

# Watershed Level Sustainable Development Index in Rondônia, Western Amazon: Index Construction from Factor Analysis

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## Abstract

*Objective: to build a sustainable development index for the river basins of Rondônia, using factor analysis as an analytical model. Method: factor analysis was used as a tool for building environmental, economic, social and institutional performance indices. The adapted FECAM classification scale was adopted to express the results achieved by each river basin. Results: The set of current sustainable performance indices for the Mamoré River watersheds (0.444) was considered a low index, although the best compared to other basins; the Madeira River (0.419, low index); the Guaporé River (0.378, low index); the Machado River (0.289, low index); the Jamari River (0.307, low index) and the Roosevelt River (0.227, low index). There has been a really insignificant improvement in the rates from 10 years ago. Conclusions: the factor analysis showed efficiency as a multivariate statistical method in the*

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*construction of sustainable development indices for the river basins of Rondônia. The management of watersheds is still very ineffective, despite being regulated by state law. It is highly recommended to institutionalize regional public policies in the form of a Master Plan for the Rondônia Watershed.*

**Keywords:** Hydrographic basins. Factor analysis. Sustainable development. Rondônia. Western Amazon.

### **I. Introduction**

The growing demand for water has exacerbated problems in many parts of the world. As a consequence, an increase in the statistics of completely dry rivers and/or streams and other sources totally unsuitable for human consumption, whether surface or underground, is observed more frequently. Therefore, much of the water extracted for human activities, from any source, has been used very ineffectively [1]. Decree No. 24,643 of 1934 (Water Code) already regulated the use of water in Brazilian territory. Although it is recognized that the Water Code established an advanced policy for the time, its regulation was limited to aspects related to the development of the electricity sector, leaving aside multiple uses and the protection of water quality [2]. The problems arising from water resources have been constantly pointed out by many researchers as an increasingly worrying scenario. For Peixoto Filho and Brondarovsky [3], part of the available fresh water cannot be considered suitable for human consumption, because many times, industries, agricultural activities and sanitation companies do not treat the water used in their processes, before returning it to water. to the environment, and end up harming the aquatic environment. Corroborating this, Rebouças [4] states, among other aspects, that the misuse of water, deforestation, occupation of river banks and the waterproofing of urban soils end up generating serious problems in the water environment.

The United Nations World Report on Water Resources Development 2017 points out that “two-thirds of the world's population live in areas that are affected by water scarcity for at least one month a year” [5]. Population growth, economic development, changes in consumption patterns, among others, are factors that have contributed, according to the World Water Assessment Program (WWAP), to the increase in the rate of water demand by 1% per year, and the forecast is for a significant increase in the coming decades. The use of water in industries and homes will increase faster than in agriculture, but the agricultural sector will still be the biggest consumer, especially in developing countries and emerging economies [6]. The demand becomes increasingly greater than the availability, and in this sense Barros and Amim [7] consider that population and economic growth has aggravated the problems related to water, generating pollution and scarcity of water resources. The United Nations points out that millions of people are affected every year by floods and billions are exposed to critical situations of water scarcity. The intensity of water problems varies according to the region and is aggravated by local factors, including climatic conditions, regional, environmental, social and economic aspects [8].

According to data from the National Water Agency - ANA [9], the Brazilian territory covers 12% of the available water resources on the planet, divided into 12 hydrographic regions that guide the implementation of the national water resources policy. The three largest hydrographic basins in the country, Paraná, São

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Francisco and Amazonas, together, hold the largest volume of fresh water in the world. And even so, some regions of the country do not escape experiencing water scarcity, which impelled the Federal Government to adopt measures in the search to guarantee the preservation of water resources, in the face of a management based on environmental, social and economic sustainability, adapting laws and implementing public policies [10]. In the 1980s, with the establishment of the National Institute for Environmental Policy (PNMA), Brazil started to have a structure to deal with environmental issues, which contributed to boost the formulation of new rules related to water management [11]. The Federal Constitution of Brazil, promulgated in 1988, played an important role in the management of water resources, because it defined waters as goods of use and changed the dominance of waters in the national territory, previously defined by the Water Code 1934. Article 21, item XIX of the Federal Constitution of Brazil grants the Union the competence to establish a National System for the Management of Water Resources and define criteria for granting the right of use [12].

According to Setti et al., [1], water resources management, in a broad sense, is the way in which it is intended to equate and resolve issues of relative scarcity of water resources, as well as to make proper use, aiming at optimizing water resources, resources for the benefit of society. Lanna [13] conceptualizes water resources management as an analytical and creative activity focused on formulating principles, preparing normative documents, structuring management systems and decision-making, whose ultimate objective is to promote inventory, use, control and protection of water resources. Law no. 9,433, of January 8, 1997, instituted in Brazil the National Water Resources Policy (PNRH) and the National Water Resources Management System, which, according to article 1, presents the following grounds: a) the management of water resources must always provide for the multiple use of water; b) the hydrographic basin is the territorial unit of implementation of the National Water Program Resource Policy and performance of the National Water System Resource Management System; c) the management of water resources must be decentralized and count on the participation of the Government, users and communities. One of the PNRH guidelines is to adapt the management of water resources to the physical, biotic, demographic, economic, social and cultural diversity of the different regions of the country, the integration of water resources management with environmental management and the articulation of resource planning, with that of users and with the regional, state and national planning sectors. In the context of the State of Rondônia, Complementary Law nº 255, of January 25, 2002, “establishes the State Policy of Resources of the State of Rondônia and creates the Management System and Fund of Water Resources for the State of Rondônia and other measures”. By CNRH Resolution No. 32, of October 15, 2003, the Brazilian territory was divided into 12 Regions, as follows: Amazon, West Northeast Atlantic, East Northeast Atlantic, Parnaíba, Tocantins-Araguaia, São Francisco, East Atlantic, Southeast Atlantic, South Atlantic, Paraná, Uruguay, Paraguay. With regard to Rondônia, the State is part of the Amazon River Region, with its territory divided into 7 hydrographic basins, which are the Guaporé River, Mamoré River, Abunã River, Madeira River, Jamari River, Machado River and Roosevelt River.

Santos [14] states that water management, based on hydrographic basins, denotes: “The close connection between water, other natural resources and human activities”. In general, integrated plans for the management and management of watersheds, focused on resources associated with water, are broader and more effective when they add soil conservation measures, vegetation and fauna remnants and the control of rural and urban

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activities. The watershed as a planning unit, therefore, is accepted worldwide, as it constitutes a well-defined geographically system, where phenomena and interactions can be integrated a priori by input and production, thus watersheds can be treated as geographical units, where resources natural are integrated. It also constitutes a spatial unit that is easy to recognize and characterize, considering that there is no area of land, however small, that is not part of a river basin network and, when the central problem is water, the solution must be intimately related to its handling and maintenance [15]. In this sense Guerra [16] reports that the basins integrate a joint view of the behavior, conditions and human activities developed in them, since significant changes in any part of the basin can generate changes, effects and/or impacts downstream and in energy flows. output (discharge, solid and dissolved charges), among other consequences.

From the point of view of planning and regional development management, hydrographic basins are presented as objects of study with an integrated and unified vision of planning, enabling approaches and studies from the most diverse perspectives [17]. For Magalhães Jr [18] the watershed as a management and planning unit results from the complex interaction between the parts and the whole. The advantage is that the drainage network of a basin consists of a preferred path in most cause-effect relationships, especially when dealing with the water environment. The disadvantages are that municipalities and state boundaries do not always respect basin dividers. According to Guerra [16], the management of basin plans in Brazil, for the most part, only addressed the aspect of the use of water resources (irrigation or sanitation or energy generation), causing problems of a social, environmental, economic, political and cultural. This is because these plans are not always related to sustainable development, since the environmental capacity to support development always has a limit, beyond which all other aspects will inevitably be affected. Faced with the need to understand scenarios within this approach, authors such as Rebouças [4] suggest evaluating the environmental damages of a region, through the inclusion of factors such as water availability and demand, in addition to geo-environmental and sociocultural peculiarities, in order to guarantee the good-being of populations, economic development and conservation of environmental heritage. Currently, the management of water resources through hydrographic basins occurs throughout the Brazilian territory, through the Union and the States [12]. The aforementioned authors also emphasize that all human activities are carried out at the level of the hydrographic basin and are based on the forms of occupation of the territory and use of its waters.

The concept of sustainable development, at the international level, arises from a “philosophy of development that, from a tripod, combines economic efficiency with social justice and ecological prudence, as premises for the construction of a solidary and just society” [19]. It is a continuous and complex process, the result of a long history of the relationship between man and nature [20]. For Zambam and Fernando de Aquino [21], sustainable development is the principle of quality of life, and for this to happen, changes in behavior regarding the use and exploitation of natural resources are necessary, linking political, economic, legal, technological and cultural conditions, which make this concept viable. Lustosa [22] contributes by saying that development is sustainable because it does not deplete natural resources and makes their use possible in the future. In Jacobi's view [19], sustainable development refers to a multiple strategy or model for society, since economic and ecological feasibility must be analyzed. It is a two-pronged process, where, on the one hand, restrictions

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to the exploitation of natural resources, technological development and institutional structure are considered. On the other hand, qualitative aspects related to equity, resource use and environmental damage are considered. In this sense, the author emphasizes that development must be focused on overcoming social deficiencies, basic needs and changes in living standards considered unsustainable, in order to conserve basic resources, especially agricultural, energy, minerals, air and water [19].

In this sense, Lustosa [22] describes sustainable development as the combination of “economic growth, quality of life, environmental protection, equity in income distribution, democracy, citizen participation and appreciation of culture”; in short, it is development that encompasses political, social, economic and cultural aspects. In this way, there is an interrelationship between environmental protection and economic development. Therefore, the principle of sustainability is not limited to economic and ecological issues, it is about a balance between all the elements that make up the environment, whether natural, artificial or cultural [22]; [23]; [24]. The concept of sustainable development, despite being treated as a world reference, serving as the basis for several international conferences, is a “term much criticized and fought by researchers from different areas” [25]. This is a contradictory concept, since its defenders emphasize the need to impose limits on the use of natural resources, while at the same time emphasizing advances in economic growth. In this way, the Brundtland Report is criticized, for not giving any direction to the concept, as it does not defend the position of ecologists or defenders of the inalterability of production and consumption models, which characterizes, for the author, duality, which under the appearance of an environmental preservation policy hides questionable practices, seeking to control new business opportunities.

Corroborating, Carvalho et al., [26] from their studies, denote that in addition to bringing a new perception of the environmental crisis, the concept of sustainable development ended up generating a series of questions regarding its understanding, which creates difficulties for the operationalization of the same. Although there is resistance to adopting sustainable development as an alternative model of development, and there is no consensual definition among researchers [27], the fusion between environmental risk and social insecurity is evident, making it clear that environmental issues go far beyond mere questions, of the utilitarian market reason [28]. In the view of Grubba and Hamel [29], to establish sustainable development, it is necessary to take into account the complexity of the environment and integrate it as part of this process. Faced with an anthropocentric notion, it can be said that “ecological effects have repercussions on human life, in its conservation, reproduction and evolution”. In this way, the authors affirm that there cannot be a development that is not sustainable. Based on this logic, Lacerda and Cândido [30] point out that, in practice, sustainable development is a great challenge for society, as it requires a holistic, systemic and interdisciplinary vision regarding the rational use of natural and built environments, in order to integrate local communities in the elaboration of strategies and plans. In summary, Melo Neto and Ribeiro [31] state that all development takes place at the local level, since this is the space for negotiations, conflict resolutions and initiatives. From this point on, community involvement in local projects results in transformations that possibly imply the creation of a sustainable environment.

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Given this scenario, it is possible to affirm that in recent decades, the concept of sustainable development has acquired greater reach internationally [32]. World authorities have met at various conferences, including the Stockholm Conference in 1972, the United Nations Conference on Environment and Development (RIO 92), in 1992, the World Conference on Sustainable Development in 2002 (RIO + 10), the United Nations Conference on Sustainable Development (RIO + 20), in 2012, where participating countries sign agreements and set long-term goals (UN, 2017). In these meetings, alternatives are discussed to reduce consumerism, use natural resources rationally and minimize environmental damage, with the aim of promoting a better quality of life for populations [32]. The principles of sustainable development are based on Agenda 21, a document approved by more than 180 countries during the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992 (RIO 92). The ideas contained in the document were assimilated by the organizations of the United Nations system and several international organizations [33]. Brazil and other countries in Latin America, as well as in the Caribbean, only started the changes towards sustainable development, 20 years after Rio-92 [34]. For the authors, much remains to be done to confront the multiple challenges of the future for the consolidation of this process. The realization of Rio-92 turned the Amazon into a target of public policies and international collaborations, such as the creation of protected areas, demarcation of indigenous lands and expansion of reserves [35]. For Sawyer, policies were a way of separating society and nature, except in the case of indigenous lands and extractive areas. The author states that although protected areas can prevent the extinction of endangered species, they are not enough to maintain ecological functions that require a wider space, since environmental sustainability is not limited to ecological corridors or isolated points, it depends on the entire territory, including human presence. Based on this understanding, Abramovay [36] concludes that the most important element in a sustainable development strategy in the Amazon is the systematic application of science and technology for the sustainable use and exploitation of its biodiversity, which presupposes business and political activities, very much different from those prevailing today.

Copetti and Lottermann [37] state that environmental inequalities regarding protection and access to natural resources demonstrate that the central point is not the promotion of nature's sustainability, but the way in which society appropriates and makes use of these resources, the that highlights and relates social inequalities with environmental ones. Thus, the authors emphasize that poverty and inequalities trigger environmental crises. In this sense, sustainable development happens as long as human needs are met, increasing the productive potential and equality among all, since poverty limits individuals, making it impossible to use the environment sustainably, which ends up increasing the pressure on it [38]. Currently, the values linked to sustainable development and respect for environmental policies have been institutionalized to a greater or lesser extent, worldwide, through the media, social and environmental movements, as well as through governments [39]. This development will be achieved through the creation and implementation of public policies that ensure an increase in national income, access to basic services (health, education and economy) and the reduction of environmental impacts arising from production and consumption systems [40]. Corroborating this understanding, Custodio and Vieira [24] point out that, for sustainable development to take

place, the population must have the right to intervene in the processes of activities that may cause some environmental damage. Given the above, even if there is no consensus on the concept of sustainable development, the difficulties related to the studies of this process and the diversity of understandings on the subject, should serve as motivation to create new visions and tools, in order to present and measure sustainability [41]. In view of the above, the spatial clipping at the level of the hydrographic basins of the State of Rondônia was adopted as a central element of analysis, due to its important role for strategic planning and environmental management. In this context, the objective of the study was to build a sustainable development index for watersheds in Rondônia, using factor analysis as an analytical model. With this, it is expected that the model presented by the research can contribute to future studies and, thus, serve as a basis for academic, technical-scientific discussion within this theme.

## **II. Analytical Model Proposal**

Factor analysis was used as a mechanism to build performance indices for each parameter studied. Factor analysis is a generic name given to a class of multivariate statistical methods whose main purpose is to define the underlying structure in a data matrix. In general terms, factor analysis addresses the problem of analyzing the structure of interrelationships (correlations) between a large number of variables, defining a set of dimensions, called factors. With factor analysis, the researcher can first identify the separate dimensions of the structure and then determine the degree to which each variable is explained by each dimension. Once these dimensions and the explanation of each variable are determined, the two main uses of factor analysis - data summarization and reduction - can be achieved. When summarizing the data, factor analysis obtains dimensions that, when interpreted and understood, describe the data in a much smaller number of concepts than the original individual variables. Data reduction can be achieved by calculating scores for each latent dimension and replacing the original variables with the same ones [42]. Santana [43]; Santana [44]; Santana [45]; Santana [46]; Santana [47]; and Cavalcante [48] are some of the important authors that corroborate the study by Hair et al., [42].

For the analysis of environmental, social, economic and political-institutional parameters, the municipalities were grouped by hydrographic basins, based on the distribution adopted by the Rondônia Secretariat for Environmental Development (SEDAM), as shown in table 1. It is also noteworthy that the Abunã river basin was not included in this work, as there are no cities in its coverage area.

Table 1: Index of sustainable development by river basins in Rondônia

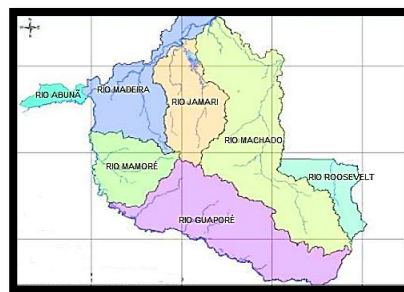
<b>Watersheds</b>	<b>Counties</b>
Madeira River	Nova Mamoré e Porto Velho
Mamoré Rive	Guajará-Mirim

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Guaporé Rive	Costa Marques, São Francisco do Guaporé, Seringueiras, São Miguel do Guaporé, Alta Floresta do Oeste, Alto Alegre dos Parecis, Corumbiara, Cerejeiras, Cabixi, Colorado do Oeste e Pimenteiras do Oeste
Jamari Rive	Candeias do Jamari, Itapuã do Oeste, Alto Paraíso, Rio Crespo, Ariquemes, Monte Negro, Buritis, Campo Novo de Rondônia e Cacaulândia
Machado Rive	Cujubim, Machadinho do Oeste, Vale do Anari, Thebroma, Ouro Preto do Oeste, Governador Jorge Teixeira, Vale do Paraíso, Jaru, Teixeirópolis, Ji-Paraná, Nova União, Mirante da Serra, Urupá, Presidente Médici, Alvorada do Oeste, Cacoal, Castanheiras, Espigão do Oeste, Pimenta Bueno, Chupinguaia, São Felipe do Oeste, Vilhena, Primavera de Rondônia, Rolim de Moura, Novo Horizonte do Oeste, Parecis, Nova Brasilândia do Oeste e Santa Luzia do Oeste
Roosevelt Rive	Ministro Andreazza

Source: Prepared from SEDAM data.

Figure 1 - Division of the Hydrographic Network of the State of Rondônia



Source: Prepared from SEDAM data.

**2.1 Analytical model**

This is a factor analysis study. The model in question follows the calculation reasoning proposed or applied by Reis [49]; Hair et al., [42]; Santana [43], [44], Santana [47], Gama et al., [50]; Fávero and Belfiore [51]. This model has already been tested and applied in other studies, such as Cavalcante [48], Paraguassu-Chaves et al., [52]; [53]; [54]; [55]; [56]; [57], where it was possible to build indexes within this methodological perspective.

A model of factor analysis can be presented in the matrix form as in Dillon; Goldstein [58]:

$$X = \alpha F + \epsilon(1)$$

Then,

X = is the p-dimensional vector transposed from observable variables, denoted by  $X = (x_1, x_2, \dots, x_p)$ ;



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$F$  = is the  $q$ -dimensional vector transposed from non-observable variables or latent variables called common factors, denoted by  $F = (f_1, f_2, \dots, f_q)$ , where  $q < P$ ;

$\varepsilon$  = is the  $p$ -dimensional vector transposed from random variables or unique factors, denoted by  $\varepsilon = (e_1, e_2, \dots, e_p)$ ;

$\alpha$  = is the array  $(p, q)$  of unknown constants, called factorials loads.

According to Gama et al., [50]; Santana [47], in the factorial analysis model it is assumed that specific factors are orthogonal, among themselves, with all common factors. Normally,  $E(\varepsilon) = E(F) = 0$  and  $Cov(\varepsilon, F) = 0$ . According to the authors, the initial structure used to determine the array of factorials loads, in general, may not provide a significant pattern of variable loads, so it is not definitive. This initial structure can be done by several methods of rotation of the factors, as Dillon and Goldstein [58]; Johnson and Wichern [58]. It was used the VARIMAX method of orthogonal rotation of the factors for this study.

The VARIMAX method is a process where the reference axes of the factors are rotated around the source until some other position is reached. The objective is to redistribute the variance of the first factors to others and to achieve a simpler and more theoretically significant factorial [42]; [43]; [47]; [50]; [49].

The choice of factors was carried out through the technique of latent root. So, the array of factorials loads, which measures the correlation between the common factors and observable variables, is determined by means of the correlation matrix, as Dillon and Goldstein [58].

For the determination of sustainable development indexes, the matrix of factor scores estimated by the factorial basis orthogonal rotation process was adopted, as pointed out by Santana [45]. The factor score, by definition, places each observation in the space of common factors. For each factor  $f_j$ , the  $i$ -th factor score extracted factorial score is defined by  $FI_j$ , expressed as follows [58]:

$$F_{Ij} = b_1 x_{i1} + b_2 x_{i2} + \dots + b_p x_{ip} \quad (2)$$

Then:

$b_i$  = are the estimated regression coefficients for the  $n$  Common factorials scores;

$x_{Ij}$  = Are the  $n$  Observations of  $p$  Observable variables.

$i = 1, 2, \dots, n$ .

$j = 1, 2, \dots, p$ .

To arrive at the equation that represents the Performance Index, Gama et al., [50]; Santana [46], show the evolutionary sequence of formulas from the previous equation. It turns out that even if the variable  $FI_j$  is not observable it can be estimated through the factorial analysis techniques, using the matrix of observations of the vector  $x$  of observable variables. In factorial notation, equation 2 becomes:

$$F_{(n,q)} = X_{(n,q)} b_{(p,q)} \quad (3)$$

In Equation 3,  $F$  is the matrix of the estimated regression from the  $n$  Factorials scores and it can be affected by both the magnitude and the measurement units of the variables  $x$ . To work around this kind of problem, replace the variable  $x$  by the standard variable  $w$ , given the ratio of the deviation around the average and the standard deviation of  $x$ , as follows:

$$\frac{x_i - \bar{x}}{S_x}$$

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With these values, Equation 3 is modified making equation 4 possible, then:

$$F_{(n,q)} = W_{(n,q)} \beta_{(p,q)} \quad (4)$$

Based on equation 4, the beta weights matrix ( $\beta$ ) with  $q$  standardized regression coefficients, replaces  $b$ , given that the variables are standardized on both sides of the equation. Pre-multiplying both sides of equation 4 by the value  $\frac{1}{n}w'$ , in which  $n$  is the number of observations and  $W$  is the transposed matrix of  $w'$ , it makes it possible to reach the following equation:

$$(5)$$

The Matrix  $\frac{1}{n}w'w$ , therefore is the matrix of intercorrelated variables or correlation matrix among the observations of the matrix  $x$ , designated by  $R$ . The Matrix  $\frac{1}{k}w'F$  It represents the correlation between the factorial scores and the factors themselves, denoted by  $\Lambda$ . With this, rewriting the equation 5, one must:

$$\Lambda_{(p,q)} = R_{(p,p)} \beta_{(p,q)} \quad (6)$$

If the matrix  $R$  is non-singular, one can pre-multiply both sides of equation 6 by the inverse of  $R$ , obtaining:

$$\beta = R^{-1} \Lambda \quad (7)$$

Substituting the  $\beta$  vector into equation 4, we obtain the factorial score associated with each observation, as follows:

$$F_{(n,q)} = W_{(n,p)} R_{(p,p)}^{-1} \Lambda_{(p,q)} \quad (8)$$

In this way, the main formula of the Performance Index (I.D.) is arrived at, where the ID is defined as a linear combination of these factor scores and the proportion of the variance explained by each factor in relation to the common variance. The mathematical expression is now represented by the following formula:

$$ID_i = \sum_{j=1}^q \left( \frac{\lambda_j}{\sum_j \lambda_j} FP_{ij} \right) \quad (9)$$

Then:

$i = 1, 2, \dots, n$ .

$\lambda =$  is the variance explained by each factor;

$\sum \lambda =$  is the total sum of the variance explained by the set of common factors.

The factorial score was standardized (FP) to obtain positive values from the original scores and allow the hierarchy of the municipalities since the values of the performance index are between zero and one. The formula that allows this hierarchy can be seen by the following equation:

$$FP_i = \left( \frac{F_i - F_{min}}{F_{max} - F_{min}} \right)$$

It can be seen that  $F_{min}$  e  $F_{max}$  are the maximum and minimum values observed for the factor scores associated with the parameters observed by municipalities in Rondônia, framed in the level of hydrographic basins, for a period of 10 years. Thus, it is based on this understanding that it was possible to determine the performance indices adopted by this research.

### **2.1.2 Tests of adequacy of the factorial method to the mass of data**

According to Gama et al., [50]; Santana [46], the two main tests with the objective of assessing the adequacy of the method to the mass concern, first, the Bartlett sphericity test, which has the property of evaluating the general significance of the correlation matrix, that is, it tests the null hypothesis that the correlation matrix is an identity matrix. In addition to the Bartlett test, the Kaiser-Meyer-Olkin (KMO) test is also widely used and is based on the principle that the inverse of the correlation matrix approaches the diagonal matrix, in this case, it seeks to compare the correlations between the observable variables. Thus, both methods were used by this research as techniques for assessing the adequacy of the method to the surveyed database.

According to Dillon; Goldstein [58]; Reis [49]; Mingoti [60]; Gama et al., [50]; Santana [46] the mathematical formulas of these tests can be seen by the following equations:

(10)

Like this,

$r_{ij}$  = is the sample correlation coefficient between variables  $x_i$  and  $x_j$ ;

$a_{ij}$  = is the partial correlation coefficient between the same variables that is simultaneously an estimate of the correlations between the factors, eliminating the effect of the other variables.

According to Hair et al., [42], the  $a_{ij}$  should assume values close to zero, since it is assumed that the factors are orthogonal to each other. Thus, according to this same author, values of this test below 0.50 are unacceptable.

Bartlett's sphericity test tests the null hypothesis that the variables are independent, against the alternative hypothesis that the variables are correlated with each other. That is,  $H_0: R = 1$  or  $H_0: \lambda_1 = \lambda_2 = \dots = \lambda_p$ , which allows us to arrive at the following mathematical formula:

$$X^2 = - \left[ n - 1 - \frac{1}{6}(2p + 5) \right] \cdot \ln |R|$$

(11)

Where,

$|R|$  = is the determinant of the sample correlation matrix;

$\lambda$  = is the variance explained by each factor;

$n$  = is the number of observations;

$p$  = is the number of variables.

The statistic has an asymptomatic distribution of  $\chi^2$  with  $[0,5p(p - 1)]$  degrees of freedom. The Bartlett test is the most common method applied to test the homogeneity of variances [61].

### **2.2 Analysis tool**

The SPSS program, version 17, was used as an analysis tool, which enabled the application of mathematical knowledge and allowed the construction of performance indices based on each parameter analyzed: environmental, economic, social and political-institutional.

### 2.3 Levels of scale

The classification adopted by the research to express the results achieved by the river basins in Rondônia is described in table 2. To evaluate the results presented, the analysis scale developed by the Santa Catarina Federation of Municipalities FECAM [62] was adopted, as described in table 2.

Table 2: Analysis scale adopted in the research

Scale	Description
Low	0,000 – 0,499
Medium Low	0,500 – 0,624
Medium	0,625 – 0,749
Medium High	0,750 – 0,874
High	0,875 – 1,000

Source: FECAM.

The scale of analysis allowed classifying the indexes presented by the river basins of Rondônia in low, medium low, medium, medium high and high, according to the results obtained in this research.

### 2.4 Indicators raised by the survey

The model was built based on the following indices: environmental, economic, social and political institutional. The combination of these four indexes resulted in the sustainable development index, as indicated in the methodology (methodological script). The indicators raised and the respective research sources, which were part of the analysis of this work, are listed in tables 3, 4, 5 and 6, below.

Table 3: Environmental Index Indicators

Indicators	Source
Deforestation	INPE <a href="http://www.dpi.inpe.br/prodesdigital/prodesmunicipal.php">http://www.dpi.inpe.br/prodesdigital/prodesmunicipal.php</a>
Percentage of the area of the municipality occupied by Conservation Units	ICMBio SEDAM
Percentage of the area of the municipality occupied by Indigenous Lands	SEDAM

Source: Own elaboration.

Table 4: Economic Index Indicators

<b>Indicators</b>	<b>Source</b>
Gross domestic product per capita	IBGE (Demographic census)
Number of cattle	IBGE (Municipal Livestock Research)
Rice production (% in relation to the State)	IBGE (Municipal agricultural production)
Coffee production (% in relation to the State)	IBGE (Municipal agricultural production)
Value of Pará nut production (R\$ thousand)	IBGE (Production of plant extraction and forestry)
Value of non-processed wood production (R\$ thousand)	IBGE (Production of plant extraction and forestry)
Cocoa production (% in relation to the State)	IBGE (Municipal agricultural production)

Source: Own elaboration.

Table 5: Social Index Indicators

<b>Indicators</b>	<b>Source</b>
Households with access to water (%)	IBGE (Demographic census)
Households with access to sewage (%)	IBGE (Demographic census)
Households with access to electricity (%)	IBGE (Demographic census)
Number of Health Units (per thousand inhabitants)	DATASUS
No. of hospital beds (per thousand inhabitants)	DATASUS
No. of doctors (per thousand inhabitants)	Atlas of Human Development in Brazil DATASUS
Illiteracy rate	IBGE (Demographic census)
Average household income per capita	IBGE (Demographic census)
Gini index of household income per capita	IBGE (Demographic census)
Proportion of people with low income	IBGE (Demographic census)
• % population with income <1/2 MW	IBGE (Demographic census)
•% population with income <1/4 MW	IBGE (Demographic census)
Proportion of children in a low income household situation	IBGE (Demographic census)

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•% children income gift <½ SM	IBGE (Demographic census)
•% children income gift <¼ SM	IBGE (Demographic census)
Unemployment rate 16a and +	IBGE (Demographic census)
Child labor rate	IBGE (Demographic census)

Source: Own elaboration.

Table 6: Institutional Political Index Indicators

Indicators	Source
<b>Collection capacity</b>	
• Per capita budget revenue	Own preparation based on data from IPEADATA, STN / FINBRA
• % own revenue	Own preparation based on data from IPEADATA, STN / FINBRA
<b>Investment capacity</b>	
• investment expense per capita	Own preparation based on data from IPEADATA, STN / FINBRA
• investment expense over realized expense	Own preparation based on data from IPEADATA, STN / FINBRA
<b>Per capita expenses by function (R\$)</b>	
• Education and culture	Own preparation based on data from IPEADATA, STN / FINBRA
• Health and sanitation	Own preparation based on data from IPEADATA, STN / FINBRA
<b>No. of municipal councils</b>	IBGE (Profile of Brazilian municipalities)

Source: Own elaboration.

## 2.5 Methodological roadmap

Next, the steps taken in this work will be described, which were considered essential for the consolidation of the process of construction of sustainable development indexes due to the object of the present study.

Table 7: Methodological Roadmap

Phases	Description
<b>1</b>	Classification of municipalities in the State of Rondônia by hydrographic basins.
<b>2</b>	Survey of official data for each municipality framed by hydrographic basins.

3	Preparation of an Excel spreadsheet with the available data according to the structure recommended by steps 1 and 2.
4	Use the SPSS tool, through factor analysis, based on the Varimax method.
5	Observe the data adequacy criteria for factor analysis.
6	Determine the performance indexes by municipalities aggregated by river basins.
7	Using the average performance indexes of the municipalities, determine the indexes for each parameter for each hydrographic basin.
8	Using the average of the parameters, determine the index of sustainable development by hydrographic basins.

Source: Own elaboration.

### **III. Analysis of The Sustainable Development Indices of The Water Basins in The State of Rondônia.**

From the 20th century, when environmental issues gained worldwide repercussion and the concept of sustainable development became a development model to be achieved, the need arose to measure the process towards sustainability, through instruments such as indicators. of development, “tools constituted by one or more variables that, associated through different ways, reveal broader meanings about the phenomena to which they refer” [63]. At first, traditional indicators (macroeconomic and pollution measurements) were not viable to indicate sustainability, making it necessary to develop new indicators that would be useful for public management decisions. Thus, it was foreseen in Agenda 21, the elaboration of effective methods for collecting and evaluating data, in the economic, social, institutional and environmental dimensions, from the local to the international scope [64]. The great challenge of sustainable development is to reconcile economic growth with environmental preservation and social justice. In this sense, indicators can be suitable instruments to assist this process, since they contain information on the economic, social and environmental situation of a given location. It is worth mentioning that sustainable development is a process under construction, so the formulation of indicators is an open work.

The main objective of indicators is to aggregate and quantify complex information, and facilitate their understanding [20]. Corroborating this understanding, Guimarães and Feichas [63] state that indicators can only be considered instruments of the sustainable development process if they add characteristics that allow the evaluation of social phenomena, enabling society's participation in the search for development, as well as offering subsidies for decision-making and project elaboration, by public managers, pointing out the possible

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variables, since society is built daily. The choice of indicators should “enable the temporal comparison within the same territory as well as the comparison between territories on a spatial and temporal scale” [63], which allows governments and society to project trends, analyze scenarios and direct public policies in the search for improvements. What is expected is that these indicators can facilitate the comparison of objectives with results, as well as the management process and indicate the gaps between the planning and execution processes of policies [63]. In this sense, “We seek to use a reduced number of truly binding indicators that provide systemic information relevant to different dimensions and sectors” [63]. The results obtained from the indicators present a partial view of reality, however, the studies must be carried out within a context that allows subsidizing analyzes and recommendations for local management. Therefore, it is necessary to “choose and develop methodologies, guidelines, parameters, criteria and instruments that adapt to the object of analysis” [64]. The complexity of problems related to sustainable development demands integrated indicators or aggregated indices that are easy to understand, as they will be the basis for the decision-making process in the search for solutions [65].

From the combination of indicators, it is possible to generate indices, “powerful tools in the process of consolidating ideas and also offering more tangible information to public policy makers” [66]. Assisting in numerous governmental actions, the indexes are also widely used by public managers, as a way of facilitating their communication, given the importance of strategic planning at the local level for the implementation of policies [66]. The formulation of sustainable development indices is a way of synthesizing a series of quantitative and semi-quantitative information, where each index results in a numerical value, the product of mathematical operations based on information collected, and which will serve as a basis for the evaluation of sustainability. According to these authors, among the existing indices, the ones that best fit the theme of sustainable development are the Sustainability Barometer, the Environmental Sustainability Index (ISA), the Sustainability Panel and the Ecological Footprint.

The construction of a sustainable development index must focus efforts so that a tool is acquired that addresses the complexity of the system in an accessible way. In this sense, even the simplest model of presentation of indices or aggregated indicators can contribute to achieving the goals of sustainable development [66]. Although several indicator systems address the dimensions of sustainable development, they cannot be adopted without being in the context of the analysis to be carried out, due to the differences that exist between the environments and the peculiarities of each place. However, this does not prejudice the use of indicators, which may vary according to the object of study [68]. A set of sustainable development indicators has been developed, tested and improved, however, this is justified by the fact that there is no consolidated methodology [68]. Choosing and considering the dimensions and aspects of the indicators of a given location are one of the main difficulties encountered, as the results will serve as a basis for decision-making, determining the sustainable development indices. The choice of indicators is important and deserves attention, so that they “reflect not only the knowledge of government institutions, but also the expectations of society” [69], since



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the results presented from these indicators determine a pattern normative, making a diagnosis viable, which will serve as a basis for formulating and evaluating public policies [67].

Next, the results achieved by the present study will be presented, aiming to demonstrate the scope of the model and the possibilities of analysis, depending on the proposed methodological instrument, as a suggestion of scientific criteria for decision making involving the theme of environmental management in hydrographic basins.

Table 8: Environmental, Economic, Social and Political-Institutional Index of the Hydrographic Basins of Rondônia (10 years ago)

<b>Hydrographic basin</b>	<b>Environmental Index</b>	<b>Economic Index</b>	<b>Social Index</b>	<b>Institutional Political Index</b>	<b>Sustainable Development Index</b>
Madeira River	0.288	0.333	0.502	0.364	<b>0.372</b>
Mamoré Rive	1.000	0.437	0.489	0.184	<b>0.527</b>
Guaporé Rive	0.206	0.246	0.338	0.361	<b>0.287</b>
Jamari Rive	0.071	0.223	0.367	0.229	<b>0.222</b>
Machado Rive	0.092	0.183	0.381	0.334	<b>0.247</b>
Roosevelt Rive	0.000	0.189	0.295	0.263	<b>0.187</b>

Source: Own elaboration.

Table 9: Environmental, Economic, Social and Political-Institutional Index of the Hydrographic Basins of Rondônia (current)

<b>Bacias Hidrográficas</b>	<b>Environmental Index</b>	<b>Economic Index</b>	<b>Social Index</b>	<b>Institutional Political Index</b>	<b>Sustainable Development Index</b>
Madeira River	0.597	0.498	0.382	0.200	<b>0.419</b>
Mamoré River	1.000	0.173	0.465	0.139	<b>0.444</b>
Guaporé River	0.476	0.174	0.521	0.341	<b>0.378</b>
Jamari River	0.249	0.199	0.446	0.332	<b>0.307</b>
Machado River	0.248	0.169	0.456	0.284	<b>0.289</b>
Roosevelt River	0.033	0.155	0.507	0.215	<b>0.227</b>

Source: Own elaboration.

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The evaluation of environmental, political-institutional, social, and economic parameters, based on the hydrographic basins of the Madeira, Mamoré, Guaporé, Jamari, Machado and Roosevelt rivers, allowed us to present the indices identified in each basin, as can be seen in tables 8 and 9 and in figures 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11. Subsequent to the results obtained, it was possible to determine the sustainable development index at the level of watersheds in the state of Rondônia.

Table 8 and Figure 2 present the environmental index of the hydrographic basins, where it is possible to observe that the Mamoré river basin (1,000), presents the high index, the best result, considering the scale of analysis adopted for the work. The low rate of deforestation and a significant number of conservation units and indigenous lands that make up this region are responsible for the environmental protection of this watershed. Table 9 and Figure 3 show that at present the environmental index of the Mamoré River basin remains at a high index (1,000), strong evidence that this region has low deforestation due to its preservation by conservation units and indigenous lands. At present, excluding the Mamoré River basin, all hydrographic basins are classified as having a low environmental index. The Roosevelt River basin (0.000) and (0.033) respectively 10 years ago and today, the Jamari River basin (0.071) and (0.249), the Machado River basin (0.092) and (0.248), the Guaporé River basin (0.206) and (0.476) and the Rio Madeira basin (0.288) and (0.597) respectively in the two periods within a 10-year interval have sustainable development indices considered low. Only the Madeira River basin currently improves its environmental performance index to medium low (0.597). The Roosevelt River basin with the lowest rates is a region that has high rates of deforestation and aggression to the environment.

Considering the Economic Index, all hydrographic basins had a low result. The Mamoré River basin (0.437) 10 years ago and the current environmental index (0.173) which in the environmental parameter obtained a high index, exhibits a low result, indicating an imbalance between the assessment factors of sustainable development. The Madeira River Basin with current economic index (0.498%) presented a significant result in relation to the others, as can be seen in tables 8 and 9 and in figures 4 and 5, which is due to livestock and wood production indicators, economic activities of great prominence in the state, considered in the economic parameter, having among the main producers, the municipalities that compose it. Despite the condition of the index considered low in the Madeira River basin, all other basins present economic indexes classified as low, distributed as follows: Madeira River Basin (0.333) and (0.498), Mamoré River basin (0.437) and 0.173), Guaporé River basin (0.246) and (0.174), Jamari River basin (0.223) and (0.199), Machado River basin (0.183) and (0.169), Roosevelt River basin (0.189) and (0.155) respectively in the two researched periods.

Regarding the social index, the Guaporé River (0.521) and Roosevelt River (0.507) basins had a low average index, while the other basins are classified with a low social index (Tables 8 and 9) and (Figures 6 and 7 ). 10 years earlier, only the Madeira River basin had a low average social index (0.502). The low and low average social index, according to the scale adopted in the research, is distributed as follows: Madeira River basin (0.502) and (0.382), Mamoré River basin (0.489) and (0.465), Guaporé River basin (0.338) and (0.521), Jamari

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River basin (0.367) and (0.446), Machado River basin (0.381) and (0.456), Roosevelt River basin (0.295) and (0.507) respectively in the two study periods. This fact is related to the low percentage of basic sanitation, lack of health structure and the issue of unemployment, observed in the development of the research, after analyzing the social indicators presented in Rondônia. Although the social index of the river basins has shown better results in relation to the economic index, these are still classified as low (considering the scale of analysis of the research), and they need effective government measures in order to strengthen the social indicators, since that social development issues have great relevance for sustainable development.

Regarding the institutional political parameter, the results presented are classified as low according to the scale adopted in the research. It can be seen in tables 8 and 9 and in figures 8 and 9, the low political-institutional indexes distributed as follows: Madeira River basin (0.364) and (0.200), Mamoré River basin (0.184) and (0.139), Guaporé watershed (0.361) and (0.341), Jamari River basin (0.229) and (0.332), Machado River basin (0.334) and (0.284), Roosevelt River basin (0.263) and (0.215) respectively for 10 years and nowadays. The low rates of political-institutional development demonstrate the need for actions and policies that can promote the improvement of the factors that influence the sustainable development of the State.

From the analysis of the environmental, economic, social and political-institutional indices presented by basins, it was possible to determine the sustainable development index in the hydrographic basins of the state of Rondônia.

In tables 8 and 9 and in figures 10 and 11 it can be seen that the Mamoré River basin (0.444), followed by the Madeira River basin (0.419), currently present the best sustainable development indices, compared to the indices obtained by the other hydrographic basins, despite being classified as a low sustainable development index. 10 years earlier, only the Mamoré River basin had an index considered to be medium-low (0.527).

The sustainable development index presented by the Mamoré River basin indicates that the environmental parameter influenced the final result.

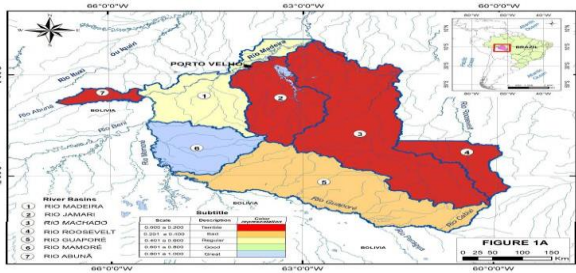
The results found, in general, reflect the way in which the State has been developing and the difficulties faced to maintain a balance between environmental preservation, economic growth, social equality and institutional political structure.

In the context of watersheds, the state of Rondônia has a low sustainable development index, according to the research, a scenario that needs to be urgently transformed, taking into account that sustainable development is the guarantee of better living conditions and well-being. performance and future generation, as defined in the Brudtland report.

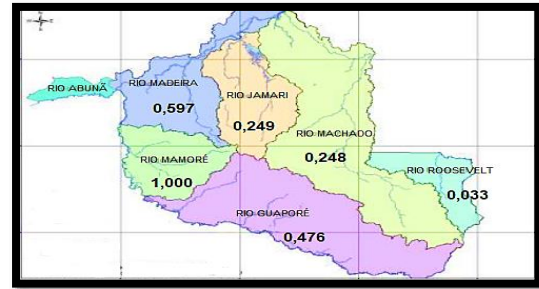
This result indicates that the objectives and guidelines of the state policy for water resources need to be applied efficiently, with the help of management tools and all the actors involved, so that in this way a development can actually be achieved that is considered sustainable.

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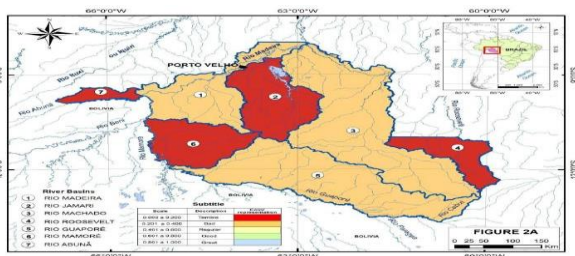
**Figure 2: Environmental index of the Rondônia watersheds (10 years ago)**



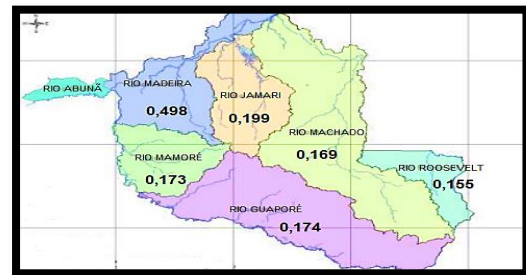
**Figure 3: Environmental index of the Rondônia watersheds (current)**



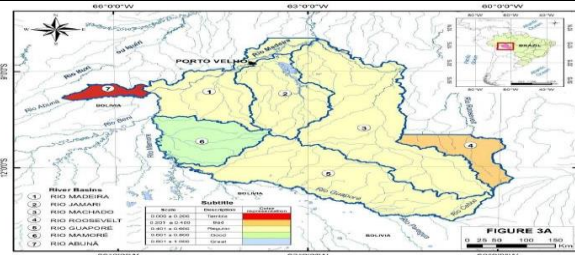
**Figure 4: Economic index of the Rondônia watersheds (10 years ago)**



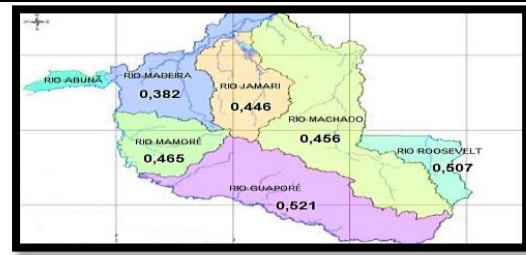
**Figure 5: Economic index of the Rondônia watersheds (current)**



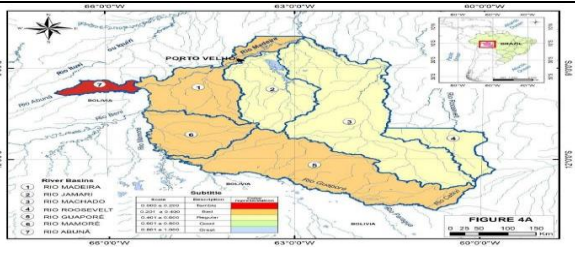
**Figure 6: Social index of the Rondônia watersheds (10 years ago)**



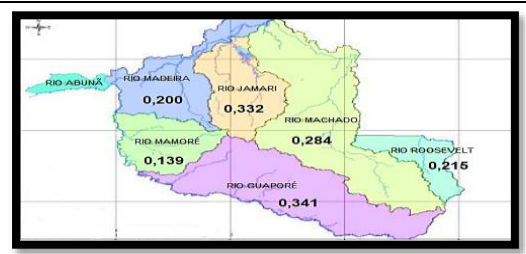
**Figure 7: Social index of the watersheds of Rondônia (current)**



**Figure 8: Institutional political index of the Rondônia watersheds (10 years ago)**



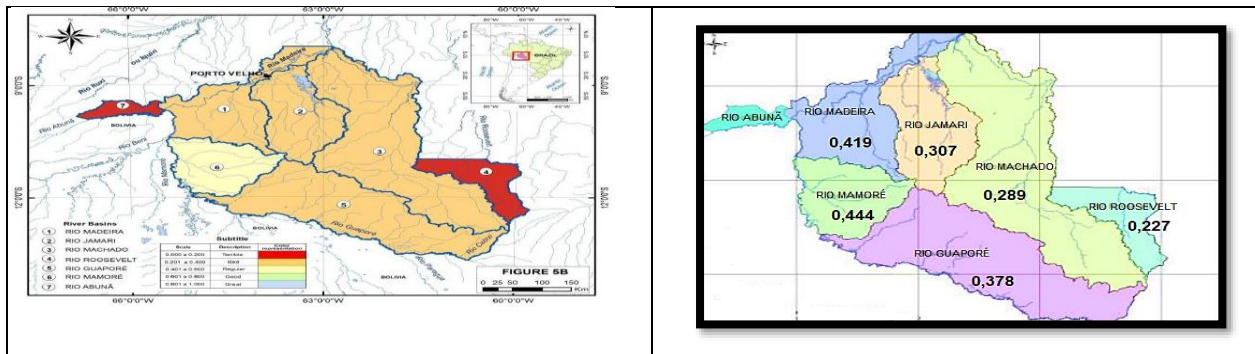
**Figure 9: Institutional Political Index of the Rondônia watersheds (current)**



**Figure 10: Sustainable Development Index of the Rondônia Watersheds (10 years ago)**

**Figure 11: Sustainable Development Index of the Rondônia watersheds (current)**

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## IV. Conclusions

Factor analysis showed efficiency as a multivariate statistical method in the construction of sustainable development indices for the river basins of Rondônia. The Mamoré River basin (0.444), followed by the Madeira River basin (0.419), currently present the best sustainable development indices, compared to the indices obtained by the other hydrographic basins, despite being classified as a low sustainable development index. 10 years earlier, only the Mamoré River basin had an index considered to be medium-low (0.527).

The results found, in general, reflect the way in which the State has been developing and the difficulties faced to maintain a balance between environmental preservation, economic growth, social equality and institutional political structure. It was also found that the incipient public policy of strengthening the paradigm of sustainable development at the level of river basins in Rondônia, has contributed to the advance of deforestation in Rondônia.

In the context of watersheds, the state of Rondônia has a low sustainable development index, according to the research, a scenario that needs to be urgently transformed, taking into account that sustainable development is the guarantee of better living conditions and well-being, performance and future generation, as defined in the Brudtland report.

This result indicates that the objectives and guidelines of the state policy for water resources need to be applied efficiently, with the help of management tools and all the actors involved, so that in this way a development can actually be achieved that is considered sustainable. Finally, it is highly recommendable to institutionalize regional public policies in the form of a Master Plan for the Rondônia Watersheds as a mechanism for planning and managing the respective areas, from the perspective of sustainable, integrated and inseparable development of their local communities.

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