The Cholistan Desert (Pakistan): EO-based approaches to investigate long-term land use and water management strategies

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Rationale

- **Earth Observation** (EO) has become an essential tool in archaeological research to address landscape investigations.
- Particularly useful in remote and **inaccessible regions**, where the availability and quality of geographic information is often very **limited**.
- Most of the EO-based research to date in marginal drylands has been limited due to poor satellite coverage and **limited temporal** and **spatial resolution**.
- These limitations are changing today -> **1)** availability of global, medium to high-resolution EO programmes (e.g. **European Union *Copernicus Programme)***, and **2)** implementation of **multi-petabyte image catalogues** and geospatial datasets in **cloud computing environments**, allowing for planetary-scale analysis on the Earth's surface.

Study area

- An extreme **arid ecotone** highly sensitive to the annual variation and the long-term change in the **Indian Summer Monsoon**.
- The area was core to the development of the **Indus Civilisation** (ca. 3300-2500 BC).
- Subject of considerable **historical interest** due to the presence of an extensive network of **relict riverbeds.**
- Limitations of old surveys: -> **1)** coordinates were often **inaccurate**, **2)** unclear information regarding the **extension** and **significance** of sites, and **3)** little exploration of **taphonomic processes** affecting preservation and visibility of mounds and surface scatters.
- Political **instability** in the region -> need of **EO-based** approaches.

Objectives

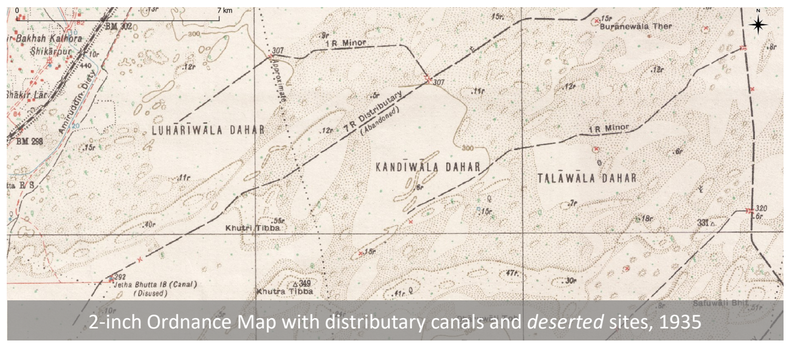
1. To accurately **detect** and **map landscape features** of archaeological, historical and environmental interest at different spatial scales -> **1)** ancient sites, **2)** relict geo-morphological, and hydrological features, and **3)** seasonal water and monsoonal dynamics.
2. To identify **historical** and **modern landscape alterations** of anthropic origin -> **1)** changes in traditional land use and water management strategies; and **2)** thaphonomic biases affecting archaeological visibility and preservation.
3. To reconstruct past **hydrological systems** and **palaeosoils** to understand the distribution of ancient sites.

Google Earth *Engine* data

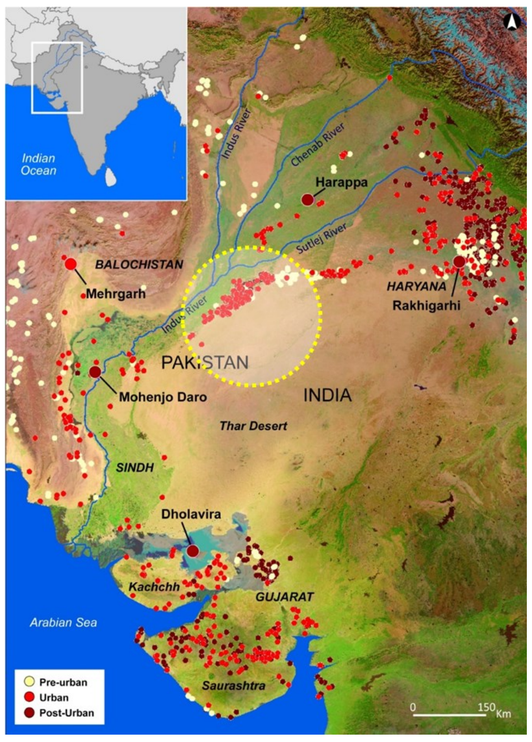
- **Multispectral** -> Landsat and Sentinel-2 archives
- **Radar** -> Sentinel-1 archive
- **DSMs** -> ALOS 30m

Historical data

- Historical **descriptions** & maps of former **Bahawalpur state** (1750s-1940s).
- Historical **topographical maps**: British Ordnance Survey, 1-4 inch (1870s-1940s), and US Army Map Service, Series U502 (1955).



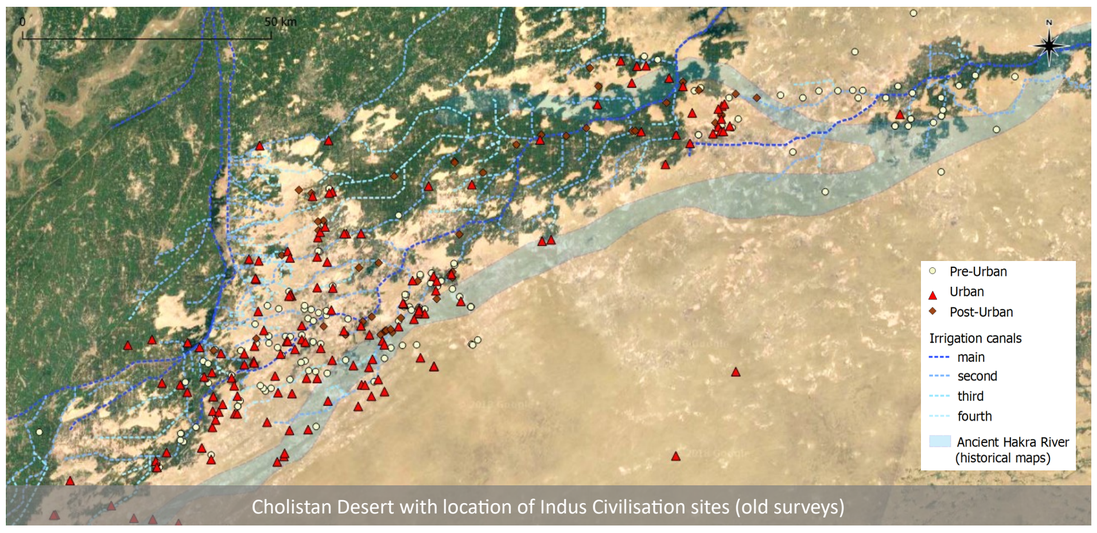
2-inch Ordnance Map with distributary canals and *deserted* sites, 1935




Archaeological mound


Medieval fort


Scattered surface materials



Cholistan Desert with location of Indus Civilisation sites (old surveys)

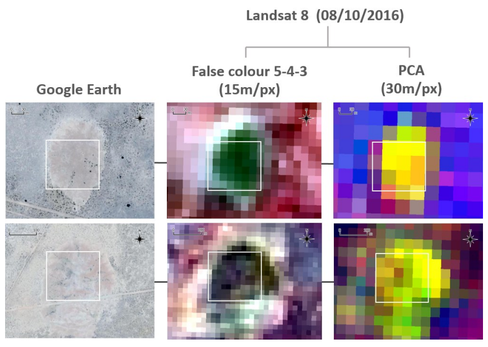
Engine + R: analysis & preliminary results

Example: detection of archaeological mounds

- **Multi-temporal** analysis and **multi-sensor** integration.
- Image **exploration** -> **PCA**, spectral indices.
- **Machine learning** algorithms: **LDA,** RF, SVM.
- **JavaScript** & **R** scripts -> GE *Engine* data reproducibility.
- Smooth **integration** with GRASS, QGIS, SAGA.

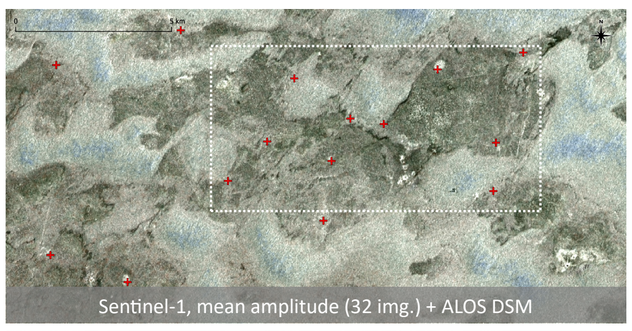
Multispectral exploration (PCA)

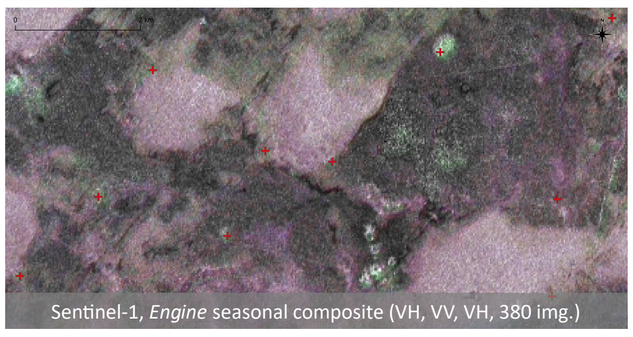
- Exploration of **spectral variability** and singular spectral signatures for unique features/land cover units, and evaluation of potential **training data**.



Radar (Amplitude & Polarisation)

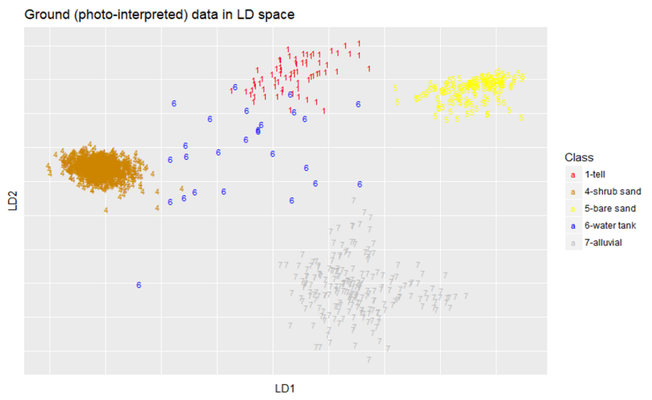
- Evaluation of **multi-temporal SAR** backscatter values to targeted land cover units (e.g. mounds, sand dunes and alluvial plains).

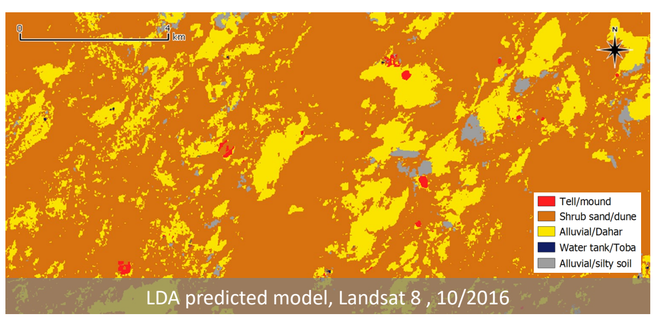

Sentinel-1, mean amplitude (32 img.) + ALOS DSM


Sentinel-1, *Engine* seasonal composite (VH, VV, VH, 380 img.)

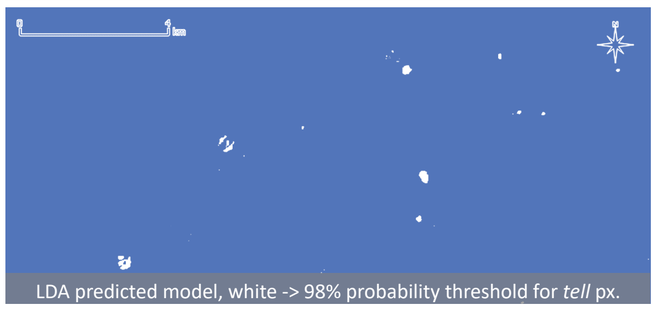
Supervised classification (LDA)

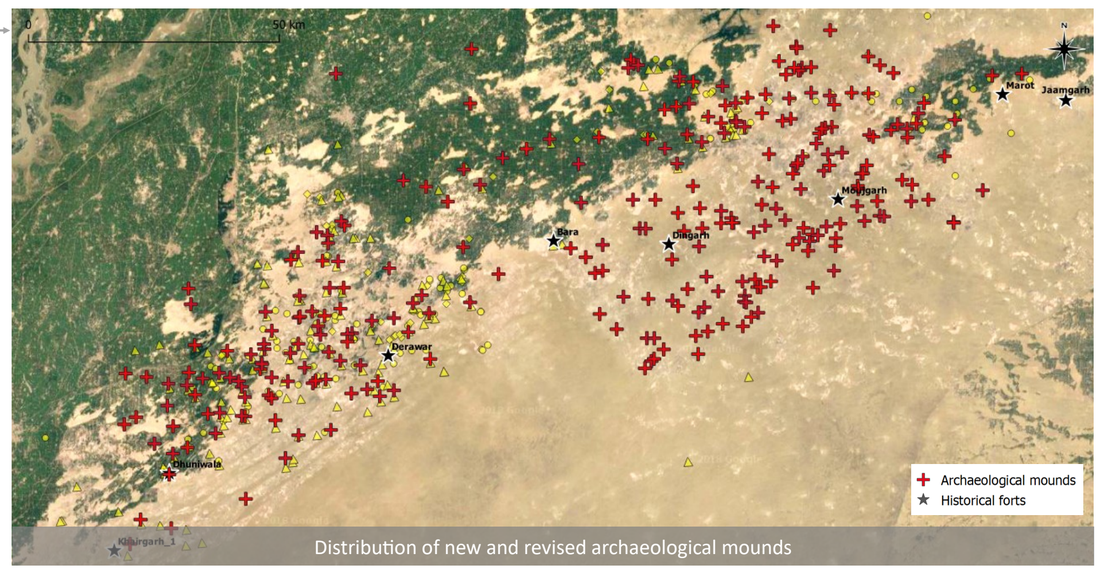
- LDA -> an ordination in a reduced space (akin to a PCA) that **maximizes** the **among-group variance** as specified in a training set, producing a linear transformation in which the classes are **optimally separated**.
- Useful to check **consistency** of training data input.
- **Posterior probability** threshold -> modelling LDA's predictions for classified groups.





LDA predicted model, Landsat 8 , 10/2016


LDA predicted model, white -> 98% probability threshold for *tell* px.



Distribution of new and revised archaeological mounds

Highlights

- Irrigated lands -> site preservation and **visibility threatened** by the expansion of mechanised agriculture (large irrigation canals starting in 1910-20s).
- Desert -> **exceptional presence** of archaeological and historical features, and evidence of desert expansion and retreat (e.g. fossilised sand dunes).
- **44 endangered historical forts** (including Derawar area -> UNESCO Tentative List).
- **285 new and revised archaeological mounds** (54 featured in old topographical maps; 75 corrected from old surveys).
- Forts and mounds located in **relict alluvial plains** (*dahar*), near present-day water tanks (*tobbas*) -> seasonal flooding providing local ecological services.
- Historical forts and **caravan routes** (IX-XIX century) -> descriptions of fort destruction due to abrupt flood events (e.g. 1804, 1805).

What's next?

- *Engine* **integration** with **high-resolution** data (i.e. Pléiades, TerraSAR-X, TanDEM-X).
- **Texture** & **segmentation** analyses to improve supervised classifications (i.e. reduce false positives).
- Multi-temporal **spectral indices** to identify soil/vegetation patterns related to relict **palaeochannels**.
- Hydrological **GIS modelling** & spatial analyses.

MarginScapes
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