VALIDATION ROADMAP

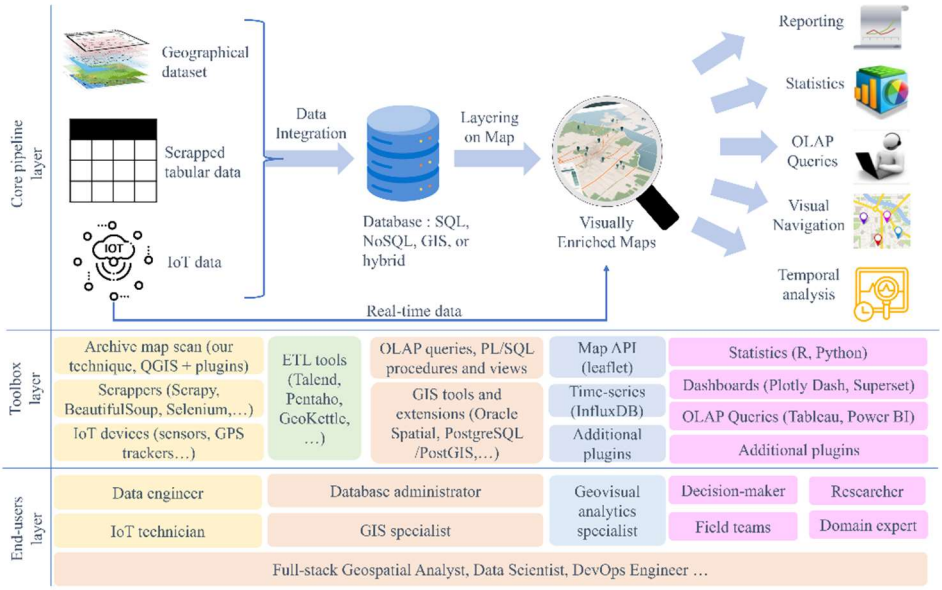


Fig.1. Framework of meta-visualization on maps integrating multimedia and open data through a decision support system.

I. General validation roadmap:

We define a general roadmap to validate the study for any project through the proposed framework, as follows:

1 Defining users' groups
2 Making focus groups with discussions
3 Surveys Q/A
4 Optionally, IRB approval, depending on case study.

We delve into each step in the following section, illustrating the validation process on our specific case study on precision agriculture.

II. Validating our proposal through the case study:

Step 1: Defining users' groups

For our specific case study, we involved different users from various working profiles. We categorized these users into three user groups:

- Data specialists: more than 10 members of ISI team, from LSI laboratory (USTHB), with Data engineers (3), Data scientists (3), Database Administration experts (2), GIS experts (2), and Full stack geospatial analysts and GIS specialists (3)
- Agronomists: 4 members of GDRN team, University of Naama, Algeria.
- Environmental scientists: more than 5 members/experts of Electronic Instrumentation and Metrology from INSEM Team - USTHB and GDRN Team University of Naama (See Section III).

Step 2: Making focus groups and discussions

Before involving discussions, we have started validation process using our metrics. For the data acquisition and map scan properties extraction, we have used our metrics explained in the paper (Section 3.1 in the article).

For soil sampling protocol, we have used international standards adopted in USA, Canada, Europe, and Algeria. A synthesized protocol has been set to fit the specific requirement of the precision agriculture study (appendix 1).

For climatic data and crop properties, many articles have been used and scrapped to compare and fill missing data about climate and crop properties (referenced in our article). The data has also been discussed in focus groups and surveys.

Focus groups have been made in three main events: two seminaries of LSI Lab (Laboratoire des Systems d'Information – Information Systems Lab) on June 2024 / September 2024, involving more than 10 participants (data scientists, GIS experts, etc.), and one brainstorming session in workshops of the IoT school event at USTHB (Dec 2024, link: https://www.linkedin.com/feed/update/urn:li:activity:7270497295882764288/) involving 8 participants in our specific precision agriculture session (with professors, professionals of agro-industrial sectors, and researchers).

During these three events, all the steps of the framework and the experimental study have been discussed and validated, mainly:

- Web-scrapping process and obtained data (climate, crops, regions…)
- Georeferencing process
- Data warehouse schema
- Recommendation OLAP query
- Users' profiles and Interfaces
- Spatial and Temporal analysis

These aspects have been approved and many suggestions have been considered. The recommendation depends both on (1) the data quality and (2) the OLAP query.

- We have started by validating our data warehouse and OLAP query by our experts in ISI team of LSI Lab. The members are experts in data warehousing, GIS, data engineering etc. More Query validation details are given in Github repository Stage 3.
- Then, we needed to check the obtained data with agronomists. To do so, we have launched a survey with Q/A about our system. The details of the survey are given in the next subsection.

Step 3: Survey Q/A

After exposing and explaining the framework and its implemented functionalities, a discussion was made followed by a survey of 12 questions has been given to a group of five (5) agronomists and environmental scientists. The participants are members of GDRN team of University of Nâama and USTHB. Four categories of questions were given in French and English languages (Appendix 2):

- Soil sampling,
- Crop recommendation,
- UI/UX for different users' profiles.
- Meta-visualization concept utility.

	Utility	Data Relevance	Results
Soil Sampling	High	Yes	High accuracy
Crop recommendation	7.80/10	Suggested additional properties.	Required source data improvement
UI/UX	Good	Yes	Intuitive for medium to high experienced users from agronomic sector.
Meta-Visualization Concept	High	-	Global Appreciation: Helps efficiently showing hidden insights for spatiotemporal analytics.

The answers (see Appendix 2) where majorly positive about the relevance of the soil sampling system, the accuracy of the recommendation, performance of spatial and temporal analysis, and the general framework. Suggestions were made to improve the source datasets for more accuracy on the recommendations. Other suggestions are considered for future work.

III. Users Affiliations

- ISI (Ingénierie des Systèmes d'Information – Information Systems Engineering) Team, part of LSI (Laboratoire des Systèmes Informatiques – Computer Science Systems Laboratory), at USTHB.
- GDRN Team : Gestion Durable des Ressources Naturelles dans les Zones Arides et Semi-Arides, Naama University.
- Members of the INSEM team (INStrumentation Électronique et Métrologie – Electronic Instrumentation and Metrology) from USTHB, which focuses on developing sensors and measurement instruments for industry, biomedical applications, the environment, construction, and agriculture. Indeed, the team has an experimental orientation, specializing on one hand in the development of analog and digital electronic circuits, and on the other hand in the design, modeling, fabrication, and calibration of sensors primarily dedicated to medical exploration and therapy, as well as industrial and environmental applications.

APPENDIX 1: SOIL SAMPLING

1. International Standards:

ISO Standards (International Organization for Standardization)

- ISO 10381-1:2002 – Guidance on the design of sampling programs.
- ISO 10381-2:2002 – Guidance on sampling techniques for contamination studies.
- ISO 10381-3:2001 – Guidance on safety in soil sampling.
- ISO 10381-4:2003 – Procedures for site investigations (human exposure).
- ISO 10381-5:2005 – Guidance on sampling for soil assessment in urban areas.
- ISO 18400-101:2017 – General requirements for sampling and pretreatment.

ASTM Standards (American Society for Testing and Materials)

- ASTM D1587-00 – Thin-walled tube sampling of soils for geotechnical analysis.
- ASTM D1452-09 – Soil investigation and sampling by auger borings.
- ASTM D4700-15 – Soil sampling for environmental investigations.
- ASTM D6282/D6282M-14 – Direct push soil sampling for environmental applications.

US EPA Standards (U.S. Environmental Protection Agency)

- EPA SW-846 (Test Methods for Evaluating Solid Waste) – Includes soil sampling for contamination.
- EPA 530-D-02-002 (RCRA Waste Sampling Guidance) – Regulatory compliance sampling.
- EPA 600/R-12/003 (Environmental Investigations Standard Operating Procedures) – Field sampling guidelines.

2. USA Soil Sampling Standards

Reference of soil sampling guide in Michigan, USA : https://www.canr.msu.edu/resources/a-field-guide-to-soil-sampling

3. Canadian Soil Sampling Standards

Canada follows federal and provincial guidelines, often aligned with international standards but tailored to local conditions (e.g., permafrost, mining impacts, agriculture).

- Canadian Environmental Quality Guidelines (CEQG) – Includes soil sampling protocols for contaminants.
- Federal Contaminated Sites Action Plan (FCSAP) – Guidance on soil sampling for risk assessment.
- Canadian General Standards Board (CGSB): CAN/CGSB-157.1-M91 – Sampling soils for volatile organic compounds (VOCs).
- Ontario Regulation 153/04 (Records of Site Condition, RSC) – Rules for soil sampling in property transactions.
- Alberta Tier 1 & 2 Soil and Groundwater Remediation Guidelines – Sampling methods for oil and gas sites.
- British Columbia Contaminated Sites Regulation (CSR) – Soil sampling for industrial sites.

4. European Soil Sampling Standards

The EU has harmonized soil sampling methods under the European Committee for Standardization (CEN) and national regulations.

- EN ISO 10381 Series (Adopted from ISO but with EU-specific guidance)
    - EN ISO 10381-1 – Planning soil sampling programs.
    - EN ISO 10381-5 – Urban soil sampling.
- EU Soil Monitoring Law (Proposed 2023) – Aims to standardize soil health sampling across member states.
- European Environment Agency (EEA) : LUCAS Soil Survey – Pan-European topsoil sampling program (0–20 cm depth).

5. Algerian Soil Sampling Standards

In Algeria, soil sampling standards are influenced by a combination of national regulations, international norms (ISO, ASTM), and sector-specific guidelines (e.g., agriculture, environmental protection, and oil/gas industries). Below are the key standards and frameworks used in Algeria:

- Agricultural Soil Testing Manuals – Guidelines for soil fertility and salinity sampling (0–30 cm depth).
- Institut National de la Recherche Agronomique d'Algérie (INRAA) – Provides soil sampling methods for irrigation and crop management.
- Hydrocarbons & Industrial Sector (SONATRACH/ANRH): Oil & Gas Industry Standards – SONATRACH (Algeria's state oil company) follows ISO 10381 and ASTM D4700 for soil sampling near drilling sites. ANRH sets guidelines for soil sampling in water catchment areas.

5.1 Algerian Standards Institution (IANOR)

The Institut Algérien de Normalisation (IANOR) adopts and adapts international standards, including:

- NA 17025 (ISO/IEC 17025) – Covers lab competence in soil analysis.
- NA ISO 10381 series – Soil quality sampling (same as ISO but localized).
- NA EN 16179 (Sludge & Soil Sampling) – For waste-amended soils.

A. Agricultural Sampling

- Grid/Zoning Method – Common in large farms (e.g., cereal crops in the High Plateaus).
- Depth: 0–30 cm (plough layer).
- Parameters Tested: pH, salinity (EC), organic matter, NPK.

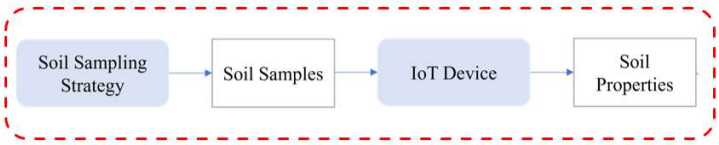
B. Environmental & Contamination Studies

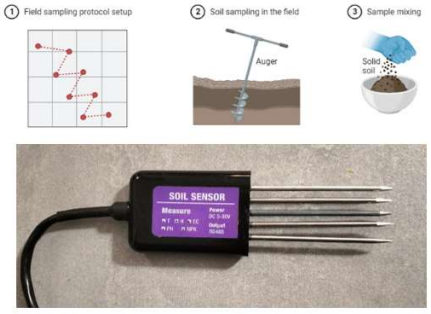
- Hotspot Sampling – Near industrial areas (e.g., Annaba's steel plant, Hassi Messaoud oil fields).
- Composite Sampling – For baseline studies (e.g., Saharan soil monitoring).
- Standards Followed: ISO 10381-2 (contamination), ASTM D1587 (geotechnical).

Here is a brief summary of the synthetized soil sampling protocols for crop planning:

Aspect	USA (USDA-NRCS/EPA)	Canada (AAFC)	EU (CAP/LUCAS)	Algeria (INRAA/IANOR)
Governing Body	USDA-NRCS, EPA, State Ag. Labs	AAFC, Provincial Labs	EC/JRC, National Agencies	INRAA, IANOR, Ministry of Ag.
Sampling Depth	**0–15 cm** (routine), **0–30 cm** (subsoil)	0–15 cm (tillage), 0–30 cm (no-till)	0–20 cm (LUCAS), 0–30 cm (national)	0–30 cm (standard), 0–50 cm (orchards)
Sampling Method	**Grid/Zone/Composite** (precision ag.)	Grid/Zone/Composite	LUCAS Survey, Composite	Random/Grid/Zone
Key Tests	pH, OM, N-P-K, CEC, micronutrients, **heavy metals (EPA 6200)**	N-P-K, pH, OM, micronutrients	pH, OC, heavy metals, N-P-K	pH, salinity, OM, N-P-K, $CaCO_3$
Frequency	**1–3 years** (varies by state/crop)	2–4 years	3–5 years (CAP-linked)	3–5 years (irregular)
Regulatory Link	**NRCS Conservation Programs**, EPA Superfund (contaminated sites)	CFI Guidelines, OMAFRA	CAP Subsidies, EU Soil Strategy	INRAA Manuals, IANOR NA ISO

METHODOLOGY





Proposed sampling protocol:

- Timing: Ideally in the fall (autumn).
- Density: 1 to 4 per acre.
- Subsamples: A zigzag pattern to collect approximately 15 subsamples per sample, with a depth of 25-30 cm.
- Tool: Blades, tubes or augers. It has to be uncontaminated and provide similar sampling units.
- Preparation: Collected soil subsamples are thoroughly mixed to achieve a homogeneous mixture that represents a soil sample.

Usage: Soil sensor needles are inserted into the sample to measure: NPK levels, pH, electrical conductivity (EC), temperature, and humidity.

APPENDIX 2: SURVEY

English version:

Soil sampling

Q1- Do you agree that field sampling is better than regional properties for crop agriculture?

…….(Yes/No/Other)

Q2- Do you think we need a soil sampling strategy to know field properties?

…….(Yes/No/Other)

Q3- Do you agree with this soil sampling strategy?

…….(Yes/No/Other)

Crop recommendation

Q4- Do you think the selected properties and dimensions are relevant to the crop agriculture?

…….(Yes/No/Other)
…….(Optional : Suggestions)

Q5- Do you agree with the predicted yields (Q/ha) from the data of agriculture ministry?

…….(Yes/No/Other)

Q6- What do you think about the recommendations for each field?

…….(from 1 to 10/10)

Q7- Are the observed data relevant?

…….(Yes/No/Other)

Q8- Do you think the decision system is helpful for crop planning?

…….(Yes/No/Other)

Visual Analysis

Q9- Do you think the visualization system is helpful for spatial analysis?

…….(Yes/No/Other)

Q10- Do you think the visualization system is helpful for temporal analysis?

…….(Yes/No/Other)

Q11- Is the Map interface intuitive for agronomists?

…….(Yes/No/Other)

Q12- Is the Map interface intuitive for environmental scientists?

…….(Yes/No/Other)

Version Française:

Échantillonnage des sols

Q1- Pensez-vous que l'échantillonnage local par champs est plus pertinent que les propriétés régionales pour les cultures ?
…….(Oui/Non/Autre)

Q2- Selon vous, une stratégie d'échantillonnage des sols est-elle nécessaire pour déterminer les propriétés locales ?
…….(Oui/Non/Autre)

Q3- Approuvez-vous cette stratégie d'échantillonnage des sols ?
…….(Oui/Non/Autre)

Recommandations

Q4- Les propriétés et dimensions sélectionnées vous semblent-elles pertinentes pour l'agriculture ?
…….(Oui/Non/Autre)
…….(Optionnel : Suggestions)

Q5- Les rendements prévus (Q/ha) du ministère de l'Agriculture vous paraissent-ils fiables ?
…….(Oui/Non/Autre)

Q6- Que pensez-vous des recommandations pour chaque parcelle ?
…….(de 1 à 10/10)

Q7- Les données observées sont-elles pertinentes ?
…….(Oui/Non/Autre)

Q8- Ce système d'aide à la décision est-il utile pour la planification agricole ?
…….(Oui/Non/Autre)

Analyse visuelle

Q9- Le système de visualisation facilite-t-il l'analyse spatiale ?
…….(Oui/Non/Autre)

Q10- Le système de visualisation facilite-t-il l'analyse temporelle ?
…….(Oui/Non/Autre)

Q11- L'interface cartographique est-elle intuitive pour les agronomes ?
…….(Oui/Non/Autre)

Q12- L'interface cartographique est-elle intuitive pour les scientifiques environnementaux ?
…….(Oui/Non/Autre)

SURVEY RESULTS :

	R1	R2	R3	R4	R5
Q1	Yes	Yes	Yes	Yes	Yes, but requires stakeholders' involvement
Q2	Yes	Yes	Yes	Yes	Yes
Q3	Yes	Yes	Yes	Yes	Yes, can be optimized for large scale.
Q4	Partially Suggestion 1*	Yes Suggestion 3*	Yes	Yes Suggestion5*	Yes
Q5	Yes	Other Suggestion 4*	Do not know	Yes, but need more data.	Yes
Q6	9/10	7/10	8/10	8/10	7/10
Q7	Yes	Yes	Yes	Yes	Yes
Q8	Yes, Suggestion 2*	Yes	Yes	Yes Suggestion 6*	Yes
Q9	Yes	Yes	Yes	Yes	Yes
Q10	Yes	Yes	Yes	Yes	Yes
Q11	Yes	Yes Medium expertise	Depends on case study.	Yes Medium expertise	Yes Medium-high expertise
Q12	Yes	Yes Medium expertise	Depends on case study	Yes Medium expertise	Yes Medium-high expertise

*Suggestion 1: In particular cases (e.g., hyper-arid regions, hydric stress, humid and hot agricultural zones during the summer), climatic parameters, primarily temperature and humidity, must be measured daily. Cereal crops may be contaminated by molds, with humidity and temperature being among the main variables influencing their growth. Thus, it is suggested to monitor the climate factors daily, considering the specific type of crop involved and its biological cycle.

*Suggestion 2: it may be improved for specific cases (e.g., cryptogamic disease, sensitive crop, etc.)

*Suggestion 3: Add indicators SAR & ECE.

*Suggestion 4: Depends on the process of data acquisition adopted by the ministry itself. Needs to be discussed.

*Suggestion 5: Consider crop rotations.

*Suggestion 6: Consider real-time weather forecasting and ML prediction for plant disease etc.