ISSN 1980-0827 – Volume 19, Number 4, Year 2023

Water availability and land use/occupation in hydrographic basins in southwestern Goiás

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Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 19, Number 4, Year 2023

ABSTRACT
Obtaining in-depth understanding of the correlations between land use and occupation and the hydrological responses to that in hydrographic basins is a need. This knowledge is fundamental for effective water management in these areas, especially in predicting future scenarios and critical situations. This study evaluated the behavior of precipitation and surface flow duration concerning land use and occupation over 40 years in the Verdinho, Verdão, and Monte Alegre rivers, southwestern Goiás, Brazil. The methodology involved obtaining satellite images from the USGS Earth Explorer, processing, and supervised classification of land use/occupation using QGIS and its extensions, generating percentage values of native vegetation, irrigated agriculture, and built-up areas for each basin. Rainfall and river flow data were also collected from Hidroweb-ANA to obtain historical series. The results indicated that over a period of 40 years, land use and occupation caused alterations in the water availability of the studied hydrographic basins. During this period, there was a reduction of approximately 35% in the Q95% flow duration of the water bodies, even though annual accumulated rainfall remained relatively regular. The activity of grain irrigation increased by over 10,000% in the period, being the main responsible for the reduction of local water availability.

KEYWORDS: Water resources. Irrigation. Water scarcity.

1 INTRODUCTION

With a territorial extension of 8,386.827 km², the municipality of Rio Verde, Goiás, one of the main agricultural centers in the country, has experienced significant population growth in recent decades, going from 69,902 inhabitants in 1980 to 247,259 in 2021 (IBGE, 2023). This increase has proportionally elevated the demand for water resources in the municipality, leading to a growth in conflicts between public supply, industrial, agricultural, and livestock sectors. For instance, the Ribeirão Abóboras and Ribeirão Lages hydrographic basins, located within this municipality, host one of the main water conflicts in the central-western region of the country. There is not enough water supply to meet the users' demand. In August and September, the end of the dry season, the water situation in this water source becomes highly critical, leading to rationing (CBH BOIS, 2019).

A similar imbalance in the water balance between water supply and demand is observed in many other hydrographic basins in Brazil. The growing water demand from agricultural, livestock, industrial, and urban activities, paired with a constant (or reduced) water supply from surface and groundwater sources, can lead the country to incalculable social, economic, and environmental losses (LANDIM, 2021).

Land use and occupation directly impact the dynamics of the hydrological cycle in hydrographic basins, potentially changing water supply. For example, the removal of native vegetation in these areas can lead to increased peak flows (floods) and reduced minimum flows, as well as a decrease in the water retention time in the hydrographic basin and silting up of water bodies (HIPÓLITO E VAZ, 2017). Anthropogenic activities such as irrigated agriculture, livestock, industry, and human water supply, among others, contribute for a high demand for water in hydrographic basins, further reducing water availability in water bodies.

With the increased emphasis on global climate changes, it is necessary to deepen the understanding of the correlations between land use and occupation and hydrological behavior in hydrographic basins. This is fundamental knowledge for effective water management in these areas, especially in predicting future scenarios and critical situations.

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2 OBJECTIVE

This study aimed to assess the hydrological behavior (precipitation and surface flow duration) concerning land use and occupation over a period of 40 years, in 03 significant hydrographic basins in southwestern Goiás, Brazil.

3 MATERIALS AND METHODS

3.1 Study Area Definition

Three hydrographic basins in the municipality of Rio Verde, Goiás, were selected for this study: Rio Verdinho, Rio Verdão, and Rio Monte Alegre. These hydrographic basins are important areas in the municipality, as they have intense agricultural, livestock, and agro-industrial activities, and partly contribute to the water supply (Rio Verdinho) for the city of Rio Verde. Table 1 and Figure 1 present general information about these hydrographic basins, obtained from the Hidroweb-ANA system.

Table 1 - Characteristics of the Rio Verdinho, Rio Verdão, and Rio Monte Alegre hydrographic basins, in southwestern Goiás.

Hydrographic Basin	Characteristics
Rio Verdinho	- Main river length: 3,645.27 km - Hydrographic basin area: 1,427.33 km² - Drainage density: 2.55 km.km-² - Outlet: (Lat.: -17.48, Long.: -50.66) EPSG 32722, WGS 84, 22S - River gauge station: 60785005 (Lat.: -17.47, Long.: -50.77) - Rain gauge station: 1750008 (Lat.: -17.47, Long.: -50.77)
Rio Verdão	- Main river length: 2,414.51 km - Hydrographic basin area: 1,314.78 km² - Drainage density: 1.84 km.km-² - Outlet: (Lat.: -17.32, Long.: -50.99) EPSG 32722, WGS 84, 22S - River gauge station: 60774000 (Lat.: -17.36, Long.: -51.08) - Rain gauge station: 01751004 (Lat.: -17.36, Long.: -51.08)
Rio Monte Alegre	- Main river length: 2,324.84 km - Hydrographic basin area: 898.24 km² - Drainage density: 1.77 km.km-² - Outlet: (Lat.: -17.30, Long.: -50.70) EPSG 32722, WGS 84, 22S - River gauge station: 60778000 (Lat.: -17.33, Long.: -50.77) - Rain gauge station: 01943007 (Lat.: -17.33, Long.: -50.77)

Source: The authors, 2022.

The outlets selected for delimiting the study region were those close to the current locations of the river and rainfall monitoring stations. This choice allows for a more faithful correlation between the flow and precipitation data and the influence area of each hydrographic basin.

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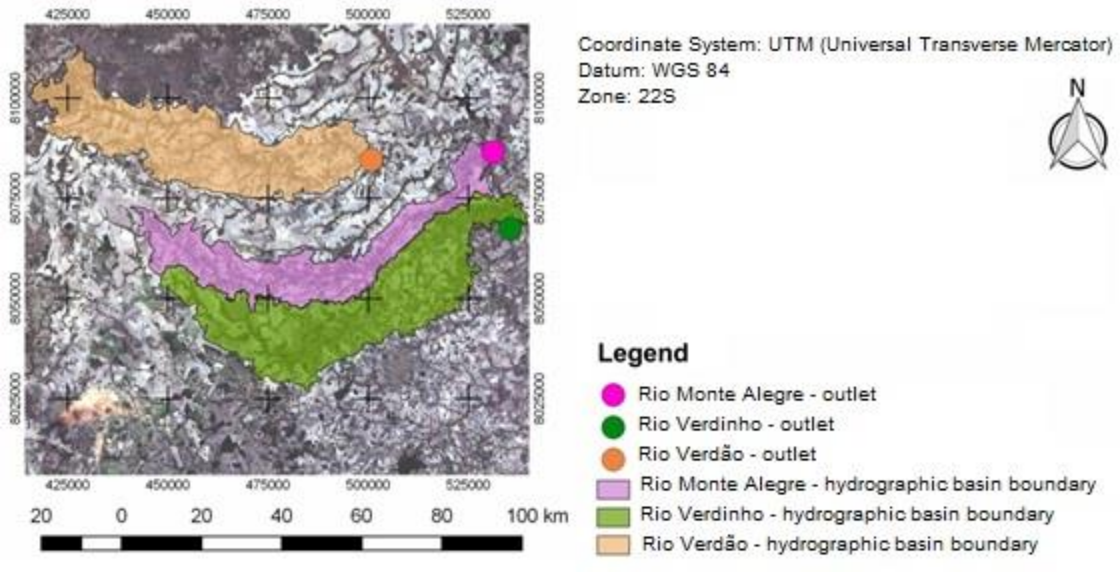
Figure 1 - Location map of the Rio Verdinho, Rio Verdão, and Rio Monte Alegre hydrographic basins, in southwestern Goiás.



Source: The Authors, 2022.

3.2 Data Collection and Analysis

This study was conducted considering the period from 1980 to 2020, analyzing variations in the following parameters in each hydrographic basin: Q95% flow duration, annual accumulated precipitation, percentage of native vegetation, total irrigated areas, and built-up areas.

3.3 Flow and Precipitation

Data on the flow of water bodies and precipitation in the hydrographic basins were obtained from Hidroweb, an integrated tool of the National System of Information on Water Resources managed by the Brazilian National Water Agency (ANA). It allows access to various telemetric data collected by the Brazilian National Hydrometeorological Network (RHN), such as rainfall and river flows, using the codes of the observed monitoring stations.

With these data, it was possible to calculate the Q95% flow duration and annual accumulated precipitation from 1980 to 2020.

3.4 Morphometry of the Hydrographic Basins

To obtain information regarding the area, main river length, and drainage density of each hydrographic basin (presented in Table 1), satellite images available in the United States Geological Survey (USGS) database were used. This step involved registering, logging in, and individually requesting the images through the LSDS Science Research and Development (LSRD) service. Using the Earth Explorer Platform on the USGS website, it was possible to identify the region comprising all three hydrographic basins and the municipality of Rio Verde, represented

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by the WRS Path 223 and WRS Row 072.

The QGIS software, a free and open-source geographic information system, was used for image processing.

3.5 Mapping of Native Vegetation

The mapping of native vegetation was not conducted annually but every 10 years. To identify these areas, the best representative satellite images for the study period were chosen. The images from 1980 and 1981 did not have good quality; therefore, images from 1982, 1990, 2000, 2010, and 2020 were selected for download and analysis of native vegetation, as shown in Table 2. The period of the images between July and August was considered, which has the least cloud interference and consequently better visibility.

Table 2 - Satellite images used for the analysis of native vegetation in the studied hydrographic basins.

Nomenclature and reference of satellite images per year
1982 - LM03_L1TP_239072_19820723_20180413_01_T2 (Date: 07/23/1982)
1990 - LT05_L1GS_223072_19900813_20170130_01_T2 (Date: 08/13/1990)
2000 - LT05_L1TP_223072_20000824_20161213_01_T1 (Date: 08/24/2000)
2010 - LT05_L1TP_223072_20100820_20161014_01_T1 (Date: 08/20/2010)
2020 - LC08_L1TP_223072_20200831_20200906_01_T1 (Date: 08/31/2020)

Source: The Authors, 2022.

The Dzetsaka Classification Tool, another extension of QGIS, was used for this step. This algorithm allows the selection of regions with pixel similarities for the classification of regions within the hydrographic basin. In this study, the hydrographic basins were divided into two regions: those referred to as "Native Vegetation" and those referred to as "Other," which represent everything that is not native vegetation.

More than 100 similar regions for each of these two types were manually selected and classified. The program then automatically generated the final result for all the hydrographic basins, containing the percentage of native vegetation for each satellite image found.

3.6 Mapping of Irrigated and Built-up Areas

The determination of irrigated and built-up areas present in the studied hydrographic basins was done manually using the satellite images obtained and the QGIS software for the years 1982, 1990, 2000, 2010, and 2020.

For each of the images, files in "false color composite" (NFC) were created by combining specific bands of each satellite (bands 4, 3, and 2 were used for Landsat 5; bands 5, 4, and 3, in that order, for Landsat 8, indicating the combination of near-infrared, red, and green bands). This composite facilitated the visualization and identification of different soil categories. With the processed images, a "polygon" type vector was created, and a "Class" category was included to refer to the classification given to each shape assigned to this same vector. Thus, for each studied basin, vector shapes were created, identifying possible irrigation

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pivot points and potential houses and buildings along the hydrographic basins.

Regarding irrigation pivots, the only method used for large-scale irrigation in the region, they exhibit distinctive geometric shapes, often a circular or semicircular shape.

As for built-up areas, small areas with similar color pixels and space between them are observed, usually connected to main roads by smaller roads (TESTEZLAF, 2017). The growth of built-up areas also implies an increased demand for water resources in the hydrographic basin, as these constructions are related to activities such as pig farming, poultry farming, cattle farming, and others.

The areas of the hydrographic basins were fully analyzed, and all manually delimited geometric shapes were used to generate an attribute table for each created vector. Within the "Attribute table" tab, a new field was created through the field calculator to obtain the specific value of each area of the delimited geometric shapes. The differentiation between the "Irrigation Pivots" and "Built-up Areas" classes was made using this same attribute table, and the sum of the irrigated and built-up units and areas was obtained using MS Excel spreadsheets.

3.7 Gap Filling

In years with missing or incomplete data, both for flow and precipitation, interpolation was performed using the simple regression method to fill in the null fields.

For the flow data of the Rio Verdinho hydrographic basin, the interpolated values were for the years 1992, 1993, and 1994. However, for the Rio Verdão and Rio Monte Alegre hydrographic basins, all flow data were already filled, so no interpolation was required.

In the study of precipitation, for the Rio Verdinho hydrographic basin, the interpolated data were for the years 1992, 1993, 1994, 2007, 2015, and 2016. As for the Rio Verdão hydrographic basin, the interpolated data were for the years 1990, 1991, 1992, 2015, and 2016. The Rio Monte Alegre hydrographic basin did not require interpolation as all data were already filled.

4 RESULTS

4.1 Flow Duration and Accumulated Annual Precipitation

Figures 2, 3, and 4 present the behaviors of annual Q95% flow duration and accumulated annual precipitation (between 1980 and 2020) for the Rio Verdinho, Rio Verdão, and Rio Monte Alegre hydrographic basins, respectively.

Observation for the three studied hydrographic basins shows a tendency of reduction in the annual Q95% flow duration over the evaluated years. This decline corresponded to a decrease in water availability at rates of 0.10, 0.16, and 0.08 m^3/s per year for Rio Verdinho, Rio Verdão, and Rio Monte Alegre, respectively. The percentage reduction in the annual Q95% flow duration over the 40 years represents 28%, 46%, and 33% for Rio Verdinho, Rio Verdão, and Rio Monte Alegre, respectively.

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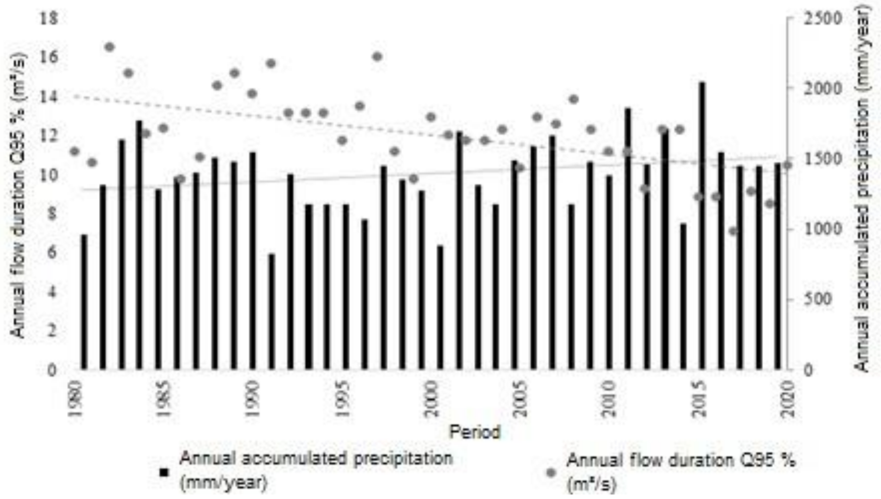
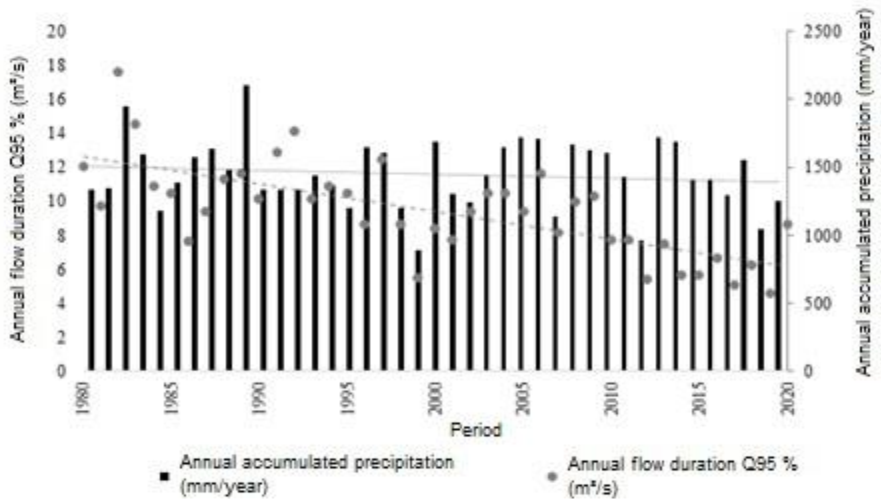
Figure 2 - Annual accumulated precipitation and annual Q95% flow duration of Rio Verdinho.



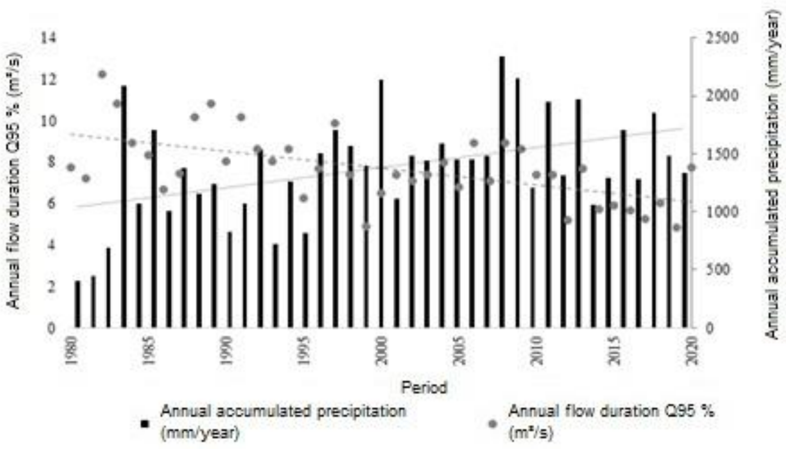
Source: The Authors, 2022.

Figure 3 - Annual accumulated precipitation and annual Q95% flow duration of Rio Verdão.



Source: The Authors, 2022.

Figure 4 - Annual accumulated precipitation and annual Q95% flow duration of Rio Monte Alegre.



Source: The Authors, 2022.

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On the other hand, the tendency for rainfall was the opposite. Despite fluctuating in some years, the annual accumulated precipitation showed a behavior with a rising or constant tendency, meaning there was no reduction in the volume of rainfall. The average annual accumulated precipitation in all the studied hydrographic basins was above 1,300 mm/year.

Souza et al. (2017) also observed a reduction in the flow rates of Rio das Fêmeas, an important hydrographic basin in western Bahia (also prominent as an agricultural region). However, in that case, the behavior of precipitation was a decline, opposite to what was found in this study.

Despite the maintenance or increase in rainfall volume in the studied hydrographic basins, the flow duration of the rivers in these areas is declining. This suggests that there are factors influencing the hydrological cycle in these areas over time, such as land use and occupation.

4.2 Land Use and Occupation

One of the factors that can explain the decrease in the annual Q95% flow duration in the studied hydrographic basins is the increase in water demand for irrigation in recent decades. Figure 5 depicts the growth of center pivot irrigated areas in the Rio Verdão hydrographic basin. Additionally, there has been significant growth of other human activities in these areas, indicated by the built-up areas. These areas mainly host agro-industrial activities such as poultry or pig farming, which also demand water resources. Figure 6 shows the increase in human activity in the hydrographic basins, in terms of total irrigated area and total built-up area over the years.

Over the studied decades, there has been significant growth in irrigated and built-up areas in all evaluated hydrographic basins. Between the 1980s and 2000s, the predominant activity in the region was livestock farming, which requires much less water than irrigated grain agriculture (mainly corn and soybeans), dominant in the following period, from 2000 to 2020.

For the Rio Verdinho hydrographic basin, the total area dedicated to center pivot irrigation increased gradually and more slowly. However, for the Rio Verdão and Rio Monte Alegre hydrographic basins, the sum of areas dedicated to center pivot irrigation more than doubled between 2010 and 2020. In the year 2020, for instance, the total irrigated area in the three areas of this study was approximately 5,200 hectares.

The water demand for irrigation depends on several climatic factors (temperature, precipitation, atmospheric pressure, etc.) and the plant physiological characteristics of the planted crops. Considering, for example, an irrigation depth of 200 mm per crop cycle (a value used in some regions of the state of Goiás for maize cultivation, according to Alves Júnior et al., 2017), the water demand from the studied water bodies (to irrigate the 5,200 hectares) was 1.04x107 m^3 in just 120 days (the crop production cycle time). This demand represents, in terms of water withdrawal from the water bodies, approximately 1.0 m^3/s, which is a considerable value and helps explain the reduction in the Q95% flow duration rates of the evaluated rivers. The irrigation depth of 200 mm is a conservative estimate, as other irrigation projects in the Rio Verde region use much higher values (close to 400 mm/cycle).

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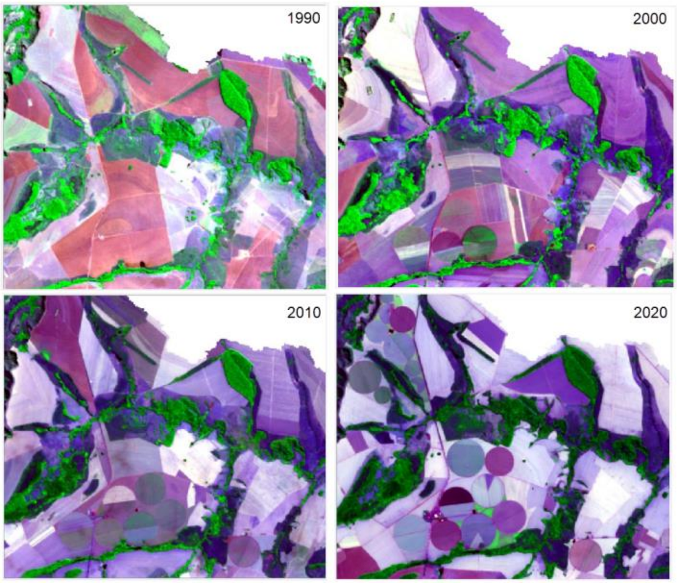
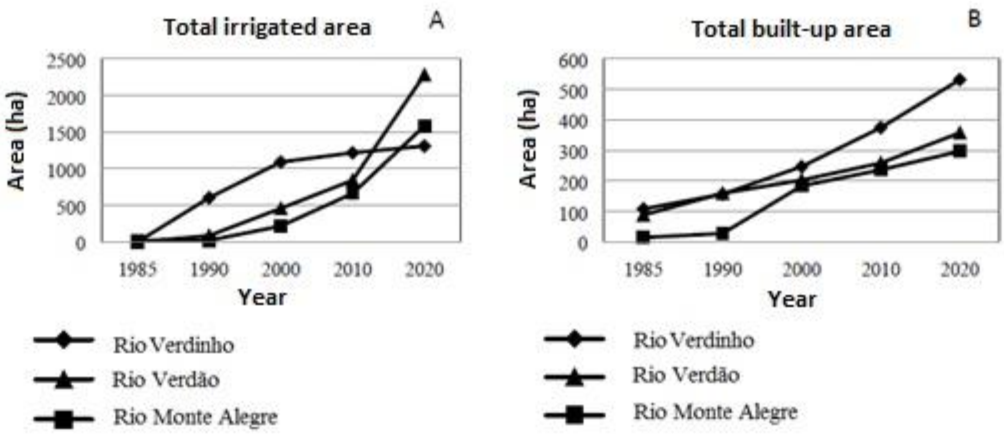
Figure 5 - Growth in land use and occupation for irrigated agriculture (indicated by circles in the images) in the Rio Verdão hydrographic basin.



Source: The Authors, 2022.

Figure 6 - Total irrigated area (A) and total built-up area (B) in the studied hydrographic basins.



Source: The Authors, 2022.

Another factor that drove irrigated agriculture in the region was the growth of corn and soybeans as commodities, with increased commercial export potential in recent years (G1, 2023). Similarly, the growth of agribusiness activities, with the installation of several companies in the city and region, played a role. Notably, grain processing industries and slaughterhouses are prominent, stimulating the growth of corn and soybean production for animal protein production.

In these hydrographic basins, there are also constructions related to cattle feedlots, grain storage silos, farms, and other activities that demand groundwater, such as poultry and pig farms. Each pig in finishing units, for example, requires about 8.3 liters of water daily (EMBRAPA, 2016). In a farm with 5,000 pigs in the finishing system, the water demand would be 41,500 liters a day, typically extracted from the underground aquifer.

The increased extraction of groundwater can reduce the availability of aquifers and affect the base flow of surface watercourses. Thus, groundwater consumption directly affects the water availability of water bodies, especially during dry periods (HIPÓLITO E VAZ, 2017; SCHMIDT et al., 2022).

4.3 Areas of Native Vegetation

Table 3 presents the statistical survey of the percentage of native vegetation obtained from satellite images over the years for the three hydrographic basins under study.

Table 3 - Statistics of the percentage of native vegetation in the hydrographic basins over the study years.

Hydrographic basin	Average (%)	Median (%)	Maximum (%)	Minimum (%)	Coefficient of Variation
Rio Verdinho	16.90	17.16	18.32	13.92	0.0115
Rio Verdão	15.18	14.82	17.35	12.52	0.0156
Rio Monte Alegre	15.77	16.53	17.29	13.70	0.0134

Source: The Authors, 2022.

It can be observed that the coefficients of variation for all the studied hydrographic basins presented very low values. This is an indication that there was basically no significant change in the total native vegetation between the years 1980 and 2020. These small variations may even fall within the estimated errors for the chosen method of image evaluation and processing. Therefore, it is understood that the reductions in the flow of the water bodies observed over the years do not have an important direct correlation with the loss of native vegetation in these areas. It is estimated that the increase in water demand (mainly for irrigation) is the main factor responsible for the decline in river flows.

According to the Brazilian Forestry Code (BRASIL, 2012), in the Cerrado biome, the native vegetation in a rural property should be 20% of the area (legal reserve) plus the areas of permanent preservation (APPs), which represent the springs, riverbanks, or other specific areas. In this study, it can be observed that the values of native vegetation do not exceed 19% (summing up legal reserves and APPs) in any hydrographic basin. That is, the conservation levels of these areas are very low.

It is worth noting that deforestation can have significant impacts on the hydrological cycle of hydrographic basins, especially on the rates of water infiltration into the soil and surface runoff, altering the water retention time in the drainage area. The presence of native vegetation, for example, increases the rate of water infiltration into the soil, favoring the increase of base flow (which will feed the water bodies during the dry season). Similarly, native vegetation favors the reduction of peak surface runoff, decreasing the intensity of floods. On the other hand, hydrographic basins with high levels of anthropization (deforestation, soil sealing, and other activities) are more susceptible to extreme hydrological events: low water flows in water bodies during dry season and floods during rainy season (VANZELA et al., 2010; HIPÓLITO E VAZ, 2017; SOUSA et al., 2019).

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Electronic Journal "Environmental Forum of Alta Paulista"

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5 CONCLUSIONS

Throughout the 40 years of study, it was observed that land use and occupation have caused changes in the water availability of the studied hydrographic basins. During this period, there was a reduction of approximately 35% in the Q95% flow duration rates of the water bodies, even though the annual accumulated precipitation remained relatively consistent.

The activity of grain irrigation, the main water-consuming activity in the world, showed the most significant growth during the studied period. In 40 years, the irrigated area in the hydrographic basins increased by more than 10,000%. Therefore, this is estimated to be the primary activity responsible for the reduction of local water availability.

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