A Remote Sensing Approach to Characterize the Hydrogeology of Mountainous Areas: Application to the Quito Aquifer System (QAS), Ecuador

Dissertation Research Proposal

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Outline

• Motivation
• Goals
• Objectives
• Setting
• Research Plan
• Methodology
• Expected outcomes
Motivation

• Climate change, intensive use of water resources, management problems and population growth are threatening the global availability of water

• To find new sources of water and to improve the knowledge of the existing ones, reliable and timely water information is of paramount importance

• Michigan Tech has developed strong programs in remote sensing applied to Natural Hazards and Resource Protection. One of the targeted areas is Latin American, where countries face many natural hazards and threats to resources
Ground water: An alternative

http://ga.water.usgs.gov/edu/waterdistribution.html

AVAILABILITY

Spatial distribution, Protection, Quality
The initial and most prevalent applications of remote sensing in hydrogeology is lineament analysis in hard rock terrains.

The objective is to pinpoint locations for follow-up detailed geophysical investigations and well drilling.
Satellite Remote Sensing Potential for Regional Studies:

- Broad range of wavelengths
- Different spatial scales
- Different temporal resolutions
PIRE PROJECT IN BOACO-NICARAGUA

Volcanic Terrain
Non ideal conditions
Some Limitations of Remote Sensing

• Geometric aspects of fractures & discontinuities:
  – Dip
  – Depth
  – Aperture, Zone Width
  – Water-Bearing Potential

• Contribution to the local/regional ground water flow (connectivity)
To Address Limitations (i.e., to “see” deeper)

Surface Geophysics

Hydrochemistry
Research Goals

1) Refine and test a remote sensing-based protocol for:
   a) characterizing fracture networks in regional aquifer systems,
   b) delineating discontinuities and boundaries of local and regional aquifer systems, and
   c) evaluating their control on hydrological behavior.

2) Test and enhance these protocols using geophysical data, geochemistry, structural geology and hydrogeological data.
OBJECTIVES

• Develop and test remote sensing techniques to map surface expressions of geological lineaments and discontinuities.

• Identify faults and discontinuities by correlating lineament maps to existing geology and geophysical data.

• Evaluate infiltration/exfiltration potential of fractures and discontinuities using thermal imagery.
OBJECTIVES (cont)

• Evaluate the interconnections between different components of the hydrogeological basin by integrating datasets.

• Foster a collaborative international approach to conducting systematic research in order to improve understanding of complete aquifer systems and establish a foundation for continued research and monitoring.
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Aquifer Location & Setting

South America

Ecuador

Quito

Guayaquil

Cayambe

Antisana

Ilaló Volcano
Mapped Faults in QAS

Source: Radarsat Image 02/21/2003
Fault Maps: Villagómez, 2003
Tectonic control in the QAS

Deformation in the Guayllabamba depression

Villagomez, 2003
Structure of collaboration to study the QAS

MTU

Universidad Central del Ecuador (UCE)

EMAAP-Q

Escuela Politécnica Nacional (EPN)

University of Montpellier (Fr)

IRD France

INAHMI
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• Intellectual merits and anticipated impacts
RESEARCH PLAN

- Fractures Identified Using Satellite Remote Sensing
- Fractures Geometry (VLF-EM & Geoelectric Methods)
- Fracture characterization
  - Geophysics
  - Hydrochemistry, Isotope analysis, Existing data
- Integration into Regional Hydrogeological Model

Faults / discontinuities

Integration into Regional Hydrogeological Model

- Infiltration
- Exfiltration
RS – Lineament Mapping

- Select Imagery Types
- Digital Image Processing
- Initial Evaluation of Image Products
- Lineament Interpretation
- GIS Analysis
- Ground-truth Lineament Map
- Image Evaluation

*Methodology by Bruning, 2008

Lineaments derived from 30-m DEM
Thermal Bands Analysis

Ilaló Volcano

NONO
QUITO
GUAYLLABAMBA
Cayambe

High : 9.06125
Low : -0.00659

Radiance

Aster Night Image
TIR – B10 (stretched) 2007/09/07
RS-Thermal analysis

INDEXES

NDVI = (NIR - Red)/(NIR + Red)

NDWI = (RNIR – RSWIR) / (RNIR + RSWIR)

High : 0.840491
Low : -0.909091
High : 0.927835
Low : -0.944444
Geoelectrical Methods

- **B: 1D**
- **Limestone (aquifer)**
- **Claystone**
- **C: 2D**
- **Fault**
- **Clay lenses**

VES1, VES2, VES3, VES4, VES5, VES6, VES7

- 20 Ωm
- 30 - 40 Ωm
- 350 - 500 Ωm
- 20 m
- 100 m
Very Low Frequency-Electromagnetics (VLF-EM)

Adapting from the WADI instruction manual, ABEM Instruments, Inc.
Hydrochemistry

Piper Diagram and Hydrochemical Processes (Appelo, 1993)
Environmental Isotopes

\[ \delta^{18}O = -3.620 (\pm 0.137) \times \log_{10}(\text{altitude}) + 1.923 (\pm 0.004) \]

\[ r = -0.925 \quad n = 34 \]
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Methodology
Three phases approach

Phase I
Regional Hydrogeological Assessment

Phase II
Remote Sensed and Geophysics Based Hydrogeological Evaluation and Validation

Phase III
Remote Sensed and Geophysics Based Hydrogeological Evaluation
Phase I

Topography and RS analysis → Geology Analysis → Evaluation of existing hydrogeology data

Regional Conceptual Model → A
Phase II

Lineament / Discontinuities Mapping

Hydrogeological Characterization of fracture, discontinuities and boundaries

RS Assessment

Geophysics Assessment

Hydrochemistry / Isotope Assessment

Hydraulic Assessment

Local Conceptual Model

Existing models

Validation

Final Conceptual Model
Phase III

- Lineament Mapping
- Hydrogeological Evaluation of fracture, discontinuities and boundaries
  - RS Assessment
  - Geophysics Assessment
    - Potential areas for detailed studies
    - Local conceptual model

Methodology For Remote Sensing Based Hydrogeological Evaluation
Scheme of collaboration for this project

**MTU**
- Remote Sensing (MR)
- Regional Analysis (MR)
- Surface Geophysics
- MR/ATT

**UCE & EPN**
- Ves reinterpretation
- Hydraulic Analysis
- Hydrochemistry

**EMAAP-Q**
- Provide data
- Logistics

**IRD / INAHMI**
- Use similar methodologies in other regions of Ecuador

**Montpellier Univ.**
- Isotope Lab Analysis
- Sharing data
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Desired Outcomes for RS Techniques

• Appropriateness for hydrogeological characterization in fractured aquifers

• Effectiveness & limitations for detecting faults, fractures, and discontinuities

• Influence of fracturing on hydrologic behavior
Desired Outcomes for RS Techniques

- Demonstrate the importance of including remote sensing techniques in regional hydrogeological analysis for water resources evaluation and management

- Effectiveness of international collaboration for complex hydrogeological studies
Questions?