A Monte-Carlo based method for the identification of potential sewer mining locations

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Who is who...

Sewer Mining Pilot (Athens)

- EYDAP Athens Water Supply and Sewerage Company, Greece (CASE)
- NTUA, National Technical University of Athens (RTD)
- CHEMiTEC Water & Environmental Technologies, Greece (SME)
- TELINT RTD Consultancy Services, UK (SME)
Context

- Athens has suffered rapid urbanisation resulting in few urban green spaces
- **Reuse**, but at what **scale**?
- Need for innovative management options and technologies for reuse needed to irrigate (primarily) green urban areas (incl. devastated peri-urban forests).

Current status

- Main WWTP in an **island** (Psytalleia)
- Increased energy costs for transp.
- Peri-urban forests devastated by fires
- Water scarcity
Enter Sewer Mining...

The Athens Pilot brings together two emerging technologies:

Fully automated packaged treatment plants featuring membrane based, small footprint, sewer mining technologies that allow direct mining of sewage from the network, close to the point-of-use with minimum infrastructure required and low transportation costs for the effluent.

Distributed low energy sensor networks coupled with distributed ICT intelligence (e.g. Advanced Metering and Monitoring Infrastructure, AMIs) innovative in terms of data fusion (b) data communication (c) interoperability and (d) mobile solutions for remotely controlling and operating the distributed infrastructure (against stringent performance criteria, incl. health and water quality standards).
Main concept

The following general concept was developed as a basis of applications of the proposed solution:
Benefits to be explored

Benefits
Case Athens is an opportunity to:

- **Increase reuse efficiency** with treatment at the point of use
- **Decrease transaction costs** compared to “centralised” reuse (licensing / footprint / local communities)
- **Increase % of reused water** within the highly constrained urban environment
- **Improve urban quality of life** through improved ecosystem services and;
- **Create new market for SMEs** that can provide this service to, e.g. local municipalities

Upscale opportunities
Deployment in the east coast of Attica for:

- Urban green
- Reduced water treatment cost
- Reused water withdrawal to avoid saltwater intrusion

A win-win scenario → SMEs will sell raw sewage using the existing centralised sewerage network of the water company and water companies will be able to sell untreated sewage, while also minimise the load to their centralised treatment facilities.

Map of Attica, Greece
Identification of potential locations for sewer mining units: A Monte-Carlo approach

Step 1: Spatial data pre-processing
Identification of:
1. Sewage network topology and assets (e.g., manholes, pipes)
2. Hydraulic characteristics (e.g., pipe diameter, slope)
3. Land uses (areas that will benefit from sewer mining – e.g., parks)
   - Locate neighborhood sewer network components (e.g., nodes)

Step 2: Monte-Carlo Simulation
Inputs: Uncertain parameters $X$ (e.g., Variation coefficients of wastewater discharge, $BOD_5$ loading).

Step 3: Results post-processing
- Calculate metrics (e.g., utility functions, risk functions) & perform multi-criteria analysis
- Location(s) selection

Outputs: Quantities of interest (e.g., concentration of $BOD_5$ at each pipe).
Step 1 (a): Spatial data pre-processing

**Import:**
1. Sewage network topology and assets (e.g., manholes, pipes)
2. Hydraulic characteristics (e.g., pipe diameter, slope)
3. Land uses (areas that will benefit from sewer mining – e.g., parks)
4. Other spatial data (e.g., aerial photo)
Step 1 (b): Spatial data pre-processing

**Pre-process:**

**Why?**
Identify land uses (areas that will benefit from sewer mining – e.g., green areas, parks)
- Locate neighborhood sewer network components (e.g., nodes)

**How?**
- Add offset to green areas (e.g., 10m).
- Locate the nodes that are inside each offset area.
- Find the path from each “selected” node → Exit (e.g., WWTP).

This path is unique for each node due to the “collective nature” of sewer networks.

- Offset green areas (10m)
- Locate nested nodes
Step 2: Monte-Carlo Simulation

Why?
- The purpose of Monte-Carlo simulation is to propagate the uncertainties of input parameters to the outputs.
- Also, allow the use of probabilistic objective functions (metrics).

How?
- Identify uncertain parameters $X$
  - Daily and hourly variation coefficients of wastewater discharge
  - $\text{BOD}_5$ loading
- Identify output of interest
  - $\text{BOD}_5$ concentration of each pipe

Alternatives?
Similar, a scenario-based approach (instead or in conjunction with Monte-Carlo) could be employed (e.g., worst, middle, high conditions).

Next step?
- Define probabilistic objective functions (metrics).
- Post-process the results
Step 3: Results post-processing

Metric $Z$ originally proposed by von Bielecki & Schremmer, (1987) and Pomeroy, (1990) for a **single** pipe $i$ in order to quantify the probability of H$_2$S build-up:

$$Z_i = \frac{0.3 \times 1.07^{T-20} \times [BOD_5]_i}{J_i^{0.5} \times Q_i^{1/3}} \times \frac{P_i}{B_i}$$

Where, $i$ is the pipe index, $T$ is the sewage temperature ($^\circ$C), $J$ is the pipe slope, $Q$ is the discharge (m$^3$/s), $P$ is the wetted perimeter of the pipe wall (m) and $B$ the surface width (m) of the stream.

Modified Index $Z$ of Pomeroy for a **chain** of pipes $n$:

$$Z_c = \sum_{i=1}^{n} a_i \times Z_i$$

Where, $a_i = L_i / L_{tot}$, $L_i$ is the length of pipe $i$, and $L_{tot}$ is the total length of pipes of chain $n$.

According to Pomeroy, (1990) if a pipe has $Z_i > 7500$ then there are high chances of H$_2$S formation which could lead to odour and corrosion problems.

**Why?**

The purpose of this step is to use metrics (e.g., utility functions, risk functions) that quantify the output of interest (in our case H$_2$S build-up) for a **chain of pipes** (node $\rightarrow$ exit node).

**How?**

- Employ a modified version of the “quasi-quantitative” indicator $Z$.
- Calculate the $E[Z]$ for given reliability level ($R > 75\%$) for each path for each green area using the $N$ simulation runs.
- For each green area select the path with minimum $E[Z]$.

**Alternatives?**

Similar, other metrics can be used that quantify the exact amount of H$_2$S in terms of mg/l.

**Next step?**

Multi-criteria analysis and selection of potential locations for sewer mining units.
For each green area the optimal node for the SM placement is already found (step 3a).

Fuse the information regarding H$_2$S build-up and green area water demand.

Green area 1 and 2 are suitable for SM placement.

Green area 1 and 2 were selected based on a desired reliability level.

Why?
The purpose of this step is to use multi-criteria analysis in order to identify potential locations for sewer mining unit placement.

How?
- We have already calculated E[Z] for each node thus we can combine this information with:
  - Information regarding the water demand in the areas of interest (green areas)
    - We select as rough indicator for water demand the area (m$^2$) of the park.

Alternatives?
Similar, the actual water demand of each area can be calculated if relevant information is available.

Also other metrics can be employed in

Next step?
- Selection of potential locations for sewer mining units.
- Further analysis and modelling of sewer mining unit for the selected locations.
Study area: Kalyvia Thorikou, Greece
Study area results: Kalyvia Thorikou

Optimum path of green area (ID 3)
The GUI of Sewer Mining Placement Tool

Step 1: Load spatial data and pre-processing

Step 2: Setup Monte-Carlo Simulation

Step 3: Results post-processing
REFERENCES

Thank you!

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