RIVER SPRINGS IN SUSTAINABLE WATER MANAGEMENT: AN OVERVIEW OF THE CASE OF BELO HORIZONTE, BRAZIL

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ABSTRACT
The search for sustainable water management is, nowadays, a common issue present in several countries' environmental policies. In this setting, alternative principles and fundaments in water management are important. This text discusses the relevancy of the river springs in sustainable water management. It's based on studies of 79 river springs in the city of Belo Horizonte, southeastern Brazil. Even though water management is a process that depends on a broader context in different levels (local, regional, national and international), and the local protection of the river springs is a crucial link in the harmonizing chain of relationships between man and water. In this sense, the Brazilian case illustrates the reality of developing nations. Some of the territorial intervention strategies and water management conservation steps currently applied in Belo Horizonte seek to modernize the relationship between society and the environment, minimizing human pressures and impacts and striving for river springs and water protection.

1. INTRODUCTION

1.1. The evolution of Water Management approach in Brazil

It has been internationally accepted that the search for sustainable development is intrinsically associated with management processes and territorial planning that contemplate and integrate the ecological, social and economical dimensions of environment. When it comes to development and management, sustainability involves the search for more harmonious relationships between humanity and nature, realizing the community's demands and the desire to maintain the limited natural resources within their quantity and quality.

Recent discussions over the need for "modernizing" water management around the globe are almost always associated with incorporating environmental sustainability principles. One of the most important has been the strategic choice of adequate management and planning territorial units, which has led to the prioritizing of the hydrographical basin as a water management tool in the National Policy for Water Resources (Brazil, 1997).

Therefore, water management is seen as a potentially applicable instrument in the process of achieving sustainable development. This term was initially proposed in 1980, in the World Conservation Strategy final report (IUCN, 1980), but was officially known only in the Brundtland Report ("Our Common Future"), ordered by the United Nations as a preparatory document for the Conference on Environment and Development in 1992, in Rio de Janeiro. The roots of the term, however, are associated with the so-called Eco-development, a term inserted by Maurice Strong in 1972, who, at the time, was Secretary General of the first Stockholm Conference. Since then, the evolution of the concept has been through discussions on the complementarities between development notions (change, evolution) and sustainability notions (maintaining certain conditions in time).

The sustainable development concept has evolved over the last years, adjusting itself to the new context of awareness towards environment management at a global level. Some of the sustainable development's essential principles, however, have been consensually accepted: economical growth, social equity and ecological integrity. The integration of these principles would permit the partition of the costs and benefits of human environmental intervention in a socially impartial manner. Therefore, at a decisional level, sustainable development demands that certain questions be considered, such as the irreversibility and uncertainty of the decisions (precaution principle), the thought plurality and the interdisciplinary (IFEN, 1999).

It has been largely accepted that the search for environmental sustainability can not be done without establishing goals for environmental quality, institutional strengthening in order to achieve these goals, and applying economic instruments to rationalize water usage and income generation (IBAMA, 2002). In this sense, the process of environmental management depends on establishing action and investment priorities, aspects which depend on informational bases on the regional environmental situation. Information acts as a basis for the decision, so the environmental indicators help the management processes and the public policies towards protecting and improving human life quality and environmental quality as a whole (Magalhães Jr, 2007).

In Brazil, the traditional water management "paradigm" adopted in the 1950's was influenced by the TVA American program (*Tennessee Valley Authority*), bringing to the forefront the regional development of the waters but also the negative effects of a centralizing system. The deficiencies in this model were not overcome, but summed up to the increasing environmental degradation problems that resulted from the national development model, which would be worst in the 1970's and 1980's: rarefaction of the water in quantity as well as in quality, worsening of the social problems, low quality sanitation services, among others. This “crisis” situation coincided with the exhaustion of the Keynesian economic model which had provided social stability and prosperity to a great part of post-war market economies.

In the 1980’s and 1990’s, was intensified the discussion of new environmental management values and principles in Brazil, accompanying the international water protection movement and the resulting propositions of many meetings on water and environment which became more and more frequent (The Global 2000 Report to the President; CEQDS, 1980; World Conservation Strategy; IUCN, 1980; International Conference on Water and the Environment, Dublin, 1992; United Nations Conference on Environment and Development, RJ; 1992; Summit of the Americas on Environmental Review -San Juan, 1995; among others). The maturity of the Brazilian society, in environmental terms, is reflected in the ongoing discussions and applications of various principles that are related to sustainable water management. This process reflects the renewal of the political, legal and institutional water resources system’s in the country as well as in the academic, technical and scientific level. Organizing efforts and pressures in order to control environmental quality more effectively in different social sectors has increased its potential and allowed more strengthen mobilization so as to treat environmental issues as a “new” public intervention system (Johnson, 2001).

The 1980’s and 1990’s were marked by an expanding debate on the need for change in the country’s water management system in order to assure water in quantity and quality terms for current and future needs in a sustainable perspective. Gathering concessions from international experiences and the Brazil’s own internal discussions at a legal and institutional level, a water management policy structure became urgent, since the country was scarred by the lack of a water management plan and a fragmented and discontinuous management system.

Bearing in mind principles such as the water as an economic good and the decentralized and participative management, the search for solutions for the degradation and thinning of water resources implied a gradual valorization of non-structural measures of preventive character in Brazil. The National Policy for Water Resources’ principles required that the search for harmony between structural and non-structural measures be a necessary approach in an environmental sustainability context. The structural human interventions in river beds have been more and more questioned due to its resulting socioeconomic and environmental impacts. With some delay when compared to countries such as the United States, England and South Korea, the debate on river and water systems restoring or revitalization has been established gradually in Brazil by the end of the 1990 decade.

This evolutional process of environmental consciousness in Brazil marks an attempt to placate human needs and the availability and protection of natural resources. In the context of struggles to apply sustainable water management principles, managers have started to seek compatibility between economic growth and environmental protection. As in the world, the incorporation of the sustainability discourse in public policy in Brazil was not only due to the maturing of environmental thinking, but also because of the need to support the economic model based on unsustainable production.

The search for sustainable water management, intensified at the beginning of the 1980’s, presented a set of inter-related motivations as a result of human personal and social, economic and politic-institutional aspects. From the 1980’s on, a greater share of Brazilian society became more aware of the importance of environmental issues and the need for water protection. The appearance of non-governmental organizations (NGO) focused on environmental protection, environmental movements and increased popular presence in participative decisive forums certified this new phase.

The convergence of motivations to a greater or lesser extent resulted in decisive changes and improvement of the Brazilian legal system regarding water management. The promulgation of the Water Law’s in 1997 and the consequent creation of the National Water Resources Policy and the National Water Resources Management System (NWRMS) reflected the growth and modernizing process of water management in Brazil. That Law organized the planning and water management sector in the country, being based on some underlying principles that illustrate its advanced concept: the hydrographical basin as a planning component, the water’s multiple uses; the finite and vulnerable aspects of water resources; the water resources economic value; the decentralized and participatory water management process, among others.

By overcoming the legal improvement level, the country is currently situated in an urgent technical and institutional improvement phase, in order to apply what “*is written*”. This phase must include decision-making system articulation, databases improvement and management tools operability in several levels of the NWRMS. In this last aspect, the *water governability* is the base of Brazil’s water management system reform, anchored by the triad *participation*, *information and evaluation.* Shared management is seen as a fundamental column in sustainable water management, being referred to as “the only likely way to exceed the static public management and privatization limits” (Barraqué, 2001).

Despite the creation of an improved legal-institutional system, its operability and effectiveness is a challenge that has not quite been achieved. Among the obstacles, the country’s vast territorial extension, the lack of financial resources to subsidize the basin’s committees functions, and the lack of instruments and data for efficient local management stands out. In this later case, one should note that the water management processes associated to municipal, regional and federal public policies depend on adequate interaction and integration of environmental information. A important part of the problems and challenges are associated to the water usage conflicts, the compatibility between availability and water demands and the protection of water resources in quantity and quality involving local issues, mainly in small first order hydrographical basins or in fluvial stretches close to the springs. On the other hand, most of the hydrological data in Brazil are generated in hydrological monitoring stations located within in the country's main rivers, that is, those that present more interest for hydro electrical energy purposes.

Even with the increasing number of hydrological stations and growing databases, the fluvial spatial units are not always taken into account in Brazil. So, how can the hydrographical basin committees members turn their responsibility as participative council members without adequate databases at a local level? The environmental information gaps at a local and regional level have been considered important obstacles to the effective operability of the Brazil's National Water Resource Policy (Magalhães Jr, 2001).

The compatibility of different scales is, therefore, a challenge that must always be present in the pursuit of sustainable water management. Physical and man-structured spaces are organized as to form territorial units with different importance in light of the focus given to water management. In this way, hydrographical basins can have very different sizes that vary from millions of square kilometers to just a few square kilometers (micro basins). Even if a municipality is placed in only a small part of a hydrographical basin, its territory's hydrological health (in quantity and quality) depends on adequate management of the entire basin for which it is situated in, since the limits of the hydrological unit does not coincide with the political-administrative limits. Sustainable water management demands, therefore, the consideration of physical-territorial limits, such as the National Water Resource Policy did.

The importance of the local management scale is clearly illustrated in the role of the elements that constitute the hydrographical network. The sources, elements that mark the beginning of the superficial watercourses' formation, are a determining factor in hydrological and environmental equilibrium. The sustainable superficial water management policies and processes cannot be implemented without the protection of the sources that form the hydrographical network. However, its consideration demands local approaches, since these sources are punctual spatial elements and cannot be properly managed at either the regional or national levels.

1.2. Belo Horizonte and the pursuit of sustainable urban water management

Minas Gerais is one of the most developed states of Brazil in socio-economic terms, despite the strong regional differences. It is located in the southeast of the country, and has an area of 586,523 km² (6.9% of the national territory). The population is estimated at 19.3 million in 2007 (IBGE, 2007). The capital, Belo Horizonte, has 2.4 million inhabitants, while its metropolitan area has 5 million inhabitants. The city is located at the Velhas River basin, one of the most important brazilian hydrographic courses.

The Velhas River is the most extended tributary in the São Francisco River basin, the largest entirely brazilian hydrographical basin, and has its sources in the city of Ouro Preto. The entire basin covers an area of 29,173 km², in which there are 51 municipalities with a population of approximately 5 million inhabitants (IBGE, 2007). The Velhas River extends itself for 761 km, crossing Belo Horizonte and its metropolitan area, before flowing into the São Francisco River. The Velhas basin is of a major significant for its economic and social importance, being responsible for most of the Belo Horizonte metropolitan area (BHMA) water supply.

The São Francisco basin withholds more than 500 municipalities, covering about 2,700 km from its headwaters in the Canastra Ridge (MG) to Piaçabuçu municipality (Alagoas state, southeastern Brazil). Belo Horizonte is located in the upper São Francisco basin, which drains into seven Brazilian states: Minas Gerais, Bahia, Goiás, Paraná, Pernambuco, Alagoas and Sergipe (Figure 1). TheLuso-Brazilian occupation story of the Velhas River basin began in the late 1600's with the first explorers in search of gold and precious stones. The discovery of such riches in the upper Velhas River basin determined the so-called Gold Cycle in Brazil and originated the first urban areas, such as the cities of Ouro Preto and Sabará. Consequently, it triggered the basin's environmental degradation process. The changes caused by manual mining were more intense in the floodplains, low terraces and river beds, where the sandy sediments and gravels were mined. In 1730, it was noted that the Sabará and Velhas rivers began to become muddy due to washing the alluvial deposits (DEAN, 1996). From 1898, with the transfer of the capital state from Ouro Preto to Belo Horizonte, an emerging center of urban and industrial development was consolidated, and it has generated a new round of mining activities characterized by iron mining and steel deposits next to the banks of the upper Velhas River. The area has one of the largest iron ore reserves in the world (Iron Quadrangle geological unity).

Belo Horizonte has followed the national and international trend of accelerated urbanization and degradation of fluvial environments within the 20th century. The city was the first planned city in the country (1894 to 1897), but its project, based on the positivist ideas of the New Republic did not observe the environment's hydrographical arteries. The Arrudas River, a tributary of the Velhas River and the main watercourse that crosses the city, was channeled and had its intricacies controlled for the sake of progress and the need to contain the constant flooding that generated major damage and killed people during the 20th century. These floods reflected the increasing process of soil impermeability in the urban area and increased superficial flows and fluvial outflows. The main streets and avenues of the city were geometrically designed in a checkered perpendicular mesh, in which the streams were not prioritized.

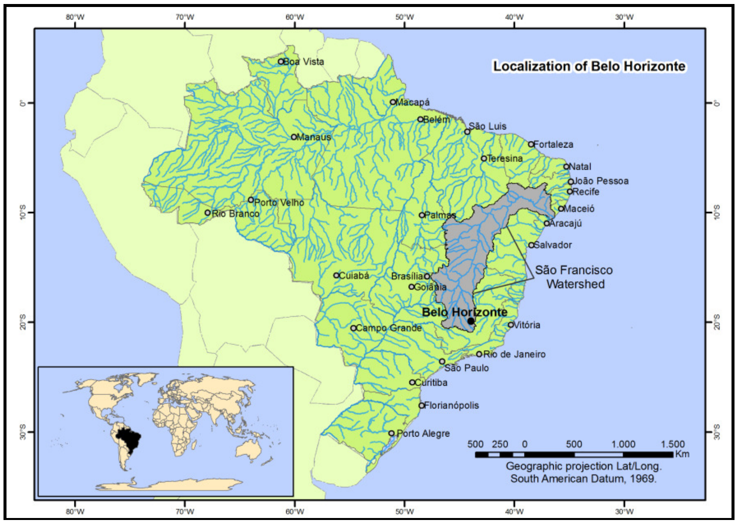

Figure 1: Location of Belo Horizonte.
Source: Statistical and Geographical Brazilian Institute cartographic database

In addition to the accelerated changes of fluvial natural conditions, the watercourses of Belo Horizonte also became the main means of transporting domestic sewage and industrial waste. Water pollution derived from untreated sewage would become, in the 21st century, one of the city's main environmental problems. The original urban project provided proper management of municipal waste, but in practice this has not been effectively implemented (Champs *et al.,* 2005). Population growth was accelerated during the 20th century, mostly by the arrival of immigrants from the rural areas of outlaying states. The population increased from less than 400 thousand in the 1950's to over two million inhabitants in 2000 (Costa, 1994, IBGE, 2002). As a result, the daily liquid and solid wastes volume generated in the city grew dramatically, turning the rivers into open sewers.The urban sprawl of Belo Horizonte in 2000 reached 83% of the municipal territory, so that the city's few non-impermeable areas are restricted to small and fragmented sites (Felippe & Magalhães Jr, 2008). In addition to the decreased surface drainage promoted by impermeability, more than 63% of the preferred areas of aquifer recharge is rated within medium to low efficiency in underground recharge, being affected by the transformation of urban space and the alteration of the dynamics of underground water. This process has been responsible by long-term impacts in terms of the flow regularity and sources continuity (Felippe & Magalhães Jr, 2008).

Nowadays, Belo Horizonte has a high coverage rate of water supply and sewage collection, 99.9% and 91.1% of the population, respectively (COPASA, 2002). However, only 10% of sewage is treated, which is reflected in the continuing pollution. About 200,000 people have no sewage collection and some 10,000 people have no access to clean water, especially the lower classes of the population. The public power and the sanitation company of Minas Gerais have intensified investiments in sewage treatment plants in recent years and it is forecasted that within a next few years almost all the sewage generated within the city will be treated before being released into the local rivers.

However, by draining the most industrialized and populated region of Minas Gerais, the Velhas River basin continues to suffer accelerated water degradation. The Metropolitan Region of Belo Horizonte has a clear negative influence in the river´s water quality. The river stretch downstream of the urban agglomeration is the most polluted of the entire basin. In addition to receiving large amounts of untreated industrial pollutants, the rivers also receive waste from local mining activities.

The new ideas and strategies about river and urban water systems restoring and revitalization came to Brazil and Belo Horizonte in the 1990´s. After years of ongoing discussions in relation to urban drainage and sanitation, the local government began to pursue the implementation of modern management techniques, in a context of sustainability (Macedo, 2009). Therefore, the "Plan of Municipal Sanitation" in 2001 and the "Drainage Master Plan" in 2002 were established as the water resource management policy at a municipal level (Champs *et al*., 2005).

In 2003, was developed the Environmental Recovery and Sanitation Program in Belo Horizonte, also known by DRENURBS. This program proposes the integrated approach of environmental, social and health problems in hydrographical basins whose streams, though degraded by pollution and banks occupation, still kept their natural unchanneled beds (PBH, 2003). The program aims to clean up the watercourses with the implementation of sewage collectors, interceptors and water treatment, reducing flood risks with the deployment of flood control and floodplain evacuation, the control of sediment production with the elimination of gullies, containment and revegetation of the banks, and the integration of streams in the urban landscape by aligning drainage interventions with those of sanitation, roads, environmental, housing and leisure (PBH, 2003). The project was implemented with a participatory process, addressing the people directly affected by the interventions.

As pointed out by Macedo (2009), the DRENURBS allowed the implementation of modern ideas to revitalize and restore urban streams through the prioritization of non-structural techniques, instead of the traditional approaches of making watercourses artificially through structural techniques. In other countries such as the United States and Germany, this intervention logic is older being known as the Urban Stream Restoration (Helfield & Diamond, 1997, Riley 1998, Brown, 2000; Benhardt *et al*., 2005, Walsh *et al*. 2005). According to the international literature, it is of great importance to make assessments about the restoration of watercourses, although these are not often used (Davis et al., 2003).

Along with the implementation of DRENURBS, the city of Belo Horizonte and the Federal University of Minas Gerais (UFMG) became partners in the project *Sustainable Water Management Improves Tomorrow's Cities' Health* (SWITCH), led by the *Institute for Water Education* (IHE) of *United Nations Educational, Scientific and Cultural Organization* (UNESCO). The project is headquartered in Delft, Netherlands, and formed by a network of thirty-three institutions from fifteen countries. The SWITCH project intend is to generate change in attitudes in the urban water management field by proposing alternative solutions that are integrated with the proven data of sustainable water management. The SWITCH is composed of academics, urban planners, water supplying companies and consultants, working closely with general population and their local governments for the adoption of more sustainable regulations concerning urban water. These are based on geographical, climatic and cultural characteristics that are site-specific, through research, training and dissemination of knowledge among all affected society sectors (U.S., 2006). The DRENURBS is related to the SWITCH as a learning platform for Latin American countries, because it proposes a new model of surface water management, based on sustainable urban drainage and watercourses insertion in the cities policies.

Even during the 1990's, the Velhas River water degradation motivated the creation of so-called Manuelzão Project by professors oft the Federal University of Minas Gerais. The Manuelzão Project works very closely with the Velhas River Hydrographical Basin Committee, established in 1998 to meet the principle guidelines of decentralized and participatory management established in the National Water Resources Policy.

The projects goals aim to restore environmental quality of the Velhas River's water, its final goal being to strive for bathing and fishing conditions. Since 2003, the Project is part of a water quality monitoring program in the basin. An initiative that indicates new trends in Brazilian water management is the monitoring of benthic bio-indicators in the context of Manuelzão Project. Bio-monitoring is performed by laboratories of the Federal University of Minas Gerais, focusing on the benthic macro invertebrates as indicators of environmental health, apart from the physical-chemical parameters of water quality (Rosenberg & Resh, 1993). The bioindicators are potentially useful to aid in water quality evaluation after water flow restoration interventions (Gumiero *et al*. 1998; Ruley & Rusch, 2002, Davis *et al*., 2003).

In this context of water management modernization in Belo Horizonte, in the current century, the focus on river beds and floodable river banks cannot go unaccompanied by water spring management. The springs' environmental health determines the existence and quality of the entire fluvial system, be it urban or not. This text seeks to discuss the importance of river springs in sustainable water management, adopting the illustrative case of Belo Horizonte. The protection of springs appears in this work as a strategy that should be part of future initiatives to search for sustainability in water management in Brazil and in the world. In this sense, it is assumed that the valorization of information at a local and regional level must contribute in order to support management policies and programs in all spatial spheres. Based on the case of Belo Horizonte, one can illustrate that sustainable water management in the tropics is more easily understood and perceived by society as a proposal from the local citizens. By valuing the experiences in smaller river units, though essential for the water systems' overall environmental balance, we are enhancing the creation of informational networks as the basis for large water systems management.

2. THE IMPORTANCE OF SPRINGS IN SUSTAINABLE URBAN WATER MANAGEMENT

The increasing consequences of environmental impacts on the globe in the 21st century created an international conjuncture in which environmental issues have been placed at a parallel importance to economic and social discussions, under the sustainable development term. The great human interventions on the environment now seem to entice fear towards a – not so distant – future that is destined to utter chaos in the human-nature relationship. It is an inherent fact that these great environmental transformations are foreseen and qualitative and quantitative natural resource scarceness is predicted.

The human changes of natural environment seem to climax in the urban environment. Cities are often seen as nature's antithesis, possessing its specific geo-ecological conditions that are profoundly distinct from the original conditions of the site (Troppmair, 2004). In this way, the water, previously considered a physical element, becomes part of the human condition (Swingedouw, 2006), with socially determined functions and uses. Thus, the issue of water in an urban environment is crucial, not only under the connotation of a natural *resource*, but also of an *element* of the environment (Rebouças, 1999).

The urban watercourses are completely different from those traditionally observed in a natural space. The hydrological cycle is, therefore, an open system and largely influenced by human activity, beeing a hydrosocial cycle. In this way, water movement in this environment cannot be understood as a mathematical resultant of hydrometrical potentials, but as a consequence of social power flows (Swingedouw, 2004).

In this context, the river springs are key elements for water management in the urban environment. The main rivers that serve human activities, mostly in the humid and sub-humid tropics, are superficial. However, the existence of watercourses is determined by springs, from the transfer of underground water to the surface.

Underground flows converge to zones with lower hydrometric potential, promoting the subterranean water's exfiltration to the surface (Ward & Trimble, 2004). Exfiltration is the primary factor responsible for originating springs, contributing towards the formation of several superficial water manifestations (such as rivers, streams, lakes, etc.), along with the precipitation which affects the channels directly or through the pluvial draining in its sources (Feitosa & Manoel-Filho, 1997; Fetter, 1994).

Studying the springs of a metropolis area is instigating and complex, since the hydrological dynamic is vulnerable to human actions. The urban environment is the main spatial expression of human pressure on the waters, since the effective economic systems, seeking production and richness, generate an increasing need for water resources.

In the case of Belo Horizonte, people have reported the disappearance of uncountable river springs. Some are drained directly into the pluvial network, occurring like little rivers completely channeled underground. In fact, the urban drainage network in Belo Horizonte was oriented under the attitude of channeling and rectifying rivers for a long time (Medeiros, 2009). Therefore, the environment around the springs had not been preserved and many springs were drained (Genrich, 2002). The springs that still register a relatively high natural degree are practically restricted to urban conservation units identified as green *islands* in Belo Horizonte's urban stain.

The first conservation steps are originally thought out under the logic of protected areas, in the 19th century, in the United States. They were related to "wildlife" and untouched natural landscapes. This way, the conception was absorbed by the first conservation units that sought to protect "nature" from the urban-industrial society, establishing a myth that such spaces would be the lost paradise (Diegues, 1996).

However, mainly from the 1960's, when the environmental movement started, new reasons were created for the conservation units. These areas would be the remains of an equilibrated environment, in which the ecological processes should be maintained as well as the ecosystem diversity. Simultaneously, strategic natural resources should be protected, guaranteeing their future benefits (Camargos, 2001).

The antithesis *untouched versus transformed*, or *natural versus artificial*, has been gradually overcome by the concept of planned uses and sustainability, not segregating man and nature. In 2000, the Brazilian legislation on conservation units was reviewed, and the Law 9.985 was promulgated creating the National Conservation Units System (SNUC).

It is notable that, despite maintaining the ecological and biodiversity discourse, there is a paradigmatic change reflected in SNUC's own objectives: sustainable development. The protection of environmental systems possesses a purpose beyond its own maintenance, which confuses itself with the effective economic system's feedback. In this sense, the SNUC considers two conservation unit categories: i) units of integral protection, aiming mainly to maintain biodiversity; ii) units of sustainable use, which seek compatible conservation and resources use (Silva, 2005).

In an overall look, urban municipal parks have been created within the SNUC as integral protection units, in which the basic goal is to "preserve nature, being only permitted the indirect use of its natural resources" (Brazil, 2000. Art. 7, §1). However, because of the difficulties of implantation of the SNUC in urban areas, the urban conservation units have been sustained only by their own management plans, when they exist. Nevertheless, a series of environmental impacts is registered within municipal parks due to urban occupation in its surroundings. In reality, however, urban conservation units are mainly configured as a leisure and recreational space with secondary objectives related to environmental education.

Although, the importance of these green islands amidst the concrete concentration in a metropolis is indubitable. In Belo Horizonte's case, the municipal parks are practically the only spaces capable of presenting river springs in a good state of conservation. However, there is a rising need for studies that interpret the environmental impacts in these spaces due to the dense urban occupation surrounding them. Such efforts tend to lead conservation unit management, broadening the protection possibilities.

In 2008 there were 64 parks managed by the Municipal Parks Foundation (FPM) of Belo Horizonte's City Hall (PBH). These conservation units are distributed throughout the municipal territory (Figure 2), possessing variable infrastructure and landscape characteristics. There have been no studies conducted so far that identify springs within these parks. Generally, the information is not systematized, being usually cared for by the individual management's teams of each park. However, it is believed that part of these conservation units shelter springs that form the city's main draining channels, even though these are currently mostly channeled.

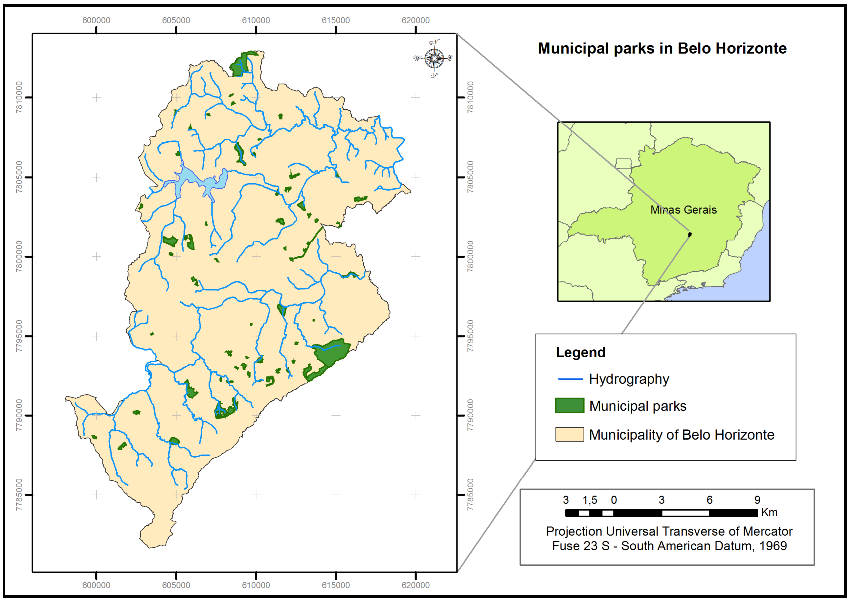

Figure 2 - Municipal Parks in Belo Horizonte
Source: PBH (2003)

The insertion of river springs within Belo Horizonte's environmental planning and management has presented itself more frequently since the DRENURBS/Nascentes program that seeks, among other goals, springs conservation (Medeiros, 2009). Parks created by restoration of valley bottoms predicted in this program have its springs mapped and identified. However, these actions do not extend to the monitoring of these springs environmental quality, nor its waters.

The springs are not restricted to the interior of conservation units, but these areas are preferential for their study. The protection degree they possess, despite all the possible problems that may exist within the parks, gives these springs a set of characteristics that are very similar to the original conditions of springs.

River springs are singular environments, with a complexity that is still little understood. They are environmental elements with prime importance to the hydrological dynamic, since they mark the passage of subterranean water to the surface through exfiltration. In this sense, they are partially responsible for the origin of the most accessible water resources, at least for most of the population and economic sectors; since the financial costs for using superficial water is considerably smaller than subterranean water, especially in tropical countries, such as Brazil.

The environmental importance that characterizes the river springs imposes the obvious need for protecting these elements in order to maintain a hydrological and environmental balance. In Brazil, since 1965, when the Law 4.771 which regards Permanente Preservation Areas was promulgated, springs have been considered environmental elements which demand conservation (Brazil, 1965).

The National Environment Council (CONAMA) Resolution n. 303/2002 regulated this condition instituting a permanent preservation area around a spring or a water source with a minimum ray of fifty meters, in such a way that protects, in each case, the contributing hydrographical basin (Brazil, 2002). This implies that the spring's perimeter cannot be used for any other purpose than that of environmental preservation.

The legal demand, by itself, would already be an extremely plausible reason for many studies that sought to understand and protect springs. However, what can be perceived in reality is a general disrespect towards environmental legislations in Brazil, which is reflected in the continued degradation of many springs. Apart from not fulfilling the minimum preservation ray, the contributing hydrographical basin is completely ignored. If, on one hand, applicability of the legislation is questionable, its accomplishment is as well.

Even though this scenery is not exclusive of Belo Horizonte, the capital's situation is drastic. The fact that the urban stain occupies over 80% of the municipal territory this alone promotes the degradation and even destruction of most of Belo Horizonte's springs. The few non-occupied areas in the municipality are basically restricted to conservation units. In these places, environmental conditions are considerably more balanced, allowing the occurrence of many springs.

Nevertheless, in face of the unquestionable need for protecting the river springs, which is provided by law since 1965 in Brazil, in realities is has little effect as of now, the intention is to contribute with the comprehension of the dynamics and the characteristics of the springs in urban areas, collaborating with the management of those environments. It is believed that there is no possibility of protecting the springs and, consequently, the water resources, without knowing their location and environmental characteristics.

3. METHODOLOGY

The urgency of the spring protection is particularly present in urban/metropolitan debate. As was previously demonstrated, the specific legislation for most Brazilian urban zones has not guaranteed, in environmental terms, the necessary river spring protection over time; this is partially due to the lack of legal operability and also due to the several speculative and real estate interests in the urban space.

In order to verify the river springs' environmental quality, three municipal parks within the municipality were selected. The spatial distribution of these conservation units elucidates the different ways of space appropriation, as well as the different geologic-geomorphologic contexts within the metropolis. The Mangabeiras Park, with 60 studied river springs, the Lagoa do Nado Park, with 12 river springs and the Primeiro de Maio Park, with seven river springs, were chosen for this study (Figures 3, 4 and 5). The identification and characterization of the studied springs are presented in Felippe *et al.* (2009).

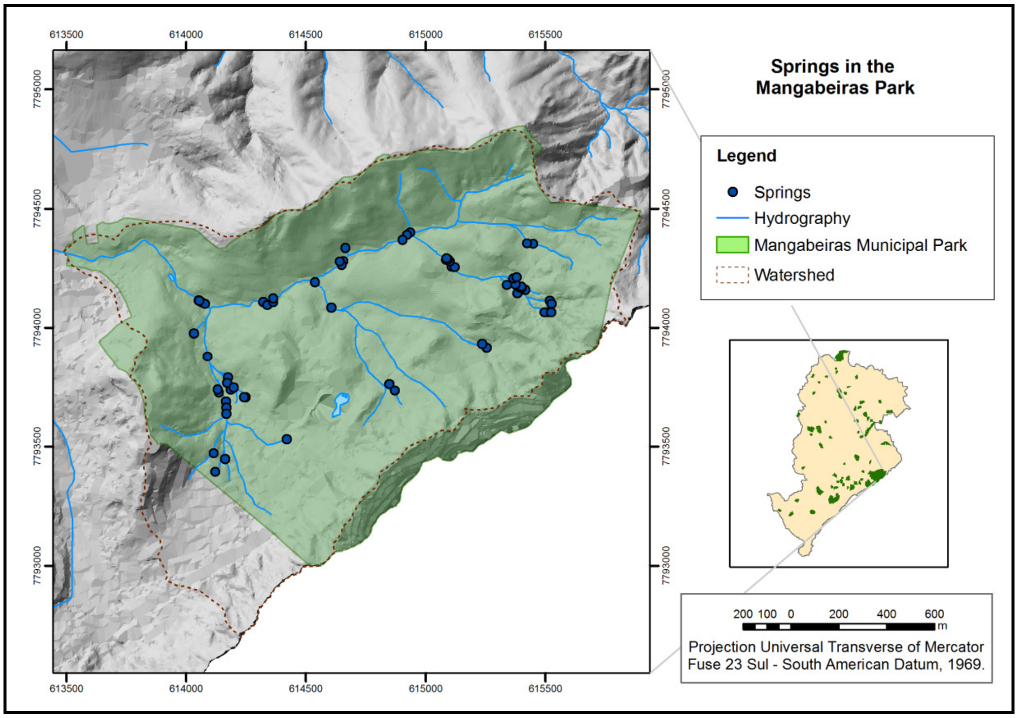

Image 3: River Springs in the Mangabeiras Park.
Source: Felippe *et al.* (2009).

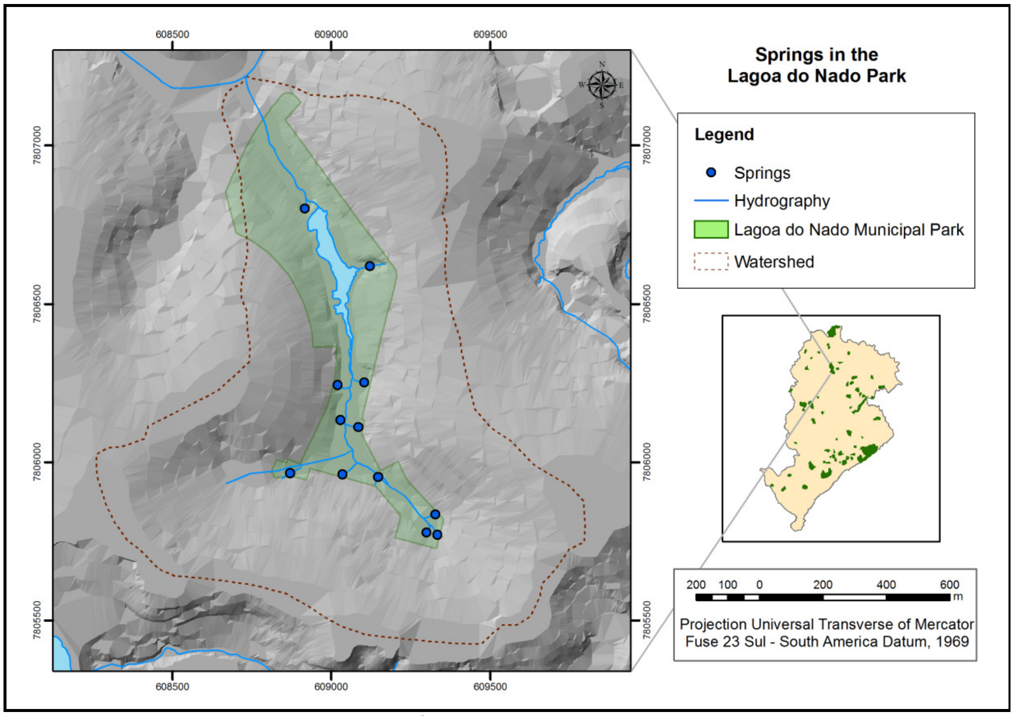

Figure 4 – River Springs in the Lagoa do Nado Park.
Source: Felippe *et al.* (2009).

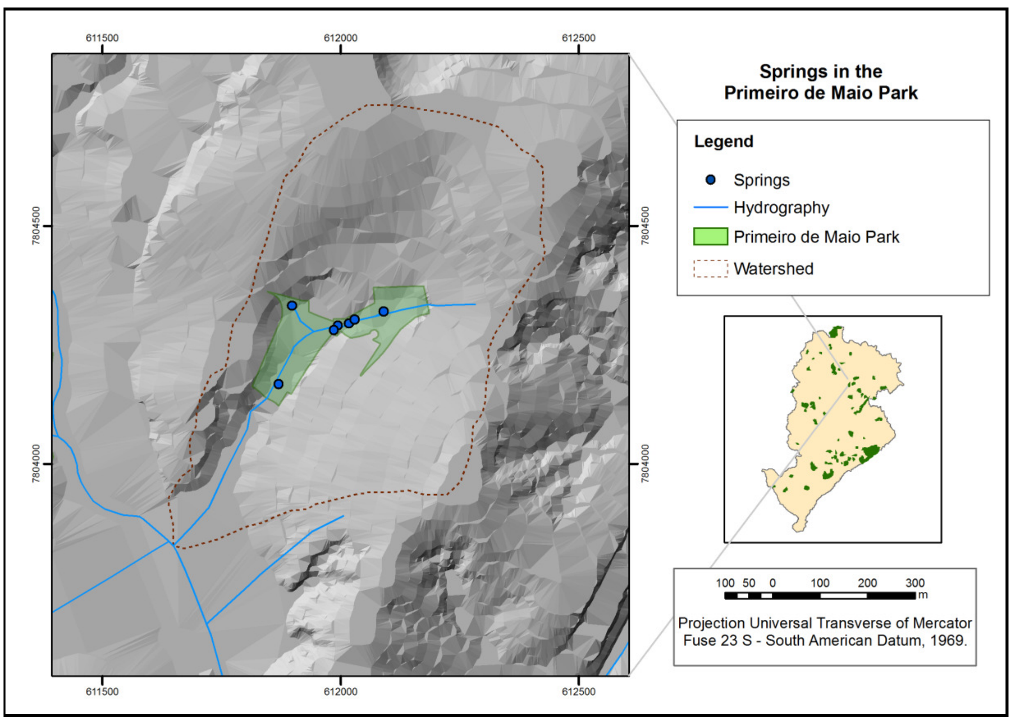

Figure 5 – River Springs in the Primeiro de Maio Park.
Source: Felippe *et al.* (2009).

In urban parks, the surroundings configure themselves as a complex constructed space, where the density of people, services, material and immaterial goods, is the key to interpret the environmental interventions. In this sense, it is practically inevitable that the urban conservation units present negative environmental consequences of the changes taking place in its neighborhood. Yet, in these green areas encrusted into the metropolis the most important aspects of environmental balance take place.

Environmental quality is a concept that carries an intrinsic subjectivity degree. Something can be *good* or *bad* when we consider the use of resources. Indicators are, thus, used to minimize the subjectivity and measure, from abstractions, the environment's quality as opposed to the impacts and transformations it has suffered (Magalhães Jr, 2007).

Considered as a set of modifications in the environment promoted by human activities, with an ecological, economic and social effect (Singer, 1985 *apud* Genrich, 2002), the environmental impacts were evaluated in this study from the physiographic interpretation of the springs. As a technique, the Macroscopic Environmental Impact Index applied to Springs (IIAN), presented by Gomes *et al* (2005), is a interesting tool. According to the authors, the proposal is based on the Classification of Spring's Impact Degree in the National Water Resource Information System (Portugal) and the Water Quality Evaluation Guide (Brazil).

The goal of this procedure was to verify, in a qualitative way, the river spring's protection degree. For such, the Environmental Impact on Springs Index (IIAN) was critically reread, so as to adapt its variables to the needs and goals of this paper, without, however, harming the original methodological presumptions. On the inverse of the IIAN, the springs' protection degree is defined.

The technique consists in the sensorial (macroscopic) and comparative evaluation of some key elements in identifying environmental impacts and their consequences on the spring's quality. The eleven parameters used were: water color; odor of the water; garbage around the spring; floating material (garbage on the water); foam in the water; oil in the water; sewage indicators in the water; state of surrounding vegetation; uses of the spring; accessibility to the spring; proximity to urban equipments.

The evaluation of the springs' environmental quality should be endorsed by its waters' quality parameters. Generally, alterations in the natural conditions of the springs' waters can affect the entire water system. Therefore, the environmental handling of springs seeks primarily to guarantee water in quantity and quality to maintain the hydrological balance.

In an urban setting, the main sources of pollution in the water environments are associated with sanitation deficiencies (Carmo, 2002). In these conditions, pathogenic microorganisms in the effluents can come into contact with watercourses, altering their quality. Furthermore, the contamination risk exposes the population which uses the water vulnerable.

In this sense, the water quality must be, inevitably, linked to the resource's use (or intended use) (von Sperling, 2005). In the Brazilian context, the CONAMA Resolution n. 357/2005 stipulates tolerable levels of water quality parameters for its several purposes (Brazil, 2005). The presence of pathogenic microorganisms in the water is essential in interpreting its level of pollution and or contamination. Diseases carried through the water account for 70% of medical occurrences in the world (Barbosa & Barreto, 2008), the main diseases being cholera, typhoid and paratyphoid fever, gastroenteritis, salmonellas and diarrhea (von Sperling, 2005; Mormul *et al*, 2006).

The possibility of disease transmission through water can be evaluated indirectly, through organisms that indicate fecal contamination. These are not necessarily pathogenic, but their origin (warm blooded animals' intestines) indicates the presence of other enteric, but pathogenic, microorganisms (von Sperling, 2005; Mormul *et al*, 2006). For this, the bacteria of the *Coliforms* group have been the main biological indicators of fecal contamination and risk of pathogenic organisms being present (von Sperling, 2005). Several types of bacteria belong to the *Coliforms* group, not all being indicative of fecal contamination. Thus, mostly those named fecal *Coliforms* are extremely interesting, since they include the enteric types *Escherichia*, *Enterobacter* and *Klebisiella* (Mormul *et al*, 2006).

Another kind of bacteria that is potentially disease causing and is transmitted through water is the *Salmonella sp*. Like the fecal *Coliforms*, the *Salmonella* possesses an enteric life cycle, indicating feces pollution. Furthermore, it causes diseases considerably dangerous to human health. Therefore, the Brazilian legislation (Brazil, 2004) states that the *Coliforms* group cannot be present in the water destined towards human consumption, including individual sources such as wells, mines, springs, among others.

With the intention of accurating the studied springs' water in Belo Horizonte's urban parks, , the presence of microbiological contamination was verified.The number of Colony Forming Units – CFU – for *total Coliforms, fecal Coliforms* and *Salmonella sp.* was counted in all the identified perennial springs. The water samples were collected during a winter field research study, in the months of June and July of 2009 (months of water scarcity in Belo Horizonte). Therefore, only 58 springs had their microbiological parameters evaluated, exactly those that maintained flows in the low pluviometric period.

4. DISCUSSION AND RESULTS

4.1. Consequences of urban occupation in the springs' dynamics

Urban occupation causes innumerable environmental alterations and consequently impacts the water resource dynamics. In the metropolitan space – such as in Belo Horizonte – it is impossible to disregard the fundamentally anthropoid aspects that modify the landscape by a very unnatural logic. Thus, comprehending how the environment is transformed, interpreting the processes that show the impacts and their consequences is essential for both current and future environmental resource management.

The waters that seep from these springs form the first draining canals, still inside the parks. These waters further downstream, enter the urbanized area and are usually channeled or turned into sanitary avenues. Thus, the springs' water quality is essential for the water quality of those rivers that run throughout the city. Furthermore, within the conservation units, recreational activities are allowed on these watercourses.

Nonetheless, maintaining good spring water quality parameters within the parks depends on a series of environmental conditions, not only restricted to the surroundings of the springs, but extending to its superficial and subterranean hydrographical basins and the associated water-bearing recharge zones. With this, a theoretical reflection exercise permits glimpsing casual relationships, these being extremely useful for handling the springs.

Hall (1984) theoretically synthesizes a series of impacts caused by urbanization in a water system. In an overall manner, these can be compacted into two lines of thought: i) increase in the demographic density, which tends to broaden the water resource demands and, simultaneously, compromise its quality; ii) increase in construction density, which tends to waterproof the soil and modify the draining system, altering the local hydrological balance characteristics.

In a broader sense, all urban areas are, a larger or smaller extension, affected by these processes, altering the characteristics of their water systems. However, the impact intensity in metropolises such as Belo Horizonte is considerably larger, promoting more severe consequences to the population and the environment.

The most visible short-term consequence of urbanization is the flood increase, both in number and intensity (Hall, 1984). The reason for such a response of the water system is the diminution in infiltration capacity, which is due to the removal of foliage, soil compression and more importantly, its impermeability. Still, the urban impacts can generate effects that will only be acknowledged by the population after decades, with what can be irreversible damaging effects.

Felippe & Magalhães Jr (2009a) enumerated, based on the theoretical revision on the theme and on the field observations, a series of urban environmental impacts and their possible – and probable – consequences in the qualitative and quantitative dynamic of the springs (Table 1). This practice allows elucidating the proposed discussion by generating information based on Belo Horizonte's reality.

TABLE 1: ENVIRONMENTAL URBAN IMPACTS AND THEIR CONSEQUENCES IN THE SPRINGS' DYNAMICS

IMPACTS	GENERAL CONSEQUENCES IN THE WATER SYSTEM	CONSEQUENCES FOR THE SPRINGS
Soil impermeability	Increase in quantity and speed of superficial draining. Reduction of the water-bearing zones recharge. Intensification of erosive processes, increase in sediments in the watercourses and floods.	Decrease in outflow. Disappearance.
Solid and liquid residue (fuel, sewage, dumpsters, etc)	Pollution of subterranean water.	Decrease in water quality.
Withdrawal of subterranean water.	Lowering of the freatic level.	Decrease in outflow. Disappearance.
Withdrawal of vegetation coverage.	Intensification of erosive processes, residue buildup, floods. Decrease in water retention. Increase in superficial flow energy.	Decrease in outflow. Disappearance.
Constructions	Spring draining.	Changes on natural conditions Disappearance.
River channeling.	Increase in flow speed and energy. Alteration in the rivers' influence/effluence pattern.	Changes on natural conditions. Decrease in outflow.
Urban heat island	Alteration in the rain pattern. Alteration in the recharge pattern.	Alteration of outflow.

Source: Felippe & Magalhães Jr (2009a).

Thus, it is believed that the main consequences of the urban interventions in the spring dynamics are the outflow alterations. In extreme cases, the decrease of the flow can mean the spring's disappearance, its transformation into a temporary spring or its migration downstream. This is explained by the fact that hydrological systems involve a chain of interconnected processes, in which the rupture of energy and matter flows alters its dynamic and consequently the springs' characteristics.

The studied springs have different outflows, mainly between 5a and 7a magnitudes, according to Meinzer's classification (Meinzer, 1927). In fact, the outflow variability is conditioned by a series of elements in the natural state, however, as well as man induced spatial alterations (Felippe & Magalhães Jr, 2009b).

In Belo Horizonte, substituting thickets and brushwood along the riverbanks by residential or commercial lots is a complex process, inherent to urbanization, but with severe consequences. According to Genrich (2002), in 1994 all the springs of the high portion of Córrego Vilarinho's basin – in the north area of

Belo Horizonte – presented watercourses in natural channels with vegetated banks, but in 2001, several springs had been channeled or even extinct.

As was previously mentioned, the subterranean water flows are extremely important in maintaining hydrological balance and they are the determining factors in the springs' space distribution (Rebouças, 1999). Therefore, urban interventions that alter the infiltration percolation tend to modify the subterranean flow patterns and consequently the exfiltration in discharge zones – low hydraulic potential. Furthermore, the impacts directly on the water bearing zones, such as subterranean draining for construction or water withdrawal for consumption, alter the phreatic water volume, impacting the springs.

Thus, protecting the springs' areas does not guarantee the hydrological balance maintenance, since they are the result of a complex water dynamic which involves the recharge to the discharge, promoted by superficial and underground processes. Alterations in the subterranean water volume and the superficial areas downstream of the springs are potentially threatening to them. In a space where not even the Permanent Preservation Areas, foreseen in the Brazilian environmental legislation, are respected, the parks gain importance, since they allow using the hydrographical basin as a spring management and handling unit.

4.2. The environmental quality of the springs in Belo Horizonte's parks

Considering that all the springs evaluated by the IIAN are found within conservation units, one could say that the obtained results were worrying and confirmed the complexity of environmental protection in metropolitan areas. Although a purely quantitative analysis guides toward a more optimistic response regarding the spring's protection degree in the studied parks, the spatiality of the IIAN demonstrates that each park's reality is considerably distinct (Chart 1).

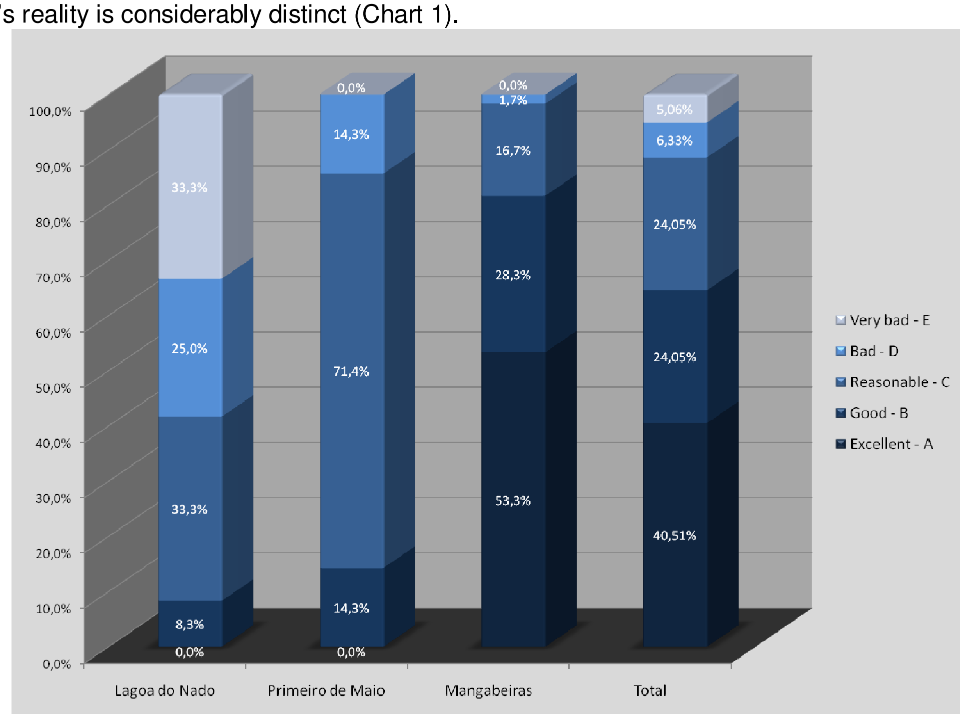

Chart 1 – Distribution of the springs by protection degree in the studied parks.
Source: Field research.

In the set of springs, it is noticeable that the majority – 64.6% – possesses a great or good protection degree, with percentages of 40.5 and 24.1% respectively. On the other hand, only 11.4% of the springs were classified with terrible and bad protection degrees. Furthermore, in the intermediate category is 24.1% of the total of studied springs.

However, when observing the isolated data by parks, it is verifiable that the weight of the total number of springs in Mangabeiras Park masks the result and induces mistaken conclusions. Effectively, all the class A springs are found in this park, representing 40.5% of the set and 53.3% of the Mangabeiras sub-set. In other words, no springs with great protection degree were found in the Lagoa do Nado Park, neither in Primeiro de Maio.

In the Mangabeiras Park, class A and B springs account for 81.6% of the total, none of which were classified with a terrible protection degree and only 1.7% with a bad degree. The parameters that most contributed positively with the IIAN were *color of the water* and *foam*. On the other hand, the *accessibility* parameter presented the worst results in Mangabeiras Park, with 25% of the springs being classified as bad, followed by *use*, due to tourism and leisure activities within the park.

Among the studied parks, the Primeiro de Maio Park has the second best result for IIAN. The vast majority of this park's springs – 71.4% -- are found in protection class C. The other 28.6% are equally divided among classes B and D, with good and bad protection degrees, respectively. It was noted that Primeiro de Maio Park did not present any spring in the extreme classes – A or E. The main characteristic that limited the good conditions of Primeiro de Maio's springs was degradation of natural conditions or even the absence of vegetation in various localities in the park; yet this result should be considered positive, especially for a recently created park, with a small area and surrounded by urban stain, mainly in the superior portion of its basin (Felippe *et al*., 2009).

In turn, the Lagoa do Nado Park presented the worst results for the IIAN report. Like Primeiro de Maio, none of the springs were classified in class A, however, only 8.3% are in class B. Class C – with a reasonable protection degree – holds 33.3% of Lagoa do Nado's total springs and class D, 25%. Thus, the Lagoa do Nado Park was the only one to present any spring in this class, producing a total of 5.1% in the total of springs.

In fact, the springs with a terrible degree show simultaneously: sewage indicators, easy access to passersby, degraded vegetation and distance to urban equipment smaller than 50 meters. It also contributes toward the reduction in environmental quality of these springs and the convergence of superficial flows originated in the urbanized area.

These characteristics confirm the heterogeneity among the conservation units. Their spatial characteristics, as well as the surroundings', define the possibilities and impossibilities of protection within. Furthermore, the hydrographical basin can be a key element in interpreting the parks' susceptibility to impacts: the more a hydrographical basin is inserted into the boundaries of the park, the more chances it has of being preserved.

At last, it is possible to affirm that the simple establishment of a conservation unit does not guarantee maintaining the local environmental balance, as several authors have stated. However, the fact that the springs found within the urban parks are, most likely, those with the highest protection in a metropolis is undeniable.

4.3. Microbiological contamination of the springs

There is a great variability as for the presence of the *Coliforms* and *Salmonella sp.* in the studied springs. Notably, the *total Coliforms* were considerably more active in the samples, whereas the *Salmonella sp.* was rarer. In 79.3% of the samples, the *Coliforms* were present, but the *fecal Coliforms* were found in 31% -- 20 samples. As for the *Salmonella sp.*, they were verified in 24.1% of the cases (Chart 2).

The average total of *Coliforms* found in the 58 samples was 1,146 CFU/100ml, an amount considered high for the expectations, considering the spring's environment. The data for *fecal Coliforms* and *Salmonella sp.* had similar statistic behavior. In both, the mode and the median was zero. The averages were also considered low, being 141 CFU/100ml for the *fecal Coliforms* and 91 CFU/100ml for *Salmonella sp.*

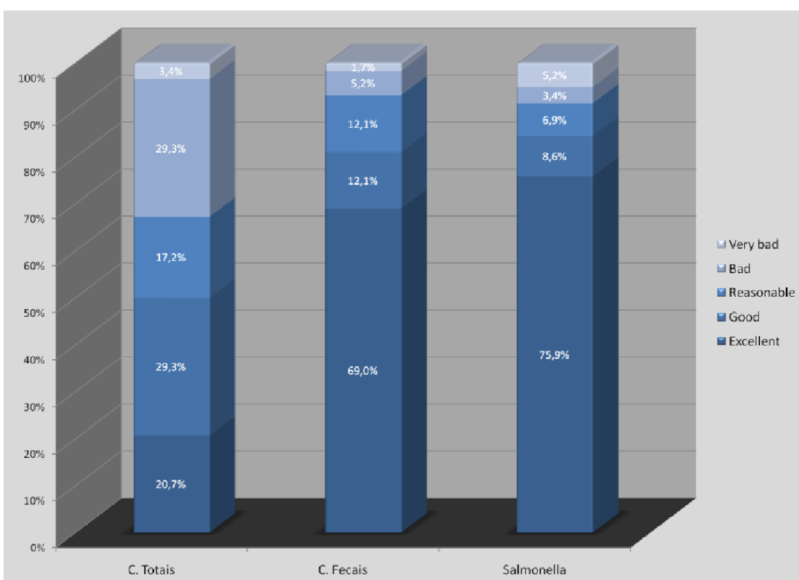

Chart 2 – Quality of the springs according to the evaluated microorganisms.
Source: Field research.

The *total Coliforms* showed themselves far better distributed according to the classes. This is because since they are "environmental" *Coliforms* (von Sperling, 2005), they are naturally found in the environment and thus, few samples presented zero CFU of these microorganisms. The magnitude of the "good" and "bad" classes' also stood out, each with 29.3% of the samples. On the other hand, 18 samples – included in the "bad" and "terrible" classes – presented over 1,000 CFU/100ml, an amount that makes the water inappropriate even for leisure (Brazil, 2004).

Nevertheless, as was previously stated, the more significant parameters to indicate water contamination by fecal residue are those of *fecal Coliforms* and *Salmonella sp.*, since these bacteria are not found in the environment other than in the intestines of homoeothermic animals. It is noted that the distribution of these microorganisms is quite heterogeneous among the classes, with the vast majority in the samples falling in the "great" category.

As for the *fecal Coliforms*, out of the 31% of the samples that were positive for these bacteria, over half is found in the "good" and "reasonable" classes, indicating amounts lower than 360 CFU/100ml. However the situation is critical in 1.7% of the cases, which resented amounts higher than 900 CFU/100ml, this is considered extremely high for these microorganisms. Comparatively, although these springs are found within conservation zones, the obtained results are similar to those found by Mormur *et al* (2006), in three springs of a slum in Campo Mourão, in Paraná State.

The risk of contamination in waters in which *Salmonella sp.* is found is so high that there are no safe amounts related to these bacteria stipulated in the Brazilian legislation (Brazil, 2004). Even so, 24.9% of the samples collected in the studied parks' springs were positive for *Salmonella sp.* Although 15.5% are found in the "good" and "reasonable" categories – with amounts inferior to 180 CFU/100ml – an expressive 5.2% are found in the "terrible" class, including two cases which exceed 1,000CFU/100ml.

Nonetheless, according to the National Health Surveillance Agency (ANVISA) (Brazil, 2004), only 20% of the samples would figure within the potable standards in microbiological terms. However, the quality of the water does not depend only on releasing pollutants, but also on the watercourses's capacity in assimilating these substances and reestablishing its natural characteristics (von Sperling, 2005).

It is known that in the soil itself (polluted or not) there are bacteria constituting an edaphic ecosystem. Thus, it is probable that springs in which the water stays longer in contact with the soil will be enriched with these bacteria. Of the measured bacteria, the *total Coliforms* are found in a non-polluted environment, naturally. As for the other types, in principle, there is a polluting source.

The concentration of disease-indicating microorganisms in the diffuse springs was larger, on the average, when compared to the other exfiltration forms. This occurs since in these cases the water reaches a larger area and, is in contact with the soil. Thus, pollutants that are left on the surface are more easily destined to the water of diffuse springs.

On the other hand, the punctual springs, mainly those in ducts, have much less contact to the soil. As soon as the exfiltration occurs, the tendency is to form a channel, restricting the influence of the substances present on the surface. Additionally, it is known that the most common pollution concentration is found on the surface, reaching deeper layers of the ground only in specific cases. Hence, it is perfectly understandable that diffuse springs (within the same environmental context) have a higher quantity of pollutants.

In other words, this means that diffuse springs are more susceptible to environmental degradation. In the same pollution situation, these tend to be more affected than punctual springs, and, simultaneously, transmitting the pollutants into the watercourses downstream. In this sense, protecting the diffuse springs' environmental quality should be even more essential, despite the difficulty in a large exfiltration area.

Finally, it is evident that simply delimitating a conservation unit is not sufficient to guarantee the springs' quality. Even within the parks, there are negative consequences of man's work, mainly in urban areas, in which the spatial alteration is even more expressive. This can be demonstrated by the springs' protection degree and by the pathogenic microorganisms' quantification in its waters.

Moreover, it was noted that there are considerable differences among the springs' protection degree among the studied parks. This occurs mainly to the conservation areas' territorial characteristics, but also to the handling that takes place within it. Concurrently, one cannot ignore the specific characteristics of each spring, which may indicate a higher or lower vulnerability to environmental degradation.

5. CONCLUSION

To understand the river springs' environmental reality is essential for the sustainable management of water resources, since they represent the exfiltration of subterranean water and the beginning of the watercourses. In an urban setting, this assertive matter is even more evident, as there is already a typical water quality and quantity degradation scenario, a consequence of spatial artificiality. To know where the springs are located, understanding how they seasonably behave and to identify their characteristics, regardless if they are located in a conservation area or not, are the first steps toward guaranteeing the protection of water resources today and, unmistakably, in the future.

The study of the springs is uncommon in the water resource management processes around the world, either due to the difficulties inherent to its methodological tools or due to its deliberate inconsideration or lack of knowledge and underestimating its importance. In Brazil, the study of springs is rare in scientific literature. The traditional environmental and water resource management policies have been focused on structural interventions in the urban setting, where the exaggerated artificiality of the fluvial means generates flood risks, as well as material and human damage risks. In this sense, the control of fluvial channels by canalization and rectification was always considered a logical and accepted policy politically and socially, seeking to drain the flood flows as quickly as possible. As most urban rivers in Brazil are polluted by sewers, the structural interventions also often seek their removal from the urban landscape by building highways and other urban elements over the fluvial beds.

With the expansion and consolidation of the structural intervention in urban fluvial environments logic, water resource management in the cities loses its environmental character qualities. Managing springs and other physical elements has not been a priority; the main focus has been eliminating the risks that the water may bring to the population, a fact that is an expected consequence of the intense occupation of the urban space, including in naturally fragile areas that are subject to floods and hillside erosions. Sustainable water management should not only seek managing the consequences of the occupation processes, but also managing its causes. Urban water management in Brazil should not continue to be seen, in a simplistic manner, as an exclusive synonym of pluvial draining and channeled rivers management. In Belo Horizonte, the recent initiatives of renovating rivers in natural beds, by the local public power, soothe those who criticize exclusively structural approaches in treating urban waters.

Many of Belo Horizonte's and other large Brazilian cities' springs have been extinct. Most of the ones left are found in urban parks. In this sense, spring management is intimately linked to these parks' management. By managing the springs properly, society is making it possible to protect the entire draining network. On the other hand, altering the springs' environmental quality will invariably lead to the deterioration of the rivers' water quality.

Frequently, the known springs are the last natural hydrological elements present in the urban space; which increases, even more, their need for protection. However, it is evident that the connotation here used is not restricted to delimitating permanent preservation areas, but also, to the handling of these environments, once the springs' protection degree can be critical even within conservation areas.

The ultimate goal for future generations should be sustainable water management policies that contemplate the natural springs, as the life source of the entire hydrographical systems. To guarantee the springs' environmental balance, keeping them free of contaminants and anthropologic interventions even in urban environments, even those located in densely occupied areas. Making this the first step to ensuring that future generation will be provided with ample water high in quantity and quality.

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