

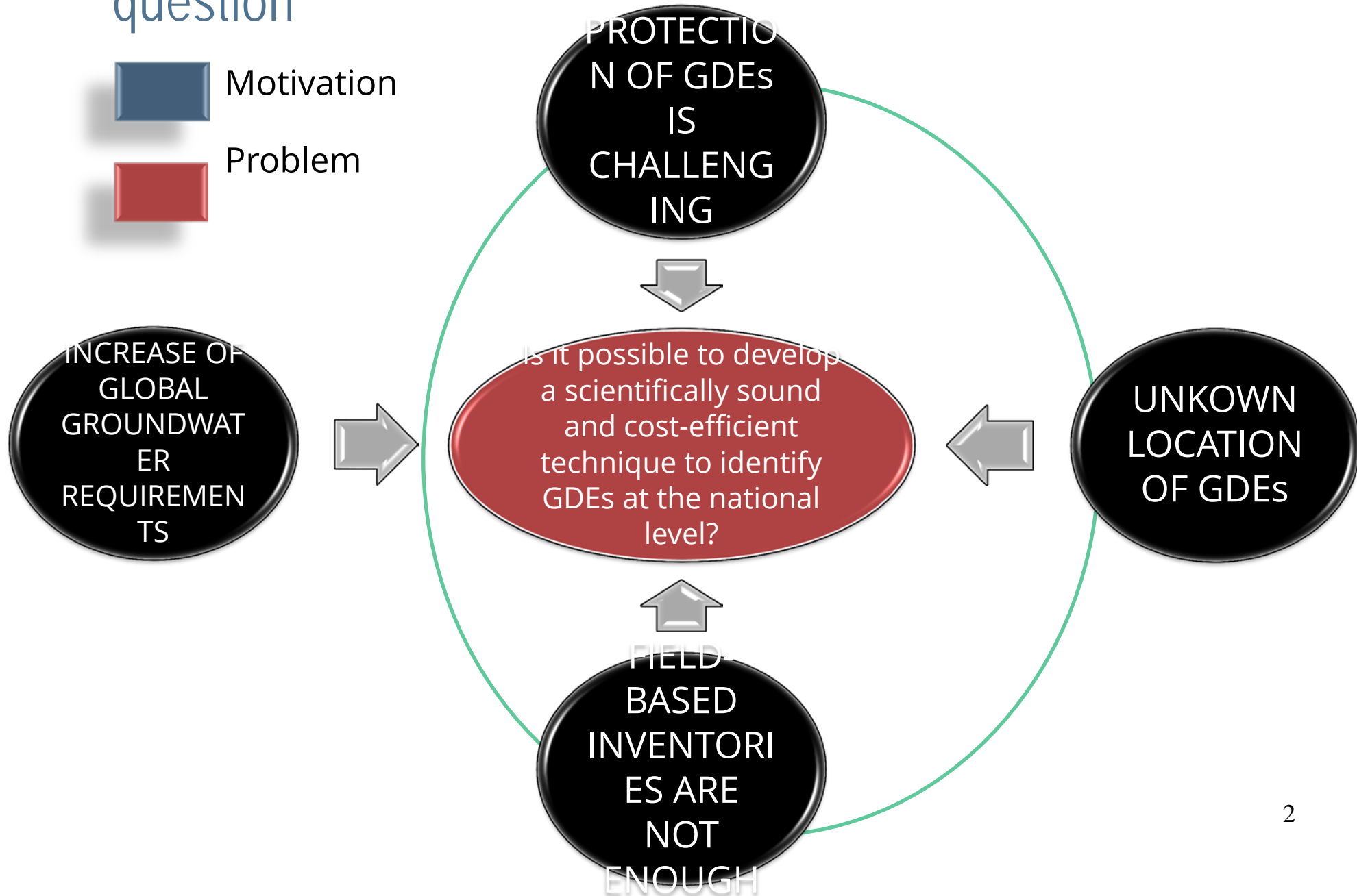
Remote sensing for groundwater in the Earth system

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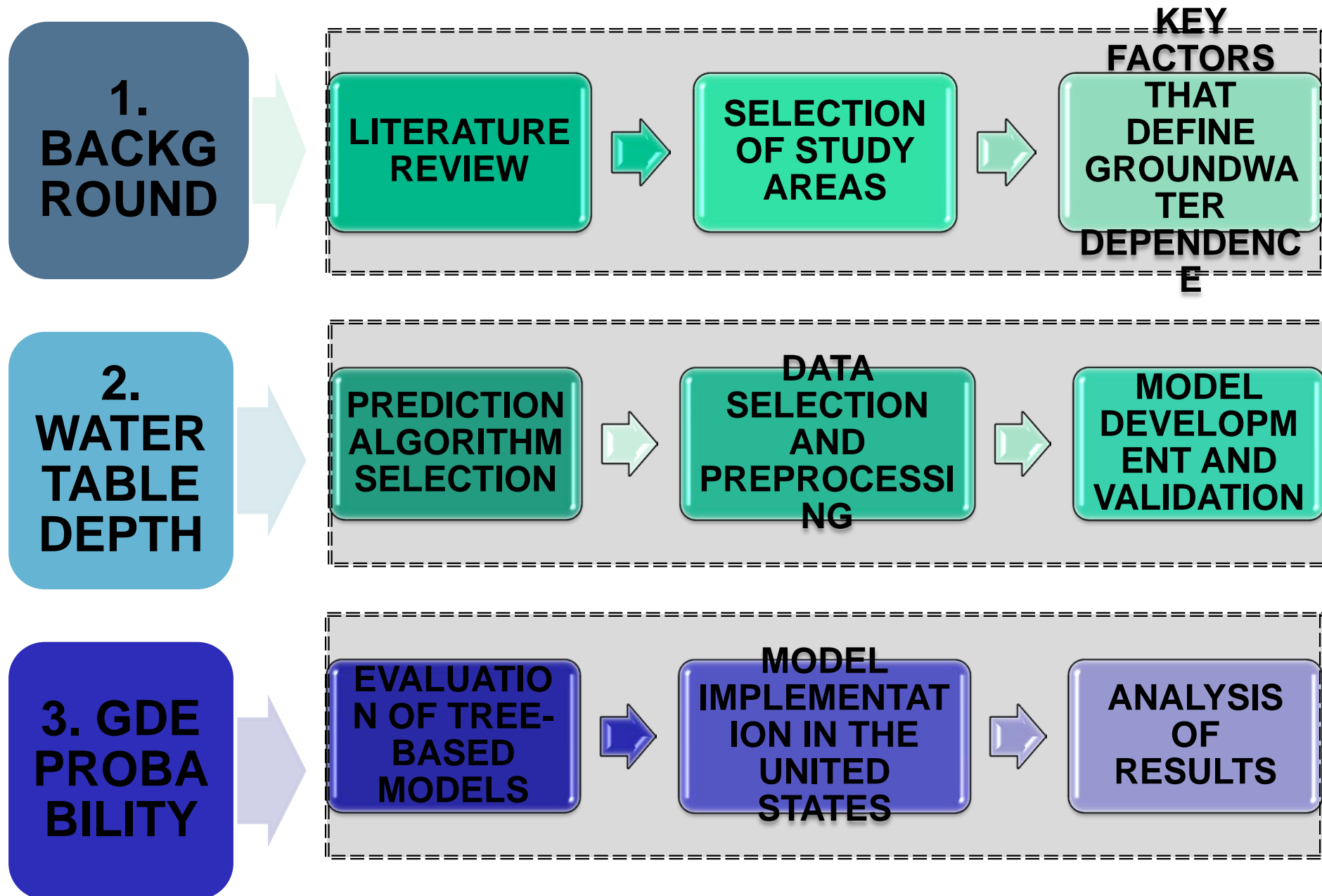
Motivations and research question



Goals of research

- Map areas of shallow groundwater by empirical nonlinear regression with geospatial predictors (including remote sensing fields) at 1 km resolution
- Combined shallow-groundwater and climate maps to estimate pointwise probability of groundwater-dependence ecosystems (phraetophytes)

Overall logic



Literature review

I. Pérez Hoyos, N. Krakauer, R. Khanbilvardi, and R. Armstrong, "A review of advances in the identification and characterization of groundwater dependent ecosystems using geospatial technologies," *Geosciences*, vol. 6, no. 2, 2016.

Geosciences 2016, 6(2), 17; doi:10.3390/geosciences6020017

Open Access

Review

A Review of Advances in the Identification and Characterization of Groundwater Dependent Ecosystems Using Geospatial Technologies

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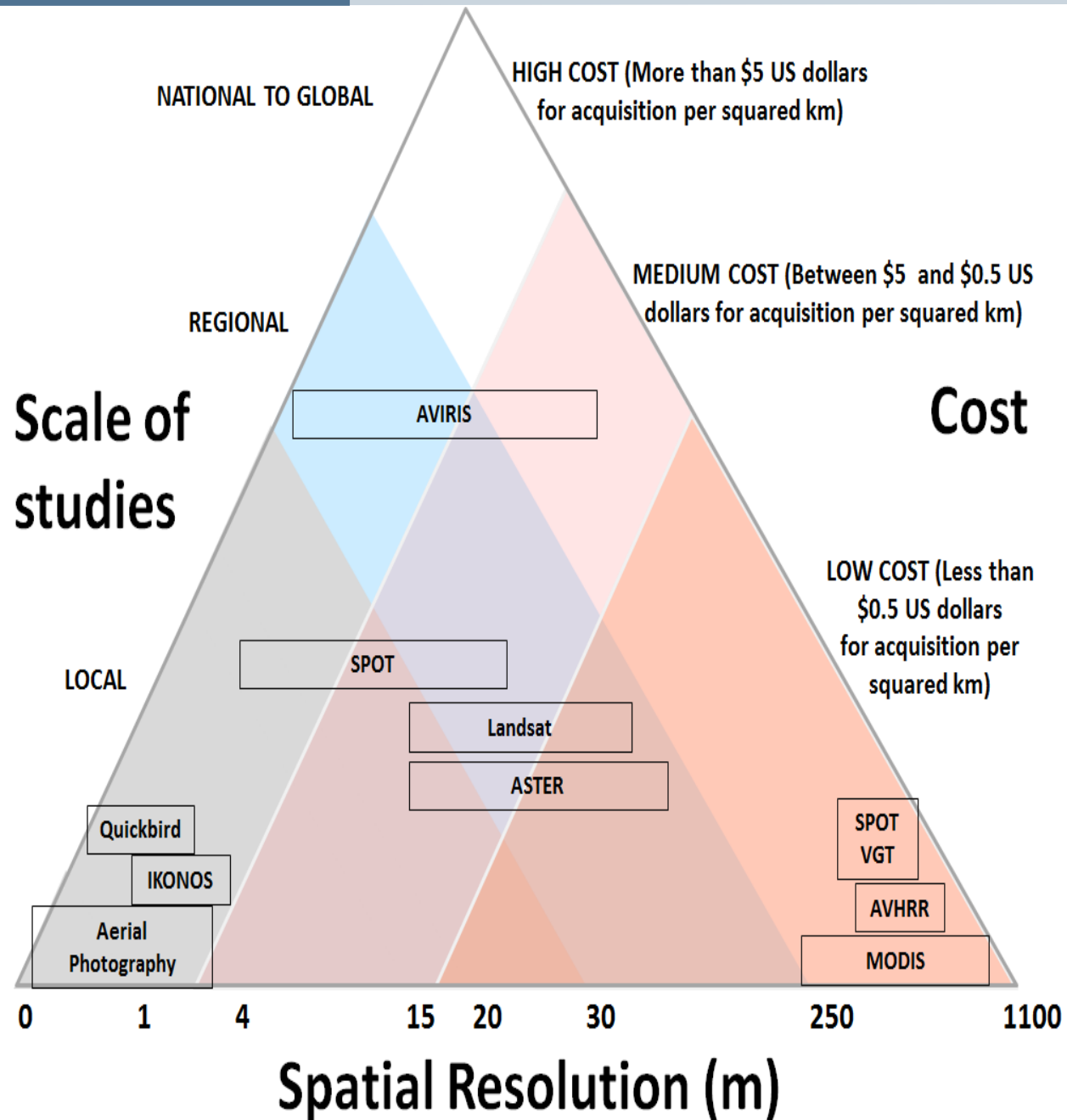
Academic Editor: Jesus Martinez-Frias

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Abstract: Groundwater Dependent Ecosystem (GDE) protection is increasingly being recognized as essential for the sustainable management and allocation of water resources. GDE services are crucial for human well-being and for a variety of flora and fauna. However, the conservation of GDEs is only possible if knowledge about their location and extent is available. Several studies have focused on the identification of GDEs at specific locations using ground-based measurements. However, recent progress in remote sensing technologies and their integration with Geographic Information Systems (GIS) has provided alternative ways to map GDEs at a much larger spatial extent. This paper presents a review of the geospatial methods that have been used to map and delineate GDEs at spatial different extents. Additionally, a summary of the satellite sensors useful for identification of GDEs and the integration of remote sensing data with ground-based measurements in the process of mapping GDEs is presented.

Keywords: groundwater dependent ecosystems; geographical information systems; remote sensing; mapping

Relevant remote sensing methods classified

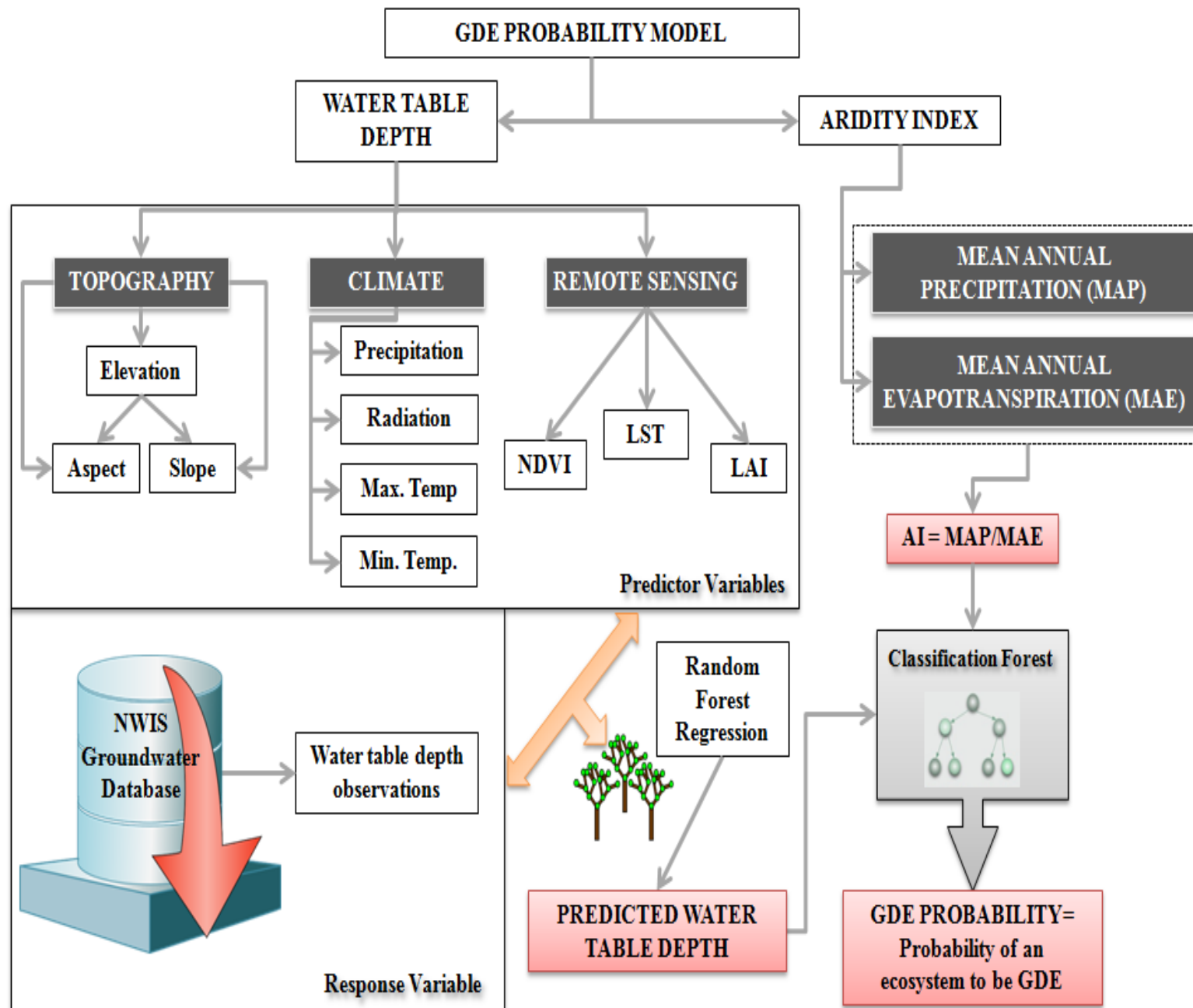


Key factors that define groundwater dependence

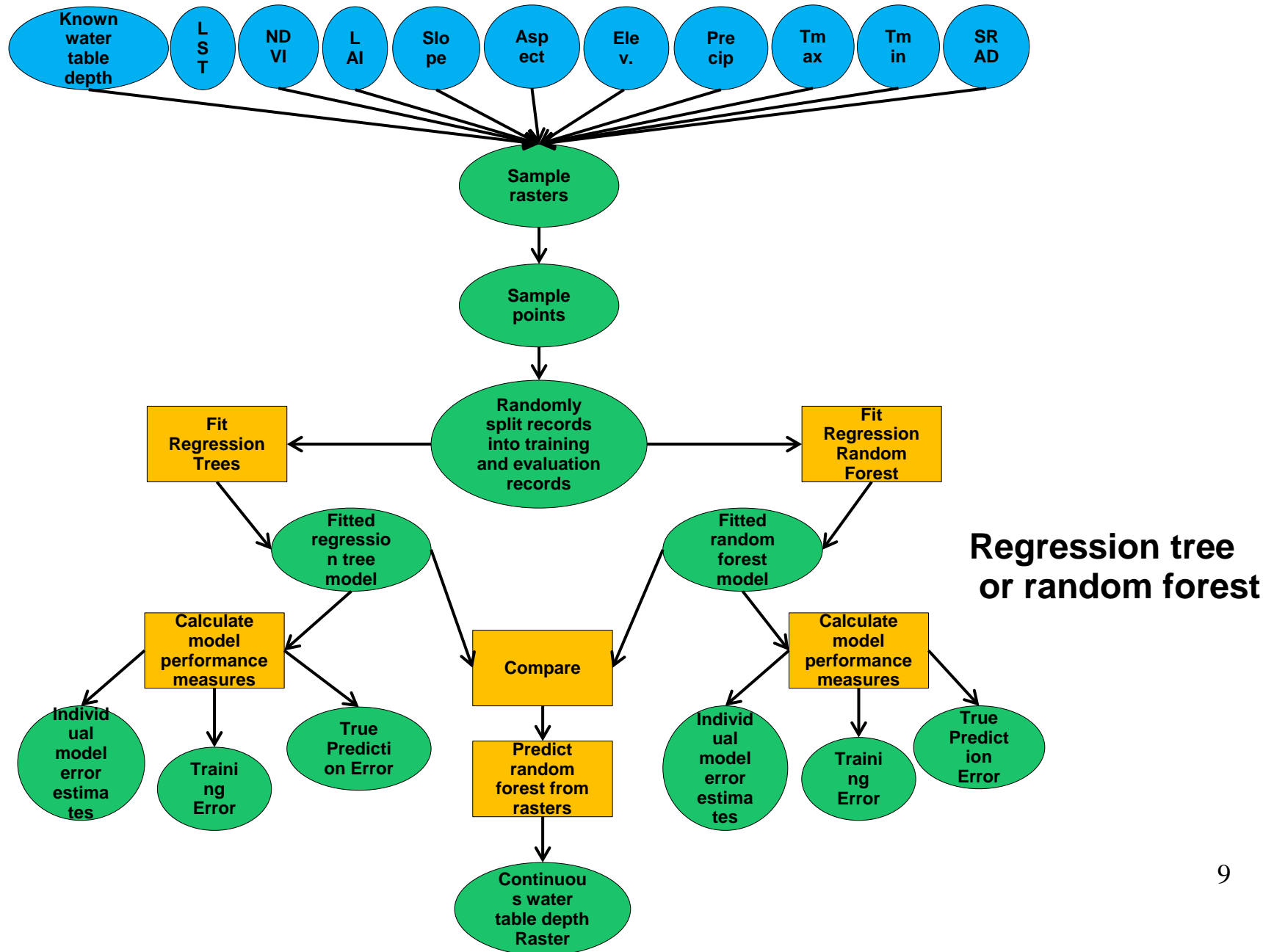


**Availability of groundwater
versus alternative water sources**

Modeling workflow



Water table depth prediction



Predictor variables (Nevada maps)

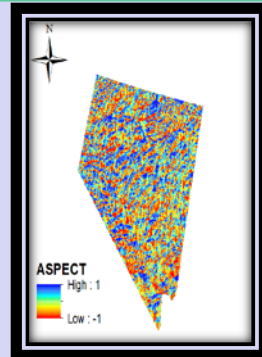
topography



Elevation (DEM)

Meters (m)

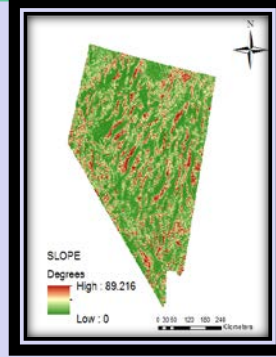
(U.S. Geological Survey 2013)



Aspect (Cos_asp)

Unitless

(U.S. Geological Survey 2013)

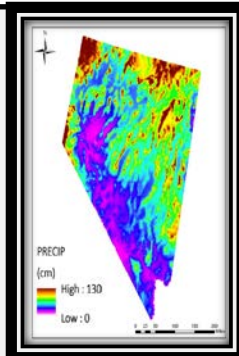


Slope

Degrees

(U.S. Geological Survey 2013)

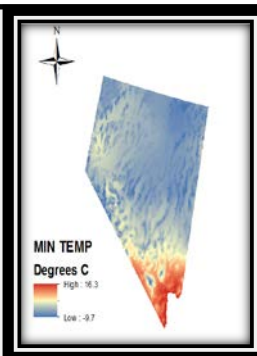
climate



precipitation

centiMeters (cm)

(Thornton et al., 2014)



Minimum temp.

Degrees celsius

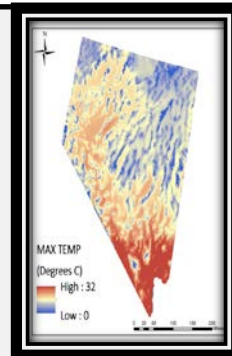
(Thornton et al., 2014)



radiation

MJ/m²/year

(Thornton et al., 2014)

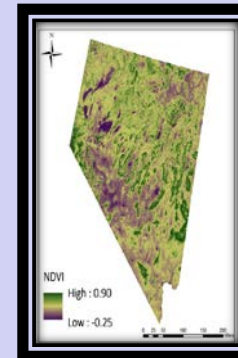


Maximum temp.

Degrees celsius

(Thornton et al., 2014)

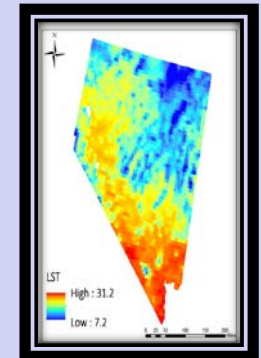
Remote sensing



ndvi

unitless

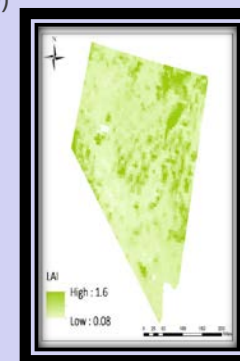
(Land Processes Distributed Active Archive Center, 2000)



lst

Degrees celsius

(Land Processes Distributed Active Archive Center, 2000)



lai

m²/m²

(Land Processes Distributed Active Archive Center, 2000)

WTD training data

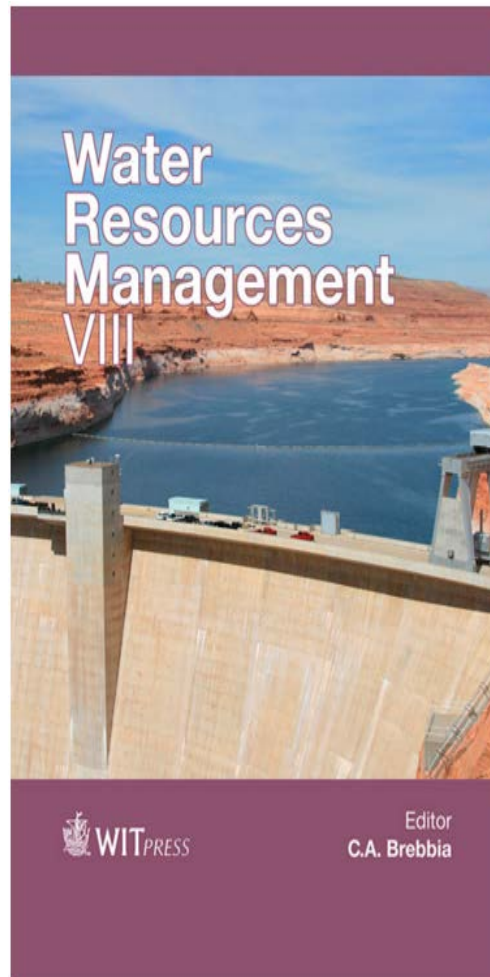
- ❖ Water table depth observations downloaded through the European Union collaborative project Global Water Scarcity Information Service (GLOWASIS)
- ❖ UNITED STATES: Water table depth observations at 567,946 sites maintained by the United States Geological Survey (USGS) from 1927 to 2009
- ❖ NEVADA: 6,478 sites
- ❖ CALIFORNIA: 20,995 sites
- ❖ WASHINGTON: 55,711 sites

WTD model evaluation (Nevada)

PERFORMANCE MEASURE	TRAINING ERROR (number of points = 4,538)		TRUE PREDICTION ERROR (number of points = 1,940)	
	REGRESSION TREE	RANDOM FOREST	REGRESSION TREE	RANDOM FOREST
MEAN ABSOLUTE ERROR (meters)	10.69	3.90	10.84	7.52
ROOT MEAN SQUARE ERROR (meters)	14.65	6.22	14.89	11.90
PEARSON CORRELATION COEFFICIENT	0.50	0.94	0.47	0.71

Publication

I. C. Pérez Hoyos, N. Krakauer, and R. Khanbilvardi,
“Random Forest for Identification and Characterization of
Groundwater Dependent Ecosystems,” WIT Trans. Ecol.
Environ., vol. 196, pp. 89–100, 2015.



Water Resources Management VIII 89

Random forest for identification and characterization of groundwater dependent ecosystems

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Abstract

Anthropogenic actions such as groundwater pumping, agricultural practices, industrialization, and waste disposal can greatly affect groundwater resources which would eventually drive changes in vulnerable ecosystems. Therefore, it is clear that there is a need to identify the locations of groundwater dependent ecosystems (GDEs) to enable the development of policies that adequately address their protection. The purpose of this study is to propose a method based on geospatial data sets and random forest algorithm to map the distribution of GDEs in the United States at 1 km spatial resolution. This paper presents the results in Nevada. The method is based on the principle that ecosystems will use water in proportion to its availability and the dependence on that resource will be expected to increase with higher aridity of the environment. Results show that random forest is a promising technique for the identification and characterization of GDEs using geospatial data sets as predictor variables.

Keywords: groundwater dependent ecosystems, random forest, overlay analysis, water table depth, aridity.

1 Introduction

Groundwater Dependent Ecosystems (GDEs) are plants, animals, and other organisms that depend on groundwater to maintain their structure and composition, as well as to sustain their life processes. There are several types of GDEs, but they all depend on the surface or subsurface expression of groundwater. The main categories of GDEs include the following [1–3]. Terrestrial vegetation (phreatophytes) and fauna, baselink in river systems, ecosystems in streams and

Publication

I. C. Pérez Hoyos, N. Krakauer, and R. Khanbilvardi,
“Prediction of water table depth from geospatial and
remote sensing data using random forests,” WIT
International Journal of Sustainable Development , 2016
(Under review).

PREDICTION OF WATER TABLE DEPTH FROM GEOSPATIAL AND REMOTE SENSING DATA USING RANDOM FORESTS

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¹NOAA Cooperative Remote Sensing Science and Technology (NOAA CREST Center), City College of New York, New
York, USA.

ABSTRACT

Humans are increasingly extracting groundwater for agricultural, industrial, and residential purposes without taking into account the aquifer's natural replenishment rates and the water required for the support and maintenance of terrestrial, aquatic, and coastal ecosystems. For this reason, significant efforts are still required to understand the relationship between groundwater and the ecosystems they support. Knowledge of patterns in groundwater depth can be useful in understanding the global distribution of shallow-groundwater features such as springs, lakes, rivers, wetlands, and their associated ecosystems. However, water table depth is only measured at relatively few points in space and time, and for this reason it is poorly known in many regions. In this study, a methodology to predict water table depth at 1 km spatial resolution using geospatial and remote sensing datasets calibrated with water table depth observations from well sites is proposed. An ensemble learning algorithm called Random Forest (RF) is used in order to model the distribution of groundwater in Nevada and California. Results show that RF is a technique that can be effectively used to better understand the drivers of water table distribution, especially using remote sensing data as a complement to field-based observations which can be limiting for long-term studies and monitoring of remote areas.

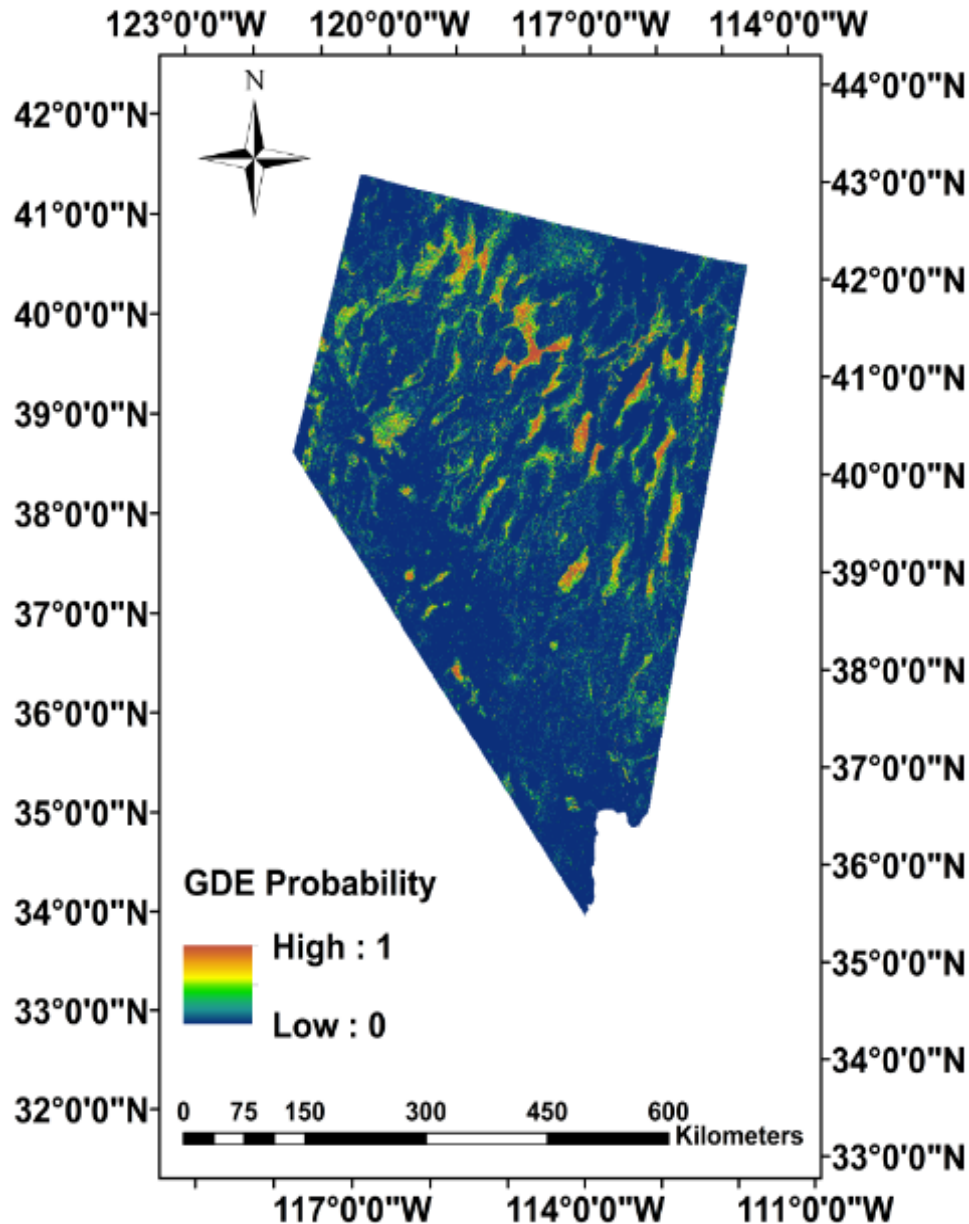
Keywords: water table depth, random forests, geographical information systems, remote sensing.

1 INTRODUCTION

Groundwater table, also called water table, is defined as the boundary between ground that is completely saturated with water and unsaturated ground above it. Technically, groundwater refers to water that is below this level. Several aspects influence the depth at which water table is found. Some of the most important aspects are topography, climate, lithology, and water extraction practices [1]–[4]. Humans are increasingly extracting and using groundwater for agricultural, industrial, and residential purposes. Groundwater also plays a critical role in sustaining and maintaining the ecological integrity of many terrestrial, aquatic, and coastal ecosystems. For this reason, efforts are required to understand the relationship between groundwater and the ecosystems they support. Groundwater dependent ecosystems are typically found where groundwater is shallow, such as topographically low areas and breaks of topographic slope [5]. Therefore, knowledge of patterns in groundwater depth can be useful in understanding the global distribution of shallow-groundwater features such as springs, lakes, rivers, wetlands, and their associated ecosystems. However, water table depth is only measured at relatively few points in space and time, and so is poorly known in many regions.

In this study, a new methodology to predict water table depth at 1 km spatial resolution using geospatial and remote sensing datasets calibrated with water table depth observations from well sites is proposed. An ensemble learning algorithm called Random Forest (RF) is used in order to model the distribution of groundwater in Nevada and California. Additionally, RF implementation is performed excluding remote sensing variables with the purpose of evaluating the contribution of this type of variables in this study.

GDE probability estimates



Function of modeled WTD
and climate (aridity index)

Training data: phreatophyte distribution
maps from USGS

Average GDE
probabilities:

•Vegetation with shallow (≤ 10 m) water table =
0.5

•Intermediate (10-30 m) water table = 0.08

•Deep water table (> 30 m) = 0.02

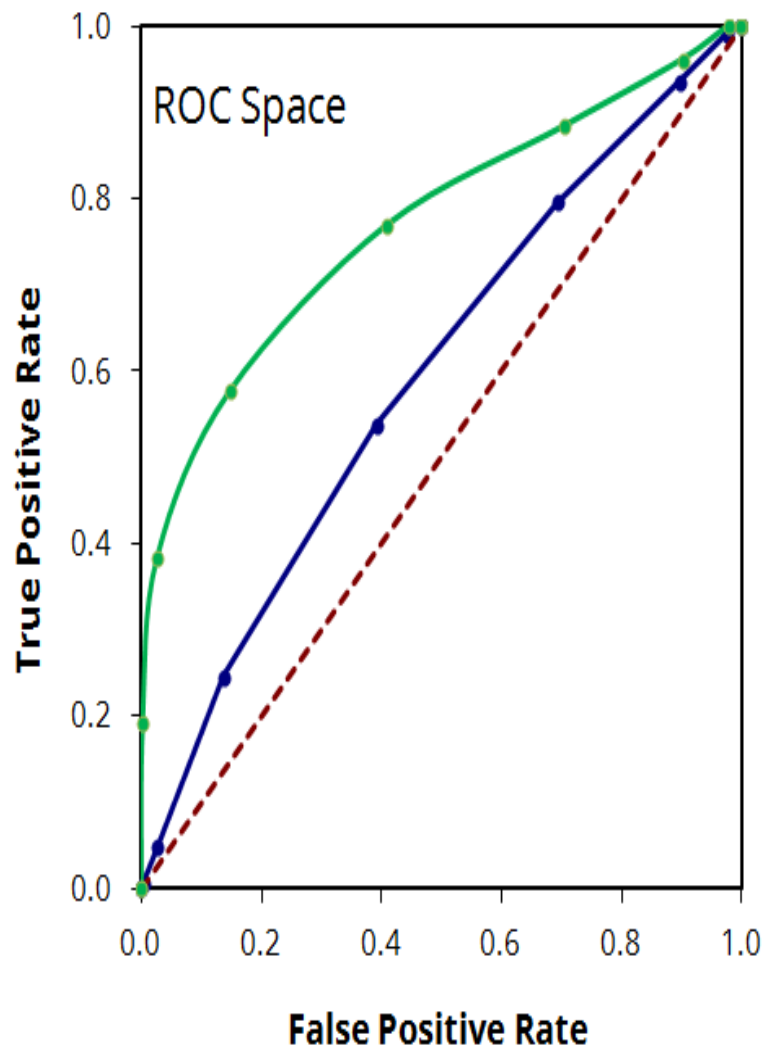
•Arid climate = 0.10

•Semi-arid climate = 0.08

•Dry sub-humid and humid conditions = 0.0

MODEL SELECTION USING ROC CURVES

A receiver operating characteristics (ROC) curve is useful for visualization and selection of classification models based on their performance.



Area under the curve

	Test Data (n=85,888)	Training Data (n=200,40 5)
TREE MODEL		
CLASSIFICATION TREE	0.74	0.74
RANDOM FOREST	0.81	1.0

Publication

I. Pérez Hoyos, N. Krakauer, and R. Khanbilvardi, "Estimating the Probability of Vegetation to Be Groundwater Dependent Based on the Evaluation of Tree Models," *Environments*, vol. 3, no. 2, 2016.



environments



Article

Estimating the Probability of Vegetation to Be Groundwater Dependent Based on the Evaluation of Tree Models

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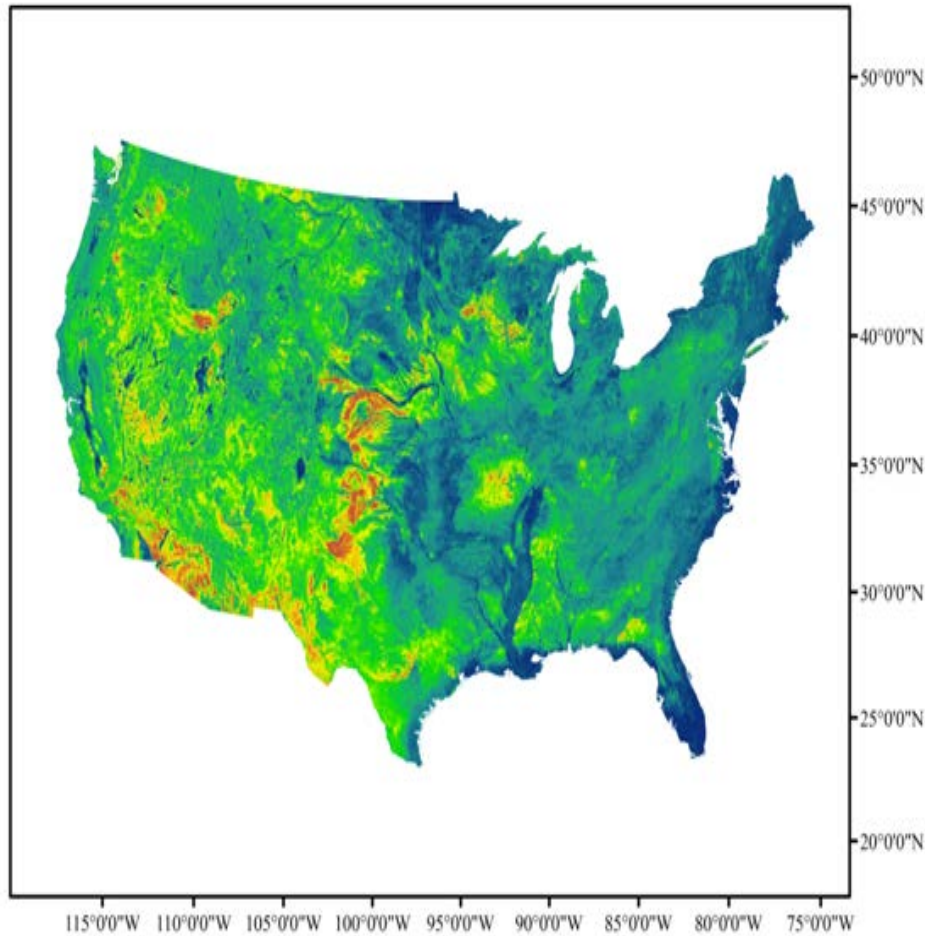
Academic Editors: Luigi Berardi and Daniele Laucelli

Received: 28 January 2016; Accepted: 22 March 2016; Published: 2 April 2016

Abstract: Groundwater Dependent Ecosystems (GDEs) are increasingly threatened by humans' rising demand for water resources. Consequently, it is imperative to identify the location of GDEs to protect them. This paper develops a methodology to identify the probability of an ecosystem to be groundwater dependent. Probabilities are obtained by modeling the relationship between the known locations of GDEs and factors influencing groundwater dependence, namely water table depth and climatic aridity index. Probabilities are derived for the state of Nevada, USA, using modeled water table depth and aridity index values obtained from the Global Aridity database. The model selected results from the performance comparison of classification trees (CT) and random forests (RF). Based on a threshold-independent accuracy measure, RF has a better ability to generate probability estimates. Considering a threshold that minimizes the misclassification rate for each model, RF also proves to be more accurate. Regarding training accuracy, performance measures such as accuracy, sensitivity, and specificity are higher for RF. For the test set, higher values of accuracy and kappa for CT highlight the fact that these measures are greatly affected by low prevalence. As shown for RF, the choice of the cutoff probability value has important consequences on model accuracy and the overall proportion of locations where GDEs are found.

Keywords: groundwater dependent ecosystems; decision trees; random forest; GIS; remote sensing; phreatophytes

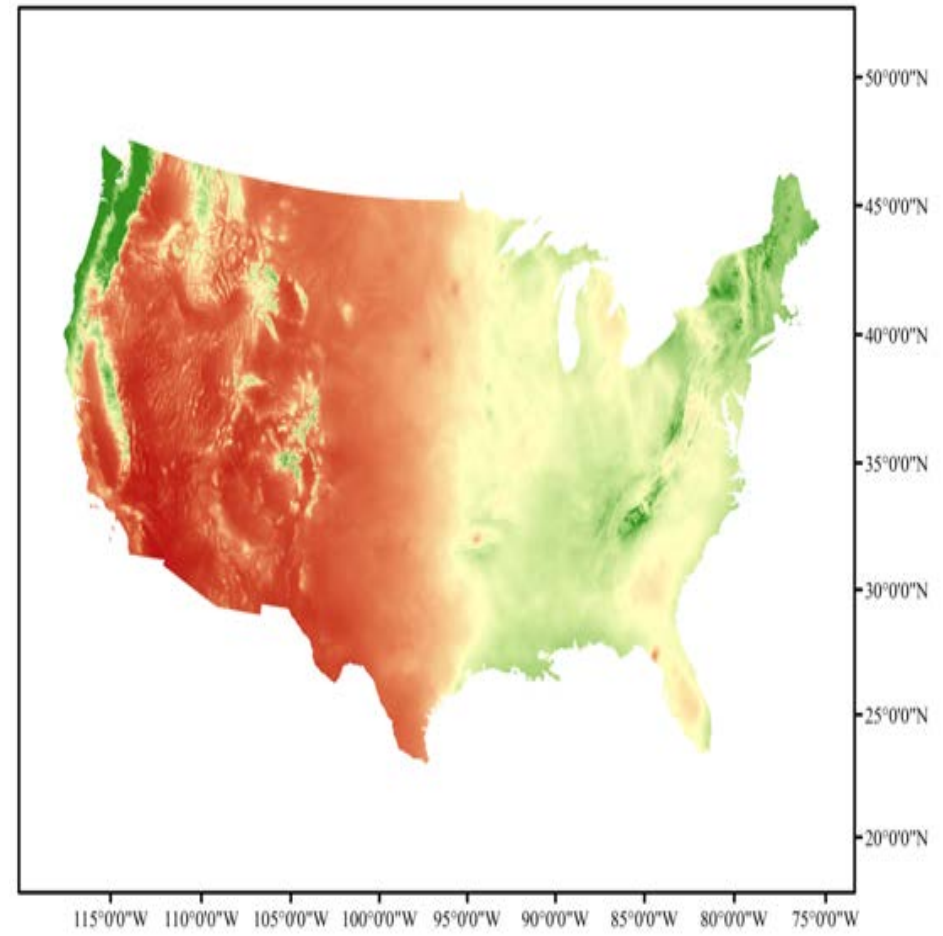
Model implementation in the United States



Water Table Depth (m)

0 375 750 1,500 Kilometers

High : 150
Low : 0



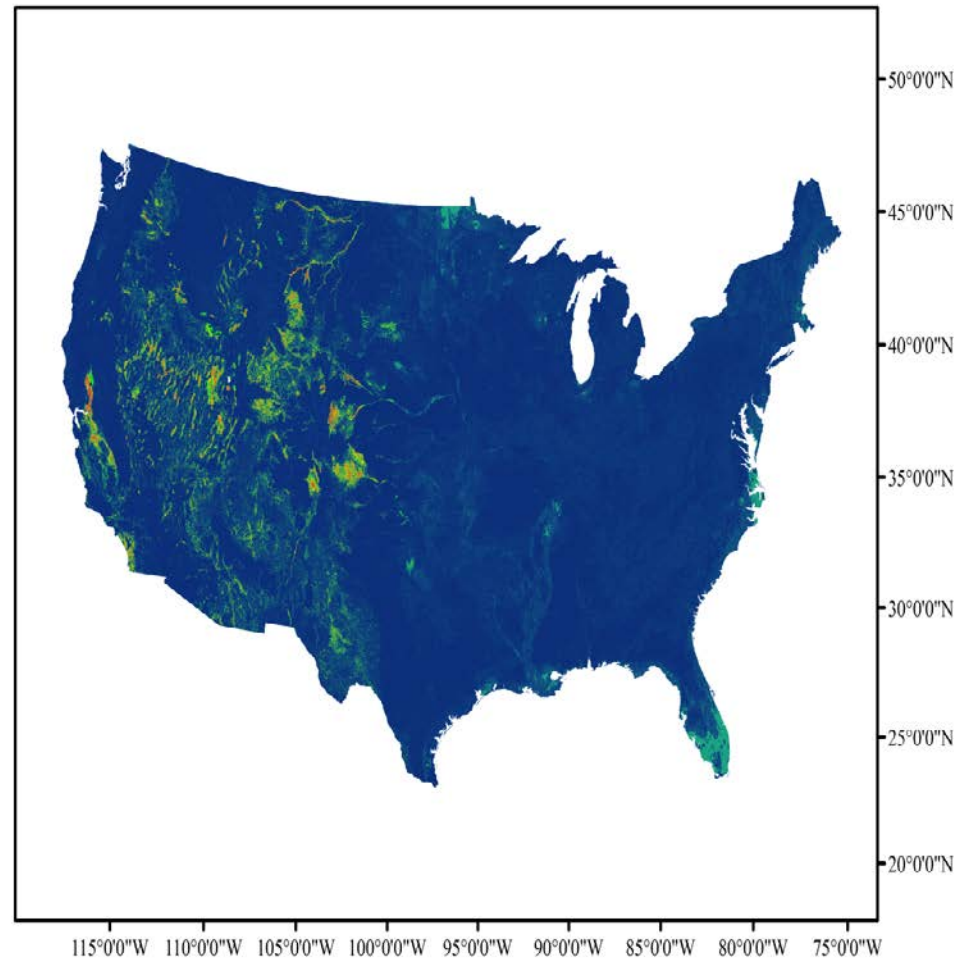
Aridity Index

0 375 750 1,500 Kilometers

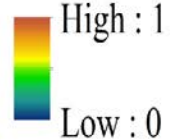
High : 10.2108
Low : 0.0254



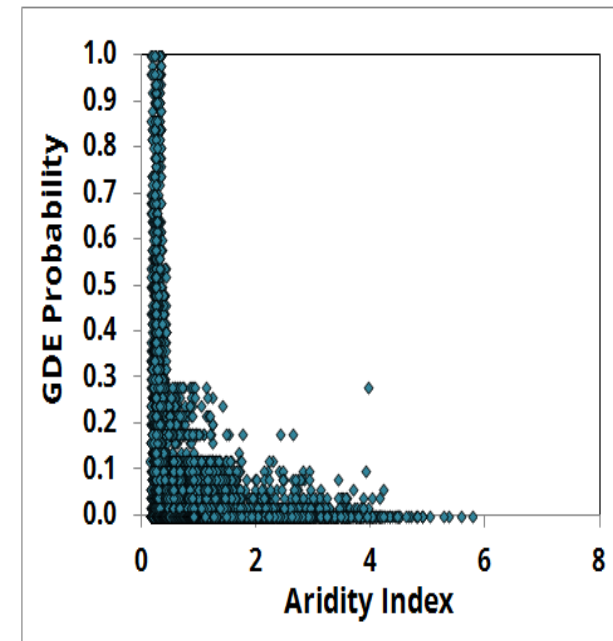
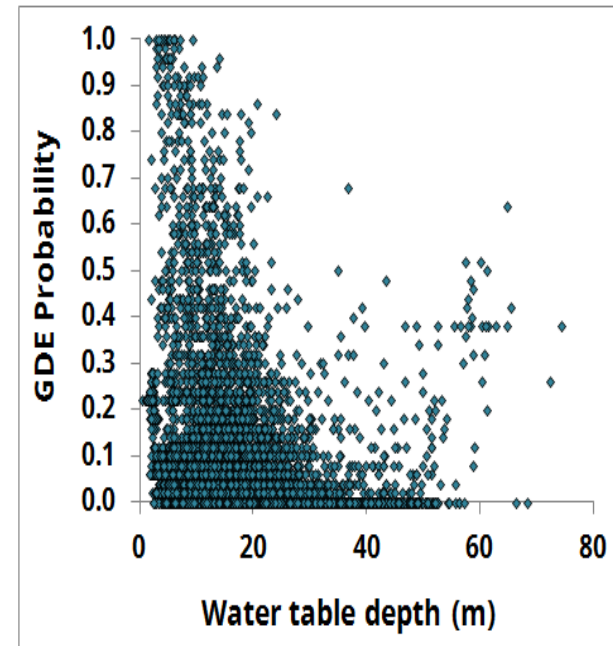
GDE probability estimates



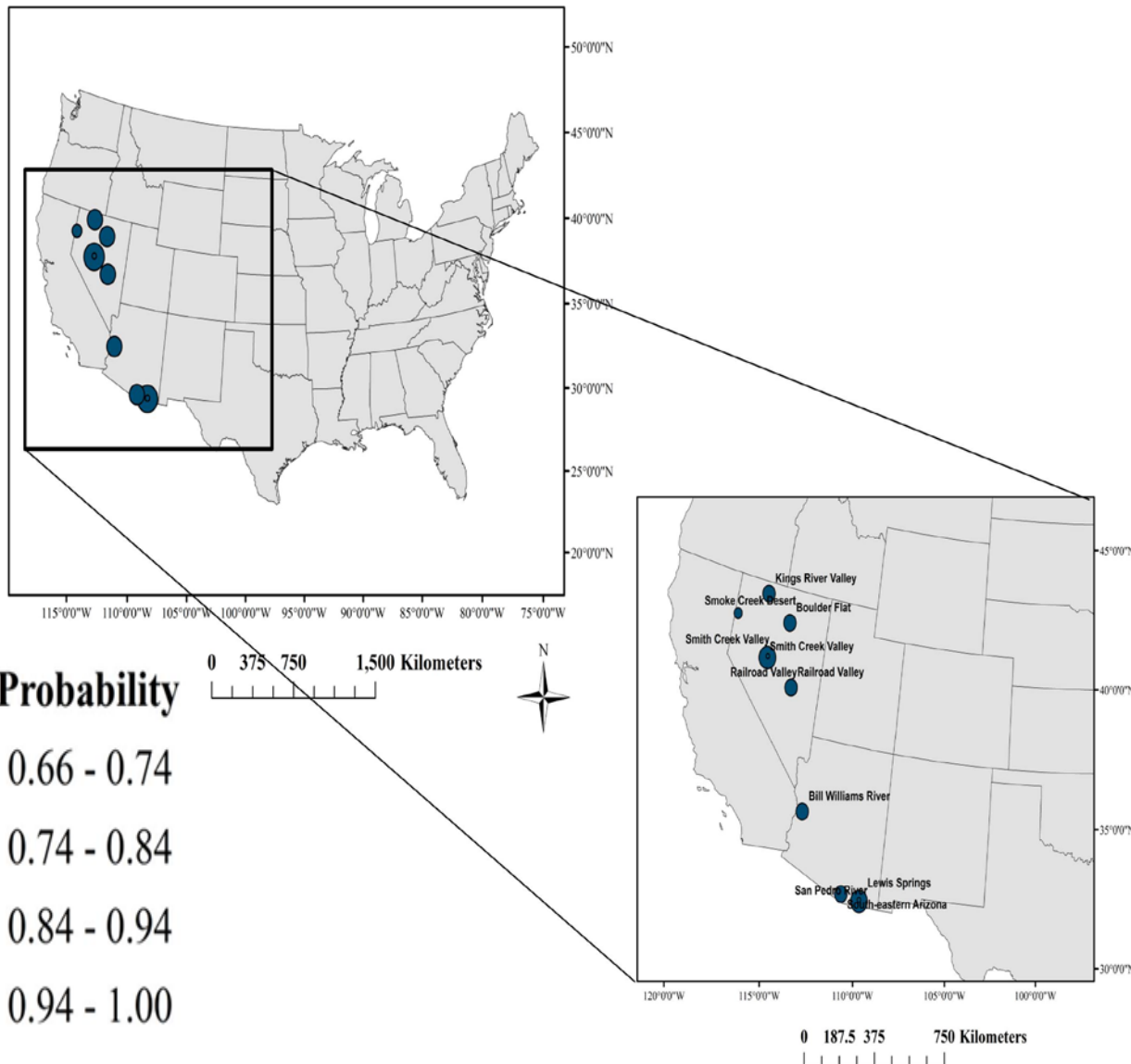
GDE Probability



0 375 750 1,500 Kilometers



Validation of results




ID	Name	GDE Probability
1	Smoke Creek Desert	0.840
2	Kings River Valley	0.880
3	Boulder Flat	0.900
4	Smith Creek Valley	1.000
5	Smith Creek Valley	0.660
6	Railroad Valley	0.920
7	Railroad Valley	0.920
8	Lewis Springs	1.000
9	San Pedro River	0.740
10	Bill Williams River	0.660
11	South-eastern Arizona	0.900

Average GDE probability value is 0.840

USA GDE map made available online

<http://www.arcgis.com/home/item.html?id=fbf0c6e36c2a4e88a0eb9ae142fd7452>

GDE Probability



This map depicts the probability of an vegetation to be groundwater dependent. For more information please refer to: <http://www.mdpi.com/2076-3298/3/2/9>
<http://www.mdpi.com/2076-3263/6/2/17> <http://www.witpress.com/elibrary/w>

Map Package by isabel55.ph@gmail.com
Last Modified: April 28, 2016

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Description

This map presents the probability of vegetation to be groundwater dependent (GDE Probability) in the United States at 1 km resolution as estimated from random forest algorithm. The GDE probability was estimated by modeling the relationship between the known locations of phreatophytes and two predictor variables that are considered to define groundwater dependence, namely water table depth and aridity index.

Properties

Tags [groundwater dependent ecosystem](#), [phreatophytes](#), [conservation](#)

Conclusions

- ❑ WTD and GDE distribution for the USA was estimated at 1 km resolution based on free geospatial and remote sensing data sets and regression/classification forest algorithms.
- ❑ The approach could be applied globally and could be useful for comparing with groundwater-resolving ESM outputs.
- ❑ The main products from this research, water table depth and GDE probabilities, can be used to gain ecological and hydrogeological insights for groundwater resource management built around the recognition and management of GDEs.
- ❑ Could extend to estimate time-varying (rather than “average”) WTD and GDE distribution.

Publications

- ❑ I. C. Pérez Hoyos, N. Krakauer, and R. Khanbilvardi, "Random Forest for Identification and Characterization of Groundwater Dependent Ecosystems," WIT Trans. Ecol. Environ., vol. 196, pp. 89–100, 2015.
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- ❑ I. Pérez Hoyos, N. Krakauer, and R. Khanbilvardi, "Estimating the probability of an ecosystem to be groundwater dependent based on the evaluation of tree models," Environments, vol. 3, no. 2, 2016.
- ❑ I. C. Pérez Hoyos, N. Krakauer, and R. Khanbilvardi, "Prediction of water table depth from geospatial and remote sensing data using random forests," WIT Int. J. Sustain. Dev. Plan., 2016 (Under review).

Thanks!

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- Questions?