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Relevant parameters for characterizing mountain rivers: a review

Parâmetros relevantes para caracterização de rios montanhosos: revisão

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ABSTRACT

Mountain rivers are situated in a large portion of the terrestrial surface, especially in headwaters regions, and have been used for various purposes such as recreation, sporting activities, water resources and hydroelectric power generation. However, hydrogeomorphic characteristics of mountain rivers are not fully understood. In this context, the present paper aimed to identify relevant parameters for characterizing rivers in these environments based on bibliographical review. It was identified which parameters have been used and how they have been used to characterize mountain rivers in distinct classifications. The most cited parameters were channel gradient, relation between river width and depth, entrenchment ratio, discharge, sediment transport and grain-size distribution. Also, the current situation related to researches in fluvial geomorphology in mountain rivers in Brazil was evaluated, and the strong need of field survey as basis for the best understanding of mountain fluvial dynamics and characterization was verified.

Keywords: Fluvial characterization; Mountain environment; Hydrogeomorphology.

RESUMO

Rios montanhosos estão presentes em uma grande porção dos territórios do planeta, especialmente nas regiões de cabeceiras, e vêm sendo utilizados para diversos fins, tais como recreação e atividades desportivas, mananciais de água e geração de energia hidrelétrica. Entretanto, suas características hidrogeomorfológicas ainda não são plenamente conhecidas. Neste contexto, o presente trabalho abordou os parâmetros relevantes necessários para caracterização de rios nestes ambientes a partir de revisão bibliográfica, em que se buscou avaliar o modo como os rios estavam sendo caracterizados e quais parâmetros hidrogeomorfológicos estavam sendo analisados em diferentes classificações. Os parâmetros mais comumente utilizados na caracterização de rios montanhosos são a declividade do canal, a relação entre largura e profundidade do rio, o grau de entrincheiramento do canal, a vazão, a carga de sedimentos e a granulometria dos sedimentos. Ainda, avaliou-se o cenário brasileiro no que tange a pesquisa em hidrogeomorfologia fluvial em rios montanhosos, constatando-se a necessidade de realizar mais atividades em campo para melhor entendimento da dinâmica fluvial montanhosa e caracterização fluvial.

Palavras-chave: Caracterização fluvial; Ambiente montanhoso; Hidrogeomorfologia.

INTRODUCTION

Mountain environments are presented in a large portion of continents and oceanic islands, being that in South America they represent up to 22% of its territory (BRIDGES, 1990). Although there are several classifications to define what is a mountain (FAIRBRIGDE, 1968; KING, 1967; BATES; JACKSON, 1984; PRICE, 1991), it is not yet a consensus if they should be classified by esthetic standards or by morphological parameters such as height, altitude or shape. According to Faria (2005), it is convenient to classify the mountains by its height which can be defined as the vertical distance between their basis and summit, and to consider the mountains as the environments whose height is more than 300 m.

As reported by Wohl (2010), mountain rivers show typical characteristics such as high slope, high oscillation between minimum and maximum discharges, high mobility of bedload sediments, countless transitions between sub and supercritical flow, limited supply of fine sediments, large variation in channel geometry associated to sediment supply, debris flow occurrences and high channel entrenchment ratio. Fryirs et al. (2007) commented that in mountain rivers the water and sediment move quickly in the catchment, accomplishing hydrogeomorphic processes more extremely.

In Brazil, although mountain rivers have been used for different purposes (tourism, recreation, hydroelectric energy, etc.), there are still a few studies about them and theirs characteristics (for example, FARIA; MARQUES, 1998; FARIA, 2000, 2005, 2014). According to Kobiyama et al. (2006, 2018), the occupation and use of mountain catchments have been intensified. Such requests occur exactly where the hydrogeomorphic processes are more intense and still less studied.

Therefore, the objective of the present study was to evaluate the relevant parameters for characterizing mountain rivers, as well as dealing with their measurement, limitation, difficulties and problems. Thus, it was sought to discuss the characterization of mountain rivers to the Brazilian community which is still lacking in these studies.

RIVER CLASSIFICATIONS

Several authors have been proposing different approaches for classifying rivers: (i) channel orders; (ii) process domains, where the physical processes occurring in rivers are considered; (iii) fluvial channel patterns; (iv) interactions between channel and floodplain; (v) mobility and bed material; (vi) channel units; (vii) hierarchical classifications; and (viii) statistical classifications. The use of distinct classifications is conditioned basically with the analysis purpose, i.e., the degree of detail and the objective.

Classifications based on channel order (HORTON, 1945; STRAHLER, 1957) or on its magnitude (SHREVE, 1966) offer few information about channel morphology. However, they emphasize the structure of the drainage network, and describe the size and the relative location of channels in a catchment. Wohl (2000) commented that the majority of mountain rivers do not have or have a few tributaries, being normally up to second order. However, some rivers in mountain environments in Brazil could be up to fourth order, in regions as Serra do Mar, Serra da Mantiqueira, Serra do Caparaó and some regions of Atlantic Forest.

Classifications based on physical processes that occur in rivers (SCHUMM, 1977; ROSGEN, 1994; MONTGOMERY; BUFFINGTON, 1997, and so on) used to divide them into sediments' production or source, transfer or transport, deposition or river response to sediment zones. Montgomery (1999) developed the concept of process domains, i.e., portions of the fluvial network characterized by specific interrelated set of processes and disturbances, channel morphologies and aquatic habitats that correspond approximately to sediment production, transport and deposition zones. In addition, the rivers classification based on the process domains identifies fundamental geomorphic units in the landscape that structures the river behavior.

Another way is from pattern analysis of fluvial channels (LANE, 1957; ROSGEN, 1994; BRIERLEY; FRYIRS, 2005) where the studies are based on continuity of determined pattern and deal with the factors (sediment size, bedload transport, roughness, width and depth of channels) that change these patterns. The factors can be also slope, specific energy, relation between width and depth, capacity and competence of bedload material. Approaches derived from Schumm (1977) provide good conceptual models that assist to recognize also the channel morphology and their responses to disturbances in discharge and sediment supply, and include morphologies that are presented in mountain rivers, for example, Church (1992, 2006).

The interactions between channels and floodplains (STEVENS; SIMONS; RICHARDSON, 1975) aimed to identify the controls of the physical and morphological processes both for rivers and plain. They are not associated to mountain rivers once their analyses focus on plains. This kind of classification aims to describe long-term process in channels, especially the plain rivers.

When classifying rivers due to sediment mobility and bed material (BUFFINGTON, 2012; CHURCH, 2006), they are divided according its substrate, if they are alluvial fans or gravel bedload channels. Montgomery et al. (1996) proposed that gravel bedload channels occur where the sediments transport capacity exceeds their supply, meanwhile alluvial rivers occur where the sediment supply corresponds or exceeds the transport capacity. Benda (1990) commented that gravel bedload rivers also can occur in reaches which had a debris flow occurrence and which do not necessarily have fluvial characteristics. Church (2002, 2006) presented a refined scale for classifying bedload mobility defined in terms of Shields critical stress, where sediment size, transport regime, channel morphology and stability are related. Whiting and Bradley (1993) proposed a classification for mobility of headwaters rivers from mechanics equations, considering the potential loss of mass in the adjacent hillslope, the mode of transport and the channel competence for moving the deposited material and if the sediment pulse is deposited in the river or not. This classification is particularly attractive, because it is strongly based on processes and allows quantifying the disturbance risk to the fluvial system and their potential to response to it.

Classifications based on channel units (BISSON et al., 1982; MONTGOMERY; BUFFINGTON, 1997; ZIMMERMANN; CHURCH, 2001; BUFFINGTON et al., 2002, 2009) evaluate the morphological units encountered in reaches such as pools, bars, steps and riffles. These units also form structures in blocks of large morphological reaches as step-pools, riffle-pools and cascades.

Several studies tried to understand the hydraulics in these types of units as well as their physical and biological characteristics in steep channels (e.g., GRANT; SWANSON; WOLMAN, 1990; ZIMMERMANN; CHURCH, 2001; HALWAS; CHURCH; RICHARDSON, 2005). Since they are characteristics observed in small reaches of the rivers, Montgomery and Buffington (1997) commented that these classifications are over detailed for major applications in catchment scale and that it causes some difficulties to investigate the mechanics of pluvial processes. However, they are extremely important concerning steep rivers (MOIR et al., 2009), i.e., mountain rivers.

Considering hierarchical classifications (FRISSELL et al., 1986; BUFFINGTON et al., 2003; CHURCH, 2006), the river network can be divided into homogeneous reaches based on channel patterns, so that the morphology and channel conditions are evaluated in detail at different scales. The analysis is performed in catchment level, acting in successive scales of physical and biological conditions, which allows a holistic approach. Historically, hierarchical classifications have been developed emphasizing mountain rivers (BUFFINGTON; MONTGOMERY, 2013). However, the process domains are still not well explained. Figure 1 shows a scheme of hierarchical classifications.

Furthermore, there is a statistical classification (THOMPSON et al., 2006) whose main objective is to predict morphological channel characteristics from spatial statistics for classifying reaches based on distinct bedload topographies. In this case it is important to identify spatial patterns that could be replicated in channels with similar architectures.

According to Buffington and Montgomery (2013), the use of one classification to the detriment of another can be related to advances in science and regional needs, as well as the purpose or philosophy behind classification. Currently, hierarchical classifications are in vogue because they approach the need in holistic studies covering the whole catchment and also physical and biological processes on different scales besides being developed for mountain rivers. However, a common mistake that river classifiers take is the indiscriminate use of some processes described by an author without appropriate field survey that corroborate these arguments. As these hierarchical classifications were established specifically for mountain rivers, the present study adopted them.

MOUNTAIN RIVERS

In her book entitled “Mountain Rivers Revisited”, Wohl (2010) commented that the most consistent characteristics of mountain rivers may be their high slope. However, the author confirmed that this characteristic is strongly related to others such as limitation of channels resistant to erosion and hydraulically roughness associated to gravel bedload sediments, highly-turbulent flow with large variations between critical and supercritical flow, high spatio-temporal variability of bedload material, high longitudinal variation in channel geometry, high entrenchment ratio, among others.

Mountain rivers that are present in headwaters regions are subject to geomorphic alterations in time and space. According to Sklar and Dietrich (1998), these alterations include process transition from hillslope to channel as well as transitions from bedrock to gravel bedload or from gravel bedload to sand bedload.

Due to the facts that the river characteristics are not continuous in its extension and also that the river shows geomorphic alterations in time and space, it is very important to identify the places where these characteristics suffer from changes. In other

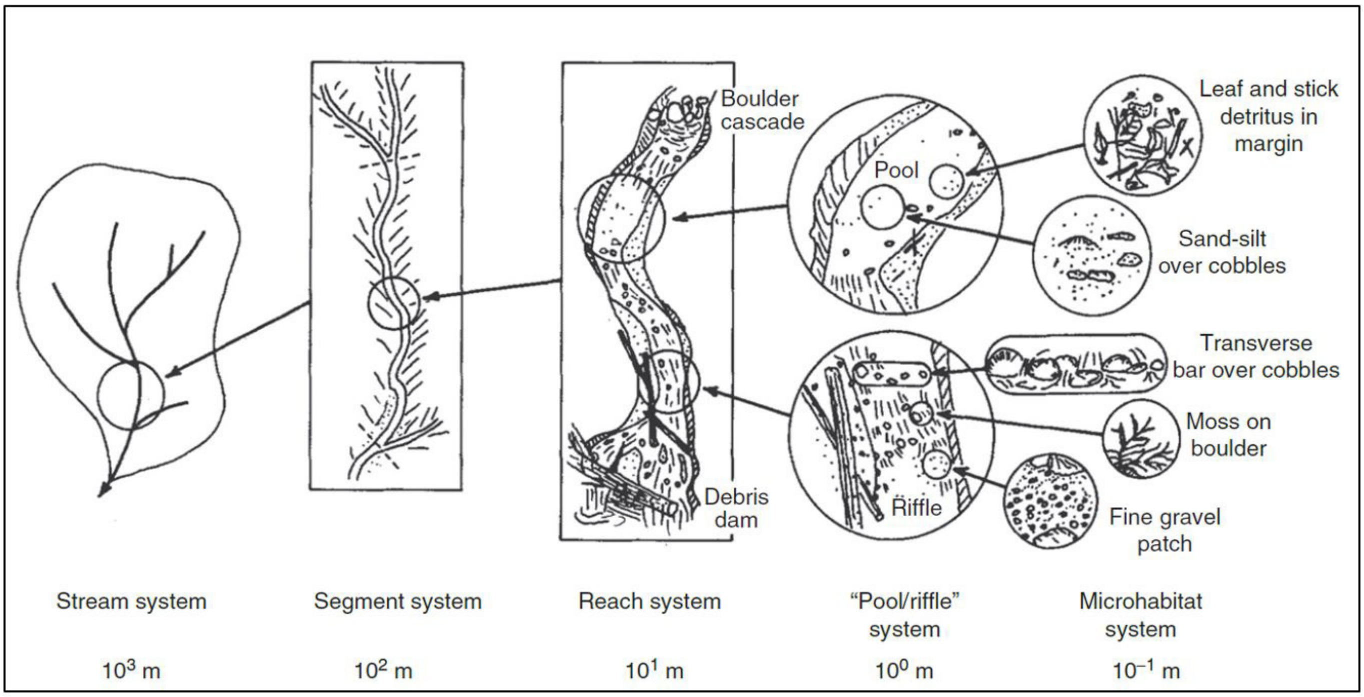

Figure 1. Hierarchical classification of river. Source: Frissell et al. (1986).

words, a part of the river can be considered as mountainous meanwhile another as alluvial.

Lin and Oguchi (2009) evaluated longitudinal and transversal profiles in rivers over one mountainous catchment, and demonstrated that topographic characteristics present different levels of organization between steeper and flatter regions. According to them, meanwhile the global gradient of the catchment is determined by the longitudinal inclination, the transversal slope plays an important role in less steep areas, which evidences the need to evaluate the channel steepness in field.

Ohmori and Shimazu (1994) analyzed different hazard types (debris flow, turbidity flow and floods) in mountain rivers and their relations with geomorphic parameters. The authors reported that these different types can occur in distinct locations of channels, depending upon the channel steepness in a reach.

Buffington and Montgomery (2013) commented that, due to the fact that river classifications are extremely qualitative, the characterization of fluvial environments is still quite empirical and, thus, measuring mountain rivers remain still a hard task.

Based on an analysis of different classifications, the most commonly used and most useful parameters related to rivers in mountain environments are identified (Table 1). The channel gradient, width, depth, entrenchment ratio, discharge, sediment load and grain size are commonly used regardless of the type of river classification. Next, these relevant parameters will be discussed by considering mountain environments.

RELEVANT PARAMETERS

Channel gradient

As mentioned above, the channel gradient is, probably, the most consistent parameter in the mountain rivers analysis (WOHL, 2010). It affects hydraulic process of discharge and sediment transport, and is related with other characteristics such as occurrence of channel units and alteration in flow regime.

Moreover, the utilization of the unique value for channel gradient causes to subestimate hydrogeomorphic processes that

Table 1. River classifications and commonly-used parameters.

Classification	Main Authors	Common used parameters	Relation with Mountain Rivers
Channel order	Horton (1945), Strahler (1957)	Stream order; number of tributaries	Intermediate
Process domains	Schumm (1977), Rosgen (1994), Montgomery and Buffington (1997), Montgomery (1999), Brierley and Fryirs (2005)	Width, depth, channel gradient, type of terrain, entrenchment ratio, roughness	Strong
Channel patterns	Lane (1957), Leopold and Wolman (1957), Schumm (1977), Church (1992, 2006), Brierley and Fryirs (2005)	Geometric plain view, entrenchment ratio, channel gradient, sediment size, sediment load, riparian vegetation, roughness, sinuosity, width, depth	Strong
Channel – Floodplain Interactions	Melton (1936), Stevens, Simons and Richardson (1975), Nanson and Croke (1992), Beechie et al. (2006)	Width, depth, sinuosity, water quality (physical and chemical)	Weak
Sediment mobility and bed material	Gilbert (1917), Whiting and Bradley (1993), Montgomery et al. (1996), Dietrich et al. (2005), Church (2002, 2006), Bunte et al. (2010)	Channel substrate, capacity, competence, Shields critical stress, entrenchment ratio, sediment size, channel gradient, width, depth, sediment load, discharge, sediment connectivity, sediment transport (bedload or suspension)	Strong
Channel units	Bisson et al. (1982), Sullivan (1986), Grant, Swanson and Wolman (1990), Montgomery and Buffington (1997), Zimmermann and Church (2001), Buffington et al. (2002), Buffington et al. (2009), Lave, Doyle and Robertson (2010)	Channel substrate, capacity, competence, Shields critical stress, entrenchment ratio, sediment size, channel slope, width, depth, sediment load, discharge, occurrence of bars, steps, rifles and pools and their morphometric characteristics.	Strong
Hierarchical	Frissell et al. (1986), Paustian et al. (1992), Buffington et al. (2003), Church (2006)	Stream order, number of tributaries, width, depth, channel gradient, entrenchment ratio, roughness, channel substrate, capacity, competence, sediment size, sediment load, discharge, sediment connectivity, sediment transport (bedload or suspension), occurrence of bars, step, riffles, pools and their morphometric characteristics; presence, location and orientation of leaves and debris in margins	Strong
Statistical	Thompson et al. (2006), Zimmermann, Church and Hassan (2008)	Geometric plain view, entrenchment ratio, width, channel gradient, discharge	Intermediate

occur in headwaters regions and to superstimate the processes that occur in floodplains. Therefore, the utilization of hierarchical classifications in different scales for characterizing mountain rivers is suggested.

Mountain rivers englobe transitions in channel patterns, i.e., the transitions between bedrock and gravel or between gravel and sand bed (SKLAR; DIETRICH, 1998). As a sediment transport is related to channel gradient, one of the main proposals is to verify its condition where the patterns´ changes occur. Wohl, Vincent and Merritts (1993) described in detail channel units characteristics, and verified that in the gradients over 0.002 m/m it can be possible to observe this kind of change in morphology. Several studies about channel gradient in mountain areas (LENZI, 2001; MAO; COMITI; LENZI, 2010; BUCKRELL, 2015) demonstrated that the gradient in mountains is usually with magnitude of cm/m meanwhile floodplain environments with magnitude of cm/km (LEFAVOUR; ALSDORF, 2005).

The ways to measure channel gradient depend on the scale required in the analysis: river, segment, reach of channel units which are all demonstrated in Figure 1. For a river scale, remote sensing and geoprocessing from Digital Elevation Model (DEM) with good resolution (for example, 1:50,000) can be used. For a segment scale which has its magnitude of 10^2 m (FRISSELL et al., 1986), both DEM with appropriated resolution and topographic and topobathymetric data can be used.

An analysis of reach (10^1 m) and channel units (10^0 m) requires field survey with total station, differential GPS topographical level and/or drones in order to obtain topographic and topobathymetric data (Figure 2a). According to Arroyo et al. (2010), the utilization of LiDAR (Light Detection and Ranging) allows obtaining information from the terrain with 50-cm resolution. In the case of the step-pool morphology analysis, the gradient value depends on the step approach. In other words, different ways to measure in field generate different values of gradient. For example, the measurement can be performed from the beginning of the upstream pool to the end of the downstream pool (α_{AD}) or from the upstream step to the downstream step (α_{BC}) (Figure 3).

Relation between river width and depth

Morphometric parameters as width and depth are commonly required for characterizing mountain rivers, especially its width/depth relation. According to Rosgen (1994) Classification, the value of this relation must be lower than 12 for river types Aa+, A, B, F and G which indicate the mountain rivers in his Classification due to channel slope and geometric plain view criteria. It should be here mentioned that Rosgen Classification does not refers directly to mountain rivers, although the proposal index shows similarities that allow them to be classified in the previous mentioned classifications.

In general, these parameters are not easily obtained with remote sensing techniques. The river width, however, can be measured with images from a reasonable number of pixels, once the pixel resolution may cause measurement errors. In mountain environments, the grid resolution from an image is very commonly

Figure 2. Field survey and measurement: (a) morphometric parameters by using total station; and (b) discharge by using ADCP. Source: Elaborated by the author.

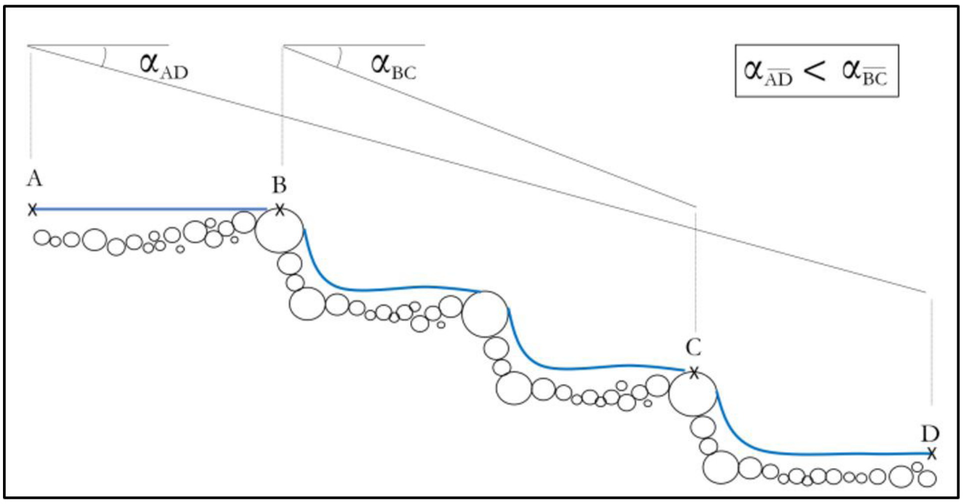

Figure 3. Step-pool sequences with different gradients that can be obtained from the same channel unit.

larger than river's dimensions, which makes the obtention of morphometric parameters from remote sensing techniques impossible. In this case, field survey becomes indispensable.

Thus, the obtention of parameters as width and depth in reach scale should be performed by using a total station and a measuring tape. In this way, these parameters can be measured together with the channel gradient. Hence, the importance of hydrometry and topo-bathymetry in field survey increases.

Entrenchment ratio

Entrenchment ratio of a river indicates how it is excavated in the landscape (ROSGEN, 1994), i.e., how the river is limited laterally by banks and hillslopes. It is related to vertical contention of rivers, and allows making some inferences about the channel's adjacent area. The entrenchment ratio is determined by the relation between flood prone areas and channel width. The flood prone area is estimated as the width measured for the river elevation corresponding to the double of maximum river depth for a specific cross section.

Therefore, obtaining the entrenchment ratio requires knowing the river depth and the flood prone area in the study site. These data come from detailed field survey by using total station and measuring tapes. In case the mean depth is known and a DEM with good resolution is available, the measurement of the flood prone area could be estimated by Geographical Information System (GIS) techniques.

Rosgen (1994) showed various examples of the typical entrenchment ratio. Thereby, this parameter can be estimated from comparison between typical values showed in Rosgen analysis and study site, emphasizing that mountain rivers should be classified as Aa+, A, B, F or G. On the other hand, non-mountain rivers present high values of this parameter. It means that they do not have significant lateral control of the margins and banks, allowing the large spread of channel and the connection among rivers, lakes and meanders during flood events.

Discharge

It is almost impossible to perform traditional methods for measuring discharge in mountain rivers during flood events due to its high velocity and sediment mobility (CHEN, 2013). In addition, discharges during floods could change very quickly in short time, making it indispensable to perform the measure as fast as possible. This temporal variation must be a characteristic of mountain rivers.

In mountain rivers the time of concentration used to be very short, of magnitude from a few minutes to one hour, which still makes it difficult to perform systematical discharge measurements for covering all the flood events. Because of its short time of concentration, the floods in mountain rivers are considered as flash floods (KOBIYAMA; GOERL, 2007). Furthermore, as the response time is very short, the field surveys have been frequently combined with extreme rainfalls. This fact also increases difficulty in measurements.

Therefore, the use of ADCP (Acoustic Doppler Current Profiler) (Figure 2b) is strongly recommended to measure discharges in mountain rivers. This use allows obtaining the relation between velocities and areas in a more reliable way than traditional methods during flood events. In addition, the use of ADCP allows performing the measurement quickly than traditional methods (GAMARRO, 2012). However, mountain rivers used to present low depths, which can cause some difficulties to perform the measurement. Therefore, it is necessary to look for an appropriated transect that at least has the minimum depth for the ADCP use and also provides a security for the field workers.

It is important to highlight that for non-mountain rivers it is not difficult to apply the traditional methods with a propeller current meter or ADCP, as described in the technical report of large rivers discharge measurements (ANA, 2014). Also, the utilization of satellites images can be used for estimating discharges at a cross section of an alluvial river. LeFavour and Alsdorf (2005) demonstrated the possibility to estimate discharges in a river belonging to the Amazon region with the remote sensing. The authors commented that bathymetry was the unique parameter that could not be obtained by image, however, due to a very large river whose other parameters could be estimated, the bathymetry could be neglected since the calibration process used a well-known river gauge station.

In this way, it is highlighted that water discharge measurements in mountain and alluvial rivers are obtained by different ways. The present study, therefore, emphasizes that both methods and temporal changes are important items in river classification, once mountain and alluvial rivers differs consistently in these subjects.

Sediment load

The sediment transport in mountain rivers is one of the parameters that have the most uncertainty in their values. According to Brardinoni et al. (2015), the sediment dynamics in mountain rivers depends on a series of complex interactions among river discharge, activation of sediment sources from different types, and river morphodynamics.

Sediment load has large uncertainty associated to its estimative (BUFFINGTON; MONTGOMERY, 2013), once there is a lack of direct observations in field with appropriate quality and quantity that could allow the development of physically-based sediment models (BRARDINONI et al., 2015)

Montgomery et al. (1996) followed the hypothesis of Gilbert (1917) in which gravel bedload rivers occur where the transport capacity exceeds the sediment supply, meanwhile alluvial rivers occur where the sediment supply corresponds to or exceeds the transport capacity. Schumm (1977) commented that the channel patterns and their stability are influenced by sediment size and transport mode (of suspension, mixed with bedload, or bedload). In case of the suspended sediment load, there are several attempts to estimate their quantity by using turbidity sensors (SARI; CASTRO; KOBIYAMA, 2015; SARI et al., 2016).

In mountain rivers which used to present low suspension sediment load, bedload discharge is the main way of sediment transport (MONTGOMERY et al., 1996). According to Merten and Minella (2015), in case without a measurement of bedload sediment discharge, it is recommended to use Einsten or Colby equations or also a supposition that a certain percentage of the suspension represents the bedload discharge. In Brazil, it is very common to consider 10% of the total sediment transport as bedload (CARVALHO et al., 2000). By monitoring a river in semi-arid region in Brazil, Cantalice et al. (2013) showed that the percentage of bedload to suspended sediment load varied from 4 to 12.72%. Although Macedo et al. (2017) investigated the bedload transport, their study area was a floodplain area without mountain environments.

To understand the sediment dynamics and sediment load transport is a fundamental task for classifying rivers as mountain rivers or not. However, it is quite difficult to observe the transformation from mountain to alluvial river, which needs the improvement of field surveys in mountain environments. Even it could be hard and time-consuming, it is necessary to estimate the amount of sediment load. Thus, further the need for the field hydrometry just increases.

Sediment size

The spatial and temporal distribution of the sediments can strongly affect the water discharges conditions, the turbulence structures and the sediment transport rates (BATHURST, 1987; RICKENMANN, 2001; DEY et al., 2011; TSAKIRIS et al., 2014). Large sediments strongly increases the spatial variability of discharge and turbulence intensities in a reach scale (DEY et al., 2011; OZGOREN et al., 2013).

Due to its great importance in the water flow dynamics in rivers, the sediments size distribution should be described in order to demonstrate its characteristics as accurately as possible. The sediment size is used, for example, to estimate hydraulic characteristics for incipient sediment movement (MAO; LENZI, 2007). There are some parameters of interest, as D_{16}, D_{50}, D_{84} and D_{90}.

Although exists a diversity in sediment measurement methods in rivers (CHURCH; MCLEAN; WOLCOTT, 1987; ISO, 1992; RAMOS, 1996), a few papers provide information on bedload material sampling in small mountain catchments (BUNTE; ABT, 2001). In order to describe such size distribution in mountain rivers, Bevenger and King (1995) proposed a counting sediment procedure, in which the grains are sampled since a cross section from bank to bank.

Fang, Liu and Stoesser (2017) commented that large sediments are capable to promote changes in the field of discharges and that they may cause flow deacceleration, corridor and vortex formation, internal and external turbulence and redistribution of shear stress. When large sediments are neglected, these alterations as well as sediment transport ratio may be subestimated. In this way, the importance of spatial distribution of large sediments, i.e., the maximum sediment sizes, or D_{100} must be emphasized.

Hence, it is very clear to say the need to perform field survey to describe appropriately the sediment size in rivers. Mao, Comiti and Lenzi (2010) verified sediment size distribution through field survey and evaluated the river competence in an Italian Alps catchment. They utilized markers in a widely range of sediment size that allowed them to infer possible discharges capable to transport these sediments. Buckrell (2015) evaluated differences in sediment size distribution for pools and riffles sequences, and reported that they are considerable distinct in sediment size, which requires further investigation in situ. In addition, distinct technologies could be used for estimating the sediment size, such as the drone images processing (MU et al., 2018) or satellite images (CASADO et al., 2015). Mu et al. (2018) performed machine learning to identify morphological characteristics of the sediments. Although this technology has been advancing very rapidly, field survey, i.e., field hydrometry, is still necessary for obtaining basic data.

BRAZILIAN SCENARIO

The development and occupation have been increasing significantly in Brazilian mountain regions (KOBIYAMA et al., 2018). According to Hewitt (2004), the growing use of mountain areas has been rising the hazard for hydrologically-extreme events due to pressure for development and environmental changes.

Mountain environments have been served as alternative for water supply from large rivers that water quality are now deteriorated on its quality (PAIXÃO; KOBIYAMA; CAMPAGNOLO, 2017). Such situation stimulates public agencies to build up capitation, treatment and feed water infrastructure in these regions.

In addition, mountain regions have been increasingly sought after and exploited for recreation and ecotourism activities. Data from National Parks and Conservation Units Visitors showed that, in Federal areas, the total number of visitors grew from 3 million in 2007 to more than 8 million in 2016 (IBAMA, 2016). An expressive number of federal conservation areas are located in mountain regions, for examples, Aparados da Serra, Serra Geral, Chapada dos Guimarães and Itatiaia National Parks.

As exploitation and occupation of mountain environments have been rising in Brazil and the studies referred to these areas still are scarce, it is important to incentivize basic studies about mountain rivers characterization. Such studies will subsidize the comprehension of the water and sediment dynamics in these environments.

Faria (2000) evaluated the influence of vegetation on fluvial processes in first order catchments, highlighted that woody debris (tree trunks, branches and leaves) interfere in water flow by diverse ways, and commented that the sediment delivery in these catchments occurs in pulses when such structures are destroyed. Assessing geomorphic responses in fluvial first order channels, Faria (2014) reported that sediment transport presents a very differentiated dynamics when compared with larger rivers and, therefore, the first order channels demand more studies.

By using principal component analysis and cluster analysis, Sodré et al. (2007) performed a multivariate analysis for describing and classifying morphometric parameters in catchments in Alto Jequitaí-MG. The analyzed parameters were altimetry, terrain slope, hillslope curvature, contribution area and catchment perimeter. The authors segmented catchments according to their similarity patterns, evidencing that spatial patterns reflect the similar dynamics among them.

Silveira and Ramos (2007) carried out a spatial analysis of environmental parameters and hydrological behavior of a mountain catchment at Serra dos Órgãos-RJ. For this analysis, the authors used the Ground Penetration Radar (GPR) to evaluate the distribution and transition of soil horizons in field, investigated the sediment size distribution at distinct locations in the catchment and used fluviometric data with 30 minutes of temporal resolution. The field survey allowed the determination of landscape development patterns for different lithological units in the catchment, indicating factors that act as controllers in the relation between rainfall and discharge in this mountain region.

Olszevski et al. (2011) evaluated the morphology and the hydrological aspects by using morphometric characteristics of the terrain and the drainage network in order to predict the hydrological behavior. Lopes (2012) used topographic attributes for trying to establish the relation between topography and discharge in the Altíssimo Rio Negro catchment (PR/SC). Such attributes were obtained from GIS processing and field survey for discharge measurements.

Telles, Rodrigues and Silva Neto (2016) carried out automatic calibration of hydrodynamic simulator by using direct and reverse problems, whose objective was to minimize the difference between experimental data referred to river level and simulated values obtained in the direct problem. The authors utilized data with 15 minutes of temporal resolution, and obtained the satisfactory results. However, the authors stated that the results could be better in case they had more parameters in the analysis, i.e., if they had more detailed description of hydrogeomorphic processes that occur in mountain environments. One of the main propositions of Telles, Rodrigues and Silva Neto (2016) was to consider the roughness variability along the channel so as to make the prediction more realistic to physical characteristics observed in terrain. It indirectly means that reach scale needs to be better described for a good representation of its processes.

Studies related to modeling and water quality have been increasing in Brazil. For exemple, Von Sperling (2007) recommended the use of nine parameters (temperature, pH, dissolved oxygen, BOD, thermotolerant coliforms, total nitrogen, total phosphor, total solids and turbidity) for evaluating the water quality index.

Girardi et al. (2016) evaluated the changes in water quality during rainfall events in the Cubatão do Sul river catchment, in Santa Catarina state. In the study were evaluated two sub-catchments, being one of them predominantly mountain environment. The temperature, electrical conductivity, turbidity, pH, ammonium ion and dissolved oxygen were treated. The authors observed that the catchment is influenced by discharges with short return periods and the water quality keeps a uniform behavior during dry and rainy periods in the mountain sub-catchment which is mostly preserved.

Rodrigues et al. (2012) tried to estimate dispersion pollutant parameters in mountain rivers by using the Luus-Jaakola algorithm. They commented that the dispersion of pollutants in natural streams have been based on classical experiments that consider a Gaussian distribution of one substance concentration, however, it is not verified in mountain environments. Thus, when using advection-dispersion model, they had good estimative to calculate transport of a conservative substance.

Hence, it is observed that studies on mountain rivers are still a few when compared with alluvial rivers and floodplains in Brazil. Such situation probably implies that researchers are more interested in larger catchments and large rivers because of the hydroelectric energy generation and also because of the fact that the large portions facilitate studies using remote sensing. That is why, in order to better understand mountain rivers, Brazilian researches should add efforts on field surveys activities, carrying out in situ measurements, since mountain rivers have been increasingly used by the Brazilian society.

CONCLUSIONS

Due to increasing use of mountain environments in Brazil, it is suggested that river classifications must be performed by considering their uses for different purposes.

For characterizing mountain rivers, it is proposed to use hierarchical classifications where rivers are evaluated on different scales of analysis (river, segment, reach, channel units, etc.) in order to analyze the relevant parameters for its characterization. According to Wohl (2010), the most permanent parameter in the analysis of mountain rivers is the channel gradient. Thus, in the impossibility of a complete characterization of a river, channel gradient may offer subside for preliminary characterization of mountain rivers. It is emphasized that for a complete estimative field observations are necessary, which requires financial expenditure and time.

The identification of the minimum relevant parameters needed for characterizing mountain rivers is a demand both for scientific community and for Brazil, once this country has been intensifying the use and occupation of mountain environments and there is a lack of studies in such environments. Thus, based on the literature review, it was observed that the most utilized parameters for characterizing mountain rivers are: channel gradient, discharge, relation between river width and depth, entrenchment ratio, sediment load, and sediment size.

Although some parameters can be measured with geoprocessing techniques, most of them should be measured in situ. It strongly indicates the importance of performing hydrometry, topography and topobathymetry in field survey.

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Maurício Andrades Paixão: First author, responsible for the final writing, made corrections and suggestions.

Masato Kobiyama: Second author, helped to write the paper, made corrections and suggestions.