INTERNATIONAL CONFERENCE
GROUNDWATER, KEY TO THE SUSTAINABLE DEVELOPMENT GOALS
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A GIS machine learning method to map groundwater potential: insights from the Abéché and Biltine case studies, Chad

Gómez-Escalonilla, V.; Vogt, M.L.; Destro, E.; Holecz, F.; Origgi, G.; Isseini, M.; Djoret, D.; Martínez-Santos, P.

Important of Groundwater knowledge

- Water resources are fundamental for the development of human society. In the current context of climate change, it is necessary to study the availability of water resources.

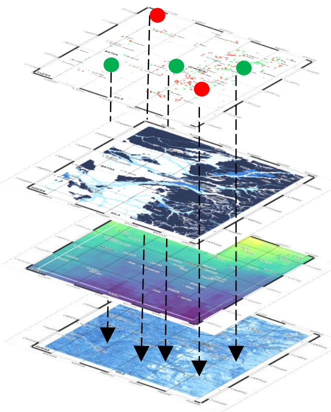
- Groundwater supply for drinking and agricultural purposes has an important role in the Abéché and Biltine area, where more than 200.000 people live.

- The geological settings along with scarce precipitation limit the storage capacities and recharge to the aquifers. However, productive wells in some specific areas encourage the identification of promising hydrogeological targets.

WHAT IS GROUNDWATER POTENTIAL MAPPING?

❖ **Groundwater potential mapping** (GPM) is gaining recognition as a tool to underpin planning and exploration of groundwater resources . GPM may be understood as a means to estimate groundwater storage in a given region, as a measure of the probability of finding groundwater, or as a prediction as to where the highest borehole yields may occur. The starting hypothesis is that the GPM can be inferred from a **series of explanatory variables spatially-distributed** and a training set of points where the outcome of the target variable is known.

❖ A **machine learning approach** based on the application of multiple supervised classifiers is proposed. A spatially-distributed set of explanatory variables (from remote sensing data and geological/hydrogeological surveys) for groundwater occurrence was compiled into a geographic information system.



Borehole data

Geology

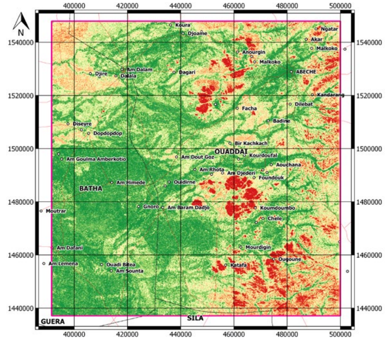
Precipitation

TWI (Topographic Wetness Index)

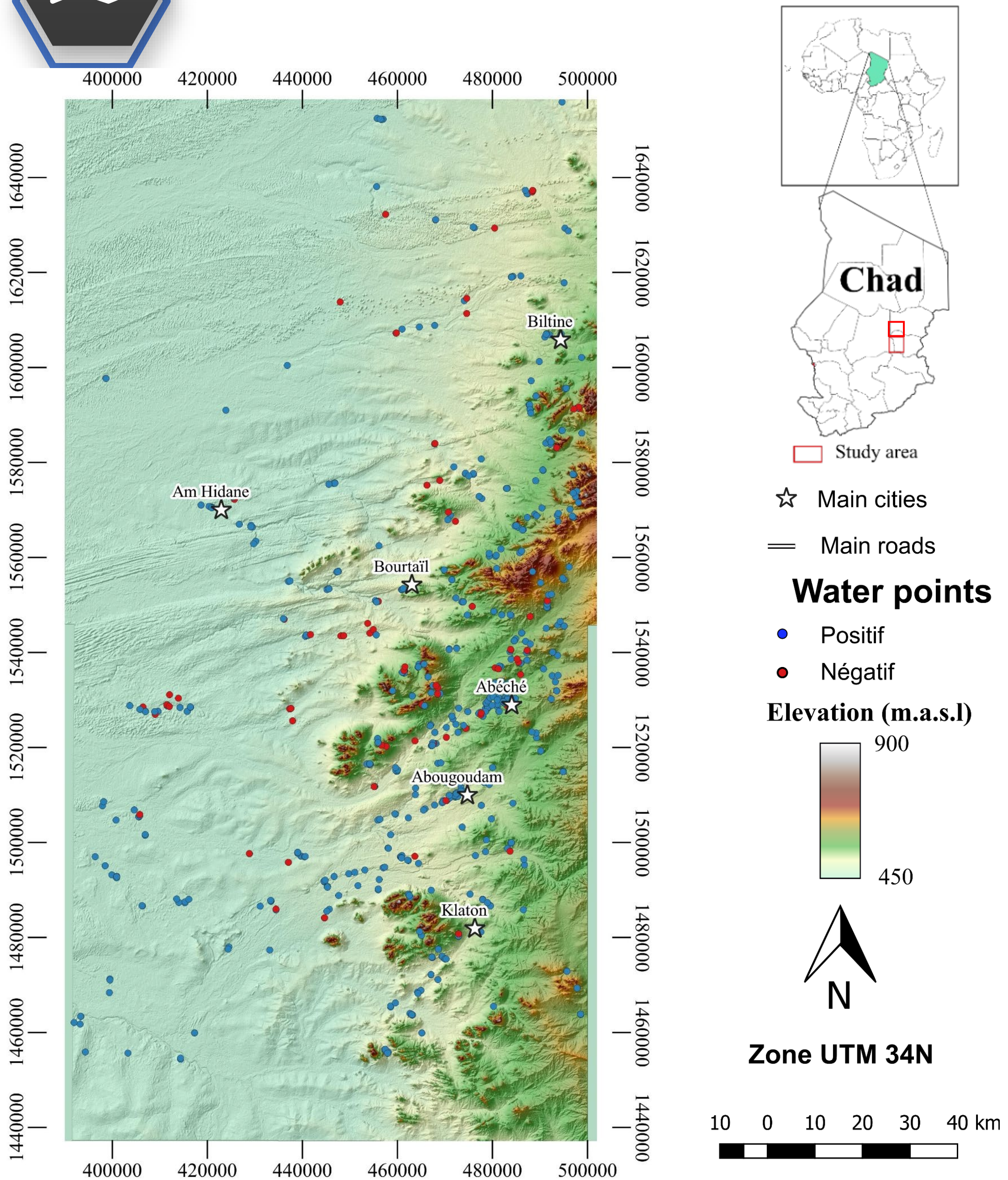
MLMapper

ML

Groundwater potential map

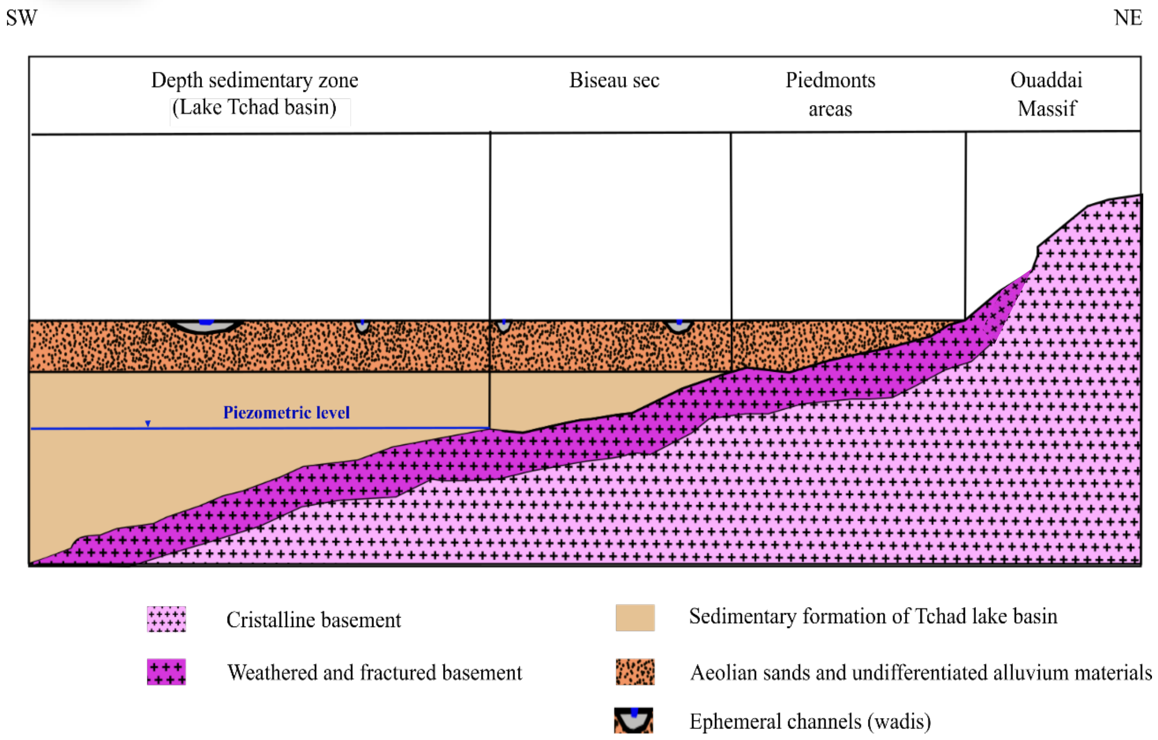


STUDY AREA



- The study area covers **24,000 km²**
- The landscape is predominantly flat in the western part (400 m.a.s.l.), hillier towards the east, where altitudes exceed 850 m.a.s.l.
- Climate is hot semi-arid
  - Mean daily temperature is 29 °C
  - Yearly rainfall amounts to 370 mm. Monthly precipitation is irregularly distributed.
- Some ephemeral streams flow only after heavy rainfall in this area from east to west.

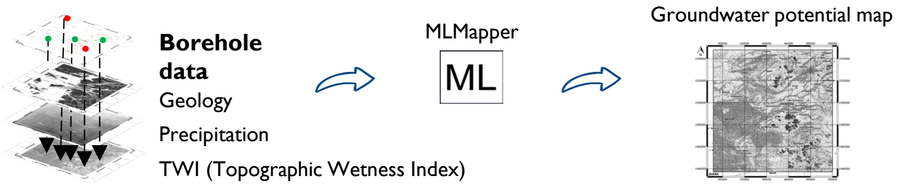
GEOLOGICAL AND HYDROGEOLOGICAL CONTEXT



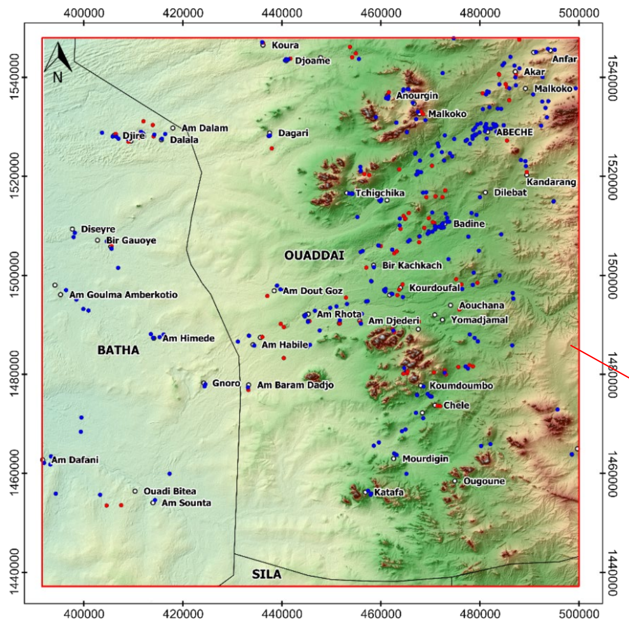
The area is characterized by:

- **Precambrian basement** (East) composed by granitic massifs. In some areas the crystalline substratum is weathered, thus resulting in low to moderate productivity aquifers.
- **Pliocene-Quaternary Chad** formation (West). Consists mostly of unconsolidated sediments, while theoretically permeable, these are largely unproductive along the contact with crystalline outcrops. The transition zone between the crystalline basement and the productive sedimentary domain is known as the "biseau sec". It represents an area where groundwater percolates from the crystalline outcrops into the sedimentary basin without necessarily resulting in a permanent water table.
- **Quaternary alluvium** associated with ephemeral streams running from the eastern highlands to the western flats. Although of limited thickness and vulnerable to contamination, alluvial aquifers are important as a source of drinking water, as well as a mechanism for the recharge of underlying crystalline and sedimentary units.

Methodology – Water points databases

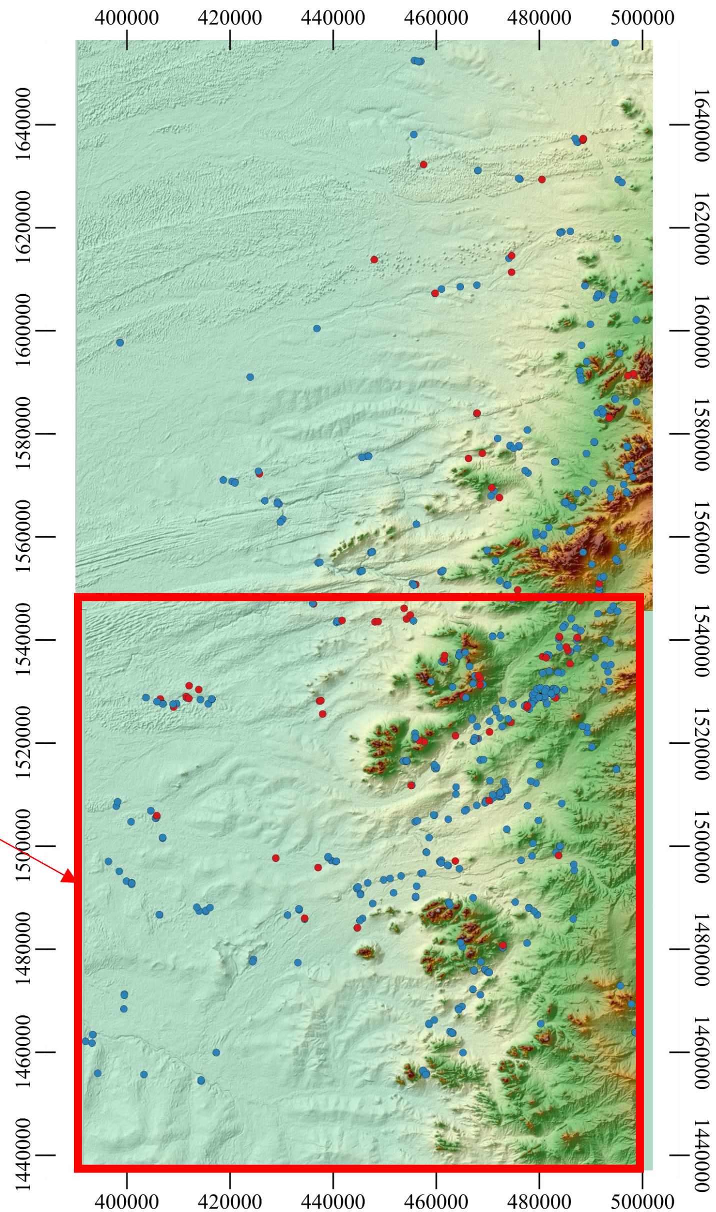


Water points databases



Water points (Abéché):

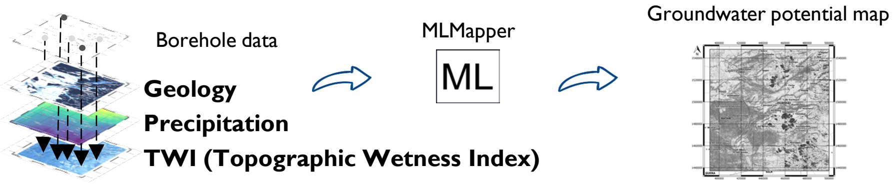
313	Positive water point (presence of water)
106	Negative water point (no water)



Water points (Abéché + Biltine):

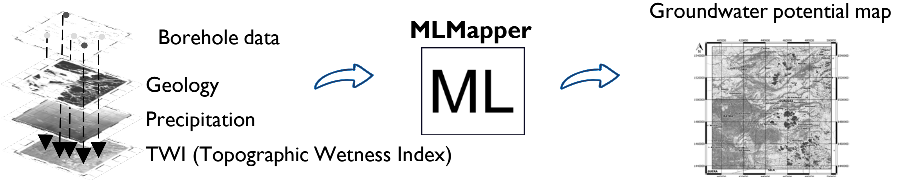
611	Positive water point (presence of water)
265	Negative water point (no water)

Methodology – Explanatory variables



Name/shorthand	Description	Unit of measurement	Source
Land cover dry	Land cover at end of the dry season (December 2017 - March 2018)	Dimensionless	Sentinel-1/-2
Lithology	Geological domains per rock type	Dimensionless	Landsat-8
Precipitation	Cumulated precipitation wet season (June-September 2018)	Millimeter	MSG
Evapotranspiration	Evapotranspiration dry season (December 2017 - March 2018)	Millimeter per day	Landsat-8
Fracture density 100 m	Fracture density with a 100 m radius	Dimensionless	AW3D-WorldDEM
Fracture density 250 m	Fracture density with a 250 m radius	Dimensionless	AW3D-WorldDEM
Fracture density 50 m	Fracture density with a 50 m radius	Dimensionless	AW3D-WorldDEM
Distance ephemeral channels	Distance to channels classified as ephemeral due to their seasonal regime	Dimensionless	AW3D-WorldDEM
Geomorphology	Landform	Dimensionless	AW3D-WorldDEM
Elevation	Topographic elevation	Meters above sea level (m.a.s.l.)	AW3D-WorldDEM
Aspect	Direction of the slope	Direction	AW3D-WorldDEM
Slope	Slope	Degree	AW3D-WorldDEM
Topographic wetness index	Steady state wetness index. Quantifies topographic control on surface hydrology.	Dimensionless	AW3D-WorldDEM
Saturated thickness	Difference between hydraulic heads and basement depth	Meters	Field data
Hydraulic head	Interpolated hydraulic heads from field measurements (January-February 2020)	Meters above sea level (m.a.s.l.)	Field data
Basement Depth	Interpolation of the stratigraphic data from borehole drilling	Meters	Field data
COH Dry min	Minimum value of coherence dry season	Dimensionless	Sentinel-1
COH Wet min	Minimum value of coherence wet season	Dimensionless	Sentinel-1
Min COH difference	Difference between COH Dry min and COH Wet min	Dimensionless	Sentinel-1
VV Dry mean	Mean value of VV intensity dry season	dB	Sentinel-1
VV Wet mean	Mean value of VV intensity wet season	dB	Sentinel-1
Mean VV difference	Difference between VV Dry mean and VV Wet mean	dB	Sentinel-1
NDVI Dry	NDVI at end of the dry season (December 2017 - March 2018)	Dimensionless	Sentinel-2
NDVI Wet	NDVI at end of the wet season (June-September 2018)	Dimensionless	Sentinel-2

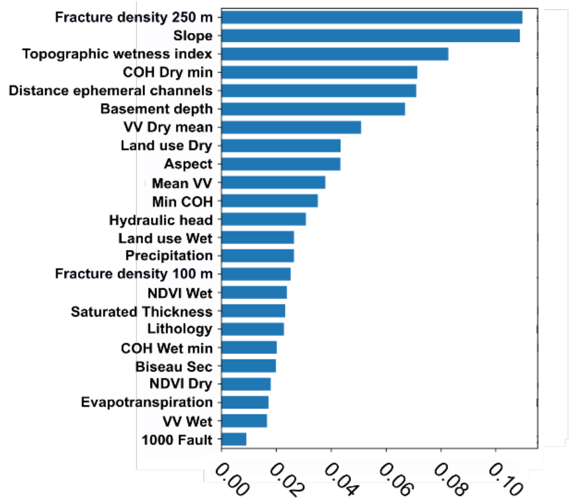
RESULTS



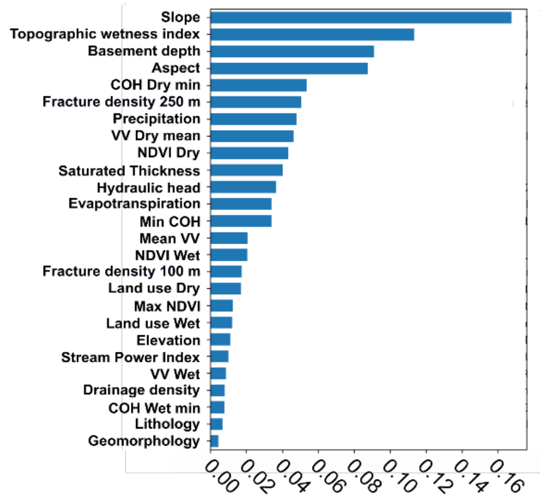
Abéché water points

Algorithm	Train	Test	F1 score 0	F1 Score1	AUC
Random Forest Classifier	0.880	0.841	0.810	0.861	0.872
ExtraTrees Classifier	0.980	0.842	0.813	0.861	0.885
Logistic Regression	0.820	0.815	0.790	0.834	0.856
AdaBoost Classifier	0.815	0.805	0.803	0.807	0.843
Gradient Boosting Classifier	0.823	0.821	0.794	0.852	0.866

ExtraTress



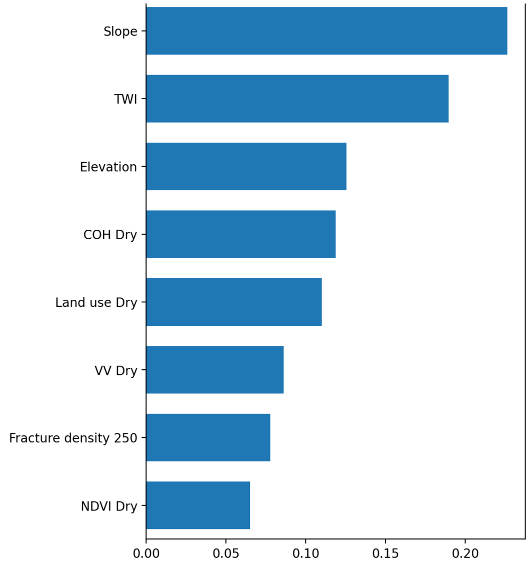
Random Forest



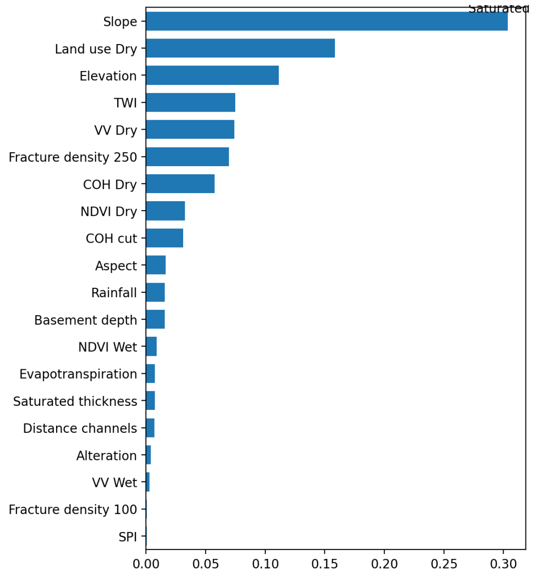
Abéché and biltine water points

Algorithm	Train	Test	F1 score 0	F1 Score1	AUC
Logistic Regression	0.879	0.886	0.780	0.920	0.862
Random Forest Classifier	0.925	0.894	0.790	0.930	0.867
AdaBoost Classifier	0.904	0.886	0.780	0.920	0.886
Gradient Boosting Classifier	0.917	0.886	0.780	0.920	0.889
ExtraTrees Classifier	0.894	0.886	0.770	0.920	0.881

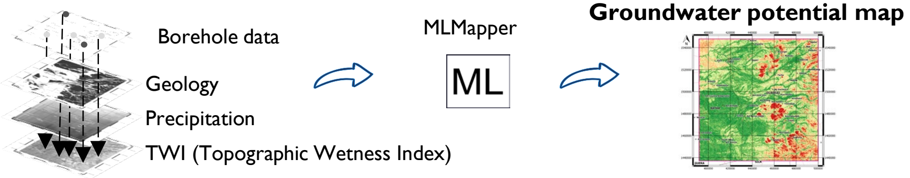
Random Forest



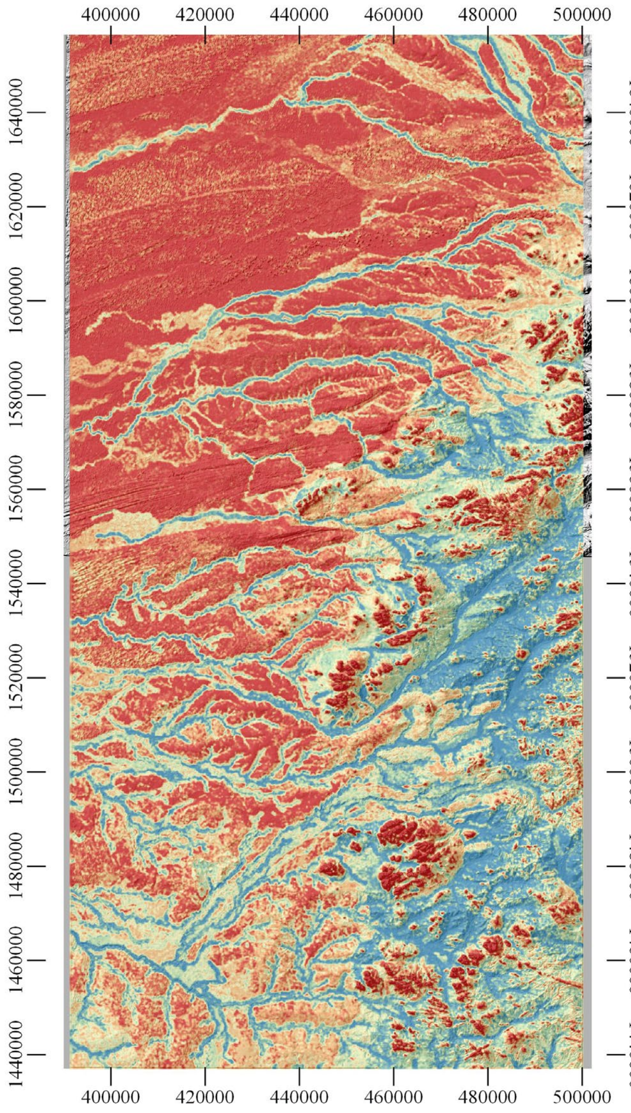
Gradient Boosting



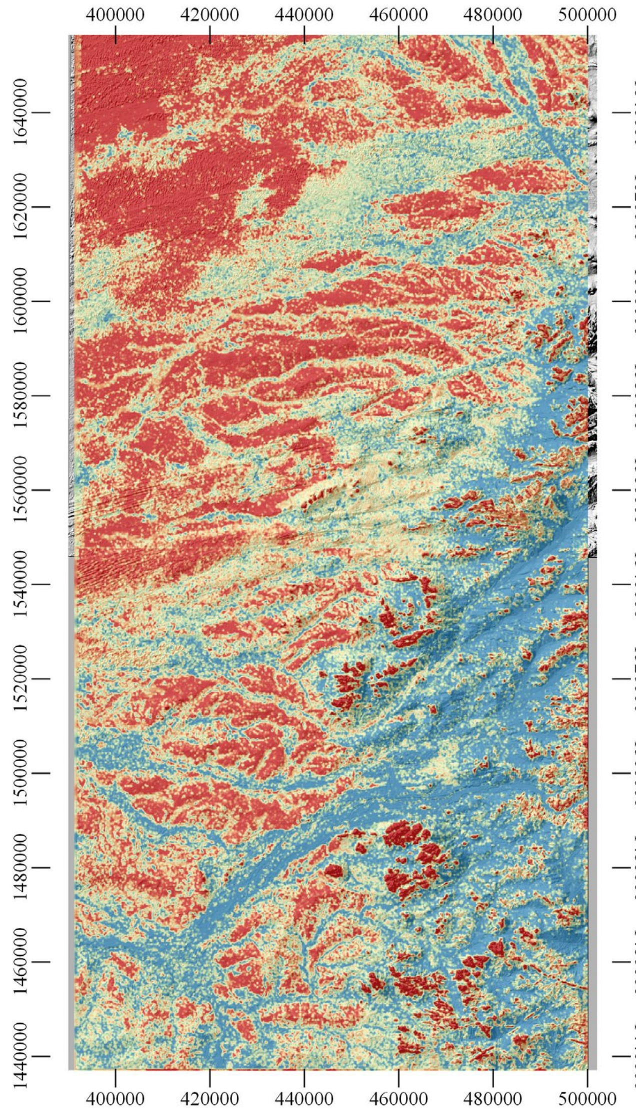
RESULTS



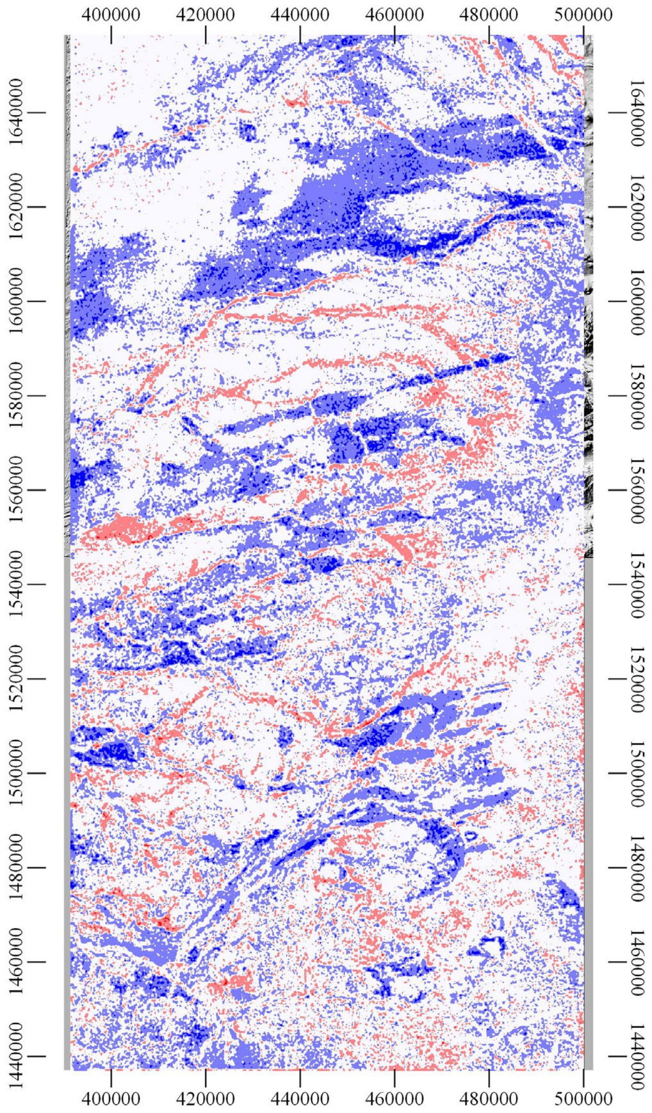
Abéché water points for predict Abéché and biltine (Map 1)



Abéché and biltine water points (Map 2)



Difference Predictions = Map 2 – Map 1



Difference Predictions = Map 2 – Map 1

- <= -0.6
- -0.6 - -0.2
- -0.2 - 0.2
- 0.2 - 0.6
- > 0.6

Groundwater potential

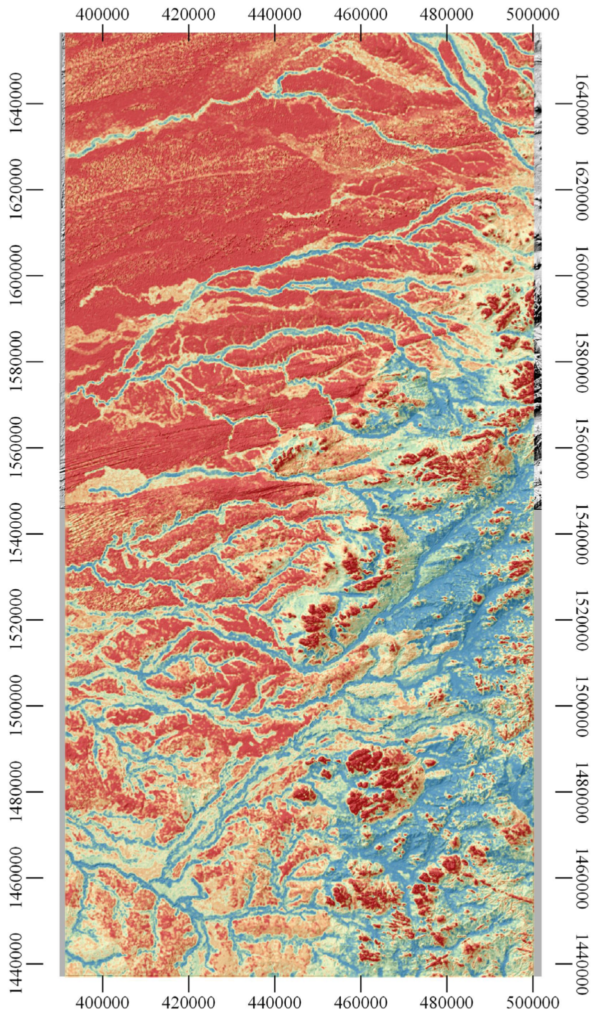
- 0 - 2 (Very low)
- 0.2 - 0.4 (Low)
- 0.4 - 0.6 (Moderate)
- 0.6 - 0.8 (High)
- 0.8 - 1 (Very high))

N

10 0 10 20 30 40 km

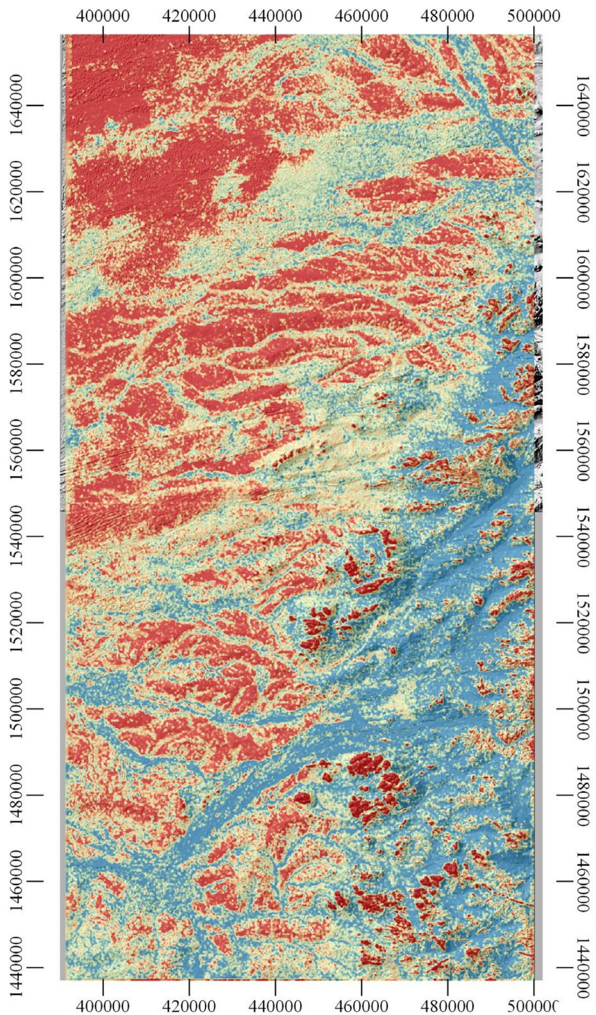
RESULTS

Abéché water points
(Map 1)



- ❖ **GPM map 1** developed using only the Abéché region water points:
  - Predict as high or very high potential areas the **70%** of positive boreholes of Biltine region
- ❖ **GPM map 2** developed using the Abéché and Biltine region water points:
  - Predict as high or very high potential areas the **90%** of positive boreholes of Biltine region

Abéché and biltine water points (Map 2)

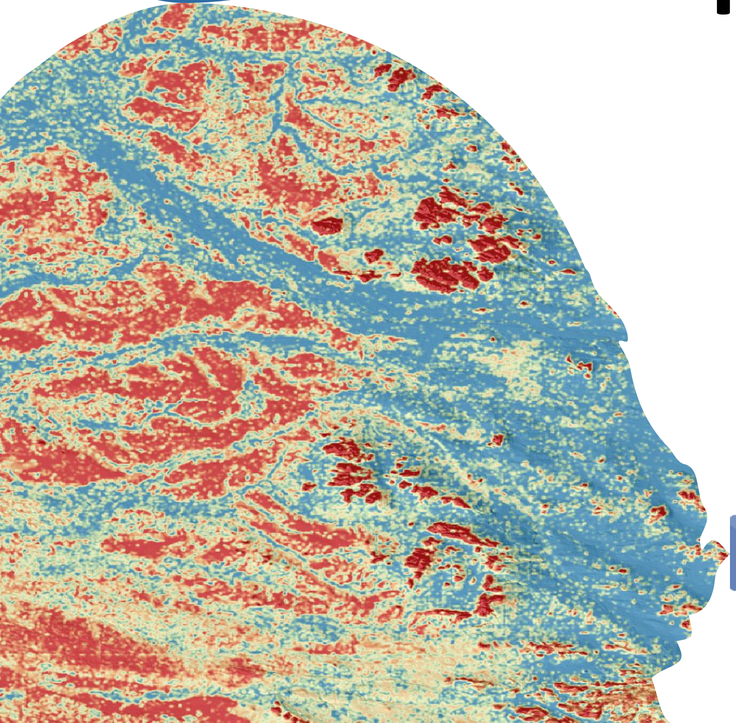


CONCLUSIONS

❖ Groundwater is a crucial resource in arid regions of developing countries, where a large share of the population relies on boreholes and excavated wells for drinking supply. GPM elaborated by **GIS-machine learning methods** can be used to help in large-scale groundwater exploration campaigns in order to improve the locations of the boreholes.

❖ From a **methodological standpoint**, this research highlights the importance of **having good field information** to improve results. Despite this, **extrapolation** of Abéché well conditions to predict the groundwater potential of Biltine area led to **a 70% successful prediction of positive boreholes**.

❖ From a **case-specific perspective**, the results show the areas of best groundwater prospect to take place in **valleys, piedmonts and in the weathered basement areas**. Conversely, basement outcrops and the transition zone between the crystalline mountains and the sedimentary basin are less likely to result in productive boreholes. These findings are conceptually in agreement with the hydrogeological context.



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Thanks for your attention

Merci pour votre attention

Email: vigome01@ucm.es