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Spatial and temporal evaluation of water availability in vegetation in the Terra Nova-PE basin, using ADIVA

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ABSTRACT
The water availability in the vegetation is an important parameter to evaluate the water conditions of the place and the environment. Vegetation responds quickly to water availability. Thus, the objective of this study is to evaluate the water availability of vegetation in irrigated areas, riparian forest, and natural vegetation of the caatinga, during the period of 2021 and 2022 in the Terra Nova-PE basin using drone images. Twenty drone flights were carried out in different areas of the basin and the application ADIVA - Analysis of the Vegetation and Water Index. Water availability changes the environmental conditions of the place. The riparian forest responds very quickly to water availability. The caatinga biome is of great importance for retaining water during the rainy season and ensuring that the region continues to have healthier environmental water conditions throughout the year. This shows the great importance of the natural caatinga vegetation for water availability in the hydrographic basin, as well as for the efficiency of the environmental service provided by the hydrographic basin.

Keywords: Hydrology; NDWI; UAV; remote sensing

Introduction

The conditions of water availability in a hydrographic basin are of paramount importance for better environmental management of the area and decision-making regarding economic development solutions, solutions to social problems and ensuring water and food security.

Land surface water bodies provide crucial ecosystems and social services (Rad et al., 2021, Sohl et al., 2019; Pourmohamad et al., 2019). They are, however, vulnerable to various climatic and anthropogenic stressors (Rad et al., al., 2021). Understanding the dynamics of water bodies is critical for both short-term operations and long-term planning of water and land management. Remote sensing provides an inexpensive, consistent, and accurate approach to monitoring changes in surface water using upwelling electromagnetic radiation (reflected and emitted) from land surfaces (Rad et al., 2021).

Precise mapping of water availability in semi-arid regions can provide useful information for managing water resources, droughts, and the rainy season, supporting definitions of water policies and decision-making processes. Remote sensing techniques have demonstrated powerful capabilities to map and monitor surface waters considering water availability in targets Ji et al (2009). The most used methods are based on reflected solar radiation or on active microwave emissions McFeeters (1996). The first can be divided into single-band and multiband methods, where two or more combinations of spectral bands allow highlighting the difference between water surfaces and land areas. Near-infrared radiation (NIR) is used in single-band techniques because it is highly adsorbed by water, while highly reflected by vegetation and dry soil. Low reflectance values at NIR frequencies are associated not only with the presence of water, but also with wet and uncovered soils. To get around this problem, the joint use of other frequencies was investigated and the normalized water difference index (NDWI) together.

Different studies have been carried out by the Research Group SERGEO - Remote Sensing and Geoprocessing at the Federal University of Pernambuco, link - The Remote Sensing and Geoprocessing Laboratory (SERGEO / UFPE) carries out research, teaching and extension activities aimed at the use of technologies innovative methods for characterizing and monitoring natural resources, https://sites.ufpe.br/sergeo/, with the aim of assisting in the management of water resources in Pernambuco, Luz and Galvincio (2022A), Luz and Galvincio (2022B), Torres et al (2022A), Torres et al (2022B), Nishiwaki et al (2021).

The Terra Nova-PE basin is undergoing important spatial, social, economic and environmental transformations due to the São Francisco Water Integration Project-PISF. Thus, studies that may contribute to a better detailing of the hydroenvironmental conditions of the basin can be of paramount importance for its management.

This study intends to analyze the water conditions of the vegetation in areas of riparian forest and natural vegetation of the caatinga, using the ADIVA application and UAV- Unmanned Aerial Vehicle images.

Material and methods

The Terra Nova watershed is located in the semi-arid region of the state of Pernambuco, with an area of 4,909.09 km2 and is a sub-basin of the São Francisco River, Figure 1. It receives water from the PISF. It is in constant transformation due to having had this supply of water from the São Francisco.

The NDWI used in this study follows the same equation and class interval proposed by Alex et al (2017), in which negative values correspond to water. High values and positive vegetation.

In this study, four flights of the UAV-Unmanned Aerial Vehicle were used for the Terra Nova-= PE basin. The flights had a maximum height of 120 meters and overlapping sides of 90%. The flights were carried out during the years 2021 to 2022, considering the rainy and dry season of the basin.

UAV images were processed in the ADIVA application, Galvincio et al (2022). Rainfall, average, minimum and maximum daily temperatures of the basin under study were also used. As was also shown the water availability in the average soil in the basin. The aim was to verify the hydroclimatic conditions that had some relation with the NDWI responses in the UAV images. Hydroclimatic data were obtained from SUPer, https://super.hawqs.tamu.edu/, Luz and Galvincio (2022). Daily, monthly and years weather conditions from 1961 to 2021 were also analyzed using SUPer. Today we can analyze the current conditions. But the future depends on climate variations and knowing the past can help predict the future.

In SUPer, data were obtained on soil moisture, precipitation, plant growth, stress and nutrient losses in plants and the landscape.

The simulation was using SWAT-Soli Water Assessment Tolls version 2012 with two warm-up years and on a daily scale.

Figure 1- Localização espacial da área em estudo.

Results

Figures 2 to 5 show the RGB of four flights carried out in the Terra Nova watershed in the years 2021 and 2022. In the RGB images it is possible to observe the different land uses and occupation of the area imaged with the UAV. Note that Figures 2 and 3 predominate caatinga vegetation with different characteristics, Fig2 open caatinga and fig 3 dense caatinga. For these two situations, descriptive statistics are presented in Table 1. Figures 4 and 5 predominate riparian forest and irrigated family farming. Like a small river area preserved by the PISF. These figures show spatial transformations that occurred due to the presence of transposed water from the São Francisco River.

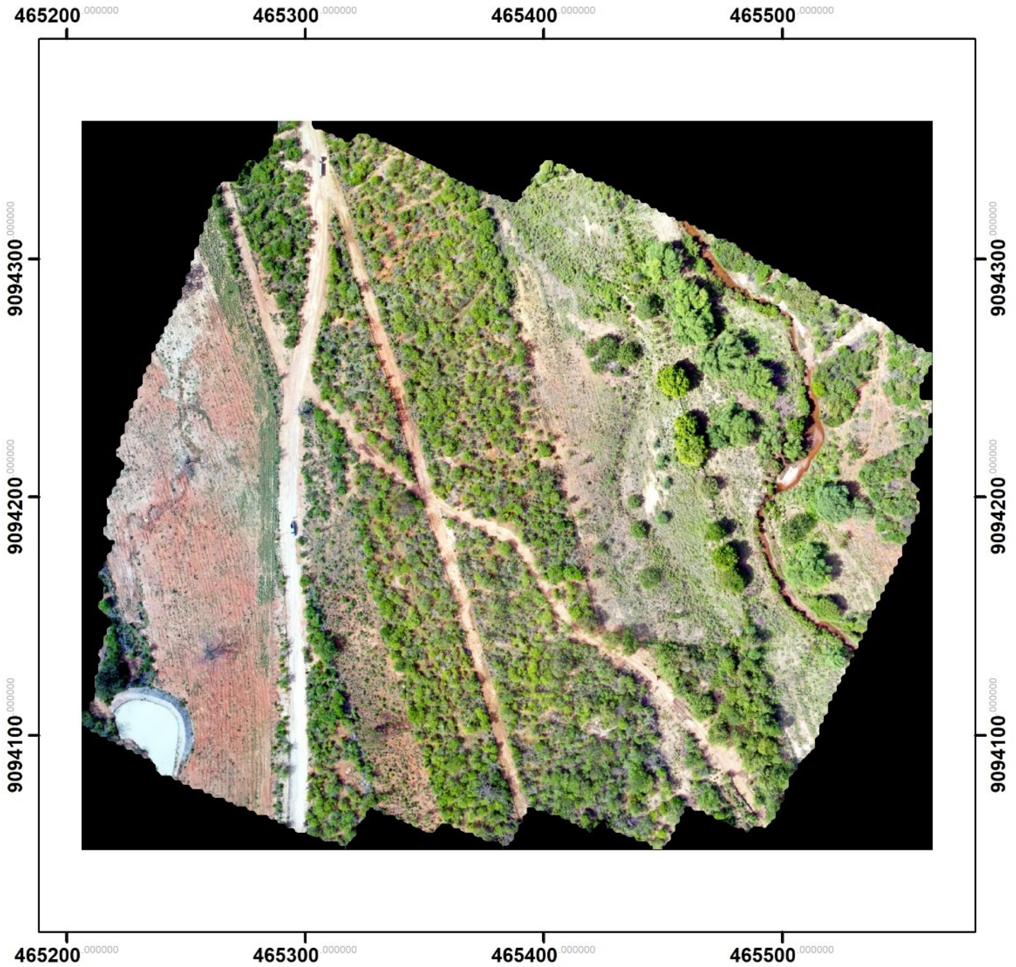

Figure 2- Caatinga open vegetation.

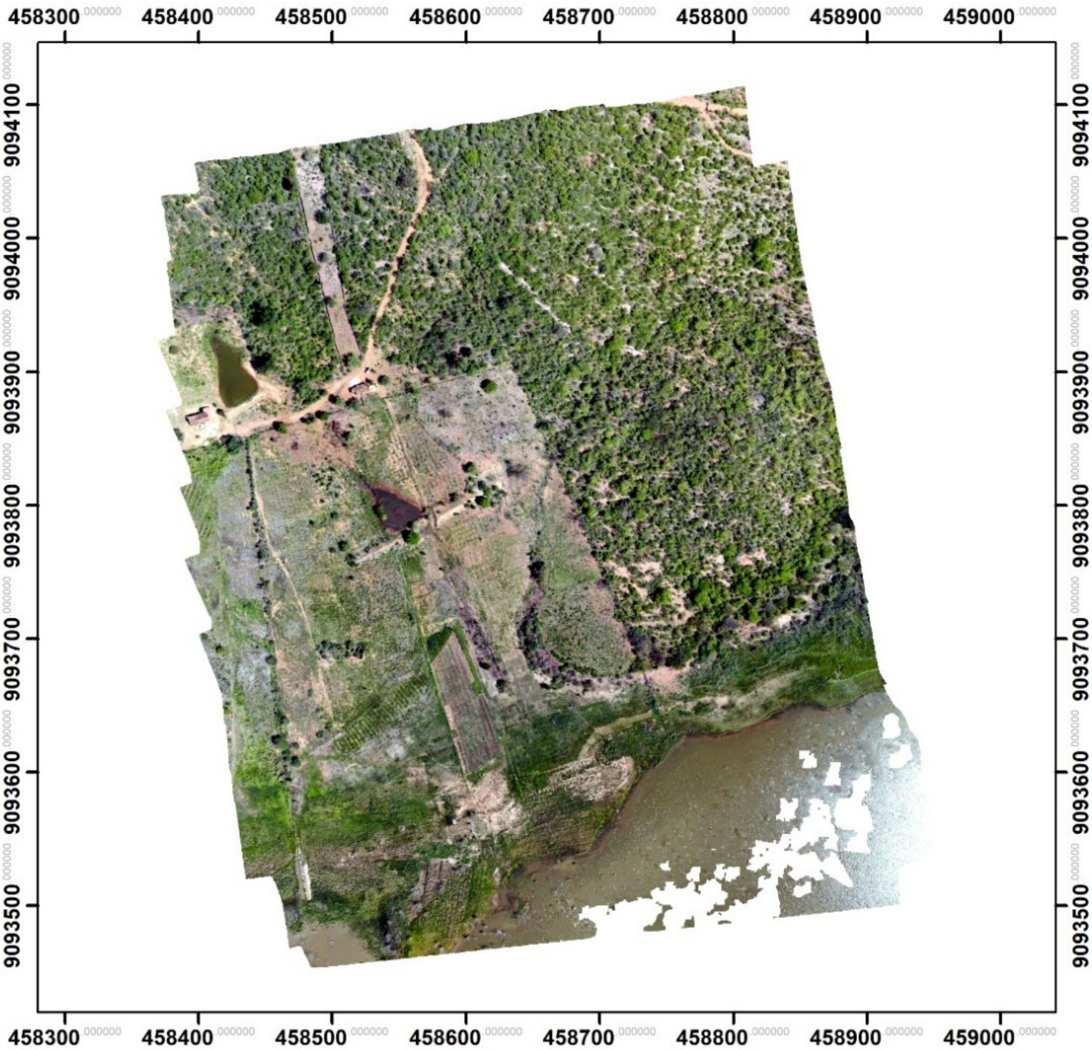

Figure 3- Caatinga biome/dense vegetation (Milagres site).

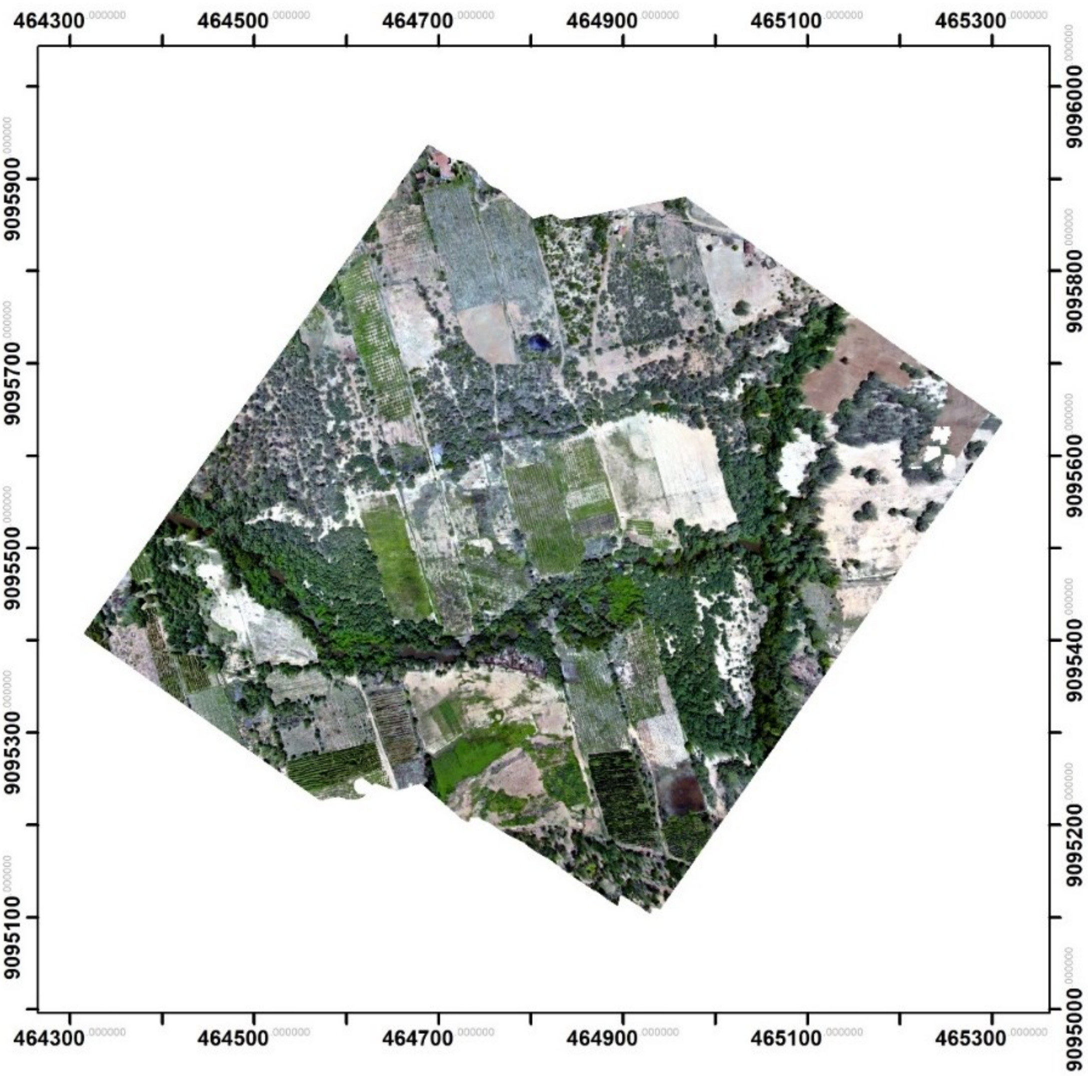

Figure 4- Irrigated agriculture, riparian forest and Caatinga biome.

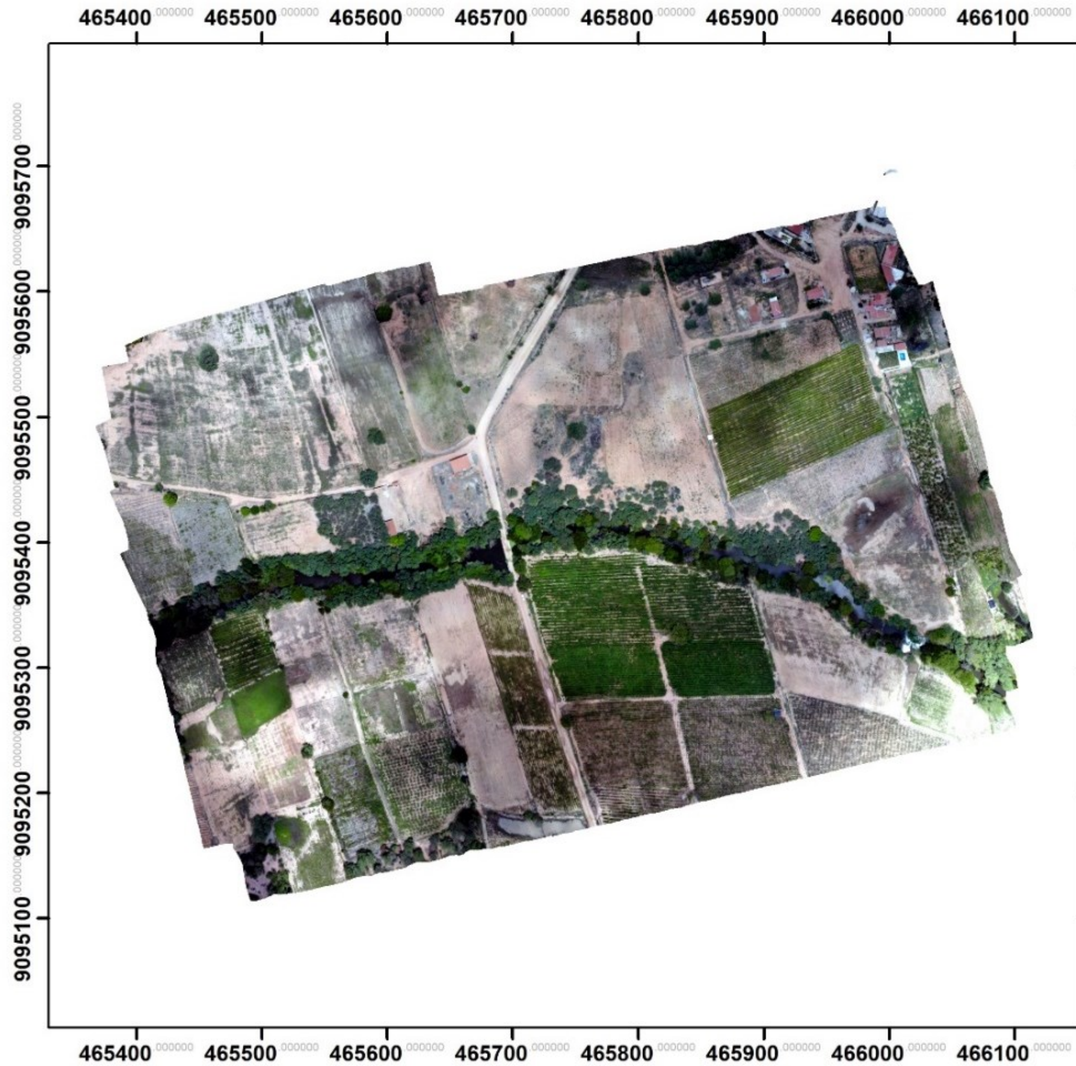

Figure 5- Irrigated agriculture (passion fruit culture) and riparian forest.

The more negative the NDWI, the more water available in the soil and/or on the surface. It is noted that the flights carried out in December 2021 show that the area with the greatest water availability is the irrigated agriculture and riparian forest, Table 1 and Figures 6 to 8. The degraded caatinga (open caatinga) had an average NDWI lower than that of Caatinga dense. Irrigated family farming presented a balance between the two periods with high water availability. This water comes from the São Francisco River Integration Project-PISF. The average monthly water balance of the basin Terra Nova, Table 2. It is important to note that the highest monthly average water availability occurs in March and December is the pre-rainy season. That is, drone imaging occurs in the period of highest water availability and the beginning in the filling of the soil. These conditions are of paramount importance for the results of this study. In the figures 6 to 8 it is possible to perceive the presence of water availability due to water from the PISF. That is, the PISF has brought important changes in the environmental water conditions of the area.

After analyzing the specific conditions for the areas imaged with UAV, the soil moisture and precipitation conditions of the watershed were analyzed, Figures 9 to 15.

Table 1- Descriptive statistics of processed UAV- Unmanned Aerial Vehicle images.

Reservoir Margin: Terra Nova- 12/09/2021			Irrigated agriculture, riparian forest and Caatinga biome-12/07/2021		Milagres site- Caatinga biome dense 03/08/2022		Passion fruit culture and riparian forest – 12/08/2021		Open Caatinga 12/07/2021	
Parameter	Down	Above	Down	Above	Down	Above	Down	Above	Down	Above
Average	-0.17755	0.020916	-0.317	0.084285	-0.30033	0.075864	-0.32908	0.084926	-0.13996	0.170572
standard deviation	0.073685	0.054807	0.195961	0.051752	0.167287	0.062928	0.197667	0.078802	0.181087	0.104417
median	-0.17801	0	-0.28277	0.081306	-0.28277	0.059223	-0.30631	0.064752	-0.04687	0.163351
min	-0.52868	0	-0.90797	0.003633	-0.76611	0.003633	-0.86895	0.003633	-0.71534	0.003633
max	-0.00196	0.34495	-0.00196	0.484998	-0.00196	0.484998	-0.00196	0.484998	0	0.423199
area_rel	0.33	0.67	0.86	0.14	0.92	0.08	0.91	0.09	0.62	0.38
area_ha	4.723223	9.42712	31.69422	5.007103	20.69777	1.835173	21.29465	2.117665	6.798895	4.116634

Table 2- Average monthly water balance values.

Mon	Rain (mm)	SURF Q (mm)	LAT Q (mm)	Water Yield (mm)	ET (mm)	PET (mm)
1	76.42	5.73	2.77	15.24	35.15	230.82
2	85.66	7.58	3.14	23.84	38.78	192.05
3	121.52	10.99	4.55	39.47	69.18	199.20
4	83.46	5.90	3.27	38.62	52.62	182.36
5	31.82	0.95	1.29	27.75	27.41	175.03
6	11.99	0.06	0.45	13.93	9.47	160.20
7	9.88	0.04	0.30	5.63	9.49	175.63
8	2.86	0.01	0.08	1.68	4.03	219.40
9	2.83	0.02	0.08	0.77	1.87	256.56
10	9.25	1.06	0.33	2.29	4.07	287.80
11	23.64	1.30	0.64	3.22	10.06	276.90
12	51.05	3.09	1.81	7.68	26.02	

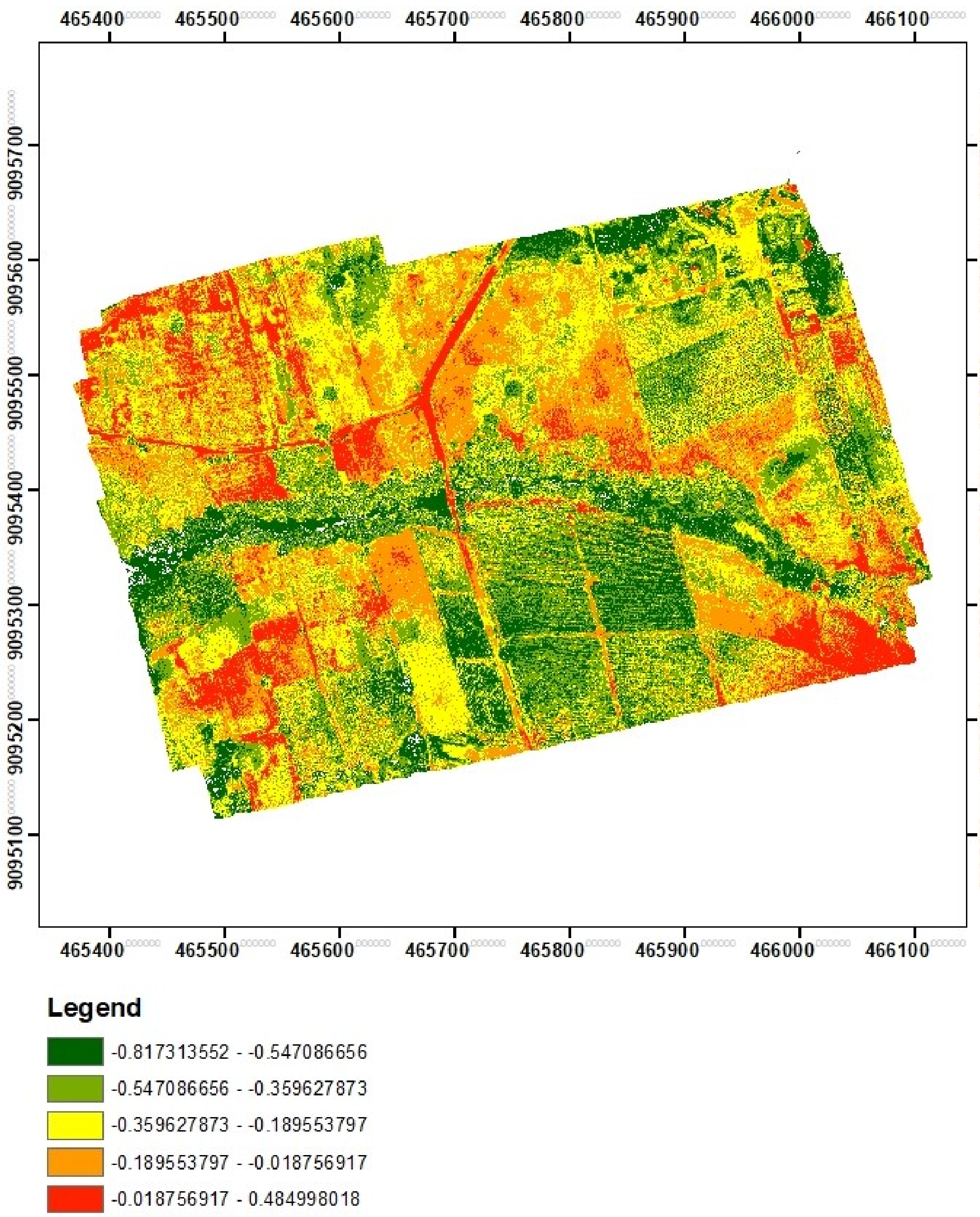

Figure 6- NDWI-Passion fruit culture and riparian forest, in 12/08/2021.

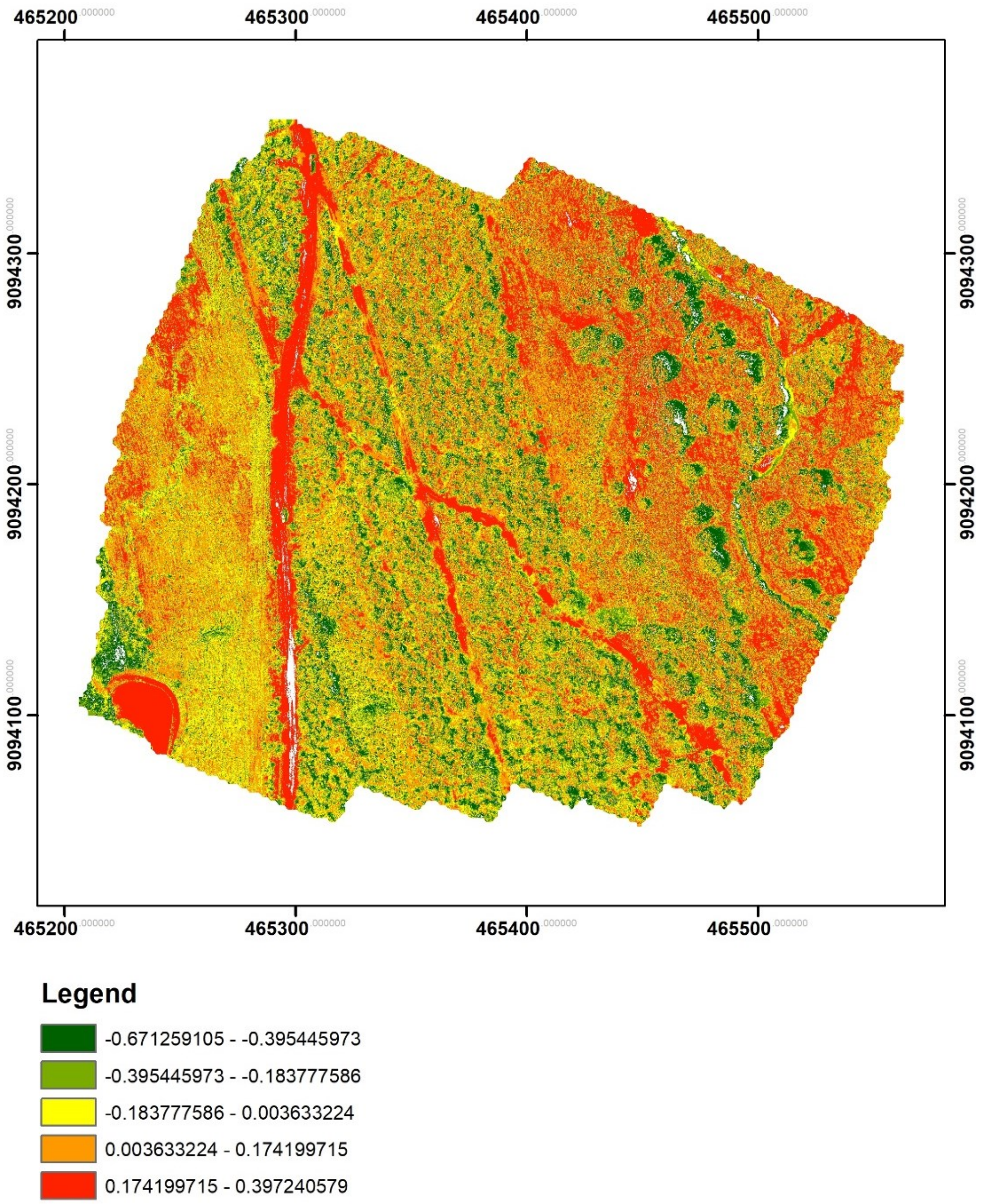

Figure 7- NDWI of the open Caatinga, 12/07/2021.

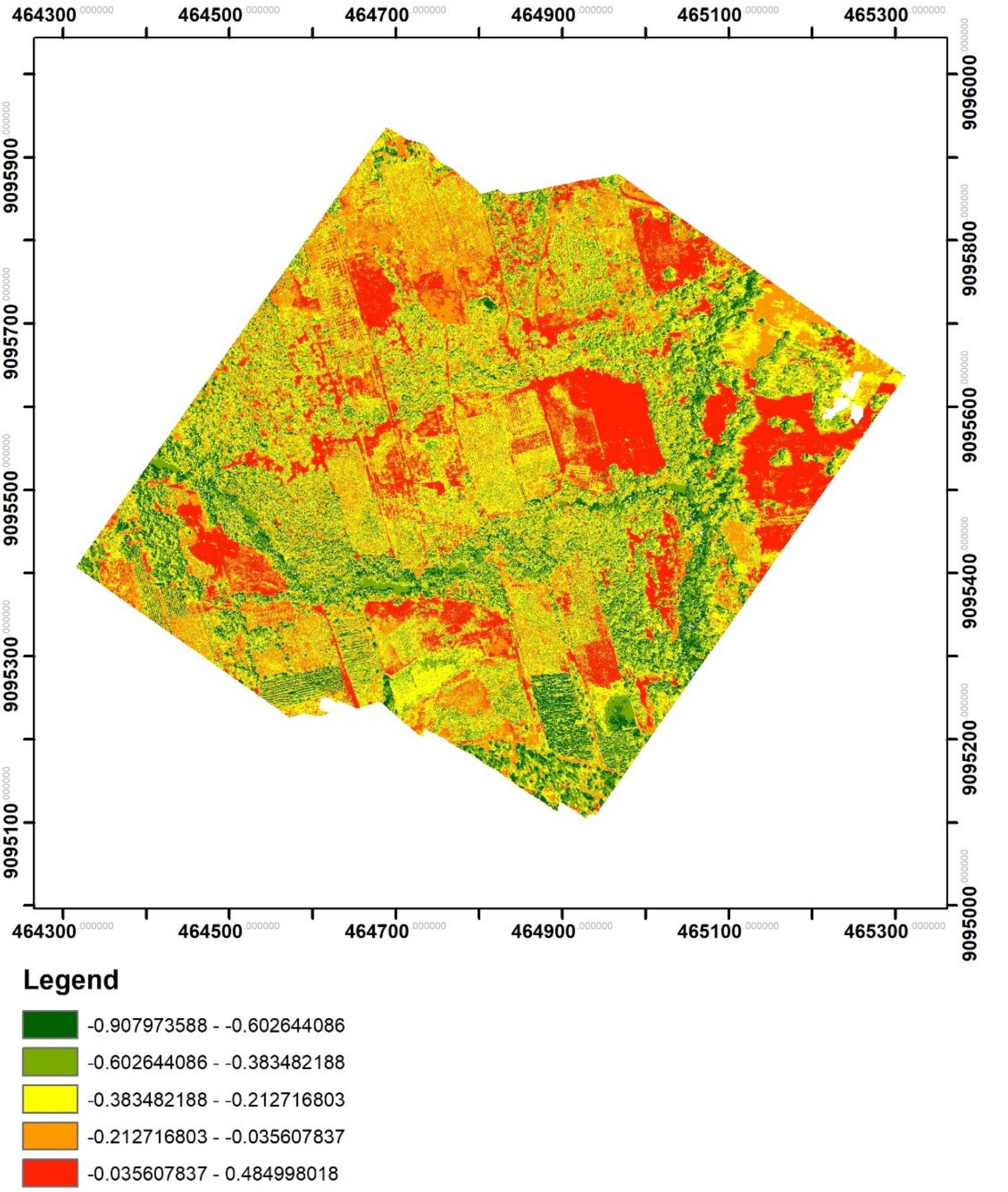

Figure 8- NDWI of the Irrigated agriculture, riparian forest and Caatinga biome-12/07/2021.

Knowing the temporal water conditions of the place is of great importance for a better management of the area. Thus, Figures 9 to 15 show the temporal conditions of soil moisture and precipitation in the basin under study. Note that the average daily soil moisture does not exceed 2 mm. In the monthly scale, the maximum can exceed 60mm, the monthly minimum is around 20mm. This represents around 10% of the monthly precipitation. Note that 2000 was a very dry year in the basin, where soil moisture conditions were around zero. These conditions cause a lot of impact in the region, social, economic and environmental. That year 19998-2000 was an El Nino year.

"The Oceanic Niño Index (ONI) has become the de-facto standard that NOAA uses for classifying El Niño (warm) and La Niña (cool) events in the eastern tropical Pacific. It is the running 3-month mean SST anomaly for the Niño 3.4 region (i.e.,5ºN-5ºS, 120º-170ºW). Events are defined as 5 consecutive overlapping 3-month periods at or above the +0.5 anomaly for warm (El Niño) events and at or below the -0.5 anomaly for cool (La Niña) events. The threshold is further broken down into Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4), Strong (1.5 to 1.9) and Very Strong (≥ 2.0) events. For the purpose of this report for an event to be categorized as weak, moderate, strong or very strong it must have equaled or exceeded the threshold of the highest category for at least 3 consecutive overlapping 3-month periods", https://ggweather.com/enso/oni.htm

El Niño and La Niña are part of the same atmospheric-oceanic phenomenon that occurs in the Equatorial Pacific Ocean (and in the adjacent atmosphere), called the El Niño Southern Oscillation (ENSO). ENOS refers to situations in which the Equatorial Pacific Ocean is warmer (El Niño) or cooler (La Niña) than the historical average. The change in the temperature of the Equatorial Pacific Ocean has global effects on temperature and precipitation, http://enos.cptec.inpe.br/

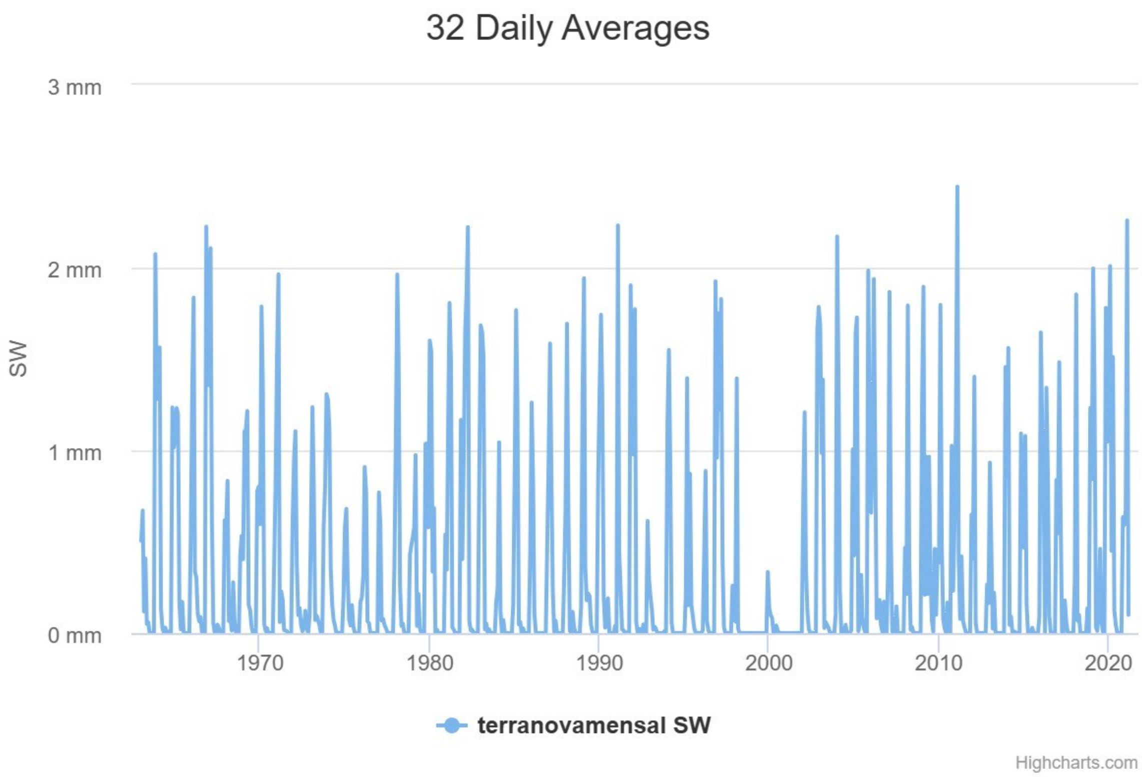

Figure 9- Daily averages of the soil water-SW in Terra Nova, basin.

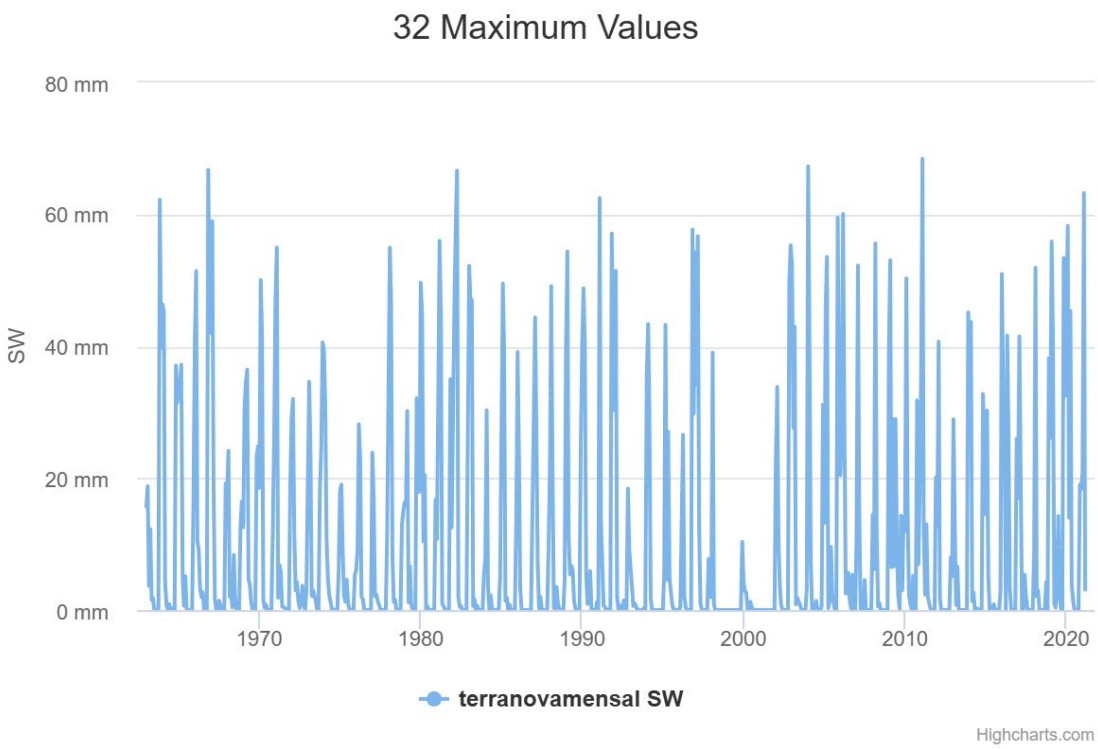

Figure 10- Maximum values in soil water-SW in Terra Nova basin.

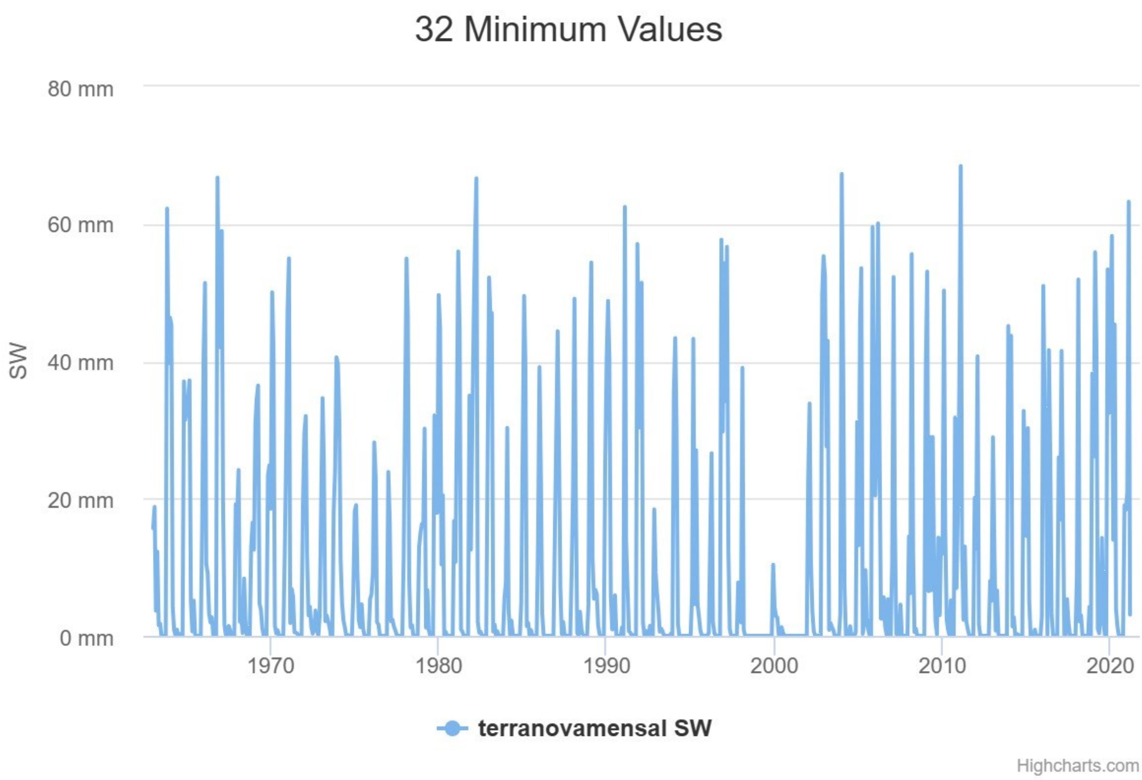

Figure 11- Minimum values of the soil water-SW.

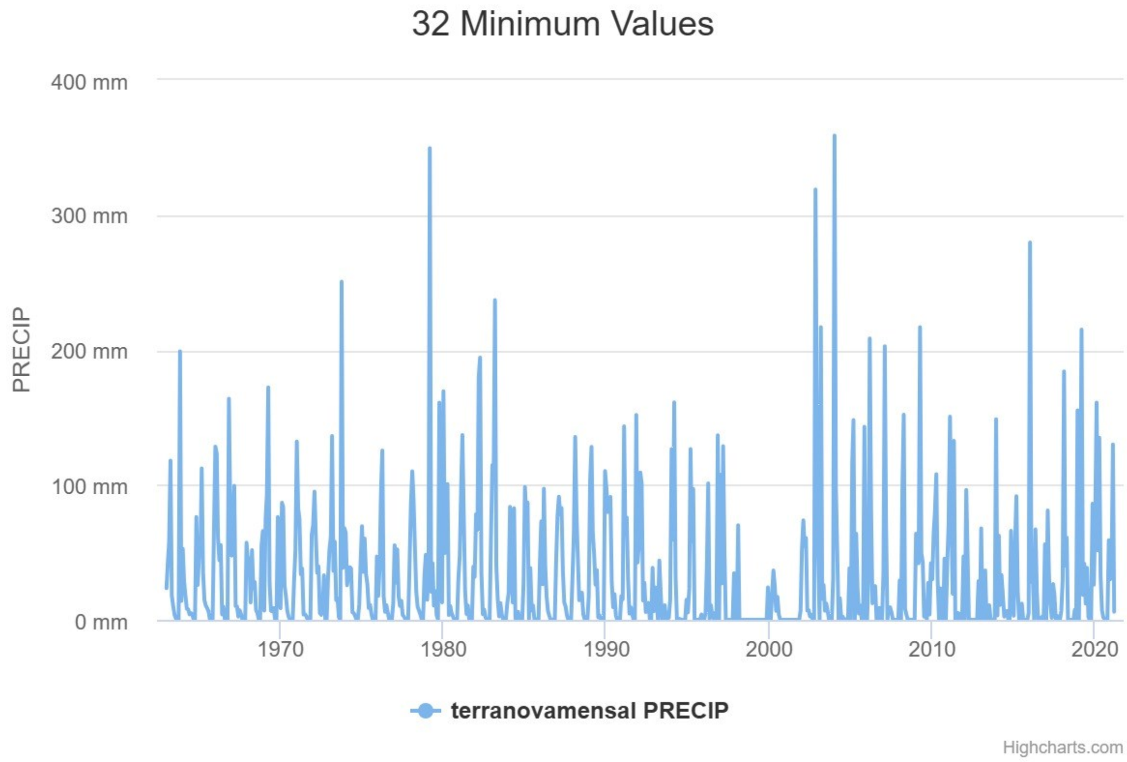

Figure 12- Minimum values of precipitation in Terra Nova basin.

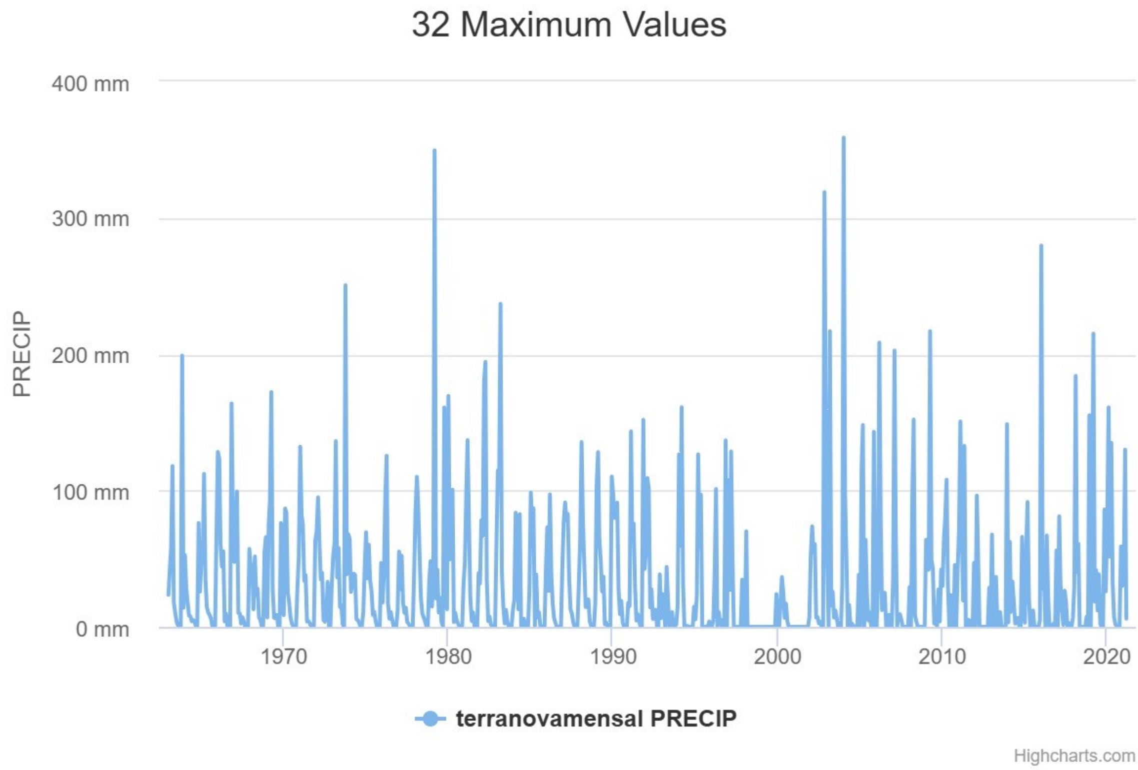

Figure 13- Maximum values of the precipitation in Terra Nova basin.

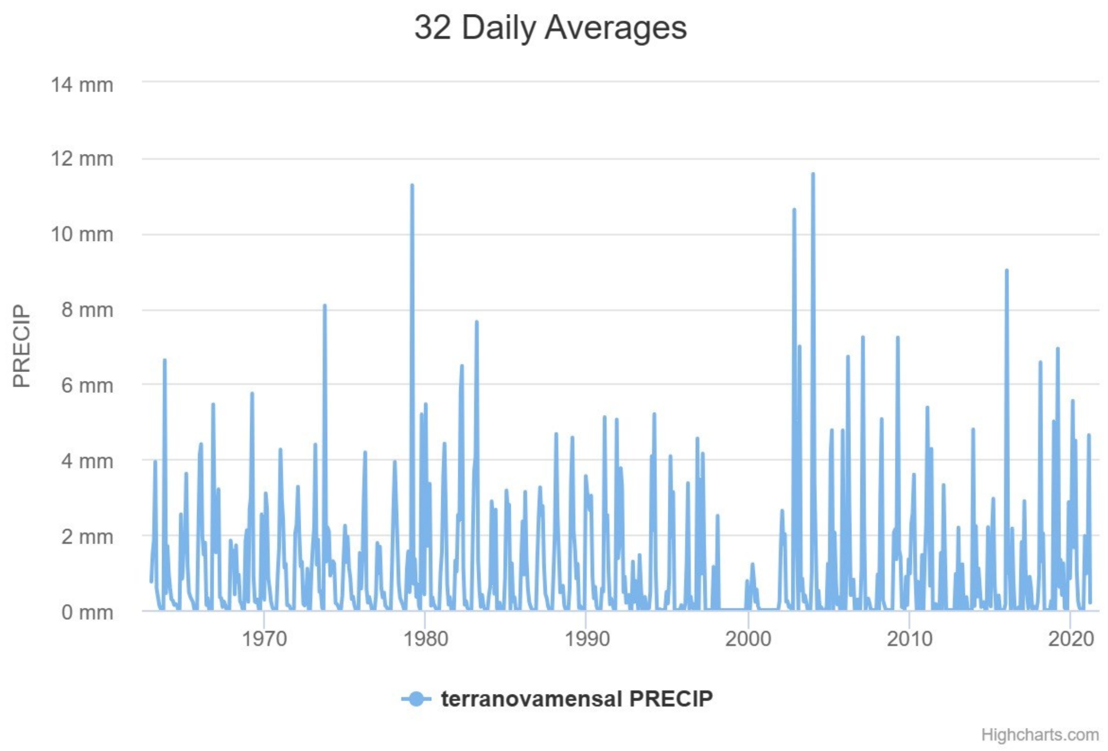

Figure 14- Dayle averages of the precipitation of the Terra Nova basin.

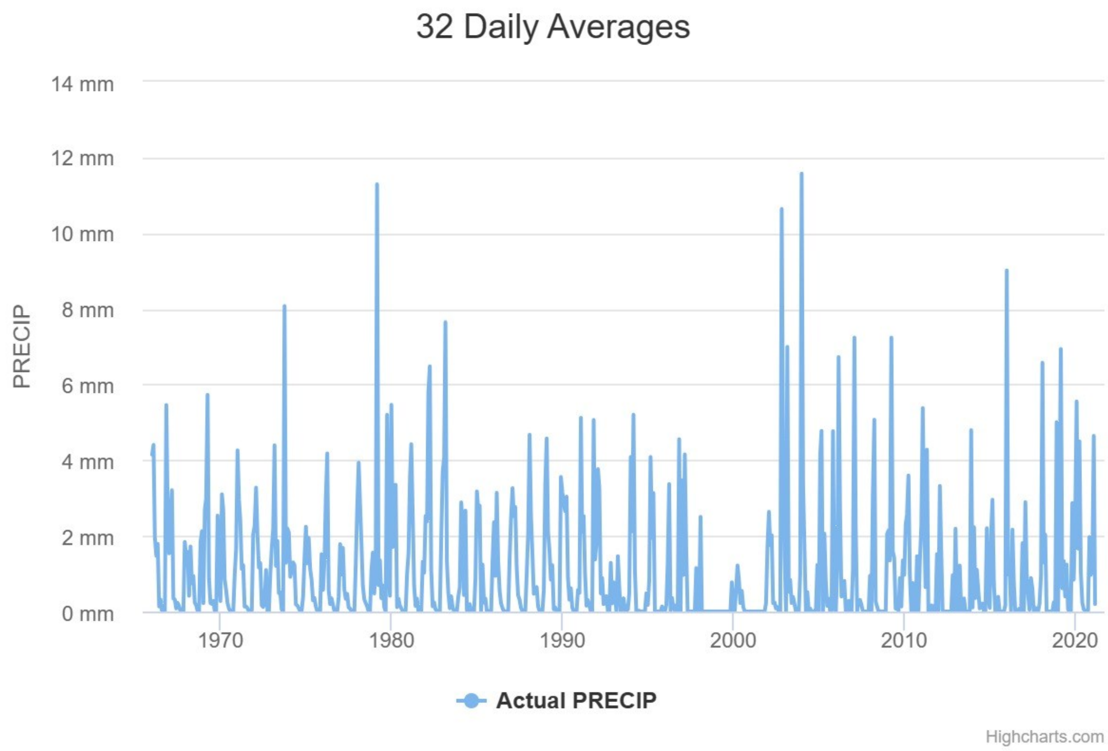

Figure 15- Daily averages of the precipitation in Terra Nova basin.

Figure 16 shows average annual plant growth in the Terra Nova basin and stresses related to water availability and temperature. It is noted that on average in the year the plants in the Terra Nova basin undergo 2 days of stress related to temperature, 172 days of stress related to water availability. These conditions interfere with the amount of plant biomass.

These environmental conditions cause variations in nutrient and phosphorus losses to occur throughout the year, Table 3.

Temperature Stress Days	1.860
Water Stress Days	171.710
Nitrogen Stress Days	47.250
Phosphorus Stress Days	22.140

Messages and Warnings

- More than 100 days of water stress

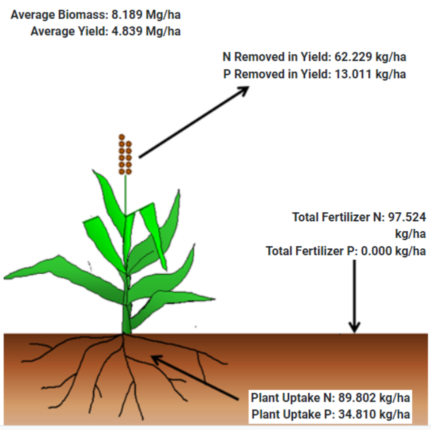

Figure 16- Plant growth.

Table 3- Lanscape nutrient losses.

Nitrogen Losses (kg/ha)

Total N Loss	29.572
Organic N	2.475
Nitrate Surface Runoff	0.488
Nitrate Leached	25.685
Nitrate Lateral Flow	0.586
Nitrate Groundwater Yield	0.338
Solubility Ratio in Runoff	0.165

Phosphorus Losses (kg/ha)

Total P Loss	0.599
Organic P	0.561
Soluble P Surface Runoff	0.038
Solubility Ratio in Runoff	0.063

Discussion

The normalized difference water index (NDWI) has been extensively used for different purposes, such as delineating and mapping surface water bodies and monitoring floods. However, the assessment of this index (based on multispectral remote sensing data) is highly affected by the effects of atmospheric aerosol scattering and built-up land, especially when green and near infrared bands are used. In Liuzo et al (2020), a modified version of the NDWI was developed to improve precision and reliability in the detection of water reservoirs from satellite images.

In addition to water availability in reservoirs, the NDWI can also be used to assess water availability in the watershed with different uses. In addition, the great advantage is to obtain conditions in spatial details when using drone images. These data can help in watershed planning with greater efficiency when using different products with different spatial scales such as, for example, punctual drone images, and with less temporal detail, satellite images with different spatial and temporal resolutions and hydrological models with estimates. on different temporal and spatial scales, such as the SWAT-Soil Water Assessment Tools and the SUPER tool. The combination of all these technologies can bring high social, economic, and environmental benefits, as the decision to monitor and manage the watershed brings a reality far superior to the actions that are still taken today due to little or no temporal and spatial detail.

Conclusions

Water availability changes the environmental conditions of the place. The riparian forest responds very quickly to water availability.

The caatinga biome is of great importance for retaining water during the rainy season and ensuring that the region continues to have healthier environmental water conditions throughout the year.

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