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Incorporation of Satellite Data to the Characterization of Water Table Level in the Santa Fe plains, Argentina

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Abstract: The Argentine province of Santa Fe is part of the Chaco-Pampean plains. The distribution, frequency and spatio-temporal intensity of rainfall and surface runoff is variable over the province. As for the underlying unconfined aquifer it has been affected by significant climatic fluctuations over the last thirty years. The climate is also closely linked to sea surface temperatures in the tropical Pacific Ocean and other oceanic regions of the planet, as well as other large-scale climatic phenomena. The climate and the water resources system have a special relationship, since they depend on the hydrological cycle which is itself part of the climate system. When the physical conditions of the system allow it, the recharge in transit can reach the aquifer, manifesting level rises. These conditions are consistent with the definition of Sophocleous of 1991 who defines recharge as the water that percolates through the lower limit of the unsaturated zone of the aquifer and produces measurable level rises. The objective of the present research is to incorporate satellite data to the characterization of water table level behavior, together with the traditional rainfall analysis as the contribution to interpret and validate remote sensing data, providing a tool for groundwater resource assessment, for an environmentally sustainable, economic, and social development.

Key words: water table level, groundwater storage, satellite data, plains hydrology, El Niño–Southern Oscillation (ENSO)

1. Introduction

Knowing the availability of groundwater is a topic of relevant importance. The incorporation of satellite data to the traditional analysis made with field measurements is an innovative issue for the evaluation of the resource. In lowland areas, the water table levels fluctuation is associated with the variability of precipitation as first input to the unconfined aquifer. For this reason, these data are considered as filtered climatic data [1]. Specifically for the analyzed area of Rafaela in the province of Santa Fe (Argentina), regional studies have been compiled to evaluate the influence of physical and climatic changes on the runoff regime [2] and the effect of inter-annual variability in the context of climate change and macro-scale events [1, 3]. among other references of interest. Regional studies show the use of satellite data to analyse the variation in water storage [4] as well as to evaluate changes in groundwater storage [5]. The last reference includes the validation with field data. In this sense, the present scientific contribution is related to the characterization of the response of the water table level to precipitation and its relationship with the NASA's Global Land Data Assimilation System (GLDAS) [6].

2. Material and Methods

2.1 Study Area and Data Used

The work is developed considering water table level (NF) and precipitation (P) data from the Experimental

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Station INTA [1] Rafaela (Latitude = -31.18° and longitude = -61.55°) located in Castellanos department of the province of Santa Fe (Argentina) as well as groundwater storage (GWS) data from GLDAS, contained in the 0.25° grid (Fig. 1).

The analysis of precipitation and water table level at Rafaela for the series 1902-2000 has reflected the changes in trends and jumps in the mean as of 1970 which corresponds to the start of the hyper-humid period [1]. This paper analyzes the monthly precipitation of the 1970-2020 series, calculating the accumulated values for the wet period of November-April and the period with less precipitation from May-October, taking as a reference the concepts of Giacosa et al. (2007) [2]. With the average of monthly water table level, its slopes are calculated for the above-mentioned periods.

2.2 Field Data Analysis

The method of analysis considers the interpretation of the average slope of the water table in response to the accumulated precipitation in the November-April and May-October periods. The depths of the initial water table depths for each period were also identified and were defined ranges of analysis (between 0-2 meters, 2-4 meters, 4-6 meters. and greater than 6 meters), according to the root depth of vegetation that is closely related to evapotranspiration (Fig. 2a).

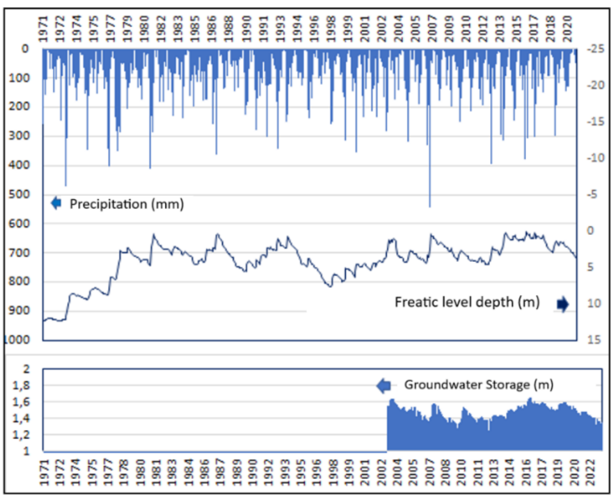

Fig. 1 Monthly precipitation, water table level depth and groundwater storage data GWS.

The Fig. 2b shows the behavior of precipitation and water table levels for the periods of analysis. Macroscale events are also identified – ENSO in its warm (El Niño) and cold (La Niña) phases for region 3.4 (Fig. 3) — defined by the values of the ONI (Oceanic El Niño Index).

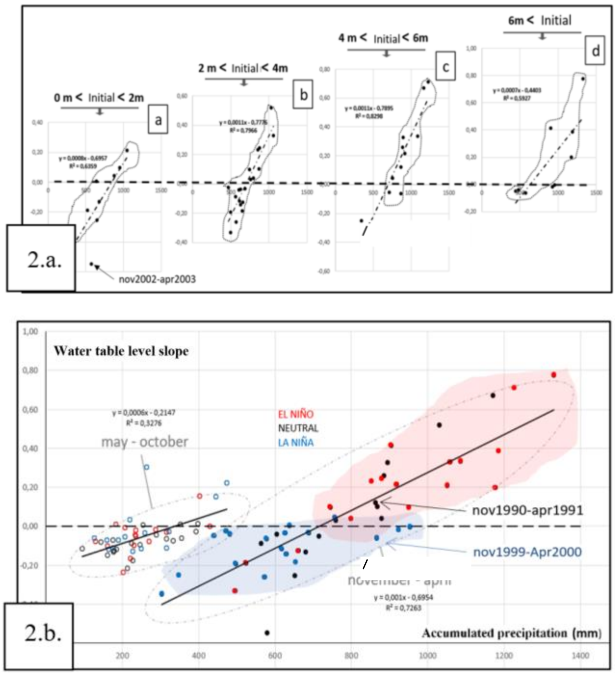

Fig. 2 Accumulated precipitation vs water table level slope - Periods: Nov-Apr (•) & May-Oct (°).

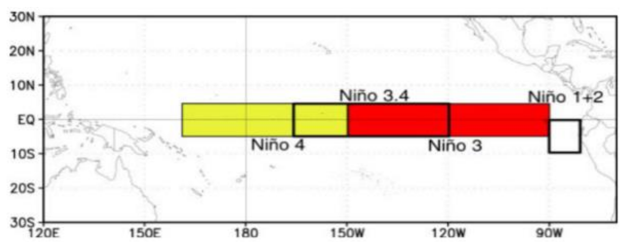

Fig. 3 El Niño regions in the Pacific Ocean [4].

2.3 Satellite Data Analysis

In relation to satellite information, groundwater storage data (GWS) from the GLDAS CLSM (Catchment Land Surface Model) model are used. The NASA's GLDAS system processes ground-based and satellite observation data products using advanced land surface modelling and data assimilation techniques to

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generate optimal fields of land surface states and fluxes [6]. GWS information has been available since February 2003, on a daily basis and in a 0.25° grid.

The data are obtained through “Giovann”, which is an interactive online analysis and visualization interface online GES-DISC [3].

The analysis method of the relationship between water table level field data) and GWS satellite data considers the comparison of slopes and evaluation of coincidences calculated at the percentage level. Fig. 4 shows the relationship of water table level slopes versus GWS slope.

3. Results and Discussion

In reference to NF-P shown in Fig. 2., for the two periods of analysis (November-April and May-October): (1) The comparison between the water table level slope and accumulated precipitation shows a clear pattern of greater response of the aquifer to higher precipitation and vice versa. (2) During the periods May-October the amplitude of the water table level slope is bounded (±0.20) while for the period November-April it widens to a range between -0.40 and 0.80, which is linked to climatic variability. (3) Considering the depths of the unconfined aquifer, it was observed that from 2 m onwards, response patterns are generally slower and even slower at greater depths.

Between 0-2 m, the responses are affected by soil saturation up to the surface and horizontal movements predominate, which is why considering precipitation

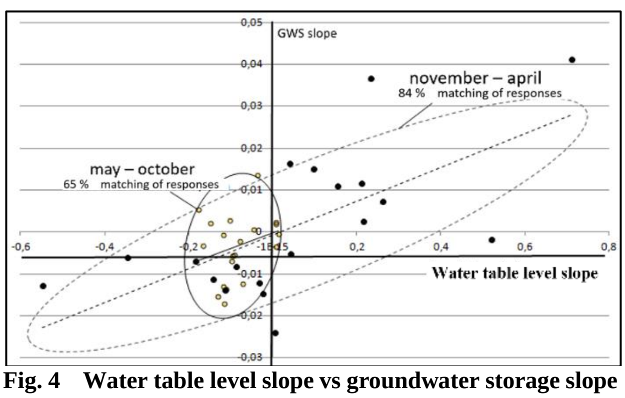

Fig. 4 Water table level slope vs groundwater storage slope Periods: Nov-Apr (•) & May-Oct (°).

alone is not sufficient for the analysis. Result for November 2002 - April 2003 reflects the post-flood recession with a water table level slope of -55% was observed despite accumulated rainfall of almost 600 mm (Fig. 2a).

Particularly for November-April period, (1) the cloud of points with positive slope shows 63% of “El Niño” events and those with negative slope respond to “La Niña” events in 65% of the cases. (2) Although a pattern of coupled responses is observed, the points that move away from the cloud reflect other factors that intervene in the recharge process, not considered in this analysis. As an example, we compare the slopes of average water table levels for the periods Nov. 1990-Apr. 1991 and Nov. 1999-Apr. 2000 with similar accumulated precipitation (863 and 867 mm respectively) and initial water table levels (5.11 and 5.62 m respectively), where the responses show opposite behaviors (+0.12 and -0.06).

This may be associated, in principle, to soil moisture content (Fig. 2b).

About the relation Water table level slope — GWS shown in Fig. 4., in the two analyzed periods (November-April and May-October), the comparison of the water table level slope versus the slope of the satellite groundwater storage data, indicates a pattern of accompanying satellite signals to the fluctuations of the unconfined aquifer (74% considering all periods and reflecting a better reaction of 84% for the November-April series). Non-correspondences are observed for the periods: (1) November-April started in 2007, 2013 and 2016 where satellite data record decreases that are not verified with water table levels and (2) April-October 2004, 2011, 2013, 2014 and 2019 where satellite data record increases that do not correspond with measured water table levels.

4. Conclusions

The comparison of phreatic slope with cumulative precipitation shows a clear pattern of greater aquifer response to higher precipitation.

When the water table level is close to the surface, the hydrological system is more sensitive to climatic variability (more marked rises and recessions) and to climatic variability (sharper rises and recessions) as well as the addition of horizontal surface movements.

It is generally the case that El Niño events result in an increase in water table levels while in La Niña events the opposite effect.

In addition of knowing the precipitation forecast and how to estimate it as a function of ENSO, it would be interesting to add the soil moisture forecast in order to optimize the analysis. In-deed, a neutral period (which can be close to a weak El Niño or La Niña) may induce antagonistic responses.

Given the difficulty of knowing soil moisture field data, the availability of other sources of satellite data, such as GLDAS Soil Moisture could be considered.

5. Final Consideration

The incorporation of satellite information for the characterization of physical processes is still an innovative topic in plains areas. The present research is a contribution to interpret and validate remote sensing data, providing a tool for groundwater resource assessment, for environmentally sustainable economic and social development.

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