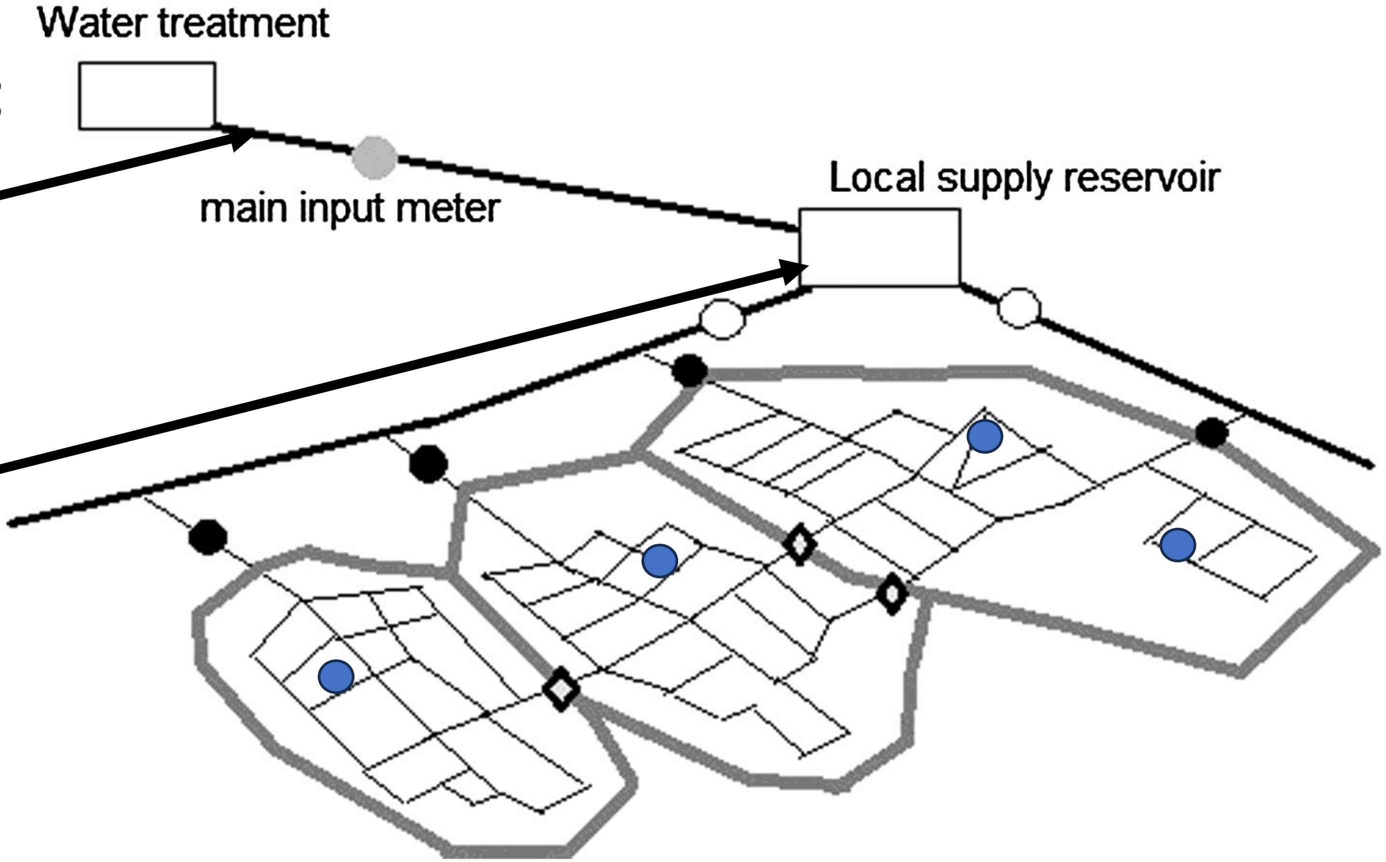
Main monitoring parameters:

- Microbiological
- Metals
- Chemical
- Aesthetic

Water treatment works (daily)

Customer taps (randomly)

Supply reservoirs (weekly)



Source: Ferrari, G. et al.(2014). ″Graph-Theoretic Approach and Sound Engineering Principles for Design of District Metered Areas.″ Journal of Water Resources Planning and Management, Volume 140,Issue 12.

Discolouration of Drinking water

Accumulation and subsequent **mobilisation** of **organic** and **inorganic** materials

- **Accumulation:** Corroding iron pipes - Treatment processes – Biofilm

- **Mobilisation:** changes in normal hydraulic conditions i.e.. burst, valve operation

- **Inorganic material:** metals (iron, manganese etc.)

- **Organic material:** pipe biofilm

- **High Turbidity**: indicator of discolouration

- **Manganese** & **Iron:** Metals related to discolouration

- **Main subject** of consumers complaints (CC) in the water sector

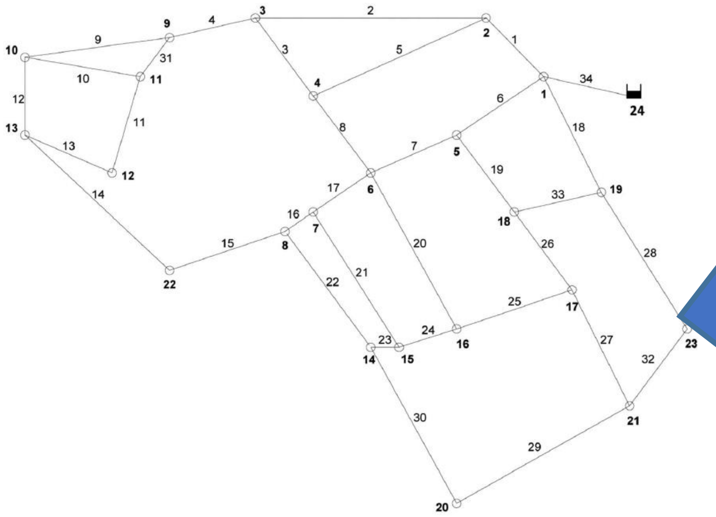
Aim of research

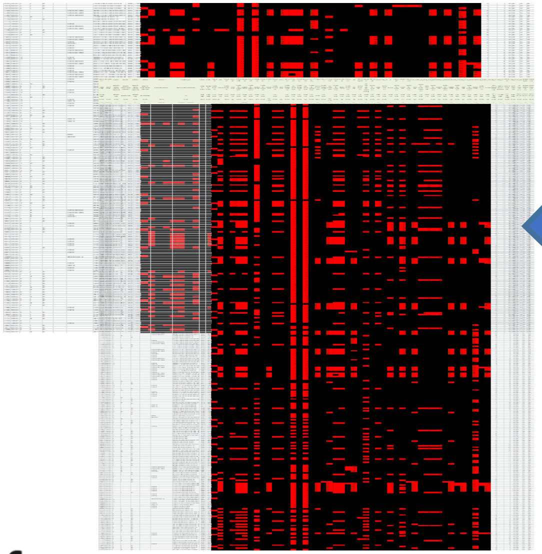
1. Investigate correlations between discolouration parameters and Complex Network Theory (CNT) centrality metrics
2. Explore which centrality metric could be useful for analysing distributed water quality
3. Find if network complexity could be informative for DMA and pipe discolouration risk

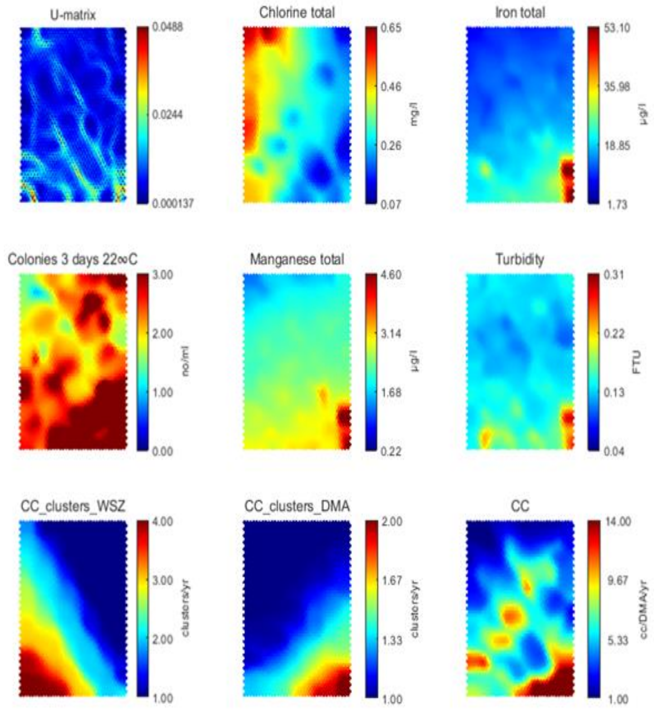
Methodology

IN THE PAST

THIS WORK





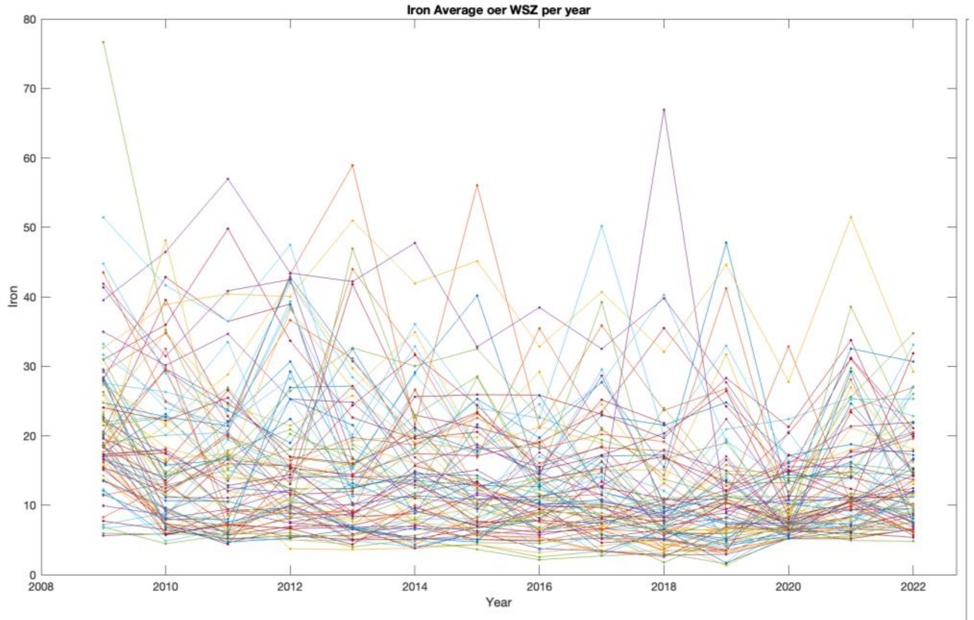


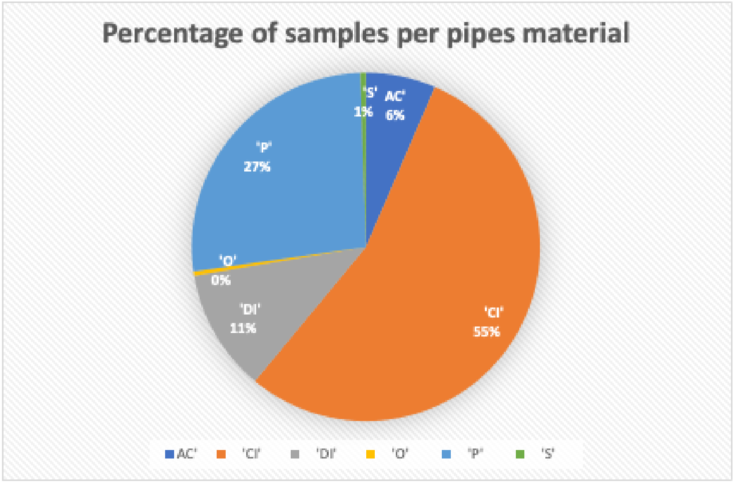
1. Correlation identification between water quality parameters and CNT metrics
2. Explore the relationships between network complexity and discolouration risk in DMAs and pipes

1. Correlation identification between water quality parameters
2. Understanding roots and causes of discolouration in WDS

Data & Data pre-processing

- Yorkshire Water (YW) serving with water more than 5 million people
- 14 years of regulatory tap water quality samples (2009-2022) collected
- Samples distributed in more than 2700 different DMAs
- 8 main regulatory parameters, i.e. total chlorine, iron, manganese, turbidity etc.
- GIS asset data information including pipe characteristics and systems' connectivity: Treatment →WSZs →DMAs
- Discolouration Customer Contact (CC) data





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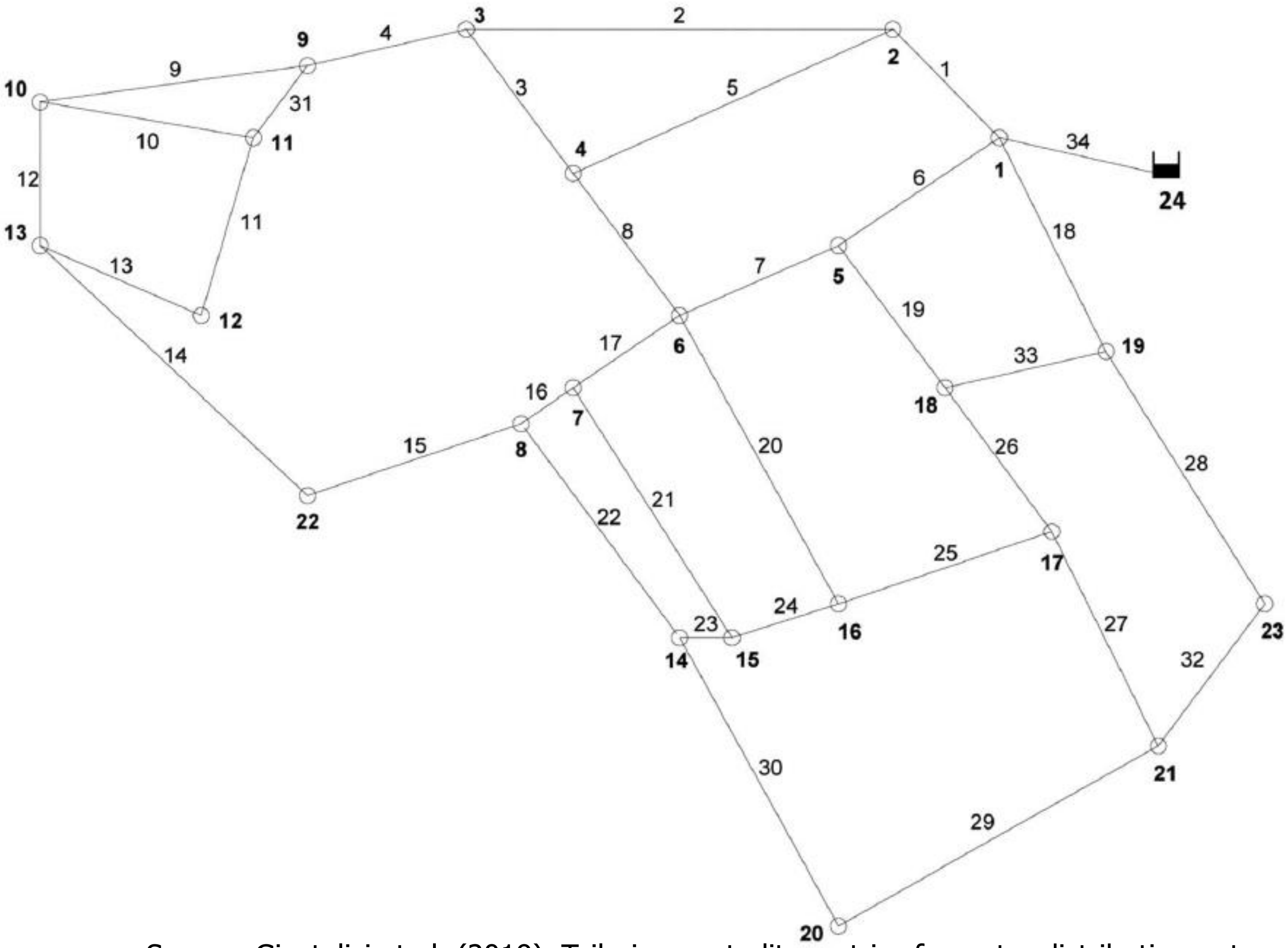
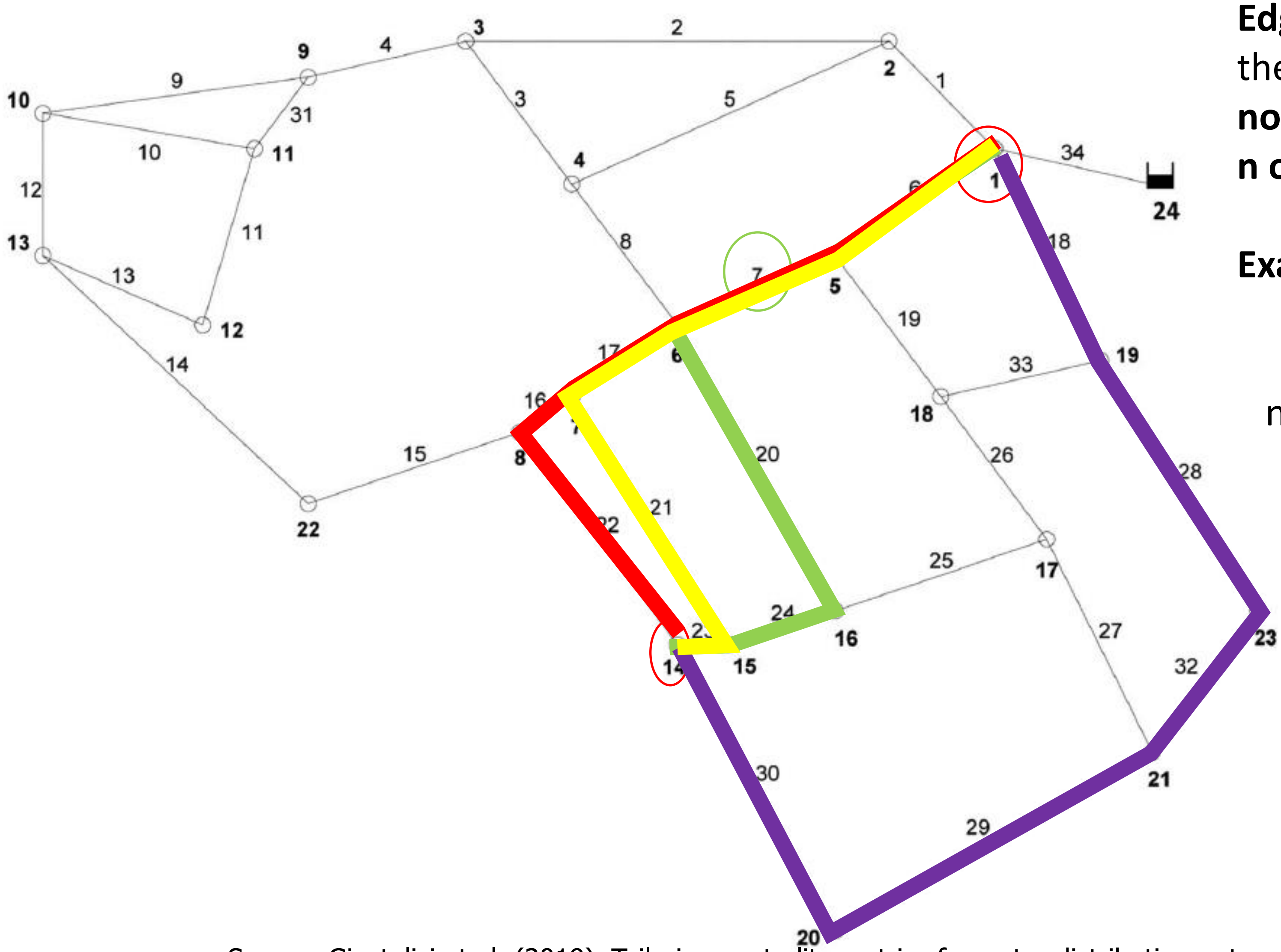
Complex Network Theory (CNT)



- Complex network theory (CNT) is based on the idea that human-made systems work as networks containing nodes connected with edges
- CNT is applied in WDN using pipes as edges and pipe ending points as nodes
- Main aim to understand WDN structure complexity, and to identify vulnerable points using centrality metrics
- CNT centrality metrics: **node and edge betweenness and degree**

Source: Giustolisi et al. (2019). Tailoring centrality metrics for water distribution networks. Water Resources Research 55,2348-2369

CNT – edge betweenness



Edge Betweenness: Edge betweenness of the **edge l**, is the ratio between the number of short paths **between nodes s and t** passing from edge l and the total number **n of short passes** between nodes s and t

Example: i = 7

s,t = 1,14

n=4 (4 short paths of 5 edges)

{6,7,20,24,23}

{6,7,17,16,22}

{6,7,17,21,23}

{18,28,32,29,30}

$$\text{Betweenness} = \frac{\textit{short paths passing through edge 7}}{\textit{total number of short paths}} = \frac{3}{4} = \mathbf{0.75}$$

Source: Giustolisi et al. (2019). Tailoring centrality metrics for water distribution networks. Water Resources Research 55,2348-2369

CNT centrality metrics processing

- Centrality metrics for both nodes and pipes for the entire YW network
- Assumption made: Each DMA is a different DWDS
- **Different metrics generated**:

a) **Edge Btw:** The edge betweenness of each pipe of YW network
b) **Edge_Btw_30DMA_ normalised :** Edge betweenness 30^{th} percentile per DMA weighted by the number of pipes per DMA.
c) **Edge_Ndegree_30DMA_ normalised :** Edge N-degree 30^{th} percentile per DMA weighted by the number of nodes per DMA.

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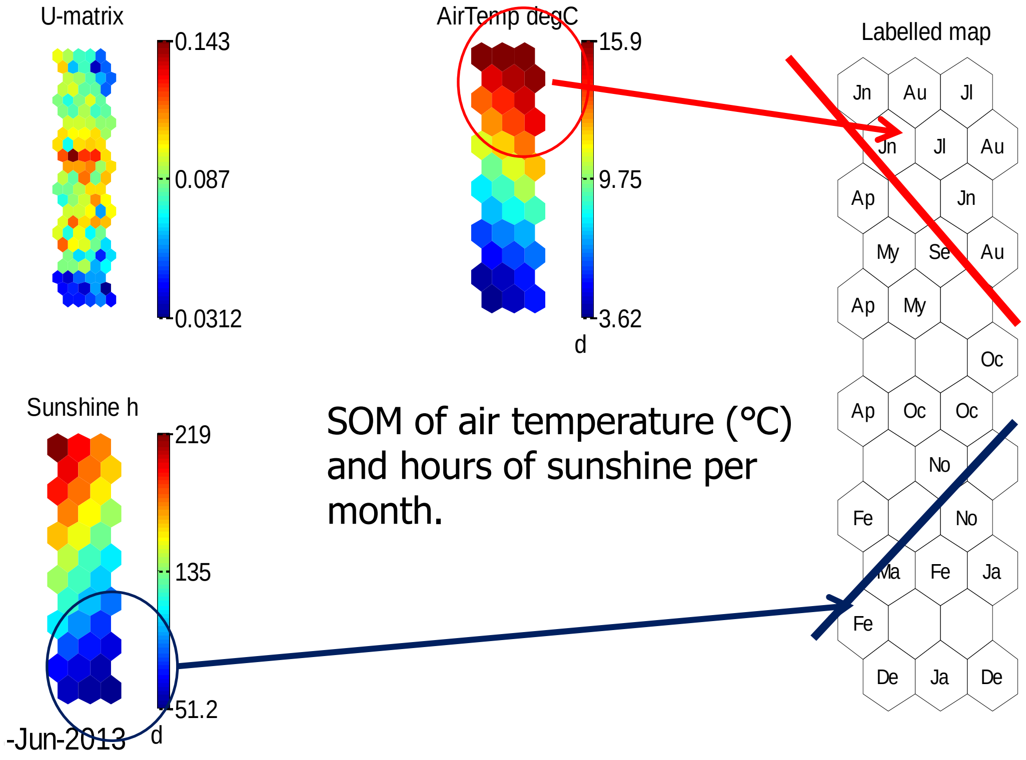
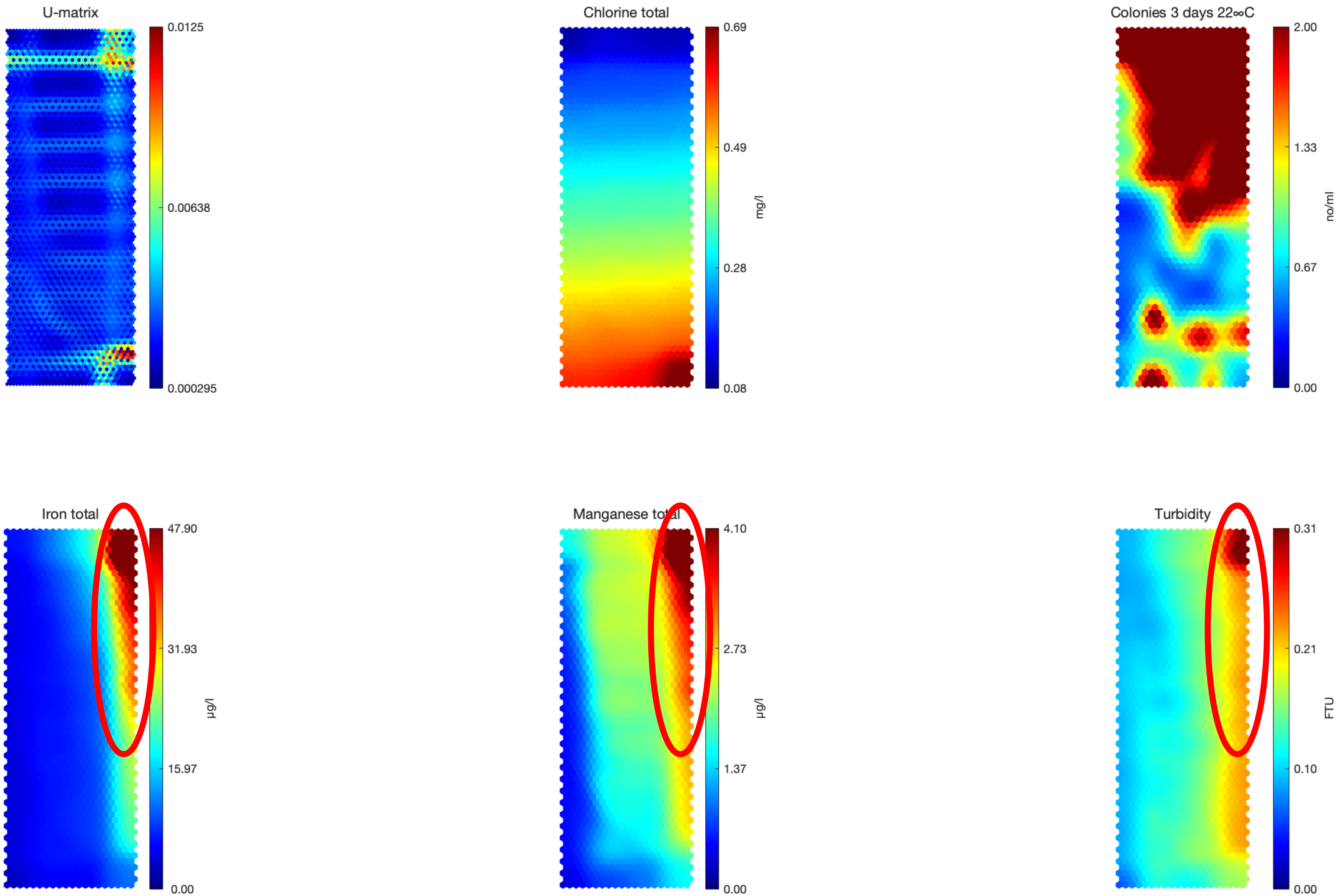
Advantages of Self Organising Maps (SOMs)



SOM of air temperature (°C) and hours of sunshine per month.

- An Artificial Neural Network unsupervised ML technique
- Good for visualizing correlations between various parameters
- Good for understanding correlations between qualitative parameters
- Robust with input vectors with missing data – main advantage comparing to PCA
- SOM MATLAB toolbox is available online (Helsinki University of Technology)

SOMs using discolouration parameters



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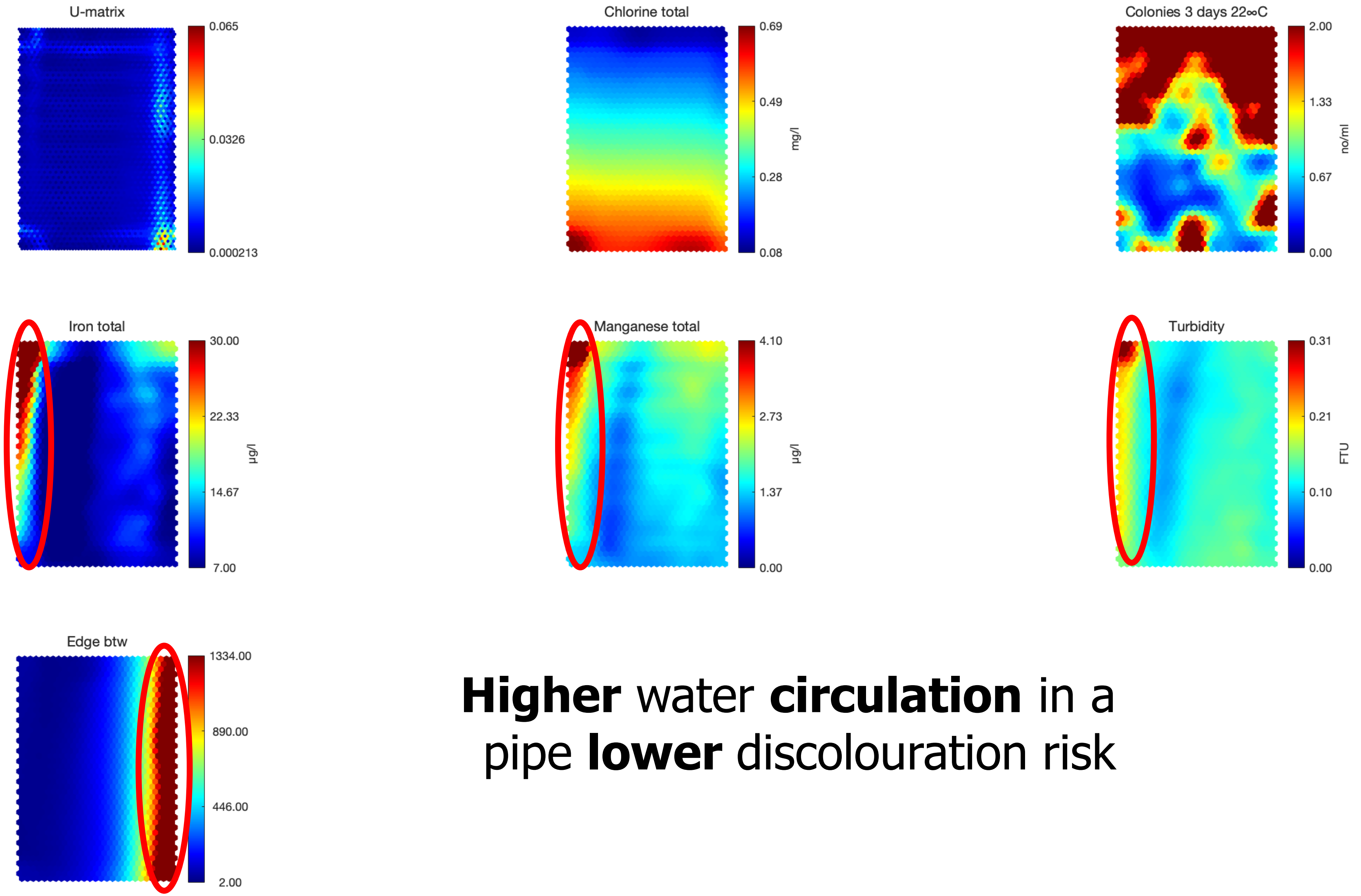
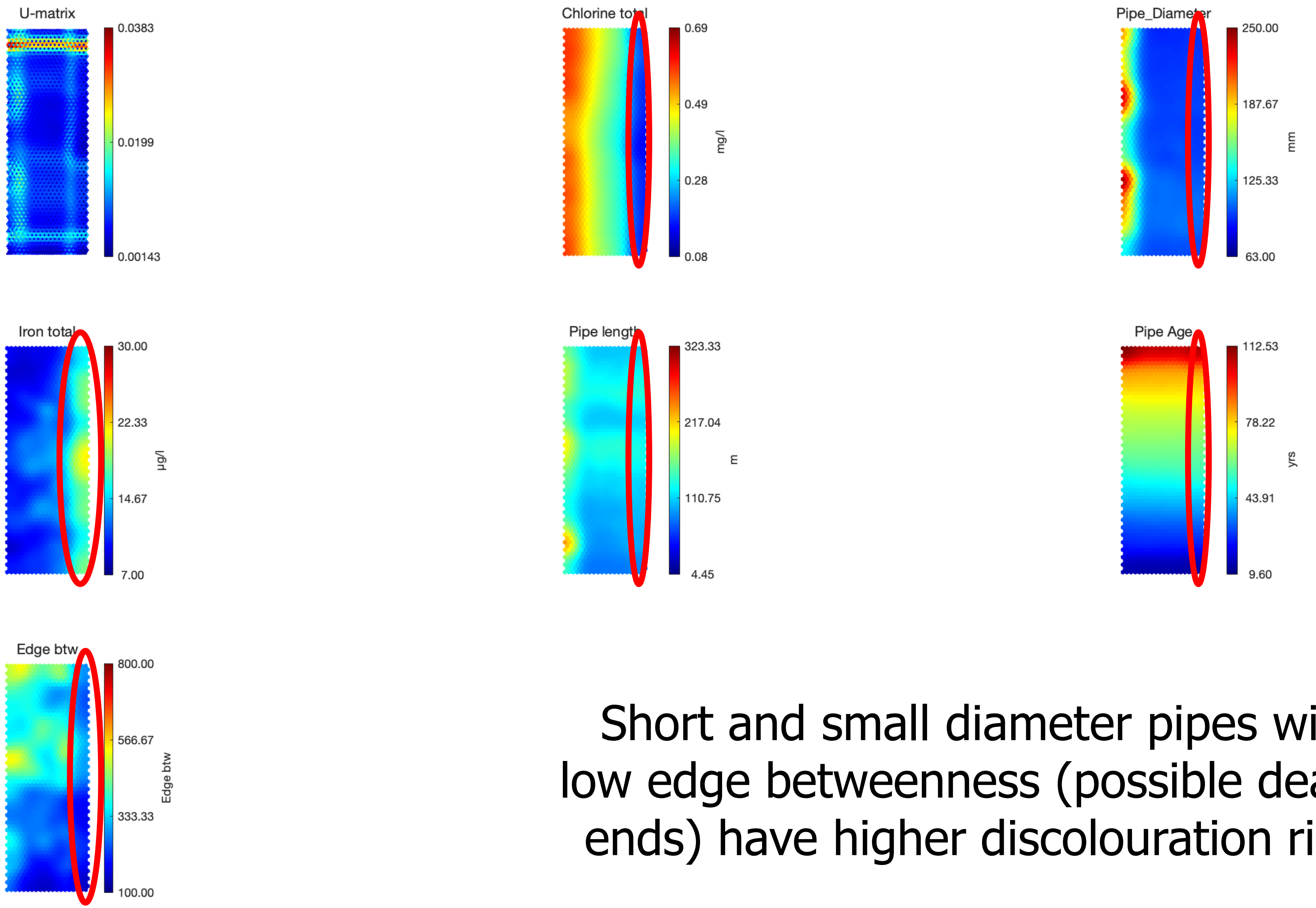
SOMs using discolouration parameters and **edge betweenness**



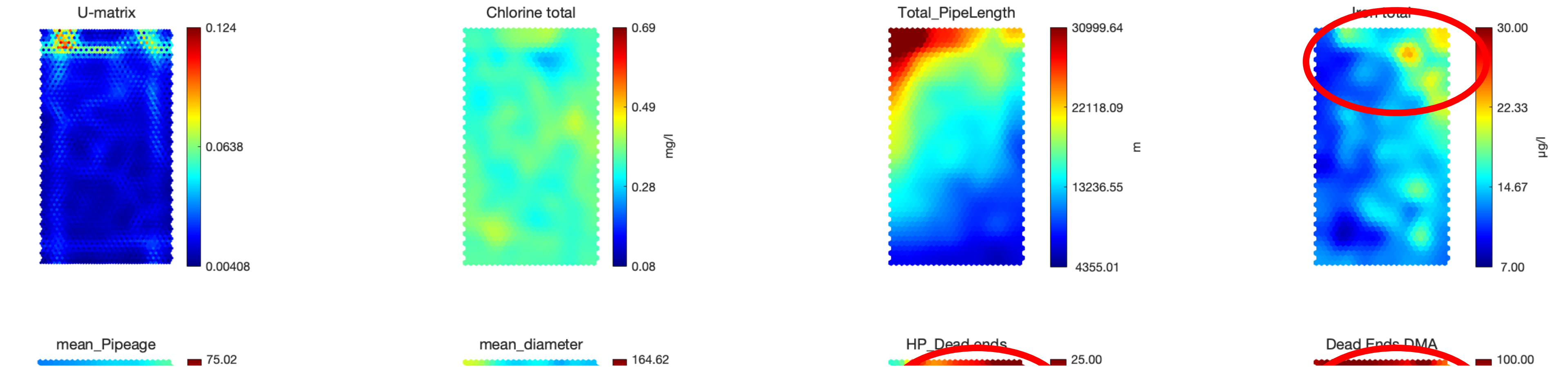
Higher water **circulation** in a pipe **lower** discolouration risk

SOMs using iron, pipe characteristics & **edge betweenness**

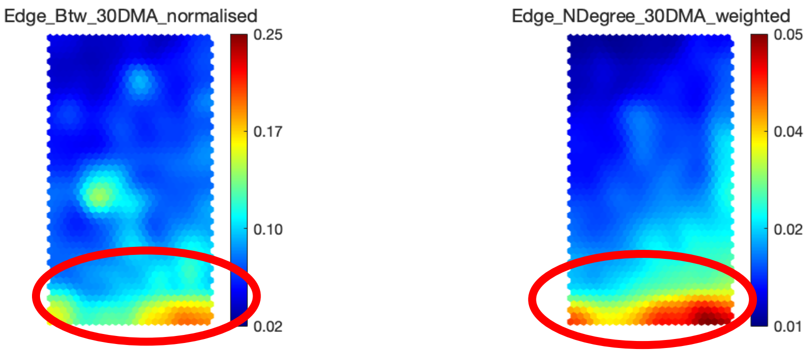


Short and small diameter pipes with low edge betweenness (possible dead ends) have higher discolouration risk

SOMs for DMA characteristics and **DMA edge betweenness and N-Degree**



- DMAs with low edge betweenness have higher iron concentrations
- DMA N-Degree could be used as an edge betweenness replacement metric



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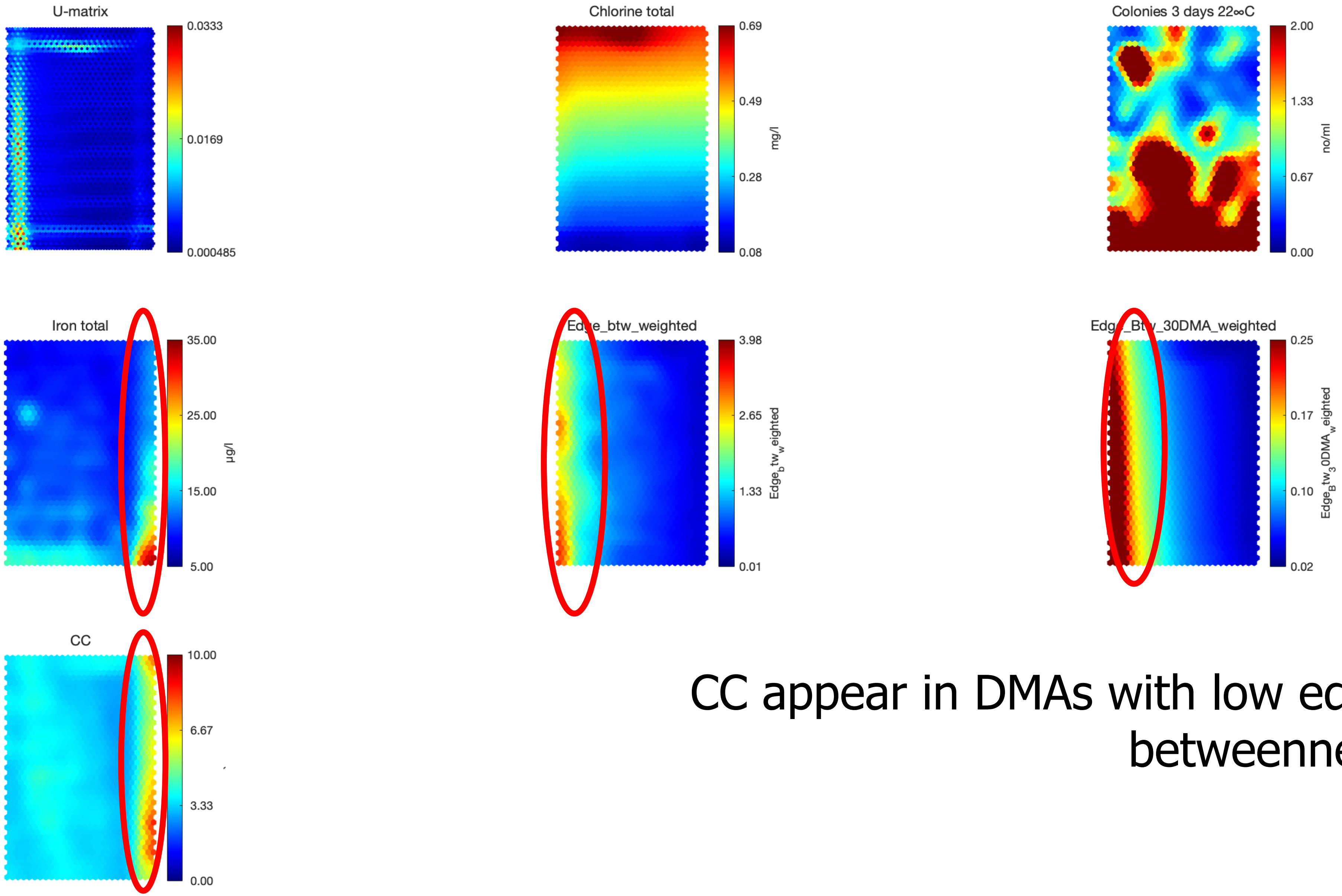
SOMs using CC data and **DMA and pipe edge betweenness**



CC appear in DMAs with low edge betweenness

Conclusions

1. SOMs outputs showed:
    a) **Reverse correlation** between **iron**, **manganese**, **turbidity** and **edge betweenness** in the pipe serving the tap
    b) **Reverse correlation** between **iron**, the number of **Dead ends** per DMA, and the **30^{th} percentile DMA edge betweenness**
    c) **High Iron** mostly appears in **short & small diameter pipes** with low **edge betweenness.**

2. **30^{th} percentile DMA edge N-Degree, 30^{th} percentile DMA edge betweenness** and **Edge Betweenness** have the potential to be a good metric for analysing the water quality in DWDS

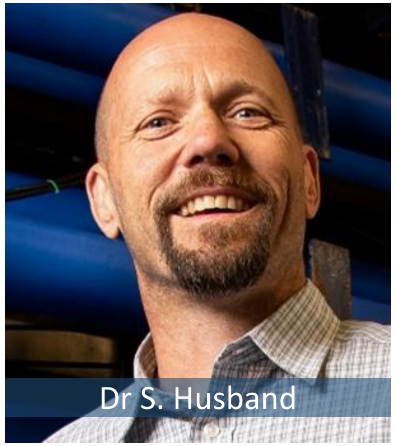
3. **A Discolouration risk ranking list** (pipes and DMAs) based on CNT metrics

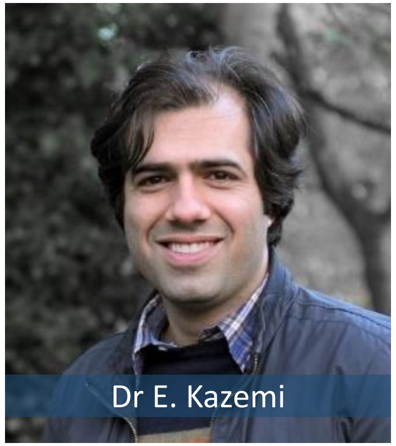
4. **Future work:** One direction (short paths) and pipe loop effect metrics, optimal design of the WDNs

Acknowledgments

Department of Civil and Structural Engineering

Water Distribution Research Group





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