Aquifer/Water Sources Drip Factor as Alternative to Measure Climatic Effects on Disponibility of Water Agricultural Irrigation in Semi-arid/Arid Zones

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Abstract. On semi-arid/arid regions (SA/A), new climatic conditions transformed irrigation water on scarce and to obtain efficiency on its use (Eu) is necessary it dosage (D). Under Crops quality and the aim to avoid losses by drainage, evaporation and runoff is necessary implement alternatives front to risks and encountered mechanisms for counteract H2Oi lack and promote Eu and D. Any aquifer to plan, requires immediately know the volumetric exchange (ΔV(x,y,t)) between regional aquifer and sources hydric. Therefore, the objective was determine the spatial variation of drip factor (Fg) between aquifer/water tributaries and take it as indicator of ΔV(x,y,t) behaviour in SA/A coastal agricultural valley of Northwest of Mexico known as “Heart Agricultural of Mexico”. Fg results respond at linear expression y = 26.70 x - 44.15, an annual range average of 413-1813 m/year governed by porous media and recharge dynamics closely linked to transitivity anisotropy low to medium (R² = -0.6) and included on range 20-70 m²/day. In few occasions the river and streams yield water to aquifer (rainy seasons), and on dry season; only the aquifer gives large amounts to all region tributaries. The low sensitivity response at dripping and climatic presence changes constitutes a high risk for H2Oi and sustainable agriculture due to continuous downward trend of watertable levels that encourage an overexploitation responding at lack water and the occurrence of big agricultural economic losses caused by the last intense droughts continually confronted this region. Knowing ΔV(x,y,t) balance helps at control water losses, at sustainable agriculture and contributes to achieving goals of Eu and D; adapted to new agricultural uses forced by climate change.

1. Introduction

Water is an essential natural resource that in the presence of climate change in some regions of the world increasingly turns out to be a scarce resource. In semi-arid/arid regions (SA/A), irrigation and drainage projects handle large amounts of H2Oi to promote agricultural production. Depending of the water source (surface or groundwater) is used different types of irrigation that depend on the forms of storage, of the transport and distribution systems and of the delivery methods of application in the field [1]. For a long time, surface water has been used for irrigation (mainly that of rivers), and in some countries, for thousands of years; it still constitutes one of the main
investments of the public sector [2], but the risk always is latent because does not mean that they cannot depend on the recharge of the local aquifer. On the other hand, the population growth urban and rural populations requires a higher consumption of \( H2O \) of quality and the current limitations of availability in terms of \( H2O \) generate peculiar forms of supply and consumption that prevail in the economy and forecast of the entire culture aimed at the economy of \( H2O \). In the current society, there are more and more problems related to the economy in the supply networks, distribution, and especially in the habits of irrigation and consumption. Undoubtedly, given the new conditions imposed by climate change, \( H2OR \) and \( H2O \) for human consumption has become a scarce commodity. In this sense, climatic alterations that also affect the hydrological cycle, demand in semi-arid/arid regions (SA/A) a relevance to achieve the efficiency in its use (Eu) and it is a directly function of the manner that occur the dosage activity (D) of \( H2O \). Under this scenario; is forces society to seek alternatives to avoid losses by drainage, evaporation and runoff by implementing new alternatives in the ways of exercising agricultural risks (drip, spraying, hydroponics, among others). Notwithstanding the activities carried out to adapt to current climate change, in most regions of the world there is still a clear need for further studies that determine factors that can positively or negatively modify the current degree of overexploitation of a regional basin aquifers, and climate change is one of the aspects that can influence the magnitude of these factors, therefore, in many modifications environmental [3]. In fact, by the year 2027 it is required that all hydrological planning must consider the effects of climate change for the establishment of the water resources/demand balance. Regardless of the 95% of irrigation projects in the world the main method of delivery of \( H2O \) is superficial and only 5% comes from aquifers, in both cases the water is distributed by gravity in the area that will be irrigated, and depending on season year; in complicated areas as SA/A, is necessary all efforts to achieve Eu and D; despite the fact that activities always face complex variables tending to cause the scarcity of \( H2Oi \). Considering that in any area to plan when began the activities to reach Eu and D, is necessary to know immediately the spatio-temporal volumetric exchange (\( \Delta V(x,y,t) \)) between the regional aquifer (common place of \( H2Oi \) extraction) and local tributaries: the objective of this study was to determine the drip aquifer/water sources factor (\( F_g \)) and take it as indicator of the spatial variation \( \Delta V(x,y,t) \) that governs the groundwater transport in porous medium (TIMP). To conduct at this proposed objective, the databases of previous work in the study area were. With their respective methodologies the hydraulic conductivity (\( K_z \), \( \text{LT}^{-1} \)), the thickness of the saturated zone (\( m \)), the hydraulic load of the aquifer (\( H_s \)), and the vertical variation (\( h \), \( \text{L} \)) of the sources with possible water carrying potential to the aquifer (in this case, river and streams) were measured. The \( F_g \) magnitude was controlled under the criteria of Konikow & Bredehoeft established in 1987 in which the influence of water bodies intervenes in the aquifer and the changes in \( h \) also intervene with \( H_s \), \( K_z \) and \( m \) of the same aquifer [4]. The foregoing will allow to establish and provide a monitoring mechanism in this water system, and in the face of the new climatic conditions, contributes with one of the activities for reach \( Eu \) and \( D \) and avoid overexploitation of the aquifer of this valley which is one of the most important of Mexico in terms of agricultural production.

2. Experiment
Spatial variation of \( \Delta V(x,y,t) \) represented for \( F_g \) under Konikow & Bredehoeft criteria was determinate with expression \( F_g(x,t) = \frac{K_z}{m} (H_s - h) \); where \( K_z \) was the hydraulic conductivity on aquifer (\( \text{LT}^{-1} \)), \( m \) thickness of the saturated zone (\( \text{L} \)) and \( H_s \) the hydraulic Head of water sources (\( \text{L} \)) that in this case river and streams were considered as the principal sources with possible potential to carrier water to the aquifer (and vice versa); \( h \) was the variation of vertical level water (\( \text{L} \)).

With the aim to calculate the depth of geohydrological basement (\( b \)), was used the data of previous geoelectric and applied the Vertical Electrical Sounds (SEV) principles [5]. To obtain the variables used on \( F_g \) expression were considered the next conditions: (1) the spatial variation of \( K_z \) was the principal parameter to determine \( F_g \), (2) the average hydraulic transitivity (\( T \)) in the aquifer is a product of \( K_z \) and \( m \) (\( T = K_z m \)) and (3) the spatial average \( K_z \) value could be obtained as
approximation through the $K_x$ and $K_y$ behaviours. The $T$ magnitude was knower using 72 pumping tests that were performed by “Theis simplified test” in different wells within the study area. $H_s$ was calculated by subtraction of $N_b$ and $N_f$, this activity was completed once the topography of the area was estimated, for which the topographic survey closest to the study area was used (18-24 November of 2017). For the average annual spatial variation of $h$ in the river and streams, eight piezometers were placed in different places: 6 in the bed of the Sinaloa and/or Petatlán River, 1 on De Ocoroni stream and 1 on De Cabrera stream (Figure 1).

In order to obtain the real average $F_g$ magnitude, was considered that a filtration and water transport process varies respect to precipitation, and in alluvial aquifers; it is usually lower during the dry season and higher in the wetter periods, but if it is combined with the absence of waste management plans and land use plans (which apparently do not exist in region); it is difficult to fight water infiltration to aquifer systems and only enters the $N_e$ by areas of favourable grains that form a high porosity being this directly promotional to the volumes captured by the aquifer during each season and accord to the dynamics of TIMP aquifer/water sources.

Therefore, this scenery similar on the study area, occur due to fact there are two season environmental, one where include the rainiest periods from July to September [6], and a large period where no there are any rain Under this conditions, exist in the zone annual changes for water collection governed by four underground scenarios

![Study area](image)

**Figure 1.** Study area and Piezometers situated on Sinaloa River, De Ocoroni and De Cabrera streams for monitoring the aquifer/water sources drip factor.

Knowing the presence four seasonal scenarios of different periods, we proceeded to perform lectures of $h$ magnitude in periodically form every 8 days for one year (including the rainy and dry season) and so proceed to perform the cabinet work. The places where field measurements were made were positioned using UTM/12 geographic coordinates with a Garmin Olathe GPS of 14 channels. In the SURFER 10.0 program using Kriging method [7], an interpolation of all the measured variables was obtained. The interpolations were stacked on the local urban trace with the aim to obtain the maps that illustrated the annual average spatial variation of each variable that intervened in the determination of $F_g$ magnitude. The details of the figures were made in the Corel DRAW suite X7.0 program and
the statistical analysis of the annual average of the measured and calculated results was made using the STATISTICA 7.0 computer program. For the relationship \[ F_g \text{ vs. } A\Delta V(x, y, t) \] range variation was established for illustrated the risk zones of the system in the face of the greater to less volumetric water exchange between aquifer/water sources.

3. Results and discussions

The interpretation of the SEVS defined the presence of a free aquifer with varying depths of 3 to 15 m. Also was present other aquifer confined of irregular geometry located at 40 m depth. The aquifers are divided by a layer of clay. Regardless of the presence of \( F_g \) that originates in the superficial region of aquifer system, and that travels to the water table, it is inferred that exist the presence of an internal drip factor \( (F_g') \) between the two aquifiers that expands throughout the region; that although it is not the objective of this work if it can be mentioned since it is part of the processes that encompass the superficial \( F_g \) characterized by the criteria of Konikow & Bredehoef (1984). The \( F_g' \) occurrence is function directly and proportional to the genesis of deposition at the beginning formation of the valley, and the SEV sounds; defined the facies properties of both aquifiers, however the presence of the clays that divides both aquifiers; auspicious the attenuation of the direct current of exploration injected into the porous medium; so that the SEVs opening at \( AB/2=150 \) m, only reach an average depth of exploration did not go beyond 80 m. However, if is considered the average annual depth of the 8.5 m in \( Ne \), the depth of penetration reached by the SEV was useful for the objectives of this work. This was due to the fact that the dynamics of the system aquifer/river/stream was developed in a scenario no more beyond 20 m deep and it includes mostly the free-form aquifer from 3 to 15 m deep. It is important to mention that until now there are no works to determine the drip factor that exists in the Valley, so the results are the first dates that show that there is a volumetric exchange of water between the aquifer of the Guasave Valley and the River Petatlán. Depending on the year season the spatial \( F_g \) magnitude manifests a variable behaviour, and according to TIMP law; this result is indicator that the scenery is changing and altered, causing that river give water to the aquifer in different seasons of the year (rainy seasons), and that, in the dry season, will be the aquifer which to give water at the river.

The piezometers of river and streams were positioned near of next populations: Puente de Guasave, Caimanero, Varal, La Cuerda, Carboneras, Puente de Bamoa, Ocoroni and Cabrera. Also on Table 1 is show the variables involved in the determination of \( F_g \) magnitude are shown in Table 1 The annual average mean of variables of Table 1 used for obtain \( F_g \) magnitude were: \( h = 0.42 \) m, \( T = 40.6 \) \( m^2/d\)ay, \( K_z = 1112.12 \) m/day, \( H_s = 26 \) m, \( m = 27.37 \) m, \( Ne = 4.87 \) m, \( Nh = 32.25 \) m and \( F_g = 1040 \) m/year. The results showed a \( F_g \) that responds in the agricultural zone to linear behaviour of expression \( y = 26.70 \times -44.15 \) characterized by annual average value rank of 413 to 1813 m/year and governing by the negative relationships between aquifer/water sources and the recharge dynamics closely linked to anisotropy of a transitivity \( (R^2 = -0.6) \) that goes from low to average within the value range of 20 to 70 m/day (Figure 2).

4. Conclusions

Are present the bases for a methodology which periodic can measure \( F_g \) magnitude and describe it behaviour for on future could help to establish a numerical modelling that allows to understand in a quantitative way the dynamics present in the aquifer/water sources interaction on this region and others basins of world. It also is support as a practical methodology that allows efficient decision making for water resource management when it is necessary to get the \( Eu \) and \( D \); principally in regions SA/A. The present results could be the initial state of the modelling [8] and it would allow to quantify future impacts that have to do with the exploitation of groundwater mainly on the flow of the rivers and the local effluents hydric [9], as well as infer the behaviour of \( A\Delta V(x, y, t) \) that result when is used more the aquifer in comparison with the use of superficial as an underground reservoir of \( H2Oi \), and in general to identify the affectation of all anthropic interventions in the exchange of flow between surface currents and groundwater.
different numerical methods to determine recharge and in this case mathematical models for
describe water holes; $F_g = \text{drip factor aquifer/hydric effluents.}$

Specifically the sprayed $H2Oi$ with sprinkles water it droplets on the surface of the earth it simulate
the effect of rain; is considered as a new technology, similar than hydroponics, drip irrigation; and
others, but relatively, all tools of alternative agricultural irrigation require a large initial investment
and more intensive management than surface irrigation, but in face of current climate change exist
many problems of water availability and exchange studies must be carried out first to ensure
investment, and the most important, is for to give guarantees for sprinkler and drip irrigation that
promise a lot potential to optimize the efficiency of water use, and over all, reduce the current
problems of $H2Oi$.

Given the risk of the availability of $H2Oi$ and given the current climatic conditions, irrigation water
has already become a scarce resource, mainly in regions $SA/A$. On this new sceneries is necessary
improvements must be made in the $Eu$ where achieving it lies in the $D$ all with the aim to avoid losses
due to drainage, evaporation and runoff.

On the other hand, the lack of quality water attributed to climatic changes also affects the
hydrological cycle and oblige to implement new alternatives in the ways of exercising agricultural
risks (eg the introduction of focused irrigation systems: drip, sprinkler, hydroponics, among others).
Under kind of problems caused by climate change, it is important to mention the existence of
different numerical methods to determine recharge and in this case mathematical models for describe
the behaviour aquifers could be used as valid tools for their management.

So in the future must be discussed exhaustive which the role that the water`s models can play on
management of water resources is necessary.

### Table 1. Annual average mean of variables used for obtain $F_g$ Magnitudes on aquifer/water sources
system for an arid/semiarid zone in Sinaloa River Valley situated on Northwest of México.

| Number | Name                  | $x$ (UTM) | $y$ (UTM) | $h$ (L) | $T$ (LT) | $K_z$ (LT$^{-1}$) | $H_s$ (L) | $m$ | $N_e$ | $N_b$ | $F_g$ (LT) |
|--------|-----------------------|-----------|-----------|---------|---------|------------------|---------|-----|-------|-------|-------------|
| 1      | Puente de Guasave     | 755547    | 2831158   | 0.45    | 25      | 350              | 17      | 14  | 7     | 21    | 413.75      |
| 2      | Caimanero             | 757729    | 2833323   | 0.2     | 40      | 840              | 19      | 21  | 4     | 25    | 752         |
| 3      | Varal                 | 759724    | 2837371   | 0.2     | 45      | 1125             | 20      | 25  | 5     | 30    | 891         |
| 4      | La Cuerda             | 762639    | 2840994   | 0.62    | 48      | 912              | 22      | 19  | 6     | 25    | 1026.24     |
| 5      | Carboneras            | 764100    | 2845480   | 0.85    | 62      | 1860             | 30      | 30  | 3     | 33    | 1807.3      |
| 6      | Puente de Bamoa       | 766824    | 2846044   | 0.825   | 35      | 1120             | 35      | 32  | 5     | 37    | 1196.125    |
| 7      | Arroyo de Ocoroni     | 761883    | 2847646   | 0.175   | 40      | 1400             | 30      | 35  | 3     | 38    | 1193        |
| 8      | Arroyo de Cabrera     | 755078    | 2848874   | 0.105   | 30      | 1290             | 35      | 43  | 6     | 49    | 1046.85     |

$h =$ water level on vertical variation of hydric effluents (L); $T =$ hydraulic transmivsity (LT-2); $K_z =$
hydraulic conductivity
(LT-1); $H_s =$ piezometric Head (L); $m =$ saturated zone thickness (L); $N_e =$ watetable depth (L); $N_b =$ Level of
water holes; $F_g =$ drip factor aquifer/hydric effluents.
Figure 2. Spatial variation Annual average magnitudes in m²/day for hydraulic transitivity and aquifer/water sources drip factor (m/year) for aquifer River Valley of Northwest of México.

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