# CALL FOR A THESIS IN HYDRAULIC ENGINEERING (ENIT)

# (2025-2028)

## Integration of SAR Remote Sensing, Geophysics and Machine Learning Modeling for Soil Moisture and Salinity Assessment in Semi-arid Context

## Host institutions

- **ENIT:** National Engineering School of Tunis, LR99ES19 Laboratory of Modelling in Hydraulics and Environment (LMHE)
- **INRGREF**: National Institute for Research in Rural Engineering, Water and Forests, LR20INRGREF02 Laboratory of Valorization of Non-Conventional Waters and Rural Engineering

## Supervisors


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### GENERAL CONTEXT AND THESIS RATIONALE

Arid and semi-arid regions face critical challenges related to water scarcity and soil fertility degradation. In irrigated agricultural, soil salinization is one of the most critical forms of land degradation, particularly in arid and semi-arid regions where water resources are limited, evaporation exceeds precipitation and irrigation practices are often poorly managed using brackish water. In Tunisia, about 50% of the total irrigated areas are considered highly sensitive to salinization (DGACTA, 2007). A low soil moisture (θ) and/or excessive salinity in the root zone could lead to crop water and/or salt stress, which will affect negatively soil fertility, crop production and farmer's income. Monitoring soil salinity and moisture is essential for sustainable soil and water management in fragile ecosystems so that proper and timely decisions regarding agricultural practices can be made. Standard methods for soil salinity (electrical conductivity of soil saturation paste extract, ECe) and water content (gravimetric) measurements and assessment rely heavily on labor-intensive soil sampling and laboratory analysis, which limits their spatial and temporal applicability. At the same time, geophysical techniques such as electromagnetic induction EMI (EM38, CMD Mini-Explorer, etc.) and capacitive sensors (5TE, WET, Terros12, etc.) offer rapid, non-destructive in-situ real time measurements of soil apparent electrical conductivity (ECa) and/or soil permittivity to estimate soil moisture and salinity (Bouksila et al., 2012; Zemni et al, 2019; Farzamian et al., 2023; Mensah et al., 2023,). On the other hand, the use of optical remote sensing had been widely employed to find correlations between soil salinity and vegetation indices in arid and semi-arid regions. For radar remote sensing, there is a greater potential for soil salinity detection compared to optical images as the radar backscattering is sensitive to dielectric constant highly affected by salinity (Lasne et al., 2008; Engman, 1991; Hoa et al., 2019). However, despite the growing interest in remote sensing applications for both soil water content and salinity mapping, very few scientific studies have explored the integration of radar imagery with ground-based geophysics methods (EMI, dielectric sensors) for accurate soil water content and salinity estimation and mapping (Sahbeni et al., 2023). The potential of using radar data, sensitive to the soil's dielectric properties, as an indirect indicator of soil salinity remains largely under-investigated, particularly in operational contexts. To date, most studies have either focused on optical remote sensing or limited radar applications to soil moisture monitoring, without systematically validating radar-derived salinity indicators using high-resolution in-situ EMI measurements such as those obtained from CMD Mini-Explorer surveys or capacitive sensors. This gap highlights the need for robust, cross-validated methodologies that combine the spatial coverage of radar data with the depth-resolved accuracy of EMI and /or capacitive sensors measurements for more reliable and scalable salinity assessment. As for the radar-based models of soil salinity, it has been shown that direct correlations of the radar signal to the soil salinity remains low suggesting the combination of various factors derived from radar signal with salinity measurements to derive more accurate models, essentially based on machine learning algorithms such as Multilayer Perceptron Neural Networks (MLP-NN), Support Vector Regression (SVR), or Random Forests (RF) (Hoa et al., 2019; Jiang et al., 2018, Chen et al., 2021). Thus, and considering the state of the art in this field of research, this thesis aims to bridge the gap between satellite-based observations and geophysics ground measurements to develop a validated scalable method for soil moisture and salinity measurements and mapping using the synergy between radar imagery and geophysics data.

## METHODOLOGY

### 1- Literature review

Conduct a comprehensive literature review to explore recent advances in:

- Soil salinity and moisture impact on soil fertility and crop production
- SAR images potential in soil moisture and salinity assessment
- Geophysics methods (EMI, TDR, FDR, TDT, etc.) and models calibration for soil moisture and salinity measurements and monitoring
- Water and soil salinity inversion models based on machine learning methods

This review will provide a solid foundation for developing the proposed approach.

### 2- Ground data collection and preprocessing

- Collect Landuse field observation in the study region
- Collect and analyse spatial EMI_ECa data (using the CMD Mini-Explorer in selected field sites (on Sentinel Satellite Overpass Dates) in both rainfall and irrigated plots.
- Analyse the real time measurements of soil data from capacitive sensors in the irrigated plot (in case no significant correlation could be found between EMI_ECa-ECe_or EMI_ECa-θ)

- Soil sample collection, field measurements and laboratory soil analysis (θ, dry soil bulk density (Bd), ECe, soil particle size, pH, organic matter, etc.)

**3- Remote sensing data acquisition and pretreatment**

- Update land use of the study site based on Sentinel-1 and Sentinel-2 image classification algorithms
- Preprocessing and radiometric calibration of SAR Sentinel-1
- Processing of SAR Sentinel-1 images to derive backscatter coefficients with multiple polarizations and texture feature extraction

**4- Mapping of soil properties based on geophysical methods**

- Soil moisture and salinity Geodatabase of the study sites based on remote sensing, geophysics and soil properties.
- Calibrate EMI_ECa data with ECe measurements and or soil water content (θ) using linear and/or nonlinear models
- Generating soil salinity and moisture maps

**5- SAR inversion models and machine learning for soil properties assessment**

- Analysis of relations between radar backscatter coefficients, in-situ soil capacitive probe data (permittivity Ka, ECa) and laboratory-measured ECe and/or θ data
- Configuration and training of soil properties machine learning based models
- Performance assessment of machine learning based models used for soil properties mapping
- Soil salinity and moisture mapping validation by remote sensing and geophysics integration

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## REQUESTED QALIFICATIONS

The qualifications required to successfully carry out this research topic are:

- A solid understanding of the physical principles of remote sensing (optical and radar)
- A sound knowledge of soil physics and related processes
- Experience in mapping soil properties (soil salinity and moisture content)
- Proficiency with Sentinel image processing tools (e.g., SNAP Toolbox) and QGIS
- Familiarity with a programming language such as MATLAB for machine learning applications

- Additional programming skills (e.g. R, Python) for collecting and preprocessing in situ data
- Strong writing and oral presentation skills

**CV and Motivation letter to send to:**

- hedia.chakroun@enit.utm.tn

**Schedule**

- Application deadline: **June 30th, 2025**
- Candidate interviews: **7-14th July 2025**
- Recruitment will be validated by the ENIT Doctoral school where the applicant is enrolled.