REVIEW

HYDROPEDOLOGY

Hidropedologia

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ABSTRACT

Pedology consists of a sub-area of Soil Science that studies the soil and its origin as well as its inter-relationship with the landscape. Hydrology is the science that studies the water in nature in its different mediums (atmosphere, soil and rock), using the watershed as a reference for analysis of the water dynamics and also its interaction with the landscape. The relationship between these two branches of knowledge has been the object of debate and analysis in recent years, contributing to the creation of a multidisciplinary science, which seeks to integrate the respective fields of research. As such, for Hydrology, Pedology has been fundamental for enabling a foundation for the processes associated to the generation of runoff and groundwater recharge, especially concerning the micro-morphological analysis of the soil and the horizons which may impede the water flow, and their relationships with the soil structure. For Pedology, Hydrology can be fundamental to the understanding of the soil formation processes in the different landscapes, in the context of materials deposition as well as the shaping of the relief, as consequence of the soil-climate-drainage interaction, and its importance for pedogenesis. Therefore, the understanding and the deepening of the pedologic analyses, on a microscale and in toposequence in a specific landscape, and its insertion in the theories of Hydrology will allow the development of more realistic, physically based hydrological models and less parameterization dependence, this now being one of the most important challenges for the hydrologist.

Index terms: Hydrology, pedology, soil hydrology, geomorfology.

RESUMO

A Pedologia consiste de uma subárea da Ciência do Solo que estuda o solo e sua origem bem como sua relação com a paisagem. A Hidrologia é a ciência que estuda a água na natureza nos seus diferentes meios (atmosfera, solo e rocha), utilizando a bacia hidrográfica como referência para análise da dinâmica da água e sua interação com a paisagem. A relação entre esses dois ramos do conhecimento tem sido objeto de debate e análise nos anos recentes, contribuindo para a criação de uma ciência multidisciplinar, a qual busca interagir os respectivos campos de pesquisa. Assim, para a Hidrologia, a Pedologia tem sido fundamental por possibilitar um embasamento sobre os processos associados à geração do escoamento e recarga subterrânea, especialmente no tocante à análise micromorfológica do solo e aos horizontes ou camadas subsuperficiais de impedimento ao fluxo de água e suas relações com a estrutura do solo. Para a Pedologia, a Hidrologia pode ser fundamental no entendimento dos processos de formação dos solos, nas diferentes paisagens, tanto no contexto de deposição de material quanto da conformação do relevo, fruto da interação solo-clima-escoamento, e sua importância para a pedogênese. Assim, o entendimento e o aprofundamento das análises pedológicas, em microescala e em topossequência, numa determinada paisagem, e sua inserção nos fundamentos e teorias da Hidrologia permitirão o desenvolvimento de modelos hidrológicos mais realísticos e embasados fisicamente, e menos dependentes de parametrização, sendo este um dos desafios mais importantes para o hidrólogo atualmente.

Termos para indexação: Hidrologia, pedologia, hidrologia do solo, geomorfologia.

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INTRODUCTION AND CONCEPTS ASSOCIATED TO HYDROPEDOLOGY

Hydropedology consists of a science whose approach is typically multidisciplinary and its application is quite wide within the various branches of knowledge of Soil Science as well as of Hydrology. Currently, where the concern with natural resources is more and more necessary, the soil and water are fundamental elements to understand the balance between the need for agricultural production and environmental sustainability and, in this context, Hydropedology can provide a significant contribution for the better understanding of the soil-water interaction in a specific landscape.

The interdisciplinarity of Hydropedology, according to Kutílek & Nilsen (2007), is associated to the interaction among Pedology, Soil Physics, Soil Micromorphology, Soil Hydrology and the aspects associated to the topographical conditions and the landscape. Therefore, Hydropedology seeks to fill a gap

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between Pedology and its conceptions linked to the soils genesis and their influence on the hydrological conditions of a wider system, as in a watershed.

The problems linked to the traditional studies that involve Soil Science refer basically to the indiscriminate use of deformed soil surface samples or the preparation of packed soil columns on which hydrological studies are made linked to the flow (movement) of water in the soil profile. In this context, the whole conception linked to the structure of the soil and its physical, chemical and biological medium are compromised. According to Lin (2011), such studies can promote important deviations in the aspects fundamentally associated to the soil structure, macropores and specific characteristics of each of the horizons that compose the pedologic unit, compromising the results arising from such studies. It is exactly in this context that Hydropedology becomes necessary, because it emphasizes the original meaning of Pedology and its interaction with the geophysical environment.

As such, the interactions between soil and water are close and they cannot be separately studied in an effective manner. Lin (2010), among other scientists interested in Hydropedology, defines it as an interweaving between Soil Science and Hydrology, promoting the interface between the pedosphere and the hydrosphere with emphasis on the soils and the associated landscape. According to Lin (2010) and Lin (2011), Hydropedology, in the field of the physical geosciences, is considered the science of the 21st century by promoting the break of two paradigms: the paradigms of Pedology and Geomorphology.

According to the "US National Research Council" (NCR, 2001), which was also mentioned by Lin (2010), the science linked to the understanding of the hydrological cycle and its interaction with the landscape, should look for an integrated study of the "Critical Zone" (CZ) being that this makes up the great challenge of geosciences in the 21st century. Concisely, the CZ is associated to a zone that goes from the top of the vegetation (canopy) to the base of the aquifer, in other words, it is where all the main processes associated to the hydrological cycle occur, the vegetable covering and its relationship with the atmosphere, pedosphere, hydrosphere and the lithosphere being taken as reference. In reality, it is understood that all environmental processes that involve plant covering to aquifer systems should be jointly conceived. And it is exactly in this context that Hydropedology is inserted, because the atmosphere finds subsidies in hydrometeorology, and the behavior of the water in the aquifers, in hydrogeology, thus a science is lacking that approaches the interaction between the water flow in the soil profile (vadose zone) until its recharge process and all of the consequences of this interaction.

As examples of the importance of Hydropedology, two case studies will be highlighted in the sequence, both in the sense of application of hydrological models in watersheds.

Holländer et al. (2009) applied 10 hydrological models classified as conceptual to simulate the water balance in a 6 ha watershed in Germany, supplying them with soil texture data and indexes linked to the topography, as occurs with the great majority of the hydrological models. None of the 10 models simulated adequately the 3 years of water balance observed. The problem is that none of the models was capable of picking up the significant influence of the soil crusting (surface impermeability), characteristic of the pedologic unit in question, causing therefore, for which high water infiltration capacity and maintenance of the baseflow due to the predominantly sandy texture was expected, to systematically produce higher overland flow.

Another example of this type of problem that Hydrology faces was related by Menezes et al. (2009) and Mello et al. (2008), which worked in the Lavrinha Creek watershed, in Mantiqueira Range region (Figure1). Having general knowledge of the Geomorphology and Pedology of this area as a basis, it was expected that the generation of overland flow would be very high in this watershed, because the predominant soils are relatively impermeable and shallow (Cambisols (Inceptisols) and Litholic Neosols (Entisols)) and they are associated to quite steep topographies (average slope from 35 to 40%). Besides these aspects, the Atlantic Forest, that represents the native vegetation of the area, presents high evapotranspiration demands, for including individuals of large size. However, the monitored hydrological behavior has shown a substantial predominance of the baseflow (groundwater flow) and sub-surface flow at the expense of the overland flow, causing these watersheds, occupied by Atlantic Forest, to be highly water yield due to their water storing capacity originating from of the previous hydrological year. What Mello et al. (2008) observed was that applying Lavras Simulation of Hydrology (LASH) (MELLO et al., 2008; BESKOW et al., 2011) to simulate different soil uses in the region of the Mantiqueira Range, the substitution of native forest for pasture would produce higher water yield capacity. Because the evapotranspiration of the pasture is very low, there would be a higher surplus of water for recharge in the structure of the model, which was not confirmed during the 6 years of hydro-climatic monitoring of the area.

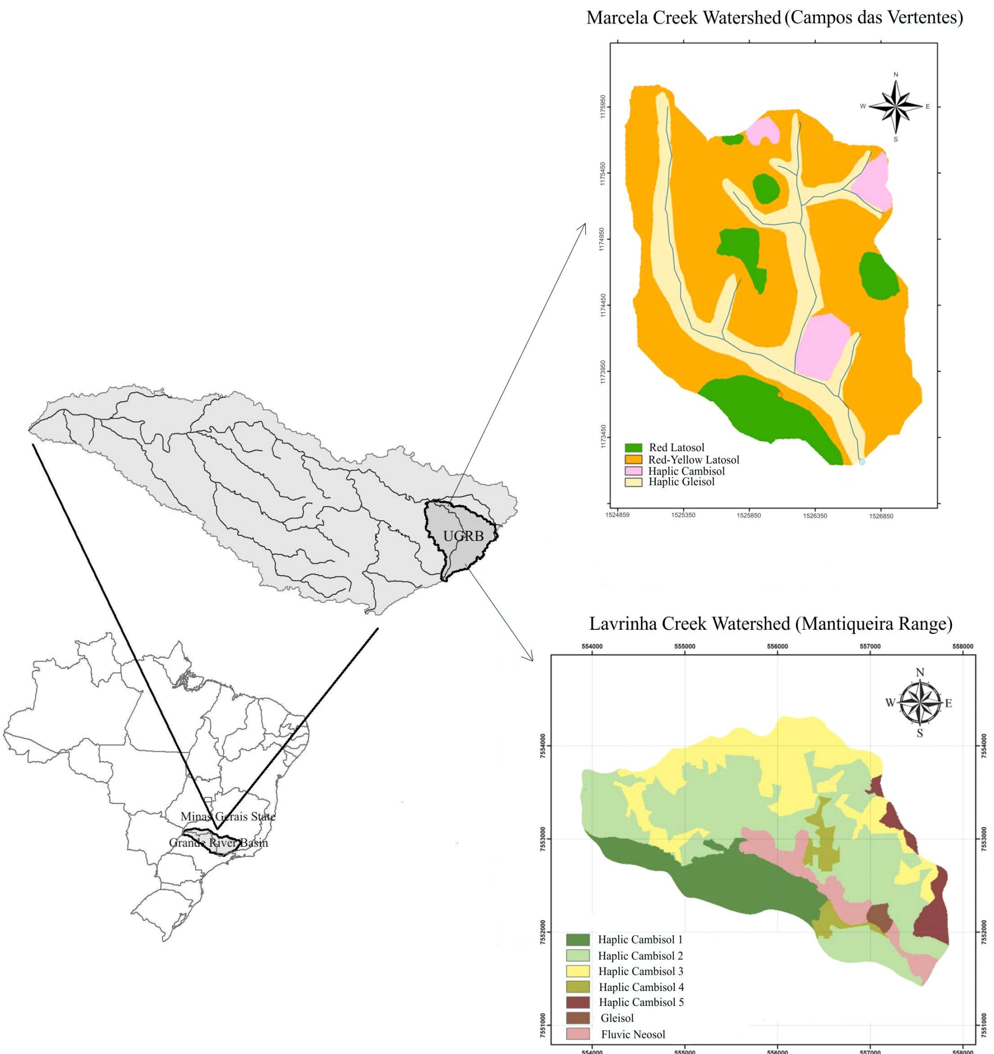

Figure 1 – Geographic location of the Upper Grande River Basin (UGRB) and of the watersheds of the Lavrinha Creek (Mantiqueira Range) and Marcela Creek (Campos das Vertentes) and their respective soil maps (MENEZES et al., 2009 and MOTTA et al. 2001).

What the models did not observe was that in the Mantiqueira Range region, the function of the Atlantic Forest goes beyond a simple consideration concentrated on the evapotranspiration rates. The accumulated organic matter during decades, facilitated by the low temperatures during the year, especially below the canopy, promotes the formation of a thick litter layer, that produces two important effects, according to Price (2011): first, as the forest presents a dense canopy, its water storage capacity is also high and, as a consequence, high intensity rains are minimized by the interception. Second, the slightly decomposed organic layer promotes a temporary water storage, conducting it through preferential flows to the saturation zone, causing it to have time to be stored and then, transmitted. Another important detail is that in spite of the geology of the area being granite-gneiss, in other words, very consolidated rock, with low storage capacity rocks, the saturated zone finds space in the detritic material deposition areas and, or, in the fractures originated near them, facilitating the storage process. No hydrological model has the capacity to predict such behavior, so great is the interaction and complexity of this ecosystem, that finds explanations in the interaction among Pedology, Geomorphology and Climatology.

Lin (2011) comments on something very important about some aspects related to what was reported previously. Among other observations, the advent of computers and software applied to Hydrology has been provoking a race to development of models and little importance has been given to data observed in the field. Very few new theories have been developed, such as the Laws of Darcy, Buckingham, Horton, among others, which fundamentally work with the interaction between Hydrology and Pedology. This means that no new theory has been proposed for the field of Soil Hydrology, there being an important gap remaining in the understanding of the soil-water interaction processes in the landscape.

In this context, in spite of many Hydropedology topics having been studied in the past, especially linked to Soil Hydrology, the development of Hydropedology as a multidisciplinary field, taking the "Critical Zone" concept mentioned previously as a reference, a new perspective and a more integrated approach to the study of the soil-water interactions, having spatial and temporal scales as reference, has been suggested (LIN, 2003). Figure 2 presents a scheme that seeks to demonstrate the interaction between Pedology and Hydrology in a landscape, integrating, in turn, the scales of observation of both sciences.

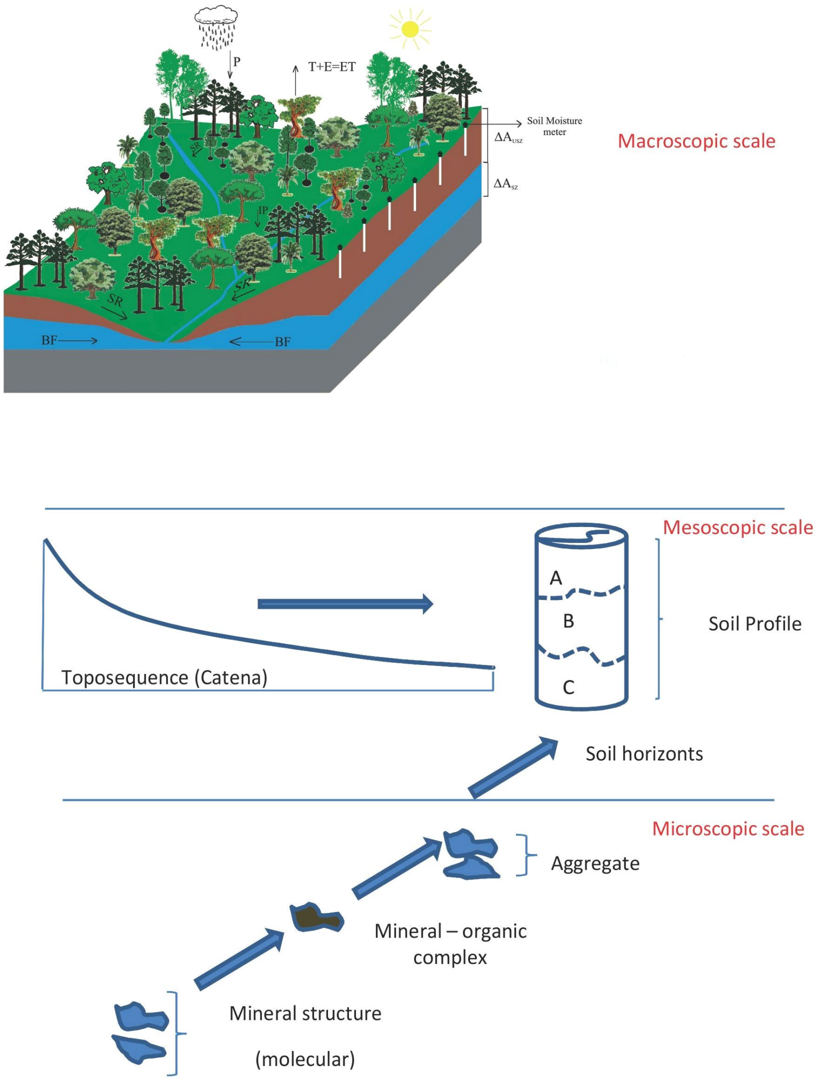

Figure 2 – Fundamental characteristic of Hydropedology: connection between the micro-, meso- and macro-scales (Adapted from LIN, 2003).

The objective of the figure 2 is to characterize how the interaction among Pedology, Soil Physics and Hydrology, which are the pillars of Hydropedology, is processed; in other words, integrating the phenomena that occur on a micro-scale (pores and aggregates), meso-scale (toposequences) and finally the macro-scale (watershed). As such, it is possible to understand how the soil structure formation processes, which are quite influenced by mineralogy (FERREIRA et al., 1999; RESENDE et al., 2011), characterize the pedogenetic horizons, which vary along a toposequence and characterize the landscape of a watershed. At this point, one can describe a feedback process, in other words, the landscape characterized by the aspects associated to Pedology also influences the pedogenesis in a toposequence by the hydrological processes that occur in the watershed, especially the erosion and the sedimentation and the soils that are formed based on this process.

As a practical example of these relationships, the differential behavior of Cambisols (Inceptisols) (shallow soils) can be mentioned concerning the recharge dynamics of groundwater in function of the pedoform (topography) and the characteristics of the watershed. In a headwater watershed of the Mantiqueira Range (Figure 1), Menezes (2011) obtained very superior values for this recharge in Cambisols with linear pedoform in comparison with Cambisols with convex pedoform, these latter belonging to the Marcela Creek watershed in the Campos das Vertentes (Figure 1). In other words, the physiography of the watershed was more effective than the topography.

CHARACTERISTICS AND ASPECTS OF HYDROPEDOLOGY

According to Lin (2011) and Kutilek & Nielsen (2007), it is possible to generate an important synergy with the connection of Pedology with Soil Physics and Hydrology, considering the concept of Hydropedology as the interaction between the pedosphere and the hydrosphere. The two main fields of activity of Hydropedology, according to Lin (2011), are:

a) how the soil and its physical, chemical and biological properties in a specific landscape (watershed) exercise control on the primary hydrological processes? and

b) how the hydrological processes (hydrological cycle) in a landscape can contribute to the soil forming processes, their evolution and spatial variability?

It is possible to notice that the second objective is the opposite of the first. According to Lin (2011), this objective has been ignored by traditional Soil Hydrology, which has only concentrated on the modeling of the hydrological flows in the vadose zone towards the saturated zone.

The first interface between Pedology and Hydrology can be understood as how the soil, in its totality, is structured from the microscopic to the macroscale level, considering: the **solid components** (texture, aggregation and horizons), the **porous space,** such as the pore size distribution, morphology of the pores and their communication networks, the liquid, gaseous and biological portion within porous space, and the **interfaces between the solid components and the porous space**, such as the pores size and the soil solution that involves the aggregates, soil matrix- macropores, soil-root, microbe-aggregate, horizon-horizon, soil-parent material. According to Lin (2011), these interfaces are zones frequently active for biogeochemical reactions or primary mechanisms for preferential flow formation in the soil profile. Several water flow restrictions have been registered in the Brazilian literature involving specific soil horizons. Such restrictions act as retardants to the water movement, promoting decrease of the flow towards the saturated zone and aquifers, and promoting substantial increase in the baseflow and sub-superficial or lateral flows.

As examples of horizons restrictive to the water flow in the soil profile the following can be mentioned: fragipan (cemented by silica), ortstein (cemented by iron oxides and organic matter), plinthite (clay mixture, poor in humus and rich in iron and aluminum), petroplinthite (plintite irreversibly hardened due to the crystallization of iron oxides caused by exposure to moistening and drying cycles) and duripan (cemented mainly by silica and secondarily by iron and carbonates) (RESENDE et al., 2007). In the context of Hydropedology it is fundamental to identify and to map the depth of occurrence of these restrictive soil horizons in the landscapes (RESENDE et al., 1988).

To aid in the structuring of the hydrology simulation models, modern non-invasive techniques could be applied to them to enable improvements for the calibration of the hydrological models such as computerized tomographies, micromorphology (behavior of the structure on a microscopic and micro-relief scale), remote sensing, geophysics techniques and finally, techniques that allow to identify the behavior of the soil profile in a microscopic context. However, even if this can be effectively carried out, to improve the resolution of the field investigations and to associate the pedogenetic characteristics to the hydrological functions in a more effective way constitute very great challenges.

The soils are made up of several horizons and each one presents a distinct architecture, in other words, the arrangement of the mineral particles together with the organic and liquid compounds in the soil characterize it, with the associated pores and aggregates, and consequently, the porous space for the geobiochemical reactions that are processed in this environment. In this context, there is a great heterogeneity in the soil profile and the existence of preferential flow occurs in practically all the soils. However, local aspects, such as the existence of a forest ecosystem in geobiochemical equilibrium, can produce distinct pores size, and continuity. Clothier et al. (2008) mention that the preferential flows can occur from the spatial scale of pores (mm), going through the scale of aggregates (cm/dm) and horizons (cm/m), to the secondary channels of a slope (m/km) until the rivers and main channels of a large hydrographic basin (km). In temporal terms, the preferential flows can act in reactions that are processed from 1 to 10 seconds, during hydrological events in which the drainage is processed as a function of the geomorphology of the hydrographic basin (from 1 to 100 hours), during the seasons of the year (months) and even annual variations themselves. In Brazil, there is lack of depth investigation of soil profile and more detailed samplings as well as of monitoring of some less permanent attributes (as for instance, organic matter content and quality, macrostructure, bulk density, etc.) with time, particularly under different soil use and management.

It can be seen how complex the hydrological cycle dynamics is, especially if analyzed in the light of Hydropedology. In figure 3 a diagram of a landscape is presented with the connections existent between the soil and the behavior of the hydrological cycle, including the soil horizons, the percolation zone, the saturated zone and the critical zone, as well as the existence of possible sub-surface preferential flow, formed as function of the pedological attributes and soil use.

In this figure, it is possible to observe the possibilities of groundwater recharge in a watershed and how the Pedology can influence on these aspects. The recharge is processed starting from the infiltration of surface water and through the soil profile, reaching the aquifers (this process can take days, months or years depending on the characteristics of the aquifers, such as their depth, geology and transmissivity). However, in function of the pedogenetic characteristics of the horizons, an important sub-surface concentration can occur and from this, the water flow can also contribute to the saturated zone and the flow in the channel (this process can take from hours to days). Still, on the other hand, the formation of the preferential flow below the surface can significantly influence the formation of the saturation zone as well as the sub-surface drainage and the in depth recharge. Therefore, under certain specific conditions, a watershed can present the prevalence of specific preferential flows and, consequently, have the hydrological cycle affected

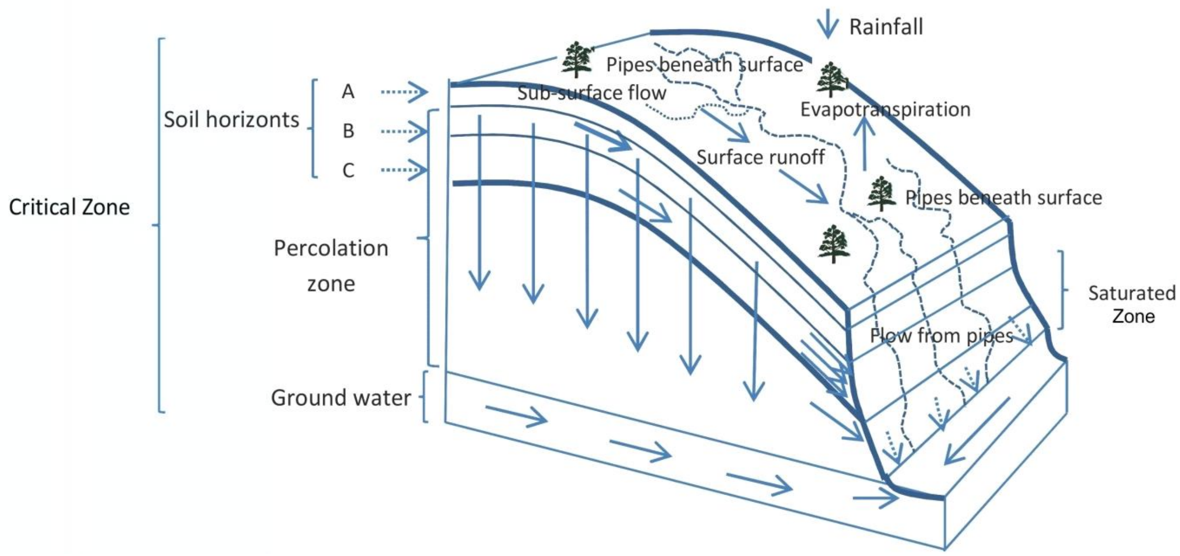

Figure 3 – Hydrological cycle in a landscape comprising the pedological, hydrological and geomorphological elements of a watershed and possible inferences on the various pathways through which water can travel to reach the saturated zone and from there to the channels (Adapted from LIN, 2010).

by the soil behavior of the watershed itself (MENEZES et al., 2009; ALVARENGA et al., 2011).

In view of these aspects, Lin (2003) proposes some gaps that need to be filled by Hydropedology, which are commented below.

a) **The soil structure**: basically, to quantify the soil structure and its impact on the water flow. This is one of the great challenges of Hydropedology, in other words, how to join this information to the models and theories of Hydrology, because the processes associated to the hydrological cycle occur on a watershed scale and the soil structure and its impediments to the water flow occur within the soil profile. A new basis of the soil porous medium geometry consists of a field that still needs to be improved so that there is a more effective contribution to the understanding of the flows in watersheds.

b) **Preferential flows:** these are other great challenges to Hydropedology, especially in headwater landscapes (watersheds) occupied by native forests, and they are also associated to the soil structure. In the reality, preferential flows are characterized as a function of the behavior of the soil structure associated to the behavior of the soil biological and chemical attributes. The identification, under the current conditions, is not satisfactory to describe the behavior of its interface with the soil matrix. In this sense, a technical or interpretative soil classification system can be developed to differentiate the soils in terms of the water flow patterns in the soil profile. This investigation has fundamental importance for the understanding of the hydrological behavior of the soil under permanent use with native forest under high altitude conditions. According to Nogushi et al. (1997), it is well-known also that the development of these preferential flows is part of a more complex hydrological system and that with the existent theories and the little availability of field data, it is not possible to properly understand the hydrology of these environments. In this sense, continuing the work of Menezes et al. (2009), Alvarenga et al. (2011) identified saturated soil hydraulic conductivity values of the soil varying from 3 to 5 times higher in areas under native forest than in areas occupied by pastures at the Mantiqueira Range (Figure 1). It is noteworthy that in these studies, the topography as well as the pedologic unit, were the same, that indicates that a micromorphological analysis of the structure and the associated pores would add important value to the identification of the causes of these preferential flows.

c) **Hydromorfology of the soil**: Pedology can apply aspects of the macro and micromorphology to support inferences on the soil structure behavior and consequently to understand Soil Hydrology better, especially, its hydraulic properties (saturated hydraulic conductivity, drainable porosity, etc.), aiding in the soil classification and genesis processes. The morphological characteristics of the soil are important for the understanding of the water flow behavior in the soil profile, which offer much more relevant information than characteristics such as consistency of aggregates and their resistance. However, a gap still exists associated to the quantitative use of this information, in other words, how to model the soil morphology for its insertion into hydrological models. The continuous acquisition of field data associated to the water table level and soil moisture as well as through the continuous use of remote sensing techniques and computerized tomography can supply this quantitative information associated to the soil morphology and micro-relief and, consequently, infer about soil classes in terms of their drainage characteristics and such properties as their saturated hydraulic conductivity.

d) **Movement of water on the surface of a watershed:** the movement of water under different surface conditions of a given landscape and the understanding of the impacts of flows on the pedologic processes and, consequently, on the spatial variability of the soil consist of areas of Hydropedology that needs to be better understood. In this sense, Lin (2011) mentions that the development of conceptual models on the movement of water on the surface is the key for the understanding of the transport of pollutants, water quality, watershed management and identification and delineation of lowland areas. For this, according to the author, the union of Pedology with surface Hydrology and Geomorphology can produce good conceptual models and go beyond the simple application of the laws associated to groundwater movement, such as the law of Darcy-Buckingham and the equation of Brooks & Corey, or hydraulic models of flow propagation in channel. Indeed, the hydrological models consider, in their structure, the baseflow and sub-surface flow only based on the above-mentioned laws and they place all the complexity of a process such as this on the empirical calibration of models based on the observed flows. This leads to an incomplete understanding of these flow components in relation to the overland flow, promoting inadequate simulations of the land-use in a given landscape. A proof of this situation is that for a same model applied to different conditions, large intervals for the same parameter can be obtained. Therefore, a question that needs an answer and which has been troubling to the hydrologists: how to explain the variability of an unknown parameter having the physical process of the hydrological cycle and mainly, Soil Hydrology as a basis? The answer probably lies within the field of Hydropedology acting.

APPLICATIONS OF THE HYDROPEDOLOGY

As previously explained, Hydropedology works towards improving the prediction of the hydrological phenomena through expansion of knowledge about the behavior of the micro-scale soil attributes related to the water flow and their relationships with the macro-scale hydrological behavior. In this sense, some evolutions are possible, especially in the context of understanding the behavior of the water in the soil profile, its redistribution and formation of preferential flows. Some experiences are reported below in which Hydropedology has been, at least partially, applied to improve the understanding of the processes linked to the large great scale water balance.

Development of maps as basis for interpretations related to the groundwater recharge potential on a watershed

In this context, the works of Menezes (2011) and Alvarenga (2010) are framed, both seeking the development of a pedologic and,or, geomorphological indicator that allows, after the mapping stage, to identify areas with higher or lower groundwater recharge potential. The results obtained were compared with hydrological and climatic data observed in different watersheds of the UGRB (Figure 1).

In the study of Alvarenga (2010), it was developed a linear index attributing weight to each indicator after a data normalization process was sought through indicators directly associated to the soil hydrology and filed observations. The indicators used by the author seek to understand the water dynamics in the soil profile, and they are basically associated to the saturated soil hydraulic conductivity, drainable porosity and bulk density. More than 500 areas were sampled in the space of the UGRB upriver from the fluviometric gauging station of Madre de Deus de Minas and, after the processes described above, the proposed index was mapped with basis on geostatistics, evaluating its spatial distribution in the region. The crossing between this index and the hydrological characteristics of watersheds under continuous monitoring enabled the validation of the index as an appropriate indicator. It is noteworthy that the author applied data directly monitored in the field.

The work of Menezes (2011) consists of an approach based on Fuzzy logic to develop recharge indicators, which were structured based on the pedological and mineralogical characteristics, soil parent material and indexes related to the topography. The Fuzzy logic was applied seeking to analyze the recharge potentiality of aquifers, following the steps below:

a) **Establishment of the possible soil-landscape relationships:** identification of the typical pedologic unit of each of the watershed, relief characteristics such as a concave or convex surface, predominance of linear landforms and flood plains. In this study, the wetland soils were considered as watershed discharge area and thus, without importance for the groundwater recharge.

b) **Quantification of the relationships between soils and attributes of the terrain:** in this case, the author applied, as criterion, the geomorphological and pedologic knowledge acquired based on field works conducted in the study area, supported by the description and analyses of the soil profiles. The soil-landscape relationships of the previous step were analyzed using the digital land model (DLM). A DLM differs from a digital elevation model (DEM) by the vectorial indication of ordered numbers that allow to represent the spatial distribution of the terrain attributes through the landscape. The higher the resolution, the better the understanding of the soil/terrain relationships will be, especially if moisture indexes are used, such as the Topographical Moisture Index, which relates the ratio between the area of contribution upstream per unit length and the tangent of the slope at the local. High values of this index indicate plausible saturation values and they are usually associated to the lowest areas of the terrain and usually present lower saturated soil hydraulic conductivity.

c) **Development of groundwater recharge indicator maps:** the soil-landscape relationships, which incorporate the index, were also associated to different soil uses because these are fundamental to characterize certain soil properties associated to the groundwater recharge. In this case, the author based on the fact that native forests present better water infiltration and redistribution conditions than extensive pastures and annual crops, and this condition was based on the work of Alvarenga et al. (2011), which found saturated soil hydraulic conductivities up to 5 times higher in the native forest conditions at the Mantiqueira Range in relation to the pastures for the same soil-landscape condition.

d) **Crossing of the mapped information with the macro-scale hydrological behavior:** in this case, Menezes (2011) as well as Alvarenga (2010) compared the generated indexes to the flows in the watersheds studied, being that predominance of the baseflow in a specific watershed in relation to the rainfall and the total flow was the indicator applied for validation, because this flow component is a primary consequence of the recharge process.

The situations characterized in these studies were motivated by the hydrological behavior of watersheds at the Mantiqueira Range. In them, there is high participation of the baseflow, in spite of the general pedological and geomorphological characteristics initially indicated the opposite, in other words, prevalence of overland flow and low baseflow and, or, sub-surface flow contribution was expected. Any traditional hydrological model would make such a prediction. However, Hydropedology enabled the unequivocal understanding of how the groundwater recharge process can occur in the conditions of the Mantiqueira Range in comparison with other environments (the Campos das Vertentes as example) which soil-landscape relationships theoretically would be more favorable to this process.

Development of maps as basis for interpretation of the pedological units on watershed scale

The development of methods and models to estimate properties associated to Soil Hydrology consists of an extremely useful area for the application of Hydropedology. In Brazil, there is a notoriously poor availability of field survey data in terms of identification of hydrological attributes of the soil due to the shortage of resources for these purposes. Indeed, the soil mappings are usually developed on small scales (1:250,000; 1:500,000; 1:750,000 or 1:1,000,000) and the most detailed studies concentrate on more specific works and are actually quite rare.

In this sense, methods for mapping of these attributes and their subsequent interpretation in pedological terms consist of valuable tools for Pedology and for the hydrological modeling distributed in watershed. Menezes (2011) tested some interpolators towards promoting the mapping of soil physical attributes in two different geomorphological environments in the UGRB, in the South of Minas Gerais (Figure 1). The author tested the methods of ordinary kriging, regression kriging and terrain mapping attributes (Terrain Attribute Soil Mapping-TASM), which includes predictive maps of soil properties in a continuous sense, using Fuzzy logic concepts. The premise of the TASM technique is that one or two, of the five soil formation factors, control the soil distribution in the landscape. Thus, when the climate, organisms, parent material and time are relatively constant, the relief (topography) would be the main mechanism of soil differentiation. However, when the parent material changes, a new group of exploratory variables should be developed to define the patterns associated to the soils. Besides these factors, the soil use can also be applied as a control variable and consist of a soil property characterizer element.

Along this same line, however, applying the Self Organizing Maps (SOM) technique, Iwashita et al. (2012) developed maps to estimate the saturated soil hydraulic conductivity considering a non-linear approach among the geomorphic nature of the slopes, especially the occurrence of concave and convex reliefs, to map the hydrological attribute of the soil considering low availability of data textural. The method used by the authors identifies relationships among the characteristics of the relief such as slope and horizontal and vertical curvatures. The method was shown unbiased and an important tool in the context of identification of uncertainties in the prediction of the variables.

FINAL CONSIDERATIONS

Hydropedology represents a conceptual and methodological progress fundamental for the development of several Geosciences fields of investigation because it possesses a multidisciplinary nature and application of modern techniques. Its application extends to the various branches of knowledge associated to the Soil Science, Hydrology and Geomorphology.

In this regard, one of the great contributions of Hydropedology consists of the decrease in the distance existent among the specialists of these branches of knowledge, keeping in mind that scientific research and practice show the importance of the integration of the knowledge of Pedology and Hydrology. In the hydrological cycle context, especially, in the aspects related to the water yield and groundwater recharge processes, and also in the context of the mapping of pedologic units and their more important attributes in the hydrological context, consist in the unquestionable contribution of Hydropedology, and consequently to environmental sustainability.

In spite of Hydropedology still consists of an area of recent investigation and in Brazil the studies mentioned in this revision are pioneer, it is believed that new works can be conducted in order to demonstrate and consolidate Hydropedology among the pedologists as well as the hydrologists, seeking to break some paradigms (and resistances) existent in these knowledge branches. This becomes necessary because studies that investigate nature cannot proceed separately under penalty of not effectively contributing to new knowledge and discoveries.

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