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PROTOCOL TO MEASURE INFILTRATION SUBCUENCAS OF THE CORNER OF THE VITTORIA AND THE MOUNT OF THE ALTA CUENCA DEL GUADALQUIVIR

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Hydrological abstractions such as infiltration, percolation, evaporation, transpiration and interception are fundamental parameters in the process of simulation and modeling of the water balance in a basin. These parameters allow us to analyze and determine the degree of reduction experienced by precipitation from the atmosphere to reach the earth's surface and eventually become runoff. However, the degree of knowledge of these abstractions is the product of a research process that will reduce the uncertainty that accompanies the results of all hydrological modeling.

This work describes the experimental protocol developed for the sub-basins of the Vittoria corner and the mountain stream belonging to the upper Guadalquivir river basin in Tarija, Bolivia. The main objective of the protocol is to obtain the infiltration parameters and soil types that make up the study areas. Minidisc infiltrometers were used to collect data in the field at more than 200 points distributed in the experimental sub-basins. The results have allowed to describe, characterize and elaborate soil maps and hydraulic characteristics such as infiltration that will be used in the modeling of the water balance of the upper Guadalquivir basin

Keywords: *Hydrological abstractions; water balance; minidisc infiltrometer; hydrological modeling; infiltration*

PROTOCOLO PARA MEDIR LA INFILTRACIÓN EN SUBCUENCAS DEL RINCÓN DE LA VITTORIA Y DEL MONTE DE LA ALTA CUENCA DEL GUADALQUIVIR

Las abstracciones hidrológicas como la infiltración, percolación, evaporación, transpiración e intercepción son parámetros fundamentales en el proceso de simulación y modelación del balance hídrico en una cuenca. Estos parámetros permiten analizar y determinar el grado de reducción que experimenta la precipitación desde la atmósfera hasta llegar a la superficie terrestre y convertirse finalmente en escurrimiento. Sin embargo, el grado de conocimiento de estas abstracciones es producto de un proceso de investigación que permitirá reducir la incertidumbre que acompaña los resultados de toda modelación hidrológica.

Este trabajo describe el protocolo experimental desarrollado para las subcuencas del rincón de la Vittoria y de la quebrada del monte pertenecientes a la alta cuenca de río Guadalquivir en Tarija, Bolivia. El objetivo principal del protocolo es obtener los parámetros de infiltración y tipologías de suelos que conforman las áreas de estudio. Se utilizaron infiltrómetros minidisc para el levantamiento de datos en campo a más de 200 puntos distribuidos en las subcuencas experimentales. Los resultados han permitido describir, caracterizar y elaborar mapas de suelos y de características hidráulicas como la infiltración que serán utilizados en la modelación del balance hídrico de la cuenca alta del Guadalquivir.

Palabras clave: *Abstracciones hidrológicas; balance hídrico; infiltrómetro-minidisc; modelación hidrológica; infiltración*

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1. Introduction

Basin yield studies are essential for planning infrastructures that meet the needs of people in fast-growing areas. This is better and more applicable in developing regions that often lack the data and resources to carry out the best development alternatives. The problem can be even more complicated in semi-arid regions with characteristics of very variable basins such as El Valle Central in the Department of Tarija, Bolivia (Stolpa D. 2018).

The works presented by Filgueira, R. et al., (2006), Sihag, P., Tiwari, N.K. and Ranjan, S. (2017) point out that the knowledge of the mechanisms of water movement in the superficial horizons of the soil occupies a preponderant place in many research areas, such as agronomy, civil engineering, hydrology and environmental sciences. They also indicate that one of the tasks in water management is to calculate and control it. Consequently, these processes depend on the hydraulic conductivity of the soil that must be determined in the field or in the laboratory.

The hydraulic conductivity of the soil indicates the rapidity with which water infiltrates when applied to the soil surface. This is very important when evaluating groundwater recharge or surface runoff. Therefore, it is important to obtain the in situ values of the hydraulic conductivity of the soil (Fatehnia, M, Tawfig, K. & Abichou, T. 2014).

Infiltration is a key process in aspects of hydrology, agricultural and civil engineering, irrigation design and soil and water conservation. Infiltration is defined as the maximum rate at which a soil under certain conditions absorbs rain that falls and that varies with time, especially during the initial period of rain, reaching at the end, a minimum infiltration capacity (Horton, 1940). The process depends on the properties of ground fall and initial and boundary conditions within the flow domain (Assouline, S. 2013). The infiltration rate depends on the conditions of the soil surface, while other authors like Parr J.F. y Bertrand A.R. (1960) they indicate that the infiltration depends on the mass of the ground, independently of the conditions of the surface.

There are several methods to determine the hydraulic conductivity of soils. For example, in the work of Dorsey et al. (1990) the comparison of 4 methods such as the Guelph permeameter, velocity permeameter, pumping test procedure and drilling sediment is exposed, finding a wide variability in the hydraulic conductivity measurements. In the work of Gupta et al. (1993) they used double ring infiltrometers, rain simulator, Guelph permeameter and Guelph infiltrometer, determining that the results of the first two teams are more similar, but lower than the results of the Guelph teams. Gómez et al. (2001) in his research work carried out in Spain, he compared several techniques for infiltration analysis using rain simulator, tension rings, tension infiltrometer, finding that strain infiltrometers provide higher results than other techniques. These methodologies, which have been used mostly in Europe, North America and Canada, made it possible to compare methodologies for saturated soils (Prieto, B., Támara, R., & Peroza, J., 2006).

The flow through an unsaturated soil is more complicated than the flow through spaces of pores saturated continuously. Macropores are usually filled with air, leaving only fine pores to accommodate the movement of water. Therefore, the hydraulic conductivity of the soil depends to a large extent on the detailed geometry of the pores, the water content and the differences in the potential of the matrix (Rose, C.W., 1966 & Brady, N.C.).

The method for determining unsaturated hydraulic conductivities in situ with infiltration measurements made at various voltages on the same infiltration surface is potentially valuable because it is faster than unit gradient laboratory methods and is less detrimental to pore continuity than other methods. field infiltration techniques (Ankey MD., et al. 1991). One of these equipments are the tensile disk infiltrometers that determine hydraulic properties in situ of saturated or near saturation soils (Aoki A., & Sereno R., 2005).

Infiltration-based methods are recognized as valuable tools for investigating the hydraulic and transport properties of soil. In particular two complementary methods seem to be interesting in the study of the behavior of saturated and unsaturated soil, the confined one-dimensional pressure ring infiltrometer and the three-dimensional stress disk infiltrometer methods not confined (Angulo-Jaramillo. R., et al. 2000).

Lakzian et al. (2010), Emami et al. (2012), Kaikhajesh et al. (2012) y Fereshte, F.H. (2014) mention that the direct measurement of the hydraulic conductivity of the soil is difficult, expensive and that it requires in addition to a lot of work and time, for its side Kargas G. et al., (2018) notes that disk infiltrometers, among other experimental devices used in situ, have been widely used in recent decades and allow to know the hydraulic behavior of the soil and the sorptivity of the upper layers as essential factors in hydrological modeling.

This methodology is based on the application of water to the head of constant negative pressure known on the surface of the soil through a porous disk. When the disc is in contact with the surface of the soil, water flows from the water reservoir into the pores. The level of water in the reservoirs of the disk infiltrometer is often visually controlled by the operator (Klípa, V., Sněhota, M. & Dohnal, M. 2015).

Double-ring infiltrometers and rain simulators, when used in a conventional manner, cannot directly measure the infiltration of the forest floor matrix. A disk infiltrometer applies water to the soil at negative water potentials previously determined by the operator, which causes water to infiltrate through the soil matrix. Since the water is driven by the force of capillarity to enter the body of the soil matrix and the device works with a negative water potential, this infiltrometer can only measure the hydraulic parameters of the unsaturated soil in situ (Logsdon & Jaynes, 1993; Angulo-Jaramillo et al., 2000; Šimunek & Genuchten, 1996).

On the other hand, the double-ring infiltrometer measures the infiltration of the soil beneath the layer of water that accumulates, which commonly implies a preferential flow (Zhang, J. et al. 2016). Jabro et al. (1994) they used double-ring infiltrometers to estimate the preferential movement of the bromide tracer under field conditions, to find that water evidently moved through macropores to layers of deep soil.

Bouwer, (1961), regarding the double-ring infiltrometer, it is determined that the hydraulic conductivity is determined from a well-defined flow system in a region of artificially saturated soil below the bottom of an auger hole, placing two concentric tubes in the hole of the auger and carry out certain measurements of water level drop in the inner tube. Likewise, Bouwer, (1962) indicates that the tests carried out with double ring have been carried out in the field and in the laboratory, there being good agreement between the results, this method being an adequate tool for in situ measurement of the hydraulic conductivity of the soil that is not saturated before the measurement time.

2. Goals

The objective of this work is to show a methodology used for the experimental determination in the field and to collect data on infiltration, hydraulic conductivity and cartography of the unsaturated soils of the upper Guadalquivir river basin with the initial analysis of the rincón de la Vittoria sub-basins and the Quebrada del Monte, using the effect of infiltrometers of tension and double ring infiltrometers.

3. Methodology, equipment and experimental protocol used

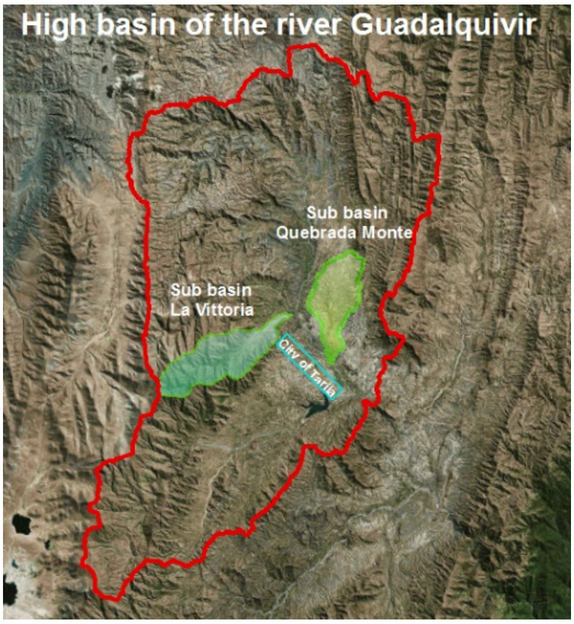
The methodology used for the experimental process of the project in the study sub-basins is described below.

3.1. Study Area

The study area is located in the upper Guadalquivir basin, considered as a semi-arid region and is made up of 8 sub-basins corresponding to the main tributaries of the Guadalquivir River (Copa & Villena, 2016). The events of the storm are typically of short duration with shallow depths of precipitation. The soils in the basin are shallow above the highly contorted bedrock in the surrounding hills and mountains. The soils of the valley consist of deep lacustrine sediments and glacial deposits where the predominant vegetation cover is the bushes (Stolpa D., et al. 2018).

Two sub-basins were selected for this first stage of study, the sub-basin of the Rincón de la Vittoria and the sub-basin Quebrada del Monte. The sub-basin of the Rincón de la Vittoria has an approximate extension of 6,115 hectares, shows a very rugged topography and greater vegetation than the sub-basin of Quebrada del Monte, which has an approximate area of 4,383 has, with a greater predominance in clay soils with low vegetation cover, being this last one of the most important expansion areas of the central valley of Tarija. Figure 1 shows the work areas of the present study.

Figura 1: Sub basins of Rincón de la Vittoria and Quebrada del Monte



3.2. Measuring equipment.

For the present work, Minidisc and Double Ring Infiltrometer were used.

In order to carry out the field tests, 3 Minidisk infiltrometers were used (Decagon Devices, Inc., 2016). This equipment has been used for being a simple and fast method that other methods of hydraulic gradient that are used in laboratory (Ankeny et al. ,1991), the figure 2 shows the MiniDisk infiltrometer.

The procedure used for its application is detailed in the manual of Decagon Devices, Inc., (2016) and in the work of Matula, S. et al., (2015). The hydraulic conductivity has been calculated using the method of Zhang (1997a y 1997b), for its simplicity and for an adequate functioning in dry - unsaturated soils.

Figure 2: Infiltrómeter MiniDisk

Alternatively to the minidisc tension infiltrometer, a double ring infiltrometer was manufactured and used to determine the basic velocity of vertical infiltration of the soil and is compared with the saturated hydraulic conductivity, the pressures are positive relative to the atmospheric pressure, figure 3 shows the infiltrometer double ring used in the study consisting of a metal ring 30 cm in diameter and 50 high and the second 60 cm in diameter and 50 cm high.

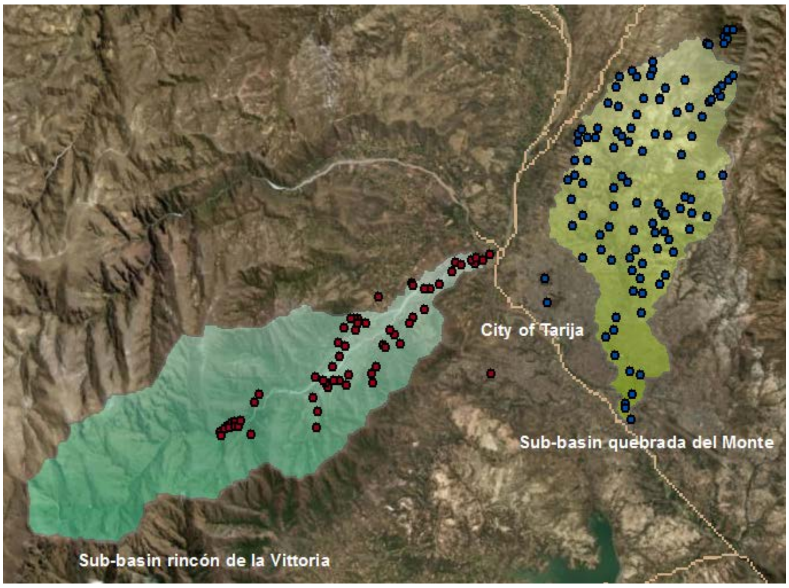
The double ring method consists of saturating a portion of the soil limited by two concentric rings to subsequently measure the variation of the water level in the inner cylinder, the time that elapses until reaching the final conditions of saturation will depend on the previous humidity, texture, the structure of the soil, the thickness of the horizon through which the water runs and the height of water in the rings (Universitat Politècnica de València).

Figure 3: Double ring Infiltrometer

3.3. Sampling points

For the experimental areas 62 analysis points were defined for the sub-basin of the Rincón de la Vittoria and 111 points for the sub-basin of Quebrada del Monte, (Blades et al. 2018). The location of the sampling points has been defined based on accessibility criteria, time of investigation, types of soils and water availability for the use of the double ring, figure 4 details the distribution of the analysis points in the zones of study.

Figura 4: Sampling points– Sub basin Rincón de la Vittoria and quebrada del Monte



3.4. Test Protocol

For the implementation of the equipment and the realization of the field tests, the following protocol was used:

3.4.1. Minidisc Infiltrometer

For the calibration and installation of the infiltrometers the methodology described in the manual was used Decagon Device Inc. (2016), under the following fundamental guidelines (Barrientos & Garzón, 2018):

- The suction must be calibrated according to the type of soil found at the work point. This, to avoid a rapid infiltration of some sandy soils or also to increase the infiltration speed in more compact soils such as clayey or loamy.
- Fill the bubble chamber three quarters (35 ml) completely with running water through the suction control tube or by removing the top cap.
- When the upper chamber is full, the suction control tube is completely slid down, the infiltrometer is inverted, the lower elastomer is removed with the porous disc to fill the water reservoir.
- Carefully fix the position of the end of the Mariotte tube with respect to the porous disc to ensure zero suction compensation while the tube bubbles. If this dimension is changed accidentally, the end of the Mariotte tube must be readjusted 6 millimeters from the end of the plastic tube of the water tank.
- The lower elastomer is placed, ensuring that the porous disc is firmly placed, the infiltrometer is kept in vertical position, so as not to spill water.
- The infiltrometer should be placed in a flat and smooth point on the surface of the soil, this ensures a good contact between the soil and the infiltrometer.
- After the infiltrometer is firmly placed, the suction is selected depending on the type of soil.
- To perform the measurements, the graduated scale should be observed initially and note in how many ml it is starting with time at zero, it should be between 90 and 95 ml.
- Initially 30-second intervals are taken until a constant infiltration is observed, depending on the type of soil the time varies.

- The infiltration volume must be at least 15 to 20 ml of water and for this you can have up to 50 minutes of infiltration due to the existence of impermeable floors.
- The data is recorded in a form created in this work.

3.4.2. Double ring Infiltometer

The preparation and calibration of the double ring infiltrometer must comply with the following procedure:

- The equipment must be installed on soils without rocky outcroppings or large stones that could damage the infiltrometer in its installation.
- The metal cylinder is stuck to a recommended depth of 10 cm and a minimum depth of 5 cm. Especially in clayey soils, with cracks or with abundant organic matter, the depth of insertion must be greater than 5 cm. For the nailing of the cylinder, it is placed on the ground and the metal plate is placed on it. Striking carefully on the plate, the cylinder is introduced, trying not to alter the structure of the floor.
- The smallest metal cylinder inside the cylinder already inserted is introduced, so that it is correctly embedded in the ground.
- The grid is placed in its position, remaining attached to the small cylinder by means of the clamps. The regulation of the height of the grid on the ground will depend fundamentally on the content of expansive clays that the soil has. It is recommended to place it at least 5 cm from the ground.
- Around the infiltrometer, with a separation of 2 cm to avoid dislocation, dig a small circular ditch 5-10 cm deep and the same width, which is filled with water every so often during the test, this with in order to control the lateral infiltration.
- Once the test is finished, the disassembly of the infiltrometer is done with the reverse procedure, taking into account that the steel cylinder can be extracted using the clamp.

For the collection and registration of data, the following steps should be followed:

- The infiltrometer fills with water up to the upper edge (puddling or flooding). The height of the water will depend on the depth to which the infiltrometer has been stuck, being between 15 and 22 cm. The infiltrated water height is measured at given time intervals (every 2 minutes at the beginning of the test and every 30 minutes at the end). After each measurement, the cylinder is immediately filled and the surrounding area moistened.
- The test is prolonged until the infiltration rate stabilizes around a value, which usually occurs approximately 3 or 4 hours after the start of the test.
- At least three tests (replicas) are carried out on a 10 m diameter circular plot to reduce soil variability.
- The data is recorded in a form created in this work.

Figure 5 illustrates the process of placing and measuring the equipment, figure 5.a for the double-ring infiltrometer and 5.b for the mini-disk infiltrometer:

Figure 5: Installation and measurement: double ring (a) and Minidisc Infiltrometer (b)

a) b)

3.4.3. Method of calculation.

For the calculation of hydraulic conductivity, the method of Zhang (1997) was used, being the most advisable for unsaturated soils proposed by Decagon Device Inc. (2016) and for the classification of the soils the infiltration parameters of Green- Ampt (1911) for different types of soils.

3.4.4. Reading and analysis of data in the field

Fatehnia, M., Tawfig, K., & Abichou, T. (2014) they point out that the infiltration rates at the end of each test are considered as the steady state infiltration rate and are used to find hydraulic conductivity values from the Zhang method (1998).

For the measurements and data records, a detailed template was used in Table 1 and 2.

Table 1: Registration form and data collection for double ring Infiltrometer

Proyect:				Description of the site and soil:	
Day/date:					
Place:					
Latitude:	Longe:				
Elevation:	Basin:			Temperature:	
Arrival Time to Place:				Precipitation:	
Start time data:				Precip. Before 5 days:	
Finished time data:				Weather:	
Time departure from place:				Wind:	
Test Water:				Infiltrometer:	
Outer rings:	Diameter:	Height:		Capacity	
Inner ring:	Diameter:	Height:		Temperature soil:	
Installation:	Depth and level:			Temperature wáter:	

Test	Time	Depth (cm)	Volume (L)	Infiltration
1	Initial:	Initial:	Initial:	Inner ring area:
	End:	End:	End:	
	Δ T:	Δ cm:	Δ L:	Δ I:
	Σ T:	Σ cm:	Σ L:	Σ I:
Notes:				
Test	Time	Depth (cm)	Volume (L)	Infiltration
2	Initial:	Initial:	Initial:	Inner ring area:
	End:	End:	End:	
	Δ T:	Δ cm:	Δ L:	Δ I:
	Σ T:	Σ cm:	Σ L:	Σ I:
Notes:				
Test	Time	Depth (cm)	Volume (L)	Infiltration
3	Initial:	Initial:	Initial:	Initial:
	End:	End:	End:	End:
	Δ T:	Δ cm:	Δ L:	Δ I:
	Σ T:	Σ cm:	Σ L:	Σ I:
Notes:				
Test	Time	Depth (cm)	Volume (L)	Infiltration
4	Initial:	Initial:	Initial:	Initial:
	End:	End:	End:	End:
	Δ T:	Δ cm:	Δ L:	Δ I:
	Σ T:	Σ cm:	Σ L:	Σ I:
Notes:				

Table 2: Registration form and data collection for minidisc Infiltrometer

Test Name:			Site Description and Soils:	
Day/date:				
Sampling area:				
Latitude:	Length:			
Elevation:	Basin:		Temperature:	
Place:			Precipitation:	
Data start time:			Previous precipitation:	
Finished data times:			Weather:	
Test water:			Infiltrometer:	
Lenght:	Diameter:	Area:	Fill suction chamber:	
Marriote tube:		Suction:	Fill reservoir chamber:	
Installation:	Depth and level:		Temp. Soil:	Water:

In order for the calculation of hydraulic conductivity to be accurate, at least 15 to 20 ml of water must be infiltrated into the soil during each measurement.
In order for the calculation of hydraulic conductivity to be accurate, at least 15 to 20 ml of water must be infiltrated into the soil during each measurement.

Time (seg)	Time ^ 1/2 (t)	Volume	Infiltration (cm)	Notes:
0	0.00			
30	5.48			
60	7.75			
90	9.49			
120	10.95			
150	12.25			
180	13.42			
240	15.49			
300	17.32			
360	18.97			
420	20.49			
480	21.91			
540	23.24			
600	24.49			
720	26.83			
840	28.98			
960	30.98			
1080	32.86			
1200	34.64			
1380	37.15			
1560	39.50			
1740	41.71			
1920	43.82			
2100	45.83			
2400	48.99			

4. Conclusions

The protocol has made possible to measure the infiltration of the soils of the experimental sub-basins and will be used for the measurement of the remaining sub-basins of the Guadalquivir.

The minidisc infiltrometers have been more effective in places with greater difficulty of access, especially in steep topographies and unsaturated soils, the double ring infiltrometer had a better performance in flat areas and with important background humidity.

The amount of water required to perform the double ring test and the availability of water has been the greatest limitation for this test, so the use of this equipment has been defined in areas near rivers, streams or other water sources.

The results obtained with the mini disk tests in the different points of the La Vittoria basin and the Quebrada del Monte reflect the most predominant soils of the upper basin of the Guadalquivir river. However, it is necessary to take into account that in the points analyzed at the edges of the watercourses a minimum layer of fine sand was observed, which makes the value of the infiltration varies, termed transitory soil, the application of the double ring being more recommendable. in this type of soil.

In future research for the rest of the sub-basins of the Guadalquivir, this protocol will be used to determine the hydraulic properties of soils for hydrological purposes

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