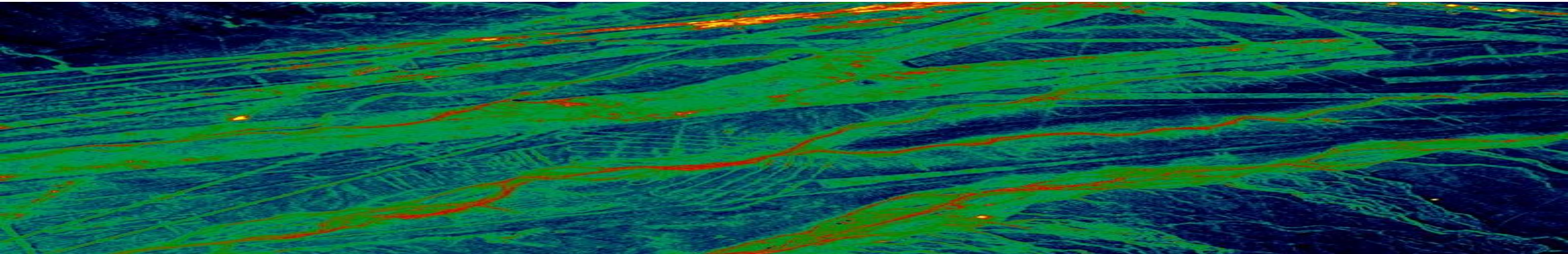




A satellite view of Nasca aqueducts

Rosa Lasaponara¹ and Nicola Masini²

¹ARGON laboratory of CNR-IMAA and ²CNR-IBAM
C. da S. Loya tito zona Industriale –Potenza Italy





Golden age of space data

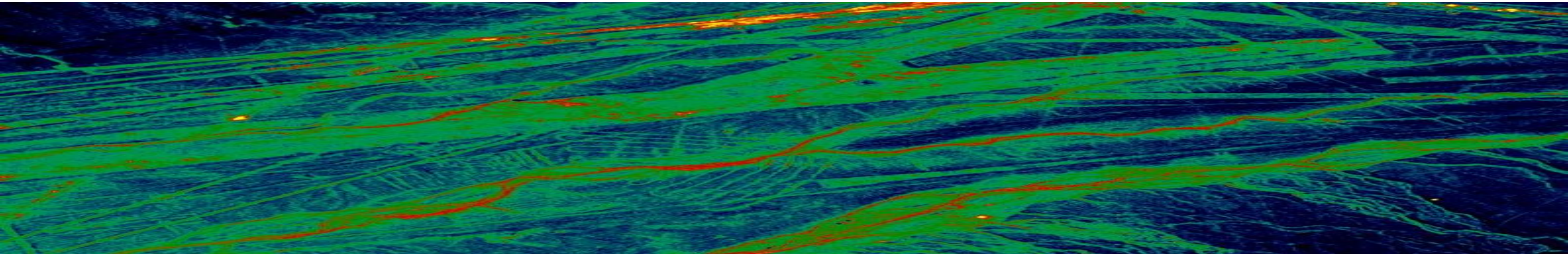
OUTLINES

Water management, shortage and retrieval: Ancient problems

Nasca acqeduct s: the response of Nasca to climatic change

Space based Characterization of Nasca environment

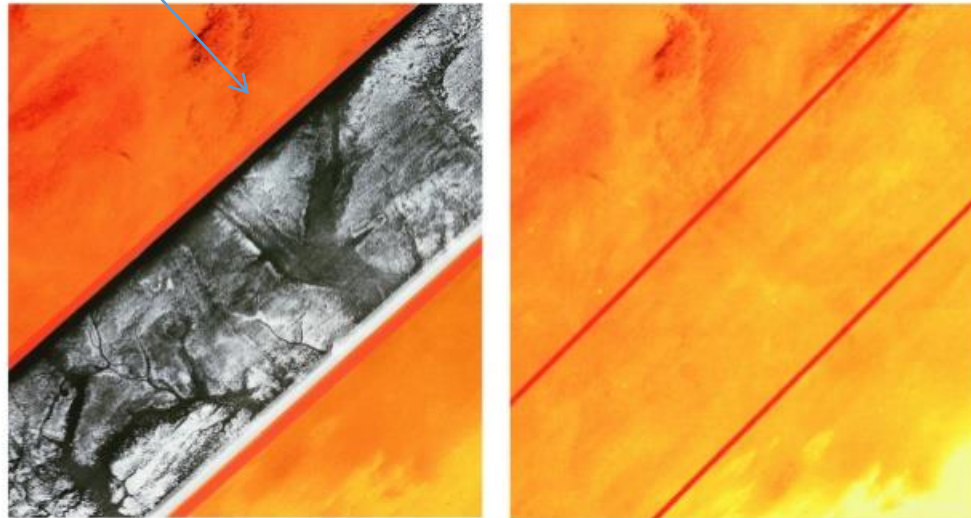
Puquios



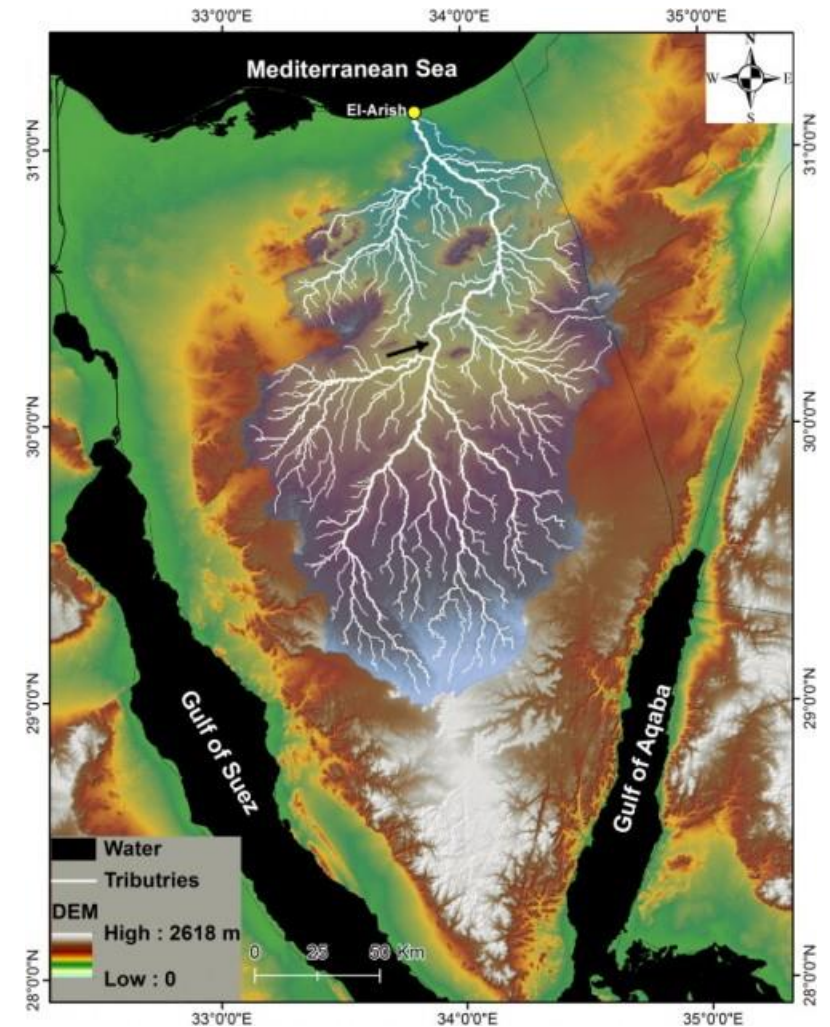
Radar rivers in the Sahara desert



Changing Environments

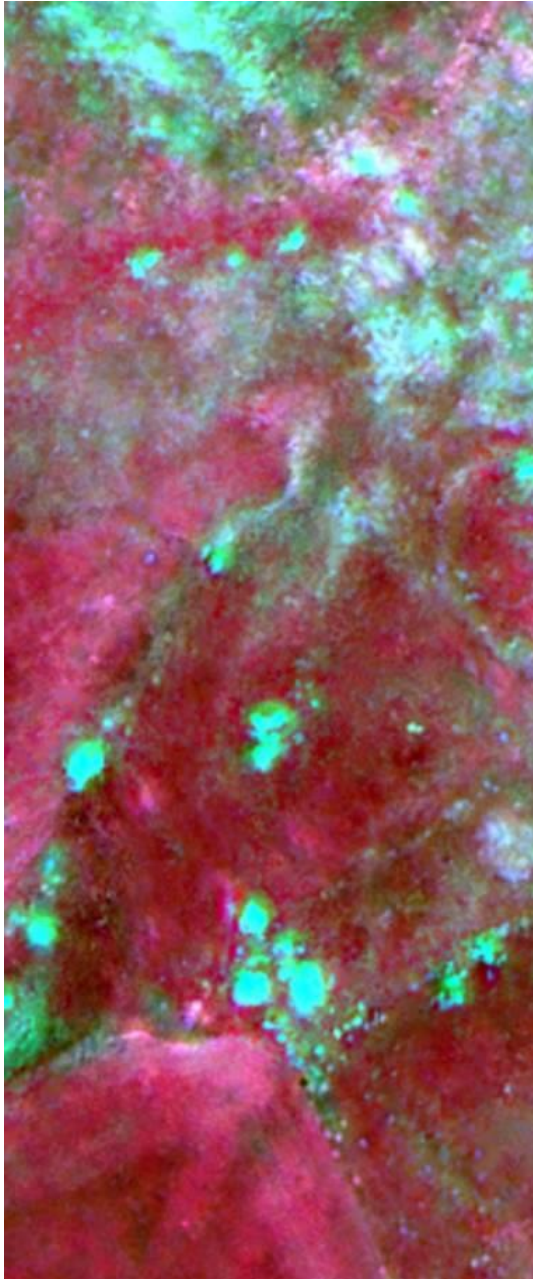


Radar images taken through dune fields of the Sahara Desert by the Space Shuttle reveal a well-developed drainage system.



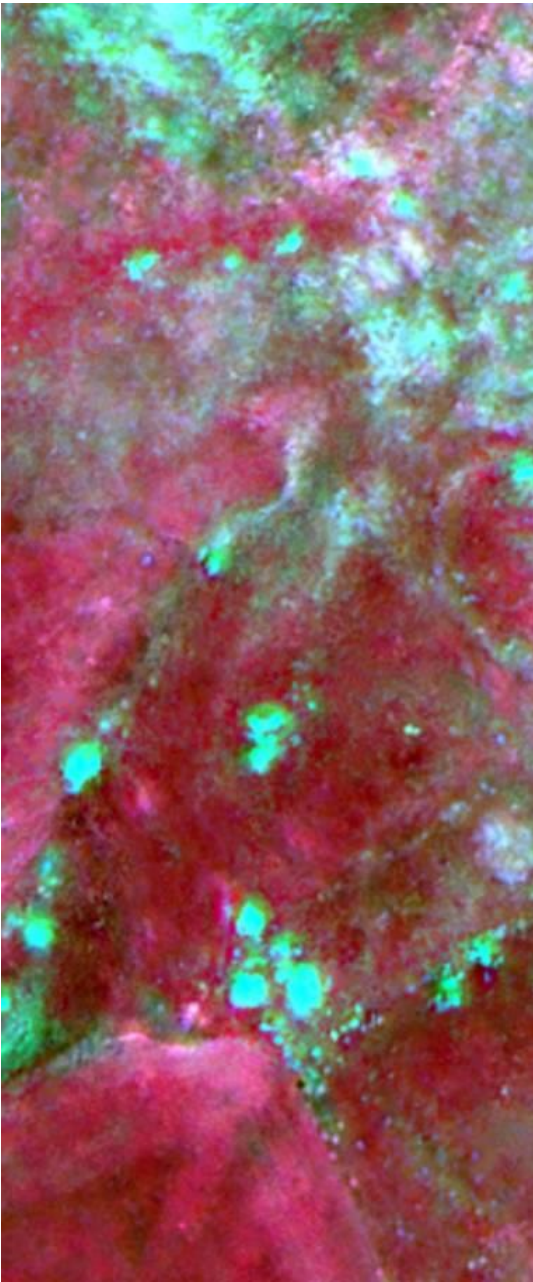
Nasa courtesy

Satellite time series available free of charge



Satellite data	Resolutions	availability	Multispectral
NOAA/AVHRR	Spatial resolutions		5 channels
	1 km	1980th	630-690 nm (red)
			760-900 nm (near IR)
			2 Thermal channels
			3700 nm
Landsat /TM	Spatial resolutions		7 channels
	30 m	1970th	450-520 nm (blue)
			520-600 nm (green)
			630-690 nm (red)
			760-900 nm (near IR)
SPOT/VEGETATION	Spatial resolutions		4 channels
	1 km	1998	450-520 nm (blue)
			625-695 nm (red)
			760-900 nm (near IR)
			nm (near IR)
ATSR	Spatial resolutions	1990th	4 channels
	1 km		Red, NIR and thermal
MODIS	Spatial resolutions	2001	36 channels
	1 km, 500m, 250m		

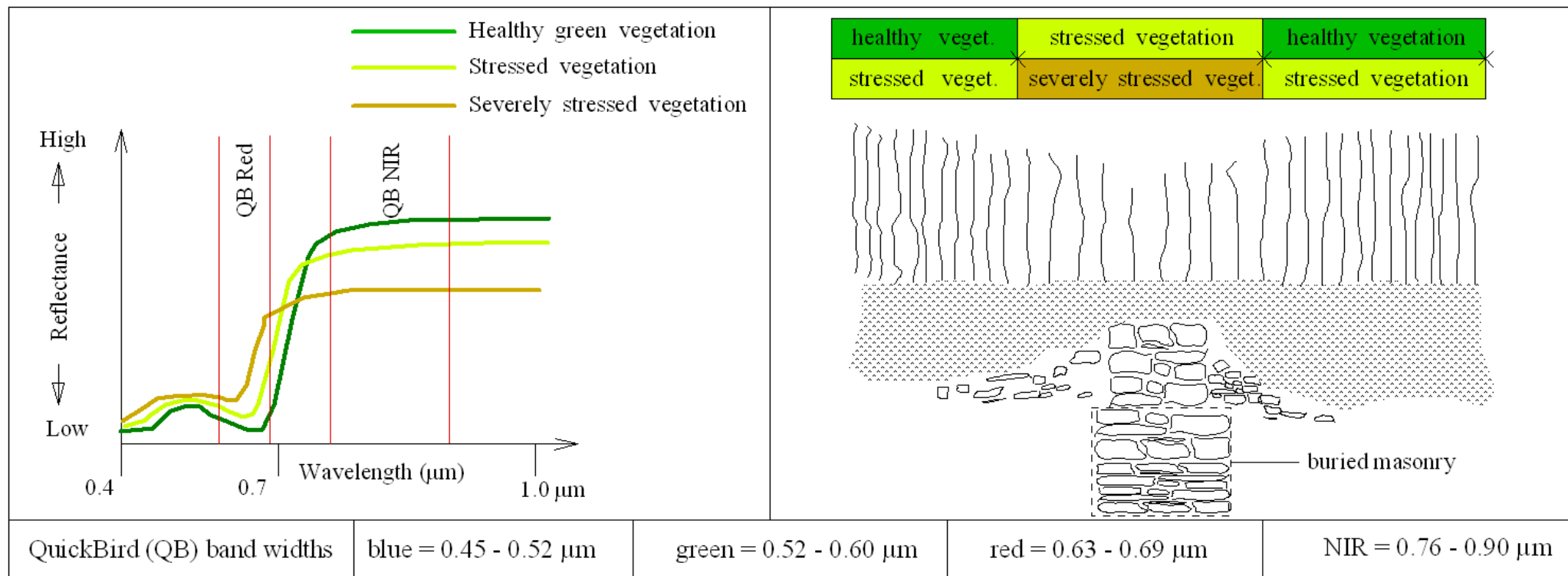
VHR Satellite



Satellite data	Resolutions	Panchromatic	Multispectral
IKONOS (1999)	Spatial resolutions	1 mt	4 mt
	Spectral range	450-900 nm	445-516 nm (blue)
			506-595 nm (green)
			632-698 nm (red)
			757-853 nm (near IR)
QuickBird (2001)	Spatial resolutions	0,61 mt	2,44 mt
	Spectral range	450-900 nm	450-520 nm (blue)
			520-600 nm (green)
			630-690 nm (red)
			760-900 nm (near IR)
GeoEye (2008)	Spatial resolutions	0,41 mt	1,65 mt
	Spectral range	450-900 nm	450-520 nm (blue)
			520-600 nm (green)
			625-695 nm (red)
			760-900 nm (near IR)
WorldView1 (2007)	Spatial resolutions	0,50 mt	-
	Spectral range	450-900 nm	-
WolrldView-2 (2009)	Spatial resolutions	0,46 mt	1,84 mt
	Spectral range	450-780 nm	400 - 450 nm (coastal)
			450-520 nm (blue)
			520-585 nm (green)
			585 - 625 nm (yellow)
			630-690 nm (red)
			705 - 745 nm (red edge)
			760-900 nm (near IR1)
			860 - 1040 nm (near IR1)

Information Extraction: physical basis for the detection of buried remains using optical data

Archaeological marks detection based on optical multispectral data



Lasaponara R., Masini N. 2007, Detection of archaeological crop marks by using satellite QuickBird, *Journal of Archaeological Science*, **34, pp. 214-221 [ISSN: 0305-4403] [[10.1016/j.jas.2006.04.014](https://doi.org/10.1016/j.jas.2006.04.014)].**

Features related to buried structures of archaeological interest

Crop-marks

Soil-marks

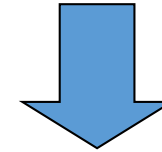
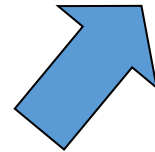
Shadow-marks



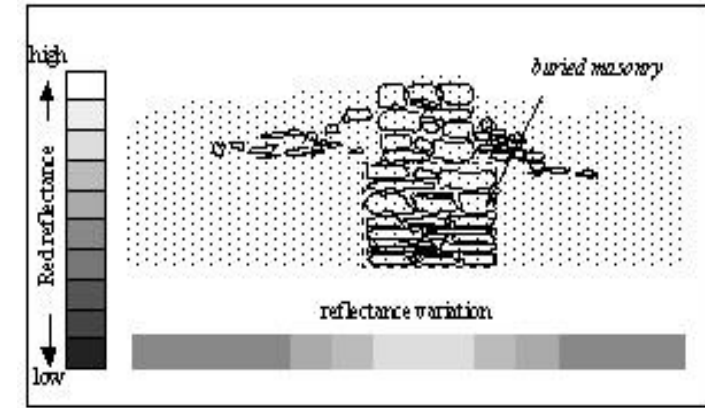
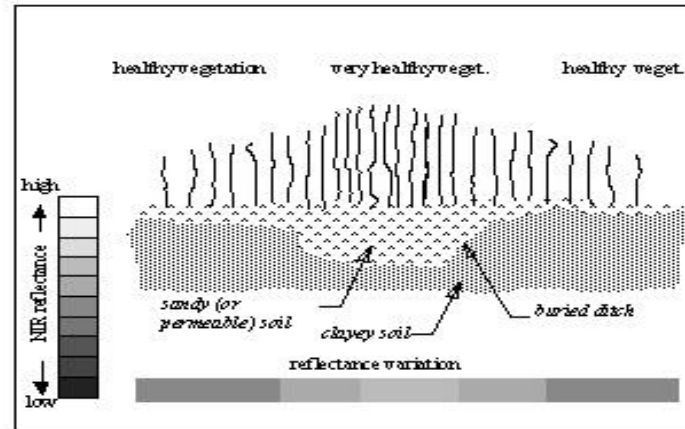
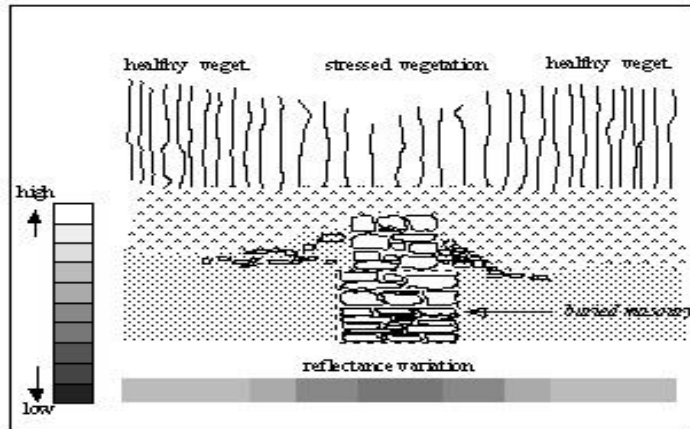
- Changes of soil constituents
- Variations of moisture content
- Nutrient deficiencies
- Differences in the plant growth



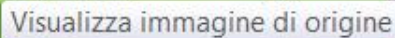
Archaeological deposit (negative/positive) cause

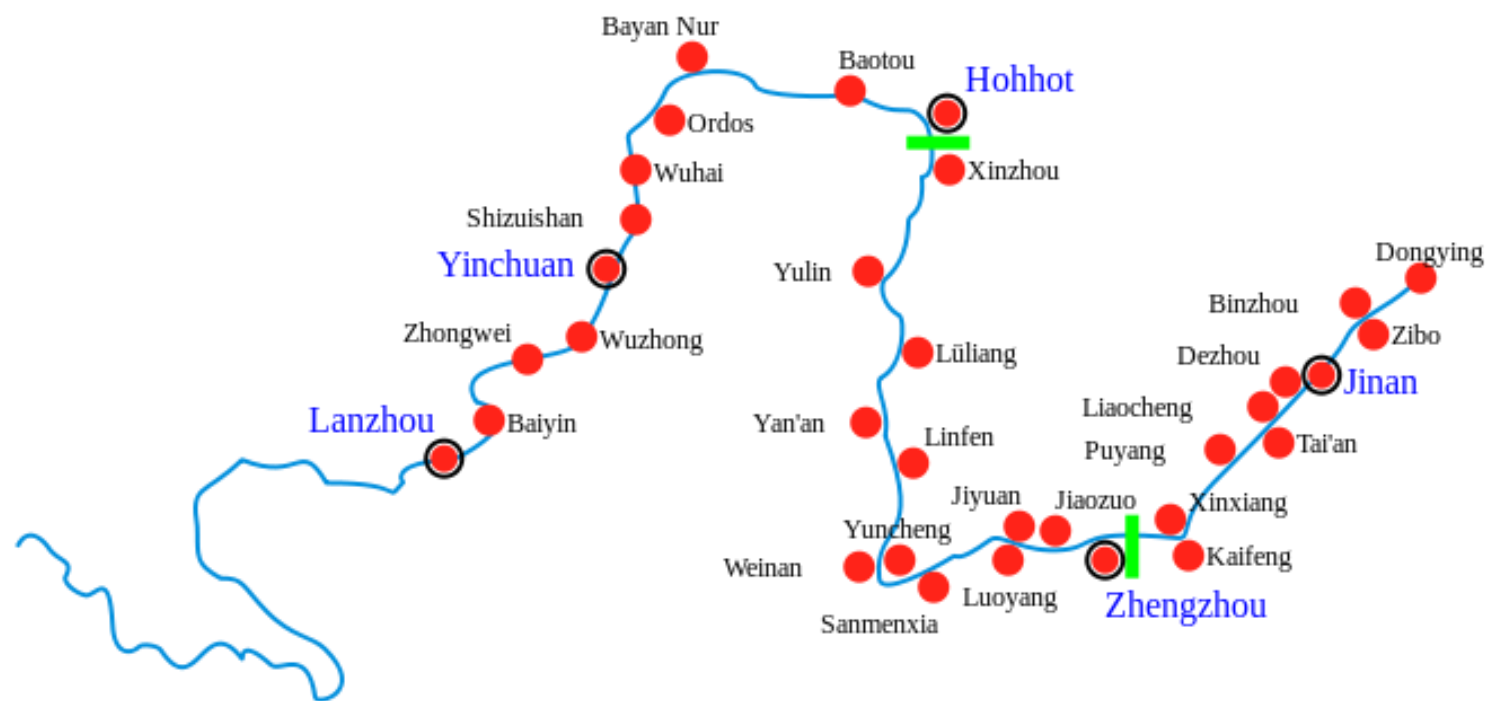


These variations induce changes in spectral response of surfaces



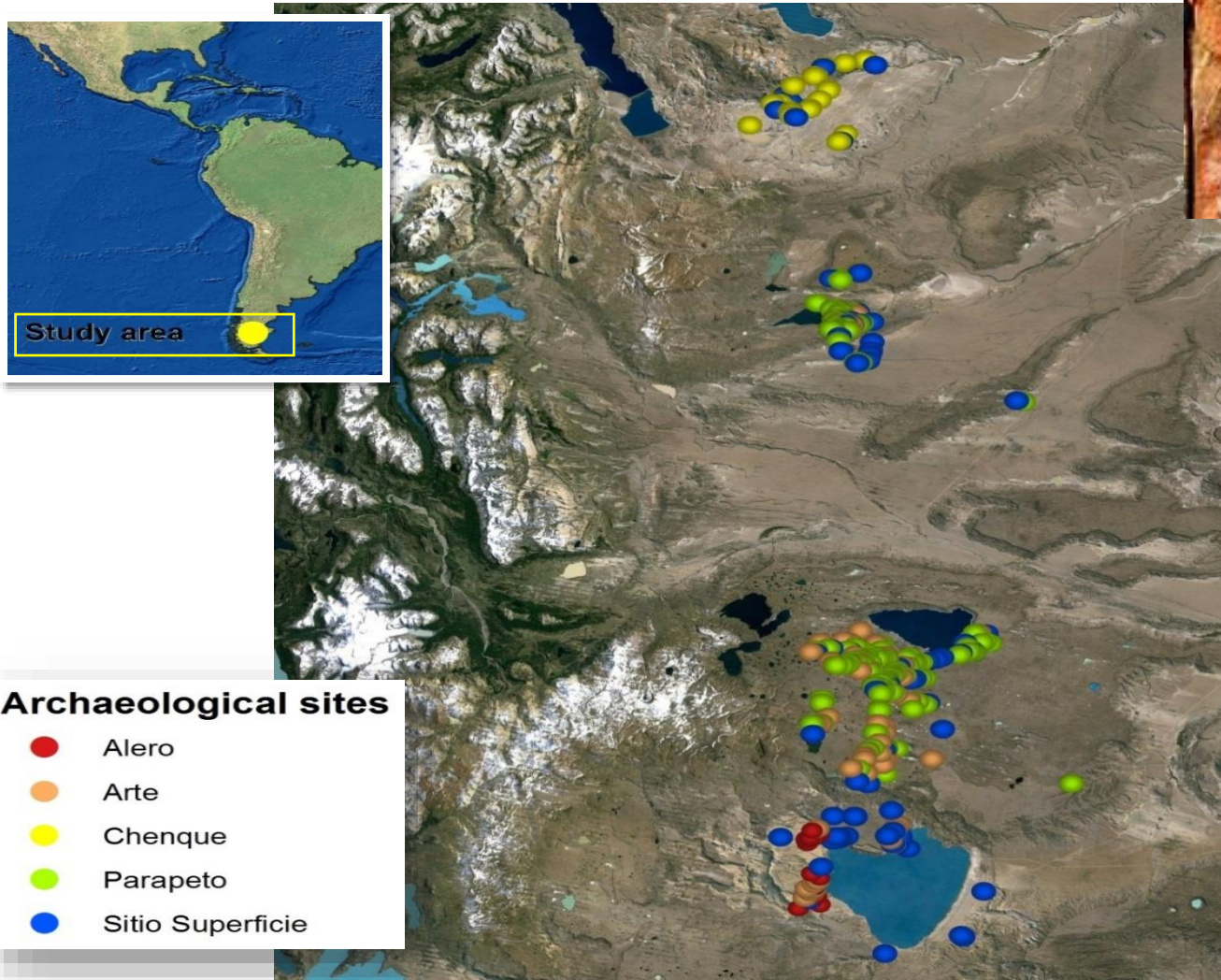
Lasaponara R., Masini N. 2011, Satellite Remote Sensing in Archaeology : past, present and future, Journal of Archaeological Science, 38, 1995–2002, [doi:10.1016/j.jas.2011.02.002](https://doi.org/10.1016/j.jas.2011.02.002).







The archaeological sites of the Santa Cruz County



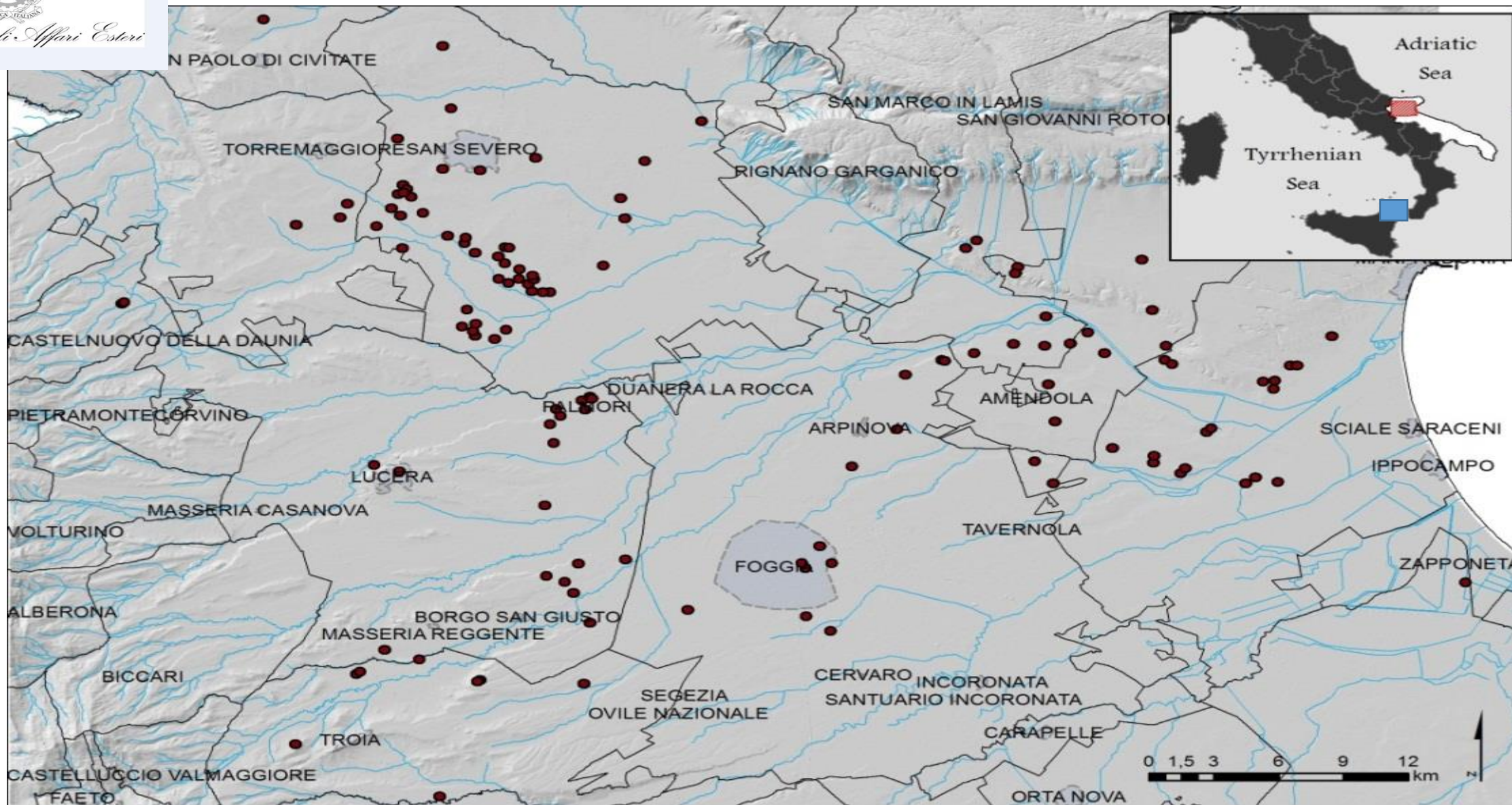
Multitemporal observation of archaeological crop-marks by UAV

Neolithic settlement near Lucera (Apulia)





Neolithic Villages in the Foggia area (Puglia)



Danese M., Masini N., Biscione M., **Lasaponara R.** 2014. Predictive modeling for preventive Archaeology: Overview and case study. [Central European Journal of Geosciences](#). March 2014, Volume 6, [Issue 1](#), 42-55

Comparative assessment of QuickBird and Pleiades data for the detection of ancient land divisions

Case study

Metapontum in Basilicata (Southern Italy)

History

- Metaponto was founded by Greeks coming from the Achaia region.
- Urban settlement date back to the Greek colonization (700 BC-200 BC)
- Roman age (200 BC – 400 AD) : the territory followed to be settled.

Ancient land divisions

They are thought to have been a network of country lanes and drainage canals as confirmed by archaeological excavation. The drainage allowed ancient populations to exploit for agriculture the original marsh land

Note

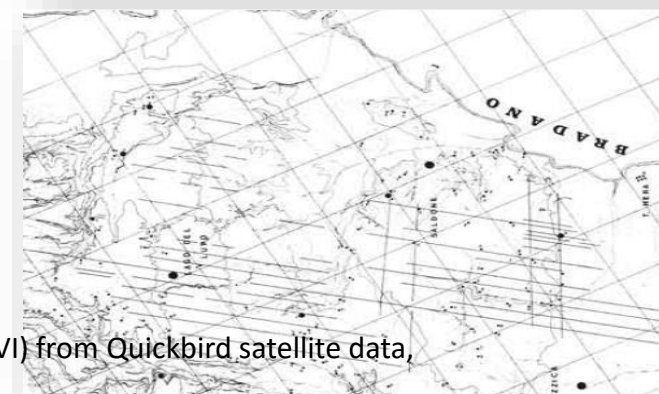
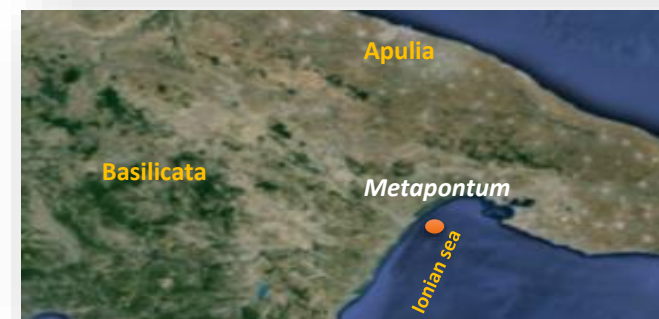
these land divisions are increasingly difficult to observe because of the destructive effects of deep ploughing machines which greatly altered the agrarian landscape during the last sixty years in Italy

Satellite dataset

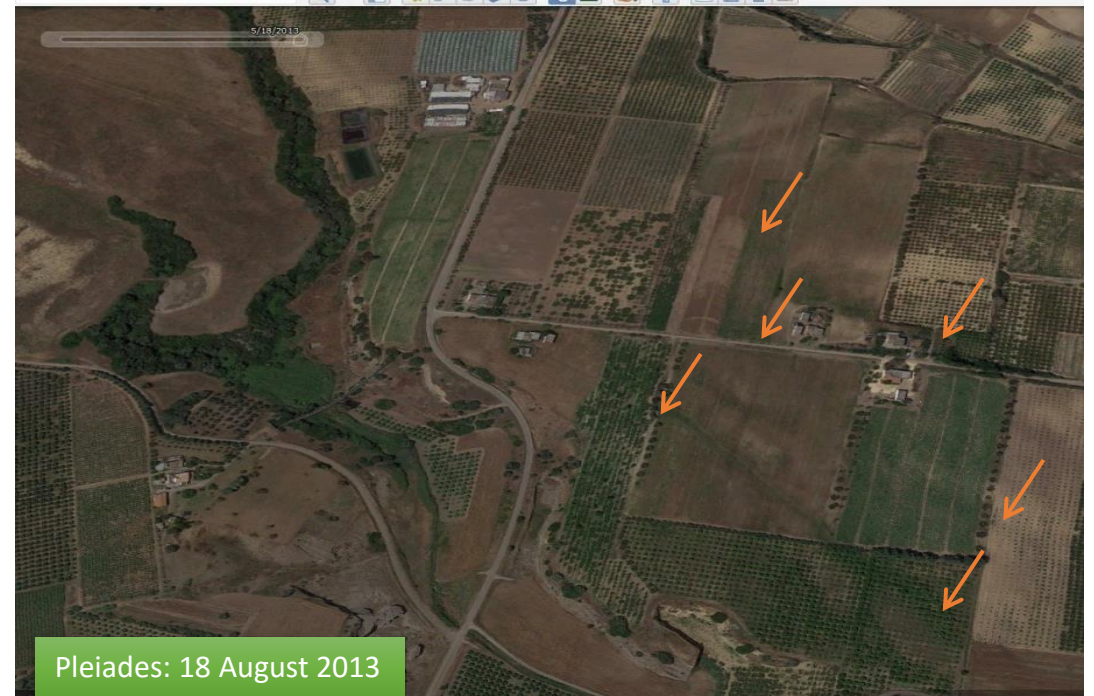
Pleiades: August 17, 2013

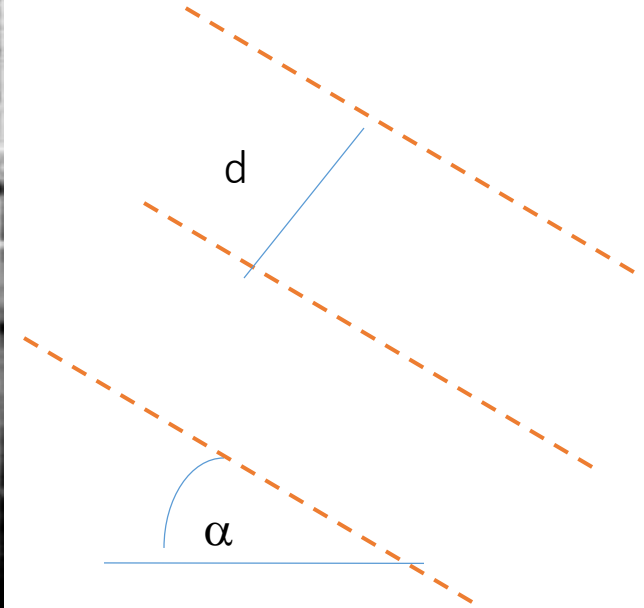
QuickBird : 28 August 2003 / 22 August 2004 / 11 August 2006

Lasaponara R., Masini N. 2006, Identification of archaeological buried remains based on Normalized Difference Vegetation Index (NDVI) from Quickbird satellite data, *IEEE Geoscience and Remote Sensing Letters*, vol. **3**(3), pp. 325-328 [ISSN: 1545-598X] [doi: 10.1109/LGRS.2006.871747]



Satellite pictures acquired on August available from Google Earth





$$\alpha=48-52^{\circ}$$

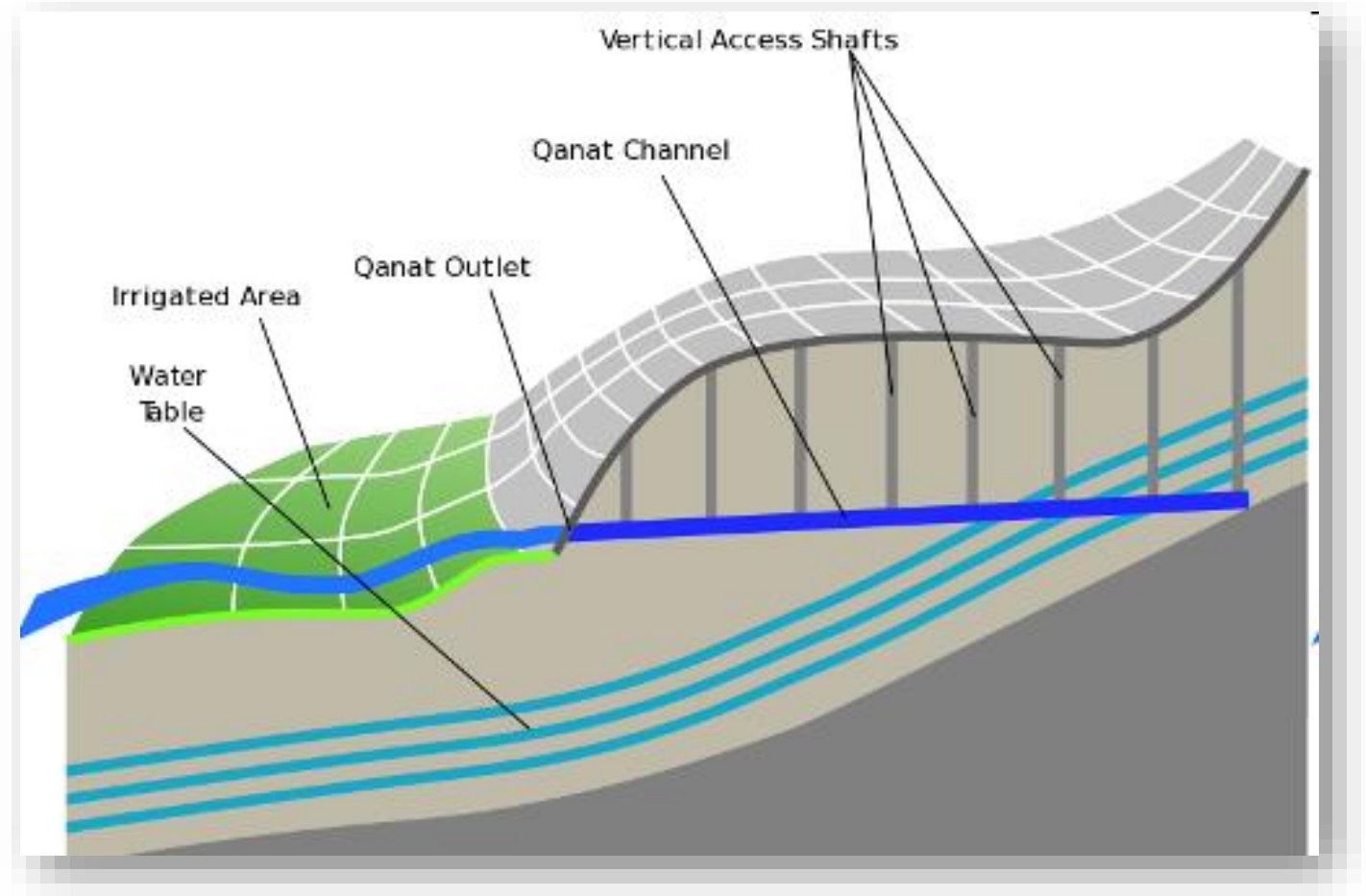
$$d=180-240 \text{ m}$$

Modern use of Ancient water management systems

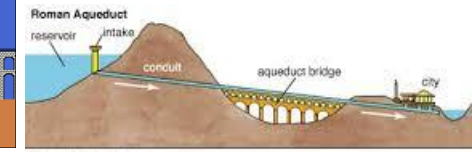
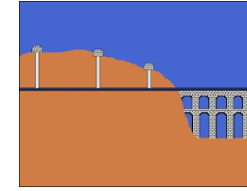
❑ Some populations in Middle East and South America still use old water management systems which provided a reliable supply of water for human settlements and [irrigation](#) in hot, [arid](#) and semi-arid climates.

❑ **Examples: *Qanats*** in Iran,

❑ These systems are based on a network of horizontal sloping tunnels and vertical wells to retrieve groundwater.



Roman aqueducts



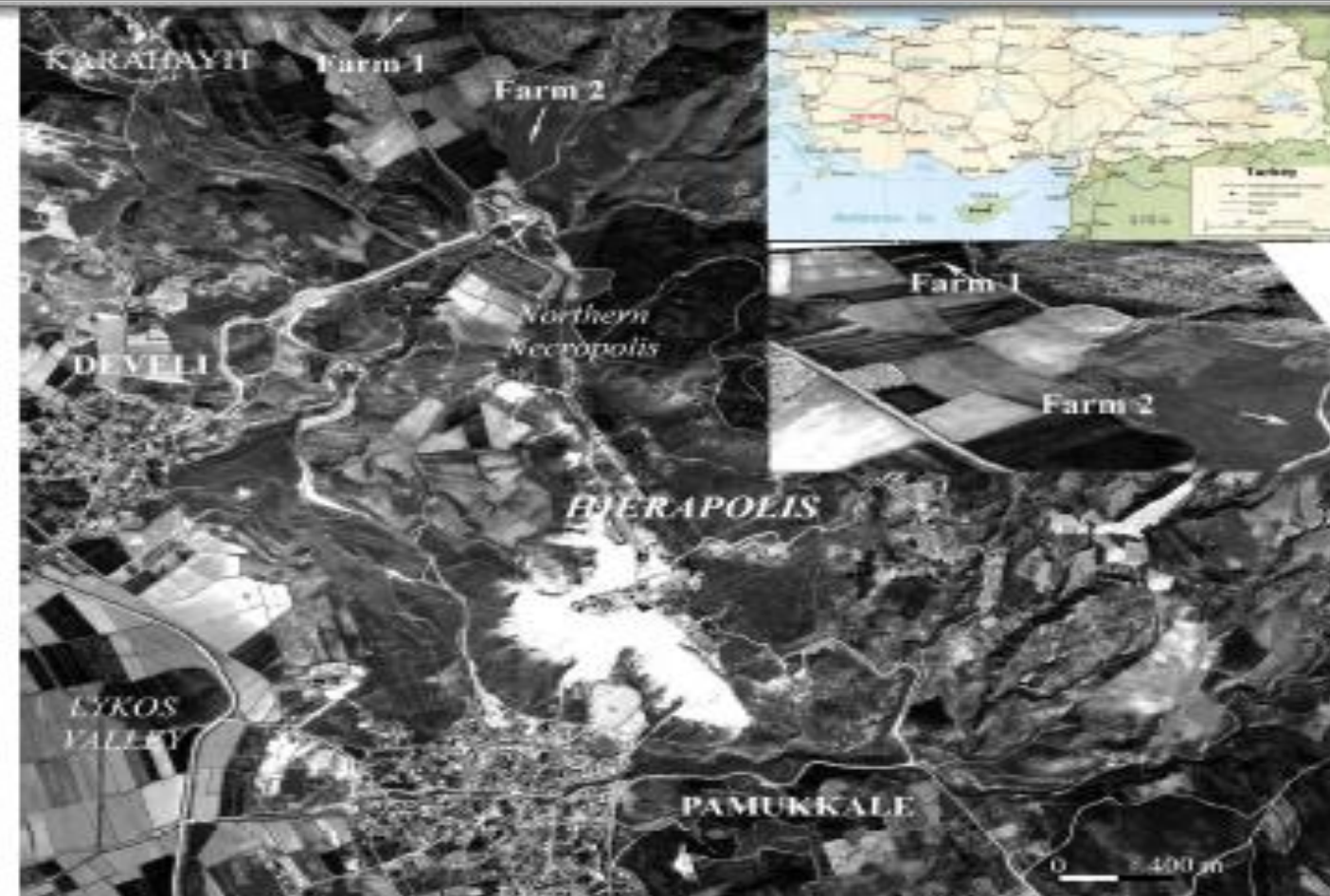
□ **Roman rural villa:** Reduction of costs, time and risk associated with archeological excavations;



Detail of the site. In evince fragments of travertine blocks, tiles, coarse ware and dolia which permitted to attribute the building to a farm and to date it to a period between the early Imperial Roman and the proto-Byzantine age

Lasaponara R, G Leucci, N Masini, R Persico, G Scardozzi 2016 [Towards an operative use of remote sensing for exploring the past using satellite data: The case study of Hierapolis \(Turkey\)](#) Remote Sensing of Environment 174, 148-164

Satellite-based archaeological research in the ancient territory of Hierapolis (Turkey)



Lasaponara R, G Leucci, N Masini, R Persico, G Scardozzi 2016 [Towards an operative use of remote sensing for exploring the past using satellite data: The case study of Hierapolis \(Turkey\)](#) Remote Sensing of Environment 174, 148-164

□ Roman rural villa:

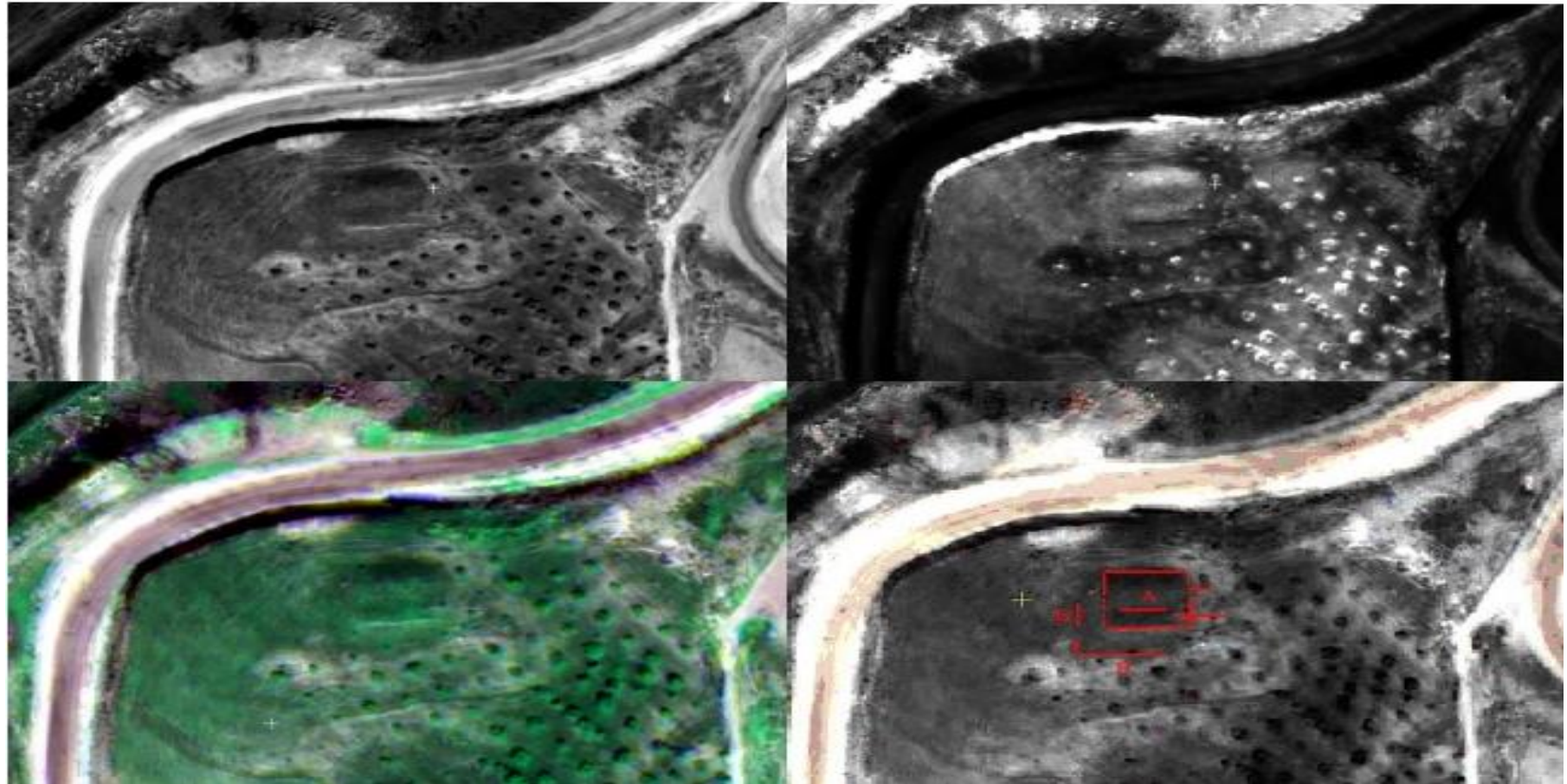


Figure . (a) QB panchromatic image; (b) PC1 component; (c) RGB composition (R=red; G=NIR, B=pan); (d) spatial characterization..

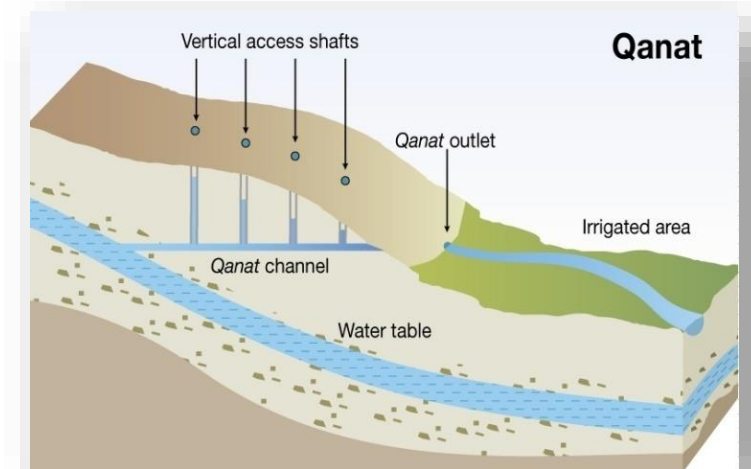


The circles indicate all the rural settlements discovered by means the integration of satellite based processing and field survey. The farm investigated in this paper is white circled.

Lasaponara R, G Leucci, N Masini, R Persico, G Scardozzi 2016 [Towards an operative use of remote sensing for exploring the past using satellite data: The case study of Hierapolis \(Turkey\)](#) Remote Sensing of Environment 174, 148-164

Water management, shortage and retrieval: Ancient problems

Archaeological evidences of early environmental manipulation such as, irrigation and artificial wet agro-ecosystems, have been found, throughout the world, even in areas where the natural rainfall was insufficient to support agriculture, as in Middle East, North Africa, Cina, South America



Qanat in Iran

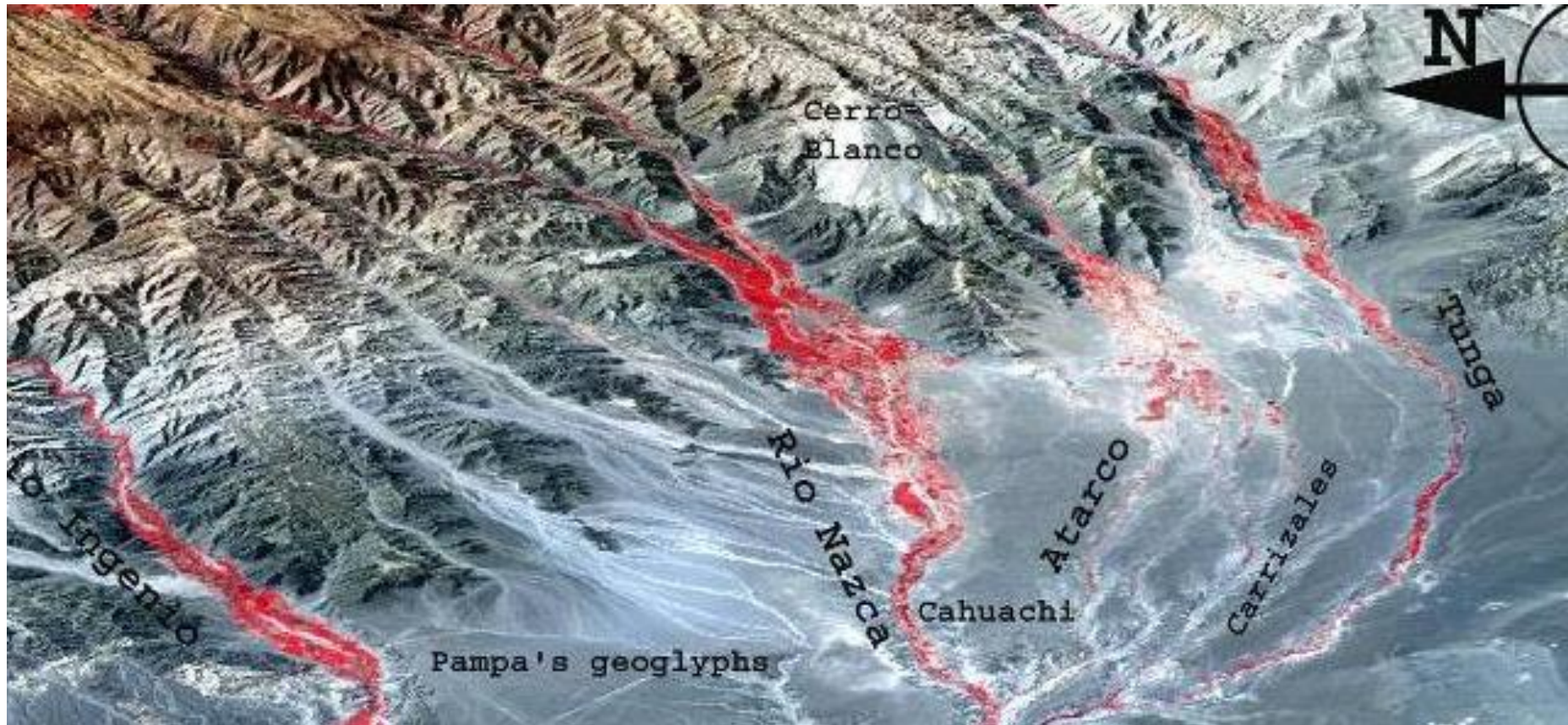


Irrigation canals in Northern Peru

The challenge of the Nasca in the most arid desert in the world



The desert drainage basin of Rio Grande de Nazca



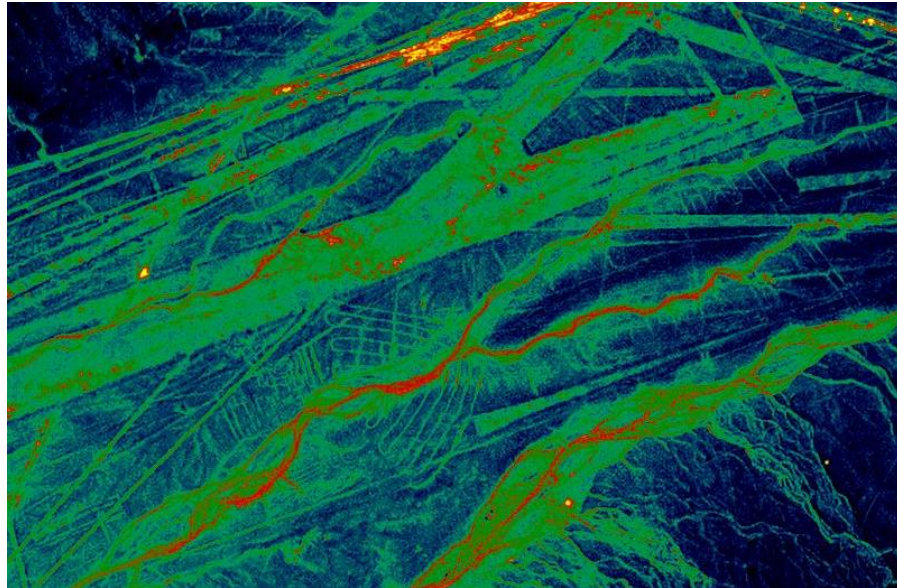
3d Aster false colour composition of Nazca drainage basin



Who were the Nasca?



Monumental architecture : Pyramids of Cahuachi



Geoglyphs



Polychrome pottery and other artifacts

- **Chronology** : 200BC-600 AD
- **Area of influence** : desert southern coast of Peru
- **Cultural patterns/features** : Geoglyphs, ceremonial architecture, polychrome pottery, textiles, musical instruments
- **Historical phases**: 8 (Nasca1,2,3..8) – pottery seriation

Lasaponara R., Masini N., Rizzo E., Orefici G. 2011. New discoveries in the Piramide Naranjada in Cahuachi (Peru) using satellite, Ground Probing Radar and magnetic investigations, *Journal of Archaeological Science*, 38, 2031-2039, doi:10.1016/j.jas.2010.12.010.

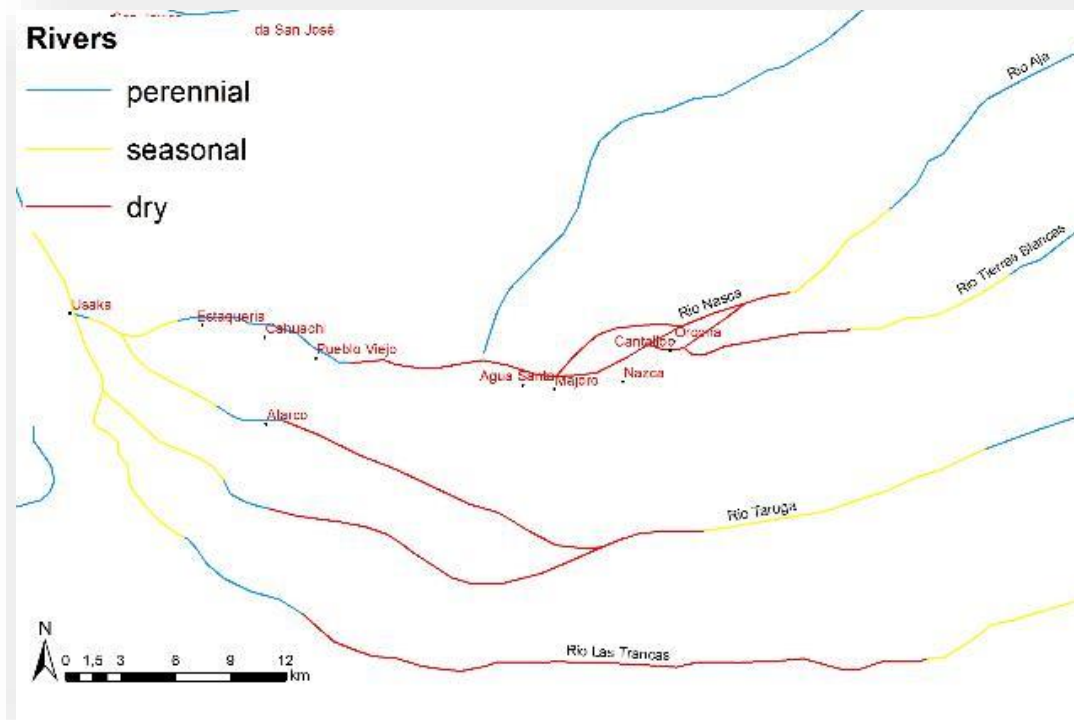
The desert drainage basin of Rio Grande de Nazca : geography, geology and climate

❑ **Location:** close to the Andean foothills composed of Jurassic and Cretaceous formations on a Pre-Montane desert formation near the coastline,

❑ **geologically** located on Quaternary sedimentary rock formations.

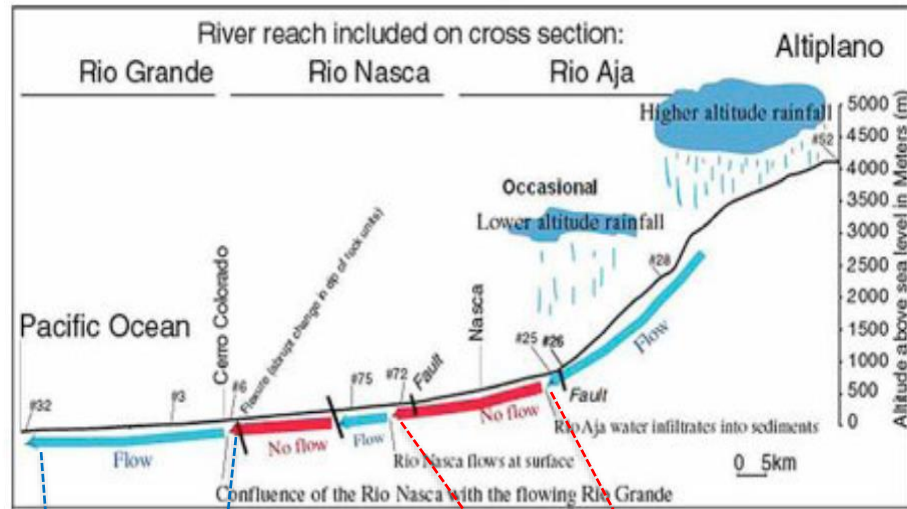
❑ **Climate:** The area is one of the most arid areas of the world due to the confluence of a cold ocean current (the Humboldt Current) along with other climatic factors

❑ The **geomorphology** of the coastal desert, has been shaped by the drainage basin of the Río Grande composed of eight tributaries with different hydraulic regime (**perennial, ephemeral, dry**)

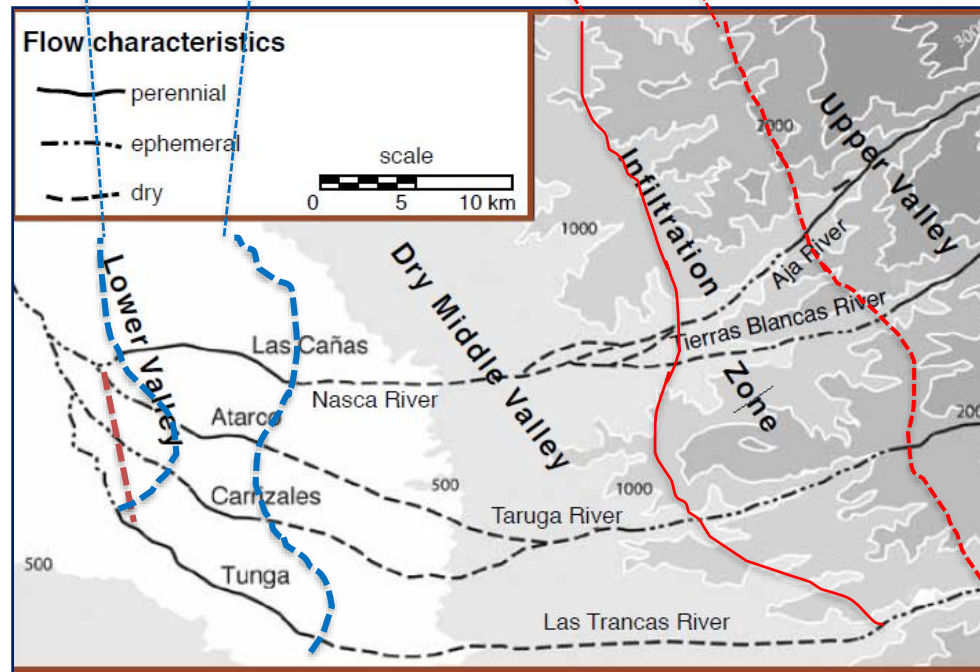


The drainage basin of Rio Grande de Nazca from Landsat ETM+: band 1.

Water: the problem of Nazca (1)



Profile after Carlson 2002



The lack of water was (and still is) due to main causes

the scarce pluvial precipitations

high infiltration capacity, and the consequent yearly significant reduction of the surface water

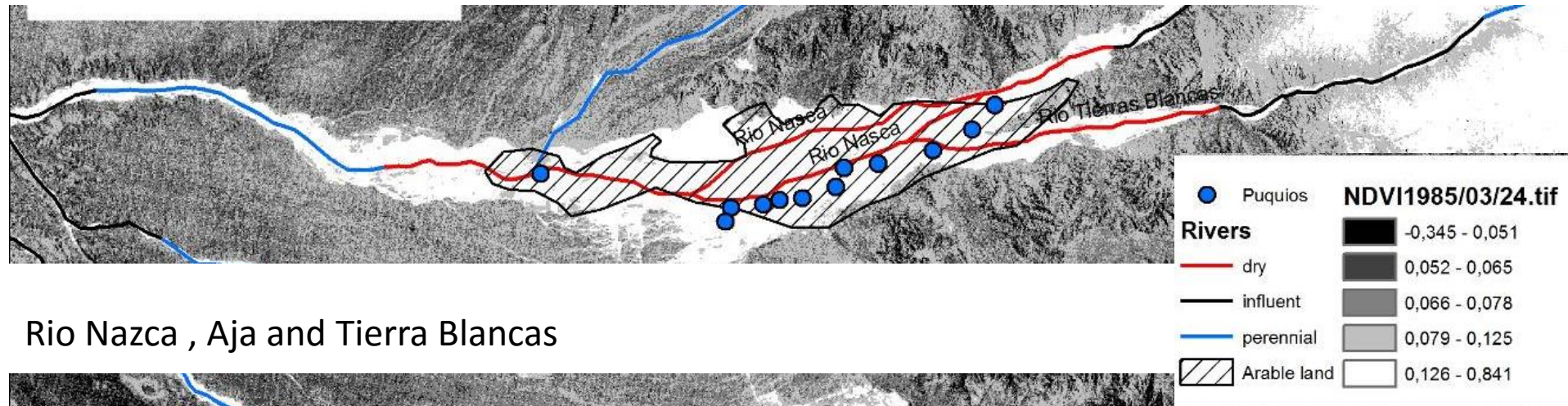
The peculiarity of the Nasca environment

Where water flows the agriculture is not possible

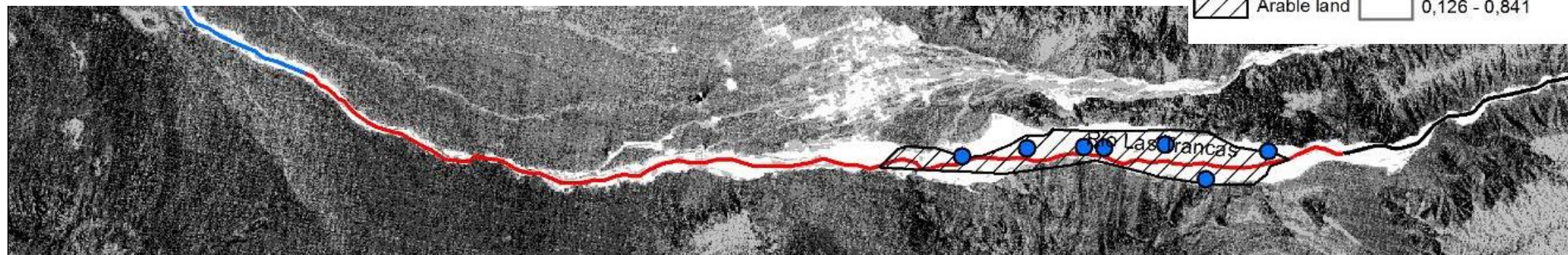
Where the **river is perennial** the arable area is **little** or the land is **not adapt** for agriculture ($H > 1000$ mt; $400 < H < 500$ mt)

Where the land is **adapt** for agriculture ($400 < H < 720$ mt)) the hydraulic regime is dry or seasonal

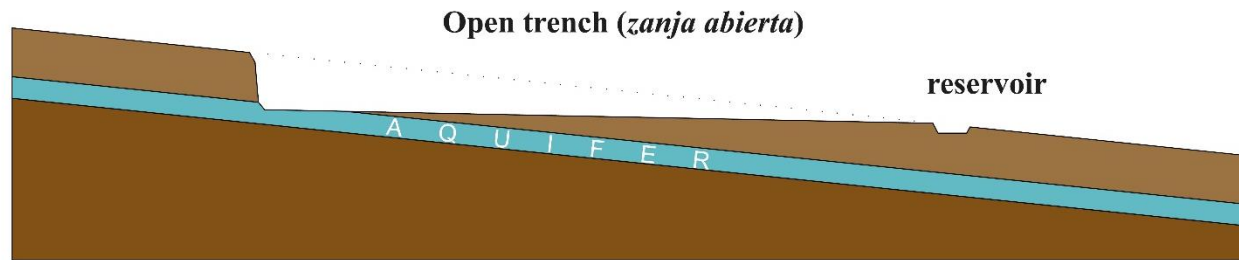
Rio Nazca , Aja and Tierra Blancas



Rio Nazca , Aja and Tierra Blancas



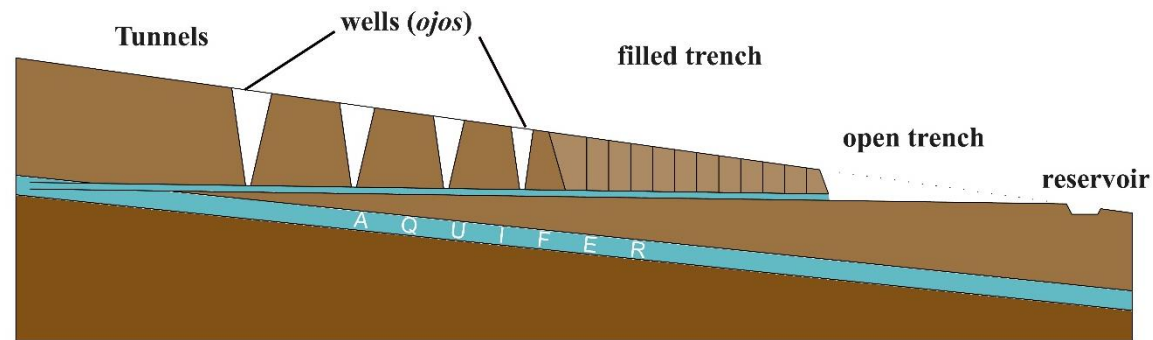
The puquios of Nazca : building features



puquios with the shape of open trenches

puquios with the shape of open trenches with borders usually covered by pebbles, have generally a base of approximately one-meter width but they spread on the surface around 10 meters or more. Some trench-shaped *puquios* present multiple branches, but their common feature is having just one canal.

puquios trench galleries (**zanja llenada o socavòn**) with extension of tunnels (**extencion tonelada**) characterized by greater length and depth compared to the open trenches. The *puquios*, built with shape of tunnels, can measure up to 10 meters of width, and they generally present a large part of their branches covered, thus creating “filled trench galleries”



puquios trench galleries with extension of tunnels

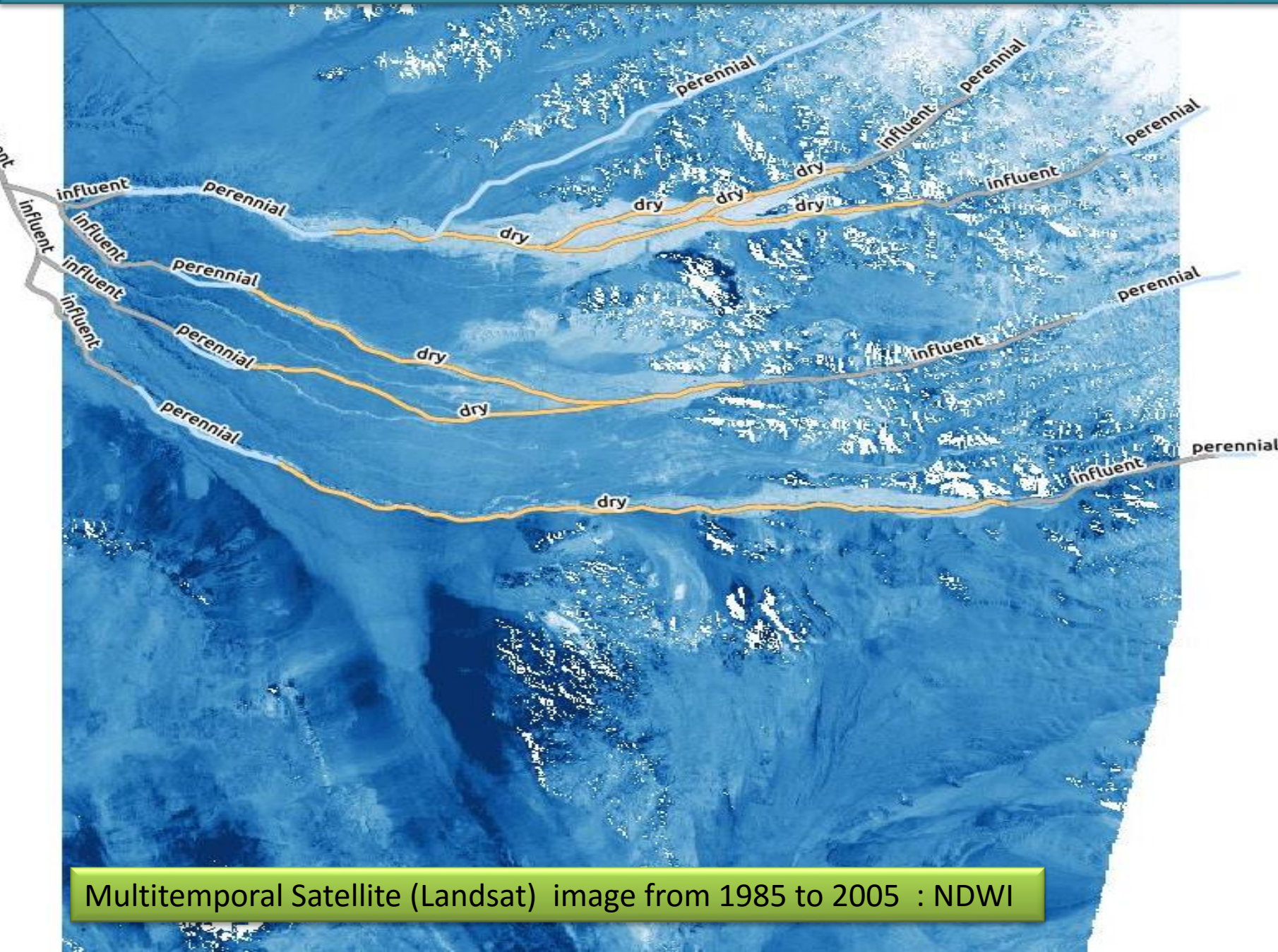
The puquios as response of Nasca to water problem



The *puquios*

Efficient water system composed of horizontal wells or open trenches which allowed to connect a point above the land surface with the underground table, thus making possible to have water available for the whole year not only for irrigation but also for domestic needs.

Hydraulic Regime of Nasca river and its tributaries

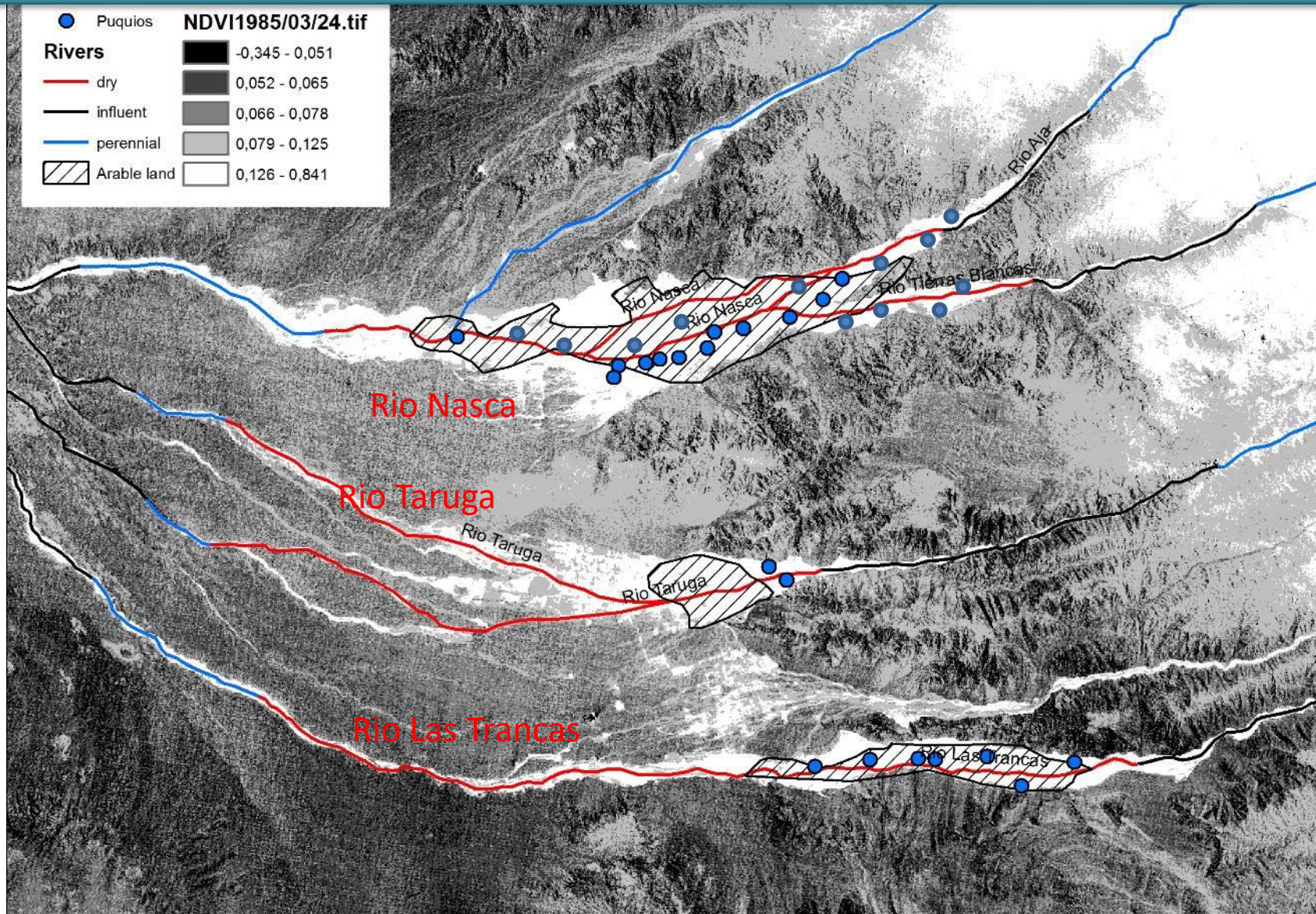


NDWI (Normalized Difference Water Index) is computed to estimate moisture content for both soil and vegetation, by using also SWIR bands, according the formula

$$NDWI = \frac{(RED - SWIR)}{(RED + SWIR)}$$

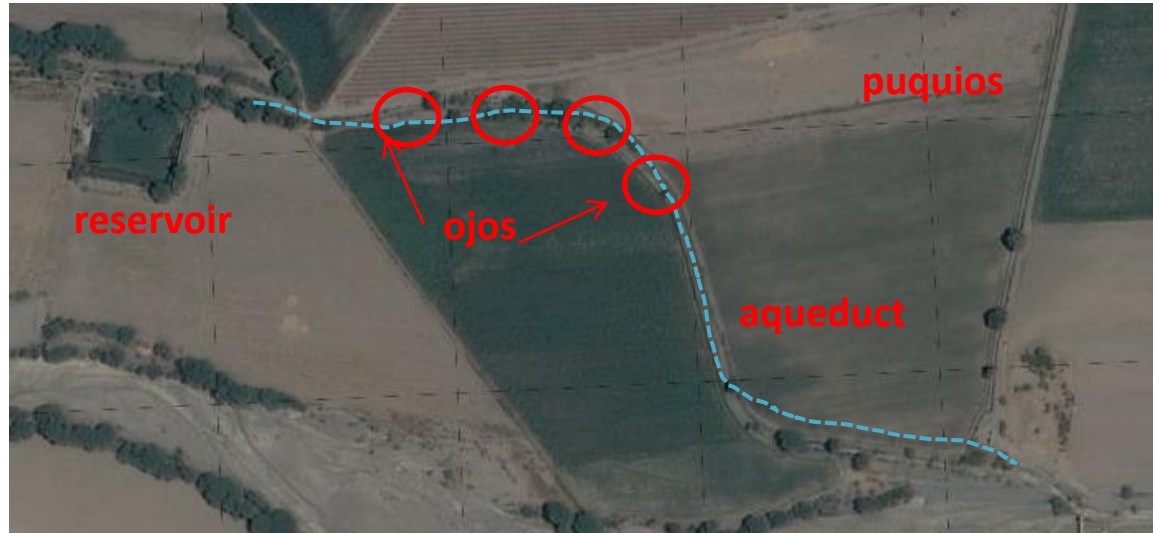
Multitemporal Satellite (Landsat) image from 1985 to 2005 : NDWI

Map of puquios



There are **36 puquios** still functioning in the Nasca drainage today, **29** in the Nasca Valley, **2** in the Taruga Valley, and **7** in the Las Trancas Valley

The puquios as response of the Nasca to water problem

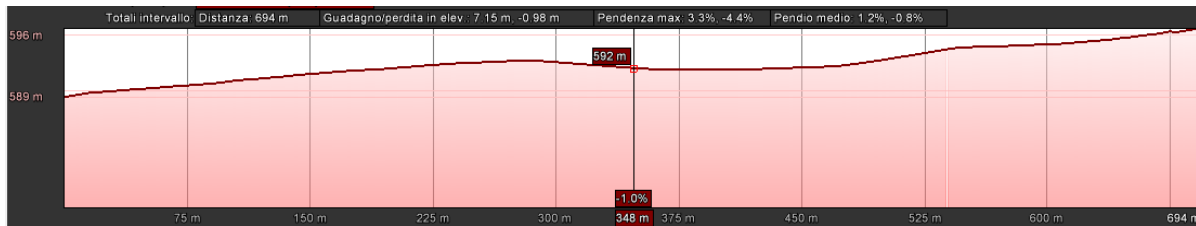


Puquio de Cantallos : detail of circular chimney



Rio taruga valley, Puquio de Santa Maria : detail of square chimney

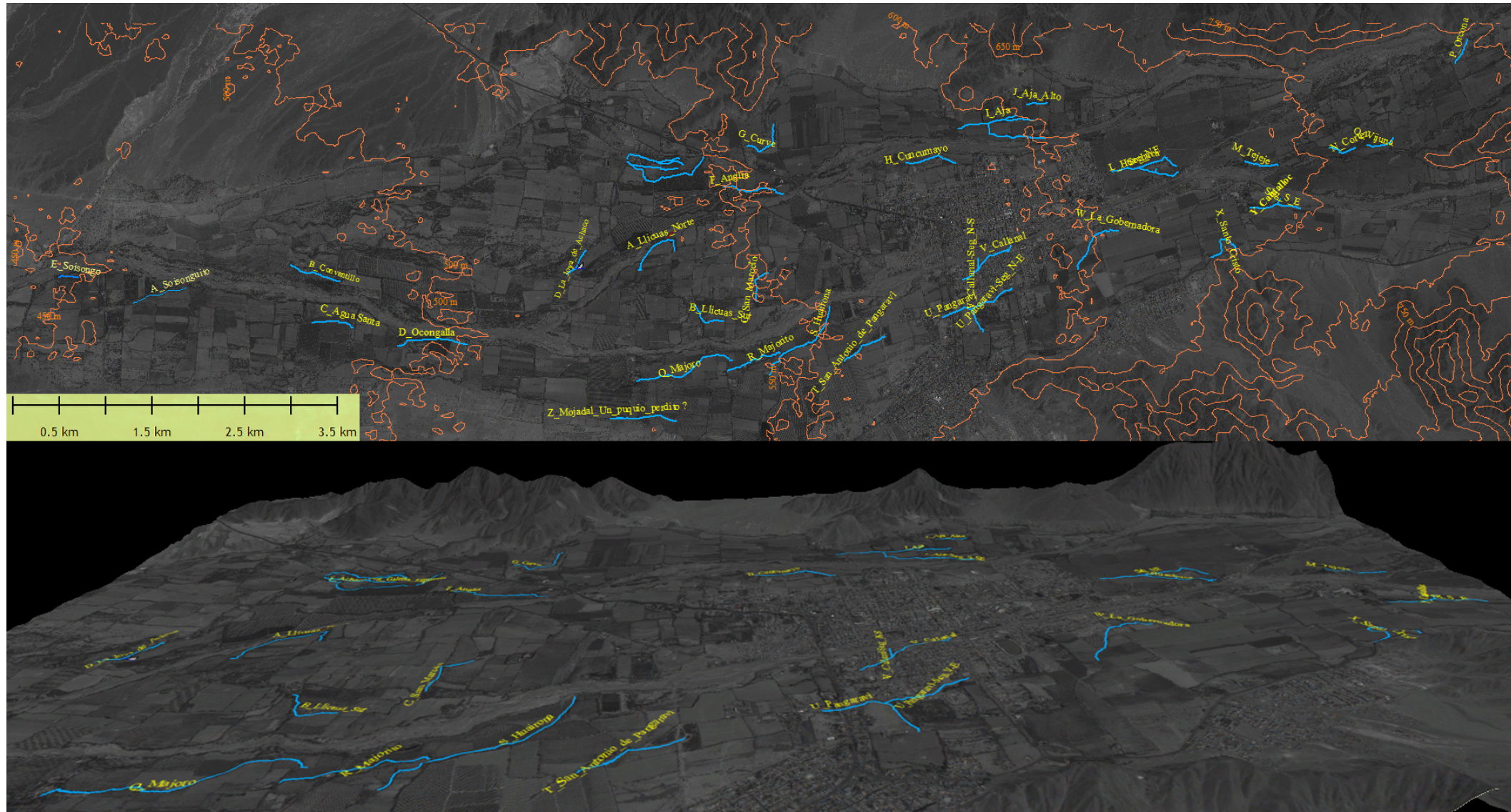
All along the galleries and at different points there are openings, also called chimneys, or more commonly, *ojos* (eyes) which allow the access to the galleries for their annual cleaning as well as the entrance of air. The shape and dimensions of the *ojos* vary accordingly to the way the galleries were built. Finally, most *puquios* flow to small reservoirs or *cochas* in their lowest extremes, right where water is directed to the irrigation streams or canals.



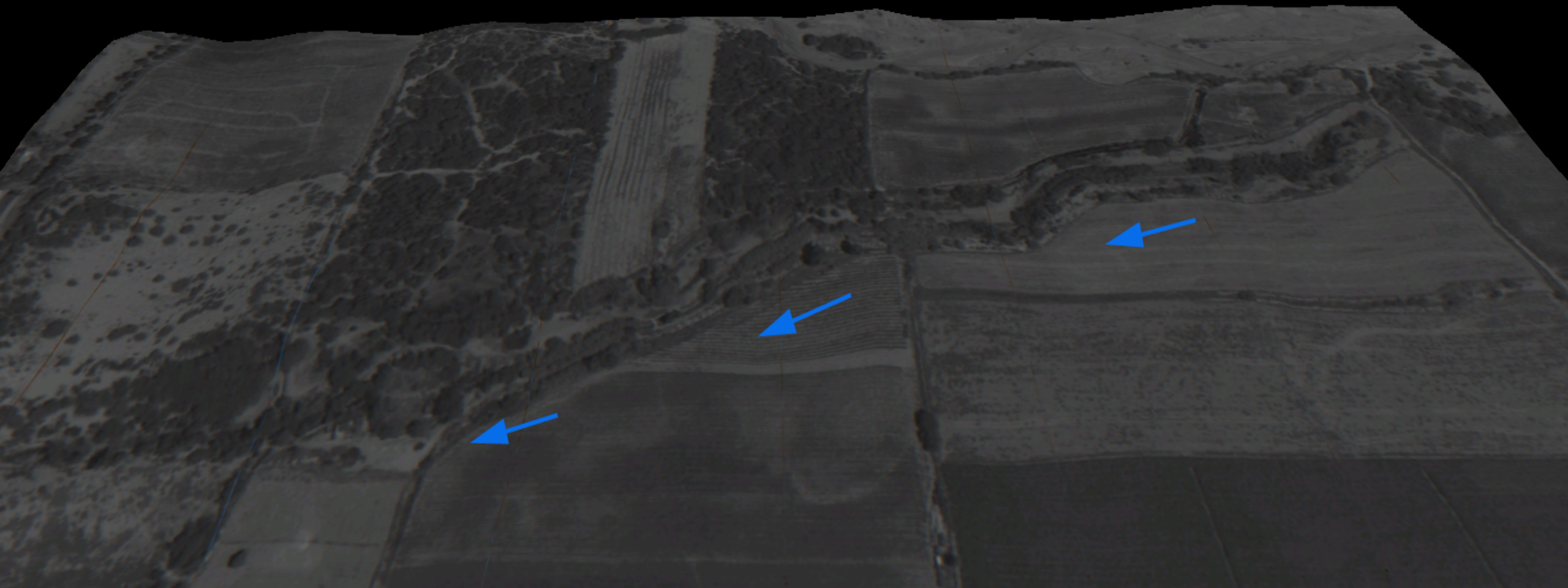
Las Trancas valley, puquio de Copara

The empirical knowledge of the different degree of soil permeability allowed them to create drainage tunnels to over 10 m deep

Map of puquios in Rio Nasca valley (n.29)



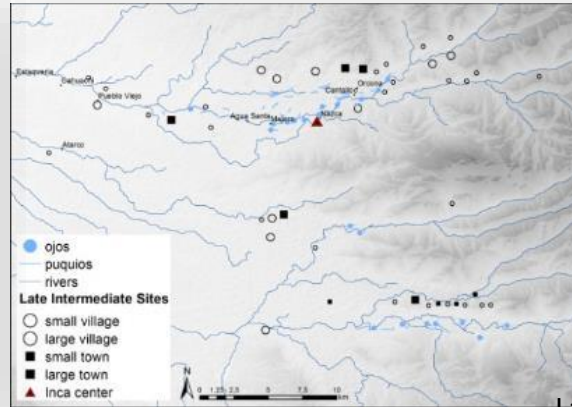
Puquio of Songuito in the Nazca river valley



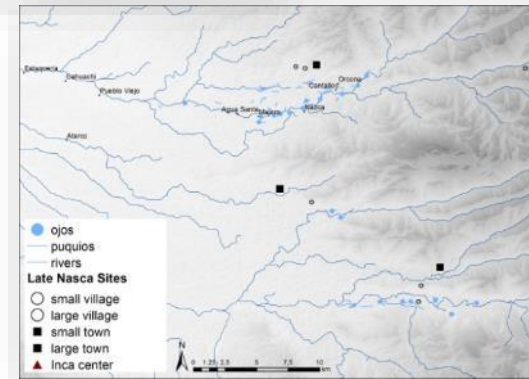
Our approach : Puquios and settlement pattern evalutaion

Numerical Dates	Nasca Valley Chronology	Standard Chronology	Uncalibrated Dates
A.D. 1532	Late Horizon	Late Horizon	A.D. 1000
A.D. 1476	Late Intermediate	Late Intermediate 1-10	
		4	
		3	
	Middle Horizon	Middle Horizon	A.D. 800
		2	
		1b	A.D. 650
A.D. 750	Late Nasca	8	
		7	
		6	
	Nasca 5	Intermediate 5	A.D. 450
A.D. 400	Early Nasca	4	
		3	
		2	
A.D. 1	Montana Phase	1	100 B.C.
		10	
	La Puntilla Phase	Early	9
		Horizon	8
		7	
		6	

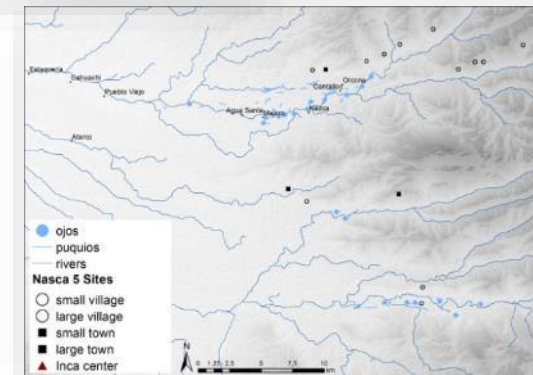
Late Intermediate (1000-1476)



Late Nasca

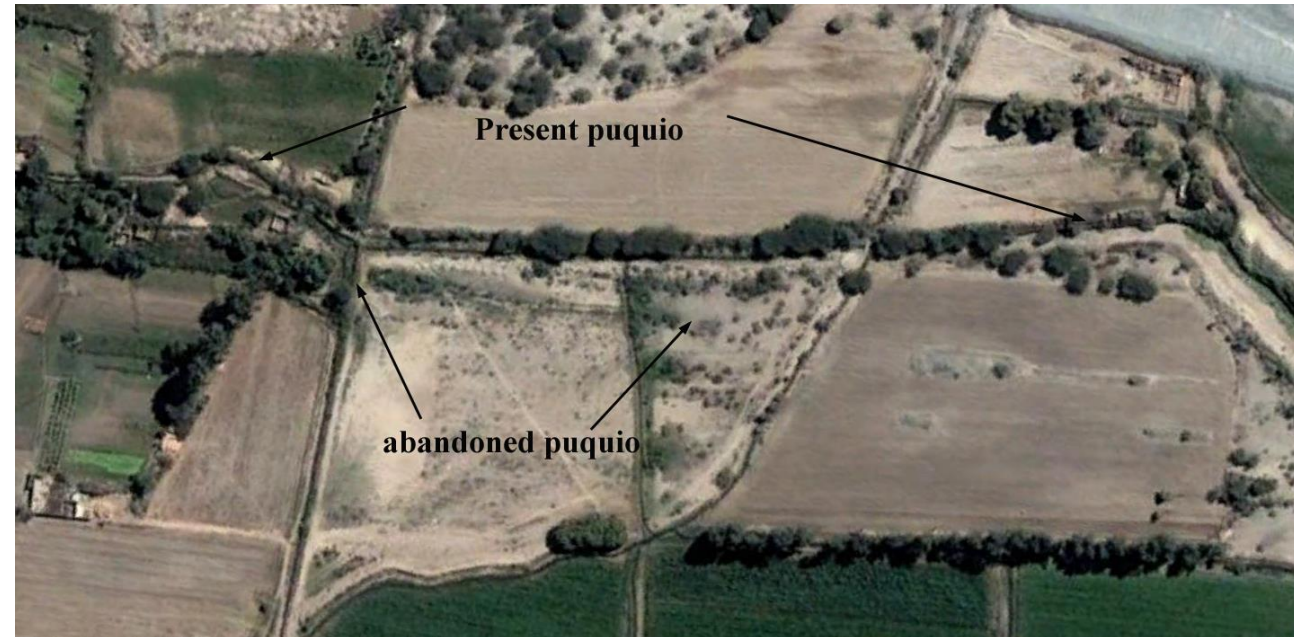


Nasca 5

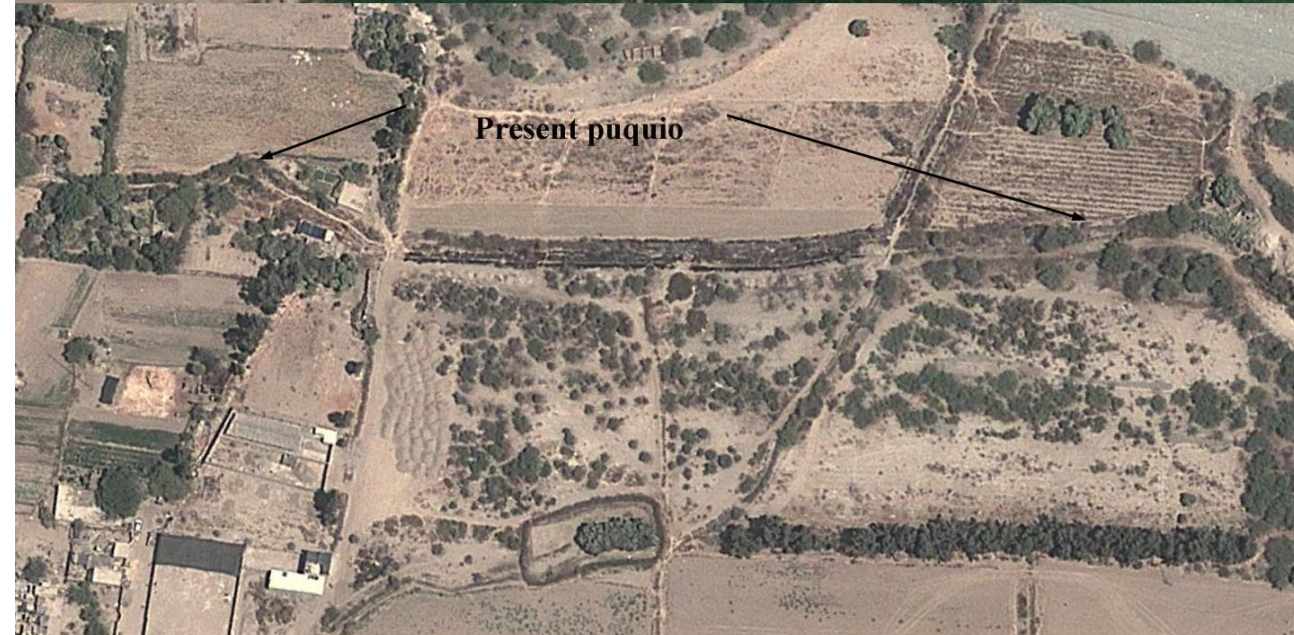


Other approach: detection of abandoned puquios or parts of puquios

2002

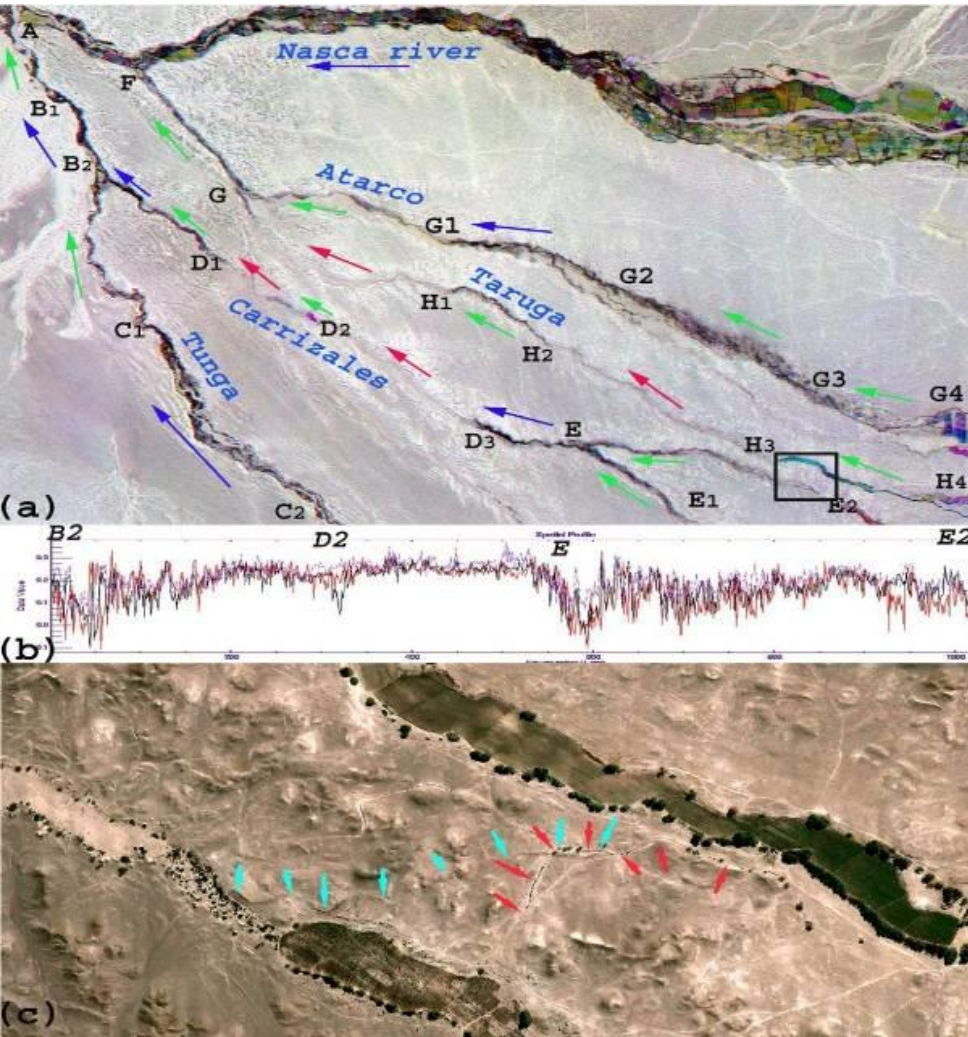


2013



Discovery of a “puquio perdido” (lost aqueduct) by satellite multitemporal data processing and geophysics

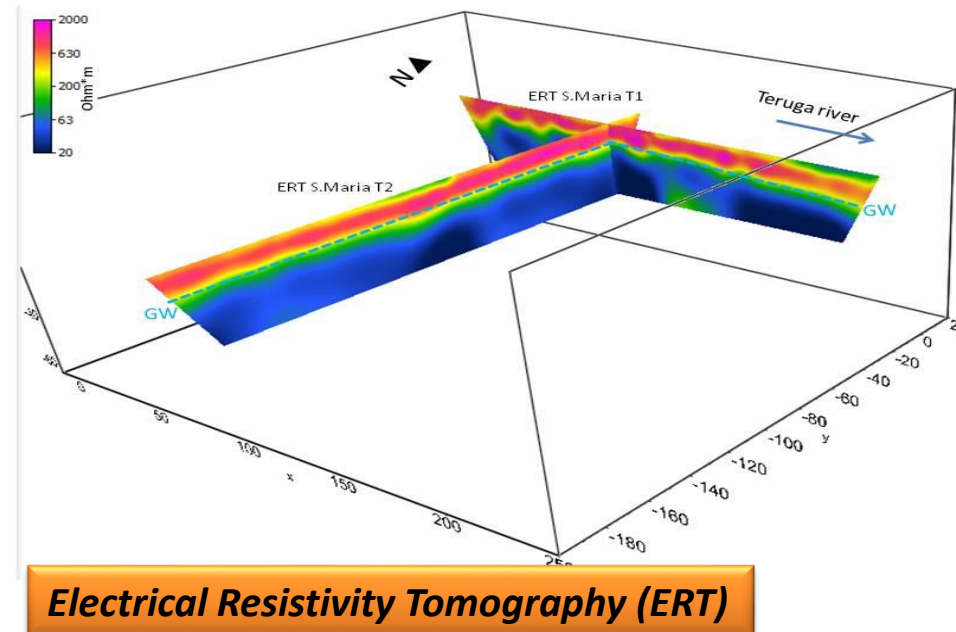
The temporal variation of NDWI and NDVI are in agreement



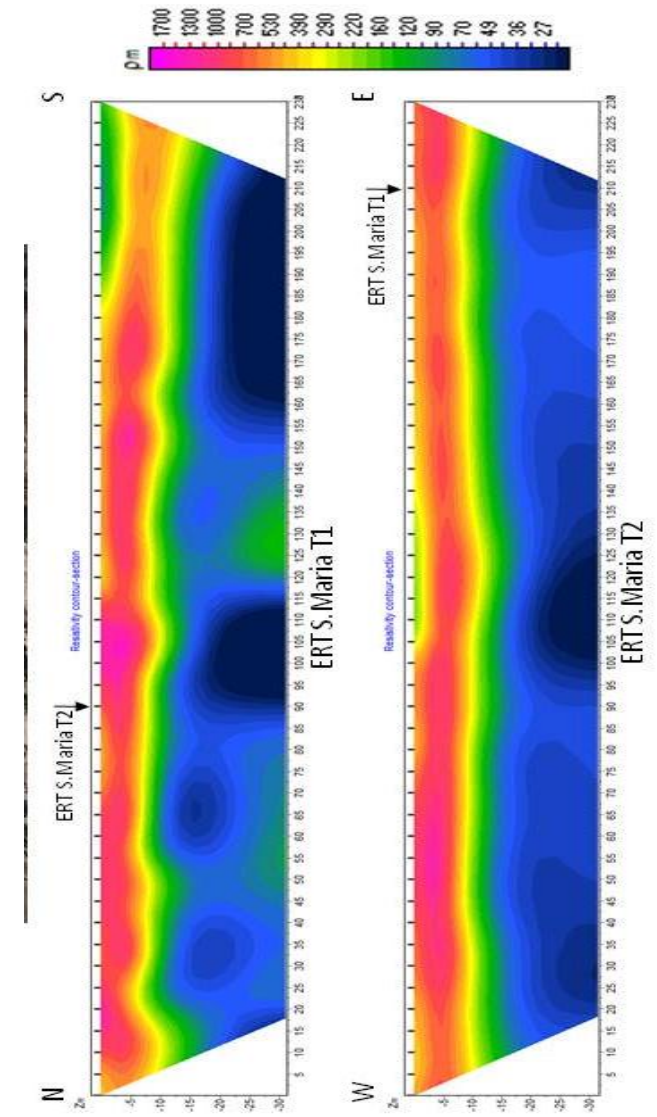
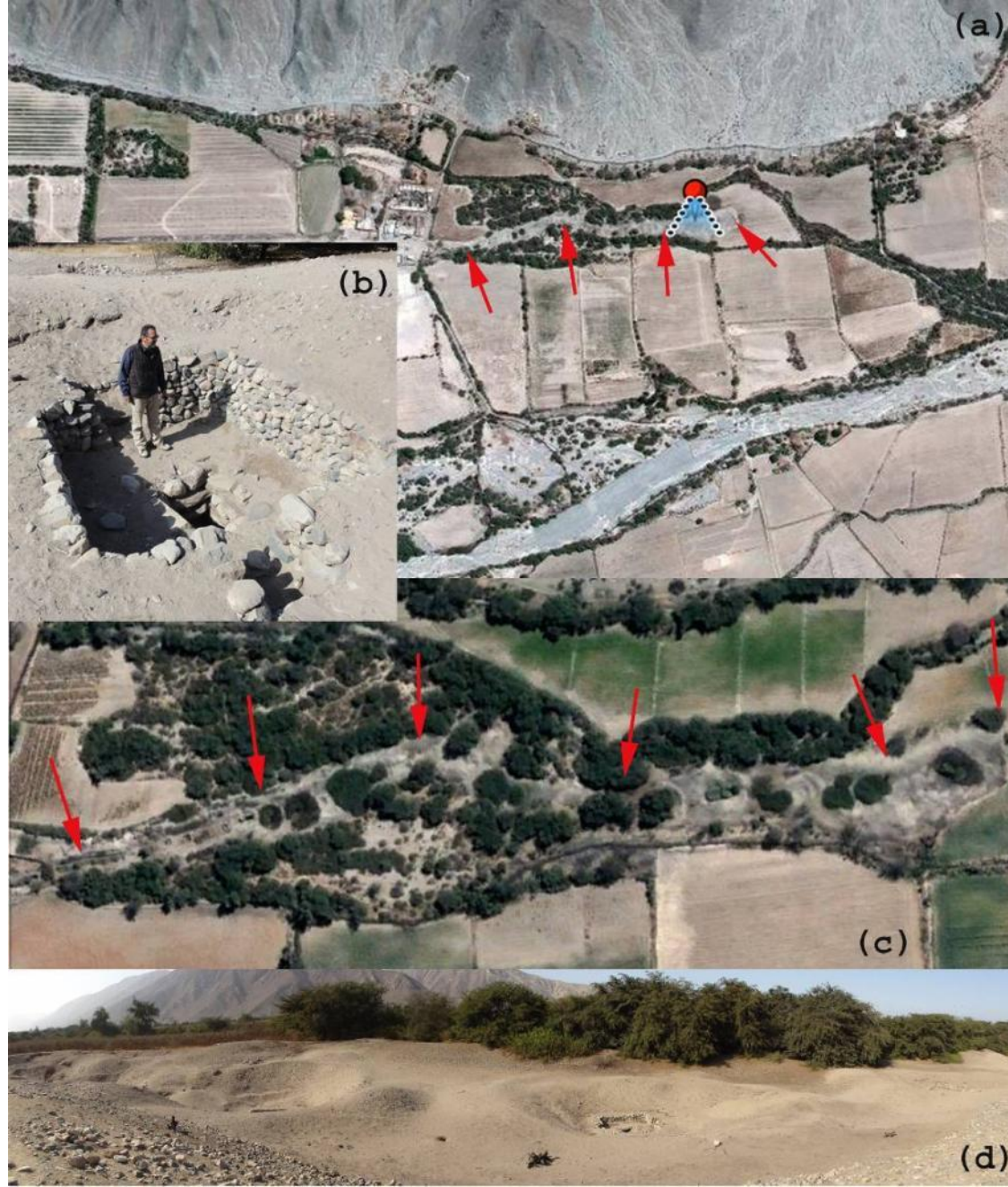
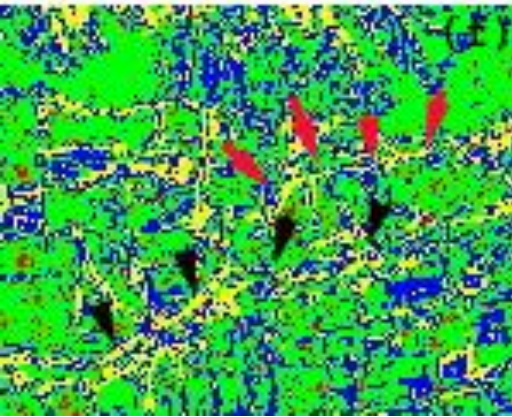
(a) RGB of NDWI provides information on the hydraulic regime (perennial, ephemeral, dry) of the four stream tributaries of the Nasca river.

(b) Spatio/temporal profile of NDWI ASTER Index of the Carrizales which allowed us the different hydraulic characteristics.

(c) Two disused puquios identified from a GeoEye scene in an area located between Carrizales and Taruga where the hydraulic regime is ephemeral, as shown by the analysis of ASTER data.



Discovery of a “puquio perdido” (lost aqueduct) by satellite multitemporal data processing and geophysics

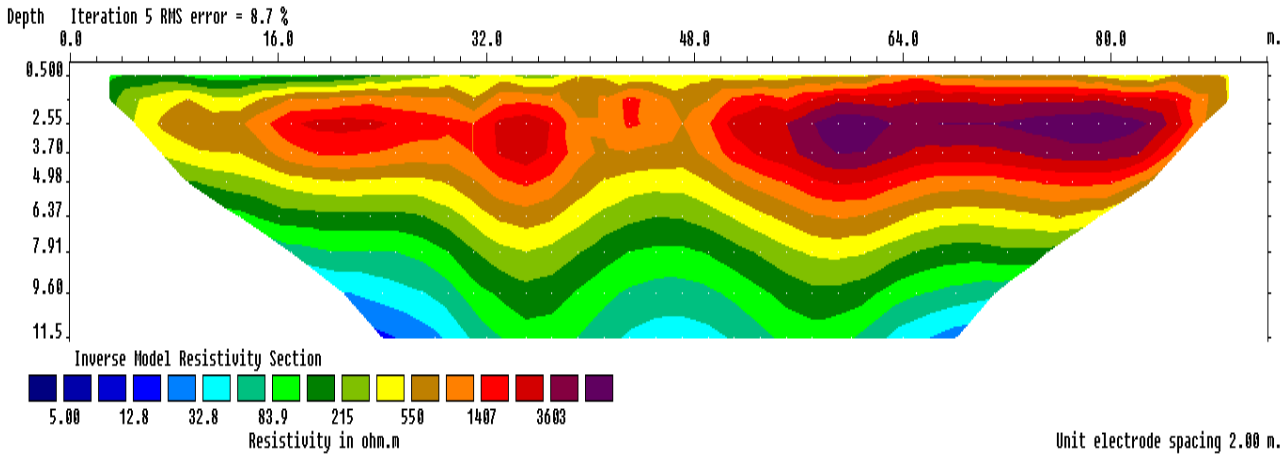


Field trip December 2013 in Cahuachi (Perù)

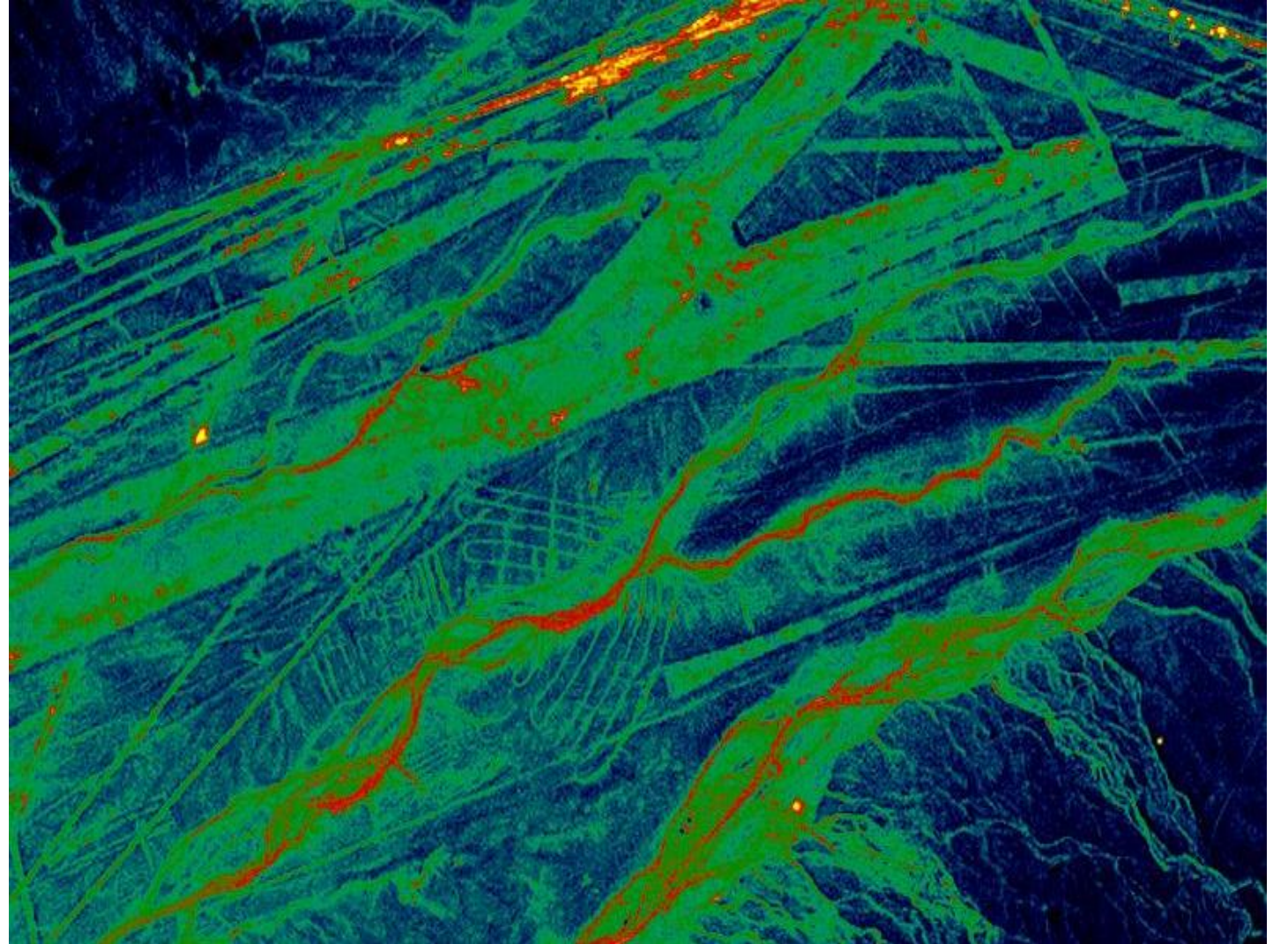
Electrical Resistivity Tomography (ERT) in Cahuachi site for groundwater research activity



Cahuachi well



Nasca lines and puquios



Conclusion

Satellite remote Sensing

Satellite data enables us:

--To characterize the hydrological regime of the area

--to discover new puquios

--to characterize their spatial distribution
in relation to urban settlements

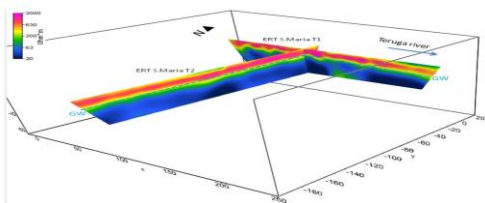
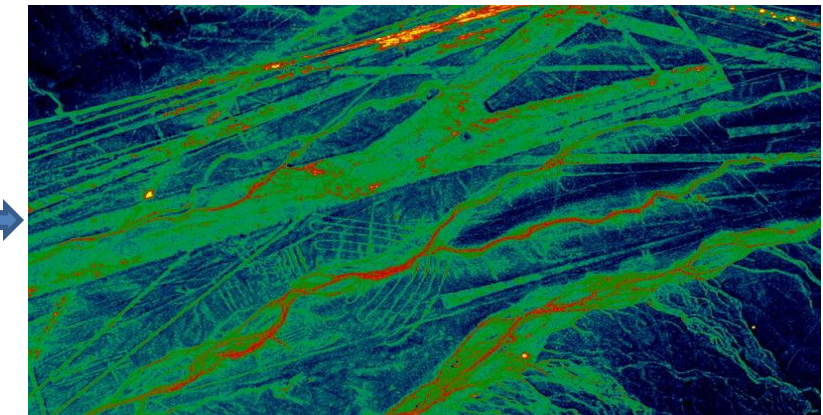
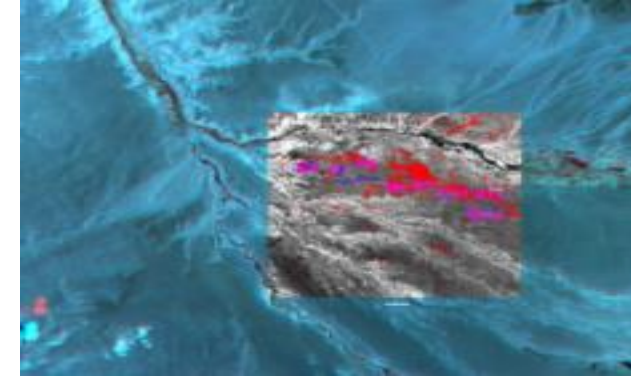
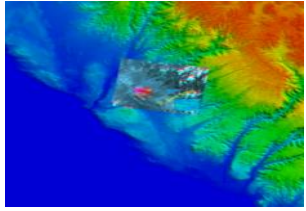
UAV

"drone remote sensing"

--to improve the knowledge
About the relationship
between puquis and Nasca lines

"Ground" remote Sensing

--to fully characterize them
--to support local communities
-- valorization



From regional perspective to site view

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The ancient Peruvian mystery solved from space

com/future/story/20160408-the-ancient-peruvian-mystery-solved-from-space

By William Park
8 April 2016

In one of the most arid regions in the world a series of carefully constructed, spiralling holes form lines across the landscape. Known as puquios, their origin has been a puzzle – one that could only be solved from space.

The holes are from the Nasca region of Peru – an area famous for **the Nasca lines**, several enormous geometric images carved into the landscape; immaculate archaeological evidence of ceremonial burials; and the rapid decline of this once flourishing society.

What adds to the intrigue in the native ancient people of Nasca is how they were able to survive in an area where droughts can last for years at a time.

The puquios were a “sophisticated hydraulic system constructed to retrieve water from underground aquifers,” says Rosa Lasaponara of the Institute of Methodologies for Environmental Analysis, in Italy. And they transformed this inhospitable region.

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Linee di Nazca, Lasaponara: "Dominavano il territorio"

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The ancient mystery of spiralling holes across Peru has been solved with the use of satellite images

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Peru's spiralling holes mystery has been solved

Matthew Dunn, [news.com.au](#) @mattydunn11

THE ancient mystery of spiralling holes carefully constructed across the barren valleys of southern Peru has finally been solved by a researcher.

Known as puquios, the holes are located in the Nasca region of Peru — a location famous for gigantic geometric images carved into the landscape.

While the origin of these formations remained unsolved for years, the use of satellite

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Peru's Puquios May Have Been Part of a Nazca Water System

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Tuesday, April 19, 2016



POTENZA, ITALY—Rosa Lasaponara of the Institute of Methodologies for Environmental Analysis and a team of researchers used satellite images to study puquios, the spiral-shaped holes thought to have been constructed between 1000 B.C. and A.D. 750 by the same people who created the Nazca geoglyphs. The distribution of the holes across the arid region, and their positions near settlements, suggests that they were part of a sophisticated

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Wikipedia article page for Puquios, showing the full content. The browser shows the URL https://en.wikipedia.org/wiki/Puquios. The page includes a sidebar with navigation links (Random article, Donate to Wikipedia, etc.), a main content area with the title 'Puquios' and a note about the town in central Peru, and a search bar. The page is partially obscured by a second browser window.

Puquios

From Wikipedia, the free encyclopedia

Note: for the town in central Peru, see [Puquio](#)

The **Puquios** are an old system of subterranean **aqueducts** near the Nazca Desert in Peru, used to bring fresh water into the arid desert. The Puquios have never been fully explored.

Contents [hide]

- 1 Debate about age
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Debate about age [edit]

This section needs expansion. You can help by adding to it. (January 2011)

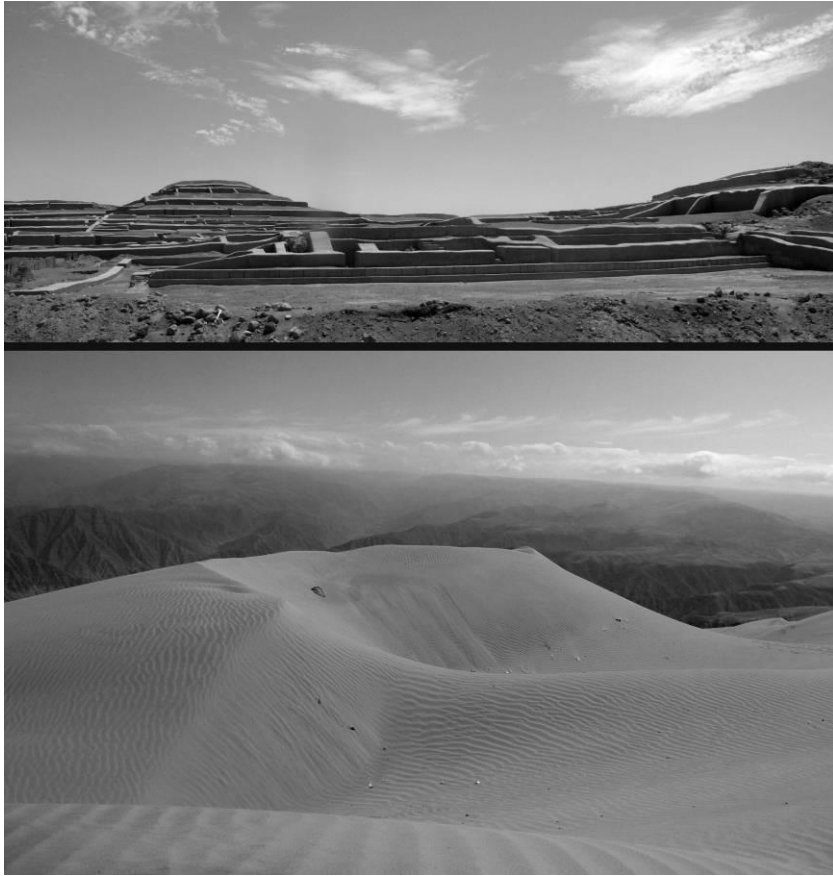
There is conflicting research regarding when the aqueducts were a response to two prolonged droughts during that time, others doubt that existence was in 1605 by [Reginaldo de Lizárraga](#), which some contend may indicate that they were built by the Spanish.^[3] There, however, is yet no evidence from Spanish texts that mentions a project to build the Puquios,^[4] nor is there evidence in early Spanish texts of water systems being already in place when they conquered the territory.^[5]

In their book *Irrigation and Society in the Peruvian Desert*, Katharina Schreiber and Josue Lanco Rojas explore puquios and show evidence that puquios were constructed by a pre-Hispanic civilization. Monica Barnes and David Fleming on the other hand, argue that Schreiber et al misinterpreted evidence and that there are easier explanations for a construction in colonial times.^[6] Some investigations have been performed to determine the age of puquios also by using radiocarbon dating of organic materials (Bonn-1972) and accelerator mass spectrometer to date rock varnishes (Clarkson and Dorn 1995). With this technique some puquios were dated to around the 6th and 7th century AD.

Satellite research [edit]

Rosa Lasaponara, Nicola Masini and their team of the Italian CNR (National Research Council), in cooperation with the archaeologist Giuseppe Orefici, studied the puquios using satellite imaging.^[8] They found clear evidence that the puquio system must previously have been much more developed than it appears today. A series of canals was used to bring to the surface water from underground **aquifers** and channel it to the areas where it was needed. Any excess was stored in surface reservoirs. To help keep the water flowing chimneys were excavated above the canals in the shape of corkscrewing funnels. These funnels admitted wind into the canals, and the difference in **atmospheric pressure** along the canal length forced the water through the system and eventually to the desired destination. By means of satellite imagery it was also possible to discover unknown puquios in the Nasca drainage basin.^{[7][9]}

References [edit]



Thank you!

