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ANALYSES OF WATER TABLE DEPTHS VARIATIONS IN AN OUTCROP AREA OF THE GUARANI AQUIFER SYSTEM IN BROTAS/SP-BRAZIL

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1 ABSTRACT

Several factors may influence variations in ground water levels. Some of these factors present static behavior while others present dynamic changes over time. The differences in management operations in agricultural sites, plant development and agricultural practices have direct impact on the unsaturated zone, as the levels of recharge and water tables can respond differently due to local conditions. Different information sources may be used and integrated in a statistical model to reveal the responses of ground water levels under certain conditions. Understanding these processes involves meeting a way of representing correlated variables together to form a new and smaller set of derived variables with minimum loss of information, removing redundancy or duplication. The objective of this study was to analyze the variations in water table depths using information from a groundwater monitoring network in an outcrop area of the Guarani Aquifer System (GAS) in Brotas, São Paulo, Brazil, associated with soil, vegetation and terrain variables, which possibly influence the groundwater dynamics. A factorial analysis was applied to identify the underlying factors which would explain this pattern of correlation within these sets of study variables. The main factors influencing the variations in water table over the monitoring period were as follows: sand particle size, terrain attributes, soil texture, soil and crop management and vegetation. This methodology can be useful for groundwater management, policy making and regulation of soil use in watersheds, and regional studies, for example, maximizing information in data analysis.

Keywords: factorial analysis, statistical modeling, recharge, Brazil

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2 RESUMO

Diversos fatores influenciam as variações de níveis freáticos. Alguns desses fatores apresentam comportamento estático enquanto outros apresentam mudanças dinâmicas ao longo do tempo. As diferenças nas operações de manejo do solo em áreas agrícolas, desenvolvimento de plantas e práticas agrícolas tem impactos diretos na zona não saturada uma vez que os níveis de recarga

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e lençóis freáticos podem responder a condições locais. Diferentes fontes de informação podem ser usadas e integradas em um modelo estatístico para revelar a resposta dos níveos de águas subterrâneas sob certas condições. Entender esses processos envolve encontrar uma maneira de representar variáveis correlacionadas juntas para formar um novo e menor conjunto de variáveis derivadas com uma perda mínima de informação, removendo redundâncias ou duplicações. O objetivo desse estudo foi analisar as variações dos níveis freáticos usando informações de uma rede de monitoramento de águas subterrâneas em uma área de afloramento do Sistema Aquífero Guarani (SAG) em Brotas, São Paulo, Brasil associadas a variáveis de solo, vegetação e terreno que possivelmente influenciem a dinâmica das águas subterrâneas. Foi aplicada a análise fatorial para identificar fatores que expliquem o padrão de correlação entre esse conjunto de variáveis observadas. Os principais fatores influenciando a variação dos níveis freáticos durante o período monitorado foi o tamanho da fração areia, atributos de terreno, textura do solo, manejo dos solos e culturas e vegetação. Essa metodologia pode ser útil para a gestão das águas subterrâneas, formulação de políticas e regulação do uso do solo em bacias hidrográficas e estudos regionais, por exemplo, maximizando as informações na análise de dados.

Palavras-chave: análise fatorial, modelagem estatística, recarga, Brasil

3 INTRODUCTION

Agricultural systems planning and implementation depends on natural resources availability. The input of groundwater, surface water and water from precipitation in a region determines not only the crop choices but also management practices. The water requirements of these crops place pressures on the water resources and influence groundwater dynamics.

The Guarani Aquifer System (GAS) is a transboundary aquifer covering approximately 1.2 million km² of the Argentinean, Brazilian, Paraguayan and Uruguayan territories. Also, it encompasses almost all the Paraná and Chaco-Paraná sedimentary basins. This aquifer system is one of the most important groundwater reservoirs worldwide and its outcrops are important groundwater recharge and discharge areas. In Brazil, the GAS has great economic importance, with several cities located under its range. Recharge zones represent 10% of its total area (ROCHA, 1997). Therefore, recharge areas are vulnerable to contamination and groundwater exploitation. One of the basic steps in arriving at a suitable water management practice is setting up hydrogeological studies (WENDLAND; BARRETO; GOMES, 2007). Additionally, groundwater monitoring provides information for planning and sustainable water use. Additionally, it allows for the detection of changes resulting from anthropogenic activities so that appropriate measures can be taken in time to avoid potential damages to the aquifer system (MANZIONE et al., 2010).

Monitoring water-table levels provide useful information for water management, giving the chance for water commissions and regulatory bodies predict the water availability in time and space. The parameters of hydrogeologic systems can vary greatly in space and time, but they are usually sparsely sampled (VON ASMUTH; KNOTTERS, 2004). Our knowledge of these system parameters is, therefore, partial at best and the most we can usually do is to quantify our uncertainty through stochastic, or related, models.

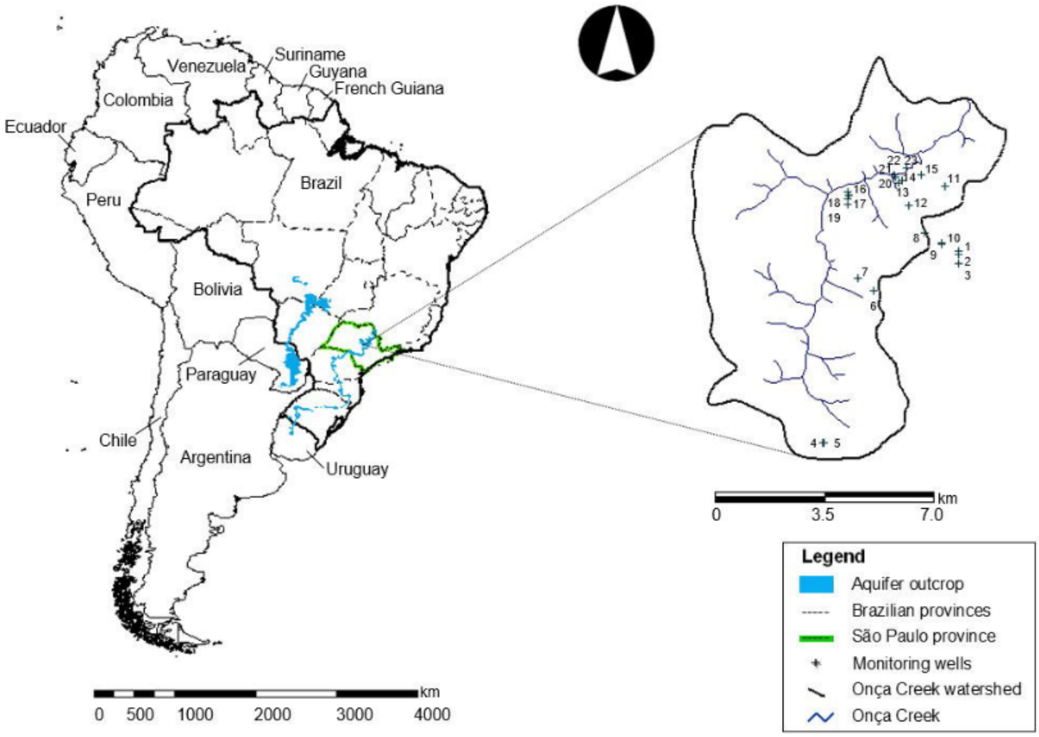
The aim of this work is to analyse water table variations using information from a groundwater monitoring network in an outcrop area of GAS in Brotas, São Paulo, Brazil.

4 MATERIALS AND METHODS

4. 1 Study area

The study area is the Onça Creek watershed, located between the coordinates 22º10' and 22º15' South and 47º55' and 48º00' West in the municipality of Brotas, province of São Paulo, Brazil; the watershed is an effluent of the Jacaré-Guaçú River (Figure 1). The topography in the basin can be described as a hillside along the monitoring wells numbered 16 to 19. The toposequence considered to be representative of the watershed is a convex shape hill with a broad top that has an over 1,500-metre length ramp and a height difference of approximately 68 metres. The slope ranges from 3.2% in the upper third to 5.0% in the middle third and 9.0% in the lower third with breaks in the slope perceived from the ground. This 5,800 ha watershed has land uses typical for São Paulo province, such as sugarcane, reforestation (with eucalyptus), citrus, pasture and some spots of natural Cerrado vegetation. The Onça Creek mainly flows over the Botucatu Formation and, at the basin outlet, over the Botucatu-basalt complex. Both units belong to the São Bento group of the Mesozoic age. Cenozoic soils present in the area are the result of sandstone weathering; the soil exhibits a homogeneous composition with no loam (WENDLAND; BARRETO; GOMES, 2007).

Figure 1. Map of the Brazilian territory and its provinces with a detail of the Onça Creek watershed



The study area is located in the outcrop zone of the GAS of São Paulo. The area is composed of sandy rocks of the Triassic age from the Piramboia Formation and Aeolian sandstones from the Botucatu Formation, which are Jurassic-Neo-Cretaceous in age. This sequence is bounded at the base and top by two regional discordances, which separate the GAS from the Palaeozoic and Neo-Cretaceous units (GASTMANS; CHANG; HUTCHEON, 2010; GASTMANS et al., 2012). The Piramboia Formation is comprised of fine sandstones that are regular to well-sorted and are intercalated with clay layers and silty to sandy mudstones. The presence of sediments deposited under wetter conditions is generally associated with fluvial facies. The Botucatu Formation is comprised of well-sorted, very-fine to fine-grained Aeolian sandstones with cross stratifications of medium to great thickness (CAETANO-CHANG, 1997; SRACEK; HIRATA, 2002).

The Botucatu sandstones of the Jurassic period have a higher hydraulic conductivity, whereas the Triassic Piramboia sandstones usually have a larger amount of clay at the bottom, which reduces, in relative terms, their hydraulic conductivity (RABELO; WENDLAND, 2009).

4. 2 Monitoring data

The Onça Creek watershed has twenty-three monitoring wells and a flow measurement station installed in the watershed for groundwater level and creek discharge monitoring, respectively. These wells were selected purposively to cover the range of land uses and hydrogeological domains in the area, in an attempt to characterise the different responses of water table depths in the basin. The filter levels of the wells varied with soil depth. Water table depths were physically observed every 15 days from April 2004 until March 2013, totalling nine years of monitoring.

A time series of precipitation and potential evapotranspiration were available from CRHEA/USP (Centre for Water Resources and Applied Ecology of the University of Sao Paulo). These daily-recorded data are available and collected continuously from 1974 until the present date. The watershed is located approximately 1.5 km away from the CRHEA station. Climatological data were also available from four automatic weather stations located in different land uses sites (pasture, sugarcane, citrus and natural Cerrado vegetation).

4. 3 Multivariate statistical modelling

To comprehend the main driving variables involved in the water table levels fluctuation, several soil properties were surveyed close to the monitoring wells. The aim of this survey was to analyse soil texture, permeability and porosity covering the major land uses of the basin. Crop variables were also incorporated in these analyses.

Forty-four soil samples were collected and analysed according to EMBRAPA (1997) at a depth of 10 to 50 cm. As a result, we obtained various percentages of sand, loam and clay from the volumetric analysis in the soil samples. A sand sieve analysis determined the percentage of sand of several grain size classes (very coarse sand, coarse sand, medium sand, fine sand and very fine sand). The same number of permeability measurements were taken using a Guelph Permeameter, according to Elrick, Reynolds and Tan (1989) and Elrick and Reynolds (1992), obtaining the field hydraulic conductivity at those sites. In addition, 204 field penetration resistance measures were obtained using a electronic soil penetrometer (PLG 1020 produced by Falker, Porto Alegre/RS, Brazil) at a depth of 10 to 90 cm to test the compaction level. The penetrometer gives the depth of maximum compaction and the mean and maximum values measured in the soil profile in near-field capacity conditions. The measures give the amount of pressure needed to push the probe through the soil in KPa, indicating how compacted the soils are and reflecting the soil quality and actual porosity. The terrain measurements, elevation, slope and distance to near drainage, were calculated from the well coordinates.

Additionally, crop development and soil management practices, such as crop rotation and eventual crop replacements, were monitored using Landsat 5 satellite images (orbit/point 220/75) from 2003 to 2012. These images were classified by land use and organised chronologically to estimate the mean crop coefficient (K_c) of the vegetation near each well during the monitoring period following the stages described by FAO (1998). We considered all cultivations, phenological stages, crop management practices and soil exposition to compute an average crop coefficient for each well, representing the water demand during the monitoring period.

The data collected in the 23 wells were comprised in the following 16 parameters:

1. Sand - percentage of sand (%)
2. Loam - percentage of loam (%)
3. Clay - percentage of clay (%)
4. *K* - field hydraulic conductivity (cm/s)
5. MSPR - mean soil penetration resistance (KPa)
6. MaxSPR - maximum soil penetration resistance (KPa)
7. MCD - maximum compaction depth (m)
8. VCS - very coarse sand (%)
9. CS - coarse sand (%)
10. MS - medium sand (%)
11. FS - fine sand (%)
12. VFS - very fine sand (%)
13. Kc - crop coefficient (-)
14. DD - distance to the nearest drainage (m)
15. EALS - elevation above sea level (m)
16. Slope (%)

From the monitoring of the water table levels time series were calculated the mean highest (MHWL) and mean lowest water level (MLWL) for the period as described by Knotters and Van Walsum (1997). The difference between MLWL and MHWL was our response variable, which is the amplitude of water table fluctuation during the monitored period that started in April 2004 and finished in March 2013. Several statistical tests were performed to evaluate the influence of these variables, alone or together, on the water table fluctuation.

The following analysis were performed using MINITAB software version 13. Factorial analysis (FA) was applied to identify the underlying variables, or factors, that explain the pattern of correlations within these sets of observed variables. Factorial analysis is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifest variables (SHAW, 2003). In this study, FA was also used to generate hypotheses regarding causal mechanisms on water table fluctuations, aiming to identify complex interrelationships among items and group items that are part of unified concepts on water table dynamics. The approach involves finding a way of representing correlated variables together to form a new smaller set of derived variables with a minimum loss of information, thereby removing redundancy or duplication from a set of correlated variables as a data reduction tool. Principal component analysis was used as an extraction method, providing a unique solution so that the original data can be reconstructed from the results and including as many factors as there are variables.

A VARIMAX rotation with Kaiser normalisation was applied to simplify the interpretation of a factor analysis. This rotation is orthogonal of the factor axes to maximise the variance of the squared loadings of a factor (column) on all the variables (rows) in a factor matrix, which has the effect of differentiating the original variables by the extracted factor. Each factor will tend to have either large or small loadings of any particular variable.

From the remaining fourteen variables, five factors were defined, including the following variables in parentheses for each group: soil texture (sand and loam); sand particle size (coarse, medium, fine and very fine sand); terrain attributes (slope, elevation above sea level and distance to nearest drainage); soil and crop management practices (mean soil resistance to penetration, maximum soil resistance to penetration and field hydraulic conductivity); and vegetation (crop coefficient denoting water consumption and maximum compaction depth indicating root exploration area).

5 RESULTS AND DISCUSSIONS

A correlation matrix was calculated revealing the variables that presented a high correlation. Clay and very coarse sand presented high correlation values, suggesting an autocorrelation between these variables and others. An all-possible-regressions procedure for variables reduction (NETER et al., 1996) was tested using a best subset algorithm applied to the data, removing clay and very coarse sand from the subsequent analysis. From the best subsets algorithm results, the best arrangement between the fourteen variables to explain water table levels changes contained six variables: sand, fine sand, very fine sand, distance to nearest drainage, crop coefficient and mean soil resistance to penetration. This choice was made using not only the R^2_p criterion but also R^2_a, C_p statistic and $RMSE_p$ (root mean square error of predictions). The chosen model was not robust enough for changes in water level prediction ($R^2_p = 76.3$ and $R^2_a = 64.4$) but revealed the main driving forces acting in this process, helping to identify the underlying factors on the water table level's behaviour.

The descriptive statistics of all samples taken in the region of the monitoring wells to characterise the soil, hydraulic, terrain and vegetation properties are presented at Table 1.

Table 1. Descriptive statistics of samples taken at the well area

Variable	Mean	S.Dev.	Min.	1st Q.	Median	3rd Q.	Max.	C.V.
K	1.83e-3	1.22e-3	3.46e-5	8.95e-4	1.76e-3	2.70e-3	4.35e-3	66.72
Sand	90.88	4.37	78.70	89.77	91.65	94.30	95.67	4.81
Loam	7.37	2.70	4.00	5.30	7.60	9.20	14.80	36.62
Clay	1.76	2.61	0.03	0.13	0.60	1.47	7.96	148.79
VCS	0.65	0.65	0.00	0.07	0.38	1.15	2.18	100.41
CS	4.78	2.63	1.06	2.79	4.55	6.06	11.33	55.13
MS	33.71	6.96	20.69	31.03	33.80	34.95	54.37	20.65
FS	42.86	5.15	28.08	41.61	43.00	46.08	50.76	12.01
VFS	18.00	5.76	4.78	16.15	17.79	18.95	36.63	32.01
Kc	0.92	0.09	0.80	0.85	0.90	1.00	1.04	9.38
DD	929.11	957.44	50.00	215.00	415.00	1599.00	2630.00	103.05
MSPR	1735.40	368.82	1086.72	1656.90	1766.00	1940.00	2305.78	21.25
MaxSPR	3322.56	1110.17	1615.35	2594.63	3368.33	3987.50	5632.00	33.41
EASL	722.11	24.30	687.00	706.50	717.00	740.50	768.00	3.37
Slope	6.24	4.07	0.00	2.59	6.04	9.26	14.14	65.26
MCD	0.33734	0.12958	0.18	0.2325	0.3034	0.42955	0.58	38.412

S.Dev.: standard deviation, Min.: minimum, 1st Q.: first quartile, 3rd Q.: third quartile, Max.: maximum, C.V.: coefficient of variation, *K*: field hydraulic conductivity, VCS: very coarse sand, CS: coarse sand, MS: medium sand, FS: fine sand, VFS: very fine sand, Kc: crop coefficient, DD: distance to nearest drainage, MSPR: mean soil penetration resistance, MaxSPR: maximum soil penetration resistance, EASL: elevation above sea level, MCD: maximum compaction depth.
Units: *K* (cm/s), Sand, Loam, Clay, VCS, CS, MS, FS, VFS and Slope (%), DD, EASL and MCD (m), MSPR and MaxSPR (KPa) and Kc (adimensional)

The results classified the soil as a sandy soil similar to loamy sand. The samples consisted of fine and very fine sands in 55.47% of the cases. The mean field hydraulic conductivity of 2.40e-3 cm/s matches with the values presented by Freeze and Cherry (1979) for fine and loamy sands, ranging from 10^{-3} to 10^{-4} cm/s in the soil. From the analysis of positional and dispersion statistics, the soil was considered homogeneous and the parental material uniform in the study area with variation within the established values for these sandstone formations. The standard deviations of some values were large, but when the scale of variation was verified we realised that some variables were more sensitive because of their small amounts found in the analysis, such as clay, VCS and CS. In the case of hydraulic conductivity, the magnitude of the values is small, with small differences generating large deviations. Even with these differences and coefficient of variation of 66.72%, the *K* values did not exceed the range of 10^{-3} to 10^{-4} cm/s for fine sands. Because the soil hydraulic characteristics do not vary at an order of magnitude we can consider the porous domain homogeneous and assign the differences in water table behaviour to land use and crop development.

The FA results were analysed using the components score and loadings. The components score are the transformed variable values that are related to each particular case within the dataset and the loadings are the weight by which each original variable should be multiplied to obtain the component score. Table 2 presents the results of the factorial analysis summarised by the five components. At each column are summarised the loads of the calculated factors for each variable and the respective communalities. When the number of factors is not reduced, the communality value should be 1, further reducing when decreasing the number of factors. We interpreted positive loads as high water table levels fluctuations and negative loads as low water table levels fluctuations.

Table 2. Factors and loads calculated using factorial analysis for the multivariate dataset influencing water table levels fluctuation during the monitored period

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
K	0.37	-0.21	-0.18	-0.78	0.16	0.84
Sand	-0.15	0.10	0.91	-0.20	0.08	0.91
Loam	0.10	-0.03	-0.92	-0.04	-0.18	0.88
CS	-0.68	-0.64	0.16	0.04	0.00	0.91
MS	-0.96	0.05	0.13	0.04	-0.06	0.94
FS	0.75	0.02	-0.39	0.08	0.09	0.73
VFS	0.84	0.29	0.11	-0.13	-0.01	0.81
Kc	-0.08	0.55	0.35	0.12	0.67	0.90
DD	0.29	0.81	0.22	-0.25	0.14	0.86
MSPR	0.05	0.32	0.29	-0.78	-0.16	0.82
MaxSPR	-0.24	0.00	0.11	-0.78	-0.41	0.81
EASL	0.20	0.90	0.06	0.06	-0.26	0.93
Slope	0.55	-0.75	0.06	-0.05	-0.09	0.87
MCD	-0.10	0.17	-0.14	-0.16	-0.92	0.93
Variance	3.32	3.02	2.20	1.98	1.67	12.18
%Variance	0.24	0.22	0.16	0.14	0.12	0.87

K: field hydraulic conductivity, VCS: very coarse sand, CS: coarse sand, MS: medium sand, FS: fine sand, VFS: very fine sand, Kc: crop coefficient, DD: distance to nearest drainage, MSPR: mean soil penetration resistance, MaxSPR: maximum soil penetration resistance, EASL: elevation above sea level, MCD: maximum compaction depth

Factor 1 (F1) can be related with sand particle size, with high load values for VFS and FS (positive) and MS and CS (negative), indicating that there is an antagonist behaviour between more fine sediments and more coarse material. This first factor explains 23.70% of all variance in the dataset.

Factor 2 (F2) variance is explained by terrain attributes, with elevation above sea level, distance to near drainage and slope as the variables with high loads. F2 represents 21.50% of the variance. The positive values of DD and EASL indicate an increase in the water table levels fluctuations against the negative values of slope, whereas high values indicate lees recharge.

Factor 3 (F3) indicates the influence of soil texture with high load values for sand and loam. Here, sand and loam influence is distinguished by the different signal of the values – positive for sand and negative for loam. This factor corresponds to 15.70% of the variance. Factor 4 (F4) presents influences of variables that characterise soil conditions due to management practices. Negative values of MaxSPR, MSPR and *K* denoted that the higher these values, the less the water table would oscillate.

As in F3, the variance of F4 is small (14.1%) when compared with F1 and F2.

Finally, factor 5 (F5) is controlled by the vegetation influence, with Kc positive loads suggesting the greater the water consumption by vegetation the higher the water table level fluctuation, and negative MCD loads indicating the deeper the maximum compaction values the lower the water table level fluctuation. The variance correspondent to F5 is 11.90%.

The variance contained at F1 and F2 corresponds to 45.2% of the total variance. The values of the communalities of each variable were high (close to 1) denoting the efficiency in reducing the number of factors and the original variance. Once factors F1 and F2 are related to soil mineralogy, this is considered the main acting variable in the water table levels fluctuation in the Onça Creek watershed.

Table 3 shows the score factors for each variable at each factor. These values indicate the variable responsible for the main influence at each factor. For F1, the main influence is attributed to medium sand. F2 is mainly influenced by elevation, whereas F3 exhibits a shared influence of sand and loam. F4 exhibits a joint influence of field hydraulic conductivity and soil compaction, whereas F5 is mainly influenced by compaction depth.

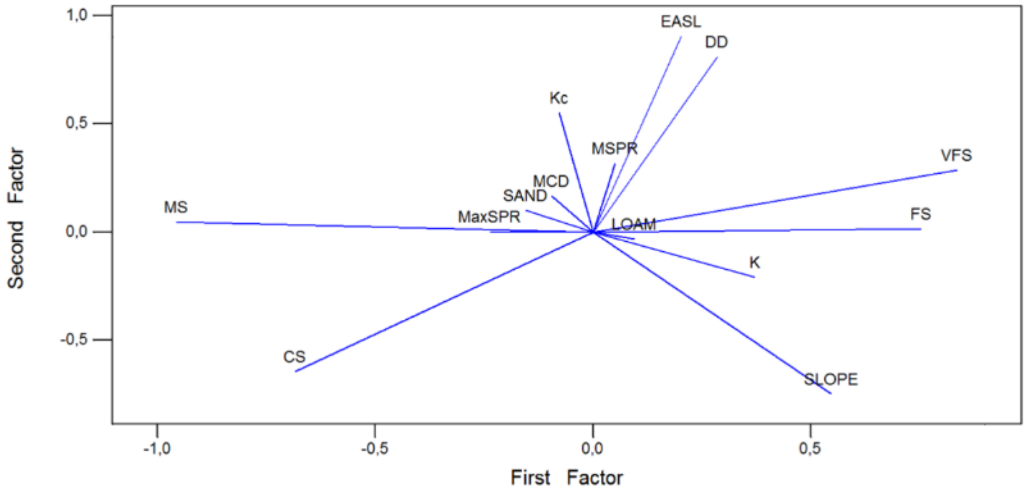
Table 3. Score factors for each variable at each factor.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
K	0.02	-0.09	-0.19	-0.51	0.30
Sand	0.06	-0.06	0.46	0.00	-0.08
Loam	-0.10	0.08	-0.50	-0.13	0.08
CS	-0.17	-0.20	0.06	-0.02	0.02
MS	-0.32	0.08	-0.06	-0.04	0.03
FS	0.21	-0.01	-0.12	0.04	0.05
VFS	0.29	0.03	0.15	0.03	-0.10
Kc	-0.08	0.18	0.00	-0.03	0.41
DD	0.03	0.25	0.01	-0.11	0.10
MSPR	-0.02	0.07	0.05	-0.38	0.00
MaxSPR	-0.10	-0.01	-0.02	-0.38	-0.12
EASL	0.05	0.03	0.03	0.14	-0.23
Slope	0.27	-0.33	0.23	0.06	-0.15
MCD	0.02	0.07	0.07	0.10	-0.61

K: field hydraulic conductivity, VCS: very coarse sand, CS: coarse sand, MS: medium sand, FS: fine sand, VFS: very fine sand, Kc: crop coefficient, DD: distance to nearest drainage, MSPR: mean soil penetration resistance, MaxSPR: maximum soil penetration resistance, EASL: elevation above sea level, MCD: maximum compaction depth

Figure 2 shows the first two orthogonal factors. The influence of the variables in the water table behaviour is verified by the magnitude and direction of the orthogonal factors of each variable. Attributes related to sand particle size and terrain have large influence when compared with other variables. For sand particle size, CS and MS vectors have opposite direction in relation to VFS and FS. The same occurs with terrain attributes, with EASL and DD presenting opposite direction in relation to SLOPE. Kc and *K* vectors present a smaller magnitude but still larger than other vectors. The other variables have small influence in the two first factors.

Figure 2. First two factors modelled by factorial analysis for the multivariate dataset influencing the water table levels fluctuation during the monitored period



Homobono and Wendland (2011) verified the influence of soil and crop variables in the water table variations at the Onça Creek watershed using cluster and correlation analysis, concluding that soil characteristics like porosity high influence the behaviour of the water table. Lucas and Wendland (2015) explored the effects of vegetation in the recharge rates, analysing the well individually. The use of factorial analysis as an exploratory tool to comprehend the structure of multivariate data is useful when analysing a high number of variables, some of them autocorrelated. Factorial analysis is available and some knowledge about the processes is already available. In this study, several variables were previously observed to determine the main reasons, or factors, that could possibly influence the water table dynamics in the watershed and their weight in this process. Other variables can also somehow influence the water table dynamics, but the aim was not to completely explain the processes. The idea was to understand the data, gain some knowledge from previous theories about the processes and develop new interpretations from the results with a different perspective. Discussing the merit of factorial analysis, Rencher (1995) states that understanding the limitations involved in the method is important when exploring a multivariate dataset and not to misuse the technique and make it a useful statistical tool.

In large countries like Brazil, many times the surveys are available in different scales, not giving the level of details needed to a local watershed management. Meanwhile, there is data available and knowledge that can the used in a statistical model to provide useful information for local authorities. The use and integration of different statistical approaches in the investigation of groundwater changes sometimes is simpler than complex mechanistic models, and produce reliable information about water table characteristics (MANZIONE; MARCUZZO; WENDLAND, 2012; VON ASMUTH, 2012).

This methodology can be useful for groundwater management, police making and land use regulation in catchment and regional studies, for example, maximizing information in data analysis.

6 CONCLUSIONS

The results in this study indicate that this methodology could be useful in groundwater management.

Factorial analysis successful indicate the major influences of sand particle size, terrain attributes, soil texture, soil/crop management and vegetation on the water table fluctuations during the monitoring period, as well as helping to understand the behaviour of the aquifer system in the watershed.

Particle size and terrain attributes were considered the main driven forces on water table fluctuations in the watershed.

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