TEMPORAL VARIATION OF GROUNDWATER QUALITY IN THE TRANSBOUNDARY PASO DEL NORTE HUECO BOLSON- EVALUATION OF 45 YEARS OF DATA

Del Hierro-Ochoa, Julio Cesar, M.S. Candidate 1; Granados-Olivas, Alfredo Ph.D. 1; Dominguez-Acosta Miguel, M.S. 1; Garcia, Tomas, Student 1; Hibbs, Barry, Ph.D. 2; Eastoe, Chistopher, Ph.D. 3.

1 Universidad Autónoma de Ciudad Juárez. jdelhier@uacj.mx; agranados@uacj.mx; mdoming@uacj.mx; tgarci@uacj.mx.
2 University of California. bhibbs@calstatela.edu.
3 Arizona State University. eastoe@geo.arizona.edu.

ABSTRACT

Water supply and water quality are technical and social challenges for border communities that share common ecohydrological regions such as in the Ciudad Juárez, Chihuahua-El Paso, Texas transboundary region. Lack of water resources in this region, such as treated surface waters from the Rio Bravo, problems with overpumping of the local aquifers, and salinization of groundwater resources, are major concerns for agencies responsible of providing water resources for a demanding binational community. Over-pumping of shared water resources from the Hueco Bolson have resulted in excessive drawdown of the water table, encroachment of brackish groundwater, and the early retirement of wells because of the dissolved solids concentration now exceeding the maximum recommended limit of 1,000 mg/L for potable water on some wells. Dissolved solid concentration data in time series tend to correlate to drawdown in wells. Several possible sources of saline waters have been suggested, which include: upcoming of saline groundwater; leakage of saline groundwater from mud interbeds; downward movement of saline groundwater from the brackish zone near the Rio Grande; and lateral migration from the saline groundwaters along the axis of the basin (Hibbs, 2003). Our research concentrates on a variety of geochemical data (1965 to 1999) to evaluate geochemical evolution of groundwater resources of the urban area for Cd. Juarez (Mexican side of the Hueco Bolson) which might be related to increasing salinity of pumped water. These data sets where plotted on computer programs using Stiff Diagrams to give a temporal and spatial interpretation in the developed parts of the aquifer system. Stiff diagrams show the absolute and relative concentrations of the three most abundant cations (Na- K\textsuperscript{+1}, Ca\textsuperscript{+2}, Mg\textsuperscript{+2}) and the three most abundant anions (Cl\textsuperscript{-1}, HCO\textsubscript{3}+CO\textsubscript{3}\textsuperscript{-1}, SO\textsubscript{4}2\textsuperscript{-2}). Water quality data indicates that a high degree of variability exist throughout the Cd. Juarez area. Wells with high concentrations of sodium are related with historical irrigation sites for active agriculture as well as for those near the Rio Bravo on the north part of the city bordering the United States. Wells with high concentration of Calcium and Sulfate, as well as, high concentration of chlorine are related to the oldest wells drilled on the city, specially those in the downtown area. Water quality decline threatens existing freshwater resources in this aquifer, which are being extracted at a rate 15 to 20 times the rate of natural recharge, limiting the extent of the aquifers life.
Introduction
Ciudad Juarez is a border town situated on the north-central part of the State of Chihuahua, Mexico (31° 44´ N; 106° 29´ W), at the limits of Mexico and the United States of America on the margins of the Rio Grande, geographic site is shown in figure No. 1. It is a semi-arid region in which water issues are very important due to its population growth (~1.3 million people) that has bring a higher demand on the amount and quality of water.

The chemical analysis of water for the determination of dissolved components is a task done by a number of qualified, private or academic, laboratories in the locality. The methods used by these labs for the determination of the dissolved components in water are standardized by "Standard Methods for the Examination of Water and Wastewater" (American Public Heath Association and others.1980) as well as, by Mexican laws that establish the limit for every component involved in the analysis. The information for the evaluation of the geochemistry of water from the Bolson del Hueco in the Ciudad Juarez area, was based on the water analysis of only 64 producing wells, administrated by the Junta Municipal de Agua y Saneamiento (J.M.A.S.) of Ciudad Juarez, Chihuahua.

Ongoing research efforts to characterized groundwater quality on the Mexican side of the Hueco Bolson is a multi-institutional task taken by regional universities along the transboundary area as well as, by different agencies responsible for providing for water resources to the community (Hibbs, 1999; 1998; Hawley, et al., 2000). It is estimated that groundwater quality has been deteriorating thru time as overpumping from aquifer system has been stressing the available groundwater resources. This study shows the evolution of GW quality on the research area throughout a period of time of over 45 years while using available GW data provided by the JMAS.

Materials and Methods
Over the years a considerable number of techniques for graphical representation of analysis have been proposed. Some of these for display purposes, to provide means for comparing the analysis with each other, or to emphasize differences or similarities. The Stiff diagrams give a more

![Figure No. 1](image-url)
distinctive pattern of the water analysis (Hem, 1989). The Stiff plotting technique, applied in this work, uses three parallel horizontal axes extending on each side of a vertical zero axis. Concentrations of three cations are plotted as well as three anions. The concentrations are in milliequivalents per liter. To facilitate the plotting of the Stiff Diagrams a RockWorks software system, 2002 version, was used (fig. 2). To get a better interpretation of the water quality analysis, an average of every five years of data was plotted on the stiff diagrams, in which the information was represented for periods of every 5 years:1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999. These data provided available information for analysis thru a period of ~35 years, (some wells had data for more than 45 years; however, continuous data for extended periods of more than 5 years was not available). The well distribution plots was divided in those with more than 20 years of use and those of less than 20 years, with a purpose of determining if the operating time of the well was a determining factor in water quality.

Figure No. 2. Representation of some of the data gathered from 1965 to 1999, for water analysis in most of the well in the Ciudad Juarez area. As shown, some of the information is not complete.
RESULTS
In order to obtain an objective analysis of the dissolved salts in groundwater, the data sets were analyzed and reported in form of cations and anions. With the use of Spectrometers of masses and atomic absorption technology, it was feasible to obtain the concentration of almost all the present elements of the periodic table in sampled waters, as well as, some of the natural isotopes. It is common to focus concentration of those elements that are greater than 1.0 mg/lt for cations, like calcium, magnesium, potassium and sodium; or anions such as chlorine, flour and nitrates; as well as, those that contribute to the alkalinity of water, like bicarbonates and carbonates. In water analysis, all solute concentration can be reported in milligrams (or micrograms) per liter, a universal standard, with the purpose of avoiding the corrections in the calculations of density. The results of the chemical studies of water before 1990 were expressed in terms of the concentration of combinations of salts, such as sodium chloride or calcium sulphate, depending on which type will precipitate over evaporation of water.

The water analysis of 16 of the 64 wells studied reported total dissolved solids below 750 mg/lt. These wells have more than 20 years in operation (wells 5, 6, 33, 38, 45, 56-56R, 58-58R, 59, 60, 66, 67, 72-72R, 80-B, 87, 92 and 106). No well with less than 20 years in operation reported lower than 750 mg/lt. of total dissolved solids concentration (Fig. 3).

Figure No. 3. Well No. 45. Data plotted annually.
Only six wells with total dissolved solids concentration between 750 mg/lt and 1,000 mg/lt with less than 20 years in operation were reported (wells 7-7R, 15-15R, 49, 78-78R, 132 and 134). Nine wells with total dissolved solids between 750 mg/lt and 1,000 mg/lt with more than 20 years in operation were reported (wells 12, 62, 64, 71-71R, 74, 76, 77, 111, and 113). Over a higher concentration of more than 1,000 mg/lt of total dissolved solids only four wells were reported, with less than 20 years in operation (wells 9-9R, 19-R, 42-R and 135-R). Wells with total dissolved solids over the 1,000 mg/lt concentration and more than 20 years in operation, six well were reported (wells 23, 37, 39, 42, 43, and 48).

According to the predominant ionic pair in water, distribution of wells represented by Stiff diagrams is: Wells with a predominant ionic pair of bicarbonate-carbonate (HCO3 - CO3 - Ca) and calcium (HCO3 - CO3 - Na) or sodium are: well No. 70-70R, 72-72R, 73-73R, 75-75R 87, 92, 95, 99-99R, 104, 115, 116, 120, 138, 141, 143 and 148. (Fig. No. 4). Wells with a predominant ionic pair of Cl-Na, are: well No. 17-R, 38, 56-56R, 58-58R, 67, 68-68R, 71-71R, 76, 77, 80B, 106, 111, 124, 184, 134, 135R y 139. (Fig. No. 5). Wells with a predominant ionic pair of Cl-Ca, are: well No. 6, 12, 33, 37, 60, 62, 113, 133 and 139. Figure No. 6. Wells with a predominant ionic pair of SO4 – Na, are: well No. 9-9R, 19-R, 42, 42-R, 45, 48, 78-78R, 128 and 132. (Fig. No. 7). Wells with a predominant ionic pair of SO4 – Ca, are: well No. 5, 7-7R, 15R, 23, 39, 43, 54R, 59, 64, 74, 98-98R And 114). (Fig. No. 8)

**FIGURE No. 4.** Representation of a well with a predominant bicarbonate-carbonate/calcium or sodium ionic pair. Wells with these characteristics are located at the southern part of the city.

**FIGURE No. 5.** Representation of a well with a predominant Cl-Ca ionic pair from an old high agricultural activity site.
FIGURE No. 6. Wells near the Rio Grande/Rio Bravo basin, in an active agricultural site.

FIGURE No. 7. Wells in the downtown area near the “Acequia Madre” canal. Presence of sulfate deals with the lithology of the area.

FIGURE No. 8. Wells near the “Acequia Madre” and “Acequia del Pueblo” canal. Presence of sulfate may be related to agricultural runoffs.

Discussion
Because some age of wells are between 20 years (no. 5, 38, 45, 59, 60, 66 and 67), good quality water has been provided to the community throughout these pumping stations, which have maintained total dissolved solids concentrations of less than 750 mg/lt. Out of the sixty four studied wells, some of these exceed the standards for groundwater quality, which are identified as wells No. 9-9R, 19-R, 23, 37, 39, 42, 42R, 43, 48 and 135-R, which extract water with more than 1,000 mg/lt.
of TDS, exceeding the limits; in which some of these, such as wells No. 9-9R, 19-R, 42-R and 135-R have less than 20 years in operation. All of them, with exception of well No.135-R display sulphate predominance. Well No. 135-R contains a bicarbonate-carbonate concentration. The bicarbonate presence of calcium or sodium (HCO3 - CO3 - Na or HCO3 - CO3 - Ca) in the water of some of the studied wells (70-70R, 72-72R, 73-73R, 75-75R, 87, 92, 95, 99-99R, 104, 115, 116, 120, 138, 141, 143 and 148) is representative of the subsurface lithology, where limestone stone fragments have been drilled. The sodium predominance on calcium occurs by cationic interchange water bearing formations. The presence of the ionic pair chlorine-sodium (Cl-Na) is representative of the wells that are in areas that presently are or were in the recent past, of intense agricultural activity (wells No. 17R, 38, 56-56R, 58-58R, 67, 68-68R, 71-71R, 76, 77, 80-B, 106, 11, 124, 131, 134, 135-R, 139 and 131). The presence of sodium might represent fine clay and lime deposits from ancestral Rio Bravo/RioGrande interbeded with gravels and sand lenses that are predominantly represented by the argillaceous sediments on which the well is operating, in which high capacity of cationic interchange might be due to the clays which is reflected on the cation exchange concentration. The chloride is an element that due to its chemical characteristics of volatileness is not usually find in significant concentrated amounts. Present ionic pair Cl-Ca in the water of wells No. 6, 12, 33, 37, 60, 62, 113, 133 and 139 is representative of the lithology of the subsurface. The calcium appears commonly in the limestone, the dolomita and plaster, characteristic of this region. Due to weathering, the dissolution of calcium is caused by cationic interchange. It is necessary to make notice that these wells do not display considerable concentrations of sulphates and bicarbonate-carbonates.

The sulphate presence in water in wells No. 5, 7-7R, 9.9R, 15-R, 19-R, 23, 39, 43, 45, 48, 54-R, 59, 64, 74, 78-78R, 98-98R, 114, 128 and 132, represent leached of biological decay or eroded systems with pyrite presence, characteristics of this region, like the dissolution of plaster. In relation to the charge of the hydrologic resources of the region, this might be due to the well sulphate presence near the drain (wells No. 5, 23, 7-R, 39 and 48) that could indicate the presence of leached sulphates that might be dragged from the agricultural regions.

**Conclusion**

The chemical quality of water in the urban area of Ciudad Juarez, Chihuahua is predominant fresh to slightly saline with total dissolved solids (TDS) concentration between 750 to 1,000 mg/l. The variable hydrochemical presence of ions, like: calcium, sodium, potassium, magnesium, bicarbonate-carbonate and sulphates, corresponds, exclusively, to the lithology and stratigraphy of this region (dissolution of dolomita, plaster and calcite) forming the water families as well as mixture of Na-Cl-SO4. The age of the well is not always related to the quality of water, since stratigraphy of water bearing formations play a major role on the groundwater quality of the area.

**References**


