ISSN: 2230-9926

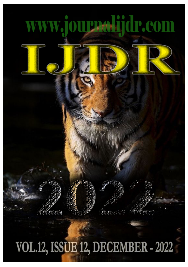
Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research

Vol. 12, Issue, 12, pp. 60911-60915, December, 2022

https://doi.org/10.37118/ijdr.25619.12.2022



RESEARCH ARTICLE OPEN ACCESS

AVAILABLE POTENTIAL AND ALTERNATIVES TO HYDROKINETIC ENERGY USE ACCORDING TO LAND USE IN SÃO FRANCISCO VERDADEIRO BASIN

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ARTICLE INFO

Article History:

Received 14th September, 2022
Received in revised form
19th October, 2022
Accepted 10th November, 2022
Published online 25th December, 2022

Key Words:

Geoprocessing, Mapping, Hydrokinetic System; Hydrokinetic Turbines; GIS.

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ABSTRACT

Environmental issues are the biggest factor in the search for cleaner energy production alternatives. The use of hydrokinetic turbines can be a viable option for communities close to rivers that have specific hydrological characteristics. Using geoprocessing techniques, it was identified and mapped within the São Francisco Verdadeiro River Basin (SFV), potential sites for installing hydrokinetic systems to generate electricity. Digital Alos Palsar Elevation Models chosen by the NASA Earth Data project and images from Landsat 8 (L8) were used. Thematic mapping and subsequent analysis of sites with hydrokinetic potential in the study unit were carried out. 10 points with known flow along the SFV river in the dry period were selected, from which the basic parameters were obtained for calculating the water velocity using the Chezy equation. The required rotor diameter for each point was calculated at the maximum depth of the section as well as the available hydrokinetic potential at each point, considering the minimum (Cp = 0.25) and the maximum (Cp = 0.593) turbine efficiency, thus the energy production capacity was calculated at each point. Based on theoretical data collection, it was found that there is no hydrokinetic potential available in the studied points of the SFV River.

Citation: ***Camila ZeniAmaral, Maritane Prior, Fabiana Costa de Araújo Schutz and Julio Cezar Girardi. 2022.*** "Available potential and alternatives to hydrokinetic energy use according to land use in São Francisco Verdadeiro basin", *International Journal of Development Research*, 12, (12), 60911-60915.

INTRODUCTION

The global energy sector faces challenges in relation to sustainability, environment, and economy (AIZED *et al.,* 2018). However, in recent years, renewable energy sources have increasingly contributed to global energy production. (NIEBUHR *et al.*, 2019). The individual sources of renewable energy prove to be fundamental, given the individual challenges of each country in determining the ideal energy mix. (APERGIS*et al.*, 2016). The use of alternative sources, even as a supplement to conventional non-renewable sources, reduces the dependence on them, the environmental impacts, and reduces the impact of the energy crisis (KLIEMANN e DELARIVA, 2015). Brazil is in constant search of renewable energy sources in order to reduce environmental impacts, exploring its energy potential, and its main current energy matrix is hydroelectric plants and small hydroelectric plants, responsible for about 70.6% of all energy produced in the country. (EMPRESA DE PESQUISA ENERGÉTICA, 2015). To obtain electrical energy from renewable and environmentally friendly sources, an initial study is necessary, in which the feasibility of the available potential is verified (ARAÚJO, 2016).

The aspects considered to determine the feasibility of the project consider technical, economic, social, and environmental criteria. Meeting these requirements is important because, even if an energy source is available, if there is no demand, the project will not achieve the economic and social objectives (PAULA e MARX, 2011). The technical issue involves an analysis of the available potential and verification of the best way to obtain this energy so that the exploitation has the expected yield (WU *et al.*, 2016). Thus, hydrokinetic systems are a technological option to guarantee universal access to electric energy services that have emerged as a sustainable alternative, capable of converting the kinetic energy of rivers or marine currents into electrical energy. These systems are viable in regions that have small to large rivers, where hydrokinetic turbines can be installed (BARRETO e VAN ELS, 2015). Such use is made possible considering the ideal characteristics provided by the Brazilian territory, such as geological conditions and hydraulic potential, which are premises for obtaining greater power generated with less environmental impact (WEGNER, 2018). This study aims to map the hydrokinetic potential of energy generation in the hydrographic basin of the São Francisco Verdadeiro River - West of Paraná in order to determine the main regions with potential for the installation of hydrokinetic turbines.

For this, the main potential areas of hydrokinetic energy production were identified, located, analyzed and mapped and alternatives were proposed for the use of the hydrokinetic potential according to each land use and occupation identified in the hydrographic basin.

MATERIALS AND METHODS

São Francisco Verdadeiro River Hydrographic Basin (SFV): The São Francisco Verdadeiro River Hydrographic Basin (SFV) is inserted in the Paraná 3 Hydrographic Basin, which drains waters to the Itaipu Hydroelectric Power Plant reservoir. The SFV river contains the most extensive and representative drainage area in the plant's incremental basin and, for this reason, it has great relevance in the water quality of the Itaipu Lake reservoir (DIAS *et al.*, 2014).The study unit is located in the south of Brazil and west of Paraná state, as seen in Figure 1.

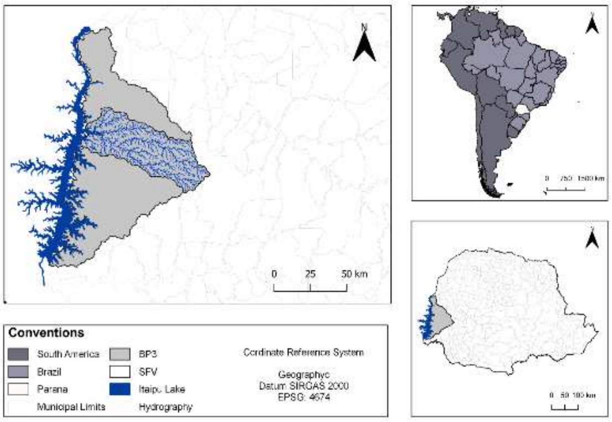

Figure 1. Location of the São Francisco Verdadeiro River hydrographic basin

It has an area of 2,219.19 km², where it has total or partial influence on 11 municipalities in the West of Paraná and has areas that are essential for the conservation of biodiversity and maintenance of resources, such as conservation units, biodiversity corridors, private heritage reserves and areas of relevant ecological interest (SILVA, 2018).

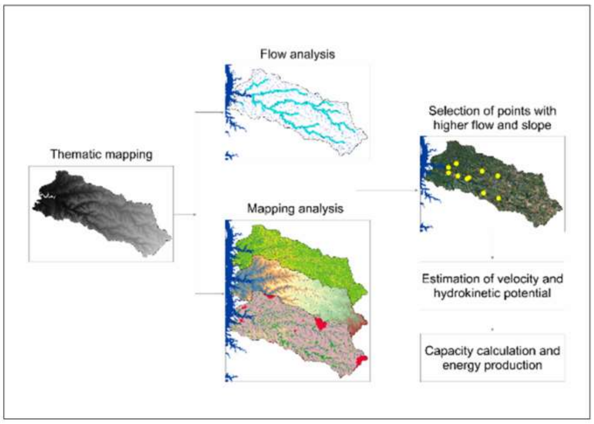

Figure 2. Main stages of the study

Preparation of thematic maps in the study area: All procedures involving geoprocessing techniques were performed in a GIS environment, using the free access software QGis 3.10. External tools such as GRASS GIS 7.8.2 and SAGA GIS 2.3.2 were used to use the entire tool package, for this, the advanced installation of QGis was carried out through the OSGeo4W network, selecting all the files necessary for the correct functioning of the tools. All procedures followed the Universal Transverse Mercator (UTM) Coordinate Reference System (SRC), Datum Sirgas 2000, EPSG: 4674. Thematic mapping includes slope identification, hypsometry, land use, hydrography, and a three-dimensional model.

Flow rates of São Francisco Verdadeiro River: The regionalization of the flow rates used in this work were obtained in Wegner *et al.* (2019),the parameters used to obtain these data consisted of morphometric characterization as explanatory variables in a multiple regression model. The 1548 points of the São Francisco Verdadeiro River with estimated flows can be seen in Figure 3.

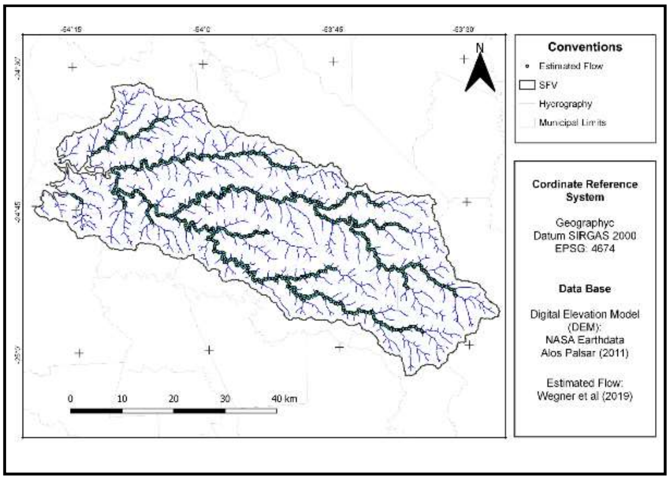

Figure 3. Location map of points with estimated flow of the São Francisco Verdadeiro River

River: Flow regionalization data considered the period from March to August, which corresponds to the dry period of the basin, thus providing reliable results for energy security.

Water speeds in the São Francisco Verdadeiro river: Ten points were chosen along the SFV river course that presented different values of flow and slope, the selected points sought to represent the course of the river. To calculate the river's current speed at each point, the flow and cross-sectional area were used. The flows rate of the 10 points is already known, and the analysis of the cross-sectional area was obtained through geotechnologies uses. The process for obtaining the profiles of the cross-sections took place with the creation of a shapefile with the type of geometry line, which comprises the width of the river (from bank to bank). Later, using the Profile Tool plugin, the DEM was selected as the base layer, and the shapefile corresponds to the river's width at each point, and thus the complement read the cross-section profile. The information contained in the profiles was distance and altitude, which made it possible to calculate the depth. This profile was exported in DXF file to Autodesk AutoCAD 2019, where the Wet Area and Wet Perimeter values were calculated. With Wet Area and Wet Perimeter values was possible to use the Chezy equation (Equation 1), with the Manning coefficient (n) to determine the average speed.

$$V = \frac{1{,}486\ R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \tag{1}$$

Equation 1: V is the average speed (m/s), R is the hydraulic radius (ratio between wetted perimeter and wetted area of the section), S is the slope and $n$is the Manning roughness coefficient (Streams and Rivers/Category 2/Regular Conditions = 0.035).

Determination of the hydrokinetic potential of the São Francisco Verdadeiro River: In calculating the hydrokinetic potential of the points located in the São Francisco Verdadeiro River, the diameter of the rotor needed to identify the swept area was calculated, which was determined as a function of the depth. The relationship used to determine the necessary rotor diameter was the same used by Cruz *et al.* (2020) and can be seen in Equation (2).

$$D = Y - \frac{1}{7}Y - \frac{2}{7}Y \quad (2)$$

Equation (2): Where D is the required rotor diameter (m) and Y is the depth (m). The hydrokinetic potential was calculated based on Equation (3) for two situations, the first in which Cp = 0.593 (BETZ, 1926), since this value is the maximum efficiency that a turbine can achieve (KUMAR and SARKAR, 2016), and the second in which Cp = 0.25, an efficiency value that small turbines in rivers can achieve (VERMAAK *et al*., 2014).

$$P = 0{,}5\ CpA\rho V^3 \quad (3)$$

Equation (3): P is the available power (W), Cp is the power coefficient and A is the cross-sectional area of the turbine rotor (m², Equation 4).

$$A = \frac{\pi D^2}{4} \quad (4)$$

Equation 4: ρ is the water density (997 kg/m³) and V is the water velocity (m/s). The calculation of the hydrokinetic potential considered only one turbine positioned at the deepest point of the stretch. Through the hydrokinetic potential values at each of the selected points, the Energy Production Capacity was calculated, Equation 5.

$$CPE = PN\ 24h \quad (5)$$

Equation 5: CPE (month) is the energy production capacity (W h^{-1}),N is the number of days in the month (considered 30 days).

RESULTS AND DISCUSSION

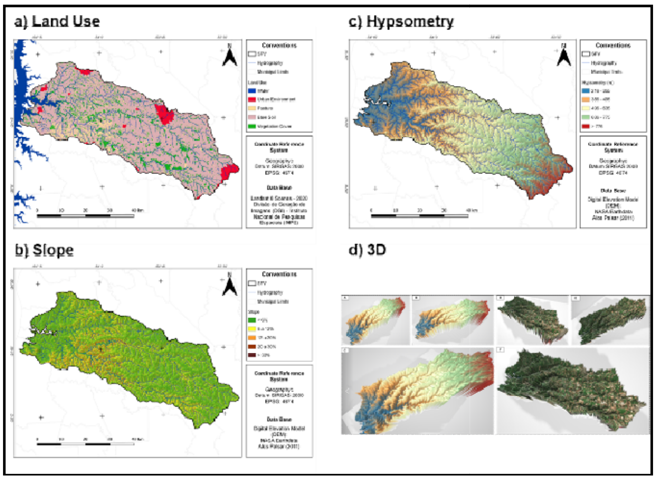

Figure 4. Thematic mapping and 3D model of the São Francisco Verdadeiro river basin

Thematic mapping of the hydrographic basin of the São Francisco Verdadeiro River: In Figure 4 a), it can be seen that there is a predominance of agricultural activities in the study site, covering about 75% of the total area (Table 1).

Table 1. Areas of land use in the São Francisco Verdadeiro River basin

Class	Area (km²)	Coverage percentage
Water	2.75	0.12%
Urban Area	92.59	4.05%
Pasture	158.34	6.92%
Exposed Soil	1724.74	75.35%
Vegetation	310.53	13.56%
Total	2288.95	100.00%

It is also observed that the areas with the highest incidence of pasture, legal reserve and reforestation are located near the mid-course sector of the basin, regions that are incompatible with agricultural mechanization practices. In the low and high course sectors of the BSFV, it can be seen that the vegetation is mainly concentrated on the banks of the drainage channels, and although in small fragments, it corresponds to 13.56% of the total study area. As for the slope in BSFV (Figure 4b), in the high course sector, the highest terrain occurs. And that in the flatter reliefs slopes defined as Very Weak to Weak (0 to 12%) predominate.

In the medium course sector, there are reliefs with the presence of slopes in the range from weak to strong (6-30%), with some occurrence of very strong slopes (>30%). In the low-course sector, the terrains have a lower elevation, close to the lake of Itaipu, and there is a predominantly very weak slope (<6%). Rocha and Bade (2018) mention that the slope is more accentuated in this region, and is associated with occupation by pasture and native or reforested vegetation. However, in the regions of medium and low slopes, agricultural uses stand out interspersed with pastures and forest vegetation. The differences in altitude in the basin under study can be observed by the hypsometric map (Figure 4c). The basin presents altitudes between 200.00 m to approximately 790.00 m. The 3D model (Figure 4d) was designed to facilitate visualization and identify differences in altitudes in the relief and slope of the basin. From the analysis of the 3D model, the characteristics related to the slope and altitude indices are visualized, confirming the fact that the areas with the highest slopes are the regions close to the SFV river, and that the areas with higher altitudes are close to the urban fractions of the hydrographic basin. In the present study, the occurrence of high slopes near the banks of the SFV river is a prominent factor.

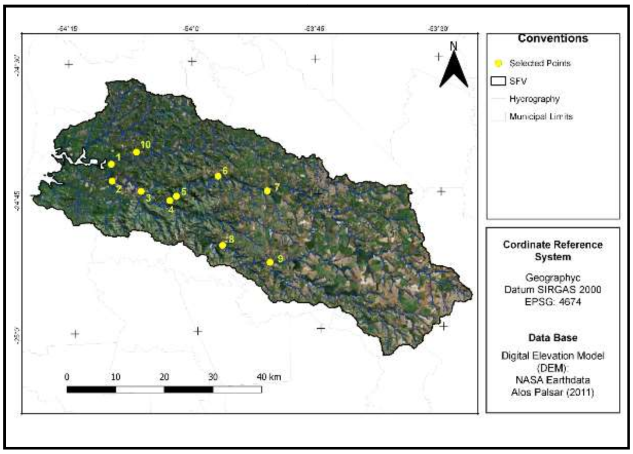

Figure 5. Location map of points with selected estimated flows

Hydrokinetic potential inSão Francisco Verdadeiro River hydrographic basin: 10 points were selected with flows estimated in the dry period of the region, illustrated in Figure 5. Just like the flow rate, the slope was one of the parameters analyzed for the selection of the regions with the better potential for THCs installation. Felizola *et al*. (2007) and Botan *et al*. (2016) cited that in places with high slopes, the water velocity is greater, and, for this reason, regions located in places with more accentuated slopes are considered to have greater hydrokinetic potential. Table 2 presents the flow and slope data at the 10 selected points. Based on the flow rates values, is possible to verify that not necessarily the highest flows are in regions with more steep areas, and these factors are not directly proportional. This situation is confirmed in Botan *et al*. (2016), who carried out a study to take advantage of the hydrokinetic potential in conditions of rivers that have a low slope and low speeds in the northern region of Brazil, in this same research, the authors emphasized that it is possible to take advantage of the hydrokinetic potential in regions with this characteristic, since that the technical project seeks adaptation to its field of operation in order to operate under the conditions of the respective scenario.

Table 2. Selection parameters

Points	Dry Period Flow ($m^3 s^{-1}$)	Slope
1	74.66	Strong – 20 to 30%
2	70.86	Very Weak – <6%
3	67.15	Weak – 6 to 12%
4	57.71	Weak – 6 to 12%
5	56.43	Weak – 6 to 12%
6	50.39	Weak – 6 to 12%
7	45.25	Strong – 20 to 30%
8	41.54	Strong – 20 to 30%
9	34.63	Strong – 20 to 30%
10	33.87	Strong – 20 to 30%

Profiles of the cross-sections analyzed: To obtain the velocity of a river, the flow rate and cross-sectional area values are needed. The cross-section profiles of each point can be seen in the complementary material. The information obtained by the cross-sections profiles of stretch width, maximum depth, and wet area were listed in Table 3. It is observed that the greatest depths observed are 8 and 10 meters.

Table 3. Data obtained through cross-section profiles

Points	Stretch width (m)	Maximum depth(m)	Wet area (m^2)
1	196.85	8.0	1349.48
2	110.34	3.0	206.89
3	194.82	4.0	690.74
4	192.16	5.0	650.39
5	263.58	10.0	1315.60
6	369.90	8.0	1815.85
7	182.57	7.0	847.66
8	231.15	6.0	924.62
9	234.73	5.0	871.87
10	173.76	7.0	708.36

Available potential and alternatives for hydrokinetic energy use according to land occupation: Based on the profile data, the displacement velocity of the river water, the necessary rotor diameter (based on the depth value in each case), the area swept by the rotor, and the hydrokinetic potential available in each point were calculated. Table 4 illustrated the results.

Table 4. Hydrokinetic potential of the São Francisco Verdadeiro River hydrographic basin

Points	Maximum depth (m)	Speed (ms^{-1})	Rotor Diameter (m)	Area Swept (m^2)	Hydrokinetic Potential (W/un. turbine)	Hydrokinetic Potential (W/un. turbine)
					Cp = 0.593	Cp = 0.25
1	8.0	0.06	4.57	16.4	0.82	0.35
2	3.0	0.34	1.71	2.31	27.40	11.55
3	4.0	0.10	2.29	4.10	1.11	0.47
4	5.0	0.09	2.86	6.41	1.32	0.56
5	10.0	0.04	5.71	25.63	0.60	0.25
6	8.0	0.03	4.57	16.40	0.10	0.04
7	7.0	0.05	4.00	12.56	0.56	0.24
8	6.0	0.04	3.43	9.23	0.25	0.10
9	5.0	0.04	2.86	6.41	0.12	0.05
10	7.0	0.05	4.00	12.56	0.41	0.17

By the data shown in Table 4, it is verified that when considering only the use of one turbine in each section, and by applying the Available Hydrokinetic Potential formula (Equation 3), none of the points obtained significant values. ABAQUE, 2016 cited that to operate a hydrokinetic system, the minimum current velocity required is 1.0 to 2.0 ms^{-1}, which can be reduced to 0.5 ms^{-1}, depending on the type of technology used. And only based on that, the fact that there is no hydrokinetic potential at the calculated points is justified since the highest velocity is 0.34 ms^{-1}. Bittencourt *et al*. (2016) also concluded that the points downstream of the Bariri and Ibitinga Hydroelectric

Table 5. Energy Production Capacity

Points	Energy Production Capacity ($W h^{-1}$)	Energy Production Capacity ($W h^{-1}$)
	Cp = 0.593	Cp = 0.25
1	590.40	252.00
2	19728.00	8316.00
3	799.20	338.40
4	950.40	403.20
5	432.00	180.00
6	72.00	28.80
7	403.20	172.80
8	180.00	72.00
9	86.40	36.00
10	295.20	122.40

Power Plants, with higher speeds, are the best for energy generation.In this study, it was also found that Point 2, which has a higher current velocity, has the greatest available hydrokinetic potential. Depth is also an important factor in determining the energy that can be extracted from the site, as long as the water level in the hydrokinetic device section is compatible with the system to be installed (SORNES, 2010). Thus, it was also observed that, together with water velocity, depth has a great influence on hydrokinetic potential, because the greater the depth, the greater the diameter and area swept by the turbine rotor. In order to obtain the Energy Production Capacity values ($W h^{-1}$) at each point, considering the two different turbine efficiency scenarios (Table 5), the calculated Hydrokinetic Potential values were used as a basis. Due to the low values of available hydrokinetic power calculated, the energy production capacity is not very significant, especially when dealing with activities aimed at rural practices. For example, considering the poultry activity, (an activity commonly developed in the study region) in which an aviary of 1,200.00 m², capable of housing an average of 14,000 birds, has a consumption of 369.35 kWh (TRICHES; GOMES, 2016), theoretically, none of the analyzed points would be able to supply the energy needs of the poultry business. Another alternative would be the Hydroelectric Generating Plants and Small Hydroelectric Plants. Wegner *et al*. (2019) identified 294 points with potential for CGHs (up to 3 MW) and 30 points with potential for SHPs (from 3 to 30 MW) in the hydrographic basin of the São Francisco Verdadeiro River, considering the restrictive aspects of installation in the region. Upon finding the potential for installing CGHs and SHPs, which demand more complex criteria, more technical parameters, and also because the São Francisco Verdadeiro River contains the most extensive and representative drainage area in the incremental basin of the ItaipuBinacional power plant, it is understood that, in a practical survey study, the hydrokinetic potential would be significant, even if on a small scale or as a supplement to another conventional energy source.

Conclusion

- In the dynamics of land use and land cover studies, it was found that the hydrographic unit of the São Francisco Verdadeiro River mainly covers agricultural and livestock uses, with some remnants of vegetation distributed along the banks of the drainage network.

- The cross-section profiles of the analyzed points showed that the river widths are greater than 100m, and depths greater than 3m, which indicated that despite the wide availability of water there is a low displacement speed.
- None of the evaluated points has great hydrokinetic potential available considering the data obtained from flow rate, depth, slope, and considering the calculation aspects for hydrokinetic potential in each point.
- To future researches are suggested case studies of the effective implementation of hydrokinetic systems, a realization of a bathymetric survey to check the profile of the cross-section and the speed values of the river's current, in addition to a more detailed projection of the desired electrical energy, as well as the study of economic feasibility.

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