Relationship between rain and groundwater in the hydrogeological sectors of the South Basin of Ciego de Ávila

Relación entre la lluvia y el agua subterránea en los sectores hidrogeológicos de la Cuenca Sur de Ciego de Ávila

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Evelyn Blanco de la Paz
Universidad de Ciego de Ávila. Ciego de Ávila (Cuba)
mabe@ciego.cav.sld.cu

Oscar Brown Manrique
Universidad de Ciego de Ávila. Ciego de Ávila (Cuba)
obrown@unica.cu

Francisco García Reina
Universidad de Ciego de Ávila. Ciego de Ávila (Cuba)
pancho@unica.cu

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Abstract

Introduction— Groundwater constitutes the main source of water in the province of Ciego de Ávila, Cuba; especially in agriculture, which occupies the main economic line, however the overexploitation of aquifers in the southern basin of the province puts the sustainability of this important resource at risk, which is renewed through the natural recharge of rainfall.

Objective— To determine the relationship between precipitation and groundwater levels in the hydrogeological sectors CA-II-2 and CA-II-3 of the Ciego de Ávila South Basin, which can constitute a way for the efficient use of water for irrigation purposes in this area of great agricultural importance.

Methodology— In the development of the research, different methodologies were used: selection of the most representative rain gauges, calculation of effective precipitation, determination of accumulated monthly and annual rainfall; as well as the annual rainfall of the wet and dry periods, completion of rainfall series by the linear regression method, use of the HidroEsta 2 program to obtain the mean hiperanual rainfall and the historical mean levels, absolute minimum and maximum of all the selected wells. The mean rainfall of the area of the sectors was determined with the Isohyet method and the charts of hiperanual limnigrams were constructed using the BARHIS software.

Results— The investigation showed that the average rainfall in the area is 1303.6 mm, higher than the historical average for the province. The water levels in the aquifer range between 0.84 m and 12.98 m; where 7.21 m is the absolute average value. The year 1988 had great variations in rainfall, levels and the exploitation of groundwater. This study suggests the need to take measures that contribute to the rational use of groundwater in this overexploited basin due to the intensive use of water resources in agricultural irrigation.

Conclusions— The study carried out was able to verify that the average rainfall in the area is 1303.6 mm, higher than the historical average for the province. The water levels in the aquifer range between 0.84 m and 12.98 m, with absolute averages of 6.52 m and 7.21 m respectively. The year 1988 presented high variability in rainfall, underground levels and the exploitation of groundwater.

Keywords— Hiperanual rainfall; effective precipitation; water recharge; groundwater level; overexploitation

Resumen

Introducción— Las aguas subterráneas constituyen la principal fuente de agua en la provincia de Ciego de Ávila, Cuba; especialmente en la agricultura, que ocupa el principal renglón económico, sin embargo la sobreexplotación de los acuíferos en la cuenca sur de la provincia pone en riesgo la sostenibilidad de este importante recurso, que se renueva a través de la recarga natural de las lluvias.

Objetivo— Determinar la relación entre las precipitaciones y los niveles de las aguas subterráneas en los sectores hidrogeológicos CA-II-2 y CA-II-3 de la Cuenca Sur de Ciego de Ávila, lo que puede constituir una vía para el uso eficiente del agua con fines de riego en esta zona de gran importancia agrícola.

Metodología— En el desarrollo de la investigación se utilizaron diferentes metodologías: selección de los pluviómetros más representativos, cálculo de la precipitación efectiva, determinación de la precipitación acumulada mensual y anual; así como de la precipitación anual de los periodos húmedos y secos, completamiento de las series de precipitación por el método de regresión lineal, utilización del programa HidroEsta 2 para obtener la precipitación media hiperanual y los niveles medios históricos, mínimos y máximos de todos los pozos seleccionados. La precipitación media del área de los sectores se determinó con el método de Isohyet y se construyeron los gráficos de limnigramas hiperanuales utilizando el software BARHIS.

Resultados— La investigación mostró que la precipitación media de la zona es de 1303.6 mm, superior a la media histórica de la provincia. Los niveles de agua en el acuífero oscilan entre 0.84 m y 12.98 m; siendo 7.21 m el valor medio absoluto. El año 1988 tuvo grandes variaciones en las precipitaciones, los niveles y la explotación de las aguas subterráneas. Este estudio sugiere la necesidad de tomar medidas que contribuyan al uso racional de las aguas subterráneas en esta cuenca sobreexplotada debido al uso intensivo de los recursos hídricos en el riego agrícola.

Conclusiones— El estudio realizado ha podido comprobar que la precipitación media en la zona es de 1303.6 mm, superior a la media histórica de la provincia. Los niveles de agua en el acuífero oscilan entre 0.84 m y 12.98 m, con medias absolutas de 6.52 m y 7.21 m respectivamente. El año 1988 presentó una alta variabilidad en las precipitaciones, en los niveles subterráneos y en la explotación de las aguas subterráneas.

Palabras clave— Lluvia hiperanual; precipitación efectiva; recarga hídrica; nivel de aguas subterráneas; sobreexplotación

I. Introduction

Land use practices have positive and negative impacts, both on the availability and quality of water resources [1]. An example of the negative impacts is the reduction of aquifer recharge due to the use of non-conservative cultivation techniques and soil compaction, which contributes to a shortage of water in dry seasons, even in regions where the water is generally abundant [2].

The scarcity of water is due to the fact that the demand exceeds the supply of fresh water in a given area [3], [4] and to the effects of global climate change that constitutes a concern to quantify the available resources in future scenarios [5], [6], [7]. These aspects are one of the great challenges of today; being necessary to improve water management to guarantee the reserve of this resource in 2050 [8], [9], [10].

In recent years, a growing trend towards the study and use of water resources has been observed worldwide, with special emphasis on problems related to groundwater [11]. In the case of Cuba, it has been estimated that the groundwater resources available for exploitation in relation to the total potential water resources are above the world average [12].

The contamination of aquifers is, perhaps, the most pressing problem that water policy will face in the coming decades. This is not a novelty; since more than twenty years ago some Spanish authors had already mentioned it [13]. In order to fight against this type of contamination, it is necessary to carry out research framed on the subject of the integral management of water resources; particularly that related to groundwater [14], [15], [16].

Due to the need for efficient management of water resources for irrigation purposes, the objective of the research was to determine the relationship between precipitation and groundwater levels in the southern basin of the Ciego de Ávila province.

II. Materials and Methods

The study was carried out in an aquifer that includes the hydrogeological sectors CA-II-2 and CA-II-3 of the province of Ciego de Ávila. The sectors are located in the central and eastern part of the southern basin of the province, with an exploitable resource for the CA-II-2 sector of 53.0 hm^3 and for the CA-II-3 of 69.0 hm^3 and a territorial extension of 230.00 km^2 and 256.34 km^2 respectively (Fig. 1).

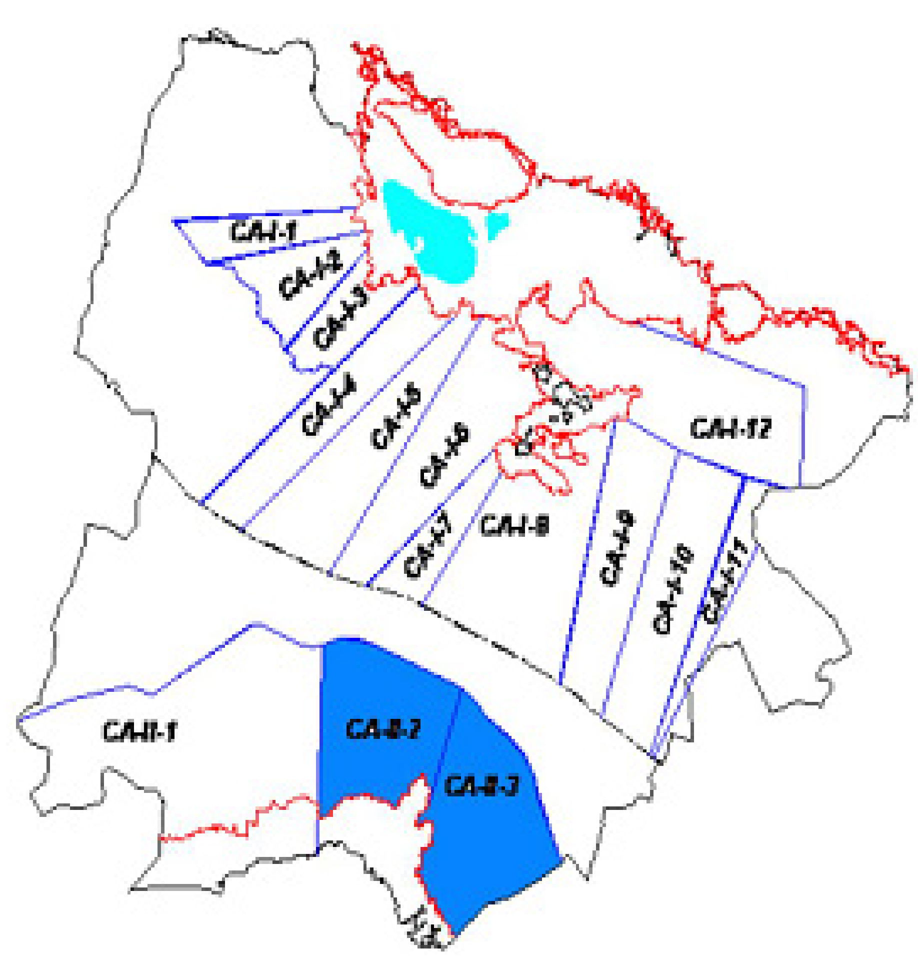

Fig. 1. Location of sectors CA-II-2 and CA-II-3 in Ciego de Ávila.
Source: Authors.

In each hydrogeological sector, the most representative rain gauges were chosen, according to their area of influence and their location in the feeding and storage area, which are those that report recharge to the mantle, identified through the hydroisohipsas maps. For each one of the selected rain gauges, the effective precipitation was calculated by the empirical equation proposed by FAO [17], the monthly and annual accumulated rainfall of all the series analyzed; as well as the annual rainfall of the wet (Llhum) and dry (Llseco) periods.

The completion of rainfall series with an extension of 30 years of systematic observations was carried out by means of the correlations between rain gauges very close to each other using the linear regression method as it is one of the most used in the estimation of monthly and annual data [18], [19], with the support of the HidroEsta 2 program [20].

The mean hyperanual rainfall and the historical mean levels, minimum and absolute maximum of all the selected wells in the monthly and annual time scales and for the dry and wet periods, were also obtained with the help of the HidroEsta 2 program. Average levels were achieved from the database of observation wells found in the study area. In general, 32 wells and 10 rain gauges representative of the area were used, which are part of the information network of order I.

The isoietic method was used to determine the average rainfall in the area of the sectors according to chilean research [21], from all the existing rain gauges within and close to the study area. These maps were made with AutoCAD CIVIL 3D software from 2015. All hyperanual limnigram graphics were built from the automated program "BARHIS", carried out by University of Ciego de Ávila [22].

III. Results and Discussion

Fig. 2 shows the location of all the rain gauges used and the value of the different isoetic curves built, which allowed determining the mean value of rainfall in the study area. This is located between the isolines with precipitation values of 1 100 m and 1 350 mm respectively.

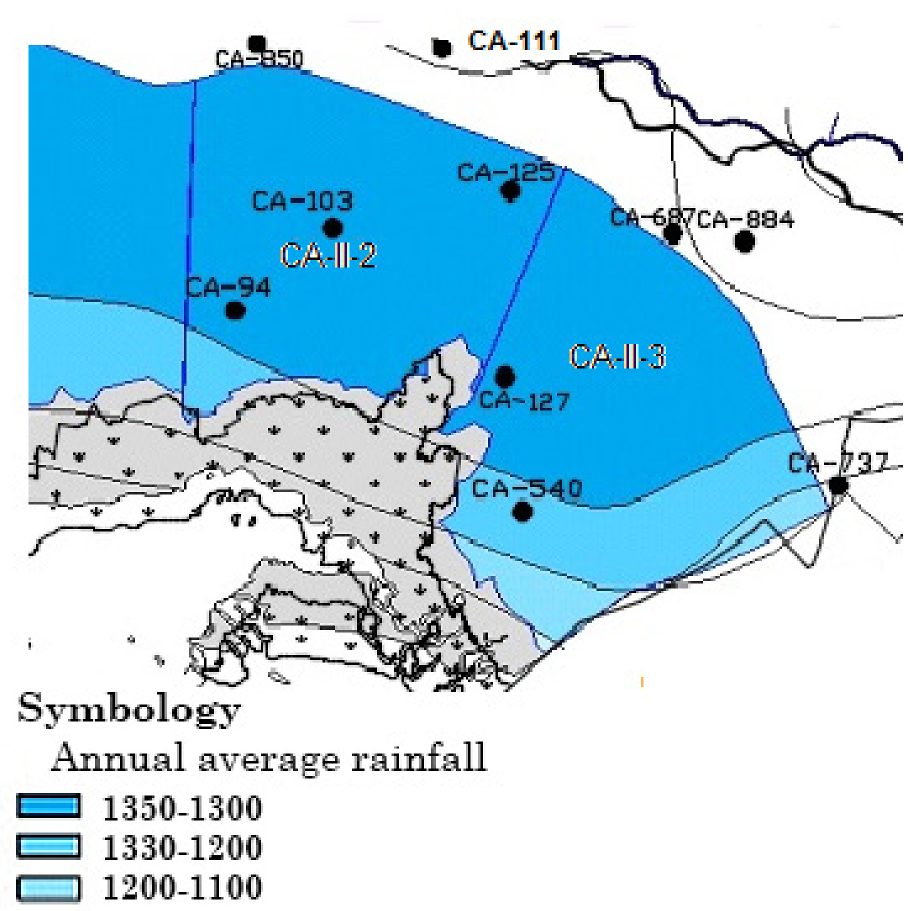

Fig. 2. Isoietic map and location of the rain gauges used in the study area.
Source: Authors.

Table 1 presents the results obtained from the mean hyperanual rainfall for the ten rain gauges used in the isoietic map, based on the correlations between the different equipment, which allowed the completion of the series of 30 years of observations (1985-2014) with a good fit in all cases, expressed through an average R^2 coefficient of 0.751.

TABLE 1. AVERAGE RAINFALL IN THE STUDY AREA.

Sector	Rain interval (mm)	Average rainfall (mm)	Area (km²)	Average rainfall* Area	Total Rain (mm)
CA-II-2	1350-1300	1325.0	220.3	291 897.5	1321.3
	1300-1200	1250.0	1.3	1412.0	
Total			231.6	306 022.5	
CA-II-3	1350-1300	1325.0	160.1	212 132.5	1285.8
	1300-1200	1250.0	68.1	85 125.0	
	1200-1100	1150.0	28.3	32 545.0	
Total			256.5	329 802.5	

Source: Authors.

In Fig. 3 the geographical location of each well selected for the study and the movement of groundwater is observed, which occurs in a direction orthogonal to the hydroisohipsas curves from the area with the highest hydraulic load to the area with the lowest load and is They go to the unloading point located in the south of the Venezuela municipality.

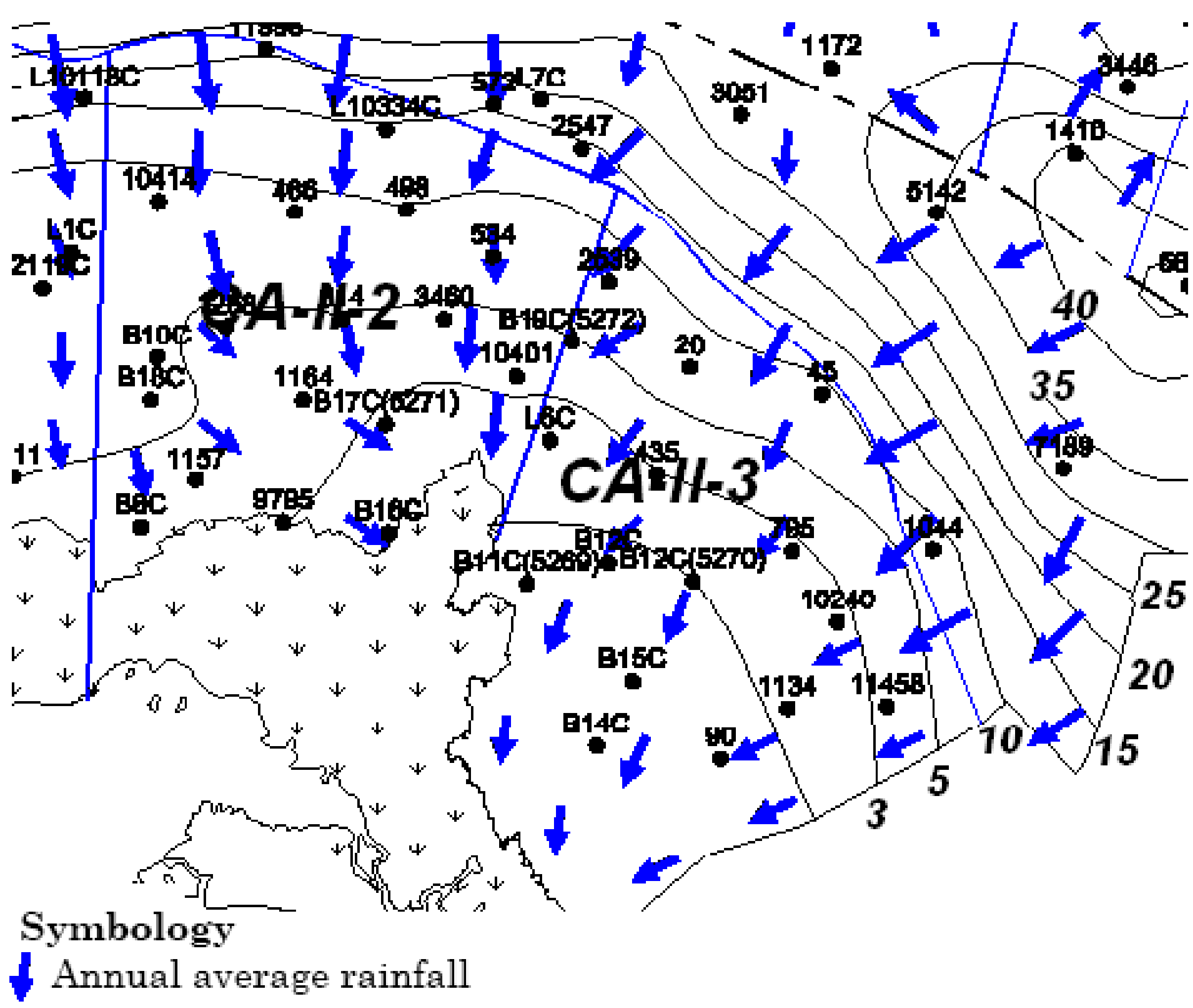

Fig. 3. Spatial location of each well in the sectors.
Source: Authors.

Table 2 shows the different water levels in the aquifer: the Historical Means (MH) for months, absolute minimums and maximums for months and the absolute minimums and maximums of the entire analyzed series. It was found that the water levels in the sectors range between 0.84 m and 12.98 m; the first being the highest recorded in the area. The results show that there is a minimum decrease in the levels, which is expressed through the average values observed in the months of May and June, which are very close to the value of the absolute maximum.

Table 2. Maximum, minimum and historical average values of the sectors' levels.

Levels (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Sector CA-II-2.												
MH	6.83	6.73	6.90	6.99	7.14	6.57	6.62	6.51	6.03	5.84	6.09	5.95
Minimum	4.91	2.55	2.55	0.84	3.92	3.18	3.21	3.27	3.36	3.64	2.93	2.81
Maximum	10.47	10.57	10.26	10.38	10.53	10.47	10.38	10.64	8.36	8.77	9.52	8.42
Absolute average: 6.52 m. Absolute minimum: 0.84 m. Absolute maximum: 10.64 m.												
Sector CA-II-3.												
MH	7.55	7.76	7.68	7.90	7.80	7.29	7.31	7.21	6.53	6.34	6.82	6.30
Minimum	5.85	6.15	1.48	6.79	5.19	4.68	4.46	4.66	1.48	1.48	1.48	1.48
Maximum	11.93	11.40	11.28	9.13	12.74	12.74	12.66	12.98	9.42	10.15	10.80	8.64
Absolute average: 7.21 m. Absolute minimum: 1.48 m. Absolute maximum: 12.98 m.												

Source: Authors.

This behavior is very important from the hydrogeological point of view, because precisely at the end of the decade of the 1980s, the first symptoms of saline intrusion appeared in the CA-II-1 sector, which is located next to of the CA-II-2 sector, a phenomenon identified in the studies carried in Cuba [22] who argue that one of the causes that caused this type of contamination in the aquifer is due in the first place to the overexploitation to which it is subjected same.

Table 3 shows the mean water level values obtained in the sectors studied for all the wells selected in the dry and wet periods.

It was shown that the lowest elevation recorded in the dry period between the two sectors was 5.30 m, reported in 1987, identifying it as one of the driest in the period studied; while the highest recorded was reached in 1996, with a value of 9.92 m.

Table 3. Average values of water levels by periods of the wells in the area.

Average water levels by periods (m)									
Sector CA-II-2			Sector CA-II-3		Sector CA-II-2			Sector CA-II-3	
Years	Dry Period	Damp Period	Dry Period	Damp Period	Years	Dry Period	Damp Period	Dry Period	Damp Period
1985	7.43	5.59	5.71	5.84	2000	9.63	9.42	7.12	6.75
1986	7.33	6.90	7.40	6.53	2001	9.24	9.26	7.10	7.16
1987	6.56	5.46	5.30	2.65	2002	9.50	10.16	7.32	8.47
1988	8.65	11.53	7.47	9.40	2003	9.31	10.02	7.48	8.26
1989	9.11	9.02	7.36	6.59	2004	8.15	7.61	6.41	6.47
1990	8.35	8.53	6.39	6.75	2005	7.30	7.22	6.13	6.64
1991	8.59	8.51	5.87	7.11	2006	7.88	8.20	7.15	7.40
1992	8.69	9.22	5.93	6.71	2007	8.05	8.70	7.67	8.46
1993	8.78	8.56	6.57	7.26	2008	8.70	7.96	7.88	7.44
1994	8.66	8.35	6.93	6.83	2009	7.38	7.11	6.88	6.93
1995	9.16	10.27	6.93	7.95	2010	6.63	6.82	6.71	6.99
1996	9.92	10.28	7.58	8.13	2011	6.90	6.97	6.98	6.70
1997	9.73	10.31	7.33	7.80	2012	7.26	8.17	7.09	7.50
1998	9.47	9.47	6.70	7.36	2013	8.37	7.08	7.04	7.16
1999	9.40	10.15	7.20	8.05	2014	6.35	6.45	6.92	6.91

Source: Authors.

In Fig. 4 the variations of the groundwater level as a function of time (months) are observed, which are a reflection of the storage change experienced by the aquifer, due to many of the input and output factors that originate in the same. These results express the interrelation of this variable with exploitation and rainfall in the same period of time; therefore, the joint analysis of the values of rainfall, levels and exploitation of water in the aquifer provided the balance magnitudes of the aquifer horizon.

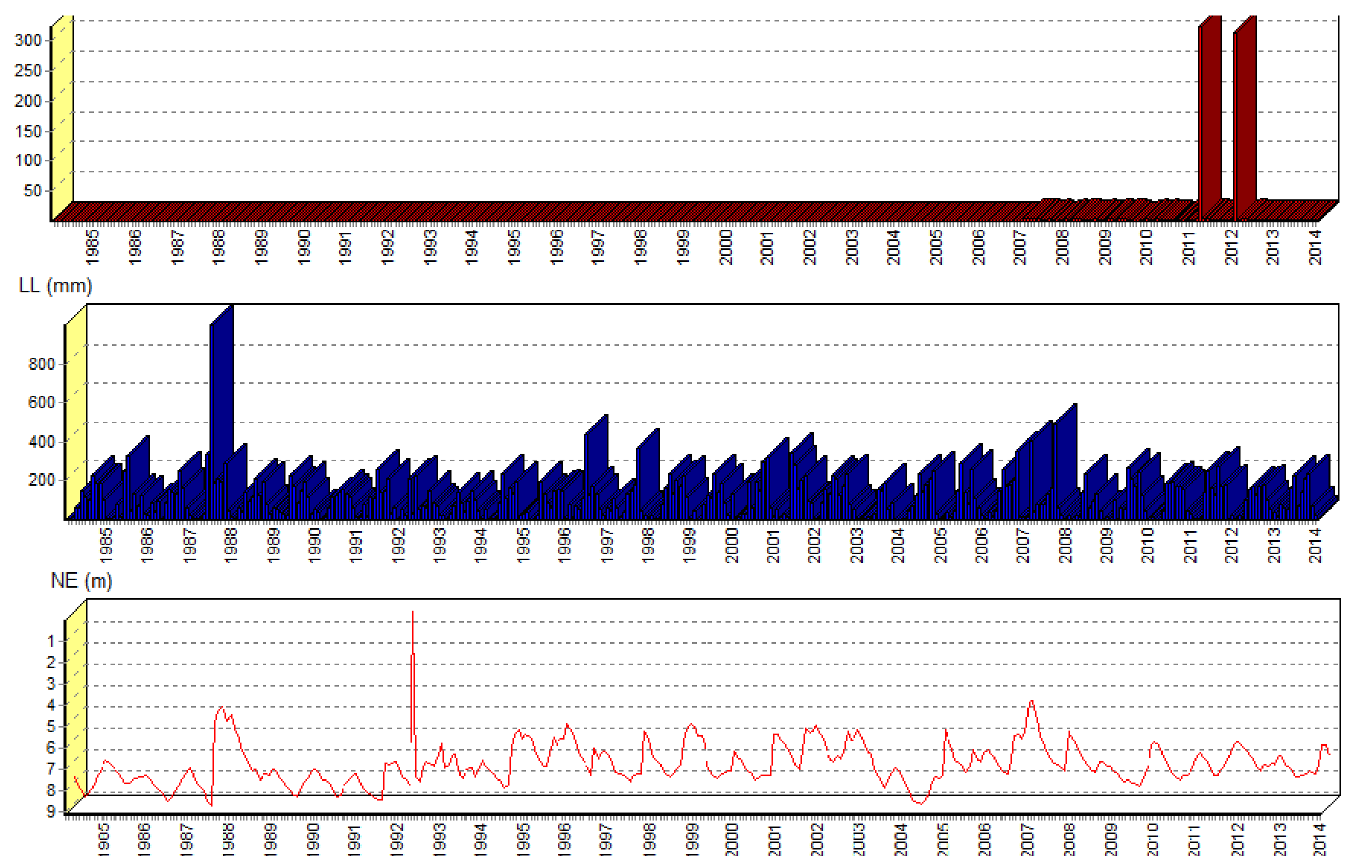

Fig. 4. Hyperanual limnigram of sector CA-II-2.
Source: Authors.

Similarly, in Fig. 5 it can be seen that the line that represents the oscillations of the groundwater level shows very well defined characteristics for each of the dry and wet periods respectively, not being the case in 1988 where the large variations both the rainfall and level values represent the most critical values of these variables.

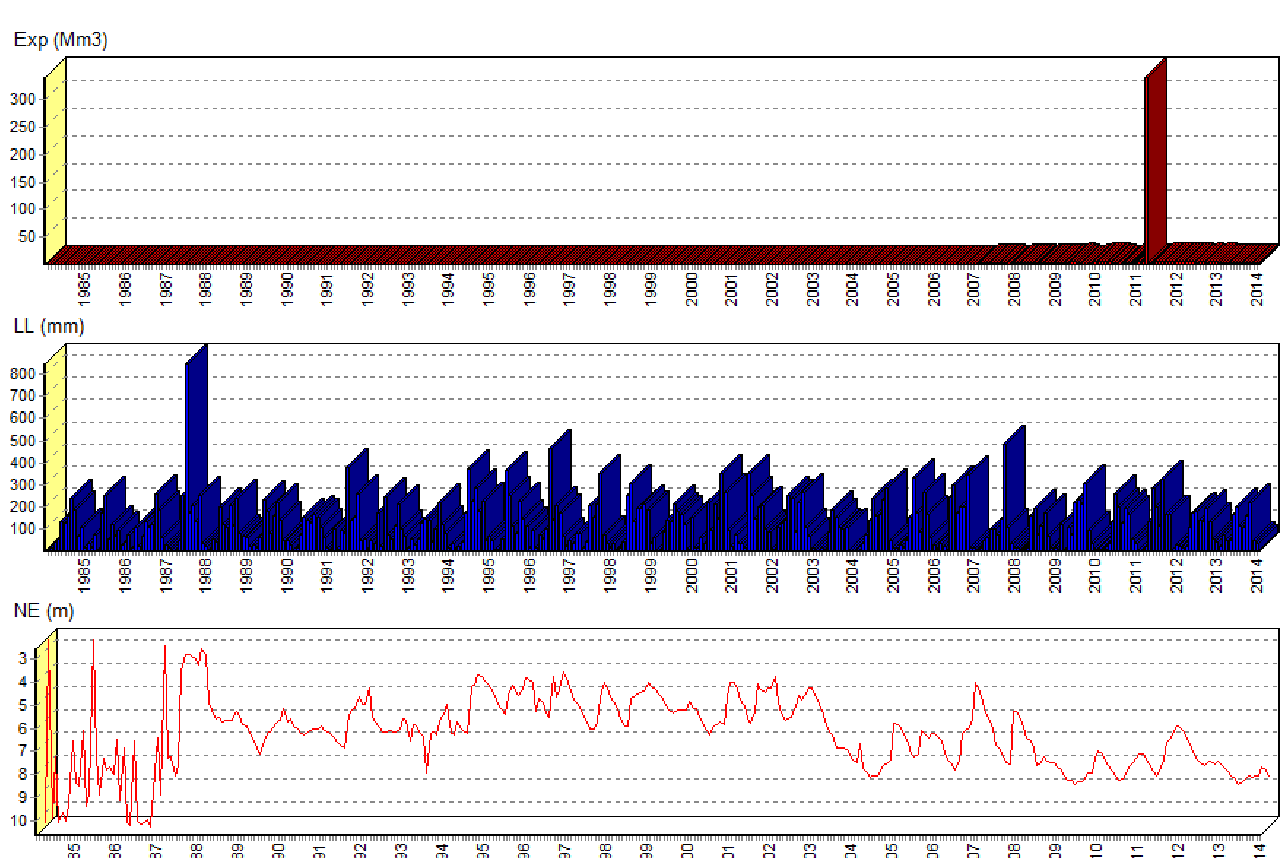

Fig. 5. Hyperanual limnigram of sector CA-II-3.
Source: Authors.

In the case of the graph that represents the extractions (Exp, Mm^3), it can be observed that in the decade of the 90s the exploitation volumes were minimal, mainly due to the economic problems presented in the country at the same time; but it was not the same way in 2011, as there is a greater exploitation of the underground resource.

In Fig. 6 scatter graphs are shown that explain the relationship between effective rainfall and aquifer recharge. The values obtained from the determination coefficient were $R^2 = 0.81$ and $R^2 = 0.84$ for the hydrogeological sectors CA-II-2 and CA-II-3 respectively, which shows the existence of an acceptable relationship between the variables analyzed. According to studies carried out in Colombia and Panama [23], [24] the values reached by these determination coefficients indicate that the relationships are of a very strong positive type, since they lie in the interval between 0.76 and 0.90. The regression equations found in each sector mentioned above were the following:

$$R = 0.0075P_{ef} - 4.98 \quad (1)$$

$$R = 0.005P_{ef} - 2.02 \quad (2)$$

Where:
R is the aquifer recharge (m).
P_{ef} is the effective rainfall (mm).

This result indicates that the main source of food for groundwater in the area is rainfall; but at the same time it suggests a rational use of water in the aquifer zone so that the transfer of rain in groundwater levels allows the natural recharge of the aquifer and the overexploitation of the resource does not affect its sustainability.

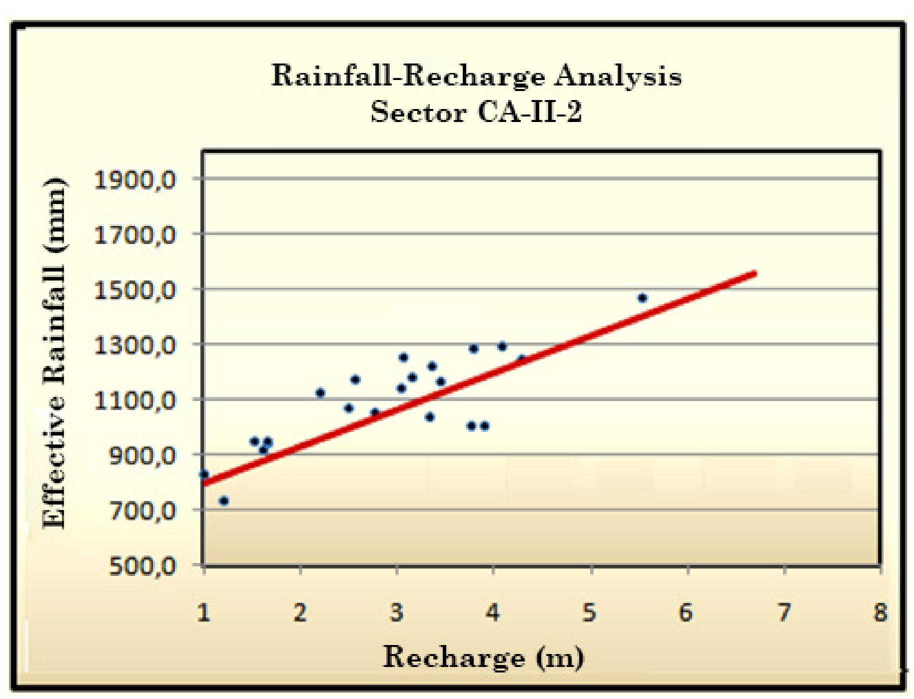

Fig. 6. Rain-recharge relationship in the CA-II-2 and CA-II-3 sector area.
Source: Authors.

IV. Conclusions

The analysis of the precipitations allowed to verify that the average rainfall of the area is 1303.6 mm, higher than the historical average of the province. It was obtained from the study of the water levels in the aquifer, that the values range between 0.84 m and 12.98 m, which identifies the values of 6.52 m and 7.21 m as absolute averages. High variations in rainfall, levels and exploitation of groundwater were found in 1988, which are a reflection of the change in storage experienced by the aquifer and express the most critical and favorable values of these variables.

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Evelyn Blanco de la Paz. Universidad de Ciego de Ávila (Ciego de Ávila, Cuba).

Oscar Brown Manrique. Universidad de Ciego de Ávila (Ciego de Ávila, Cuba).

Francisco García Reina. Universidad de Ciego de Ávila (Ciego de Ávila, Cuba).