

## **Fracture trace and alignment analysis for groundwater characterization of a non-karst arid environment in the Chihuahuan Desert, Mexico**

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**Abstract** Groundwater exploration is an ongoing task within the Chihuahuan Desert territory where water wells are tested for their hydraulic properties and geomorphic position (i.e. fracture traces and alignment) to characterize the available water resources. Several of these water wells were surveyed with a GPS unit to identify land use and vegetation cover, and using GIS coverage and perched aquifers reflected on thermal bands on Landsat-TM7 images. Highly productive wells (i.e.  $72 \text{ l s}^{-1}$ ) vs low yielding groundwater wells (i.e.  $10 \text{ l s}^{-1}$ ) corresponding with these geomorphic features were mapped. Wells located near to (i.e.  $<100 \text{ m}$ ) the identified fracture traces had better yields than those located further away from such features. The technological combination of remote sensing (RS) imagery, GIS and GPS improves the assessment of groundwater resources in desert environments.

**Key words** Chihuahuan Desert; fracture traces; geomorphology; GIS; GPS; Landsat-TM

### **INTRODUCTION**

The Chihuahuan Desert is located between Mexico and the United States of America embracing more than  $357\,000 \text{ km}^2$  as defined by its climatic conditions (Fig. 1). Within this desert, four states of the Mexican Republic: Chihuahua, Coahuila de Zaragoza, Durango and Nuevo Leon, along with Texas, New Mexico and Arizona of the USA, comprise the different regions of this shared desert ecosystem. Several major cities in the area depend upon available groundwater (GW) resources; therefore, improvement of the administration of water resources is needed to satisfy the demands of domestic households, industry, agriculture, natural habitats and recreational activities.

Successful drilling programmes in these desert environments have always been challenging; hence, new exploration techniques using remote sensing (RS) to allocate potential groundwater resources (Vincent, 1997) are required to improve traditional methods for establishing potential sites to drill for underground water (LeGrand & Mundorff, 1952). This application has proven to be successful while conducting GW research in diverse geological environments such as in non-karst sedimentary terrains located in sub-basins of the Basin and Range Province (Campbell, 1996; Hawley, 1999). Use of Geographic Information Systems (GIS), Global Positioning Systems (GPS), and RS while conducting GW research in northern Mexico is presently an ongoing task. The aim of this paper is to demonstrate that potential

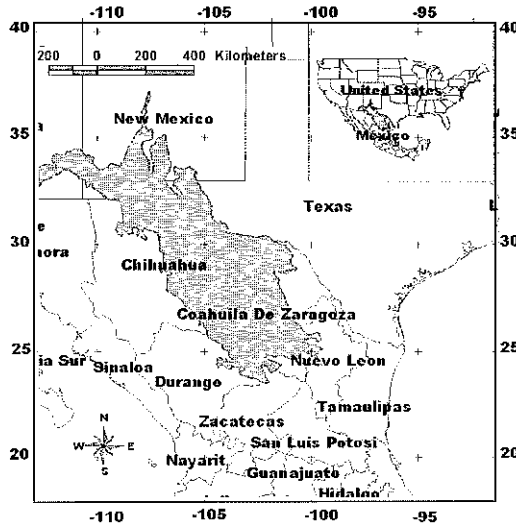


Fig. 1 Geographic location of the Chihuahuan Desert and the research area.

unexplored GW resources can be identified by the study of the spatial correlation of fracture traces and alignments.

## MATERIALS AND METHODS

The Lower Casas Grandes Basin (Fig. 1) was selected as the research area, which is located at the Palomas-Guadalupe Victoria sub-basin, north-central Mexico. Regional transboundary aquifers were identified on a 3-D shaded relief image created with hypsographic data at scale 1:100 000 and projected on ArcGIS v8.1. Landsat-TM7 imagery was used to identify and visually add to geomorphic features while using ENVI v3.4. Wells were geo-referenced with a GPS, giving a 2–5 m spatial resolution after differential correction. GW data sets from well records were available from the National Water Commission (CNA). The approach to aquifer tests was obtained by running analyses at single wells. National Index of Vegetation data was obtained from GIS coverage associated with the Mexican Territorial Ordinance Programme (Palacio, 2000).

## RESULTS

The Mimbres-Los Muertos transboundary basin extends on the Mexican side of the depositional system where the Lower Casas Grandes Basin (LCGB) is located and the Palomas-Guadalupe Victoria semi-closed basin is situated (Fig. 2, circle area).

The predominant ages of geomorphic formations present at the LCGB vary from Pre-Tertiary sedimentary rocks of Cretaceous age at Sierra de Boca Grande (SBG), where potential secondary porosity after dissolution of crevices is present (CNA, 1987), to Tertiary volcanism, Quaternary sediments, and Holocene fluvial systems.

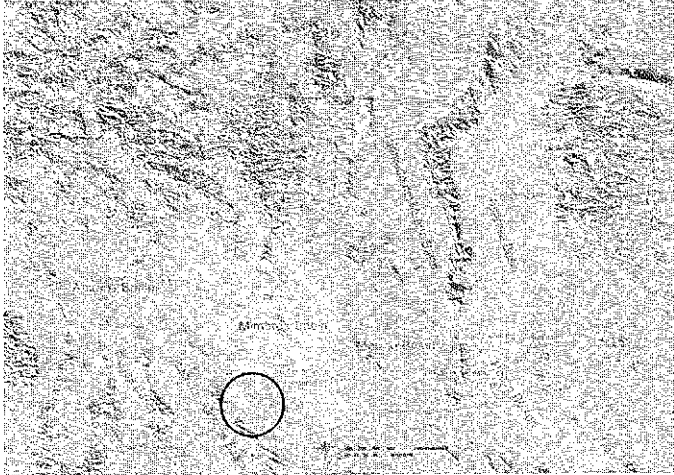


Fig. 2 Major transboundary aquifer systems and location at research area LCGB.

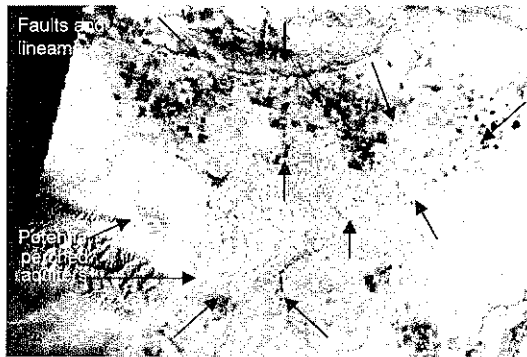


Fig. 3 TM7 image where arrows exhibit enhanced features related to GW resources.

The series of igneous extrusive small cinder cones with lava flows, and intrusive igneous materials may possibly form subsurface dikes at potential discontinuity sedimentary layers. Mapping of such hydrogeomorphic features is reflected in Fig. 3, showing a satellite thermal imagery on spectral band 6 (10.5 to 12.5 m) with a spatial resolution of 60 m per pixel. This image displays observed faults and lineaments in non-karst sedimentary material, revealing differences in soil tone and vegetation with potential perched aquifer systems located at piedmont slopes of SBG, near fracture traces.

The faults and alignments correspond to lines with an echelon formation displayed in Fig. 4, where the geo-referenced wells (dots), closer to these linear features have greater yields and hydrogeological characteristics compared to wells located far from fracture traces and lineaments. The results of aquifer tests (Table 1) demonstrate a spatial correlation between well yield and site location of wells in the research area. The wells identified as W827 and W809 are most productive ( $Q$ ); with high transmissivity ( $T$ ) and hydraulic conductivity ( $K$ ), and are sited on top of the mapped features.

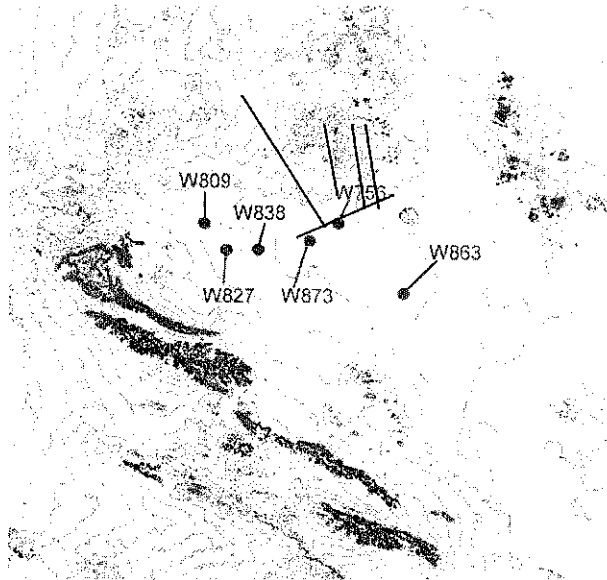


Fig. 4 GIS well location and fracture trace and lineaments at LCGB.

Table 1 Aquifer test results from selected wells.

Well ID	Geomorphic location	$Q$ ( $l s^{-1}$ )	$T$ ( $m^2 day^{-1}$ )	$K$ ( $m day^{-1}$ )	Approximate distance to fracture trace (m)
W809	Floodplain	58	121	1.53	0
W827	Basin floor	72	109	2.97	0
W838	Basin floor	10	31	1.01	850
W873	Floodplain	14	16	0.11	800
W756	Floodplain	29	130	2.17	110
W863	LCGB delta	20	49	1.6	95

With regard to the vegetation, two types mainly characterize the area, i.e. desert shrublands and halophytic vegetation. A variety of shrubs and succulents are common in the region. In the drier upland habitats where fracture traces are present, the dominant microphyllous species are *Larrea tridentata*, *Prosopis glandulosa*, *Acacia* spp., *Ephedra trifurca*, *E. aspera*, and *Fouquieria splendens*. The typical vegetation associated with drainages within the shrublands is represented by *Viguiera stenoloba*, *Rhus microphylla*, *Aloysia wrightii*, *Gymnosperma glutinosa*, *Chilopsis linearis*, *Porophyllum scoparium*, and others. The halophytic vegetation is associated with palaeo-lake environments that contain finer sediments, have higher pH levels, and may accumulate water for relatively longer periods. Shrubs adapted to this type of edaphic conditions are *Atriplex obovata*, *A. acanthocarpa*, *A. cansescens* and *Prosopis glandulosa*.

## CONCLUSION

Groundwater characterization in semiarid regions is of major importance in enabling sustainable development of desert communities. The application of technical advances, such as GIS, GPS and RS, has proven them to be potential tools to use for the location and mapping of geomorphic features, such as fracture traces and alignments related to groundwater resources. These features are related to enhanced hydrogeological parameters, relative to the common stratigraphic arrangements of the aquifer formations within the studied area.

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