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Interaction Between Surface and Underground Waters of the Itapemirim and Itabapoana River Basins in the Southern part of the State of Espírito Santo, Southeastern Brazil

Interação Entre as Águas Superficiais e Subterrâneas nas Bacias dos Rios Itapemirim e Itabapoana no Sul do Estado do Espírito Santo, Sudeste do Brasil

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Abstract

Itapemirim River basin and part of the Itabapoana River basin are located in the southern area of the State of Espírito Santo, covering 26 municipalities. Knowledge of these basins' hydrogeological characteristics provides information on the groundwater potential and the behavior of the river base flow during dry seasons. The objective of this study is to assess the relationship between surface and underground waters from the analysis of hydrograph units and information from tubular well logs. The Itabapoana River basin had the highest flow rates with mean specific capacity of 1415.1 m^3/h/m, while Itapemirim River basin wells yielded 0.6941 m^3/h/m. The percentage of underground discharge in relation to the total discharge exceeded 60% during all seasons in both basins.

Keywords: Aquifers; Base flow; Groundwater Management

Resumo

As bacias hidrográficas dos rios Itapemirim e parte da bacia do rio Itabapoana localizam-se no extremo sul do estado do Espírito Santo, abrangendo 26 municípios. O conhecimento da hidrogeologia dessas bacias, fornecem informações sobre o potencial hídrico subterrâneo e sobre o comportamento do fluxo de base dos rios, em períodos de estiagem. O objetivo do trabalho é de avaliar a relação entre águas superficiais e subterrâneas a partir das análises de hidrogramas unitários e das informações de um cadastro de poços tubulares. Os poços de maiores vazões são os perfurados na bacia do rio Itabapoana, onde a capacidade específica média é de 1415,1 m^3/h/m, contra valores de 0,6941 m^3/h/m, dos poços perfurados na bacia do rio Itapemirim. O percentual do deflúvio subterrâneo com relação ao deflúvio total apresentou valores superiores a 60% para todas as estações do ano em ambas as bacias.

Palavras-chave: Aquíferos; Fluxo de Base; Gestão de Águas Subterrâneas

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1 Introduction

The surface and underground waters must be considered as unique and inseparable natural resources that promote continuous interaction between superficial discharge and aquifers in the composition of the hydrological cycle. However, increasing human population and humans' natural predisposition to promote a better quality of life have demanded a more efficient management and planning of water resources. These actions should primarily aid the reasonable use of water resources not only now but also in the future, for the benefit of both humanity and the ecosystems that depend on them.

Groundwater has had a conspicuous importance as a source of domestic, agricultural and industrial water supply in Brazil and worldwide (Hirata, Zoby & Oliveira 2010), not only because of the increasing costs of water treatment and other factors that limit the use of superficial waters, but also because of the better understood advantages in using groundwater (Gonçalves 2001). A detailed study of the hydrographic basin hydrogeology can provide information on groundwater potential, being directly associated with the understanding of the base flow behavior (Alencar et al. 2006; Bicudo et al. 2011).

The study of the relationships between surface and underground waters should not separate one from the other, and any modification in one of these water resources can generate momentary or even irreversible transformations in the other.

The State of Espírito Santo is constituted by twelve hydrographic basins. The basins of the Itapemirim and Itabapoana rivers are located in the southern part of the state, and are greatly relevant to many environmental, social and economic aspects. Severe droughts can make surface reservoirs insufficient to comply with such water demands. Most of the Itapemirim and Itabapoana river basins overlie crystalline rocks and their potential as aquifers should be investigated as alternative for water supply (Gonçalves, Scudino & Sobreira 2005).

The adoption of the hydrographic basin as a planning unit makes a systemic and integrated vision possible, because of the clear delimitation and natural interdependence of climatic, hydrological, geological and ecologic processes (Hao et al. 2018). Having this concept in mind, we describe and interpret in this paper the arrangements, hydric potential and availability of the aquifers of the Itapemirim and Itabapoana hydrographic basins, considering the contributions of both surface and underground waters.

2 Methodology and Data Acquisition

The methodology adopted in this study makes use of the following parameters: rainfall seasonality, base flow in rivers e hydrogeological typologies.

In periods of water recession, associated with rainfall seasonality, the systems or hydrogeological units should be greatly responsible for the maintenance of the base discharges of the water courses in the region (Gonçalves, Scudino & Sobreira 2005). This aspect will help distinguish hydrogeological typologies with more or less capacity of water transmission from the aquifers to the water courses.

We must have in mind that the results obtained by production tests in wells are insufficient to measure the real aquifer potentialities and such results only indicate the capacity of water extraction by means of tubular wells, disregarding the parcel available for a sustainable exploitation (Costa & Bacellar 2010; Correa & Mello 2014; Fitts 2015).

Hydraulic equilibrium is considered to exist between the incoming water flow and the outgoing volumes in aquifer systems (Blom et al. 2017). Thus, by knowing how much is returned from groundwater to the rivers, it is possible to determine in the proportion of groundwater that participates in the total superficial flow rate. Besides, the underground unit flow rate can also be determined, as it is equivalent to the underground storage capacity of the basin in question (Gonçalves et al. 2019).

The study of the underground storage capacity of a hydrographic basin is based on the observation of the discharge during the period of water depletion or recession (Maréchal et al. 2020), which begins in April and lasts until the end of September in the study area. Depletion or recession means the decrease of water stored in the basin aquifer systems – in other words, the water course regime during periods of rainfall deficit. These parameters and their correlations were studied by means of hydrographs.

For the preparation of hydrograph units and the quantification of surface and underground components of the flow rates for the rivers of the study area, the data from four fluviometric stations located in the axes of the Itapemirim and Itabapoana rivers were used. It was observed that the fluvial regime of such rivers is well characterized, highlighting a recession period (April to September) and a flooding period (October to April) (Espírito Santo 2007).

The regulation of the base flows does not exclusively depend on the stored water resources – it also depends on the discharge of these resources to water courses. Such discharges are conditioned to the difference of hydraulic charges between underground deposits and fluvial channels for the displacement of water between the media (Bonsor et al. 2017; Killian et al. 2019). The relationship between the hydraulic charge and the transported flow rate is generally named recession curve. The recession curve characterizes the recession period of the basin aquifers by the decrease in stored water (Bernard-Jannin et al. 2016).

Due to the hydrogeological conditions of the study area, where the rocks permeability is low, the Maillet formula was used to resolve the recession curve (Gonçalves, Scudino & Sobreira 2005). The recession curve is adjusted to an expression such as the Maillet, according to Equation 1:

$$Q = Q_0 .\ e^{(-\alpha\ t)} \quad \textbf{(1)}$$

where:

Q_t = flow rate at instant t in m^3/s;

Q_0 = flow rate at the initial depletion instant t_0 in m^3/s;

α = recession coefficient;

t = period from the beginning of depletion in days;

e = base of Napierian logarithms (2.71828).

Taking the logarithmic form, the expression of the recession coefficient (α) results in, according to Equation 2:

$$\alpha = \frac{\log Q_0 - \log Q_t}{0.4343\ t} \quad \textbf{(2)}$$

The recession coefficient of a hydrographic basin is the inverse function of the size, the storage coefficient and the Darcy permeability coefficient of the aquifer systems. Therefore, the higher the size and hydrodynamic parameters of the basin aquifers, the lower the value of the recession coefficient (Castany 1967). The storage capacity is given by the Equation 3:

$$V = \frac{Q_0}{\alpha} \quad \textbf{(3)}$$

As α is calculated in days from the depletion curve, the storage capacity is given by the Equation 4:

$$V = \frac{86400\ Q_0}{\alpha} \quad \textbf{(4)}$$

This expression yields the groundwater volume above the base level stored at instant t_0 .

By means of this Equation 4 and the hydrographs drawn using daily discharge data, it was possible to obtain the recession coefficients of some segments upstream the basins of the Itapemirim and Itabapoana rivers (Table 1).

In the Itapemirim and Itabapoana river basins, 51 and 37 deep tubular well were registered, respectively. The transmissivity values (T) were obtained by pumping tests and resulting maximum and recovery flow rate values, interpreted by the method Cooper Jr. and Jacob (1946). It was performed in 15 tabular wells drilled in the Itapemirim river basin and 9 wells in the Itabapoana river basin. For the hydrogeological study of the Itapemirim and Itabapoana hydrographic basins, fluviometric and pluviometric data available on the Agência Nacional de Águas (ANA) on the site, by request, where a time series data distributed from the 1930's to 2018 can be obtained for the southern part of the State of Espírito Santo. Data from transverse profiles (depth versus section width) at the fluviometric stations were also used. The profiles show the river cross section at fluviometric stations. It was possible to analyze the processes affecting the river during the time series by considering width and depth variations, whether erosion or deposition of sediments took place in its bottom. Hypsometry and declivity maps for the Itaperirim and Itabapoana river basins were produced using SIG ArcGIS® version 10.2.2.

3 Results and Discussion

The Itapemirim River Basin, Figure 1 drains a total area of 6,014 km^2 encompassing 17 municipalities - 16 in the State of Espírito Santo (ES) and one in the State of Minas Gerais (MG) – with a population of almost 500,000 inhabitants.

The Itapemirim River headwaters are located in the Lajinha municipality (MG). The river runs for ca. 320 km from west to east, reaching Itapemirim (ES).

Table 1 Data from fluviometric stations.

Code	Station	River	Drainage Area (Km^2)	Recession Coefficients (days)
57450000	Rive	Itapemirim	2218	90
57580000	Usina Paineiras	Itapemirim	5167	65
57770000	São José dos Calçados	Calçado	144	81
57880000	Mimoso do Sul	Muqui do Sul	369	88

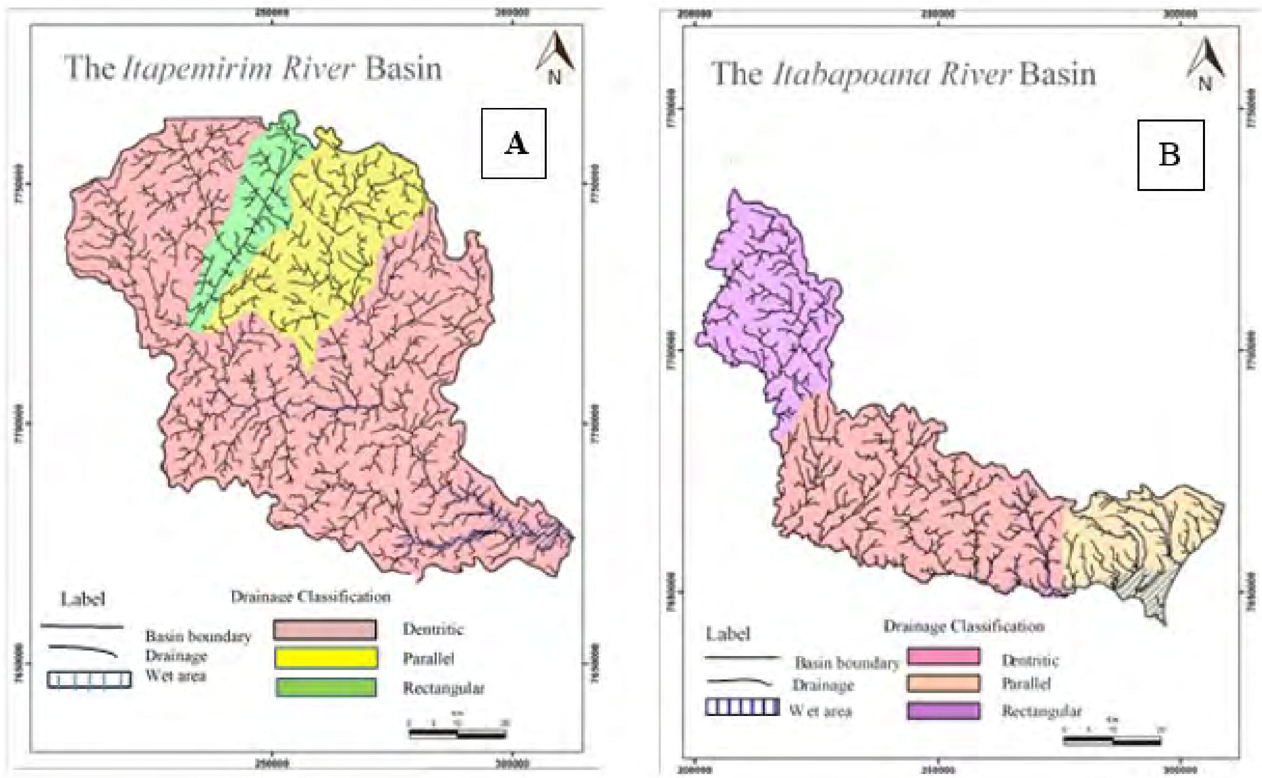


Figure 1 The hydrographic basins: A. Itapemirim River; B. Itabapoana River. Modified from CPRM (1997).

The Itabapoana River Basin, Figure 1 drains an area of 4,875 km^2 in the states of Minas Gerais, Espírito Santo and Rio de Janeiro, encompassing 18 municipalities whose total population reaches 652,000 inhabitants (IBGE 2019). The headwaters of the Itabapoana River are located in the Caparaó Ridge, in the Alto Caparaó municipality (MG) close to the Bandeira Peak.

3.1 Hydrogeology

The definition of the hydrogeological units was based on the characteristics of the litho-structural units identified in the study area, and, according to the behavior of the water conducing medium, these units can be characterized as aquifers. A proposal and systematization of the aquifer systems and their relationship with the lithostratigraphic units are presented in Table 2.

The values of the hydrodynamic parameters that characterize the registered wells are listed in Table 3. In Figure 2 the map of hydrogeological domains is presented. Due to the lithological and structural complexity, the hydrogeological behavior in the study area is also very complex.

Table 2 Aquifer systems of the Itapemirim and Itabapoana river basins.

Lithology	Aquifer system
Granites, granitoids, gneisses	Granitic-Gneissic
Fine- to coarse-grained sands in coastal bars	Coastal Deposits
Fine- to coarse-grained sandstones, argillites	Barreiras
Alluvial and colluvial deposits	Undifferentiated Detrital Covers
Quartzites, metagranites	Metasedimentary

Table 3 Wells of the aquifer systems of the Itapemirim and Itabapoana rivers basins.

Tabular wells	N.W.	Depth (m)	Q (m^3/h)	Q/s ($m^3/h/m$)	S.L. (m)	D.L. (m)
Itapemirim Basin	51	20.00 77.49 150.00	1.15 10.66 27.72	0.0360 0.6941 7.9200	1.00 8.02 38.00	5.00 44.15 95.72
Itabapoana Basin	37	16.00 72.20 300.00	0.79 10.26 32.69	0.0136 1.4151 6.5000	0.10 3.48 10.60	3.00 34.97 102.00

20.00- Minimum Value //77,49-Mean value //150,00-Maximum value; N. W. Number of Wells/ Q = Flow rate / Q/s = Specific Flow rate / S.L. Static Level / D.L. Dynamic Level

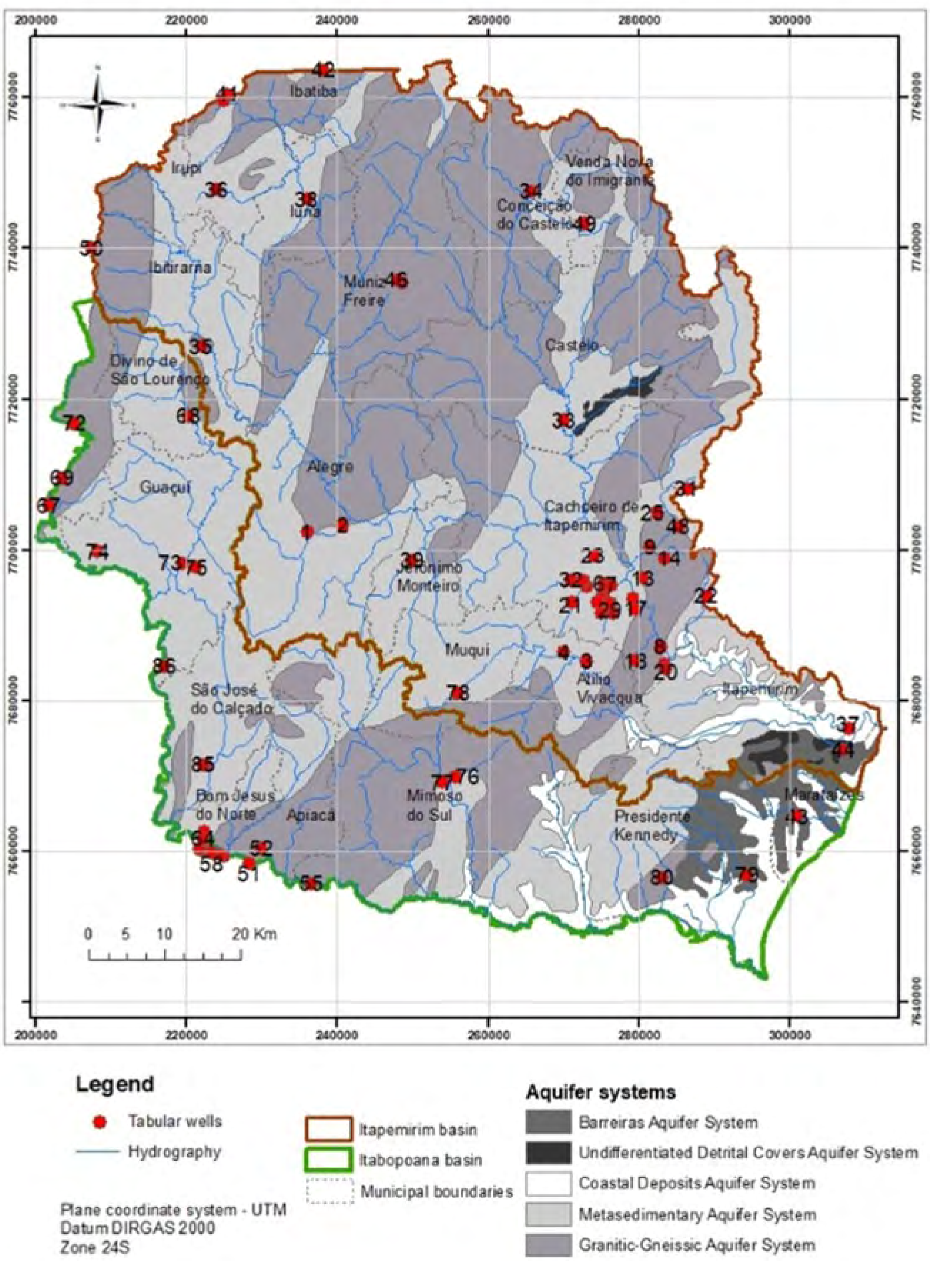


Figure 2 Aquifer systems of the Itapemirim and Itabapoana rivers basins.

For descriptive purposes, the groundwater occurrences were grouped according rock types and open structures in the following aquifer categories: aquifers in fractured rocks and aquifers in granular rocks. Regarding the aquifers by granular porosity, the groundwater storage takes place by means of pores or interstices in the rock. These aquifers are represented by the Tertiary-Quaternary covers and Recent alluvial deposits.

The aquifer medium of the fractured rocks is very weak when it comes to water storage and production and is dependent on the presence of joints, fractures, and the extension and lithology of the overlying weathering mantle (Maharjan & Donavan 2016). In the recharge of the aquifer system of crystalline terrains, the main regenerating agent of the groundwater resources is the surface hydrographic system that, acting in the zones of fracture-drainage coincidence, can ensure a constant recharge via alluvial deposits during periods of greater rainfall (Ohmer et al. 2017).

3.2 The Aquifer Systems

3.2.1. Granitic-Gneissic Aquifer System

This system is mainly represented by granites, gneisses, migmatites, granitoids, and charnockites. The aquifers are discontinuous, anisotropic, heterogeneous, fractured, either free or semi-confined by the altered rock. These aquifers present double porosity, with groundwater circulation and storage in discontinuities created by rock fracturing (fracture porosity) and interstices in the weathering mantle (interstitial porosity) (Le, Crosato & Uijttewaal 2018). In these aquifers the fracture porosity makes them more permeable and the interstice porosity more capable of groundwater storage. Due to the high local rainfall and the presence of a thick regolith, the underground recharge is potentialized. The transmissivity values obtained for eight wells drilled in these aquifers varied from 0.10 to 12.00 m^2/day, with a mean value of 3.99 m^2/day, and median of 2.20 m^2/day. The conductivity values varied from 0.01 to 0.04 m/day, with a mean value of 0.02 m/day.

3.2.2. Undifferentiated Detrital Covers Aquifer System

It is regionally verified in this system, despite the predominantly clayey-sandy lithology, a regular share of rainwater acting as an intermediate element in the water transmission to subjacent fissures. These Quaternary (Q) and Tertiary-Quaternary (T) covers almost always overlie rocks. They are mainly represented by sandy-clayey sediments, which are locally residual or show little transport.

3.2.3. Coastal Deposits Aquifer System

The coastal deposit aquifers are limited to the region of the Itapemirim River mouth and in general are not expressive in the basin. The sediments are composed of poorly sorted fine- to coarse-grained sands with a silty to clayey matrix. These aquifers are free, shallow, usually brackish, and of restricted use. The existing catchments are shallow wells known as cacimbas and ponteiras, which exploit the surficial water levels for domestic supply.

3.2.4. Metasedimentary Aquifer System

These aquifers are constituted by quartzitic metasediments of different ages and stratigraphic positions. They are favored by good groundwater storage and circulation conditions, which are improved when brittle structures (faults, fractures) are associated with them. Their occur as discontinuous linear bodies of varied thicknesses. These aquifers are fractured, discontinuous, anisotropic, heterogeneous, and free. The mean transmissivity value obtained for these rocks using the data from four wells is 210 m^2/day, with a maximum value of 610 m^2/day, a minimum value of 85 m^2/day, and a storage coefficient varying between 10^{-2} and 10^{-5}.

3.2.5. The Barreiras Aquifer System

The Barreiras Aquifer is porous, free, locally semi-confined, and of large spatial distribution. Porosity and permeability are in general good. It is composed of alluvial and fluvial sediments in a complex association of permeable/impervious strata (Araí 2006; Nunes, Silva & Boas 2011). The great heterogeneity results from the discontinuity of the aquifers (lenticular geometry) associated with permeability barriers caused by more argillaceous facies. This lithological association affects the permeability-porosity characteristics of the layers. The analysis of the hydraulic characteristics of the Barreiras Aquifer (Furrier, Araújo & Meneses 2006) indicates great heterogeneity of this underground source throughout its ample area of occurrence. The recharge of the Barreiras Aquifer is fundamentally rainwater falling on outcropping areas. During flooding periods, there is also the contribution from rivers. The thickness of the package varies a lot, once the basement crops out in some points, from a few meters to 150 m in the coastal region, with mean values of 60 m, estimated from tabular well logs. The mean transmissivity value obtained from eight wells was 162.54 m^2/day, a maximum value of 289 m^2/day, a minimum value of 95 m^2/day, and a storage coefficient varying between 10^{-2} and 10^{-5}. Due to the ample facies variation, this aquifer system is free, with characteristic heterogeneity and anisotropy (Obodovskyi et al. 2020). The thicknesses of these covers are not exactly known, but they may not reach more than 40 m, with a mean value of ca. 15 m. Thicknesses around 2 m may occur, which leads to an increased hydrogeological interest to the zones of higher potential. The system recharge is exclusively by means of direct infiltration of rainwater falling directly on the occurrences. Thirty-eight dug wells and 17 headwaters were registered in the Itapemirim River Basin. In the Itabapoana River Basin 22 dug wells and 31 headwaters were registered, the depths of these wells varying between 5.50 m (minimum) and 22.30 m (maximum), with a mean value of 12.63 m. the static levels vary from 4.20 m (minimum) to 20.60 m (maximum), with a mean value of 9.83 m.

3.3 Hydrology of the Itapemirim River Basin

To the north, the Itapemirim River Basin borders the State of Minas Gerais, corresponding to ca. 50% of the area. The geomorphology is very rugged, modeled on geological formations of remobilized fold belts. In the southern part of the basin, sedimentary deposits, the majority of which belonging to the Barreiras Formation, predominate. Considering the geology and the geomorphology, the basin is dominated by two regimes that influence the flow rate behavior. The first, to the north of the basin, is characterized by altitudes varying from 900 to 2,900 m (Figure 3A) and declivities from 20 to 45% (undulated to strongly undulated) (Figure 3B). The second is characterized by altitudes varying from 0 to 450 m and declivities from 3 to 8% (smoothly undulated). In the first, the surface flow rate is more constant and free, once the high altitudes, the high declivities, and the geological formation favor these conditions.

The historical series of the fluviometric data were collected in the stations from 1940 to 2018. The monthly mean flow rate values, considering the sum of all flow rate values during a month, seem to accompany the rainfall seasonality (Espírito Santo 2007). A drop in the values is observed from April to October (Figures 4A-B and 5A-B).

The correlation between the pluviometric and fluviometric data generates a data dispersion diagram, whose linear regression equation shows a monthly flow rate independent of rainfall (Figures 6A-B).

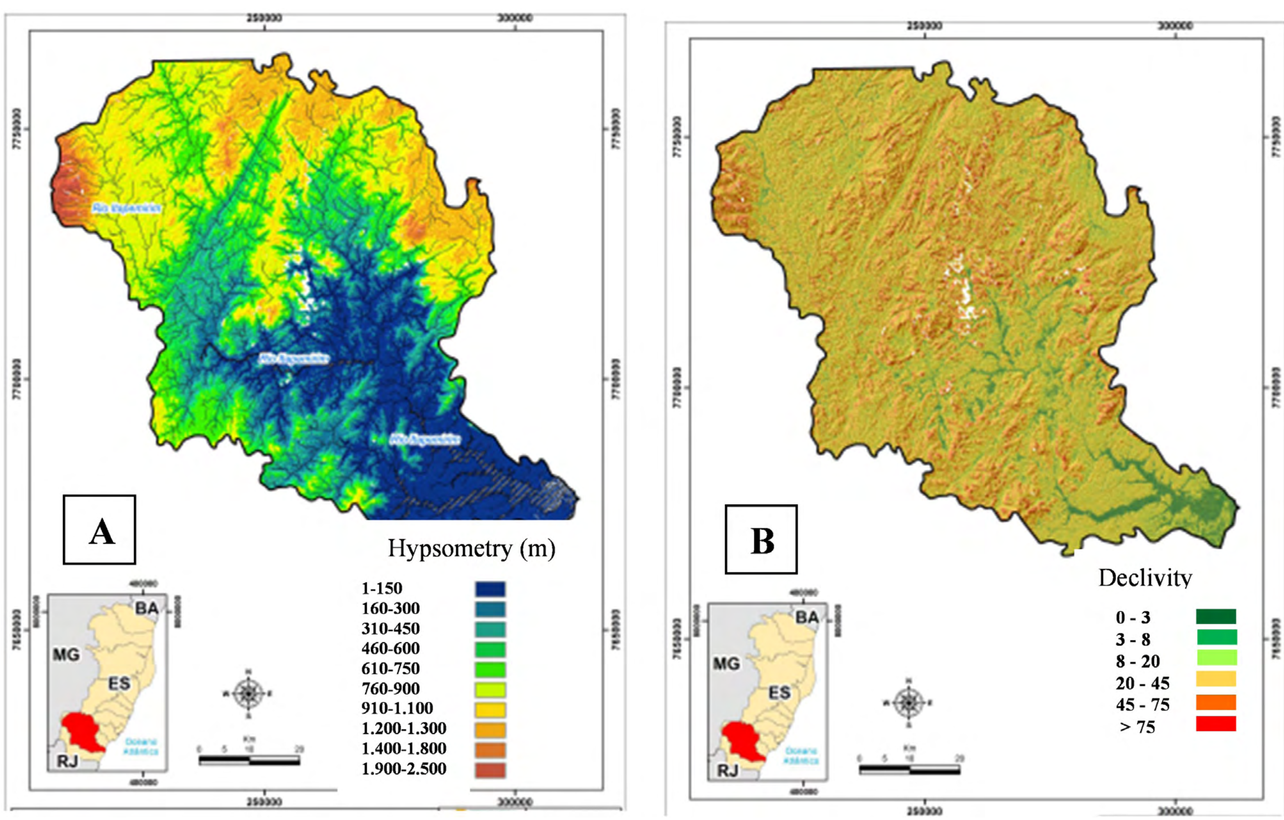


Figure 3 Itapemirim River Basin: A. Hypsometry; B. Declivity.

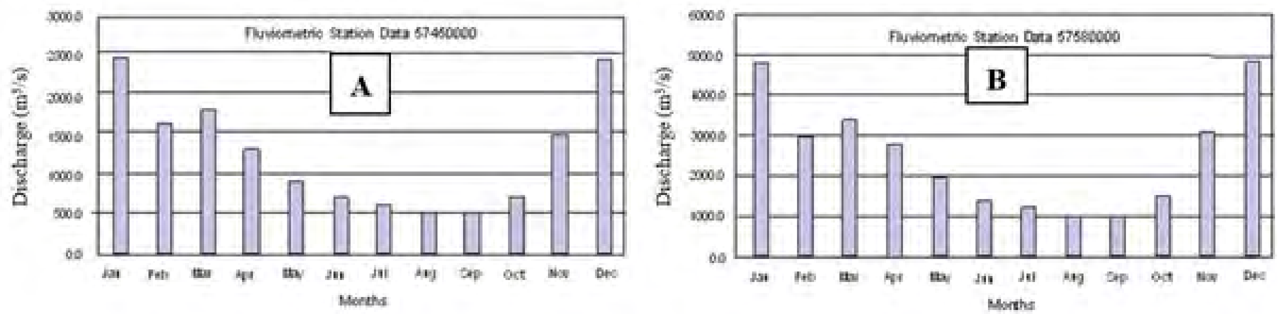


Figure 4 Monthly flow rates recorded in the fluviometric stations: A. Station Data 57450000; B. Station Data 57580000.

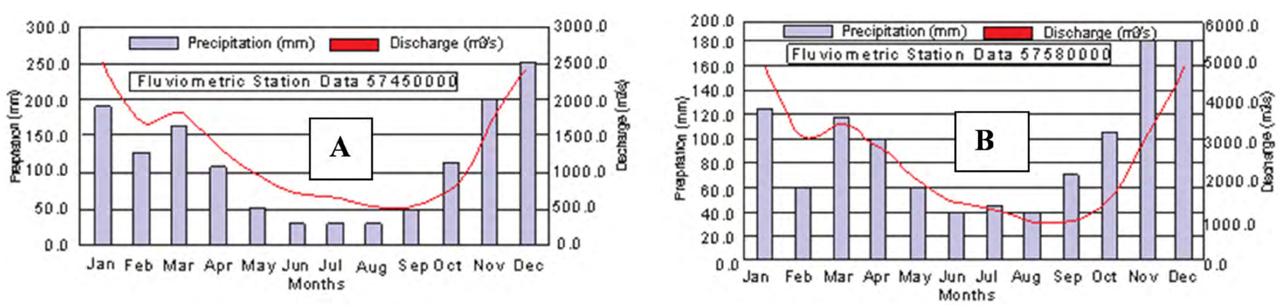


Figure 5 Relationship between rainfall data and monthly flow rates recorded in pluviometric and fluviometric stations: A. Station Data 57450000; B. Station Data 57580000.

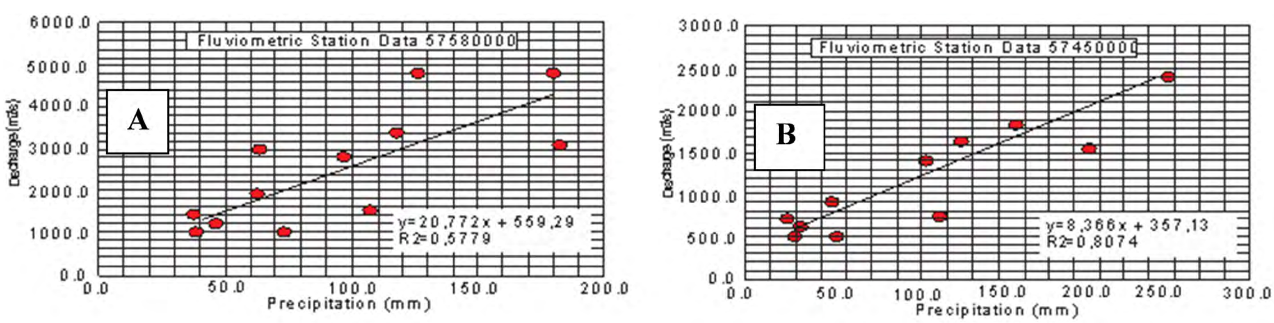
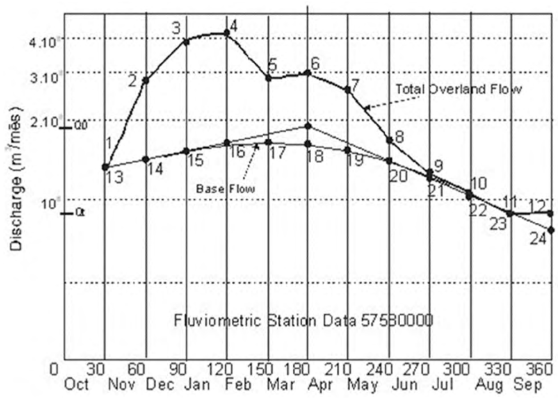


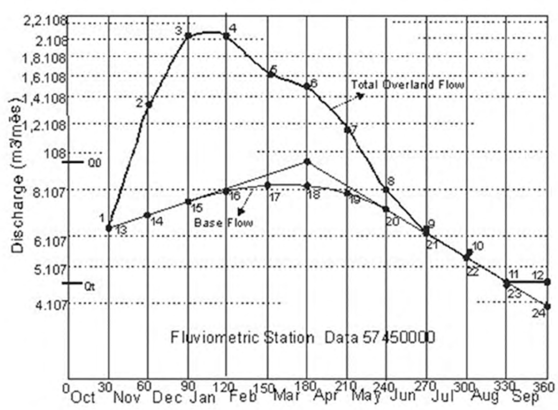
Figure 6 Dispersion diagrams of rainfall and flow rate data, recorded in pluviometric and fluviometric stations: A. Station Data 57580000; B. Station Data 57450000.

In Figures 7A-B the percentages of underground discharge are displayed in relation to the total discharges in the Itapemirim River basin, reaching very high values, greater than 60%, in both fluviometric stations, independently of the time of the year. The underground discharge or specific capacity expresses the capacity of the aquifer to recover per km^2, characterizing the potentiality of the aquifers of the sub-basin. Within this concept, it was observed that the contributions of the waters drained to the Itapemirim River decrease from up- to downstream. In this basin, the drilled wells have an average specific capacity of 0.6941 $m^3/h/m$.



A

Total Overland Flow (m^3)	Base Flow (m^3)
1 - 1,26 . 10^8	13 - 1,26 . 10^8
2 - 2,73 . 10^8	14 - 1,37 . 10^8
3 - 4,01 . 10^8	15 - 1,49 . 10^8
4 - 4,10 . 10^8	16 - 1,51 . 10^8
5 - 2,84 . 10^8	17 - 1,66 . 10^8
6 - 2,94 . 10^8	18 - 1,63 . 10^8
7 - 2,48 . 10^8	19 - 1,50 . 10^8
8 - 1,63 . 10^8	20 - 1,37 . 10^8
9 - 1,24 . 10^8	21 - 1,24 . 10^8
10 - 1,06 . 10^8	22 - 1,06 . 10^8
11 - 8,99 . 10^8	23 - 8,99 . 10^8
12 - 9,10 . 10^8	24 - 5,84 . 10^8
Total – 42,38.10^8	Total- 28,92.10^8



B

Total Overland Flow (m^3)	Base Flow (m^3)
1 - 6,25 . 10^7	13 - 6,25 . 10^7
2 - 1,35 . 10^8	14 - 7,15 . 10^7
3 - 2,15 . 10^8	15 - 7,65 . 10^7
4 - 2,15 . 10^8	16 - 8,00 . 10^7
5 - 1,60 . 10^8	17 - 8,10 . 10^7
6 - 1,50 . 10^8	18 - 8,10 . 10^7
7 - 1,17 . 10^8	19 - 8,00 . 10^7
8 - 8,00 . 10^7	20 - 7,30 . 10^7
9 - 6,10 . 10^7	21 - 6,10 . 10^7
10 - 5,65 . 10^7	22 - 5,65 . 10^7
11 - 4,75 . 10^7	23 - 4,75 . 10^7
12 - 4,75 . 10^7	24 - 3,95 . 10^7
Total - 134,7 . 10^7	Total- 81,00.10^7

Figure 7 Itapemirim River hydrographs: A. Station Data 57580000; B. Station Data 57450000.

3.4 Hydrology of the Itabapoana River Basin

The Itabapoana River Basin, is divided in two different geomorphological domains, the first from the centermost portion to the north, composed by the Differentiated Fold Belts of altitudes varying from 900 to 2,000 m (Figure 8A) and declivities from 20 to 45% (strongly undulated) and from 8 to 20% (undulated) (Figure 8B). The second domain, in the southern part of the basin, is constituted by the sedimentary deposits of the Barreiras Formation. In these terrains, altitudes from 500 to 0 m and declivities from 3 to 8% (smoothly undulated) predominate.

In the historical series of fluviometric data obtained from stations 57770000 and 55880000, it is observed that for the monthly mean values, the sum of all flow rate values obtained during the month, there is a tendency of dropping from April to October. From November to January rises in the flow rates are recorded in the fluviometric stations (Figures 9A-B).

The graphs of Figures 10A-B follow the same regimes of variations of the values presented for the pluviometric data, with drops in the flow rate from the second trimester, and beginning of the rise in the flow rate in beginning of the last trimester of the year. The graphs of Figures 11A-B show a correlation between these flow rate data and rainfall.

The correlation between the pluviometric and fluviometric data, considering the sum of the rainfall (mm) and flow rate (m^3/s) during a month, generating a mean value for the months of the year within the time series interval, shows that in both stations there are flow rate values that do not depend on rainfall. The correlation between the pluviometric (2141016) and fluviometric (57770000) stations localized in São José dos Calçados produced a data dispersion diagram whose linear regression equation points to a flow rate value of 20 m^3/s per month. For the pluviometric (2141015) and fluviometric (57880000) stations localized in Mimoso do Sul, the data dispersion diagram whose linear regression equation points to a flow rate value of 71 m^3/s per month, (Figures 11A-B). In other words, in both stations, during the drought period, the flow rate accumulated in the month reaches that value.

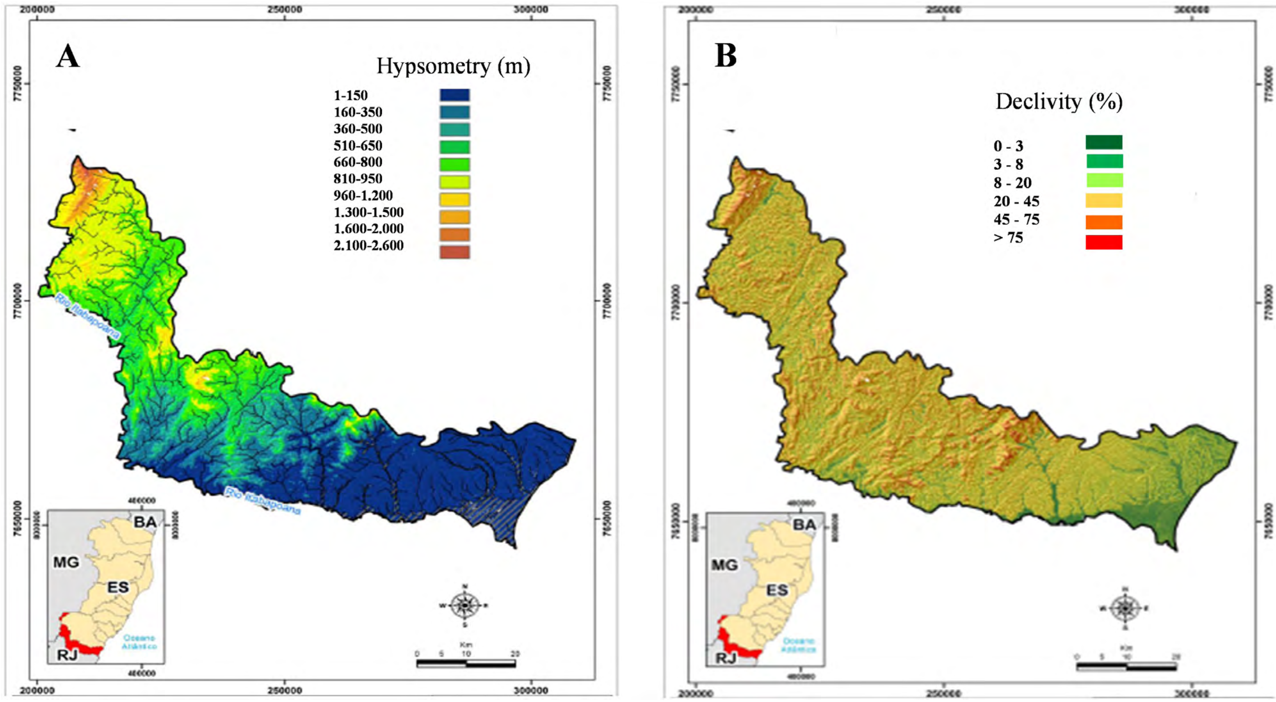


Figure 8 Itabapoana River Basin: A. Hypsometry; B. Declivity.

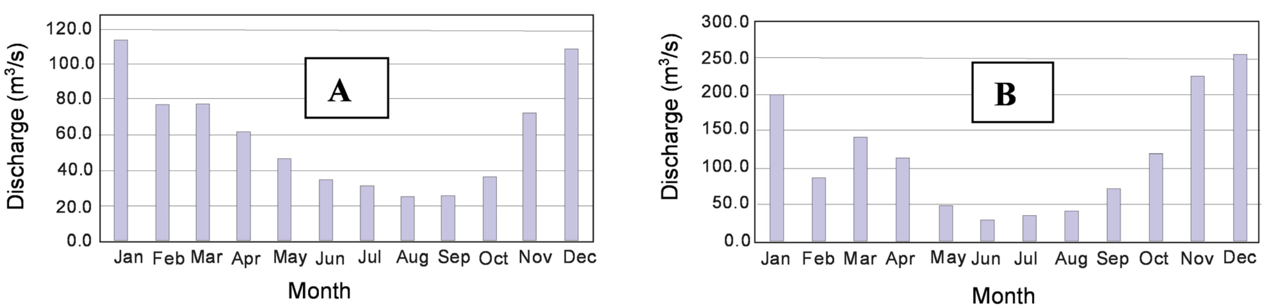


Figure 9 Monthly flow rates recorded in the fluviometric stations: A. Station Data 57770000; B. Station Data 57880000.

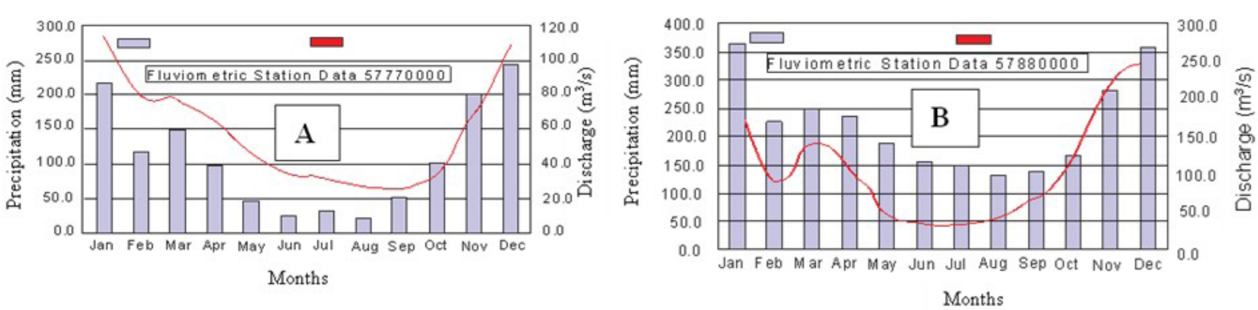


Figure 10 Relationship between rainfall and monthly flow rate data: A. Station Data 57770000; B. Station Data 57880000.

Figures 12A-B show that the percentages of underground discharges in relation to the total discharges are very high in the Itabapoana River sub-basin, exceeding 63.57% in the fluviometric station 57770000 and 72.76% in the fluviometric station 57880000, independently of the time of the year. As observed in the Itapemirim River basin, contributions of the waters drained to the Itabapoana River decrease from up- to downstream. In this basin, the drilled wells have an average specific capacity of 1415.1 $m^3/h/m$.

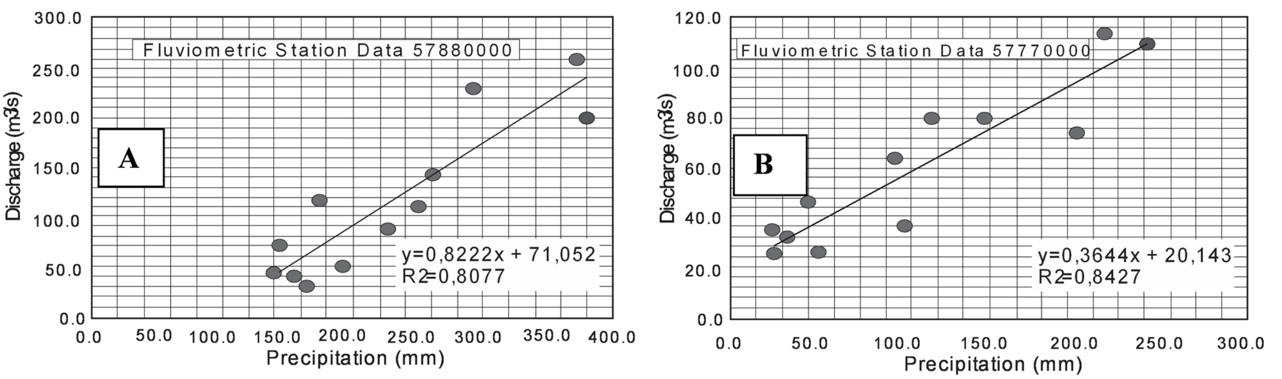
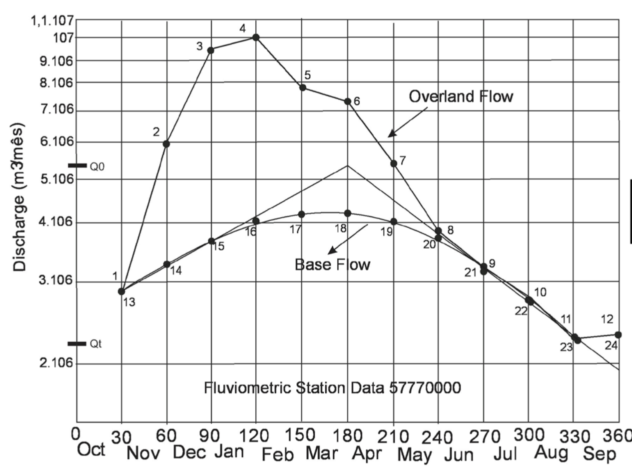
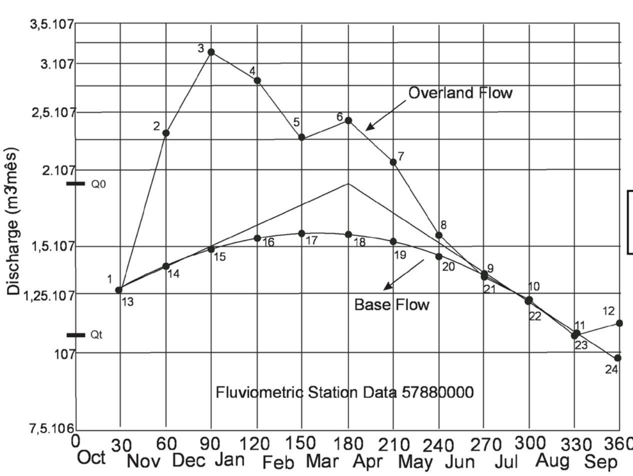


Figure 11 Dispersion diagrams of rainfall and flow rate data, recorded in the pluviometric and fluviometric stations: A. Station Data 57880000; B. Station Data 57770000.



A

Total Overland Flow (m^3)	Base Flow (m^3)
1 - 1,27 . 10^7	13 - 1,27 . 10^7
2 - 2,27 . 10^7	14 - 1,35 . 10^7
3 - 3,15 . 10^7	15 - 1,50 . 10^7
4 - 2,77 . 10^7	16 - 1,55 . 10^7
5 - 2,25 . 10^7	17 - 1,60 . 10^7
6 - 2,40 . 10^7	18 - 1,60 . 10^7
7 - 2,12 . 10^7	19 - 1,52 . 10^7
8 - 1,60 . 10^7	20 - 1,47 . 10^7
9 - 1,30 . 10^7	21 - 1,30 . 10^7
10 - 1,22 . 10^7	22 - 1,22 . 10^7
11 - 1,08 . 10^7	23 - 1,07 . 10^7
12 - 1,17 . 10^7	24 -9,95 . 10^6
Total- 22,60 . 10^7	Total-16,445.10^7



B

Total Overland Flow (m^3)	Base Flow (m^3)
1 - 2,95 . 10^6	13 - 2,95 . 10^6
2 - 6,00 . 10^6	14 - 3,20 . 10^6
3 - 9,55 . 10^6	15 - 3,65 . 10^6
4 – 1,00 . 10^7	16 - 4,00 . 10^6
5 - 7,97 . 10^6	17 - 4,10 . 10^6
6 - 7,30 . 10^6	18 - 4,13 . 10^6
7 - 5,45 . 10^6	19 - 4,00 . 10^6
8 - 3,96 . 10^6	20 - 3,93 . 10^6
9 - 3,20 . 10^6	21 - 3,12 . 10^6
10 - 2,80 . 10^6	22 - 2,80 . 10^6
11 - 2,37 . 10^6	23 - 2,37 . 10^6
12 - 2,42 . 10^6	24 - 2,42 . 10^6
Total- 63,97.10^6	Total- 40,67.10^6

Figure 12 Itabapoana Rivers hydrographs: A. Station Data 57770000; B. Station Data 57880000.

4 Conclusions

The predominant recharge in all study area, is via rainfall that infiltrates surface formations connected to fractures, and also contributions from water courses that cross fractured gneisses and granites. However, the rugged morphology does not favor infiltration, but the surface flow rate. The flow tends to the topographic lows where the perennial water courses drain the system. The natural outlets are headwaters in contact with poorly permeable strata of the crystalline basement, yielding weak flow rates.

The Itapemirim River Basin is characterized by aquifer zones of variable productivity. The wells that produce the highest flow rates are those drilled in metasedimentary rock aquifers, followed by coastal deposit aquifers. The wells that yield the low flow rates are those drilled in the granitic-gneissic aquifer system.

It is concluded that there is an important correlation between the geological, geomorphological and hydrologic conditioning factors in a hydrogeological environment in which medium to low mean porosities usually predominate, which reduces the infiltration in the Itapemirim River Basin.

The groundwater storage capacity is significant, considering that both basins are mostly constituted by fissured aquifers. However, these aquifers are overlain by a relatively thick weathering mantle and are also associated with a considerable hydrographic net, a fact that results from the permeable nature of the weathered covers.

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José Augusto Costa Gonçalves: conceptualization; formal analysis; methodology; validation; writing – original draft; writing review and editing; supervision; visualization. **Milena Stefany Lage Almeida:** formal analysis; methodology. **Eliane Maria Vieira:** formal analysis; methodology. **Brenda Luiza Ferreira Paiva:** methodology. **Mariana Araújo Mendes Ferreira:** formal analysis. **Lázaro Correa Marcellino:** methodology.

Conflict of interest

The authors declare no potential conflict of interest.

Data availability statement

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