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WAVELET TRANSFORM ANALYSIS FOR MEXICO CITY AQUIFER

Gerardo Ruiz[1]

ABSTRACT

The growth of the population in Mexico City, demand increased amount of water day with day today for providing the vital fluid is resorted to the exploitation of sources, both internal and external, the aquifer of Mexico City, the dependency of groundwater extracted from wells makes it necessary to review the conditions of the aquifer for evolutionary in the aquifers conditions; these revisions are made from the depths of groundwater; measurements obtained values can infer the effect that brings with it the exploitation of this source and at the same time can implement actions to enable their recovery.

The analysis, identification, characterization and simulation of random processes utilizing both the continuous and discrete wavelet transform are addressed. The transformed wavelet is used to decompose random processes into localized orthogonal basis functions. The time and frequency analysis make possible that the wavelet transform provides a vision into the character of transient signals through time-frequency maps, contrary to the traditional method of spectral decomposition where the time is lost. In the relatively short life of the wavelet transform it has been found its usefulness in a wide variety of applications.

The present paper will discuss the development of the continuous and discrete wavelet transform applying the coscalogram representation for two time series simultaneously, of groundwater is presented until 2009 of the aquifer of the Metropolitan area in Mexico City, for which the static and dynamic level of 225 wells measurement was made and precipitation data.

1. INTRODUCTION

The Mexico City population growth demands an increase of water, providing the vital liquid that is resorted of the internal and external resources of exploitation. The dependency of groundwater extracted from wells makes it necessary to review the conditions. These revisions are made from the depth of groundwater obtaining measurement values that can infer with the exploitation of this source and its recovery.

In order to carry out the multi-temporary study the static and dynamic levels of 225 wells, located in the aquifer of Mexico City were modeling. Thus like the hydraulic balance of the underground water to determine the overexploitation degree is presented, and additionally a new technique that relates the precipitation with the static level and see what their interaction according to the area of location.

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2. ZONE OF STUDY AND HYDROGEOLOGY

One is made up of a single system of the aquifer, which is the aquifer subsystem of Mexico City. Regionally the subsoil of the Valley of Mexico is constituted by a sequence of alluviums and volcanic products, both permeable, which allows the infiltration and underground water circulation. Aquifer is confined by lacustrine clays in the East portion of the valley and in the Western portion it works like a free aquifer, see Figure 1.

Main recharge of the aquifer comes from the infiltration of water that precipitates on the mountain that surround, it especially in the South portion due to the high permeability of the rocks. The principal discharge of the aquifer is carried out by means of pumping of wells perforated in the valley and does not exist discharges to the other basins, because the Valley of Mexico is an endorheic basin without natural exits of superficial water and groundwater.

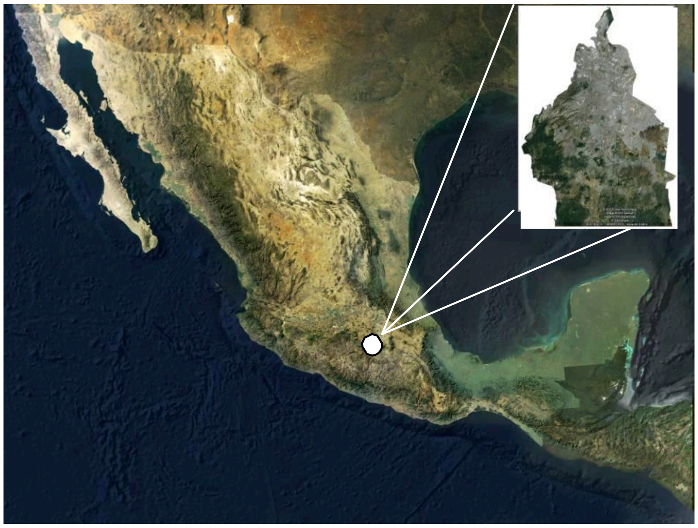

Figure 1 Location of the zone of study, Mexico City, Mexico.

Hydrogeology behavior and the hydraulic characteristics of rocks depend on their lithology, texture, structure and fracture. Based on these parameters, the rocks of the area are classified in three hydrogeology units, taking of their degree of permeability, compaction, granulometry and cementation.

Composed of three zones: Permeable units; they are grouped in this unit as volcanic products of the Quaternary, which are constituted by pyroclastic materials in all the variety of sizes, that they are consolidated slowly. They are put in with basaltic rocks with high secondary permeability has the intense fracture and vesicular texture. They form the main body of the mountain range of the Chichinautzin and Sta. Catarina, in the South and Southwest portion of the area.

Semi-permeable units; In this one includes the rocks of predominantly andesitic composition, with secondary permeability by fracture, that conform the main bodies of the mountain of “Cruces” and Nevada, which are located to the West respectively and orients of the river basin in study, as well as the andesitic rocks that constitute the mountain range of “Guadalupe” which is located to the North. It also includes the extensive volcanic fans that form flanks of the mountain (Tarango formation), made up of pyroclastic flows of intermediate composition to acid, layers of pumice, fluvial deposits and lahars.

Impermeable units; Which are included in this unit to the lacustrine materials that are located in the center of the river basin, are constituted by predominantly argillaceous materials moderately consolidated, it is considered like an aquitard, because have considerable contributes in the aquifer volume of the aquifer in long periods are considered.

3. DISTRIBUTION OF THE WATER IN MEXICO CITY

The water for the zone of study is obtained from three main sources: aquifer mantles, Lerma-Cutzamala River and Magdalena River. Aquifers are the principal supply source of water in the Metropolitan Zone of Mexico City (MZMC); the soil of this zone is volcanic and clay type. Rain plays an important role in the recharge of the aquifer mantles.

At the present, the volume of water which we extract from the aquifer is greater than what is naturally recovered of the rain, from the subsoil extracted 45 m^3/s and only 25 m^3/s recover. Consequently the soil is compacted and cause the subsidence of 0.10 m/year, although in certain places like Xochimilco, Tláhuac, Ecatepec, Netzahualcóyotl and Chalco the soil has been compacted up to 0.40 m/year in only one year; for that reason the water that is extracted contains a greater amount of minerals, that makes it lower quality. Statistical registries show annual subsidence ranging from 0.15 to 0.25 m/year in the region of the International Airport of Mexico City.

Mexico City is formed by main principal and secondary networks. The main network of pipe is formed by 690 km of length with tubes that measure of 0.5 m and 1.73 m of diameter. The secondary networks is more than 10,000 km of pipe, on interior diameter 0.5 m and have 243 tanks of storage with a capacity of 1'500,000.00 m^3, with 227 pumping station that increases the pressure on the network.

The water leads into Mexico City by means of 514 km of aqueducts and lines of conduction, which arrive at the takings of the users, by means of 910 km of primary network and 11,900 km of distribution networks. In this way, the Mexico City´s inhabitants are provided an average of 35 m^3/s. There also exist 27 water treatment plants. In the MZMC, basically exist three uses for the water: 67% are destined to the domestic sector, 17% is used in the industry and 16% are used in schools, hospitals and offices.

Water consumption minimum in Mexico City is divided by social classes occurs as: in some illegal establishments; it is around 28 l/p/day (liters per person per day), the consumption estimation average in the sectors of medium income is between 275 to 410 l/p/day and in the sectors of maximum income is between 800 and 1000 l/p/day.

Multi-temporal analysis of the evolution of groundwater is presented up to 2009 of the aquifer of the Metropolitan area in Mexico City, for which the static and dynamic level of 225 wells measurement were made. Hydraulic balance of groundwater was performed to determine the degree of overexploitation. To check changes in the static levels of the aquifer system from policies. The behavior of the aquifer was determined in recent years.

4. WAVELET TRANSFORM

The WT is a relatively new tool with great potential in the analysis of signals, and it has proved to be powerful in the solution of linear and non-linear problems Grossman and Morlet (1984), Wang (2003) and relation between two or more signals.

Wavelets are a small wave with finite energy and average zero, concentrated in time or space, which serve as a function base for the analysis of transient, not stationary, or, in general, unsteady phenomena. Unlike the Fourier Transform, which focuses around a specific frequency, the wavelet has the characteristic of an oscillatory free wave which gives the ability to simultaneously support analyses in time and frequency.

The difference between Fourier and WT analysis is that in the latter case the signal is broken down into a series of locally basis functions. Each wavelet is located in a different position on the time axis and according to its position it can take different values. The term "wavelet" or ondelettes in French owes its name to the work of Farge (1992) and Daubechies (2004), and it is a relatively new discovery in applied mathematics.

WT is an expansion in time of a signal in terms of a particular base called Mother Wavelet, such as the function:

$$\Psi(t) = (1 - t^2)e^{-t^2/2} \tag{1}$$

Wavelet analysis provides immediate information that in other methods, such as the Fourier analysis, is lost; and can be divided into two: Continuous Wavelet Transform CWT and Discrete Wavelet Transform DWT that will be presented below.

4.1 Continuous Wavelet Transform

Although any signal in terms of actual data processing is a discrete signal, the CWT is continuous on operator‶s scales, and due to the fact that during calculation it makes a smooth scrolling on the domain of the analyzed function.

Continuous analysis is used because it is easy to interpret and has a wide range of frequencies. Instead, DWT only uses frequencies in band eighths. Although the latter method is computationally more efficient and compact, it does not provide precise results for interpretation and is used primarily for signal and data compression.

Other wavelets are obtained from equation (1) by scaling 'a' and translation 'b' to Ψ*(t)* as follows:

$$_{a,b}(t) = \frac{1}{\sqrt{a}} \quad \left(\frac{t-b}{a}\right) \tag{2}$$

and CWT is defined as the sum over all time of the signal multiplied by the scaled and shifted forms of the wavelet function:

$$W_{\Psi} f_{a,b} = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t) \tilde{\Psi}_{a,b} \left(\frac{t-b}{a}\right) dt \tag{3}$$

When 'a' is increment, the wavelet $\Psi_{a,b}(t)$ closes in time, and when 'b' varies, the signal translates in time. Thereby, the scale 'a' captures the contained frequency and 'b' locates the bases of the wavelet functions.

4.2 Coscalogram

The scalogram provides the energy evolution in time a single process by mapping due square of the wavelets coefficients. If the squared coefficients values are replaced with the product of the wavelet coefficients of two different processes, the result is a view of the correlation between the processes. This is called the coscalogram -analogous to the cospectrum in spectral analysis. Like the scalogram, it has the advantage of revealing the various pockets of high and low correlation in different frequency bands. See Li and Nozaki, (1997) and Li, (1998) to determine the relationship between two simultaneously measured signals at different locations within the jet flow field.

The wavelet cross-correlation function between two signals x and y is defined for the continuous wavelet transform as:

$$C_{xy}(a,\tau') = \frac{1}{\tau}\int_0^{\tau} T_x(a,b) * T_y(a,b+\tau\,)db \qquad (4)$$

Where T_x(a,b) and T_y(a,b) are respectively the wavelet transforms of signals x and y; the asterisk denotes the complex conjugate; τ is the time period of the signal and τ' is the delay between the two signals. $C_{xy}(a,\tau')$ is then the cross-correlation between the wavelet coefficients of each signal over a time delay τ at scale a.

5. RESULTS

The main features that is found with the application of the WT is to find as relate both phenomena, such as rainfall influences the recharge of the aquifer and as response to this charge in the well.

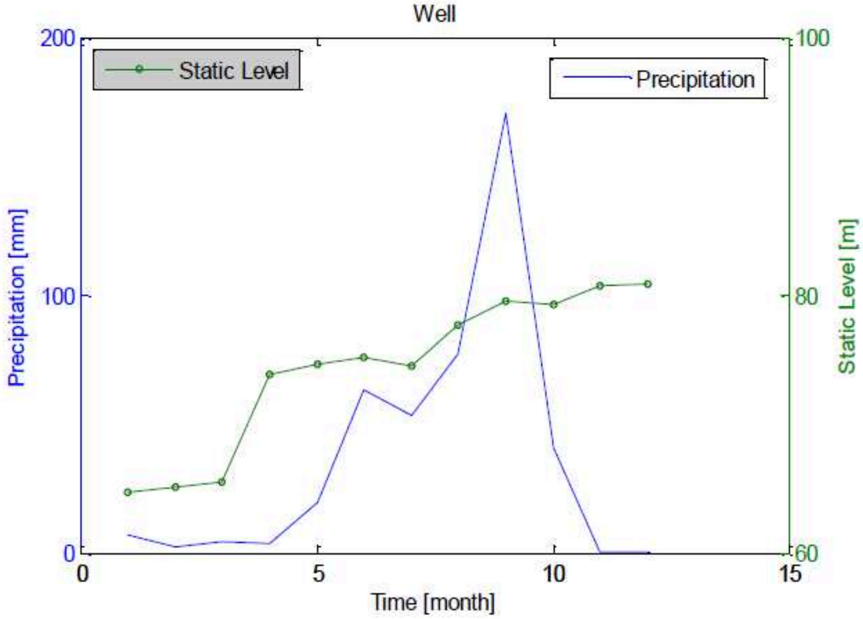

Figure 2 Signals of precipitation and static level of a well No. 21.

Applying the wavelet transform to the static level and record rainfall measures signals annual in the year of study, see Figure 2, in the well number 21, which is located in the downtown area of the city of Mexico was used, since in this area, it has the peculiarity that consists the formation soil is clay, which makes it difficult a recharge as well as it is a fully urbanized area with very little natural and artificial area for a substantial recovery of the static level in this area and in particular in that well.

In the Figure 3 applies the CWT type Morlet, for the static level data, which is the best suited to this type of data, since it uses a window Gaussian as envelope, as can be seen there is frequency large during the months of April to October, which is when you can have a higher level in the refueling of the well.

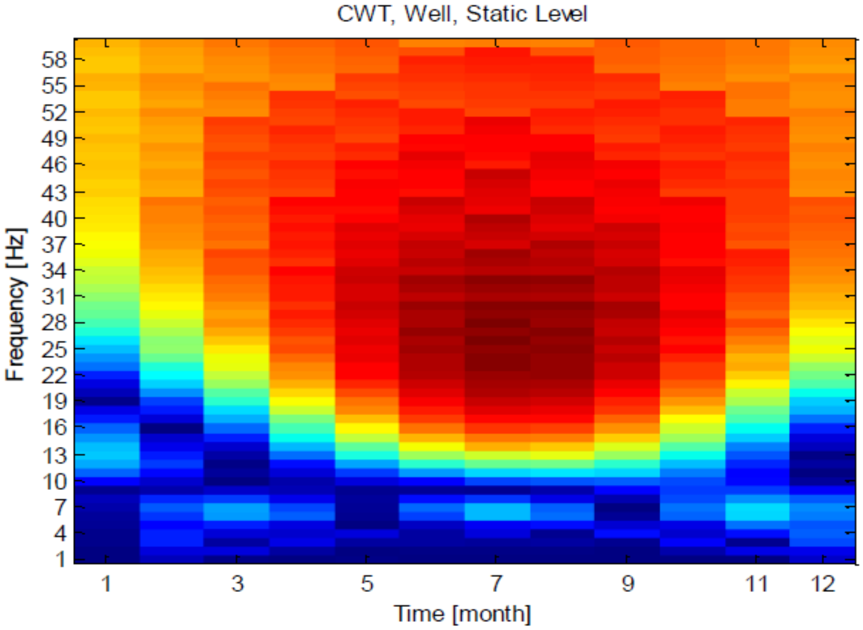

Figure 3 Continuous Wavelet Transform, Wavelet Morlet of Static Level, well No. 21.

In the same way apply you data of precipitation that is shown in Figure 4, there is that in the months of August and September corresponds to the peak seen in Figure 2, which has excess rain which infiltrates not to evacuate in the center of the Mexico Valley area, which sometimes causes large floods.

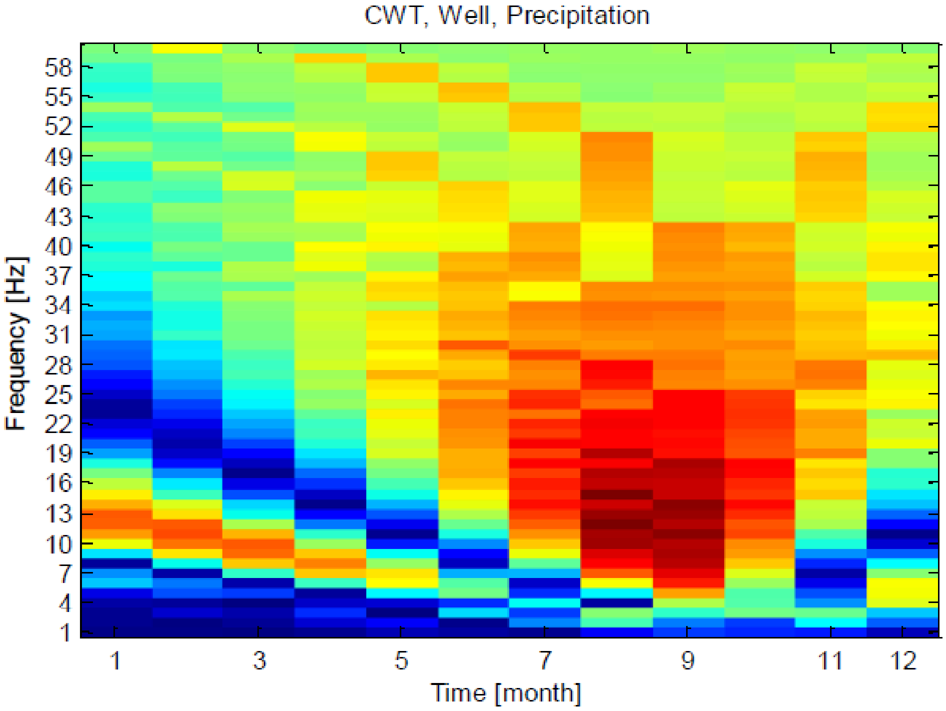

Figure 4 CWT, Wavelet Morlet of precipitation signal, well No. 21.

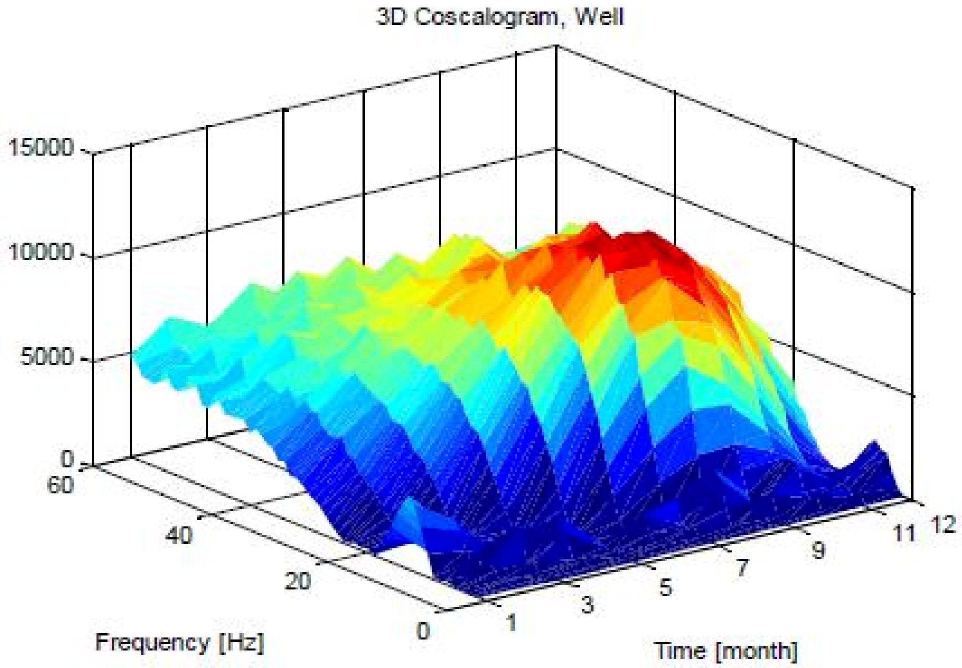

Figure 5 Coscalogram 3D, relation between precipitation signal and satic level of well No. 21.

In this figure the correlation between the precipitation and static level of well can be seen clearly.

6. CONCLUSIONS

The modeling data will provide a description of the system of the groundwater of the MZ MC which are interconnected directly or with data modeled.

The depths of the static levels vary fundamentally between 15.15 and 176.15 m, controlled by the topographic configuration and the extraction of wells. The drawdown that the greater values are in the system in the West area of Mixcoac, San Ángel and Tacubaya. The depth diminishes in the Northwest to the South, and the Northeast to the East. The greater depth 176.15 m, corresponds to the well denominated "Monte Sur N. 2", which is located in the town of Santa Cecilia located in the South system, the smaller depth 15.15 m correspond to the well Per-9 "Periferico 9", that is located in the South system near Xochimilco.

In general, the wells perforated in the portion west of the delegations Gustavo A. Madero, Miguel Hidalgo, Alvaro Obregón and the South of Xochimilco, show static levels greater to 70.00 m, in as much that in the rest of the basin, the levels vary between 30.00 and 70.00 m.

The coscalogram detects phase coupling between two different related phenomena. In this paper one applications -the relations between precipitation and static level in the wells, is very different to the traditionally methods, for example the Fourier Transform method.

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