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The Assessment of Hydrological Availability and the Payment for Ecosystem Services: A Pilot Study in a Brazilian Headwater Catchment

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Received: 24 August 2020; Accepted: 27 September 2020; Published: 29 September 2020

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Abstract: The assessment of water availability in river basins is at the top of the water security agenda. Historically, the assessment of stream flow discharge in Brazilian watersheds was relevant for dam dimensioning, flood control projects and irrigation systems. Nowadays, it plays an important role in the creation of sustainable management plans at the catchment scale aimed to help in establishing legal policies on water resources management and water security laws, namely, those related to the payment for environmental services related to clean water production. Headwater catchments are preferential targets of these policies and laws for their water quality. The general objective of this study was to evaluate water availability in first-order sub-basins of a Brazilian headwater catchment. The specific objectives were: (1) to assess the stream flow discharge of first-order headwater sub-basins and rank them accordingly; (2) to analyze the feasibility of payment for environmental services related to water production in these sub-basins. The discharge flow measurements were conducted during five years (2012 to 2016), in headwaters in a watershed on the São Domingos River at the Turvo/Grande Watershed, represented as the 4th-largest hydrographic unit for water resources management—UGRHI-15 in São Paulo State, Brazil. A doppler velocity technology was used to remotely measure open-channel flow and to collect the data. The discharge values were obtained on periodic measurements, at the beginning of each month. The results were subject to descriptive statistics that analyzed the temporal and spatial data related to sub-basins morphometric characteristics. The discharge flows showed space–time variations in magnitude between studied headwater sub-basins on water availability, assessed based on average net discharges. The set of ecological processes supported by forests are fundamental in controlling and recharging aquifers and preserving the volume of water in headwater in each sub-basin. The upstream inflows influence downstream sub-basins. To avoid scarcity, the headwater rivers located in the upstream sub-basins must not consider basin area as a single and homogeneous unit, because that may be the source of water conflicts. Understanding this relationship in response to conservationist practices installed uphill influenced by anthropic actions is crucial for water security assessment. The headwaters should be considered a great potential for ecosystem services, with respect to the "provider-receiver" principle, in the context of payments for environmental services (PES).

Keywords: flow; water discharge ecosystem services; payments for environmental services; land use; riparian forest

1. Introduction

The study of water availability in watersheds is fundamental for the demonstration of water potential and hydrological behavior of a region. It also helps with increasing the capacity of a population to safeguard access to adequate quantity and acceptable quality of water to sustain well-being and the environment. Surface and groundwater reserves are considered strategic and essential components of ecosystems and are fundamental for economic, social, and sustainable development [1,2]. The availability, quality, management, and governance of water resources are currently at the center of technical and scientific discussions [3–6].

Although most of the planet Earth's surface is occupied by water, 97.5% of available water is salty, and only 2.5% is fresh water. From the percentage of fresh water, 68.9% is concentrated in glaciers, polar ice caps, or mountainous regions, 29.9% in groundwater, 0.9% in other reservoirs, and only 0.3% make up the portion of surface fresh water present in rivers and lakes [7]. Brazil has 13% of the world volume of fresh water available, with a higher concentration in the Amazon region, where there is less population and less demand, according to the National Water Agency (ANA) [8]. The State of São Paulo, which is the most populous, has 1.6% of Brazilian fresh water [9]. The multiple uses of water resources are diversified—public supply, food production, hydroelectricity generation, navigation and industrial development, and their intensity is related to social, agricultural, and industrial development [1].

In the agriculture sector, approximately 70% of total fresh water is used in production activities. This consumption tends to increase with population growth and demand for food [10,11]. Thus, the need to obtain information and metrics that contribute to the establishment of planning measures and future management policies for water security is evident. Water security involves ensuring water quantity and quality acceptable for livelihood. It is related to the development of solutions to manage and mitigate impacts of scarcity and possible risks regarding environmental conditions and climate uncertainties, in order to guarantee human well-being, socioeconomic development and preservation of ecosystems [12–17].

The management of water resources in an integrated planning policy is increasingly needed to ensure water security in the future [3,15,16,18]. Studies showed that more than half of the global population has experienced severe water shortages for at least one month in a year, and climate change is affecting the reliability of supplies and infrastructures available in many regions [15,16,19]. According to scenario-based studies from the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC), and data modeled on WaterGAP3, it is estimated that by 2050 urban water demand will increase by 80% [20].

Brazil experiences annual imbalances between water supply and demand. A remarkable episode was in 2013–2014, in the southeastern region, in which drought affected approximately 80 million people in Minas Gerais, São Paulo, and Rio de Janeiro States [18,21–23]. There were considerable problems for public water supply, food production, energy and navigation, causing the loss of 5000 jobs and millions of tons of non-transported materials [18]. Water crises generate significant socioeconomic and environmental impacts. Thus, the development of strategies for adapting to change that represent improvements and efficiency in future availability of water in hydrographic basins is welcome.

In water security research, the working territorial unit is a watershed. That is the unit where the land use and land cover are best managed [24–28]. Research studies on water availability [29–35] and flow distribution [36–42] within this unit contribute to manage water scarcity or stress, understand availability and demand, establish grants, identify environmental impacts, and even implement public policies [43–48].

The information on flow (discharge) metrics of Brazilian drainage networks is relevant for preparing policies, projects for new dams and flood control, as well as creating sustainable management plans within the scope of land use and land cover management in the hydrographic basin. The basin is a place where several interactions between the elements of an ecosystem occur, and thus it can be considered that this space has an ecosystem function considering water and nutrient cycle, in regulation of gases, in transfer of energy, and in the water infiltration/discharge relationship. The ecosystem services generated by these functions trigger a series of benefits, directly or indirectly, that humans can be appropriate.

A single ecosystem service can be a product of two or more functions, and a single function can generate more than one ecosystem service. Discharge flow controlling management practices can enhance environmental services or minimize the impact of human activities in a territory, or even promote economic incentives aimed at conserving ecosystems and increasing these services, which is of great value [49–51]. Ecosystem services promoted by maintenance and conservation of water resources have extremely high economic and social value. Valuation of those services and their diversity have gained scientific and economic attention, and environmental service benefits and control functioning of ecosystems must provide human well-being [52–55].

The Payment for Environmental Services (PES) instrument is considered an efficient program, as it rewards those who produce or maintain environmental services and encourages those who would not promote these services in the absence of monetary stimulus [53,55,56]. The monetary compensation and reduction of tax charges can be applied, or even, use of public resources from municipal and state funds, charging water users, environmental compensation, and carbon credit [54,57,58].

In Brazil, PES initiatives are centered on projects related to water and watershed, carbon storage programs, biodiversity, and landscape protection. Some pioneering and developing examples in Brazil are: Water Producer Program from National Water Agency–ANA (https://www.ana.gov.br/programas-e-projetos/programa-produtor-de-agua); Atlantic Forest Connection Project, financed by different development agencies (https://conexaomataatlantica.mctic.gov.br/cma/o-projeto/o-que-e); Conservative Water Project of Extrema, State of Minas Gerais (https://www.extrema.mg.gov.br); Ecocredit Program in the Montes Claros State of Minas Gerais (https://portal.montesclaros.mg.gov.br).

The assessment of hydrological availability in the Brazilian watershed on headwater sub-basins should therefore be recognized and promoted as a primary strategy to support the continued provision of ecosystem services in watersheds. The potential for ecosystem services provision, considering the principle of "provider-receiver", to establish PES must be investigated in the sequel. The costs to protect and manage those areas are substantial, and PES programs are a promising strategy. The landowner will receive a financial support as compensation to guarantee the provision of water ecosystem service to a willing buyer or beneficiary (e.g., Water Supplies Companies).

The general objective of this study was to evaluate water availability on sub-basins of first order and their contribution to water security assessment on Brazilian watersheds. The specific objectives were: (1) to assess the hydrological discharge of headwater sub-basins; (2) comprehend which first-order sub-basins are higher on water flow discharge; and (3) analyze the feasibility of payment for environmental services for the water-producing sub-basins.

2. Study Area

The experimental study area was the Olaria Stream Watershed, a tributary of the São Domingos river. This river contributes with flow to the Turvo/Grande watershed, the 4th-largest water resources management unit—UGRHI-15 in the State of São Paulo, Brazil (Figure 1), according to the Hydrographic Basins Committee of the Turvo and Grande Rivers—CBHTG (http://www.comitetg.sp.gov.br). The Olaria Stream Watershed covers 9.45 km^2 and is located between latitudes 21°05′47′′ S and

21°19′35′′ S and longitudes 49°03′02′′ W and 48°42′52′′ W Gr., expressed in UTM—Universal Transverse Mercator Projection System, Zone 22K, with altitudes varying from 507 to 616 m.

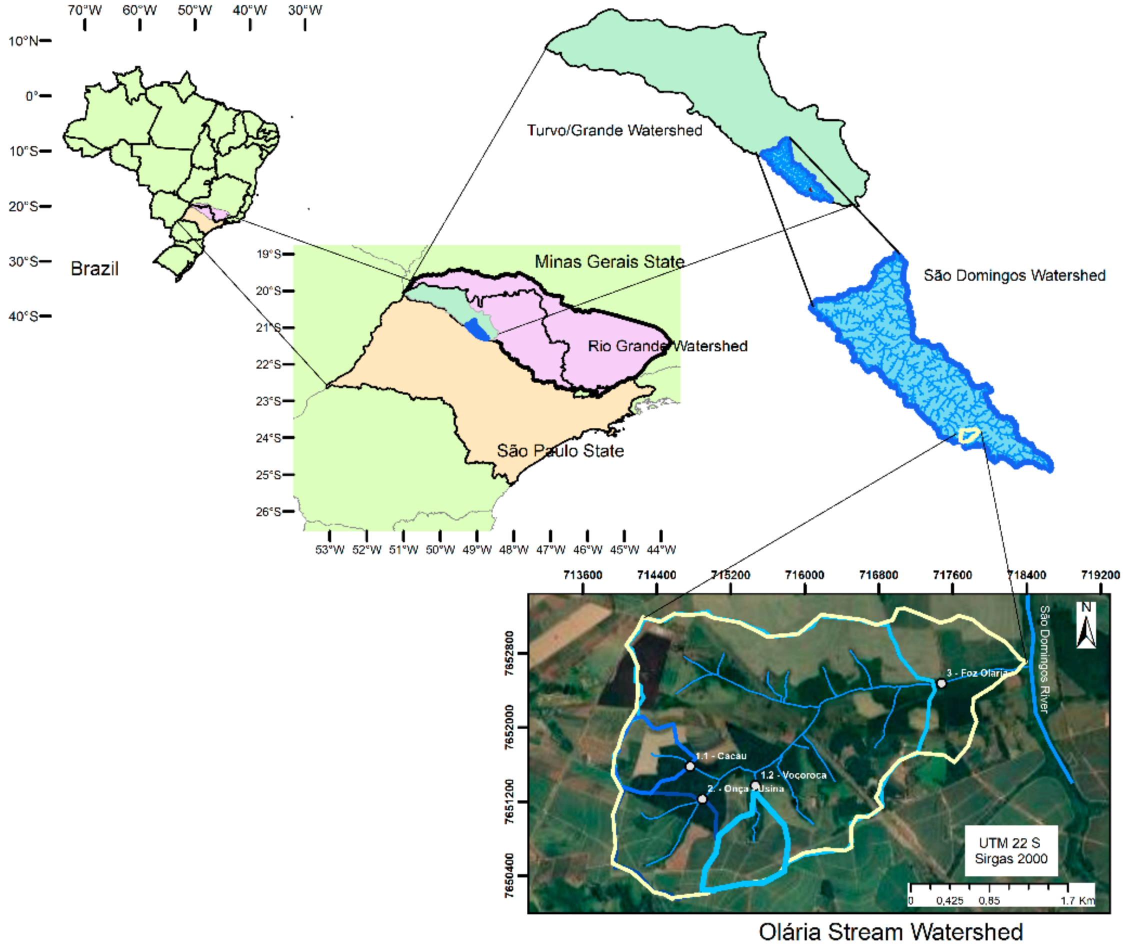

Figure 1. Olaria Stream Watershed, São Domingos River watershed, Turvo/Grande watershed, UGRHI-15, São Paulo State, Brazil.

The river flow supplies water to the municipalities of Catanduva, Catiguá, Tabapuã, and Uchoa, with a total of 169,232 inhabitants, according to data from the Brazilian Institute of Geography and Statistics—IBGE (https://cidades.ibge.gov.br). The area is socioeconomic-important for regional development, namely, the agricultural and industrial productive system. The sub-basin areas belong to Polo Regional Centro Norte, São Paulo Agribusiness Technology Agency—APTA (https://www.apta.sp.gov.br), a Department of the State of Agriculture and Supply Secretariat, São Paulo, Brazil. This unit carries out agricultural research and experimentation with annual and perennial crops, in order to meet technological demand on agribusiness production chains.

The climate is classified as Cwa, defined as a subtropical dry winter (with temperatures below 18 °C) and hot summer (with temperatures above 22 °C), with an average annual air temperature of 20–22 °C [59]. The local water balance (Figure 2), according to 30 year data (1961 to 1990) from the Brazilian Agricultural Research Corporation—EMBRAPA [60], is characterized by: average temperature of 22.8 °C; total annual precipitation of 1388 mm; average annual precipitation of 116 mm; potential evapotranspiration of 1134 mm; soil water storage of 788 mm; real evapotranspiration of 1054 mm; water deficiency of 80 mm; and water surplus of 334 mm.

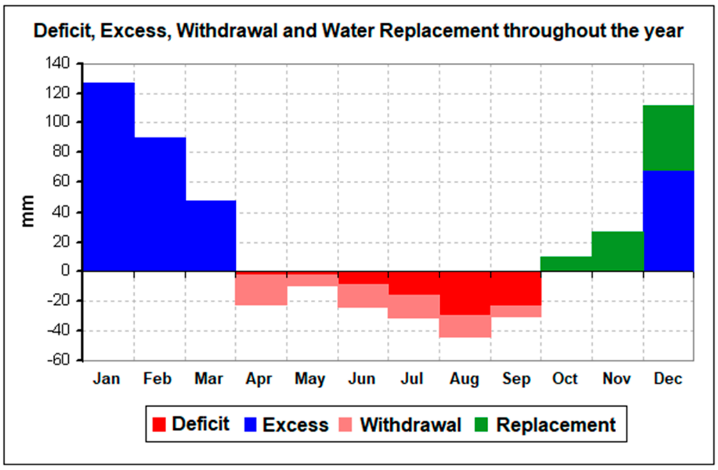

Figure 2. Water balance in the APTA-Pindorama, State of São Paulo, Brazil. Adapted from Brazil's climate database, available at the Brazilian Agricultural Research Corporation [60].

The watershed soil was classified as Red-Yellow Argisols, sandy/medium texture, with wavy and smooth wavy relief [61]. The predominant natural vegetation land cover was classified as semi-deciduous seasonal tropical forest, Atlantic Forest biome [62]. Land use was mainly distributed by urban areas, industries, agro-industries and agriculture, with a predominance of sugarcane and crop production systems such as citrus, rubber, grains, livestock, pasture, and eucalyptus [63]. The sub-basins uphill have an intense agricultural crop production and areas of native forests, considered as a Permanent Preservation Area (PPA) by Environmental Brazilian Laws.

3. Materials and Methods

Flow measurements in natural watercourses were carried out in order to determine the value of the surface runoff of a basin, its temporal variability, and the characteristics of the runoff. The activities of monitoring the amount of water in the Córrego da Olaria watershed in Pindorama-SP were initiated to understand the water in the hydrological processes and water production capacity of the sub-basins, obtaining stream flow data and the elaboration of quantitative analysis of flows, which will be indispensable for future actions and policies on land and water uses.

3.1. Discharge Flow Monitoring in Sub-Basins

The volume of water resources (e.g., discharge, flow) monitored in the Olaria stream watershed began in January 2012, as an activity of a research project entitled "Recovery of headwaters of the Polo Regional Centro Norte (Pindorama Experimental Station)". Subsequently, in 2013, it continued with the project "Monitoring water resources to assess changes associated to land use and soil management at Olaria stream watershed". The data acquisition was carried out in three sub-basins located at the headwaters of Olaria catchment and near its mouth where the stream debouches into the São Domingos river (Figures 3 and 4).

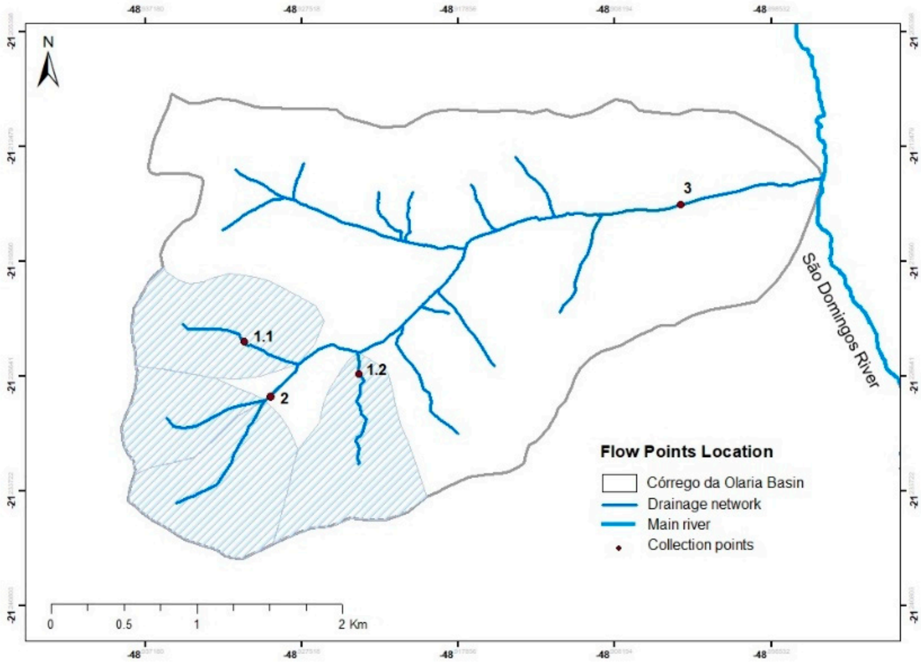

Figure 3. Drainage network of Olaria stream watershed, with identification of monitored sub-basins (1.1; 1.2; 2; 3).

Figure 4. Location of discharge flow monitoring points: (**a**) sub-basin 1.1; (**b**) sub-basin 1.2; (**c**) sub-basin 2; (**d**) sub-basin 3.

The uphill of sub-basin 1.2 (Figure 3) comprises the recovery and reforestation of a degraded area. This specific area had an aggravated erosion process due to inadequate soil management (Argisol—susceptible to erosion) (Figure 5). For decades, the coffee production system was installed uphill and later, pasture and cattle raising, with no soil conservationist practices [64]. The lack of vegetation for soil protection and its incorrect land use have severely degraded the sub-basin hills, resulting in a severe erosion process of a 700 m long gullet and some stretches, up to 15 m deep (Figure 5a) [64,65].

In order to contain the erosion process, recover the source and biodiversity, four uneven reservoirs were built (Figure 5b), interconnected by drainage channels (spillways on concrete stairs) (Figure 5c), which allowed water to pass through with a controlled flow. In addition, surrounding agricultural experimentation areas were managed with conservationist and maintenance treatments within natural vegetation land cover [64–66]. In 2011, reforestation of the surrounding stream was made within an Agroforestry System (AS), under a different management on the uphill of the sub-basin (Figure 5d). The purpose was to restore permanent preservation areas (PPA) and complement the other environmental recovery practices [66,67].

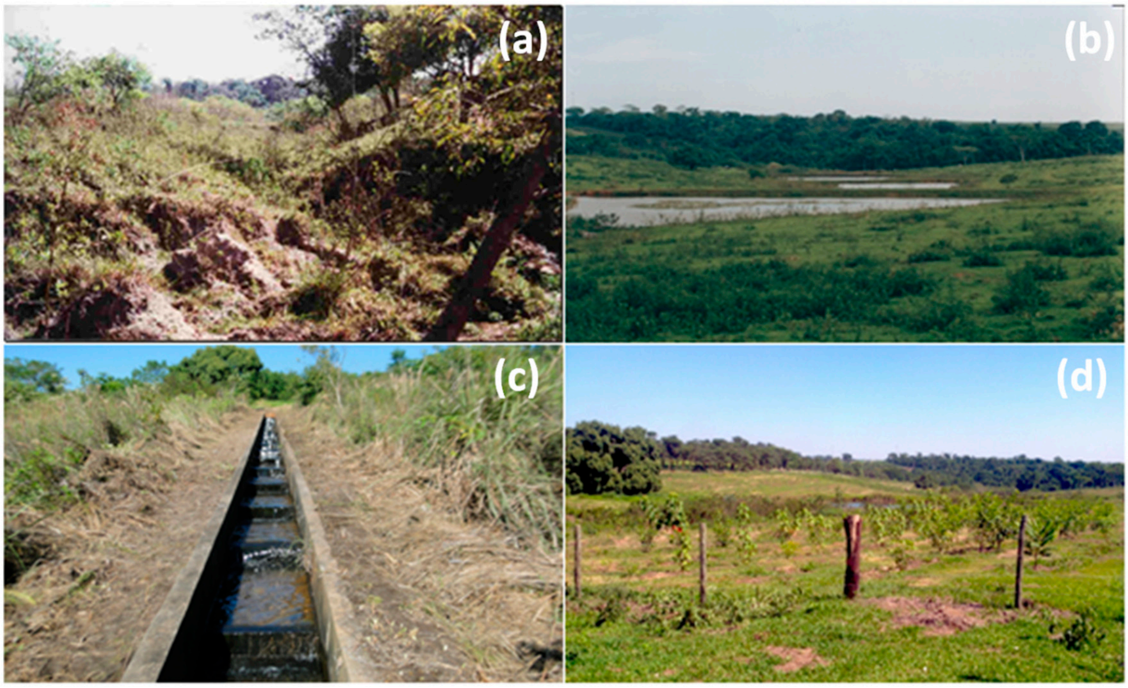

Figure 5. History of recovery and reforestation of degraded area in sub-basin 1.2: (**a**) intense erosion and gullies; (**b**) formation of four uneven reservoirs; (**c**) drainage channels; and (**d**) implementation of reforestation and the Agro-forestry System.

The selected points 1.1 and 1.2 belong to sub-basins of the 1st order, according to the characterization of hierarchical position of fluvial systems and topological ordering of hydrographic basins developed by [68]. Sub-basin 2 occurs in a micro-basin of 2nd order and sub-basin 3 on a streams junction of 3rd order (Figures 3–5). The discharge flow monitoring took place from January 2012 to December 2016. The data were collected monthly on the same point and hour sequence, from 7:00 a.m. to 11:00 a.m.

The methods used for flow measurements in watercourses are necessary to evaluate the passage of water, to obtain the measurement of the average speed of the flow in the section area and the net discharge [69–71]. The measurement of water flow in a watershed can be performed using different methods and instruments. Conventional methods include immersed current meters, which obtain the average flow velocity of the watercourse section. The velocity is then multiplied by the corresponding area, and the sum of these products will result in the average flow of the watercourse.

The measuring of flow with immersed current meters as used in natural watercourses or in artificial channels is frequent in research in Brazil. Structures are built on the riverbed, such as openings of geometric shape, as was done for this research, through which the water will flow, facilitating the measurement of the flow in the determined section [69–71]. The spillways can be: rectangular, trapezoidal, triangular, with a thin or thick threshold [69–71].

Another way of measurement could be by the artificial tracking method with the use of chemical or radioactive tracers [70,72–74]. The use of these tracers is appropriate for small watercourses, as they are considered low cost, easy to handle, presenting satisfactory results. In the past, radioactive tracers such as tritium have been used in large rivers, while tracers with fluorescents (dyes) have been commonly explored in the USA [70], especially in studies focused on groundwater [74]. However, the use of tracers introduces some problems, if the water is turbid. Suspended sediments can easily absorb some tracers and, in addition, there are normative restrictions regarding radiological protection (e.g., with the use of tritium) [70,72,73].

In this study, we opted for the electronic flow meter method (model ISCO 2150), represented as a "smart" probe". This sensor uses the concept of digital electronics. The analog level is digitized inside the sensor itself to avoid electromagnetic interference (https://www.clean.com.br/Produto/Detalhe/56).

The instrument allows the monitoring of the flow at various points along the cross section of a river, in a short period, since the communication of the device with microcomputers is direct, with the transfer of the calculated flow data automatically done, substantially reducing the time necessary to fill in spreadsheets in the field and the digitization of these data. The major disadvantage of these instruments is the acquisition cost.

The discharge flow was measured with an ISCO 2150 portable flow meter (Figure 6), which allows the measurement of total flow (m^3), flow speed (m/s), and level (m) of water. This equipment has doppler continuous wavelength technology to measure the average flow velocity (https://www.clean.com.br/Produto/Detalhe/56). The equipment has a cable with a sensor (flow meter) and a communicator cable for data transmission to a notebook. The flow was calculated using Isco Flowlink 5.1 software. The input parameters were configured considering the shape of each stream channel: round, U-shaped, rectangular, trapezoidal or elliptical; and by width section measurement (cm) of the watercourse (Figure 6a). The sensor was placed in each stream (Figure 6b,c) for six minutes in each sub-basin. The software automatically stored data every 30 s, and after finishing flow reading, the data were exported and saved (Figure 6d).

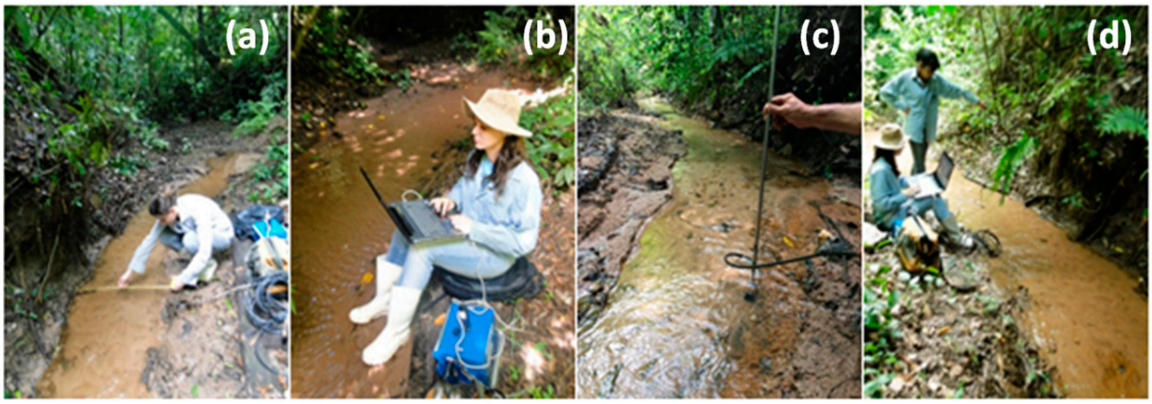

Figure 6. Flow data collection with the portable ISCO 2150 m: (**a**) width section measurement (cm) of a watercourse; (**b**) input parameters; (**c**) sensor in a watercourse; (**d**) reading flow and data storage.

In order to define the sampling points for monitoring and collecting the flow data, the area was characterized as natural sections. The 1.1 (a), 2 (c), and 3 (d) points (Figure 4) were carefully selected to determine water drainage in stream tributaries, that is, specific points where there was no separation or streambed dispersions of water flow for different parts or directions.

The flow results were subject to descriptive statistics comprising temporal and spatial analyses. The averages were showed in boxplots, with graphical representations of discharge flow distribution with a numerical summary of water flow (m^3/s). For statistical treatment, the data were processed in software R, considered a tool for statistical computing and graph production (https://www.r-project.org). The pluviometric data were collected from the Integrated Center for Agrometeorological Information—CIIAGRO (http://www.ciiagro.sp.gov.br), which provides daily data by location in online system.

3.2. Thematic Maps

The land use and land cover (LULC) thematic maps of the sub-basins were elaborated using geographic information systems (GIS) and remote sensing techniques by using a visual interpretation of LULC on high-spatial-resolution orbital images.

The ESRI's ArcMap and Google Earth Pro GIS software packages were used to view, edit, create, and analyze geospatial data in hydrological and environmental studies in watersheds [26,27,72,73]. The maps' base information was compiled from spatial databases, using maps published by the

Brazilian Institute of Geography and Statistics (https://ww2.ibge.gov.br) at a scale of 1:100,000, and a digital elevation model (DEM) that was obtained from ASTER GDEN V2 satellite image.

The geoprocessing resources served as a basis for the mapping of the compositions of land use and land cover and identification of the points of collection of the water flow and of the watershed under study. The interpretative analysis of each land use was carried out based on the exposure of colors for different spectral waves of in image, with the representation and definition of the classes in regard to sub-basins' soil cover. The classification procedure was carried out based on research works developed by [27,54] and followed the characterization of environments that reflect the watershed ecosystem upstream of the water catchment point.

The location of the sub-basins, the segmentation of drainage networks and topographic dividers were carried out, and the polygons were vectorized on each LULC. The points, lines, and polygons were plotted on Google Earth Pro software, and, subsequently, the units mapped in KML format were transferred to ArcGis®, using the KML to Layer command conversion tool. The calculation of the areas for each LULC was performed in ArcMap software using the Area tool, in order to tabulate the differences of areas in percentage, in each sub-basin.

4. Results and Discussion

The headwater volumetric flow rate of water was characterized in terms of volume of fluid per unit of time (L/s) and space (sub-basins), which passed through the stream cross-section of each drainage sampling point from sub-basins: 1.1, 1.2, 2, and 3 of the Olaria stream watershed (Figure 3). Values on descriptive statistics of discharge can be seen in Table 1.

The discharge showed a range of values from 0.09 L/s (sub-basin 1.2) to 107.99 L/s (sub-basin 3), with mean values of 2.95 L/s (sub-basin 1.1); 0.92 L/s (sub-basin 1.2); 4.84 L/s (sub-basin 2); and 13.91 L/s (sub-basin 3). The standard deviation (SD) indicates the high values spread out over a wider range (1.32 to 20.23 L/s), in a high coefficient of variation (CV), positive asymmetry ($\gamma 1 > 0$) and kurtosis coefficient.

The analysis of morphometric characteristics of each sub-basin provided a quantitative description of geometric aspects and slope of each sub-basin (Table 2).

Table 1. Descriptive statistics of discharge (L/s) of sub-basins, from 2012 to 2016.

Sub-Basin	Max	Min	Mean	Med	SD	CV (%)	AC	KC
1.1	8.50	0.18	2.95	2.50	1.57	53.2	0.803	0.0001
1.2	8.42	0.09	0.92	0.41	1.32	144.1	2.542	0.012
2	17.80	1.44	4.84	3.97	2.85	58.8	1.605	0.005
3	107.99	1.01	20.47	13.91	20.23	98.8	2.327	0.010

Max—maximum value; Min—minimum value; Mean—mean value; Med—median value; SD—standard deviation; CV—coefficient of variation; AC—asymmetry coefficient; KC—kurtosis coefficient.

Table 2. Morphometric characteristics of sub-basins at the Olaria stream watershed.

Sub-Basins	Area (ha)	Perimeter (km)	L (km)	W (km)	Sl (km)	Ha (m)	La (m)	S (%)
1.1	80.9	3.54	1.11	1.1	0.82	607	554	6.4
1.2	77.8	3.97	1.22	0.84	0.80	605	547	5.7
2	111.2	4.42	1.96	1.4	2.72	615	554	7.4
3	794	11.9	4.46	2.55	7.35	615	520	5.4

Symbols: L—maximum length; W—maximum width; Sl—stream length; Ha—high altitude; La—low altitude; S—slope.

The data obtained from dimensional morphometry (Table 2) showed that 1st-order sub-basins (1.1 and 1.2) have similarity values in terms of area (80.9 ha and 77.8 ha), perimeter (3.54 km and 3.97 km), and stream length (0.82 and 0.80 km). The highest altitude (H) was identified in sub-basin 2 (615 m), and the lowest was on point 3 (520 m). The greatest slope (S) was on sub-basin 2 (7.4%), followed by sub-basin 1.1 (6.4%), sub-basin 1.2 (5.7%), and sub-basin 3 (5.4%). The 2nd-order sub-basin had an area of 111.2 ha and a perimeter of 4.42 km.

The headwaters (sub-basins 1.1; 1.2, and 2) form an essential link in the hydrological cycle of the Olaria stream watershed. There are several approaches to topological ordering of streams based on distance from water source (headwaters) upstream to downstream to sub-basin 3. From the highest points to the lowest points, there is a hierarchical position of 1.1 and 1.2 (first order), 2 (second order) in the river system (Table 2; Figure 3), after each stream confluence. Considering the fluvial system as a continuation of the main channel (sub-basin 3), as observed in Figure 3, the headwaters are the smaller streams, of 1st-order of magnitude [68], which are the positive integer used in geomorphology and hydrology to indicate level of branching in a river system.

The headwater upstream points of first order (sub-basins 1.1, 1.2, and 2) are the extreme tributaries on the Olaria Watershed. The Strahler order is designed to morphology of a watershed and forms the basis of important hydrographic indicators of its structure. Its base is initial discharge flow line, which characterizes spring water.

The sub-basins of 1st order of magnitude (1.1 and 1.2), with similar areas (80.9; 77.8 ha), presented different hydrological behavior regarding amplitude of volumes over time (along month and years) and space (Figure 7).

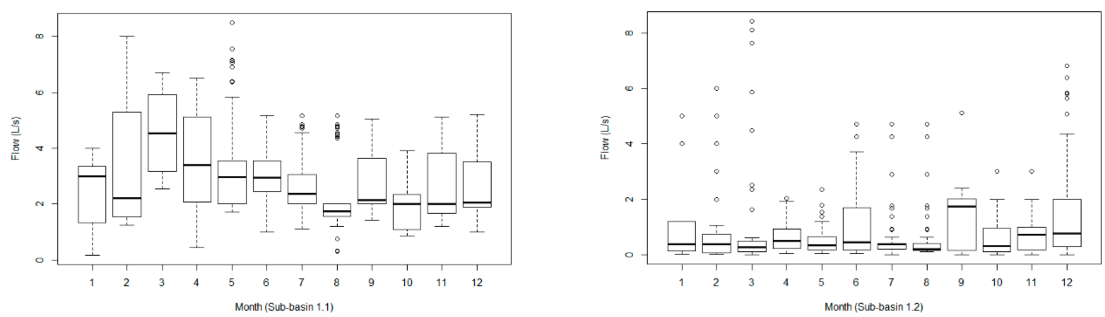

Figure 7. Sub-basins 1.1 and 1.2 discharge flow in the Olaria stream watershed, State of São Paulo, Brazil.

The minimum, first quartile (Q1), median, third quartile (Q3), and maximum values from sub-basins 1.1 and 1.2 showed that the water source of sub-basin 1.1 has higher volumetric flow rate of water transported through the given stream cross-sectional area than sub-basin 1.2, which showed the mostly outlier values along the monthly years, mainly in March (Month 3) (Figure 7).

The distribution, its central value, and its variability showed a different behavior of concentration of water flow on sub-basin 2, which has two stream branches and is along the drainage network (sub-basin 3) over the monthly monitored period (Figure 8).

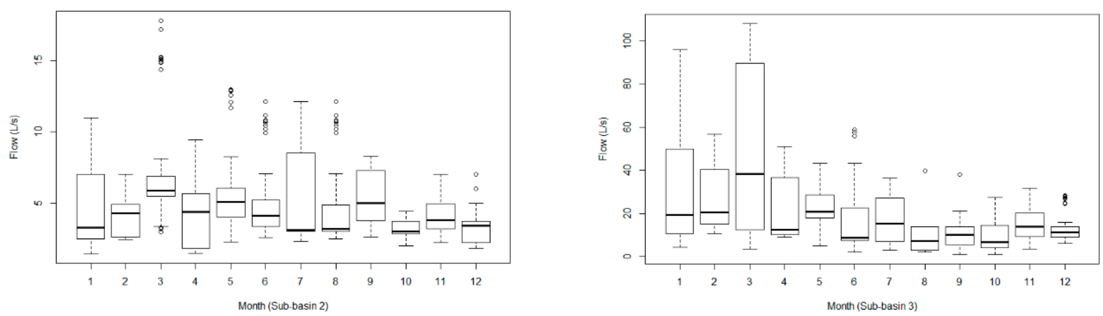

Figure 8. Sub-basins 2 and 3 discharge flow in the Olaria stream watershed, State of São Paulo, Brazil.

The distribution of annual flows in sub-basins 1.1, 1.2, 2, and 3 (Figures 7 and 8) in the Olaria stream watershed indicates the values measured on an interval scale (1.1; 1.2; interval 0–8 L/s); (2; interval

0–15 L/s); (3; interval 0–100 L/s), from month 1, January, to month 12, December. Those headwaters are considered perennial, that is, they produce water throughout the year, but with flow rates varying throughout it. If two discharges from the same order stream are merged (Figure 8, sub-basin 2), the resulting discharge flow increases from 8 L/s to 15 L/s. The 2nd order of magnitude in which two headwaters from two first-order watercourses merge (sub-basin 2) showed the average value of 4.84 L/s (Table 1). Based on volume of water from confluence (the point where two 1st-order rivers merge), a minimum value of 1.44 L/s and a maximum of 17.80 L/s were observed over 5 years.

The freshwater provided from the Olaria stream on point 3 (Figure 8; sub-basin 3) showed an average flow rate of 20.47 L/s that will be used for consumption to urban areas downstream of the São Domingos River, crop irrigation systems, and multiple uses. Through the Olaria stream watershed, the discharge flow is the environmental transport on each open channel (i.e., free surface conduits of water). The water storage and control of sub-basins within headwaters (points 1.1, 1.2, and 2) determine a constant condition of water production over time.

The water discharge recognizes water source on a watershed, which allows defining the main flow and its contribution to environmental services considering the drainage networks of 1st order of magnitude. The valuation of discharge in headwaters as an ecosystem service will benefit and control the sub-basins in a watershed functioning. In this sense, discharge can be a variable that allows development of inductive and not only repressive public policies and can be considered in the importance of ecosystem services (ES) promoted by maintenance and conservation of water resources, mainly on changing the principle of "polluter pays" to "provider-receiver", in payments for environmental services (PES) schemes [53,54].

As mentioned, this program presents an importance of balancing the dynamics of habitats and ecosystems and favors maintaining, recovering, and improving environmental conditions [54,57]. So, there is a need to recognize the anthropogenic landscapes on distribution of land use and land cover (LULC) of uphill on headwaters areas. The percentage values of LULC varied in each sub-basin, with predominance for cropping and forest cover on sub-basins 1.1, 1.2, and 2 (Figure 9).

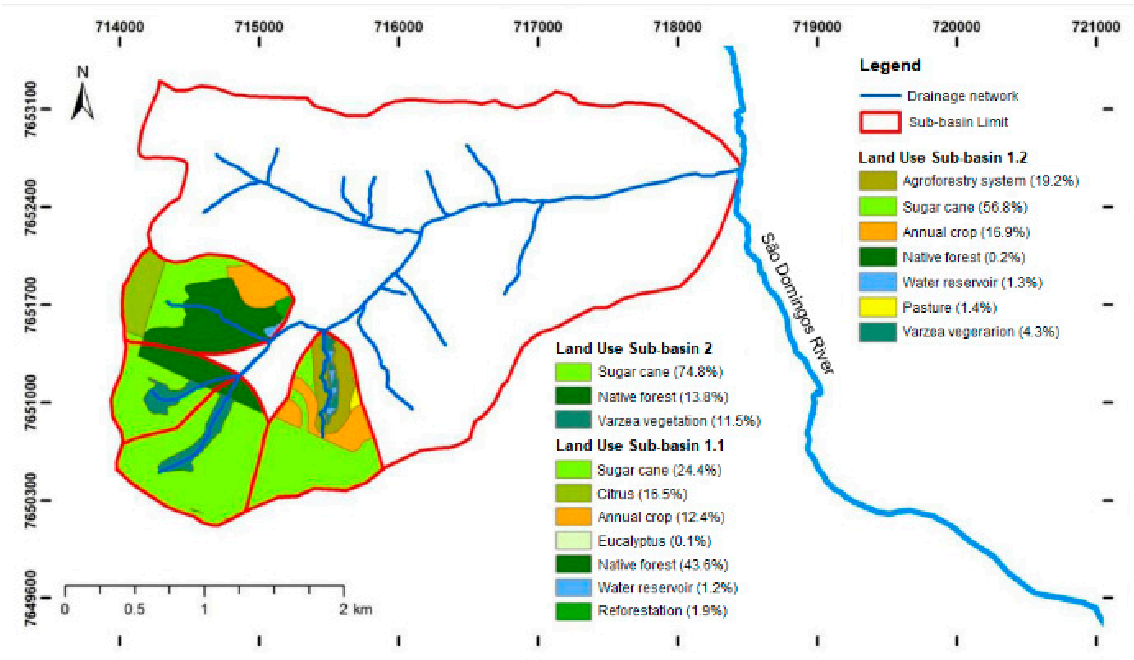

Figure 9. Land use land cover (LULC) at Olaria stream sub-basins, State of São Paulo, Brazil.

Agricultural land use was noticeable in all sub-basins (Figure 9). Sugarcane represented 74.8% (sub-basin 2), 56.8% (sub-basin 1.2), and 24.4% (sub-basin 1.1), annual crops were 16.9% (sub-basin 1.2) and 12.4% (sub-basin 1.1), citrus culture indicated 16.5% (sub-basin 1.1), and pasture 1.4% (sub-basin 1.2). Therefore, the sub-basins have significant anthropogenic influence. In addition to considerable crop areas, sub-basins are substantially covered with native forest, 43.6% (sub-basin 1.1), 13.8% (sub-basin 2). It is important to highlight the Agroforestry System (AS) 19.2% (sub-basin 1.2), which was implemented in 2011, aiming to restore the Permanent Preservation Area (PPA) on site and enable a better functioning of ecosystems, as well as promoting environmental services.

The characterization of water availability (upstream) allows taking into account the spatiotemporal heterogeneity of the Olaria Stream watershed, regarding physical characteristics (morphometric), LULC density, and topography. The headwaters' upstream sub-basins do not consider the crop area as a single and homogeneous unit, but regions that respond to the conservationist practices installed in an agricultural system.

The monthly average flows in sub-basins 1.1 and 1.2 (1–60 months) and the runoff coefficient (C) showed different hydrological behavior over time. The runoff coefficient (C) expresses the different relationships between the amount of runoff and the amount of precipitation received (Figures 10 and 11). The total rainfall values varied each year, (2012: 1152.1 mm; 2013: 1429.4 mm; 2014: 961.2 mm; 2015: 1367.8 mm; 2016: 1376.6 mm). The lowest value occurred in 2014 and the highest value in 2013.

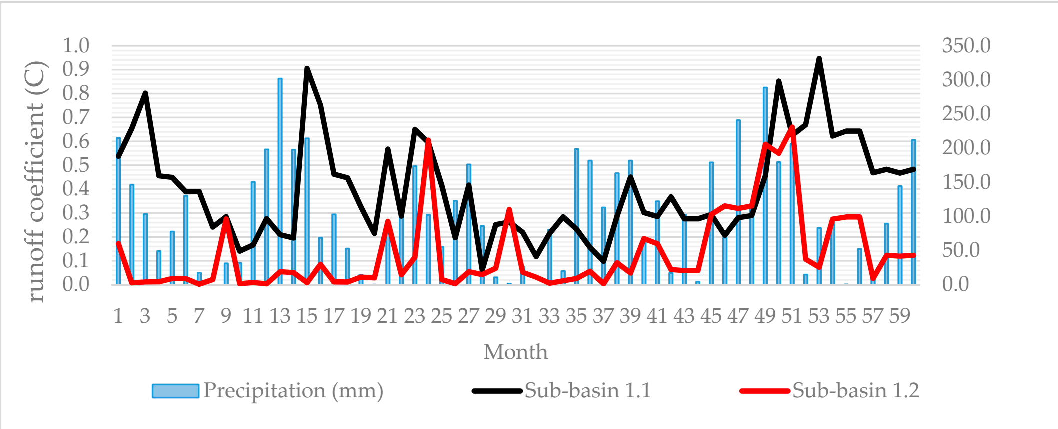

Figure 10. Precipitation (mm) and sub-basin 1.1 and 1.2 runoff coefficient (C) from January 2012 (Month 1) to December 2016 (month 60) in the Olaria stream watershed.

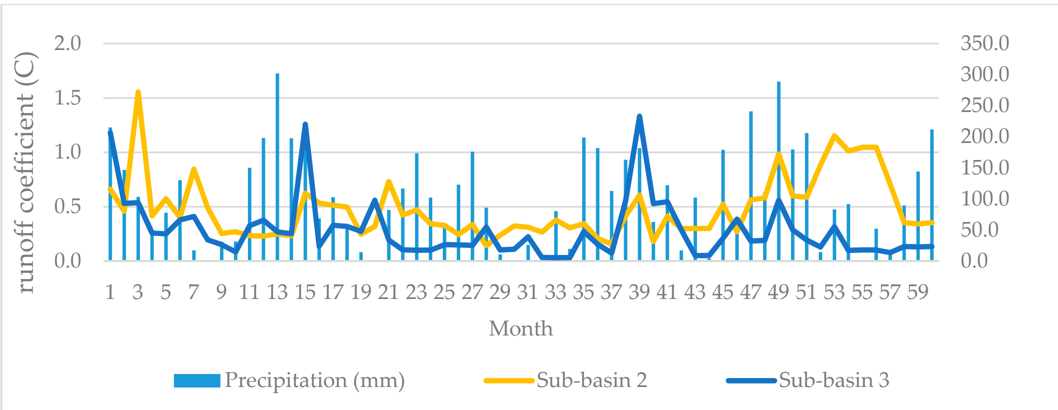

Figure 11. Precipitation (mm) and sub-basin 2 and 3 runoff coefficient (C) from January 2012 (month 1) to December 2016 (month 60) in the Olaria stream watershed.

It is important to highlight that even in months where there was no rain or there was little rainfall (May, June, and July), the headwaters continued to produce water volume in the watershed. The sub-basins' overland surface runoff after a higher precipitation shows the water running downhill over the landscape of the Olaria watershed (Figures 10 and 11). Stream discharges are directly influenced by seasonality, years (Table 3), and climatic variability; thus, critical periods in terms of water availability must be assessed in order to guarantee a safety margin for planning and management activities [74]. Discharge can be conceptualized as a result of hydrological processes of interaction between regional precipitations, infiltration, defluvium (Figures 10 and 11 and Table 3), and physiographic conditions of the watershed (Table 2), in which man's actions directly influence proper management of biodiversity conservation and water production [75]. When precipitation (mm) falls onto each sub-basin, it starts moving according to the laws of gravity, downhill to retain water in the streams.

Table 3. Sub-basins 1.1., 1.2, 2, and 3 flows (m^3/s) in the Olaria stream watershed.

	Year	Flow (L/s)		
		Average	**S.D.**	
Sub-basin 1.1	2012	2.9	1.4	c
	2013	3.4	1.7	b
	2014	1.7	0.8	d
	2015	2.1	0.7	d
	2016	4.5	1.2	a
Sub-basin 1.2	2012	0.3	0.6	d
	2013	0.8	1.4	bc
	2014	0.4	0.6	cd
	2015	1.2	0.9	b
	2016	1.9	1.9	a
Sub-basin 2	2012	5.4	3.6	b
	2013	4.4	1.6	c
	2014	2.9	0.7	d
	2015	3.9	1.6	c
	2016	7.7	3.1	a
Sub-basin 3	2012	28.2	21.3	a
	2013	23.4	22.7	a
	2014	10.4	7.8	b
	2015	26.6	25.6	a
	2016	13.7	10.9	b

The water storage in the basin system has increased, and the response of the basin has become more direct as the sub-basin area increases. On sub-basin 1.2, there is an area of old gully, recovered by soil conservation practice, with the implantation of a permanent preservation area and agroforestry system, in early 2011. It is important to note that, in this place, an increase in water production can be clearly seen from September 2013 (month 47, Figure 11), a period in which soil conservation practices were consolidating along the headwaters. This result demonstrates the importance of growth of the riparian forest area, and practices of terracing, no-till, and level planting that occurred in the uphill watershed. The effect of vegetation and forests contribute to regulation of the hydrobiological cycle and greater quantity and quality of water in watersheds [52,76–79].

The water availability values of headwaters (1.1, 1.2, and 2) showed the lowest average flow in sub-basin 1.2 (0.09 L/s). Non-forested springs present several problems, such as flood events, silting of water courses by uncovered soil, in addition to low water infiltration in the hydrological system [30,80]. The lack of forest cover drastically prevents water from infiltrating the soil, thereby supplying springs, impairing proper functioning of the hydrological regime [30,81]. The headwater (1.2) is located in a large percentage of agricultural areas and an important reforestation implantation in 2011 (Figure 11). In this place, there is a clear increase in water production in 2013, confirming results of the importance of growth of the riparian forest and a better water ecosystem service promoted within a set of environmental benefits [52,55].

The results indicate the importance of a forest to increase water production and base flow (Qbf), since forest floor provides greater water infiltration in the soil (IF), intercepts (Ic) the precipitated water (P) by means of crowns, trunks and roots, which infiltrate porous soil, percolating to the deepest layers of soil, supplying the water table levels, aquifers and, consequently, springs and riverbeds, favoring the regularization of the hydrological regime. Statements like these were made by several authors, among them [69,75,82–85]. In an area with forest cover, there is less direct runoff (Qds), avoiding sediment transport, erosion, river sedimentation, flooding, and decreased loss of nutrients from soil [69,86–89].

All headwaters are perennial in an intermittent streams condition. Even in the dry season, the volume of water remained regulated, with no water outages or water crises (Table 1, Figures 7–10). In rainy months (November to April), there were no flood peaks or episodes of maximum flows, which shows the great importance of native forest in regulating discharge flow and water availability for springs, in agreement with several studies conducted [52,69,75,82–85,90,91].

The groundwater occurs within sub-basins, and the water moves slowly on sub-basin 1.2 (Table 3). The precipitation is absorbed in the watershed, where it flows and becomes part of the surface water in different ways, as shown in Figures 10 and 11. The streams flow from 1.1 and 1.2 of the watershed, join the stream on point 3, and to the São Domingos river. Thus, groundwater flows toward a stream, and the sub-basins are used as the basic hydrologic unit for both surface water and groundwater planning purposes [79–83,88,89].

Most groundwater and surface water are interconnected, but in some environments, such as sub-basin 1.2, there was not enough groundwater discharge to maintain stream flow like in 1.1. The water availability on sub-basins of first order contribute to water security assessment on the São Domingos river watershed, which contributes water flow to the Turvo/Grande river, an important Brazilian watershed.

The water security assessment framework should consider a flow discharge on a basin-scale analysis, using an indicator, mainly on first-order sub-basins, as 1.1 and 1.2. The discharge from headwaters is a dimension of water flow and can be considered as an indicator of water security. The public policies should be elaborated to consider this point of view in making the water assessment framework on the basis of headwater flow discharge. Therefore, the water availability in watersheds is a measure of how the discharge will have a bearing on water security to a better land use land cover (LULC) governance.

Throughout the period, the sub-basins functioned as an impermeable container, returning the water received by precipitation and retaining part of that water in the water storage in the dam system. The water retention capacity is influenced by several factors, among which, the forest cover, physical characteristics and geomorphological factors, topography, hydraulic works present in the basin and conservationist planting practices [26,45,47,55,67,69].

The forest cover has the function of interception, storage, and reduction of runoff [67]. Concerning sub-basins 1.1 and 1.2, morphometric characteristics at the Olaria stream watershed (Table 2) and the stream flow along the months (Figure 11), the water retention in the basin's hydrological system varied according to geomorphologic factor, as the lower slope of the terrain, soil formation, and implementation of native tree species land cover along the dams. The agroforestry system on sub-basin 1.1 was consolidated on natural vegetation cover on the basin area system along the dam, and it was observed that the flow, over time, was more stable. However, in sub-basin 1.2, in the period of growth of vegetation cover (2011 to 2013), there was a lower volume of runoff. After the consolidation of the permanent preservation area (after 2013), the volume of flow water increases gradually, with a considerable increase after 2015. According to [89], the water absorption by the root system in the growth period of the vegetation cover increased the time of permanence of water in the hydrographic basin, causing events of less volume of water flowing to the basin from the evapotranspiration processes.

With identical amounts of precipitation, the sub-basins produced varying amounts of flow, due to different physical characteristics of the hydrographic basin and vegetation cover by area. Another factor is the topography of the terrain, which may have influenced the water storage capacity on these. In areas with a higher slope (sub-basin 2; 7.6%), there was less storage capacity than flatter areas, sub-basin 1.1 (6.4%), and sub-basin 1.2 (5.7%).

The discharge flows showed space–time variation in magnitude between studied headwaters sub-basins 1.1 and 1.2, on water availability, assessed based on average net discharges (Figure 11). Another factor that can be considered is the hydraulic works present in the basin, intended to contain the runoff (dams), sub-basins 1.1 and 1.2, which result in a reduction in the maximum flow of a basin, in view of the water storage in dams. In the Olaria watershed, the lowest flow was always observed in sub-basin 1.2. It is important to note that, in this place, there are dams that were built to stabilize a gull and to recover the local spring. These dams have drainage channels to control the speed of the water in each weir.

The new Brazilian Forest Code, Law No. 12,651 of 2012 [92], currently in force, Art. 41., establishes that the Federal Executive Government will consider the "Support and incentive program for conservation of environment" for ecologically sustainable development. However, it does not declare a deadline for such action and effectiveness. In Art. 41., mentioned above, it is reported the actions that the legislation intends to apply, as well as the monetary compensations and incentives, Items I and II, namely:

I—payment or incentive for environmental services such as remuneration, monetary or not, for the activities of conservation and improvement of ecosystems and generate environmental services, such as: sequestration, conservation, maintenance and increase of stock and reduction of flow carbon, conservation of scenic beauty and biodiversity, conservation of water and water and soil services, climate regulation, cultural enhancement and traditional ecosystem knowledge, maintenance of Permanent Preservation Areas, Legal Reserves, and restricted use.

II—Compensation for the environmental conservation measures necessary for fulfillment of the objectives of this Law, namely: Obtaining agricultural credit (with lower interest rates, limits and longer terms than in the market); Hiring of agricultural insurance; Granting of tax credits (by deducting the Permanent Preservation Areas, Legal Reserve and restricted use of the calculation basis for the Tax on Rural Territorial Property—ITR); Financing lines for the recovery of degraded areas, projects for the preservation of native vegetation, protection of species of native flora threatened with extinction, forest management and sustainable agroforestry carried out on the property or rural areas; Tax exemption for the main inputs and equipment.

Therefore, Brazil is awaiting regulation from the Federal Executive Government to have a Program for Payments for Environmental Services in force in the Law. However, compensation for the generation of ecosystem services already occurs and is distributed throughout the national territory, through actions promoted in programs and projects, with federal, state, and municipal government support, or support from private-sector companies.

Some notable examples that can be mentioned are: Water Producer Program of the National Water Agency—ANA (https://www.ana.gov.br/programas-e-projetos/programa-produtor-de-agua), being executed to initiatives by city halls, basin committees, or sanitation companies. The rural producers interested in conserving springs on their property and other priority areas for water production should seek out these institutions for applications on registration in the program and financial contemplation.

Another recognized program is the Conexão Mata Atlântica project (Project for the recovery and protection of climate and biodiversity services in the southeastern corridor of the Brazilian Atlantic Forest), which benefits, through the PES financial mechanism, rural owners who adopt conservation actions native forest, recover degraded areas, and implement sustainable production practices. This program is supported by the federal government, through the Ministry of Science, Technology, Innovations and Communications (MCTIC), and by the governments of the states of Rio de Janeiro, São Paulo, and Minas Gerais. The resources are made available by the Global Fund for the Environment (Global Environmental Facility—GEF), in order to implement actions to encourage the recovery of conservation of ecosystem services. For participation, interested parties must submit the required documentation through a public selection notice (https://conexaomataatlantica.mctic.gov.br/cma/o-projeto/o-que-e).

There are also the Payment for Environmental Services Projects, provided for the Forest Remnants Program of the State of São Paulo—Brazil, which comply with State Law 13,798/2009 (State Policy on Climate Change) and State Decree 55,947/2010 [93,94]. These projects cover various types of related environmental services: the conservation of forest remnants; recovery of riparian forests and implantation of native vegetation for the protection of springs; planting seedlings of native species and/or implementing practices that favor natural regeneration for the formation of biodiversity corridors; reforestation with native species or with native species intercropped with exotic species for sustainable exploitation of wood and non-wood products; implementation of agroforestry and silvopastoral systems that include the planting of at least 50 individuals of native tree species per hectare; implantation of commercial forests in areas contiguous to the remnants of native vegetation; and management of forest remnants to control competing species

Other initiatives comprise conservation-planting practices. Conservation practices in agricultural crops include the use of terracing, or monitoring of level curves, to direct runoff (reducing slope) and avoid erosion and damage to crops, contribute to better conditions infiltration of water in the system, in low- or medium-intensity rains [89]. Sub-basins 1.2 have a percentage of agricultural areas that receive conservationist planting treatments, which contributes to greater water infiltration into the hydrological system. The water moves within the hydrographic basin in an infinite number of superficial and/or underground trajectories, in which there is an accumulation of groundwater and less lateral flow.

The watershed ecosystem is a fundamental unit to provide an environmental service considering natural resources. The PES programs should be applied in headwaters on sub-basins in a watershed. The scheme will bring several benefits for society, balancing the dynamics of habitats and ecosystems, and favoring maintenance, recovery, or improvement of environmental conditions [54,57,95].

The sale of a best cropping production considering best management practices and an agricultural production conducted within sustainability (e.g., agroforestry production systems) brings benefit to a collectivity. The "provider-receiver" principle is based on a landowner that will offer an environmental service which generates a benefit of a better quality and quantity of water to society. Therefore, the producer that produces in a headwater sub-basin considering agricultural practices will have the right to be remunerated for maintaining soil and land on its best quality, decreasing the erosion process and preserving the natural resources as soil and water in a better quality.

The control instrument of the "provider-receiver" principle should be a land use policy. The landowner must be motivated to include the best management practices uphill headwaters as an environmental service in their decision-making regarding a better land use land cover (LULC). The conservation of land should be a financially attractive option. The productive practices with a soil and water better management and conservation should be considered as income generation on furnishing environmental services. The PES is planning a legal framework to define the economic activity and it is an instrument of public policies at the least cost to society. The ES is determined by a market established between private and public institutions to establish a market for ES compensation.

5. Conclusions

The hydrological discharge of headwater sub-basins showed space–time variation in magnitude. The water flow discharge of forested protected headwater on 1st order of magnitude produced a better quantity of water. The Olaria stream watershed has water availability, assessed based on average net discharges (flow) and indicates a potential for environmental services payment programs, with respect to the "provider-receiver" principle, and water security schemes.

The hydrological discharge of the headwater sub-basins presented a flow range from 0.09 L/s (sub-basin 1.2) to 107.99 L/s (sub-basin 3) or from 8 to 9330 m^3/day. Sub-basin 1.1 was the one that remained stable throughout the monitoring period, with an average flow of 2.95 L/s or 255 m^3/day. Sub-basin 1.2 showed an increase in volume over time, ranging from 0.3 to 1.9 L/s or 25.9 to 164.1 m^3/day.

Gully recovery management, reforestation with native trees, and agroforestry system in sub-basin 1.2, concomitant with the annual increase in flow during the recovery works, is an example of an activity indicated for receiving payment for the environmental service provided, discharging more water and quality for the owner downstream of the watershed.

This study contributes with an example of water security assessment in Brazilian watersheds, for the feasibility of paying for environmental services for the water-producing sub-basins.

Author Contributions: Conceptualization, M.B.L.S., T.C.T.P., and A.L.M.M.; methodology, M.B.L.S. and T.C.T.P.; software, L.F.S.F. and R.C.A.C.; validation, T.C.T.P., L.F.S.F., and F.A.L.P.; formal analysis, F.A.L.P., T.C.T.P., and M.Z.; investigation, M.B.L.S. and T.C.T.P.; resources, A.L.M.M. and T.C.T.P.; data curation, M.Z., L.F.S.F., and T.C.T.P.; writing—original draft preparation, M.B.L.S., M.Z., and T.C.T.P.; writing—review and editing, F.A.L.P. and M.C.L.; visualization, F.A.L.P. and M.C.L.; supervision, T.C.T.P. and F.A.L.P.; project administration, T.C.T.P. and M.B.L.S.; funding acquisition, A.L.M.M. and T.C.T.P. All authors have read and agreed to the published version of the manuscript.

Funding: The present study was carried out within the framework of the Post Graduation Research Programme of Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES); Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq); Agência do Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC); and Land Use Policy Brazilian Group (PolUS). For the author integrated in the CITAB Research Centre, the research was further financed by National Funds of FCT—Portuguese Foundation for Science and Technology, under the project UIDB/AGR/04033/2020. For the author integrated in the CQVR, the research was further financed by National Funds of FCT—Portuguese Foundation for Science and Technology, under the project UIDB/QUI/00616/2020.

Acknowledgments: The authors would like to thank: the Coordination of Improvement of Higher Education Personnel (CAPES) for the scholarship; the National Council for Scientific and Technological Development (CNPq) for Research funds; the Agronomy (Soil Science) Post-Graduation Program from the School of Agricultural and Veterinary Sciences, São Paulo State University (UNESP); The Land Use Policy Research Group—PolUS. Mariana Bárbara Lopes Simedo (M.B.L.S.), Teresa Cristina Tarlé Pissarra (T.C.T.P.), Antonio Lucio Mello Martins (A.L.M.M.); Maria Conceição Lopes (M.C.L.), Renata Cristina Araújo Costa (R.C.A.C.), Marcelo Zanata (M.Z.), Luís Filipe Sanches Fernandes (L.F.S.F.), and Fernando António Leal Pacheco (F.A.L.P.).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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