TNE-GPS^{Education} Advanced Skills for Green Sustainable Environment: An Earth Observation Hub pathway (at ENSMR, Morocco)

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Abstract

The paper presents the objectives and initial outcomes of the TNE-GPSEducation project, "Green & Pink for Sustainable Education", funded by the Italian PNRR and coordinated by the University of Foggia, involving ten Italian universities including Politecnico di Milano (POLIMI). The project promotes multidisciplinary international cooperation with partners across Africa, Asia, the Middle East, and South America. Within this framework, POLIMI contributes through the Advanced Skills programme, aimed at developing a transdisciplinary capacity-building model integrating sustainability, health, and gender equity. This model is implemented through modular Lifelong Learning Courses (LLLCs) and the establishment of an EO Hub designed to support long-term institutional collaboration and knowledge transfer. Five LLLCs have been developed, including two fully dedicated to EO. These follow a structured workflow that progresses from global EO data analysis—based on rGEE/GEE time series—to site-specific applications within the LULUCF framework, with a focus on land degradation processes in Mediterranean regions. The other three LLLCs on XR, ecosystem services, decarbonization, and Nature-Based Solutions strengthened the transdisciplinary approach, linking environmental monitoring with mitigation and adaptation strategies. Preliminary results demonstrate the effectiveness of this model in fostering shared methodologies and identifying thematic pathways for future collaboration. Among these, soil erosion emerges as a priority domain, offering a concrete entry point for joint research activities. Future developments aim to scale up the EO Hub across additional African countries, consolidating the role of ENSMR and UIR as regional nodes for EO-based capacity building and sustainable development.

1. Introduction – The TNE-GPS^{Education} Framework

The "Green & Pink for Sustainable Education" TNE-GPS^{Education} project is a multidisciplinary project created to strengthen international cooperation between 10 Italian Universities and foreign universities, promoting training and education on the topic of sustainability, addressed from different perspectives and lines of research. To reach the project's aims, different expertise have been identified: 1. modelling, natural resources' scarcity, pollution and earth monitoring, cultural landscapes and cultural heritage; 2. social tools to decrease land degradation and rural marginal areas; 3. technological innovation and of innovative teaching; 4. medicine and social innovation with a keen emphasis on gender equality and digital sustainable tools. The project merges several countries (among which Brazil, Argentina, Cambodia, Thailand, Palestine, Georgia, Morocco, China, Vietnam). These countries play leading roles in cultural, social, and academic spheres that make them central actors in the region's dynamics and developments. They represent the goal of the international educative initiatives to foster joint didactic, research, and cultural activities, maintaining high academic standards, sharing innovations, and embracing academic trends. Lecturers, staff, and students from the universities will be able to strengthen their existing skills while also acquiring new, transferable competencies that can be replicated within their respective institutions. This will create a solid relationship of exchange between all the partners that will endure well beyond the deadlines of the mobility project.

Italy's policies actively support the growth of African countries, aiming to amplify their voice and address complex global challenges in alignment with UN, EU, and CRUI–CUCS cooperation strategies: within this project POLIMI signed MoU agreements with ENSMR (Ecole Nationale Superieure des Mines de Rabat) and UIR (Université Internationale de Rabat). The WP4 "Advanced Skills (AS) courses – Positioning skills for health and green digital paths" represent the core of the transdisciplinary project, integrating socioeconomics, Earth Observation (EO) technologies, Nature-Based Solutions (NBS) design, and health.

Five (n. 5) Long Life Learning Courses addressing the Advanced Skill project program (AS-LLLC) have been modularized to create the EO Hub at ENSMR, which will act as a networking node with the other Universities in Morocco and African Countries, invited to follow the AS-LLLC at Politecnico di Milano, precisely: (A.) "Remote Sensing Techniques and Methods For Earth Observation (LLLC-EO); (B.) "SCAN - to - BIM – to - XR Process: from 3D Survey and Modeling to the Development of Immersive VR And WebXR for Sustainable Built Environment (LLLC BIM-XR)"; (C.) "Nature Based Solutions. Principles of Environmental Design and Digital Tools for Climate Change Adaptation (LLLC-Nbs)"; (D.) "From Land Degradation to Regeneration: EO monitoring within LULUCF Frameworks (LLLC-EO LULUCF)"; (E.) "Decarbon and NBS (CO_2 computation: from vegetation, CO_2 equivalent from water infiltration, retention, energy). Methods and tools (LLLC-Decarbon)". Against this background, the POLIMI contribution is structured as a longer-term capacity-building strategy centred on the creation of an Earth Observation Hub. In this perspective, the EO Hub is conceived as an operational and institutional platform for transferring methodologies, supporting thesis and doctoral supervision, and fostering future joint research initiatives. The following section introduces the architecture of the EO Hub and clarifies how its activities are organized.

2. Conceptual Framework of the EO Hub: From Global EO Knowledge to Site-Specific Applications

Within the GPS^{Education} framework, the EO Hub was co-designed with ENSMR to connect advanced training, research capacity building among academic staff, and PhD research in Earth Observation domains. Its role is to progressively guide future generations from the interpretation of global and regional EO knowledge frameworks toward the implementation of site-specific decision-making applications, with particular attention to land degradation, ecosystem regeneration, and climate adaptation challenges in North African contexts.

(a) A review of the knowledge base and the systematic use of global Earth Observation programmes, which have contributed to major advancements and to the development of services (such as the Copernicus Services) for mapping complex phenomena, including desertification processes driven by climate change and anthropic pressures (Cherlet et al., 2018). Today ≈ 30 % of the Earth's land is degraded, affecting ~ 1.5 billion people (IPCC, 2022). During the past 50 years, 20–25 % of arable land has been lost (FAO, 2021; IPCC, 2019). These programmes have documented that Mediterranean inner regions are undergoing increasing land degradation, population decline, and a progressive weakening of socio-ecological systems. Trend indicators such as Land Productivity Dynamics (LPD) derived from MODIS time series (2013–2022) have contributed to delineate the trajectories of land degradation through Earth Observation data (Li et al., 2025). Within this context, Morocco emerges as a particularly affected area, characterised by advancing desertification, soil impoverishment, and socio-economic isolation. These processes have intensified over recent decades under the influence of altered rainfall regimes and recurrent drought events, as evidenced by climate services, (i.e., Copernicus C3S seasonal rainfall forecast service).

(b) Data requirements and indicators in the LULUCF (Land Use, Land Use Change and Forestry) framework. Several Horizon Europe projects (e.g., LANDSHIFT, https://landshift.eu/) are progressively shifting capacity building towards scenario simulation to support EO-based decision-making, strengthen adaptation and sustainable actions, and enhance the FAO Land Cover Classification System (LCCS) through Living Earth systems approaches (Giuliani, 2024). This level requires robust cross-linkages between Earth Observation monitoring (e.g., vegetation trend analysis, pollution and forecast dynamics, carbon dioxide removal and biomass dynamics) orienting the adoption of policies within regional Living Spaces (Varvaris et al., 2025). Similarly, under the AFROGROW and NEMESIS Horizon Europe projects, cross-regional areas are being defined, including the Algeria–Tunisia region. Trend changes are documented using satellite image time series (e.g., Landsat, Copernicus Sentinel), enabling multi-decadal analyses (Landsat 5 TM; Landsat 8/9 OLI/OLI-2) and GIS-based land degradation indices that highlight the dynamic nature of degradation processes and support scalable solutions for climate adaptation, land regeneration, and cultural resilience. These efforts are grounded in the LULUCF and the FAO's LCCS frameworks.

(c) Site-specific EO trend monitoring of ecosystem regeneration (supported by rGEE/GEE tools). To address these complex dynamics, there is a pressing need to move beyond static assessments and adopt tools capable of monitoring ecosystem change and regeneration in near-real time. The EO Hub is conceived as a living laboratory in which local communities, regional authorities, land managers, and researchers collaborate to develop and validate adaptive territorial strategies, supported by robust Monitoring, Reporting and Verification (MRV) systems. Recent research has demonstrated the added value of coupling on-site experiments with EO monitoring based on ground-survey structures to document the transition from over-intensive cultivation to regenerative agriculture, as observed in the Murcia region (Spain) (Gabriele, 2025a). The potential of long-term EO time series to characterise evolving degradation–regeneration dynamics through seasonally oriented phenological analyses supports innovative regenerative agriculture practices (e.g., crop successions, agroforestry, forest management experiments). The site-specific analyses are introduced as crucial components for reversing land degradation and advancing innovative approaches to sustainable land management in Mediterranean inland regions.

(d) Carbon dioxide removal computation. The integration of carbon accounting into both land management and urban planning under conditions of environmental stress and pollution, through the adoption of Nature-Based Solutions, is one of the key interdisciplinary pillars of the Hub (Mussinelli et al., 2024).

(e) Potential of eXtended Reality (XR/VR) for raising awareness. The use of XR/VR to enhance awareness among local communities, stakeholders, decision-makers, and public authorities—through immersive representations of land degradation and vegetation trends—is being advanced using both proprietary and open-source tools (Banfi, 2025). In parallel, the introduction of robust geographic-domain data management, still largely absent in current XR workflows, is identified as a critical frontier for development (Gabriele, 2025b, Gabriele, 2026).

Building on this framework, the first implementation phase of GPS^{Education} has already produced measurable outcomes in terms of participation, training engagement, and the identification of thematic trajectories for future collaboration. These early results are presented in the following section.

3. First Outcomes of the Advanced Skills Programme: Participation, Capacity Building, and Emerging Pathways

The objective of creating a transdisciplinary, international capacity-building model integrating Earth Observation, sustainability, health, and gender equity has been achieved through the complementary design of modular lifelong-learning courses and the establishment of an EO Hub to enable long-term institutional collaboration and skills transfer across partner countries. Beyond describing the project structure and course offerings, the authors provide quantitative indicators (e.g., participation, capacity-building outcomes, and early impacts), with results derived from the Advanced Skills courses.

(i) Participation. The results of the Call for Application demonstrate a shared interest and a common recognition of the relevance of establishing an EO Hub. A total of 33 applications were received, of which 28 were admitted to the final selection. The total number of participants was 24 (11 Professors, 3 Assistant Professors and 10 Lecturers) from the partner universities ENSMR and UIR (15 women and 9 men), as summarised in Table 1. The results highlight a strong alignment with gender inclusivity objectives, as promoted during the initial project presentation and engagement activities.

(ii) Capacity-building outcomes and possible pathways. The Long Life Learning Courses (LLLCs) represent an ambitious international and multidisciplinary training initiative. The overview of the GPS^{Education} project can serve as a model framework for global and regional collaboration for mainstreaming EO applications and education. The courses are structured around both theoretical and hands-on sessions. The LLLC-EO and LLLC-EO LULUCF courses combined conceptual lectures with practical exercises based on Earth Observation workflows, including time-series analysis, interpretation of global datasets, and progressive refinement toward local-scale applications (Figure 1).

(iii) Impact creation. The paper presents a contribution which may spark further global and regional collaboration and support in term of early impact and possible scale-up in the future being.

Gender	Men		Women	
Age	55 +	30-54	55+	30-54
Tot. n.	1	8	0	15

Table 1. Age Ranges Indicators of the 24 participants from ENSMR & UIR coming to POLIMI for the LLLCs. Table structured for the MUR required report.

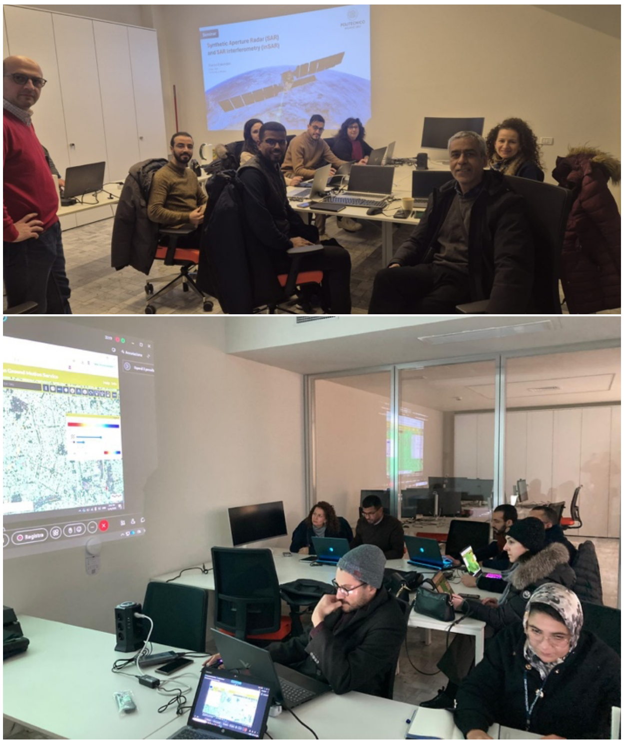

Figure 1. Long Life Learning Continuing Formation and EO hands-on activities during the LLLC-EO.

Among the outcomes of the first implementation phase, one is the consolidation of a methodological pathway capable of linking training activities with operational EO analysis. The following section focuses on the methodological progression developed within the EO-LULUCF course, showing how participants were guided from global atlases and large-scale indicators toward local interpretation and site-specific applications.

4. From Global EO Assessment Frameworks to Site-Specific Methodological Workflows

Within the EO Hub perspective, capacity building is not restricted to the acquisition of technical tools, but is organised as a methodological progression from large-scale diagnostic frameworks to local, application-oriented analysis. This progression is particularly relevant in the field of land degradation assessment.

In this context, global EO-based assessment frameworks and atlases represent the primary knowledge baseline, providing harmonised and comparable representations of land degradation processes and climate-driven dynamics across large spatial scales. Products such as the World Atlas of Desertification synthesise multi-decadal EO datasets into indicators capable of identifying critical hotspots and long-term trajectories. However, their aggregated nature and level of generalisation require further methodological refinement to support context-specific analysis and impact-oriented applications. Starting from these global premises, Land Productivity Dynamics (LPD) represents one of the most consolidated indicators for assessing land degradation trends through EO time series. LPD is derived from NDVI-based analyses computed over long-term temporal windows (e.g., 16-year moving periods such as 2001–2016 up to 2008–2023), where the reference year corresponds to the final year of each observation period. The indicator captures variations in vegetation productivity associated with ecosystem functioning, reflecting changes in plant phenology and biomass growth. Declining trends are frequently interpreted as proxies for degradation processes, although their interpretation requires contextualisation with respect to local environmental conditions and land management practices. The methodological framework for LPD analysis builds upon the non-linear phenology approach proposed by Ivits and Cherlet (2013), later implemented by the Joint Research Centre within the World Atlas of Desertification (Cherlet et al., 2018). LPD is derived from EO vegetation indices, primarily NDVI (Yengoh et al., 2015), and analysed through time-series approaches (Teich et al., 2019). For this analysis on Morocco, the LPD dataset was retrieved from Open Foris Earth Map and subsequently processed in GIS by the author (M.G.). The adopted approach for this LPD dataset is consistent with methodologies developed under the WOCAT–FAO collaboration within the CACILM2 project and aligns with recent high-resolution global LPD datasets (Li et al., 2025). The method combines non-parametric trend analysis of annual NDVI with performance metrics relative to baseline biomass conditions, enabling the identification of areas affected by incipient decline, persistent degradation, or relative stability.

As illustrated in Figure 2, the LPD analysis for Morocco highlights spatial patterns of extended degradation at both national and regional scales. The comparison between temporal windows (2016–2024) shows a clear increase in the proportion of areas characterised by negative productivity dynamics, indicating a progressive intensification of degradation trends in the study area. These results provide a quantitative basis for identifying critical zones and represent an entry point for further spatial prioritisation and targeted analysis. Coherently with this strategic direction, and within the broader reference framework of global large-scale assessments for SDG monitoring, LPD assessment is envisioned to contribute to the computation of the SDG 15.3.1 indicator for Land Degradation Neutrality (LDN), with reference to the Trends.Earth framework (Gonzalez-Roglich et al., 2019).

In this context, LPD-derived trends will support the classification of areas according to degradation status (ongoing, stable, or potentially reversible), providing a structured basis for spatial prioritisation and decision-making. The integration of LPD with complementary sub-indicators—namely land cover change and soil organic carbon—will enable a more comprehensive and policy-relevant interpretation of land degradation dynamics. In this context, LPD-derived trends will support the classification of areas according to degradation status (ongoing, stable, or potentially reversible), providing a structured basis for spatial prioritisation and decision-making.

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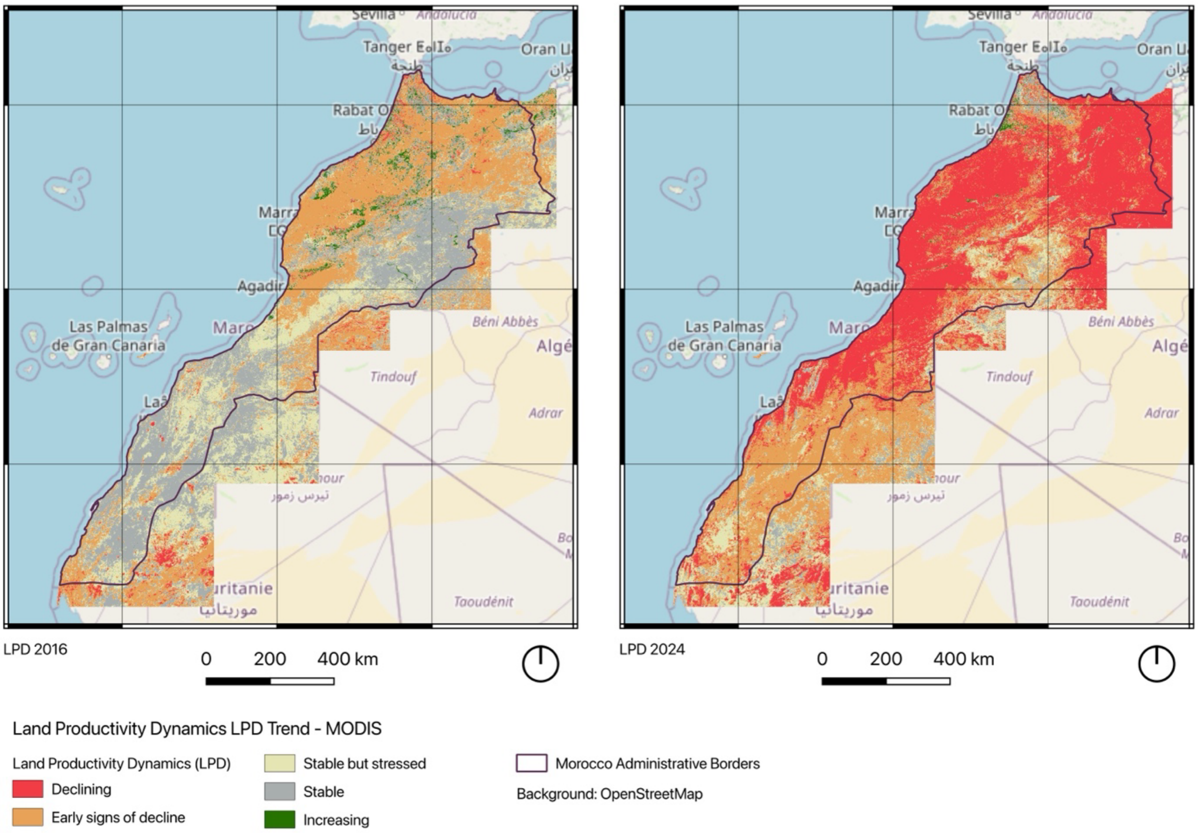

Figure 2. Land Productivity Dynamics (LPD) analysis for Morocco derived from NDVI time series (MODIS) over 2016-2024 time periods. Spatial distribution of LPD classes for two temporal windows (Left, 2016 and right, 2024), highlighting areas of declining, stable, and increasing productivity.

The integration of LPD with complementary sub-indicators—namely land cover change and soil organic carbon—will enable a more comprehensive and policy-relevant interpretation of land degradation dynamics. Within the EO Hub perspective, this framework supports the development of transferable analytical workflows for identifying priority intervention areas and designing actions aimed at avoiding, reducing, and reversing land degradation. However, while global atlases methodological approaches and LPD-based assessments provide a robust global-to-regional diagnostic framework, their spatial resolution and aggregated nature limit their capacity to capture local land management practices, short-term dynamics, and fine-scale land use processes. These limitations are particularly relevant in Morocco’s heterogeneous landscapes, where degradation and regeneration processes are influenced by the intrinsic local conditions and land management practices. To address this limitation, the EO Hub methodology introduces a progressive downscaling approach, developed and implemented within the EO-LULUCF Long Life Learning Course (LLLC), aimed at translating global EO indicators into site-specific analytical workflows. The workflow is structured as a sequence of training activities designed to bridge global assessments and local interpretation (Figure 3). In the first phase, trainees engage with Open Foris Earth Map and the QGIS plugin Trends.Earth, where they analyse LPD patterns and SDG-related indicators to identify degradation hotspots and interpret large-scale dynamics. This phase supports the understanding of EO indicator construction, temporal trend analysis, and their integration within policy frameworks such as LDN and LULUCF.

Participants perform comparisons between temporal windows, analyse spatial distributions, and extract areal statistics, to interpretate degradation patterns at regional scale. In the second phase, the analysis is refined toward local-scale land use and land cover (LULC) assessment, using platforms such as Collect Earth and Open Foris Arena, integrated with Google Earth Engine. At this level, trainees perform detailed visual interpretation of high-resolution imagery and spectral signatures, combining multi-temporal datasets, ancillary layers, and field-based observations. The exercises focus on identifying land use transitions, validating EO-derived degradation patterns, and detecting early signals of regeneration. Attention is given to the interpretation of vegetation dynamics through spectral behaviour and temporal profiles, enabling the understanding of ecosystem responses and land management practices. This multi-scale workflow—linking global indicators (LPD), regional prioritisation tools (Trends.Earth), and local validation platforms (Collect Earth)—constitutes a core methodological component of the EO Hub. It enables the transformation of EO data into operational, site-specific knowledge, supporting Monitoring, Reporting and Verification (MRV) systems and strengthening evidence-based decision-making processes. This approach —envisioned to be further developed and operationalised within the EO Hub at ENSMR— will guide researchers and practitioners to design, monitor, and evaluate sustainable land management strategies, contributing to impact-oriented applications. The methodological workflow developed within the EO-LULUCF LLLC on the one hand, strengthens analytical capacity among participants; on the other, reveals concrete thematic domains in which EO can support ongoing national priorities. In the Moroccan context, these domains extend beyond land degradation alone and include a broader set of sustainability challenges. The next section outlines the principal EO pathways identified for future Advanced Skills follow-up activities.

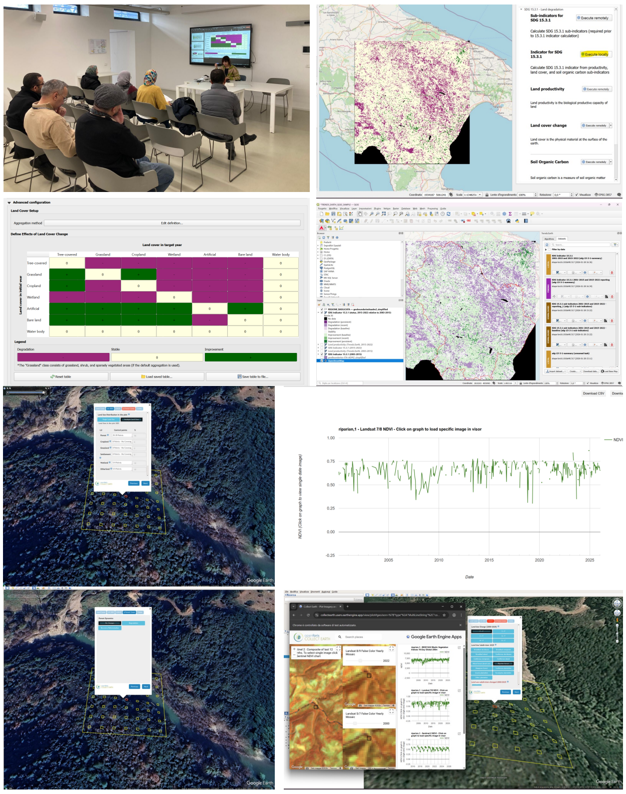

Figure 3. Example of exercises carried out during the EO-LULUCF Long Life Learning Course (EO-LULUCF LLLC). Phase 1 (top): analysis of Land Productivity Dynamics (LPD) and SDG 15.3.1 indicators using Trends.Earth QGIS plugin. Phase 2 (bottom): local-scale land use and land cover (LULC) assessment using Open Foris Collect Earth, integrating high-resolution imagery, temporal profiles, and spectral signature interpretation within a Google Earth Engine environment.

5. Advanced Skills Follow-Up: Earth Observation Pathways for Sustainable Development in Morocco

In recent years, Morocco has emerged as a regional frontrunner in sustainable development by aligning its national strategies with the United Nations Sustainable Development Goals (SDGs). The country has undertaken ambitious energy transition policies, particularly through large-scale renewable energy projects such as the Noor Ouarzazate Solar Complex, one of the world's largest concentrated solar power plants. These initiatives contribute significantly to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) and are widely discussed in the literature as benchmarks for renewable energy deployment in emerging economies (B El Hafdaoui, 2025; IEA, 2022). Morocco is also increasingly leveraging advanced technologies, including Earth Observation (EO) and geospatial analytics, to support sustainable resource management and informed decision-making.

EO applications enable continuous monitoring of water resources, contributing to improved governance under conditions of increasing scarcity (SDG 6) (Jarlan et al., 2015). Similarly, satellite-based assessments of land degradation and desertification processes support environmental conservation strategies aligned with SDG 15 (Rivera et al., 2022).

In urban contexts, geospatial tools facilitate smarter planning and infrastructure development, addressing the challenges of rapid urbanization in line with SDG 11 (El Garouani et al., 2017). In the agricultural sector, climate-smart and precision agriculture approaches—supported by remote sensing data—enhance productivity, optimize irrigation practices, and improve resilience to climate variability (SDG 2) (FAO, 2021). These approaches are particularly relevant given Morocco's diverse geography, which ranges from the Atlas Mountains to the Sahara Desert, and presents both opportunities and constraints for sustainable land and water management.

Morocco development trajectory reflects an integrated approach that combines policy reform, technological innovation, and international cooperation. By embedding sustainability principles across key sectors, the country is advancing a balanced model of economic growth, environmental stewardship, and social inclusion, as highlighted in several recent academic and institutional studies (World Bank, 2023; Nativi et al., 2021).

5.1 Priority Application Domains for EO in Morocco

In Morocco, Earth Observation (EO) offers substantial potential to address pressing environmental and developmental challenges—such as water scarcity, land degradation, and climate variability—while simultaneously contributing to socio-economic advancement. EO technologies provide continuous, large-scale, and cost-effective monitoring of natural and human systems, generating evidence-based data that supports decision-making across multiple sectors (e.g., land use, agriculture, water resources, and disaster management) (Weng, 2012; Thenkabail et al., 2018). By transforming raw remote sensing data into actionable information, EO enables the tracking of environmental change, the early detection of stress events, and the evaluation of long-term trends, thereby enhancing policy responsiveness and planning effectiveness.

Aligned with Morocco strategic priorities—anchored in the key pillars of agriculture, water resources, energy, urban planning, and environmental management—the systematic integration of EO into national and sectoral planning represents a critical pathway toward achieving inclusive, climate-resilient, and sustainable development (Wu et al., 2023; Masó et al., 2023). For example, EO applications have been shown to improve agricultural water productivity through optimized irrigation scheduling (Garg et al., 2022), inform drought early warning systems (Alahacoon et al., 2021), and support spatial planning in rapidly urbanizing regions (Seto et al., 2012). Despite these advantages, realizing the full potential of EO requires enhanced institutional capacity, inter-agency coordination, and technical expertise to translate geospatial data into operational tools and policy instruments (Koldasbayeva et al., 2024). Strengthening these capacities and scaling EO applications across sectors will be essential to maximizing benefits such as resource efficiency, climate resilience, and economic innovation. By advancing these efforts, Morocco can consolidate its leadership in EO within the African region and serve as a model for the strategic use of geospatial technologies in support of sustainable development.

Earth Observation (EO), the use of satellite imagery, remote sensing, and geospatial data, offers transformative pathways for advancing sustainable development in Morocco. Given the country's vulnerability to climate variability, water scarcity, and land degradation, EO provides a science-based foundation for informed decision-making across key sectors.

Morocco has established a strong institutional base for EO through the Royal Center for Remote Sensing, which coordinates national remote sensing programs and promotes the use of satellite data across sectors. This institutional framework supports alignment with national strategies such as climate adaptation policies, agricultural modernization, and water resource management.

5.1.1 Climate-resilient agriculture and food security

Agriculture is highly climate-sensitive in Morocco, contributing significantly to GDP and employment while being exposed to rainfall variability and drought. EO enables: (i) Crop monitoring and yield forecasting using vegetation indices (e.g., NDVI); (ii) Drought early warning systems through soil moisture and rainfall analysis; (iii) Precision agriculture (optimized irrigation, fertilization). Projects such as EO-based agricultural platforms demonstrate how satellite data can estimate crop water needs and improve irrigation efficiency under drought conditions. Pathway impact: increased productivity, reduced water use, and enhanced food security.

5.1.2 Water resource management and drought mitigation

Morocco faces chronic water stress due to declining precipitation and rising demand. EO supports: (i) Monitoring of reservoirs and dams (e.g., El Kansera Dam); (ii) Groundwater assessment and recharge mapping; (iii) Watershed and irrigation planning. Satellite data also complements large-scale infrastructure strategies (e.g., desalination and water transfer projects) by optimizing allocation and identifying priority regions. Pathway impact: Improved water allocation, drought resilience, and sustainable irrigation.

5.1.3 Land degradation, desertification, and ecosystem monitoring

Land degradation and desertification threaten rural livelihoods and ecosystems in Morocco. EO enables: (i) Tracking land-use and land-cover changes; (ii) Monitoring vegetation dynamics and soil degradation; (iii) Assessing ecosystem health in sensitive areas such as Lake Afennourrir, Dayet Aoua, etc.Pathway impact: Supports land restoration programs and biodiversity conservation.

5.1.4 Disaster risk management (fires, floods, extreme events)

EO plays a critical role in disaster preparedness and response: (i) Wildfire prediction models integrating satellite data and AI improve early detection and prevention. (ii) Flood risk mapping using GIS and terrain models for urban planning. (iii) Climate monitoring programs such as Fennec improve understanding of regional climate dynamics. Pathway impact: Reduced disaster risks and improved resilience of vulnerable communities.

5.1.5 Coastal and marine resource management

EO contributes to: (i) Monitoring coastal erosion and sea-level rise; (ii) Supporting sustainable fisheries and aquaculture; (iii) Managing marine ecosystems and pollution. This aligns with Morocco's efforts to sustainably manage ocean resources and fisheries exports. Pathway impact: Sustainable blue economy development.

5.1.6 Urban planning and sustainable cities

EO supports: (i) Urban expansion monitoring; (ii) Infrastructure planning and land-use optimization; (iii) Heat Island and pollution analysis. Pathway impact: Smarter urban growth and improved environmental quality.

5.1.7 Cross-cutting benefits of EO in Morocco

Across all sectors, EO provides: (i) Timely and cost-effective data over large and remote areas; (ii) Evidence-based policymaking tools; (iii) Integration with AI, GIS, and big data analytics; (iv) Support for national and international sustainability goals (SDGs). Earth Observation represents a strategic enabler of Morocco sustainable development strategy by bridging environmental monitoring and policy action. Through several applications such as agriculture, water management, climate adaptation, and urban planning, EO supports a transition toward a more resilient, data-driven, and sustainable economy (Figure 4).

Figure 4. Earth Observation: driving Morocco sustainable development [Image generated with NotebookLM].

Among the identified pathways, soil erosion and reservoir siltation emerged as a particularly mature and urgent field for future joint development. This theme offers a strong basis for integrating EO monitoring, land management, and hydraulic infrastructure assessment, while also addressing sustainability challenges in Morocco. The next section presents soil erosion as a priority application domain and discusses its implications for land degradation and water resource management.

6. Soil Erosion, Reservoir Siltation, and EO-Based Support for Land and Water Management

Soil erosion constitutes one of the major concerns in North African countries and particularly in Morocco where it affects up to 40% of its land area (Lamane et al., 2022). This phenomenon is linked to a bunch of parameters as: precipitation regime (irregular over time in Morocco with floods becoming more frequent and intense lately due to climate change), topography (steep topography promotes high soil erosion rates), geology and soil characters, land use and land cover, etc. Soil erosion is then a major driver to land degradation which impacts directly soil quality and functionality (Saggau et al., 2021; Stefanidis et al., 2022). It is also a direct threat and risk towards land use and valorization, as well as reservoirs viability and functionality. Indeed, millions of cubic meters are lost annually from reservoirs in Morocco due to soil erosion and sedimentation, which reduces their lifespan, increases the risk of floods and reduces their hydraulic performance (guarantee of water supply for domestic use and irrigation).

In Morocco, the dam policy has been boosted since the 1970s and the number of large dams exceeds 150 currently. This policy has played a major role in drought periods in terms of securing public water supply and affording water for irrigated perimeters (which area is accounting for more than 1.6 Million hectares), as was as the case during the last episode of drought which has begun in 2018. Hence, sustainable water management relies on safeguarding these infrastructures retention capacity, especially from siltation which conducts to the loss of 75 MCM/year (Loudyi et al., 2018). Soil erosion is naturally not the same across the whole country due to the heterogeneity of geomorphologic and climatic conditions.

The average soil erosion is ranging from 5 to 20 t/ha/year, but it can exceed this level in some regions like the northern and north-western basins where it can reach 50 t/ha/year (Dahan et al., 2012). Some dams have already lost their retention capacity like Abdelkrim El Khattabi and Nakhla. The highest erosion rate is concentrated in basins of the Atlas and Rif mountains (Lamane et al., 2022; Mohafid et al., 2024) (Figure 5).

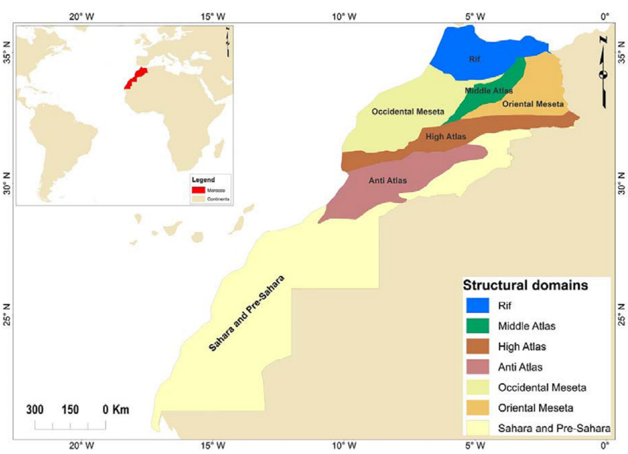

Figure 5. Situation and structural domains of Morocco (Source: Lamane et al., 2022).

Siltation rate for strategic dams of the Moroccan kingdom range between 0.5 and 18 MCM/y for Al Wahda dam, the largest dam of the country (Figure 6).

Watershed	Number of dams	Initial capacity Mm³	Siltation 2022	Siltation rate (%)
Moulouya	6	1 287.36	666.59	51.78%
Loukkos	9	1 328.21	299.54	22.55%
Deraa Oued Noun	2	866.39	192.90	22.26%
Tensift	5	250.64	53.02	21.15%
Ziz	1	347.00	54.74	15.77%
Sebou	10	6 017.80	917.74	15.25%
Souss Massa	8	819.24	121.29	14.81%
Oum Errbia	10	5 623.48	778.36	13.84%
Bouregreg	2	1 031.79	104.16	10.09%
TOTAL	53	17 571.91	3 188.34	18.14%

Figure 6: Siltation rate in major Moroccan basins updated in 2022 (Mohafid et al., 2024).

Soil erosion isn’t only caused by precipitation, runoff and wind but also by human activities, especially tillage in agricultural areas (Peng et al., 2023). This phenomenon is not only a hindrance to water security and flood protection but also has major socio-economic effects.

The cost of soil degradation was estimated at around 1.7 Billion Moroccan Dirhams in 2014 in a study conducted jointly by the department of environment and the World Bank in 2017. Several research attempted to delve into the analysis of soil erosion and reservoir siltation over many river basins, using GIS and remote sensing techniques and several empirical, conceptual or physical based models, to identify erosion-prone areas (Lamane et al., 2022). Indeed, some authors used the Revised Universal Soil Loss Equation (RUSLE) model to map soil erosion in a watershed (Brahim et al., 2020). Others used MUSLE model incorporated in SWAT (Taleb et al., 2021; Briak et al., 2016; Tairi et al., 2021). Other researches tried to estimate the soil ratio using a combination of fallout radionuclides (FRNs) and combined specific stable isotope techniques (Damnati et al., 2013; Meliho et al., 2019; Benmansour et al., 2016).

Additionally, some analysis of historical bathymetric studies were undertaken by some researchers (Mohafid et al., 2024). However, still there is a need to address this problematic in basins suffering from a rapid sedimentation of reservoirs, to afford insights to decision makers about hotspots of soil erosion and areas necessitating actions of forestation and basin management as those adopted by the National Agency of Water and Forestry (ANEF) jointly with the Ministry of equipment and water.

Hence, the use of earth observations is of high importance for countries like Morocco, where soil measures are not frequent to address soil erosion problematic and its impacts on hydraulic infrastructures and socio-economic activities.

Conclusions and Next Steps

The main aim of the GPSEducation project is to create, through the implementation of Advanced Skills, an EO Hub that will become a reference center within Morocco and beyond (e.g. Nairobi, Kenya, Technical University of Kenya and Kenyatta University), creating bridges and networks with other African countries. It has been set up and has given positive results in terms of the number of participants and the multidisciplinary interests addressed. The launch of a cross-correlation thematic map is underway, starting from the results of the outgoing mobility call from POLIMI to ENSMR and UIR in February 2026. Based on the mapping of interests focused on topics of common relevance, the activation of Doctoral and Degree Theses has been considered, involving different educational levels of students to maximise the impact from the teaching level to the student formation scale-up. The design of Advanced Skills Seminars as a Lesson Learnt follow-up will include both methodological insights and the experience of ongoing European

Horizon projects so far driven by the POLIMI research group, to support the development of new proposals within Horizon Europe projects with ENSMR and UIR. To this aim, the preliminary identification of potential pathways has been carried out, driving sustainable development in different research fields of the participants and equipping them with monitoring approaches that address local challenges, while also fostering the efforts made in Morocco in recent years across different sustainability domains. The specific pathway on the soil erosion challenge has been explored, highlighting the necessity to bridge the gap towards healthy soils and reverse soil degradation. To maximise impact creation, further actions focused on Advanced Skills follow-up are currently under planning to scale up the present experience across other African countries and to strengthen the potential of ENSMR and UIR, reinforcing their role as EO Hubs.

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