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Early Hydrochemical Evolution of Groundwater Under Landfill Leachate Influence: Case of the Tangier Municipal Site

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INTRODUCTION & AIM

Rapid urban growth in Tangier has necessitated the establishment of a new municipal landfill, raising concerns about potential leachate impacts on the surrounding groundwater system. This study investigates short-term variations in groundwater quality within a 2 km radius of the landfill between September 2023 and February 2025. An integrated approach combining hydrochemical diagrams (Piper, Stiff, Gibbs, and Wilcox), water quality indices (IBE, WQI), and statistical analyses (Pearson correlation) was employed to characterize hydrochemical evolution, trace leachate influence, and identify the most deteriorated sampling sites.

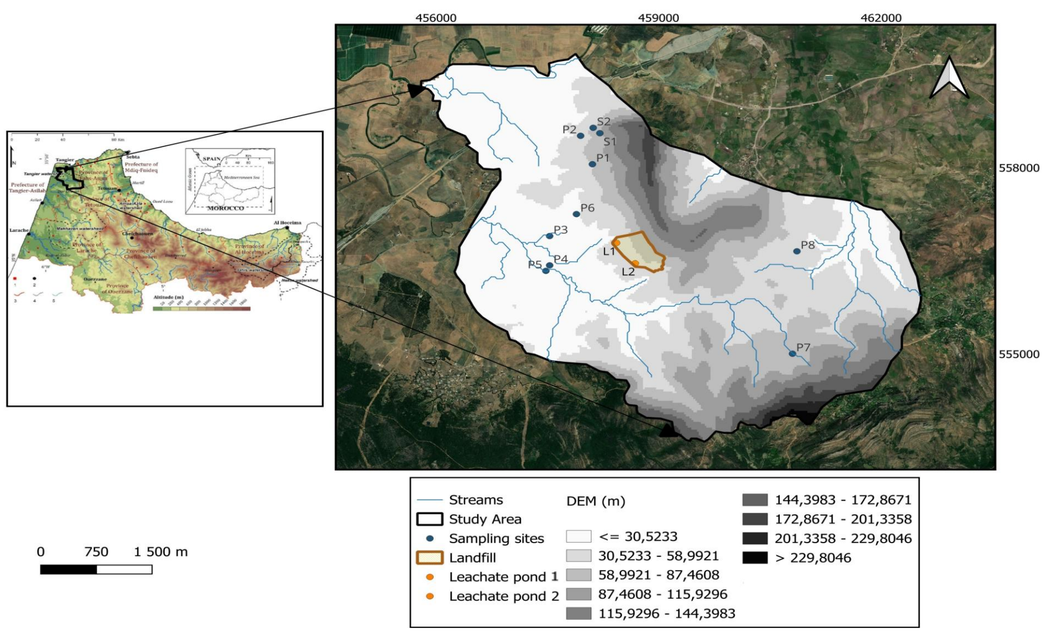


Fig 1. Study area and topographic context around Tangier Landfill

METHOD

Pipeline

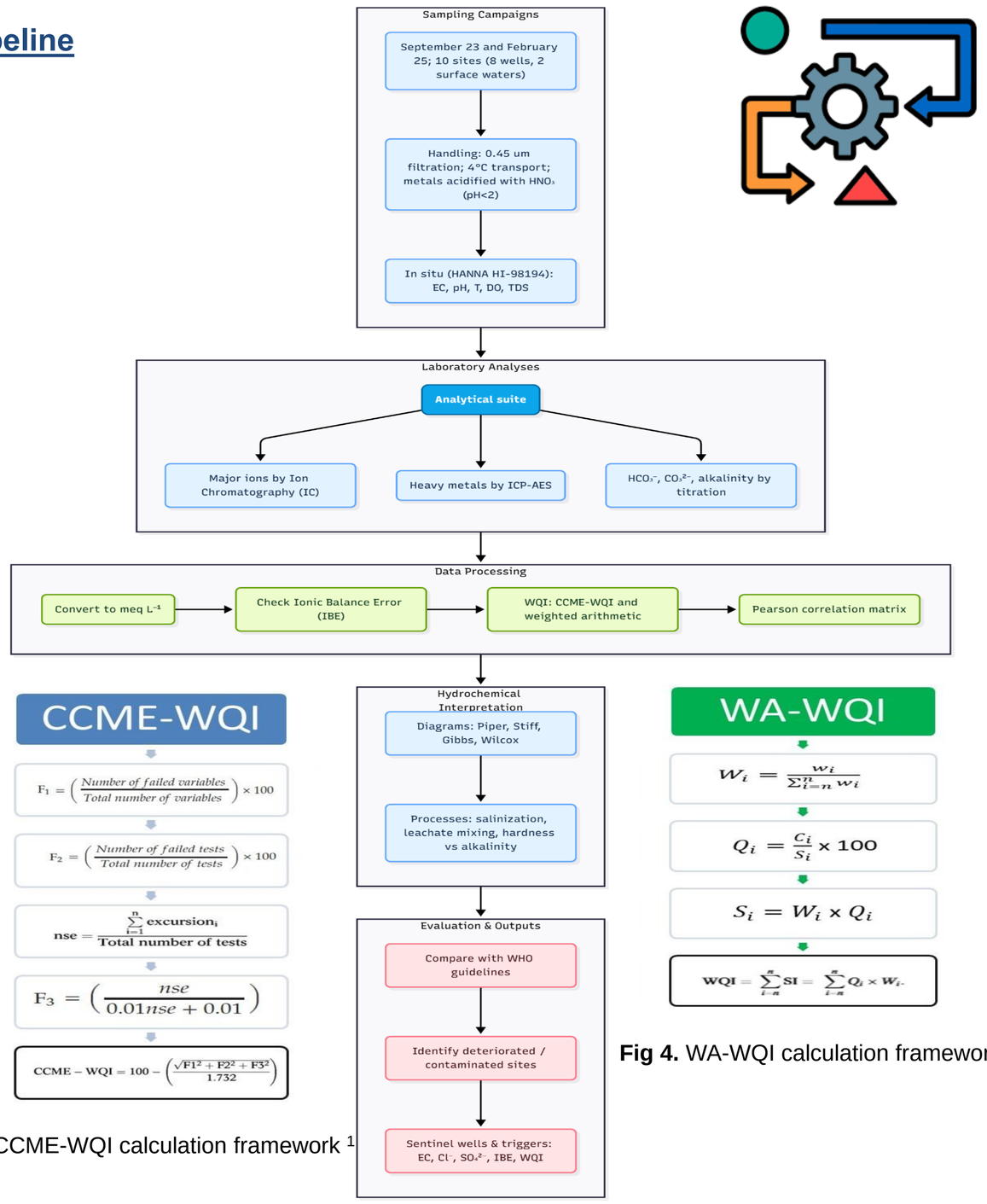
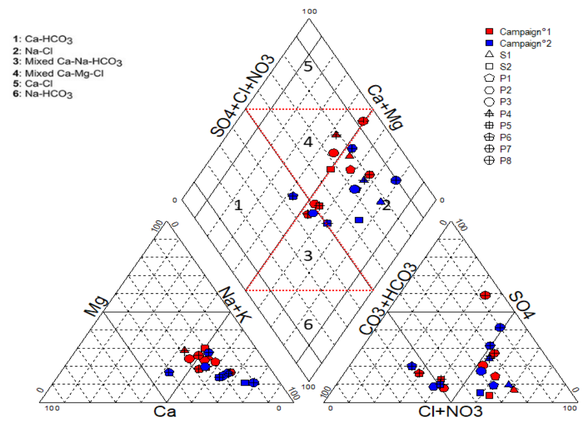


Fig 3. CCME-WQI calculation framework [1]

Fig 4. WA-WQI calculation framework

Fig 2. Methodological framework for groundwater quality assessment around Tangier Landfill

RESULTS & DISCUSSION



- Groundwater types evolve from Ca–HCO_3 (recharge waters) to mixed Ca–Na–Cl–SO_4 and Na–Cl facies along the flow path.
- Upgradient wells (S1, S2, P1, P2) retain freshwater Ca–HCO_3 signatures.
- Downgradient sites (P4, P5, P8) show Na–Cl dominance, revealing salinization and leachate influence [2] between 2023 and 2025.

Fig 5. Hydrochemical facies evolution between S-23 and F-25 campaigns (Piper Diagram)

- Campaign 1 shows most samples within the Excellent to Good and Permissible zones, indicating moderately mineralized waters suitable for irrigation.
- By Campaign 2, several wells (P1 and P3) shift toward the Doubtful to Unsuitable categories, linked to higher salinity (EC > 2,000 µS/cm) and elevated sodium percentages (>70%).
- Upgradient sites (S1–S2) remain in the Excellent–Permissible range, reflecting fresh recharge unaffected by landfill leachate.
- Downgradient wells (P3, P4 and P8) exhibit a sharp deterioration, confirming salinization and sodium hazard due to leachate infiltration and thus, require specific methods for risk reduction [3].
- The overall pattern indicates a progressive loss of irrigation suitability along the flow path, consistent with Piper and Stiff trends.

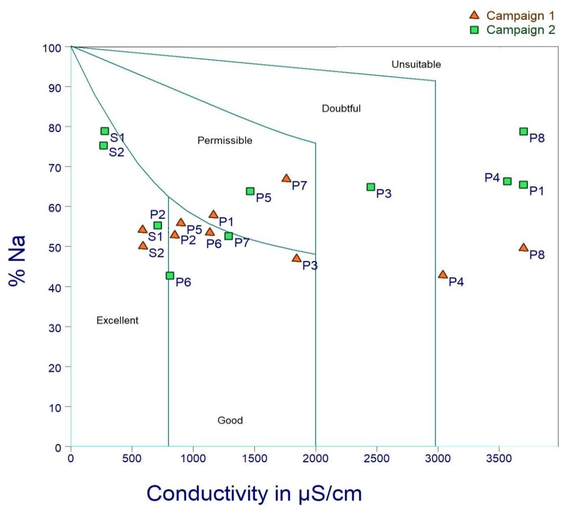


Fig 6. Irrigation Water Quality (Wilcox Diagram)

Groundwater quality evolution

Northern recharge zone (S1–S2–P1): Excellent–Good WQI → stable, limited anthropogenic impact ☑

Downgradient wells (P3–P5–P8): Persistent Poor–Marginal WQI → leachate percolation & salinity accumulation ⚠

Hotspot (P8): Stable contamination zone (high Cl^- & SO_4^{2-})

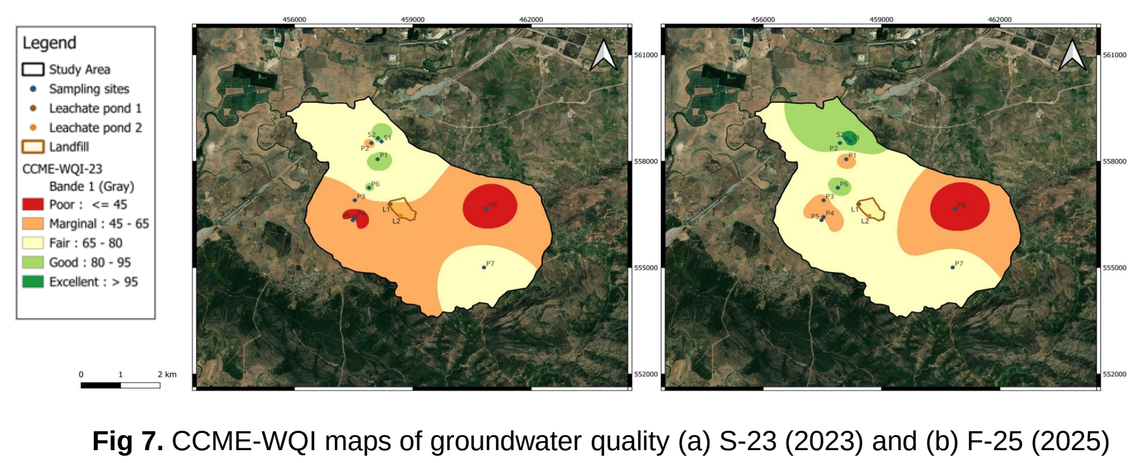


Fig 7. CCME-WQI maps of groundwater quality (a) S-23 (2023) and (b) F-25 (2025)

CONCLUSION

Hydrochemical and WQI results reveal a transition from fresh Ca–HCO_3 recharge waters to Na–Cl contaminated facies influenced by leachate migration along the downgradient flow path. Despite temporal improvement, persistent low WQI values at downgradient sites and near P8 indicate a stable contamination hotspot, underscoring the need for continued monitoring and mitigation to protect the aquifer.

REFERENCES

1. Canadian Council of Ministers of the Environment (CCME) (2001). *Canadian Water Quality Guidelines for the Protection of Aquatic Life – CCME Water Quality Index 1.0 Technical Report*, p. 13.
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