STATE UNIVERSITY OF PONTA GROSSA
PRO-RECTORY OF RESEARCH AND POSTGRADUATE
MASTER DEGREE PROGRAM IN ENVIRONMENTAL AND SANITARY ENGINEERING

SAUANA HAEFNER CENTENARO

INFLUENCE OF A FLOATING PHOTOVOLTAIC SYSTEM ON WATER QUALITY
INFLUÊNCIA DE UM SISTEMA FOTOVOLTAICO FLUTUANTE NA QUALIDADADE DA ÁGUA

PONTA GROSSA
2022

SAUANA HAEFFNER CENTENARO

INFLUENCE OF A FLOATING PHOTOVOLTAIC SYSTEM ON WATER QUALITY

INFLUÊNCIA DE UM SISTEMA FOTOVOLTAICO FLUTUANTE NA QUALIDADADE DA ÁGUA

Dissertation submitted to the Master Degree Program in Environmental and Sanitary Engineering of the State University of Ponta Grossa as a requirement for obtaining the title of Master.

Advisor: Prof. Dr. Giovana Kátie Wiecheteck

PONTA GROSSA
2022

Centenaro, Sauana Haeffner
C397 Influence of a floating photovoltaic system on water quality / Sauana Haeffner Centenaro. Ponta Grossa, 2022.
78 f.

Dissertação (Mestrado em Engenharia Sanitária e Ambiental - Área de Concentração: Saneamento Ambiental e Recursos Hídricos), Universidade Estadual de Ponta Grossa.

Orientadora: Profa. Dra. Giovana Katie Wiecheteck.

1. Water quality. 2. Floating photovoltaic system. 3. Eutrophication. I. Wiecheteck, Giovana Katie. II. Universidade Estadual de Ponta Grossa. Saneamento Ambiental e Recursos Hídricos. III.T.

CDD: 628.4

Ficha catalográfica elaborada por Maria Luzia Fernandes Bertholino dos Santos- CRB9/986

CERTIFICADO DE APROVAÇÃO - DEFESA DE MESTRADO

PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA SANITÁRIA E AMBIENTAL
Certificado nº 06/2022 PPGESA

Título da Dissertação: "**INFLUENCE OF A FLOATING PHOTOVOLTAIC SYSTEM ON WATER QUALITY**"

Nome: SAUANA HAEFFNER CENTENARO

Orientadora: Profª. Drª. Giovana Kátie Wiecheteck

Aprovado pela Comissão Examinadora:

Profª. Drª. Giovana Kátie Wiecheteck
UEPG/Ponta Grossa - PR

Profª. Drª. Taiana Cestonaro
UEMA/São Luís – Maranhão

Prof. Dr. Gabriel Alfredo Carranza
UL Lafayette/Lafayette – Louisiana (EUA)

Ponta Grossa 22 de novembro de 2022.

Documento assinado eletronicamente por **Giovana Katie Wiecheteck**, **Professor(a)**, em 23/11/2022, às 19:19, conforme Resolução UEPG CA 114/2018 e art. 1º, III, "b", da Lei 11.419/2006.

Documento assinado eletronicamente por **Taiana Cestonaro**, **Usuário Externo**, em 24/11/2022, às 07:36, conforme Resolução UEPG CA 114/2018 e art. 1º, III, "b", da Lei 11.419/2006.

Documento assinado eletronicamente por **Gabriel A. Carranza**, **Usuário Externo**, em 26/01/2023, às 18:13, conforme Resolução UEPG CA 114/2018 e art. 1º, III, "b", da Lei 11.419/2006.

A autenticidade do documento pode ser conferida no site https://sei.uepg.br/autenticidade informando o código verificador **1223529** e o código CRC **22E52D7A**.

ACKNOWLEDGEMENTS

First and above all, to God for giving me the possibility to recover health and strength to overcome the pain and endure the obstacles and be on my feet to pursue my dreams.

To my parents for being my legs when I wasn’t able to walk by myself.

To my fiancé for being my breath of hope and my biggest supporter.

To Dr. Giovana Kátie Wiecheteck for all the kindness and compression. Thank you, professor, for pushing me beyond my mind limitations and for all your knowledge shared, without you, without your support, this work would not be possible.

To Dr. Taiana Cestonaro for all the help, the friendship and for the time and knowledge dedicated to my work.

To Dr. Gabriel Carranza for the kind words and incentive throughout this work.

To Fernando, my colleague, for listening and giving me support. This master degree was much better for having you with me.

To all professors of Master Degree Program in Environmental and Sanitary Engineering of the State University of Ponta Grossa and Unicentro.

To the Water and Sanitation Company of Paraná State – SANEPAR, for opening the doors to me and to UEPG team.

To Flavia for the great work and help with my results.

“É que tem mais chão nos meus olhos do que cansaço nas minhas pernas, mais esperança nos meus passos do que tristeza nos meus ombros, mais estrada no meu coração do que medo na minha cabeça”
(Cora Coralina)

"It's just that there's more ground in my eyes than fatigue in my legs, more hope in my steps than sadness in my shoulders, more road in my heart than fear in my head"
(Cora Coralina)

RESUMO

A busca incessante por meios de diminuição de danos ao meio ambiente é um dos fatores que levam o setor de tecnologias e pesquisa a estar em constante movimento. Nesse sentido as energias renováveis, com ênfase na energia solar fotovoltaica, surgem para reduzir a utilização de combustíveis fósseis, minimizar aspectos como poluição e desmatamento e também para se beneficiar de potenciais ambientais que estão à disposição, como o sol. A energia solar fotovoltaica é considerada uma energia inesgotável e a sua utilização tem se tornado mais expressiva nas últimas décadas, porém devido ao crescimento populacional e dos centros urbanos e também das áreas de agropecuária, as áreas para instalação de grandes usinas fotovoltaicas tem se tornado escassas e assim, como forma de sobrepor a este obstáculo a instalação de sistemas fotovoltaicos flutuantes surge como alternativa, porém como todo o desenvolvimento de novas tecnologias esta possui aspectos tanto positivos como negativos relacionados ao seu funcionamento e seus impactos ao meio ambiente. Nesse sentido, um sistema fotovoltaico flutuante foi instalado no reservatório Passaúna, na região metropolitana de Curitiba, como modelo experimental, para a geração de energia ao sistema de captação de água. Este reservatório é um dos quais fornecem água para a capital do estado do Paraná e o mesmo vem apresentando elevadas concentrações de algas interferindo no sistema de tratamento da água e o também no custo do mesmo. A elevada concentração de algas é a caracterização de eutrofização e a mesma traz impactos negativos a água como cheiro, odor e dependendo de sua concentração e também do tipo de algas pode ser tóxico aos humanos. Assim, uma avaliação específica da qualidade da água e também dos impactos do sistema fotovoltaico flutuante instalado é importante, principalmente no que tange a qualidade da água. Dessa forma, o objetivo deste trabalho é avaliar a influência do sistema fotovoltaico flutuante na qualidade da água do reservatório Passaúna, principalmente relacionado ao crescimento de algas. Além de realizar uma revisão bibliográfica abrangente a respeito dos impactos causados por sistemas fotovoltaico flutuantes. Para avaliação prática da qualidade da água foram analisados cinco diferentes parâmetros de qualidade da água, pH, turbidez, nitrogênio amoniacal, nitrato e clorofila *a* em seis diferentes pontos, três internos ao sistema (I1, I2, I5) e três externos ao sistema (E1, E2, E3), além de coletas de água na superfície da água e em profundidade. As coletas foram realizadas entre os meses de junho e dezembro de 2022, quinzenalmente. Para o pH, os resultados variaram entre 7,1 a 8,4. Para turbidez variou entre 0,917 NTU a 4,567 NTU. Para o nitrogênio amoniacal, o resultado mais baixo foi 0,003 mg NH_3^-N/L e o mais alto foi 0,185 mg NH_3^-N/L. O nitrato teve o menor resultado em 0,106 mg/L e o maior 0,436 mg/L. E para a clorofila *a*, os resultados variaram entre 1,558 µg/L e 6,889 µg/L. Os resultados da clorofila *a* demonstraram que o reservatório está no estado mesotrófico, ou seja, não há eutrofização. Devido a área do sistema fotovoltaico flutuante representar menos de 1% da área do reservatório, não foi encontrada significativa influência do sistema na qualidade da água em nenhum dos parâmetros analisados. Entretanto, a literatura apresenta aspectos positivos a respeito dos sistemas fotovoltaico flutuantes como a redução nas taxas de evaporação de água e diminuição de crescimento das algas

Palavras-chave: Qualidade da água. Sistema Fotovoltaico Flutuante. Eutrofizaçã

ABSTRACT

The incessant search for ways to reduce damage to the environment is one of the factors that lead the technology and research sector to be in constant motion. In this sense, renewable energies, with an emphasis on photovoltaic solar energy, appear to reduce the use of fossil fuels, minimize aspects such as pollution and deforestation and also to benefit from environmental potentials that are available, such as the sun. Photovoltaic solar energy is considered an inexhaustible energy and its use has become more expressive in recent decades, although, due to the population and urban centers growth and also agricultural areas expansion, areas for the installation of large photovoltaic plants have become scarce. As a way of overcoming this obstacle, the installation of floating photovoltaic systems (FPS) appears as an alternative, however like all the development of new technologies, it has both positive and negative aspects related to its operation and its impacts on the environment. In this sense, an FPS was installed in the Passaúna reservoir, in the metropolitan region of Curitiba, as an experimental model, to generate energy for the water pumping system. This reservoir is one of which supplies water to the capital of the state of Paraná and it has been showing high concentrations of algae interfering in the water treatment system and also in its cost. The high concentration of algae is the characterization of eutrophication and it brings negative impacts to water such as taste, odor and, depending on its concentration and also the type of algae, it can be toxic to humans. Thus, a specific assessment of water quality and also the impacts of the installed FPS is important, especially in the regard of water quality. Therefore, the objective of this work is to evaluate the influence of the FPS on the water quality of the Passaúna reservoir, mainly related to algae growth. In addition to carrying out a comprehensive literature review regarding the impacts caused by FPS's. For practical evaluation of water quality, five parameters were evaluated: pH, turbidity, ammonia nitrogen, nitrate and *chlorophyll a* were analyzed at six different points, three internals (I1, I2, I5) and three externals to the system (E1, E2, E3). The water sample collections were done on the water surface and at half the depth of each point. The collections were carried out between June and December 2022, fortnightly. For pH, the results range were among 7.1 to 8.4. For turbidity it varied among 0.917 NTU to 4.567 NTU. For ammonia nitrogen, the lowest result was 0.003 mg NH_3^-N/L and the highest was 0.185 mg NH_3^-N/L. Nitrate had the lowest result at 0.106 mg/L and the highest 0.436 mg/L. And for *chlorophyll a*, the results varied among 1.558 µg/L and 6.889 µg/L. *Chlorophyll a* results demonstrate that the reservoir is in the mesotrophic state, meaning that there is no eutrophication. Due to the area of the floating photovoltaic system representing less than 1% of the area of the reservoir, no significant influence of the system on water quality was found in any of the parameters analyzed. However, the literature presents positive aspects regarding floating photovoltaic systems, such as a reduction in water evaporation rates and a decrease in algae growth.

Keywords: Water Quality. Floating Photovoltaic System. Eutrophication

LIST OF FIGURES

LIST OF GRAPHS

LIST OF TABLES

ABREVIATIONS

ANEEL	National Agency of Electric Energy
APHA	American Public Health Association
CETESB	Environmental Council of São Paulo State
CONAMA	National Environment Council
CRD	Completely Randomized Design
˚C	Centigrade Degrees
EPE	Energy Research Company
FPS	Floating Photovoltaic System
GW	Gigawatts
h	Hour
HPO_4^{2-}	Orthophosphate
IEA	International Energy Agency
kW	Kilowatts
kWp	Kilowatts power
km	Kilometer
km^2	Square kilometer
L	Liter
m	Meter
m^2	Square meter
m^3	Cubic meter
mg	Milligrams
MW	Megawatts
MWp	Megawatts power
NH_3^- N	Ammonia Nitrogen
NH_4^+	Ammonia
nm	Nanometers
NO_2^-	Nitrite
NO_3^-	Nitrate
ONS	National Operator of Electric System
PDE	Development Plan
pH	Hydrogenic Potential
PV	Photovoltaic
SANEPAR	Sanitation Company of Paraná State
SIMEPAR	Paraná's Environmental Technology and Monitoring System
TW	Terawatt
uC	Unities of Color
UEPG	State University of Ponta Grossa
µg	Microgram
USA	United States of America
USD	United States Dollar
UNT	Turbidity Unity

SUMMARY

1 INTRODUCTION

Nowadays, numerous efforts have been made in order to obtain clean energy, mainly to reduce the use of fossil fuels and the impacts of climate change. Wind energy, hydropower and solar energy are some of the many studied over the years. Renewable energy comes from natural sources that are naturally restored, such as sun, water, wind, geothermal energy and so on. However, some difficulties are faced as a way to capture and store these energies, not only because of their complexity, but also because of their high costs.

As one of the measures to reduce carbon dioxide emissions, Annual Climate Conference brings together world leaders to discuss how to respond to current climate change (global warming). On 2023, the Conference of the Parties (COP27) determines the limit of global warming to 1.5 degrees Celsius. Before the Paris Agreement of 2015, the world was on course for 4.5 degrees Celsius of warming by the end of the century compared to pre-industrial times. Besides that, COP27 also stablished an agreement to gradually reduce the use of coal (UNFCCC, 2022).

In this way, the usage of solar energy represents a good alternative to reinforce the COP27 agreement to deal with the impacts of climate changes. Solar energy has low maintenance and low pollution. The use of solar energy is important to reduce the emission of greenhouse gases, although the costs of solar systems are not attractive. In this same aspect, photovoltaic solar energy is seen as a source of renewable energy, as it is an alternative to deal with energy scarcity around the world (SAMPAIO; GONZÁLES, 2017). However, it is still an expensive investment, it depends on the location to be efficient and also demands on land areas to install the photovoltaic modules.

Despite studies and developments on solar energy, land availability for the implantation of large solar power plants is increasingly scarce due to the expansion of agriculture and urban areas. There are not many free spaces with large areas and no shadows to install ground-mounted photovoltaic systems. Therefore, the need for alternative spaces for the introduction of solar energy panels has been a concern. Due to the low availability of land, dense population and severe threat of deforestation, interest have been directed towards the installation of photovoltaic modules over canals, lakes, reservoirs, and oceans. Photovoltaic modules are installed over water bodies by making them float using suitable technology and such installations are called

Floating Photovoltaic System (FPS). However, many studies need to be done to understand how FPS can interfere in the water quality and in the ecosystem of the reservoirs.

Water quality in water reservoirs is affected by many different aspects. Water supply reservoirs are generally shallow and located in cultivable regions, which makes them more susceptible to the human activity. Reservoirs can receive loads of nutrients that can be point or non-point sources (ESTRADA *et al.,* 2009). This insertion of nutrients can modify the trophic state of the reservoirs.

The trophic state of a reservoir is defined by the enrichment of nutrients, such as phosphorus and nitrogen, and it is related to the unrestricted growth of algae (ESTRADA *et al.,* 2009). Eutrophication can cause algal blooms and areas with insufficient dissolved oxygen to sustain the aquatic life. In addition, some algae can produce toxins to humans especially when the reservoir is used to supply water to the population. It can increase fish morbidity, reduce reproduction and contaminate drinking water, causing negative consequences for the economy, due to the increase in public health costs and water treatment (McCRACKIN *et al.,* 2016).

FPS have showed good interference on algae growth, reducing it, which may be a good alternative for the control of eutrophication. Besides that, FPS have several advantages over ground-mounted systems such as, higher efficiency due to the water cooling effects, decreased water evaporation rates, elimination of major site preparation operations and the necessity of land that can be used to other activities, easy access to water to carry out the cleaning and maintenance of the system (SAHU *et al.,* 2016).

Passaúna reservoir in the region of Curitiba, Paraná, Brazil was chosen by the Water and Sanitation Company of Paraná (SANEPAR) to host an FPS that was installed to supply the energy to the water catchment. Passaúna reservoir is one of the supply sources for the metropolitan region of Curitiba. In this regard, and with a concern on eutrophication, a specific analysis is needed to address the trophic state of Passaúna reservoir and the influence of the FPS on water quality, mainly about *chlorophyll a* concentration.

Like any other technology, FPS is evolving with time, and the impacts of them need to be studied. This study aims to give a review of this technology by considering positive and negative aspects of it.

The results of this work are divided into two articles. The first article presents an analysis of the influence of the FPS installed in the Passaúna Reservoir on water quality, regarding the parameters of pH, turbidity, nitrate, ammonia nitrogen and chlorophyll *a*. This analysis was carried out with water collections fortnightly in the reservoir, at three internal points of the FPS and three external points, collecting water from the surface and also at half depth.

The second article shows a comprehensive literature review regarding the impacts caused by the FPS mainly related to environment impacts and water quality, considering results already obtained in the first chapter. A bibliographic review of scientific articles already published nationally and internationally was carried out, as well as master's dissertations and PhD thesis from the year 2013.

2 OBJECTIVES

2.1 GENERAL OBJECTIVE

Evaluate the influence of a floating photovoltaic system on the water quality of the Passaúna Reservoir, especially when it comes to algae growth.

2.2 SPECIFIC OBJECTIVES

- Verify the influence of a FPS by monitoring, fortnightly, parameters of water quality in the Passaúna Reservoir during six months;
- Evaluate the influence of a FPS on the algae boom, at the surface and at mid-water depth through analysis of *chlorophyll a*, at different points, including internal and external points of the FPS;
- Present the positive and negative aspects of the FPS installed in the Passaúna Reservoir, focusing on water quality and sustainability.

3 LITERATURE REVIEW

3.1 RESERVOIRS

Reservoirs are water bodies built or modified by human activity with a specific purpose: create a reliable and controllable source of water. Its main uses are domestic water supply, industrial water supply, power generation, irrigation, flood control, commercial or recreational fishing, navigation, channeling and sewage disposal (TUNDISI; MATSUMURA-TUNDISI, 2008).

Reservoirs are usually found in areas of scarcity or excess of water. In regions of scarcity, reservoirs are the means of conserving water for months of less water availability. When there is excess water, the reservoirs are used as containment to prevent flooding. In summary, the reservoirs are bodies of water that are subject to human control and other impacts (ZHANG, 2018).

Tundisi *et al.* (2005) classifies reservoirs as an interactive network between living organisms and their physical-chemical properties. Because it is a complex ecosystem, the reservoirs have variants that in turn depend on other variables, such as the function and structure of a reservoir are determined by hydrological and climatological factors. The main characteristics that differentiate reservoirs from natural lakes are spatial heterogeneity, since it has river (lotic) regions, transition zones and lake (lentic) regions, and the water retention time, which depends on the operating mechanisms. Both characteristics influence physical, chemical and biological properties of the water. In addition, the physical and biotic structures are very different from natural lakes, because lakes have a history on a geological time scale in which the reservoirs created by man do not have (RIBEIRO FILHO, 2006).

The multiple uses of hydrographic basins and reservoirs produce numerous impacts on biodiversity, water quality and the hydrological cycle, and these impacts are cumulative, since they are incorporated into the functioning of the reservoirs, their structure and function (TUNDISI *et al*., 2005). The construction of reservoirs can bring positive aspects such as the ease obtaining of water, homogeneously throughout the year, better quality water for domestic and industrial use (MARIANI, 2006), however, the construction of these artificial environments also results in negative implications, as Esteves (2011) quotes:

- Climate change resulting from increased sweating and / or evapotranspiration;
- Increase in the possibility of landslides and earthquakes;
- Increase in the water table level;
- Increase in the sedimentation rate upstream;
- Flooding of arable areas;
- Alteration in the reproduction of aquatic species;
- Modification of habitats affecting wild fauna;
- Increase in aquatic macrophytes;
- Increase in eutrophication rates;
- Expropriation and displacement of populations.

Despite the negative and positive aspects of an artificial reservoir, all reservoirs can be classified according to their trophic state and this depends on their water quality parameters.

3.2 WATER QUALITY

Not only the human species but every specie in the planet depends on water to survive and to self-develop, that is why water quality and water availability are the biggest concerns of 21st century. Water quality can be understood as water suitability measures for particular uses that are based on physical, chemical and biological parameters (KERSKI, 2017).

Due to the population growth and industrialization, water quality has been compromised. Water pollution is when the human interference contributes to the introduction of different composites to the water bodies that causes some alterations; however, when those alterations put the human or nature health in risk it is called water contamination (SPERLING, 2005). The source of residues that contaminate water can be classified as punctual such as sewage discharges launch, industrial effluents, landfills etc., or diffuse such as pesticides used at agriculture lixiviated by rain to the rivers or groundwater, etc. (BRAGA *et al*., 2005).

Besides that, water quality varies from place to place depending on some characteristics and the limits of those characteristics are specified by each government. In Brazil, the guideline of water quality parameters is the resolution number 357 created by the National Environment Council - CONAMA (2005).

Numerous parameters can compromise water quality, such as chemical, physical and biological parameters. Among these parameters, the presence of algae can compromise both water quality and the quality of the water treatment, in some cases causing an increase in the cost of this service. Algae are important living beings for the ecology of a lake or reservoir, as they are part of the food chain and they need carbon dioxide, nutrients and sunlight to reproduce, nutrients such as phosphorus and nitrogen (PIZARRO *et al.,* 2016).

Excessive algae growth can cause a process called eutrophication, which is the unrestrained growth of algae and is usually caused by the enrichment of nutrients such as phosphorus and nitrogen, which are introduced into the water mainly by the dumping of industrial and domestic sewage, as well as by the leaching of agricultural pesticides. Eutrophication causes negative effects such as the reduction of available oxygen, the death of fish, it adds odor and taste to the water and in some cases, depending on the algae that proliferate, it can make the water toxic for human consumption, which is the case of some cyanobacteria (KOSTEN; HUSZAR, 2012).

3.2.1 Quality Indicators

According to Sperling (2005), water quality is the relations of human interference and natural phenomena. In order to characterize water quality some physical, chemical and biological indicators are analyzed. In this topic some indicators are presented as they will be studied and extrapolated in this study.

3.2.2 Physical Indicators

Color is a characteristic derived from organic maters. It can be divided into true color or apparent color because the turbidity can interfere, so a parcel of its turbidity is included at apparent color and when is removed, the true color is obtained (SPERLING, 2005). It is expressed as unities of color (uC).

Temperature is the measure of heat intensity (SPERLING, 2005). Water bodies can present temperature variations among seasons, among days and even among different layers at the same water body (CETESB, 2007). In this study, it will be expressed as degrees centigrade (˚C).

Turbidity is the degree of intensity attenuation that a beam of light presents when crossing the water (CETESB, 2007). It happens because of the presence of suspended materials in the water that can be originated from natural sources such as rocks, clays, silts or from an anthropogenic source as sewage (BRAGA *et al.,* 2005). It is expressed as turbidity unity (uT) or nephelometric turbidity units (NTU).

3.2.3 Chemical Indicators

pH is the potential of hydrogen that represents the concentration of hydrogen ions, giving an indication of acidity or alkalinity of the water. pH varies from 0 to 14 and the values bellow 7 indicates acid conditions and above 7 alkaline conditions (SPERLING, 2005). There is no unity to indicate.

Phosphorus can be presented as orthophosphates, polyphosphates and organic phosphorus. The orthophosphates are directly linked to biological metabolism and their most common formula is HPO_4^{2-}. Phosphorus is present in water bodies mainly because of domestic sewage whose main source is powdered detergents and fecal organic matter. Drained water at agricultural areas can also input excessive amount of phosphorus in the water bodies. It is an essential element to the algae growth and when in high concentrations in lakes and reservoirs, it can lead to exaggerated growth of these microorganisms causing eutrophication (CETESB, 2014; SPERLING, 2005).

Nitrogen can be found as dissolved and particulate organic compounds and as the molecular form: ammonia (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-). The stages of organic pollution degradation can be associated through the relationship between the forms of nitrogen. In areas of natural self-purification in rivers, the presence of organic nitrogen is in the degradation zone, ammonia is in the active decomposition zone, nitrite in the recovery zone and nitrate in the clean water zone. Domestic sewage is the main source of nitrogen, as well as effluents from industries. In agricultural areas, runoff from rainwater through fertilized soils also contributes to the presence of various forms of nitrogen. It is an indispensable element for the growth of algae and, when in high concentrations can lead to the eutrophication. It is also indispensable for the growth of microorganisms responsible for the sewage treatment (CETESB, 2014; LIBÂNIO, 2005; SPERLING, 2005).

3.2.4 Biological Indicator

Chlorophyll a is a photosynthetic pigment which is present in every type of algae (RUDORFF, 2006) so its concentration can indicate the growth of the phytoplankton in lakes or reservoirs. It is one of the pigments capable to absorb the electromagnetic radiation and is the main component of the phytoplankton used to identify the eutrophication. *Chlorophyll a* can absorb radiation referent to blue and red band (430 e 670 nm) (MOBLEY, 1994) and also a reflectance of green region, been able to produce by fluorescence a peak of reflectance about 675 nm (KIRK, 2010) that is why it can be measured.

3.3 RENEWABLE ENERGY

Renewable energies are one of the main solutions for the reduction of greenhouse gases, thus being able to reduce social and environmental impacts, being considered of extreme importance for the improvement of the life quality. Since investments in new technologies are in high growth, the need for energy, whether renewable or not, has increased, making it essential to achieve the use of clean sources, due to the dependence on electricity and oil. Among the many sources of renewable energy, can be mention some of the most used, which are biomass, hydroelectric, solar radiation, wind, etc. (BERMANN, 2008). In that aspect, solar energy is being a well-studied and relatively well spread throughout the world.

3.3.1 Photovoltaic Energy

One of the main sources of renewable energy is the solar energy, which was discovered by French physicist Edmund Bequerel in the 19th century. Solar energy has been applied in several areas, such as transportation (cars and energy production in space), portable devices, rural areas or those that are far away, on roads with high incidence of sun, on satellites, and in the greatest use: single-family homes, condominiums and industries (JAGERWALDAU, 2007).

Solar energy generation occurs through the use of photovoltaic solar modules, which only need sunlight to become an inexhaustible source of energy and which practically does not harm the environment. All methods of capturing and / or storing this solar energy happen by the photovoltaic modules. In 1884, Charles Fritts created the first photovoltaic cell using selenium, which presented very low efficiency (1%). From many studies and the evolution of the modules, in 2007 researchers from the University of Delaware (USA), achieved better efficiency (42.8%) using crystalline solar cells. Solar energy generation is obtained by the direct transformation of solar radiation into electrical energy through the cells that make up a system, which together with the batteries and also the energy distribution system leads to homes, businesses or any enterprise that use this system as an alternative source of energy (JAGERWALDAU, 2007).

3.3.2 Photovoltaic Energy in Brazil

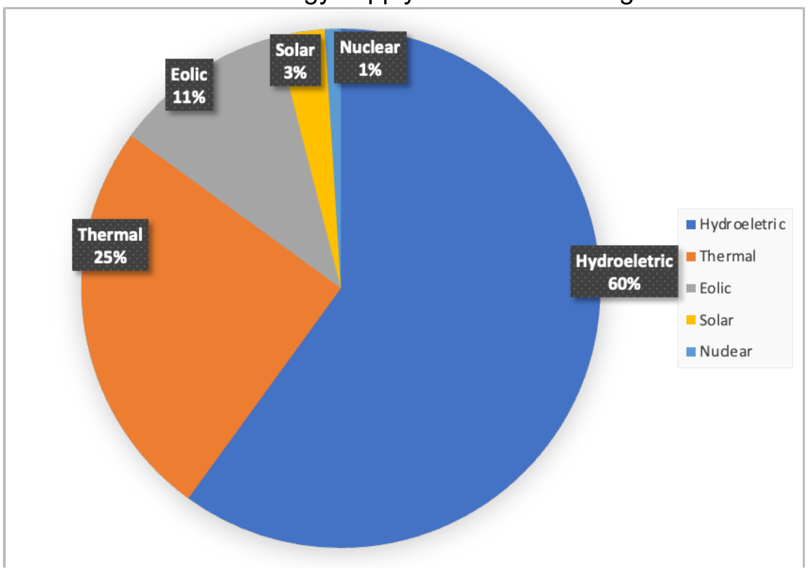
The biggest amount of electric energy produced in Brazil come from hydroelectric plants. The PDE (development plan) of 2026 predicts that 48% all Brazilian energy comes from renewable sources. From the different types of renewable energy, the photovoltaic energy stands out due to, among other reasons, the great national power still little explored (PEREIRA, MARTINS, 2018). The use of this renewable energy source is subject of climate and meteorological conditions. However, Brazil is located among Cancer and Capricorn tropics, which means that there is an elevated solar radiation incidence due to solar rays being more vertical at this region than others (TOLMASQUIM, 2016).

The levels of global irradiation incidence in Brazil vary between 1,300 kWh/m² and 2,200 kWh/m². European countries that use photovoltaic on a large scale have levels lower than those found in Brazil, such as Germany, which is one of the countries with the highest installed photovoltaic capacity (TOLMASQUIM, 2016; PEREIRA; MARTINS, 2018). The lowest annual average of solar irradiation in Brazil is equivalent to the highest level experienced in German territory (PEREIRA *et al.,* 2016).

The electricity production in Brazil is composed of a hydrothermal-wind system with a predominance of hydroelectric plants. The NIS is composed of four subsystems: South, Southeast/Midwest, Northeast and a large part of the North region, the interconnection of these electrical systems, through the transmission grid, provides the transfer of energy between the subsystems, allowing the exploitation of the diversity between the hydrological regimes of the basins (ONS, 2021).

The Brazilian electricity supply is predominantly from renewable energy, with the largest production of hydroelectric plants, composed of 16 watersheds in different regions of the country, accounting for 60% of domestic energy supply (EPE, 2022). Graph 1 shows the distribution of the Brazilian energy sources, in which 25% of the total electricity produced is from thermal energy, 11% is from wind energy, 3% is from photovoltaic solar energy and 1% is from nuclear energy.

Graph 1 – Representation of Brazilian energy supply sources used to generate electricity in 2021



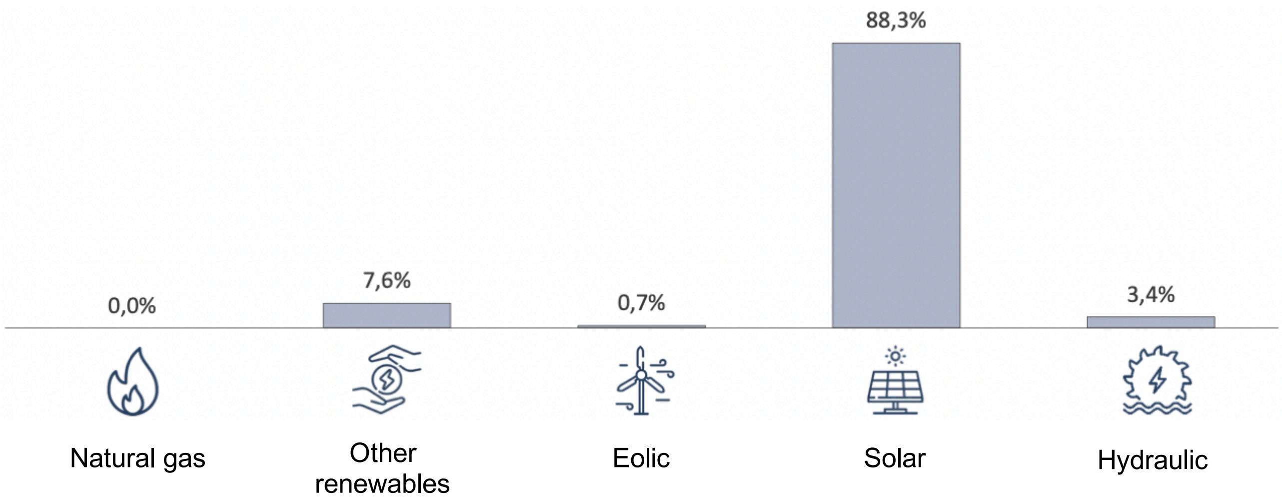
Source: Author, adapted from EPE (2022).

Since 2012, the Brazilian Electricity Agency (ANEEL) has allowed consumers to produce their own electricity, even being able to supply the surplus to the grid in their location. This generation can be carried out either from renewable sources or from qualified cogeneration. The term distributed generation encompasses micro and mini distributed generation of electricity, which has been happening after ANEEL Resolution 482 (2012).

According to ANEEL (2012) distributed mini-generation consists of an electric power plant, with an installed power greater than 75 kWp and less than or equal to 5 MWp and that uses qualified cogeneration or renewable sources of electric energy, connected to the electricity grid through the facilities of consumer units. On the other hand, distributed microgeneration is defined as a power plant that generates electricity, with an installed capacity of less than or equal to 75 kWp.

Microgeneration and mini-generation distributed in 2021 showed an increase of 84% compared to 2020 (EPE, 2022), using the energy sources shown in Graph 2.

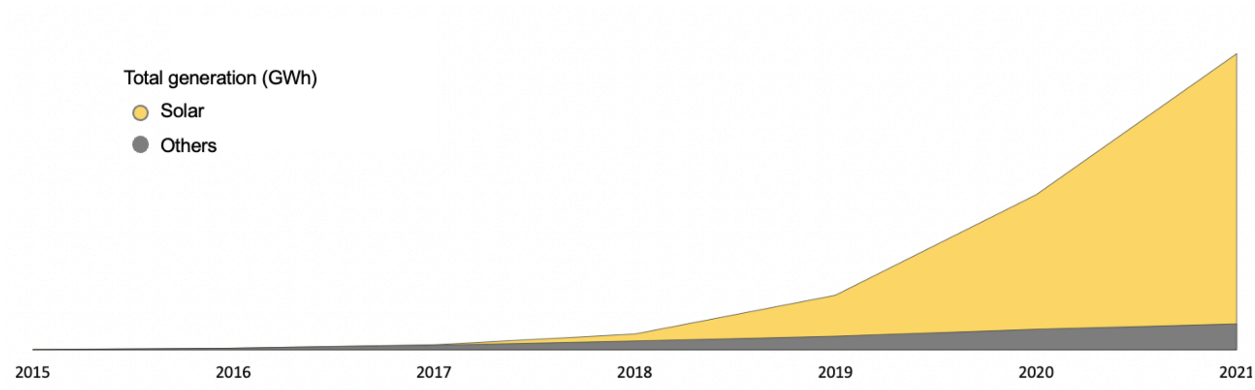
Graph 2 – Energy sources used in microgeneration and mini-generation distributed in 2021



Source: EPE (2022).

Photovoltaic solar energy represented 88.3% of micro and mini distributed generation in 2021, and was the main source responsible for the increase registered in micro and mini distributed generation. This behavior has been built up over time, the evolution of micro and mini distributed generation indicates the trajectory of continuous growth of photovoltaic solar generation at a higher rate than other sources (EPE, 2022), as ~~it~~ can be seen in Graph 3.

Graph 3 – Evolution of the solar energy use in Brazil, from 2015 to 2021

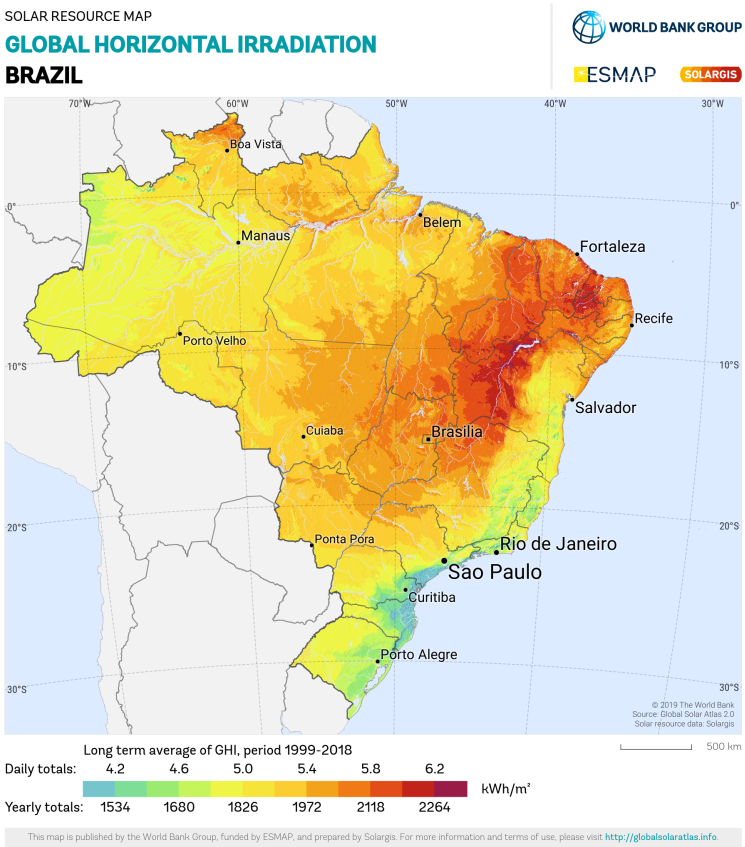


Source: EPE (2022).

Micro and mini distributed generation in Brazil based on photovoltaic solar energy reached 8,771 MWp of installed power and 9,019 GWh of generation in 2021. Although the installed capacity of thermal and hydraulic sources showed some growth in 2021, the majority share of installed capacity through solar panels is what currently defines the segment of micro and mini distributed generation in Brazil (EPE, 2022).

The global horizontal solar radiation, as shown in Figure 1, is well distributed throughout the country, with a high annual average. The Northeast region stands out for presenting the highest values of global solar irradiation. The central region of the Bahia state is the one that presents the maximum values of solar irradiation in the country, 6.5 kWh/m²/day, partially including the northwest of Minas Gerais. This region has favorable climatic conditions, with low cloud cover and high incidence of solar irradiation, throughout the year (EPE, 2012).

Figure 1 – Annual average horizontal global solar radiation in Brazil



Source: WORLD BANK GROUP; ESMAP; SERIS (2019).

Considering only the best irradiation range, between 6.0 and 6.2 kWh/m2, and only in areas already anthropized, that is, in areas of agriculture, livestock, reforestation and others, it is estimated the possibility of installing 307 GWp in photovoltaic plants, with an approximate generation of 506 TWh/year (TOLMASQUIM, 2016).

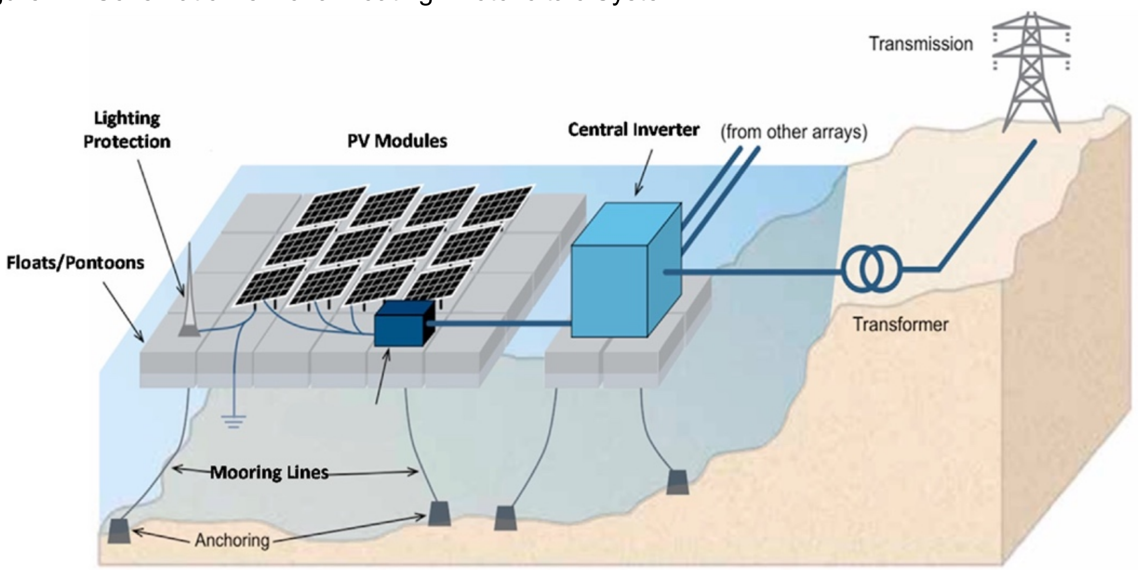
According to EPE (2019), the parameters provided to the Investment Decision Model, considering the energy policy guidelines and the potentials of each technology, indicate a photovoltaic expansion of at least 1,000 MW/year and a maximum of 2,000 MW/year, from 2023, with 80% allocated in the Northeast and 20% in the Southeast.

3.4 FLOATING PHOTOVOLTAIC SYSTEMS

One of the problems faced by solar power generation is the area required to install the solar photovoltaic plants. Those areas usually need to be big, have great solar incidence, without high vegetation nearby and flat surface. Nowadays, such areas are scarce due to the use of the land for agriculture so, an alternative is to install solar photovoltaic modules on water surface, creating floating systems.

FPS have the same technology as ground-mounted solar systems, the difference is that the floating system is placed on the top of a floating device made of polyethylene or other materials and they are introduced on water surface such as lakes and reservoirs, areas called lentic (DA SILVA; BRANCO 2018). A schematic view of a FPS is shown in Figure 2. The main components of the FPS are: floats, mooring and anchoring systems, PV modules, electric cables and connectors.

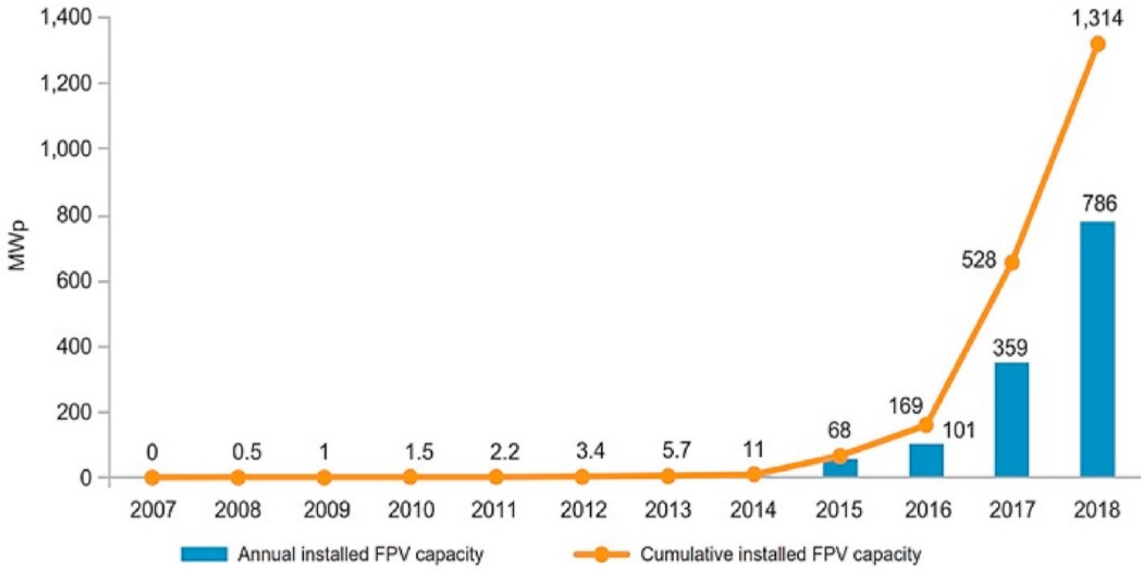
Figure 2 – Schematic view of a Floating Photovoltaic System



Source: Sahu *et al.,* 2016.

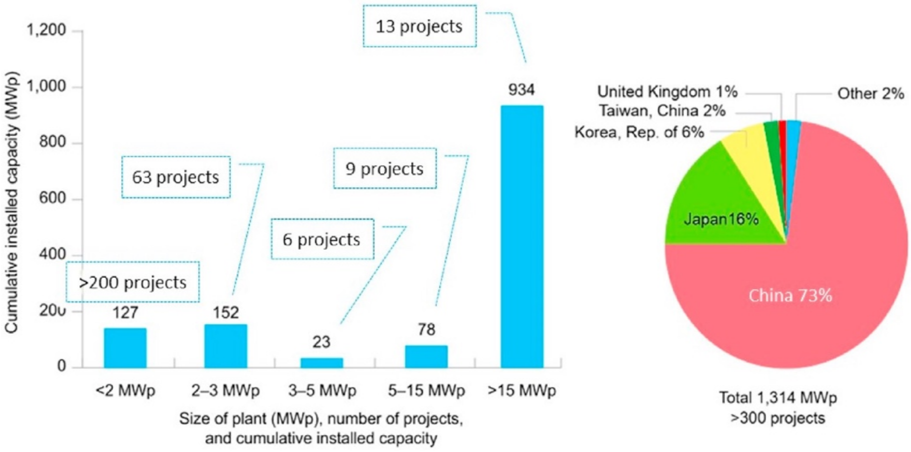
The first FPS was installed in Japan, in 2007, with energy production capacity of 20 kWp. In 2008, an FPS was installed at Far Niente winery, in the Napa Valley region of the United States, on the water surface of a lake used for irrigation. It was motivated by the need for electrical generation to supply the entire winery without losing a large area of arable land. The original system totalized a power of 175 kWp (TRAPANI; SANTAFÉ, 2014). In 2011, the floating power plant company K-water (Korea Water Resources Corporation) installed a 100 kWp FPS in the reservoir of the Hapcheon dam, in South Korea. After the installation, positive results were obtained, and so another FPS was installed the following year in the same lake, with a capacity of 500 kWp. These two projects are still generating electricity that is being marketed to Korea's national system (CHOI, 2014). Today the largest floating photovoltaic plant in operation is in China with a capacity of 150 MWp and the world capacity exceeded 1.3 GW in December 2018 (WORLD BANK GROUP; ESMAP; SERIS, 2019). In Graph 4 is showed the evolution of FPS installed capacity, annually, from 2007 to 2018, as well as the accumulated capacity of FPS installed worldwide. And Figure 3 shows the global distribution of FPS according to their size and location until 2018.

Graph 4 – Evolution of the total capacity of Floating Photovoltaic Systems installed around the world



Source: WORLD BANK GROUP; ESMAP; SERIS, 2019.

Figure 3 – Global distribution of Floating Photovoltaic Systems according to their size and location until 2018



Source: WORLD BANK GROUP, ESMAP, SERIS, 2019.

In Brazil, the first FPS installed was in the state of Goiás, in September 2017 with a capacity of 305 kWp, this system was installed by the company Ciel & Terre International and is located in a reservoir used to capture and accumulate water from the rain. This same company, also installed two other FPS's in Balbina, in the Amazon region and in Sobradinho in Bahia state, both in hydroelectric plant reservoirs with the objective of evaluating two similar systems, but in different climatic conditions (WORLD BANK GROUP; ESMAP; SERIS, 2019). In addition, some other systems are installed in Brazil, at Porto Primavera Plant, in São Paulo (STRANGUETGO, 2016), Luís Eduardo Magalhães Hydroelectric Plant, in Tocantins (DULLIUS, 2019) and also in the Passaúna reservoir, in Curitiba - Paraná, which is the study case of this work.

According to Choi (2014), FPS can be more efficient than conventional systems because of water evaporation on the back of the modules which helps to reduce the temperature of photovoltaic modules and increase its efficiency by 10%. Besides the positive aspect of efficiency, the allocation cost can also be lower due to the lack of need of a big structure with foundation as the in-land plants need (DA SILVA; BRANCO 2018).

Problems related to deforestation, bird mortality, loss of fauna and flora can be reduced with FPS installations, when compared with in-land plants (WALSTON *et al.* 2016). Bird mortality happens as a result of birds being attracted by the modules and they colliding with them and die. Deforestation happens due to the need of clean areas to the modules be efficient and capture solar radiation.

Although floating photovoltaic plants can mitigate those negative impacts, it also can cause some harm to the environment. Some impacts can include the alteration in water quality, block of sunlight penetration on water causing modifications on algae growth and in-water habitat causing loss of biodiversity (SHARMA *et al.,* 2015). However, the modification on algae growth can be considered a positive impact due to the possibility of eutrophication control on lakes and reservoirs. Studies on FPS's have shown positive results in water quality, reducing the growth of algae, enabling a reduction in the cost of water treatment and filtration, as well as a decrease in water evaporation rates, both impacts due to the creation of shadow over the body of water (GORJIAN *et al*. 2021; SANTOS, 2022; CHOI, 2014).

In arid climates, for example Australia, an estimation of 5,000 – 20,000 m³ of water could be saved per year for each MW of floating photovoltaic modules power installed (ROSA-CLOT *et al*., 2017).

Haas *et al.* (2020) concluded that a very extensive FPS drastically reduces the presence of algae, eliminating them. The same authors state the total coverage area of 40 to 60% by the FPS can significantly reduce the number of algae in 90%.

K.-water company installed more than one FPS in Asia, on its first installation they researched the aspects about the commercialization of "floated photovoltaic" and they found a reduction in algae growth due to the shading effect, natural reflectivity of the water surface and reduced sunlight penetration (SAHU *et al*., 2016).

The trends of FPS installations are increasing and it is fundamental to study the influence of them on the environment such as changes on water quality especially on algae growth and also on the rate of water evaporation. However, the influence of the FPS depends on its size, the bigger the system the greater the influence.

Following this work, the chapters that correspond to the two articles about the influence of the FPS installed at Passaúna reservoir on water quality and a schematic review of its impact and quality of water concern are presented.

CHAPTER 1 – INFLUENCE OF FLOATING PHOTOVOLTAIC SYSTEMS ON WATER QUALITY IN RESERVOIRS

ABSTRACT

Water quality and water availability are ones of the biggest concerns of 21st century. At this purpose, some reservoirs are built to supply the demand of drinking water. Water supply reservoirs are usually located close to cities or cultivable areas which makes them susceptible to anthropologic activities such as sewage disposal and fertilizer leaching, these activities can cause the water to be enriched with nutrients, mainly phosphorus and nitrogen, causing eutrophication. Eutrophication is the excessive growth of algae and can cause negative impacts at water supply reservoirs. Floating Photovoltaic Systems (FPS) can reduce the algae bloom. However, it can also present other significant impacts at the reservoir and water quality. In order to understand the influence of an FPS on the water quality, in this work were evaluated chemical and physical parameters such as pH, turbidity, ammonia nitrogen, nitrate nitrogen and *chlorophyll a* of the water at the Passaúna Reservoir, located at metropolitan region of Curitiba. The monitoring of the water quality was carried out from June to December 2021 and took place fortnightly, collecting water samples from internal and external points of the FPS as well as at the surface and half of the water depth. For pH, the results range were among 7.1 to 8.4. For turbidity it varied among 0.917 NTU to 4.567 NTU. For ammonia nitrogen, the lowest result was 0.003 mg NH_3^-N/L and the highest was 0.185 mg NH_3^-N/L. Nitrate had the lowest result at 0.106 mg/L and the highest 0.436 mg/L. And for *chlorophyll a*, the results varied among 1.558 µg/L and 6.889 µg/L. *Chlorophyll a* results demonstrate that the reservoir is in the mesotrophic state according to the classification of Pavluk and Bij de Vaate (2013), meaning that there is no eutrophication. Under the conditions evaluated the FPS did not significantly influence water quality neither its parameters, probably because the FPS is very close to the water intake and there is continuous movement of water due to the pumping system. However, its research did not evaluate the aquatic life neither the FPS interference on it.

Keywords: Water quality. Eutrophication. Floating Photovoltaic System.

RESUMO

Qualidade da água e a disponibilidade de água são uma das maiores preocupações do século XXI. Para tanto, alguns reservatórios são construídos para suprir a demanda de água potável. Os reservatórios de abastecimento de água geralmente estão localizados próximos a cidades ou áreas cultiváveis o que os torna susceptíveis a atividades antropológicas como lançamento de esgoto e lixiviação de fertilizantes, atividades essas que podem fazer com que a água fique enriquecida com nutrientes, principalmente fósforo e nitrogênio, causando eutrofização. A eutrofização é o crescimento excessivo de algas e pode causar impactos negativos nos reservatórios de abastecimento de água. Os sistemas fotovoltaicos flutuantes (FPS) podem reduzir a proliferação de algas. No entanto, também pode apresentar outros impactos significativos no reservatório e na qualidade da água. Para entender a influência de um FPS na qualidade da água, neste trabalho foram avaliados parâmetros químicos e físicos como pH, turbidez, nitrogênio amoniacal, nitrogênio nitrato e clorofila a da água do Reservatório Passaúna, localizado na região metropolitana de Curitiba. O monitoramento da qualidade da água foi realizado no período de junho a dezembro de 2021 e ocorreu quinzenalmente, coletando amostras de água de pontos internos e externos do FPS, bem como na superfície e meia lâmina d’água. Para o pH, os resultados variaram entre 7,1 a 8,4. Para a turbidez variou entre 0,917 NTU a 4,567 NTU. Para nitrogênio amoniacal, o resultado mais baixo foi 0,003 mg NH3-N/L e o mais alto foi 0,185 mg NH3-N/L. Nitrato teve o menor resultado em 0,106 mg/L e o maior 0,436 mg/L. E para a clorofila a, os resultados variaram entre 1,558 µg/L e 6,889 µg/L. Os resultados da clorofila a demonstram que o reservatório está no estado mesotrófico de acordo com a classificação de Pavluk e Bij de Vaate (2013), ou seja, não há eutrofização. Nas condições avaliadas o FPS não influenciou significativamente a qualidade da água nem seus parâmetros, provavelmente porque o FPS está muito próximo da tomada d'água e há movimentação contínua de água devido ao sistema de bombeamento. Porém, sua pesquisa não avaliou a vida aquática nem a interferência do FPS sobre ela.

Palavras-chave: Qualidade da água. Eutrofização. Sistema Fotovoltaico Flutuante.

4.1 INTRODUCTION

Not only the human species but every specie in the planet depends on water to survive and to self-develop, that is why water quality and water availability are the biggest concerns of 21st century. Water quality can be understood as water suitability measures for particular uses that are based on physical, chemical and biological parameters (KERSKI, 2017). One way to guarantee the availability of water for the population is the construction of reservoirs.

Reservoirs are built to supply the different demands of the population, such as water supply, power generation, leisure and recreation, and even fishing. Water quality in water reservoirs is affected by many different aspects. Water supply reservoirs are generally shallow and located in cultivable regions or near to cities, which makes them more susceptible to the human activity. Both, in urbanized areas by the effluent discharge which form the point load of nutrients, as well as in arable areas by the introduction of nutrients present in fertilizers, which are infiltrated and leached, forming the diffuse load of nutrients. This insertion of nutrients can modify the trophic state of the reservoirs and even cause eutrophication. The mainly nutrients to promote the eutrophication are nitrogen and phosphorus (KOSTEN; HUSZAR, 2012; KUO *et al.* 2006).

Eutrophication usually generates an excessive growth of algae which has consequences for the water body, such as changes in color and odor and clogging of filters at the Water Treatment Plants (KUO *et al.* 2006). In addition, algae can alter the turbidity of the water, and their decomposition generates the depletion of available oxygen which results in the death of fish and other organisms, altering the reservoir biodiversity (KOSTEN; HUSZAR, 2012).

The amount and variety of algae present in a reservoir depends on its limnological and geomorphological characteristics (PAERL; OTTEN, 2013). Different varieties of algae can be toxic, releasing toxins in the water and thus making the water unsuitable for human consumption (NARDINI; NOGUEIRA, 2008; PAERL; OTTEN, 2013). Furthermore, the presence of algae at water supply reservoirs can increase the cost of water treatment. The cost rises due to a more intensive water quality monitoring, application of additional chemical products and even additional specific treatments (BROOKE *et al.,* 2008).

Floating Photovoltaic Systems (FPS) can arise as an alternative to control algae growth. FPS has been studied in the last years as sustainable source of energy reducing costs when compared with ground mounted photovoltaic systems, moreover it can present some benefits such as reduce water evaporation and control the algae bloom. However, it can affect other water parameters such as temperature, *chlorophyll a*, dissolved oxygen and also nutrients as nitrogen and phosphorus, depending on the reservoirs and its location these impacts can be either positive or negative (DE LIMA *et al.*, 2021).

In order to understand the real influence of FPS at the water quality, all of the above parameters must be evaluated. Besides of monitoring the water quality for human consumption, there are also legal requirements that determine quality prerequisites, such as CONAMA Resolution 357 (2005) that determines the limits of water parameters in order to classify the waterbodies.

Thus, this research aims to monitor the water quality of the Passaúna Reservoir regarding some physical, chemical and biological parameters and to determine the influence of the FPS on these parameters and the algae blooms.

4.2 MATERIALS AND METHODS

Given the fact that each reservoir has its peculiarities, with climatic and hydrological interferences, this topic describes the study area, which is a public water supply reservoir in the metropolitan region of Curitiba, Paraná. In addition, the methodology that was used for the experimental procedures is indicated in order to evaluate the water quality in terms of some physical, chemical and biological characteristics.

4.2.1 Study Area

The study area of this work is the Passaúna Reservoir, located in the metropolitan region of Curitiba, capital of the Paraná state, with 25º30’45” S and 49º22’07” W coordinates (Figure 4). It is a water supply reservoir managed by the Water and Sanitation Company of Paraná State, SANEPAR, which provides water for 22% of the metropolitan region of Curitiba (IAP, 2017).

Figure 4 – Passaúna reservoir location map

Source: Author, 2022.

This reservoir integrates the hydrographic basin of Alto Iguaçu, which has an area of 3,621 km², which means that 28% of Paraná state population is supplied by this basin (CURITIBA, 2011). In addition, the reservoir is part of the Passaúna River sub-basin (VEIGA, 2001).

According to the Koppen classification, the study region has a temperate oceanic climate, being humid and without dry seasons, presenting cool summers and winters with frosts, in addition to sudden climatic variations on the same day. Average temperatures range from 12.9 ˚C in winter and 22.5 ˚C in summer. The average annual rainfall reaches around 1,600 mm, with winter being considered the driest season and summer with more intense rains (LEAL, 2012).

An FPS was installed in the Passaúna Reservoir, by SANEPAR in 2019. The system is close to the water pumping system which supplies the water treatment plant. The FPS produces less than 1% of the energy required by the pumps and other demands. It is composed by 396 photovoltaic modules installed on modular floating devices, comprising an area of 1,200 m² and with total capacity to generate 130 kWp of power, depending on the solar radiation received. The reservoir's area of interest is the closest to the photovoltaic modules, with an area of approximately 5,000 m² (Figure 5).

Figure 5 – Aerial view of the Floating Photovoltaic System in the Passaúna Reservoir and the area of interest

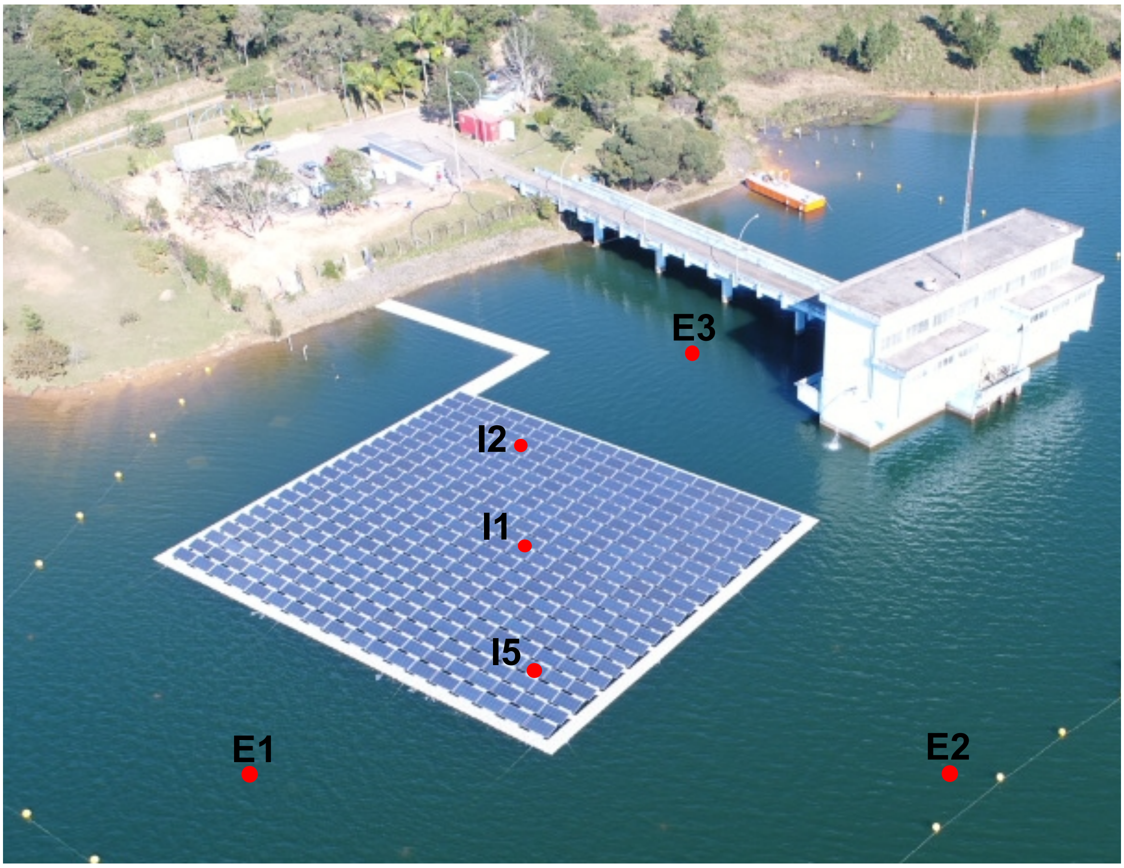
Source: Google Earth, 2021.

4.2.2 Water Sample Collection Points

As a preliminary analysis, the water samples were collected at 5 different points in the internal perimeter of the FPS (I1, I2, I3, I4 and I5), as well as in 3 points outside that zone (E1, E2, E3). The location of the water collection points was selected in order to evaluate the influence of the FPS on the water quality.

However, after some sampling days it was decided to continue the collection of only 3 internal points and 3 external points due to the similarity of the results on the internal points, which means that the 5 internal points did not present statistical significantly differences between their results of all the parameters analyzed, the statistical analysis used to compare the results was factorial analysis developed at RStudio software at 1% significance level. ANOVA were executed and the means were compared by Tukey test. Because of that, the internal points maintained were I1, I2 and I5. Figure 6 shows the location of the water sample collection points.

Figure 6 – Floating Photovoltaic System in Passaúna Reservoir and the location of water collection points



Source: Author, adapted from SANEPAR, 2021.

The collections occurred at water surface and at half of total depth of each point. The depth collection occurred at different depths according to the water level. There were variations along the months, however the average of collection depth for E1 was 2.0 meters, E2, E3, I1 and I3 was 3.0 meters and I2 was 2.5 meters.

4.2.3 Water Quality Analysis

Samples were collected fortnightly during the months of June to December 2021 so that different seasons of the year are covered, thus being able to assess the influence of climate variation and also rainfall. The established schedule is shown in Table 1.

Table 1 – Parameters, frequency of water collection, methods and equipment for the analysis of the water quality

Parameter	Frequency of water collection	Methods	Equipment	Reference
pH[1]	Biweekly	4500 H^+ - Eletrometric Method	Portable pHmeter	APHA (2017)
Temperature[1]	Biweekly	2550 - Temperature	Portable Thermometer	APHA (2017)
Nitrate nitrogen[2]	Biweekly	4500-NO_3^- B. Ultraviolet Spectrophotometric Screening Method	Spectrophotometer (220 and 275 nm)	APHA (2017)
Ammonia nitrogen[2]	Biweekly	4500-NH_3 F. Phenate Method	Spectrophotometer (640 nm)	APHA (2017)
Turbidity[1]	Biweekly	2130 – Nephelometric Method	Portable Turbidimeter	APHA (2017)
Chlorophyll a[2]	Biweekly	10200 H. Chlorophyll	Spectrophotometer (664, 665 e 750nm)	APHA (2017)

[1] *in loco*; [2] Laboratory of Sanitation at the State University of Ponta Grossa (UEPG).
Source: Author, 2021.

4.2.4 Weather Parameters

Weather parameters such as relative humidity, horizontal solar irradiance and air temperature were obtained from SANEPAR weather station located nearby the FPS. The data is collected every minute of the day, so an average of the 24 hours was calculated. In addition, the total accumulated precipitation was obtained by collecting data from SIMEPAR (Paraná Environmental Technology and Monitoring System) rainfall stations.

4.3 DATA ANALYSIS

A statistical analysis using factorial analysis was developed at RStudio software at 1% significance level. ANOVA was performed and the means were compared by the Tukey test. Initially, the prerequisites were checked, such as data and residue normality, verified by the Shapiro-Wilk test, and the homogeneity of variances analyzed by the Bartlett test. The analysis of superficial and depth water sampling points was made separately, considering that the experimental design was completely randomized (CRD) using two factors: the position of the points (internal and external) and the time (weeks of water sample collection).

In addition to the factorial analysis, the boxplot tool was also used to analyze the behavior of each parameter. All boxplot graphs were made using the mean of each water collection point separately for the results obtained for surface and depth water samples.

Eight results were used instead of ten, as the results from 08/03/2021 and 08/31/2021 were incomplete and could not be used to the analysis. The results were incomplete due to difficulties to access external points and depth points because the unavailability of the boat.

4.4 RESULTS AND DISCUSSION

This section aims to evaluate the results of pH, temperature, nitrogen, turbidity and *chlorophyll a* obtained during the field research, as well as it was important to evaluate the weather conditions to understand how these results are being influenced by the floating photovoltaic system at Passaúna Reservoir.

The total accumulated precipitation presented in Table 2 was used to discuss the results throughout this section.

Table 2 – Total accumulated precipitation data on the dates of the water sample collections

Sampling Collection Date	**Total Accumulated Precipitation (mm)**
June 22nd, 2021	73.40
July 20th, 2021	12.00
August 03rd, 2021	0.00
August 17th, 2021	110.00
August 31st, 2021	117.40
September 22nd, 2021	41.60
October 27th, 2021	139.60
November 10th, 2021	9.60
November 24th, 2021	29.40
December 07th, 2021	1.80

Source: SIMEPAR data collection, 2022.

The National Environment Council (CONAMA) of Brazil in its resolution 357 (2005) defines fresh water bodies in five different classes according to the water quality. Passaúna reservoir is classified as class II (SUREHMA, 1992). Table 3 shows the limits for class II water bodies, according to the CONAMA resolution 357 (2005), for the parameters evaluated in this work.

Table 3 – Limits defined by the CONAMA resolution 357 (2005) for water bodies class II

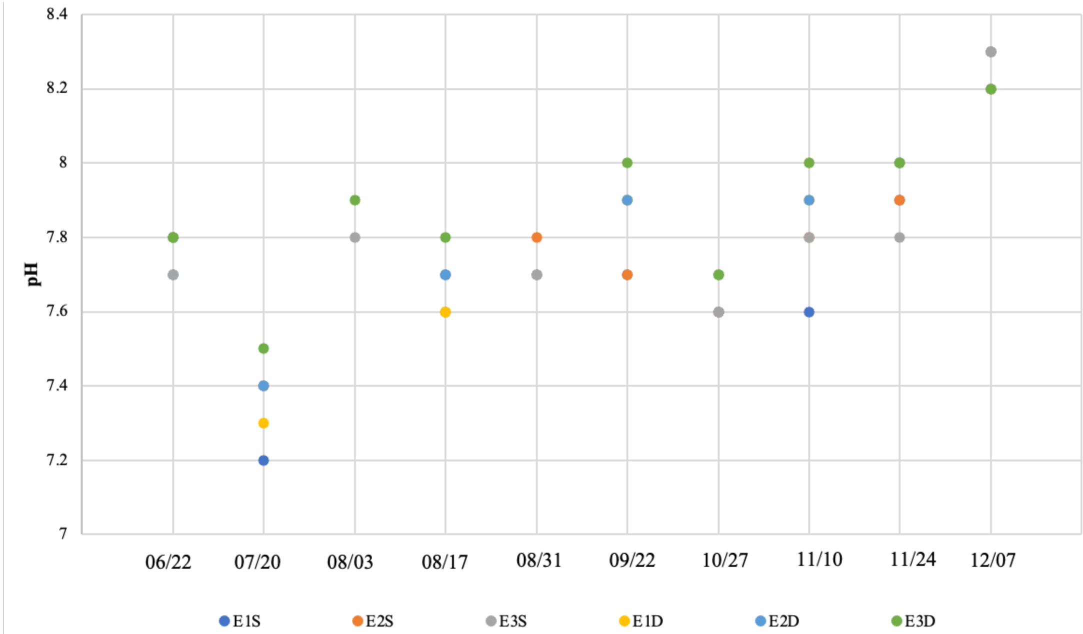
Parameter		CONAMA limits
Turbidity		≤ 100 NTU
pH		6.0 to 9.0
Chlorophyll *a*		≤ 30 µg/L
Nitrate (depends on pH)	pH > 7.5	10.0 mg/L N
	pH ≤ 7.5	3.7 mg/L N
Ammonia Nitrogen Total (depends on pH)	7.5 < pH ≤ 8.0	2.0 mg/L N
	8.0 < pH ≤ 8.5	1.0 mg/L N
	pH > 8.5	0.5 mg/L N

Source: CONAMA, 2005.

4.4.1 pH

Graphs 5 and 6 present the variation of pH to the external and internal water collection points of the FPS, respectively. In both graphs the data are presented for both surface and depth. The statistical analysis results are presented in Table 4, as well as in Graphs 7 and 8.

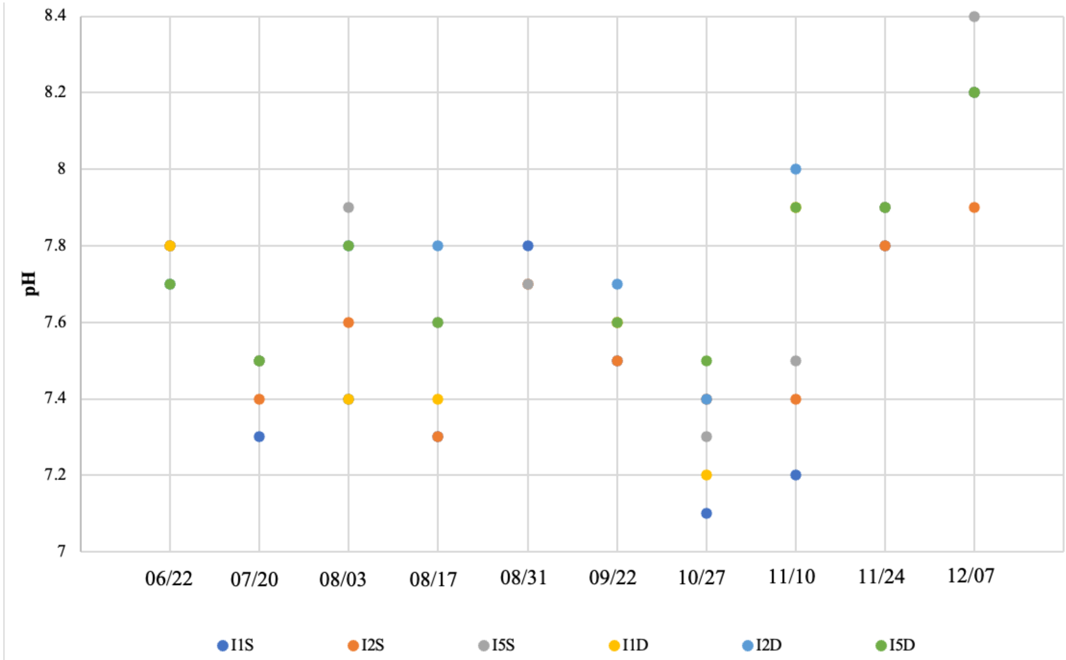
Graph 5 – pH variation at external points.



Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: The points that do not appear on the graph, with the exception of those mentioned in note 1, have concomitant results with other samples.

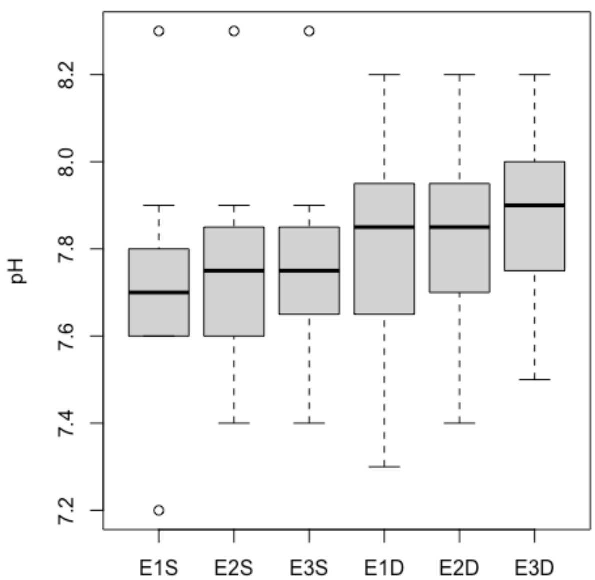
Note 3: E: external points; I: internal points; D: deep water samples; S: surface water samples.
Source: Author, 2022.

Graph 6 – pH variation at internal points.

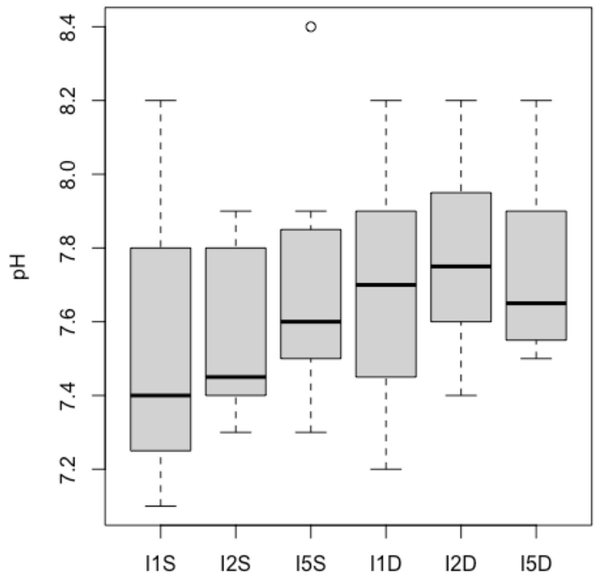


Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: The points that do not appear on the graph, with the exception of those mentioned in note 1, have concomitant results with other samples. Note 3: E: external points; I: internal points; D: deep water samples; S: surface water samples.
Source: Author, 2022.

Graph 7 – pH results of external points



Graph 8 – pH results of internal points



Note: E: external points; I: internal points; D: deep water samples; S: surface water samples.
Source: Author, 2022.

Comparing the pH results shown in the Graphs 7 and 8 it is observed that the internal water samples presented relatively lower pH values when compared to the external. pH results of water samples collected at the depth present greater data dispersion when compared to the surface.

It is known that the pH can be influenced by the rainfall and when analyzing the results, it is possible to see that the pH values decreased on day 27th of October, which was the day with the highest accumulated precipitation, as shown in Table 2. This leads to believe that with the increase of rainfall volume the pH value can decrease. Naime and Fagundes (2005) found the same affirmation and explained that the increase in rainfall, characteristic of a season of the year, influences the pH values, which decrease as a function of dilution of dissolved compounds.

In some pH measurements in the Passaúna river, carried out by two sensors between August 2018 and February 2019, a maximum value of 7.79 was verified by Sales (2020).

Along with the graphs, the statistical analysis (Table 4), showed that the highest pH values found were at external points 3 (7.875) and 2 (7.825) on the depth, and the smallest at internal points 1 (7.525) and 2 (7.563) on the surface.

Table 4 – pH results of the Tukey test for the external and internal points at surface and depth

		E1	E2	E3	I1	I2	I5
Surface	Mean	7.71	7.76	7.77	7.52	7.56	7.70
	Tukey test	ab	ab	ab	b	b	ab
Depth	Mean	7.80	7.82	7.87	7.68	7.77	7.73
	Tukey test	ab	a	a	ab	ab	ab

Note: According to the Tukey test points that have the same letter in the same line do not present significant variation from each other at 1% of significance. Source: Author, 2022.

This result is similar to the average found by Godoy (2017), he studied the water quality of the Passaúna reservoir at different locations, and at the water catchment point he also found that the pH was higher at the depth than at the surface. On the other hand, Wenjun *et al.* (2011) when analyzing water quality parameters at Panjiakou reservoir in China comparing results with and without shading light, found out that shading light influences changes in pH values, reducing it.

The higher pH value can be a result of the photosynthesis, which can rise the pH of an aquatic system due to the enrichment of nitrogen and phosphorus and the lower concentration of carbon dioxide (BUZELLI; CUNHA-SANTINO, 2013). However, the accumulation of organic matter can cause the pH of the aquatic system to decrease due to the release of carbon dioxide (MAROTTA; SANTOS; ENRICH-PRAST, 2008).

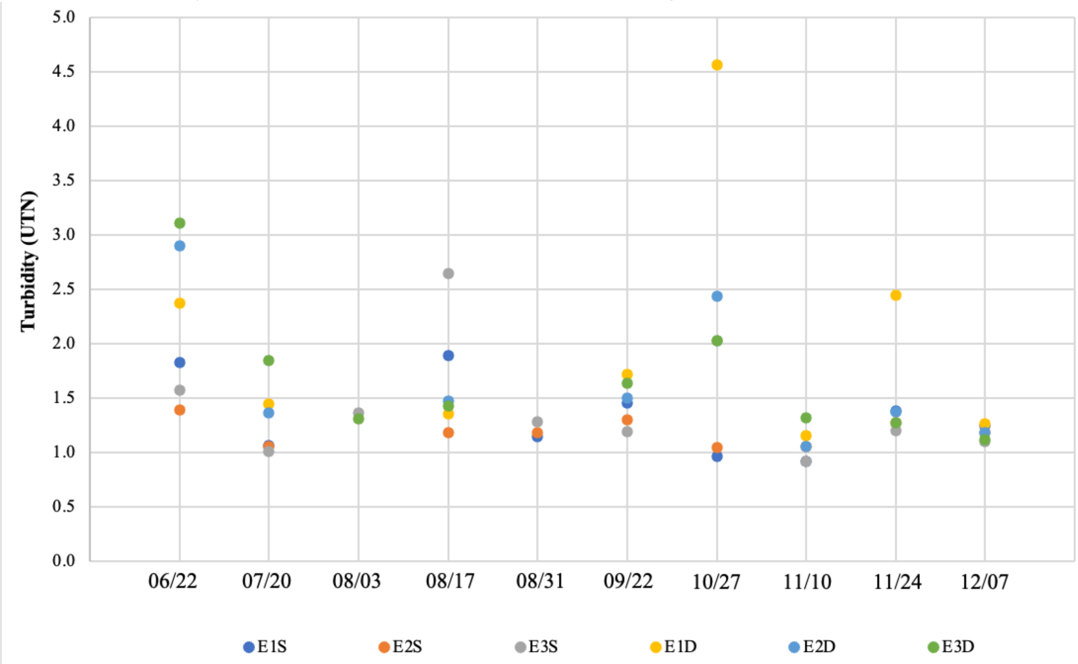
The highest and lowest values presented a statistic significant difference, while all other values showed no significant difference ($p<0.01$) from either the higher or lower values. Which means that despite the extreme values being different, the vast majority did not show significant variations ($p<0.01$). There was no significant variation in the interaction among the position of the points (internal and external) and the time (weeks of water sample collection). So, it can be said that pH is a parameter that did not presented great interference from the FPS at Passaúna Reservoir.

In addition, the values range for pH were between 7.1 and 8.4, which fits within the limits established by CONAMA (2005) for class II water bodies, that is from 6 to 9.

4.4.2 Turbidity

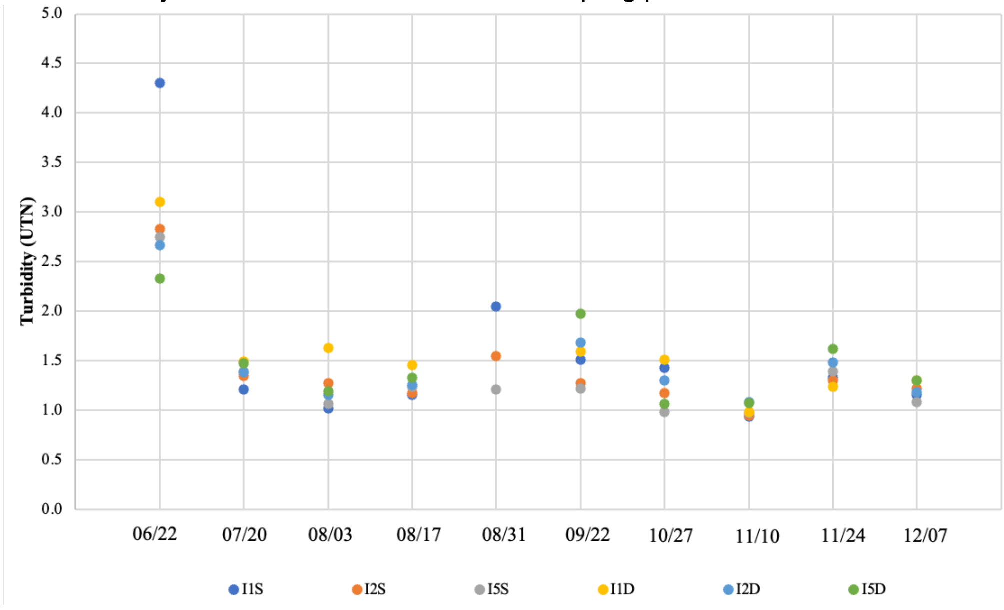
The turbidity results are shown in Graphs 9 and 10 to the external and internal points, respectively. The statistical analysis is presented at Table 5, as well as in Graphs 11 and 12.

Graph 9 – Turbidity variation at the external water sampling points.



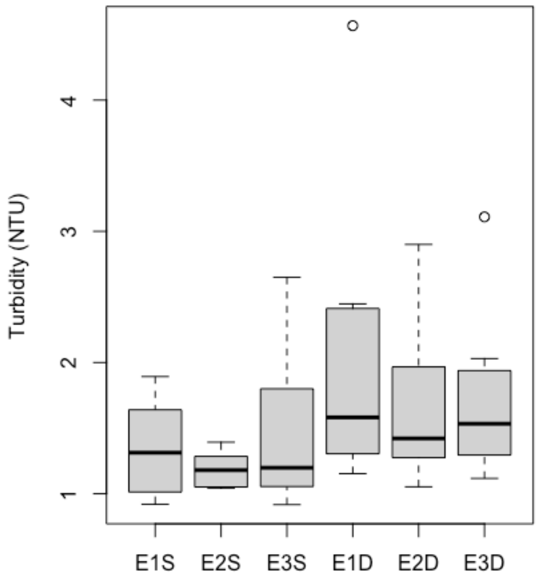
Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

Graph 10 – Turbidity variation at the internal water sampling points.

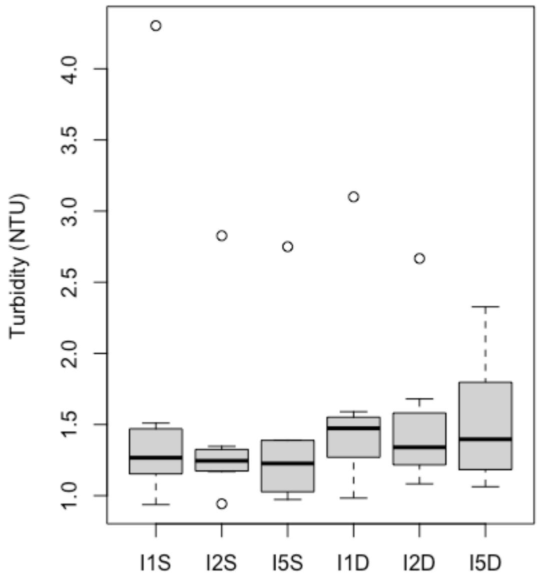


Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

Graph 11 – Turbidity results of external points.



Graph 12 – Turbidity results of internal points.



Note: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

The highest turbidity value (4.567 NTU) is at the external point 1 of depth (E1D) and the lowest value (0.917 NTU) is at the external point 3 of the surface (E3S). The highest turbidity value (4.567 NTU) was obtained at the October 27th and the average turbidity in this day was also higher than the other days, which may be a result of the total precipitation accumulated, which was the rainiest water sampling day, as shown in Table 2.

Turbidity in waters is mainly attributed to the presence of suspended solids from algae, organic debris, among others, due to natural process of erosion or from domestic and industrial effluents. Therefore, rainfall directly influences the number of suspended solids in a water body, due to the transport of particulate material by surface runoff (NAIME; FAGUNDES, 2005; RICHTER, 2009).

Godoy (2017) also evaluated turbidity at Passaúna Reservoir in different points such as buffer, Ferraria bridge, park, pumping system and dam. The values used to compare with the results of this work are at the pumping system point. He also collected samples from surface and depth. The sampling collections were in February 2016, February and May 2017. The values obtained by him to the surface are similar to the results of this research, being close to 0 UNT in February 2016, 3.39 UNT in February 2017 and 2.98 UNT in 2017 May. However, the depth results are much higher being 110 UNT, 12 UNT and 4,26 UNT in February 2016, February 2017 and May 2017, respectively.

In addition, Table 5 shows, for the majority, the turbidity values of the water in the external and internal collection points dis not present significant statistical variation ($p<0.01$). There was no significant variation in the interaction among the position of the points (internal and external) and the time (weeks of water sample collection). Therefore, the FPS did not influence the turbidity values of the water in the Passaúna reservoir.

Table 5 – Turbidity results of the Tukey test for the external and internal points at surface and depth

		E1	E2	E3	I1	I2	I5
Surface	Mean	1.343	1.184	1.459	1.627	1.407	1.376
	Tukey test	ab	b	ab	ab	ab	ab
Depth	Mean	2.040	1.660	1.720	1.584	1.503	1.518
	Tukey test	a	ab	ab	ab	ab	ab

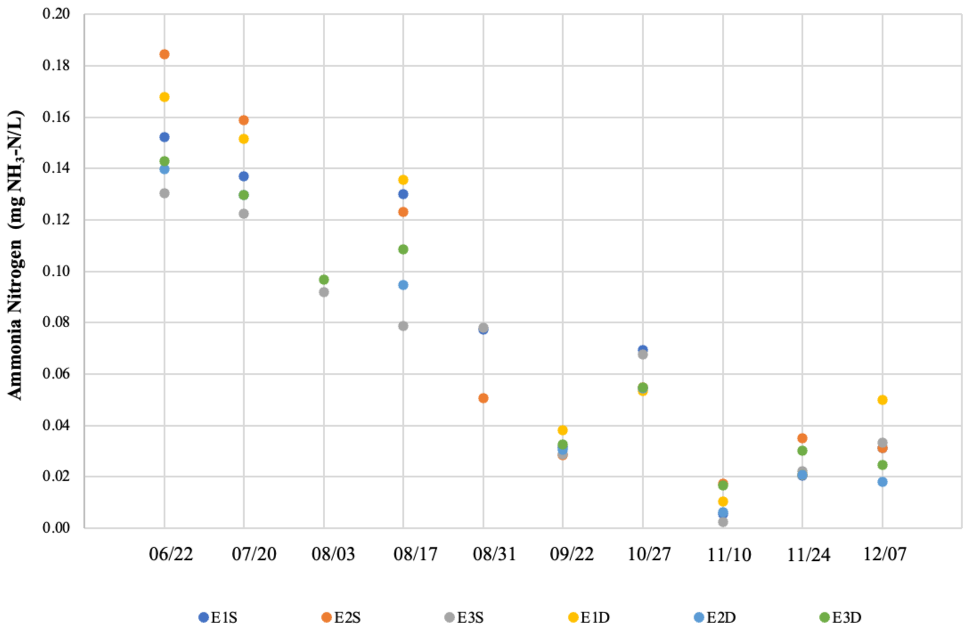
Note: According to the Tukey test points that have the same letter in the same line do not present significant variation from each other at 1% of significance. Source: Author, 2022.

The turbidity range values were from 0.917 NTU to 4.567 NTU which is way below the limit established by CONAMA resolution 357 (2005) that determines the limit of 100 NTU to water bodies class II.

4.4.3 Nitrogen

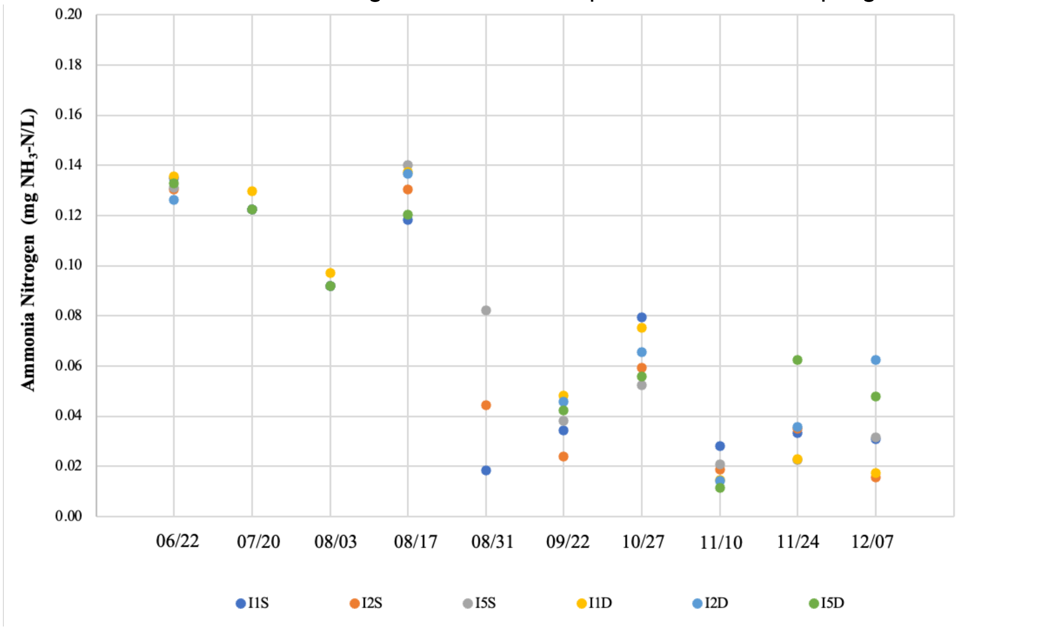
In order to analyze the variations of the nitrogen concentration in the Passaúna reservoir, nitrate and ammonia nitrogen concentrations were obtained. For both, the results were organized into tables and graphs and a statistical analysis through factorial analysis was done using RStudio software. Graphs 13 to 16 present the results of ammonia nitrogen and Graphs 17 to 20 show the results of nitrate.

Graph 13 – Variation of ammonia nitrogen at the external points of water sampling.



Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: The points that do not appear on the graph, with the exception of those mentioned in note 1, have concomitant results with other samples. Note 3: E: external points; I: internal points; D: deep water samples; S: surface water samples.
Source: Author, 2022.

Graph 14 – Variation of ammonia nitrogen at the internal points of water sampling.



Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: The points that do not appear on the graph, with the exception of those mentioned in note 1, have concomitant results with other samples. Note 3: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

Ammonia nitrogen is one of the forms of nitrogen present in water bodies. It is introduced into the water mainly by sewage disposal or fertilizer leaching. However, the atmosphere is also an important source of nitrogen due to the biological fixation performed by bacteria and algae and chemical fixation, a reaction that depends on the presence of light, and that contributes to the presence of ammonia and nitrates in the water. In addition, the washing of the polluted atmosphere by the rainwater, contributes to the presence of particles containing organic nitrogen, as well as to the dissolution of ammonia and nitrates (REISMANN, 2017).

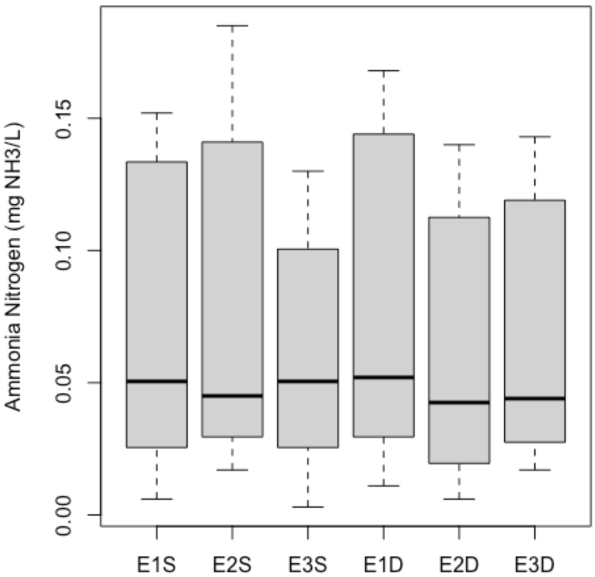
According to CONAMA resolution n° 357 (2005), ammonia nitrogen is a standard of natural waters and effluent emission. The maximum value of total ammonia nitrogen depends on the water pH (BRASIL, 2005).

The highest ammonia nitrogen value found was 0.185 mg NH_3^-N/L at the surface (E2S) and the lowest result was 0.003 mg NH_3-N/L also at water surface (E2S), below the limit of the CONAMA resolution (Table 3). Therefore, Passaúna Reservoir presented very low levels of ammonia nitrogen. Godoy (2017) obtained much higher results of ammonia nitrogen in the Passaúna Reservoir, the lower concentrations were at surface, 0.57 mg/L for surface and 1.84 mg/L for depth. Barreto (2020) researching the same reservoir obtained a very similar concentration result, a mean of 0.145 mg/L close to the water catchment.

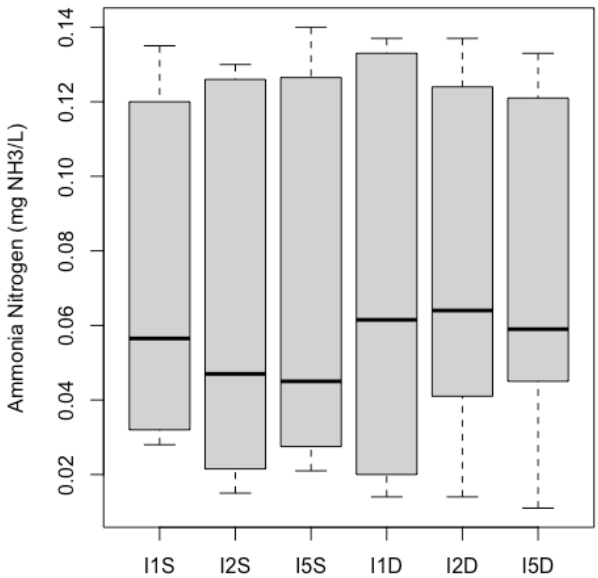
The highest concentration of ammonia nitrogen measured in the Passaúna reservoir obtained by Sales (2020) was 0.5 mg/L N, in February 2019. This value, the strictest limit across the entire pH range, corresponds to the maximum allowed by CONAMA when the pH is above 8.5. In some pH measurements in the Passaúna river, between August 2018 and February 2019, a maximum value of 7.79 was verified.

The results of the statistical analysis are presented in Table 6, as well as in Graphs 15 and 16.

Graph 15 – Ammonia nitrogen results of external points



Graph 16 – Ammonia nitrogen results of internal points.



Note: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

Table 6 – Ammonia nitrogen results of the Tukey test for the external and internal points at surface and depth

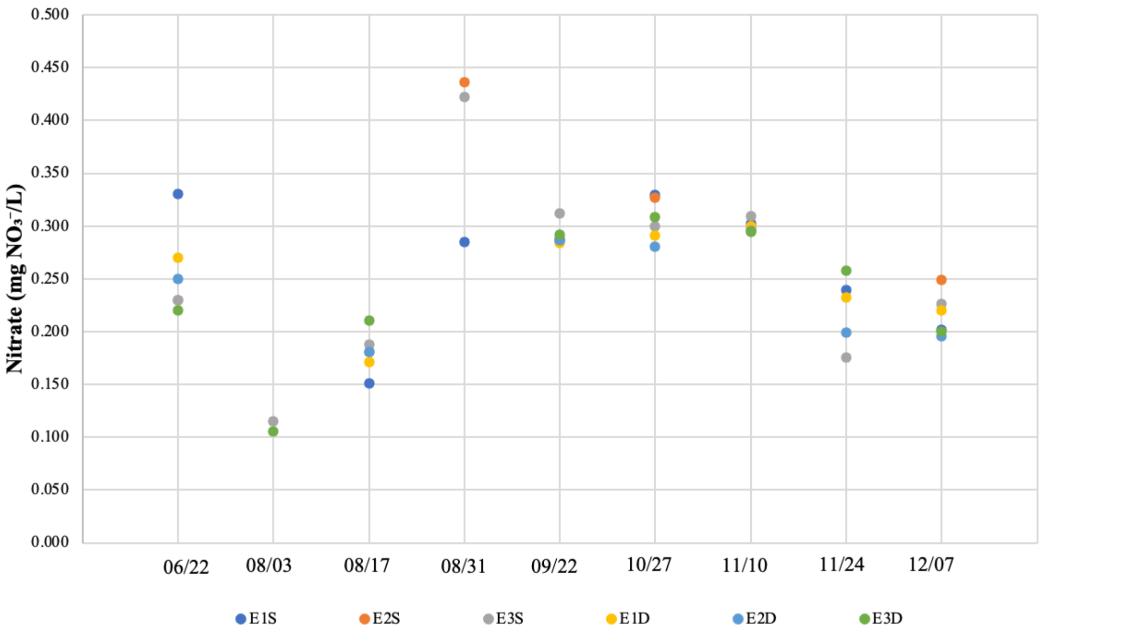
		E1	E2	E3	I1	I2	I5
Surface	Mean	0.072	0.079	0.061	0.072	0.067	0.069
	Tukey test	a	a	a	a	a	a
Depth	Mean	0.079	0.062	0.068	0.072	0.076	0.074
	Tukey test	a	a	a	a	a	a

Note: According to the Tukey test points that have the same letter in the same line do not present significant variation from each other at 1% of significance.
Source: Author, 2022.

The ammonia nitrogen is the parameter which presented the smallest variation between the points, statistically the results of ammonia nitrogen do not present significant differences ($p<0.01$) among internal and external points neither at surface and depth. There was no significant variation in the interaction among the position of the points (internal and external) and the time (weeks of water sample collection). Therefore, the FPS did not influence in the ammonia nitrogen concentrations.

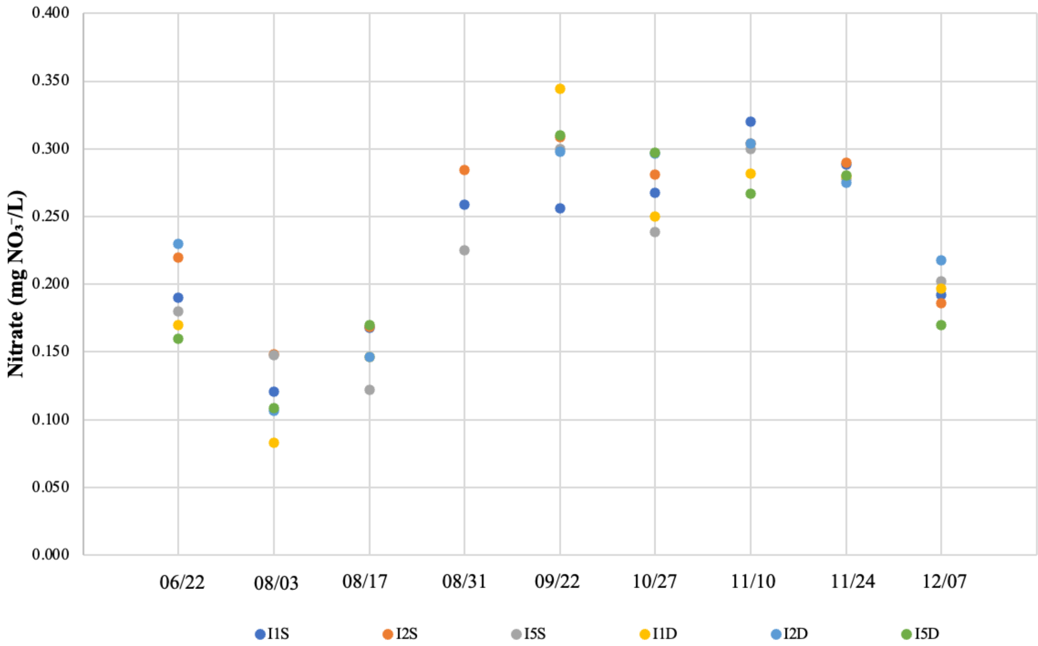
As well as ammonia nitrogen, nitrite and nitrate in the water body and in the sediment are related to production and decomposition processes of algae and mainly related to the loading of nutrients by sewage and effluents in water bodies. In water, the process of biological oxidation of ammonia, which is converted into nitrite by a group of nitrifying bacteria called *Nitrosomonas,* and later into nitrate by another group of bacteria known as *Nitrobacter*, is called nitrification (OLIVEIRA, 2017).

Graph 17 – Variation of nitrate at the external points of water sampling



Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: The points that do not appear on the graph, with the exception of those mentioned in note 1, have concomitant results with other samples. Note 3: E: external points; I: internal points; D: deep water samples; S: surface water samples.
Source: Author, 2022.

Graph 18 – Variation of nitrate at the internal points of water sampling



Note 1: On 08/03/2021 there was not collection of samples at E1S, E2S, E1D and E3D. On 08/31/2021 there was not collection of samples at depth. Note 2: The points that do not appear on the graph, with the exception of those mentioned in note 1, have concomitant results with other samples. Note 3: E: external points; I: internal points; D: deep water samples; S: surface water samples.
Source: Author, 2022.

As a comparison, the results of nitrate increased while the ammonia nitrogen decreased due to the nitrification process and vice versa.

According to Metcalf and Eddy (2003) the nitrification reactions can be affected by several environmental factors including temperature, pH, dissolved oxygen concentration and cell retention time. The nitrification rate decreases significantly at pH values below 6.8 and increase as the pH increases. Consequently, the parameters pH, ammonia nitrogen and nitrate are correlated. With increasing pH, there is an increase in the rate of nitrification, and therefore there is an increase in nitrate and a reduction in ammonia nitrogen.

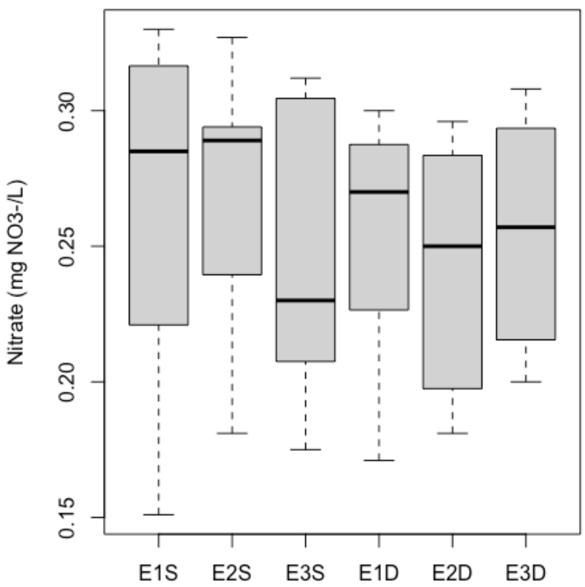
The lowest result of nitrate was obtained at external point at depth, 0.106 mg/L (E3D) and the highest result was also at external point at surface, 0.436 mg/L (E2S). The results indicated the lowest nitrate concentrations at the depth compared to the concentrations at the surface. This phenomenon can be explained due to the low presence of oxygen at depth, since nitrification does not occur in an anaerobic condition, it occurs only in regions where oxygen is available, normally in the water column or on the surface (ESTEVES, 2011).

Barreto (2020) studying the water quality of Passaúna Reservoir obtained a nitrate result of 0.225 mg/L at the water capture point which is the closest point to the FPS.

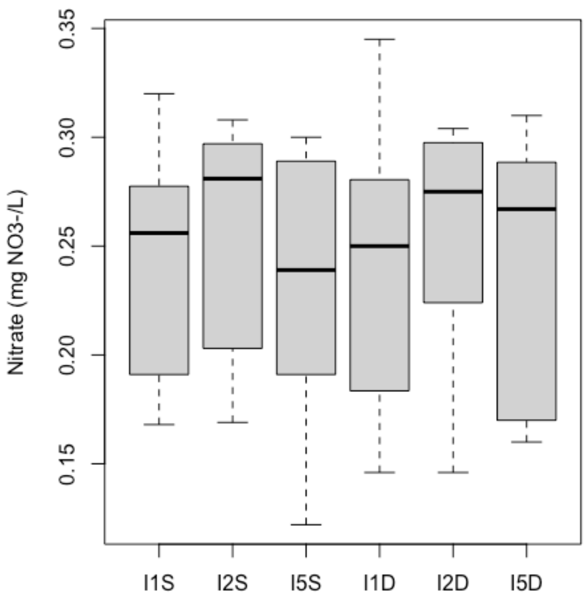
Godoy (2017) when analyzed the nitrate at the water catchment of Passaúna Reservoir observed concentration of 0.188 mg/L in February 2016 and 0.11 mg/L in February 2017. Furthermore, Barreto (2020) in research from 2018 to 2019 at Passaúna Reservoir obtained a nitrate mean of 0.225 mg/L at the water capture point which is the closest point to the FPS. This value is suchlike the means obtained in this research, shown in Table 7.

The results of the statistical analysis are presented in Table 7, as well in Graphs 19 and 20. The experimental procedure took place in a completely randomized design (CRD) such as other analyses, however with only seven collection data instead of eight due to the impossibility of obtaining results from the water sample collected on 07/20/2021.

Graph 19 – Nitrate nitrogen results of external points.



Graph 20 – Nitrate nitrogen results of internal points.



Note: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

Table 7 – Nitrate nitrogen results of the Tukey test for the external and internal points at surface and depth

		E1	E2	E3	I1	I2	I5
Surface	Mean	0.263	0.266	0.248	0.240	0.251	0.231
	Tukey test	a	a	a	a	a	a
Depth	Mean	0.253	0.241	0.255	0.238	0.252	0.236
	Tukey test	a	a	a	a	a	a

Note: According to the Tukey test points that have the same letter in the same line do not present significant variation from each other at 1% of significance.
Source: Author, 2022.

Depth and surface results did not present statistically significant difference ($p<0.01$). There was no significant variation in the interaction among the position of the points (internal and external) and the time (weeks of water sample collection). Therefore, the FPS has not influenced at the nitrate concentrations in the Passaúna reservoir.

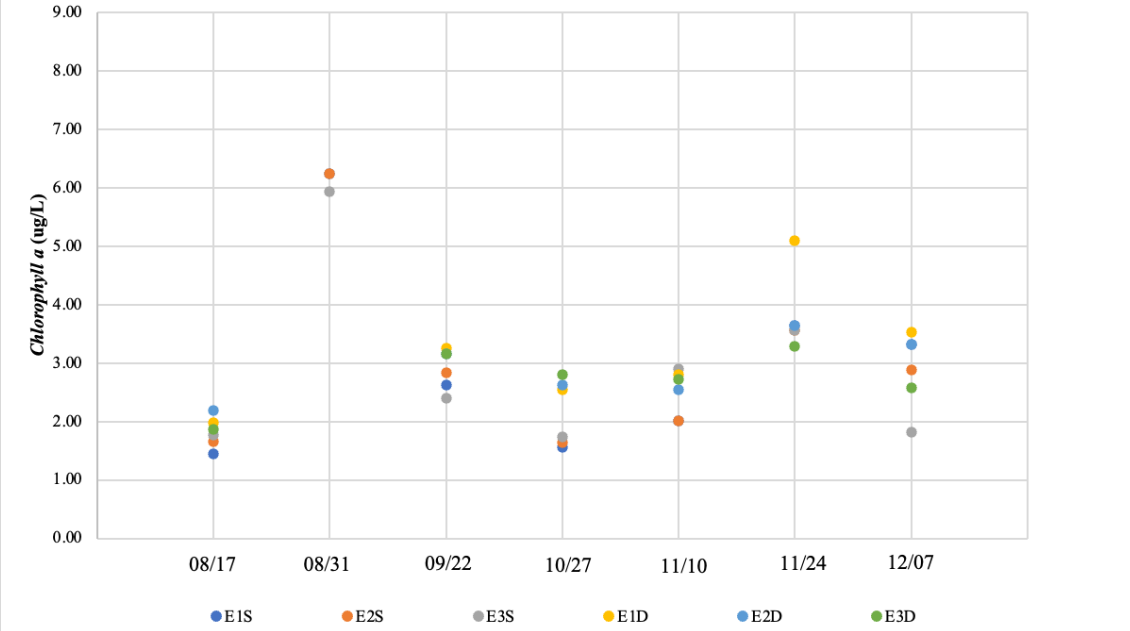
4.4.4 Chlorophyll a

The first two chlorophyll analyzes (06/22 and 08/03) had to be disregarded due to analytical problems. As a result, another methodology was adopted for the subsequent analyzes of *chlorophyll a*.

Chlorophyll a is the pigment responsible for capturing light to allow the photosynthesis and according to Rudorff (2006) all algae, marine or continental, have this pigment.

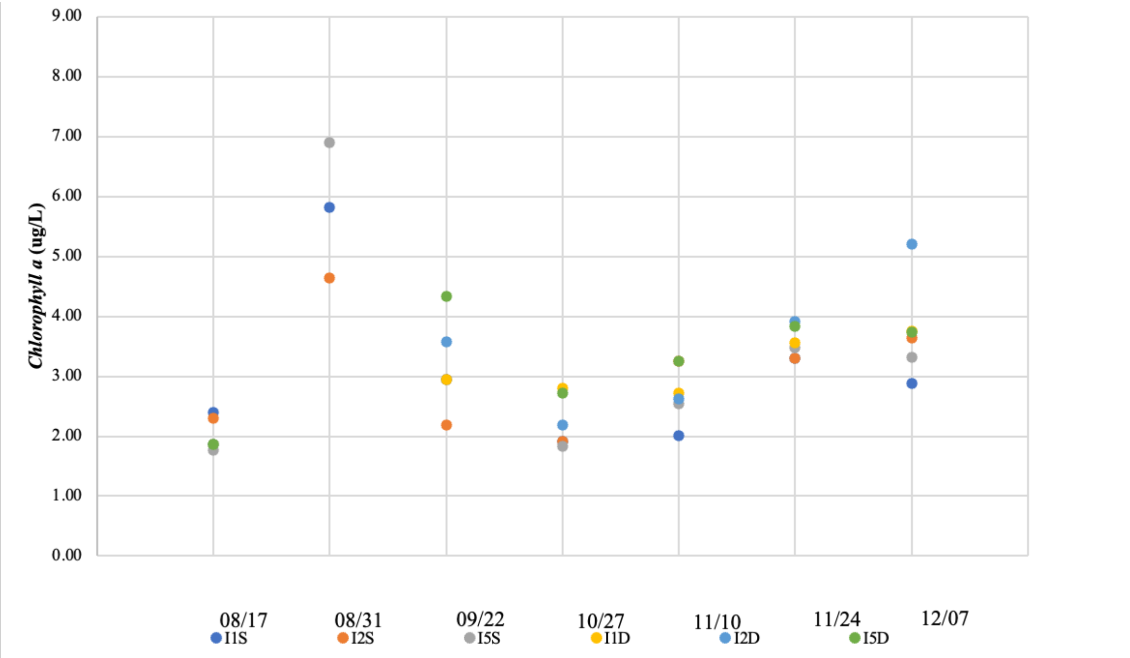
Graphs 21 and 22 present the results of *Chlorophyll a* concentration while Graphs 23 and 24 show the boxplots and Table 8 the results of statistical analysis.

Graph 21 – Variation of the *Clorophyll a* concentration at the external point of water sampling.



Note 1: On 08/31/2021 there was not collection of samples at depth. Note 2 : E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

Graph 22 – Variation of the *Clorophyll a* concentration at the external point of water sampling.



Note 1: On 08/31/2021 there was not collection of samples at depth. Note 2: E: external points; I: internal points; D: deep water samples; S: surface water samples. Source: Author, 2022.

The lowest result, 1.558 µg/L, occurred on 10/27/2021 when the total accumulated precipitation presented the highest value, it could be explained by the dilution of *chlorophyll a* across water layers. And the highest result, 6.889 µg/L, were obtained on 08/21/2021, at surface, however there were no sample collection at depth on this day.

Barreto (2020) obtained, at Passaúna Reservoir, an average of 4.2 µg/L for the water sample collected close to the water catchment and stated that this low concentration of *chlorophyll a* is due to the influence from the tributary rivers of the reservoir. This result is a little higher than the means obtained in this work, where the highest average was for internal point at depth (I5D), 3.287 µg/L. The average was obtained by calculating the mean of point results for all collection sampling days.

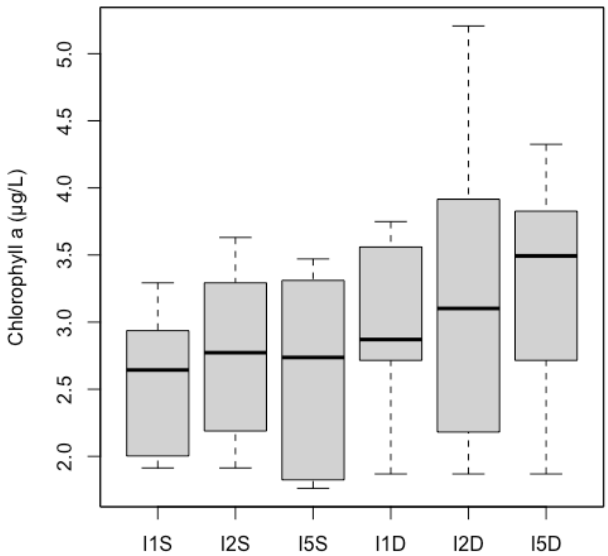
On the other hand, Godoy (2017) observed a much higher value of *chlorophyll a* at the water catchment point in October 2016, 17,25 µg/L. Sales (2020) also reached a value of 16.7 µg/L of *chlorophyll a* concentration at Passaúna Reservoir, measured by sensor, however the average value was 6.7 µg/L to sensor records and results varying from 1.9 to 8.1 µg/L to laboratory analyzes.

Sales (2020) noticed that the concentrations of *chlorophyll a* were found only in the superficial layers due to the presence of solar radiation. However, at the winter the concentrations of *chlorophyll a* were found at the deeper layers, because of the instability of temperatures in this season.

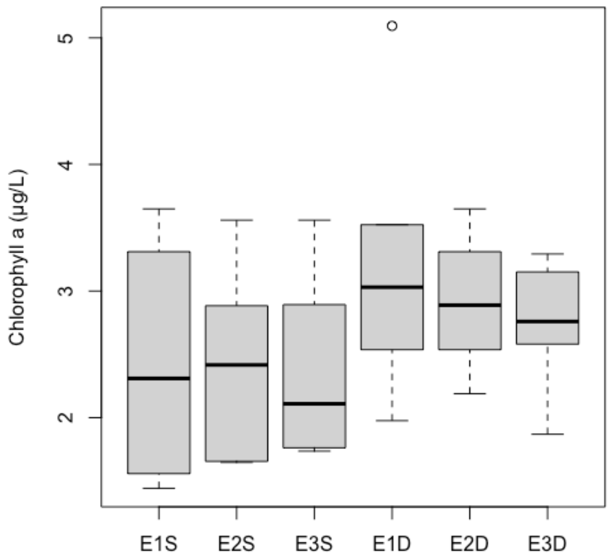
Regarding the results obtained at the external points of the FPS, the results of *chlorophyll a* were greater at the depth than at the surface. The depth average values were 3.198 µg/L (E1), 2.910 µg/L (E2) and 2.735 µg/L (E3) while the surface were 2.430 µg/L (E1), 2.429 µg/L (E2) and 2.362 µg/L (E3). This is explained by Ciotti *et al* (2006) because there is little availability of nutrients on the surface. Thus, in the layers where there are better conditions of light and nutrients, higher concentrations of *chlorophyll a* are observed, these layers are called the maximum depth of *chlorophyll a.*

This behavior also happened in the internal points of the FPS, the average of depth values was 2.939 µg/L (I1), 3.229 µg/L (I2) and 3.287 µg/L (I5), whereas the surface values were 2.572 µg/L (I1), 2.762 µg/L (I2) and 2.640 µg/L (I5). Statically there was not significant differences ($p<0.01$) among internal or external points neither depth and surface heights. There was no significant variation in the interaction among the position of the points (internal and external) and the time (weeks of water sample collection).

Graph 23 – Boxplot of *chlorophyll a* results of internal points



Graph 24 – Boxplot of *chlorophyll a* results of external points



Note: E: external points; I: internal points; D: depth points; S: superficial points. Source: Author, 2022.

Table 8 – *Chlorophyll a* results of the Tukey test for the external and internal points at surface and depth

		E1	E2	E3	I1	I2	I5
Surface	Mean	2.43	2.43	2.36	2.57	2.76	2.64
	Tukey test	a	a	a	a	a	a
Depth	Mean	3.2	2.91	2.73	2.94	3.23	3.29
	Tukey test	a	a	a	a	a	a

Note: According to the Tukey test points that have the same letter in the same line do not present significant variation from each other at 1% of significance. Source: Author, 2022.

The CONAMA (2005) limit of *chlorophyll a* is 30 µg/L for class II water bodies. In this way, Passaúna Reservoir presents average values below 4 µg/L which is far below the established limit. Regarding eutrophication, *chlorophyll a* is one of the parameters to be analyzed to determine the trophic state of a water body. The mean of the values for the internal points was 3.126 µg/L and for the external points, 2.944 µg/L. Demonstrating that the reservoir is in the mesotrophic state according to the classification of Pavluk and Bij de Vaate (2013) which determines that the maximum *chlorophyll a* concentration is 7.3 µg/L to mesotrophic state. Meaning that for the area studied, close to the FPS, there is no eutrophication.

4.5 CONCLUSION

The FPS installed in the Passaúna Reservoir has an area of 1200 m², which represents less than 0.5% of the total area of the reservoir. The results obtained in this work did not show significant variations ($p < 0.01$) in relation to the water quality parameters studied when compared the internal and external points of the FPS at the surface and when compared the internal and external points in depth.

In addition, the FPS is very close to the water intake and there is continuous movement of water due to the pumping system. Probably this is the reason that significant variations in the analyzed water quality parameters were not observed.

Regarding the physical parameters of pH and turbidity, there were no major differences, although the results showed statistically significant differences between two external points. In addition, in relation to the nitrogen, the results showed that the nitrification occurs in the reservoir and that is influenced by the pH. As for *chlorophyll a*, the highest results both at the external and internal points were found at depth.

Comparing the limits established at CONAMA Resolution 357 (2005) and the values observed for the parameters, pH, turbidity, nitrate, ammonia nitrogen and *chlorophyll a*, at Passaúna Reservoir, it is observed that the values are below the maximum limit and the water body can still be considered as class II. Moreover, the low mean concentrations of nitrogen and *chlorophyll a* suggest that the classification of the reservoir is mesotrophic not presenting eutrophication. It is important to state that the conclusions are valid for the study area close to the FPS not guaranteeing that are valid for the entire reservoir area.

Under the conditions evaluated the FPS did not significantly influence the analyzed water quality parameters, however this work did not evaluate the aquatic life neither the FPS interference on it.

CHAPTER 2 - FLOATING PHOTOVOLTAIC SYSTEMS AND THEIR IMPACTS ON WATER QUALITY

ABSTRACT

The reduction of fossil fuels usage for energy generation is a major concern of this century and the increasing use of renewable energy sources. Solar energy is a good alternative to address this objective because it came from an unlimited source, and the cost of this technology has been decreasing and tending to be less than 0.04 USD/kWh in 2030. In Brazil, a country with a high rate of insolation, this technology has been growing but is still underused. Photovoltaic energy faces some obstacles with the availability of areas for its installation and that is one reason why the floating photovoltaic system appears with the objective of using existing and available areas such as the water surface, in order to add value to the reservoirs in which this system is installed. Although, the biggest obstacle still is the cost of installation and maintenance of this technology. The floating photovoltaic system (FPS) has been used since 2007 in countries such as China, South Korea, the United States, Japan, the United Kingdom and France and studies have been carried out to evaluate the potential of its use in relation to the aspects of energy generation efficiency, reduction on water evaporation rates, and also the influence on the quality of water in reservoirs, such as reduction of algae presence. Relevant studies showed significant reduction on algae growth, a decrease on evaporation rates and a gain of efficiency due to the cooling down temperature caused by the water. Therefore, the main objective of this work was to present a literature review based on the influence of FPS on water quality, as well as to compare water quality results obtained in the Passaúna reservoir where an FPS was implanted, with other studies. The system installed in the Passaúna reservoir, with surface water coverage area less than 1% in relation to the reservoir area, does not significantly interfere with water quality in terms of pH, turbidity, *chlorophyll a*, ammonia nitrogen and nitrate parameters. However, more studies need to be developed to evaluate the FPS influence on water quality.

Key words: Floating photovoltaic systems; quality of water; algae growth.

RESUMO

A redução do uso de combustíveis fósseis para geração de energia é uma grande preocupação deste século e o uso crescente de fontes de energia renováveis. A energia solar é uma boa alternativa para atingir esse objetivo, pois veio de uma fonte ilimitada, e o custo dessa tecnologia vem diminuindo e tende a ser inferior a 0,04 USD/kWh em 2030. No Brasil, país com alto índice de insolação, essa tecnologia vem crescendo, mas ainda é subutilizada. A energia fotovoltaica enfrenta alguns obstáculos com a disponibilidade de áreas para sua instalação e é por isso que o sistema fotovoltaico flutuante surge com o objetivo de aproveitar as áreas existentes e disponíveis como o espelho d'água, de forma a agregar valor aos reservatórios em que este sistema é instalado. Porém, o maior obstáculo ainda é o custo de instalação e manutenção dessa tecnologia. O sistema fotovoltaico flutuante (FPS) é utilizado desde 2007 em países como China, Coreia do Sul, Estados Unidos, Japão, Reino Unido e França e estudos vêm sendo realizados para avaliar o potencial de seu uso em relação aos aspectos de eficiência na geração de energia, redução nas taxas de evaporação da água, e também a influência na qualidade da água dos reservatórios, como a redução da presença de algas. Estudos relevantes mostraram redução significativa no crescimento de algas, diminuição nas taxas de evaporação e ganho de eficiência devido ao resfriamento causado pela temperatura da água. Portanto, o objetivo principal deste trabalho foi apresentar uma revisão de literatura baseada na influência do FPS na qualidade da água, bem como comparar os resultados de qualidade da água obtidos no reservatório Passaúna onde foi implantado um FPS, com outros estudos. O sistema instalado no reservatório Passaúna, com área de cobertura hídrica superficial inferior a 1% em relação à área do reservatório, não interfere significativamente na qualidade da água nos parâmetros pH, turbidez, clorofila a, nitrogênio amoniacal e nitrato. No entanto, mais estudos precisam ser desenvolvidos para avaliar a influência do FPS na qualidade da água.

Palavras-chave: Sistemas fotovoltaicos flutuantes; qualidade da água; crescimento de algas.

5.1 INTRODUCTION

The search for renewable energy is a global need and is not recent. The objective is to reduce the use of fossil fuels and consequently to reduce the pollution generated. Renewable energies are the ones that come from renewable sources such as sun, wind and water. The usage of this type of energy has increased significantly over the years. In Brazil, more than half (53.4%) of the electricity generated in Brazil is through hydroelectric plants, although there was an 8.5% retraction in electricity generation through hydroelectric plants in 2021, due to water scarcity, as shown in Figure 7.

Besides that, some other renewable energies increased their usage when comparing the data from 2020 to 2021, solar energy increased from 1.6% to 2.5%, wind energy from 8.7% to 10.6%, natural gas from 9.1% to 12.8%. On the other hand, the usage of coal and its derivates also increased from 2.7% to 3.4%, it is not a significant increase, but the objective is always to reduce the use of these materials, until zero (EPE, 2022).

In addition, today it is known that the energy from hydroelectric plants is not so clean, because the construction of a hydroelectric plant causes a high environmental impact and considered irreversible. Although the electricity generated by hydroelectric plants that use hydropower, and therefore water as renewable energy, there is a change in the natural course of the river and also the need for deforestation and large flooded areas.

In this way, solar energy has become a potential alternative to the disadvantages of other renewable energy sources, mainly in some parts of Brazil where the solar irradiation is more expressive. Although it is still considered an expensive technology, it has become popular and reached the most varied sectors of the economy. According to Gorjian *et al.* (2021) the cost of solar energy will drop from 0.10 USD/kWh in 2018 to 0.04 USD/kWh in 2030, a 58% reduction compared to a 55% reduction in the cost of off-shore wind and a 25% reduction of onshore wind.

According to the annual report of the International Energy Agency - IEA (2022), in 2021, the Chinese market reached 54.9 GWp of installed capacity of photovoltaic energy, representing 31% of the global market. After China, the USA with 26.9 GWp, followed by the European Union with 26.8 GWp, and India with 13GWp, those are the countries with the highest usage of solar energy. Japan was the top 5 with an estimated capacity of 6.5 GWp. Brazil surprised in sixth place, with 5.5 GWp, making it the largest market for installed capacity of photovoltaic energy in the Latin America

According to the Energy Research Company - EPE (2022), the installed capacity of photovoltaic solar energy in Brazil grew by 40.9% from 2020 to 2021, but still represents only 3% of the country's energy.

Brazil has great potential for use of solar energy (PEREIRA *et al.,* 2016). However, the use of solar energy is not very expressive considering the high solar irradiance rates, being 1500 kWh/m² per year compared to European countries, such as Germany, for example, between 900 to 1250 kWh/m² (WIRTH, 2017). Despite having higher average annual solar irradiation than Germany, Brazil is behind this country in the ranking of installed solar energy.

Photovoltaic solar energy is obtained through the direct conversion of light into electricity using photovoltaic modules, which is the primary unit of this conversion process and is manufactured with semiconductor material such as silicon, arsenide, cadmium, among others (PINHO; GALDINO, 2014).

In this way, there is a need to invest in solar energy in Brazil, taking advantage of the country's renewable generation capacity. However, the installation of photovoltaic solar plants, requires high-value of investment, and also demands large areas for installation. It is estimated that a photovoltaic plant needs an area of 0.89 to 4.9 hectares per MW produced (DA SILVA, 2019). The availability of land is a challenge, because with the growth of the population, the cities are expanding as well as the agricultural areas for food production. In other words, one of the obstacles to the expansion of the solar energy production is the availability of area for its installation. Thus, floating solar power plants emerge as an alternative for the expansion of this renewable energy technology.

Floating Photovoltaic Systems (FPS) are already being used in some countries and studies are being carried out to evaluate their efficiency and effects on the environment. They are installed on the surface of the water, mainly in lakes or man-made reservoirs, such as in hydroelectric reservoirs, for water supply and in mines. (CARVALHO; QUEIROZ JÚNIOR, 2020).

The use of water surfaces for the installation of FPS has been observed since 2007. Since then, countries such as China, South Korea, the United States, Japan, the United Kingdom and France have adopted the technology as a way of using an area, previously idle. The first FPS built not only for research purposes was developed in

2008 in California, USA, was built by SPG Solar company to supply energy to the Far Niente winery, with a capacity of 175kWp. (TRAPANI; SANTAFÉ, 2014).

In 2011, the K-water (Korea Water Resources Corporation) company installed a 100 kWp FPS in the Hapcheon reservoir in South Korea. After the installation, positive results were obtained, and so another FPS was installed the following year in the same reservoir, with a capacity of 500 kWp. They are generating electricity that is being marketed to the Korea National Power System (CHOI, 2014). Currently the largest FPS in operation is in China with a capacity of 150 MWp and the world capacity exceeded 1.3 GWp in December 2018 (WORLD BANK GROUP; ESMAP; SERIS, 2019).

In Brazil, the first FPS installed was in the state of Goias, in September 2017, with a capacity of 305 kWp. This system was installed by the company Ciel & Terre International and is located in a reservoir used to store rainwater. The same company also installed two other FPS, one in Balbina (Amazonas state) and another in Sobradinho (Bahia state), both in hydropower reservoirs. They are being studied with the aim of evaluating two similar systems, installed in regions with different climatic conditions (WORLD BANK GROUP; ESMAP; SERIS, 2019). There are other systems installed in Brazil, such as Porto Primavera Plant, in São Paulo (STRANGUETGO, 2016), Luís Eduardo Magalhães Hydroelectric Plant, in Tocantins (DULLIUS, 2019) and, also in the Passaúna reservoir, in Curitiba, Paraná, which is the study case of this work.

According to the Where Sun Meets Water report (WORLD BANK GROUP; ESMAP; SERIS, 2019) if only 1% of the surface of all constructed reservoirs were used for the installation of FPS, the installed capacity would reach 400 GWp, moreover if 10% of the area of 1/3 of the constructed reservoirs were covered, the capacity would more than double, reaching one terawatt.

In terms of efficiency, studies indicate that an FPS can be 11% more efficient than ground-mounted systems (CHOI, 2014). However, there is a need for research to improve the comparison between the two systems in order to understand both the positive and negative impacts of the FPS installations.

Studies on FPS have shown positive results in water quality, reducing the growth of algae, enabling a reduction of the cost of the water treatment, as well as decreasing the water evaporation rates, both due to the shading effect of the photovoltaic modules on the water. Other positive impacts would be that there is no longer the need for deforestation to create new installation areas, since the installation takes place in reservoirs, which can be considered idle areas (AHLERT, 2017; STRANGUETGO, 2016; CHOI, 2014; GORJIAN, 2021).

Therefore, due to the importance of expanding the production of electricity using renewable sources in Brazil, with an emphasis on photovoltaic energy, and with the increase in the implementation of the FPS, this work aims to review the advantages and disadvantages of the FPS, mainly related to the water quality, considering the results obtained in the study carried out in the Passaúna reservoir, where some parameters of water quality were monitored at internal and external points of the FPS.

5.2 METHODOLOGY

This work presents a qualitative analysis of the impacts caused by the FPS, mainly related to the environmental impacts and water quality. A bibliographic review of national and international scientific articles was carried out, as well as works at the master's and doctoral level from the year 2013.

In addition, the water quality results obtained from June to December in the Passaúna reservoir were used, mainly those of *chlorophyll a*, to compare the environmental impacts with the consulted bibliography.

5.2.1 Study Area

The study area is the Passaúna reservoir, located in the metropolitan region of Curitiba, capital of the Paraná state, with coordinates 25º30'45” S and 49º22'07” W, as shown in Figure 8. The main use of the water in this reservoir is to supply water to 22% of the population (IAP, 2017) and is managed by the Water and Sanitation Company of Paraná State, SANEPAR. This reservoir integrates the hydrographic basin of Alto Iguaçu, which has an area of 3,621 km², that means that 28% of the population of Paraná state is supplied by this basin (CURITIBA, 2011).

Figure 7 – Passaúna reservoir location map

Source: Author, 2022.

In 2019, an FPS was installed by SANEPAR to supply a small part of the energy required by the pumping system of SANEPAR. The FPS is shown in Figures 9 and 10 and is composed by 396 floating photovoltaic modules installed on modular floating devices occupying an area of approximately 1,200 m² and with a power generation capacity of 130 kWp.

Figure 8 – Floating photovoltaic system at Passaúna reservoir

Source: SANEPAR, 2019.

Figure 9 – Floating photovoltaic system at Passaúna reservoir

Source: Author, 2021.

5.3 RESULTS AND DISCUSSION

The FPS has some specific characteristics when compared to the system installed on land and also with other renewable energy technologies. Some of the advantages and disadvantages of this system are described in this topic.

5.3.1 Efficiency

FPS has been showing greater efficiency when compared to the conventional ground-mounted system, studies indicate an increase in efficiency, because the contact, or proximity, with water reduces the temperature of the modules (ROSA-CLOT *et al.*, 2017).

High temperatures can inhibit the ability of photovoltaic modules to work at their highest efficiency, so the water surrounding the FPS has an effect of lowering the temperature of the modules, varying between 5 and 20% of cooling, depending on the region and its climate, this issue of cooling combined with the low shading region in the FPS makes its efficiency considerably higher than that of ground-mounted systems (REC, 2018)

The cooling effect of the photovoltaic modules causes an increase in the efficiency of its system as well as an increase in the production of electrical energy. Considering the semiarid region of Brazil, Sacramento *et al.* (2015) observed efficiency gains ranging from 9.52% to 14.5%, values close to those found in Korea and higher than the 8% found in Japan when compared with ground-mounted systems. (CHOI, 2014). The same author also presented results for different scenarios of reservoir coverage percentage and indicated that 7.4% of the state of Ceará and 18.8% of the city of Fortaleza could be supplied with electricity from FPS if only 5% of the surface of the reservoirs in the Brazilian semiarid region were covered by floating PV modules. On the other hand, an experimental study conducted in Italy by Cazzaniga *et al.* (2018) points out that the production of FPS is only 4% higher than structures installed on land.

5.3.2 Water Evaporation

The installation of a FPS in lakes and reservoirs impacts on their water evaporation rates, some studies indicate that there can be a significant reduction ranging from 33% in natural lakes to 50% in artificial lakes (CHOI, 2014). Rosa-Clot *et al.* (2017) carried out a study in Australia and numerically estimated that the effects of covering reservoirs through floating PV modules can reach a reduction of up to 90% in the evaporation rate, with an estimate of water saved, ranged from 15,000 to 25,000 cubic meters of water per MWp.

A study carried out concomitantly with this one, in the Passaúna reservoir, by Santos *et al.* (2022), pointed out that the percentage of water evaporation reduction depends on the size of the installed system and its significance in the size of the reservoir and, in addition, the different types of installations and modules also influence the statistics. This is because there are models of modules which can be installed with their entire surface over the water and other models which have inclinations so it leaves more surface of the water exposed. Regarding the model installed in the Passaúna reservoir, the modules have an inclination, and these allow greater water evaporation, so if 30% of the reservoir is filled with the installation of the FPS, this would result in a reduction of 18.06% in the evaporation rate of the water from the reservoir, if 70% of the surface of the reservoir were covered, the reduction in the evaporation rate would pass to 42.14%, which is presented as very significant and important data, considering water crises and changes in the climate which affect water availability. Thus, Santos *et al.* (2022) concludes that the water saved due to the installation of the FPS can be a strategy for the management of water resources and also to mitigate some of the impacts of climate change regarding droughts.

5.3.3 Environmental Impacts

Several environmental impacts are directly related to the installation of the FPS, as well as the installation and development of other technologies for producing electricity. If compared to the PV system ground-mounted, the FPS does not need to open new areas for installation, reducing the incidence of deforestation, as it uses an already available area, the water surface (GORJIAN *et al.* 2021). In addition, the issue of visual pollution is also reduced in urban areas, as it becomes one less installation and the reservoirs are normally located in more remote areas of urban centers.

Another aspect that must be taken into account is the aquatic biota and its possible changes. The interference in aquatic life by the FPS will depend on the size of this system, if it is small and does not occupy a significant area from the reservoir area, these changes may be null, but the larger the installed system, the greater its influence. In some cases, these changes can be positive, as intermediate levels of disturbance tend to increase the local biodiversity of aquatic organisms (COSTA, 2017). However, the effects of electromagnetic waves generated by the installed modules have not yet been widely studied and evaluated on aquatic life.

In addition, it is possible to have water contamination with toxic substances from oils, lubricants and paints used in cabling and structures, as well as products used for maintenance and cleaning, which can result in fish mortality and also change in water quality (COSTA, 2017). However, a positive point related to water is that the FPS need less water for cleaning, as they are positioned far from the ground so the effects of dust carried by the wind are practically eliminated (ROSA-CLOT, 2020).

From another point of view, the FPS compared to hydroelectric plants in the sense of generating clean and renewable energy has numerous advantages, since the construction of a hydroelectric plant causes a high environmental impact and is considered irreversible. This is because, despite the hydroelectric plant using only a natural and renewable source, water, during the construction process there is a change in the normal course of water, deforestation, flooding and the displacement of riverside families. After the construction process, a hydroelectric plant is installed and also a reservoir with standing water. The areas filled by water from the reservoirs are usually big areas and are considered idle (STRANGUETGO, 2016). In this way, it can be seen that these areas are available to be explored, as a form of compensation for the construction of hydroelectric plants, so the installation of the FPS in hydroelectric reservoirs can generate the improvement of the hydro energetic balance of water reservoirs, where the FPS will add value to the reservoir already built, generating more electricity (CARVALHO; QUEIROZ JÚNIOR, 2020).

5.3.4 Water Quality

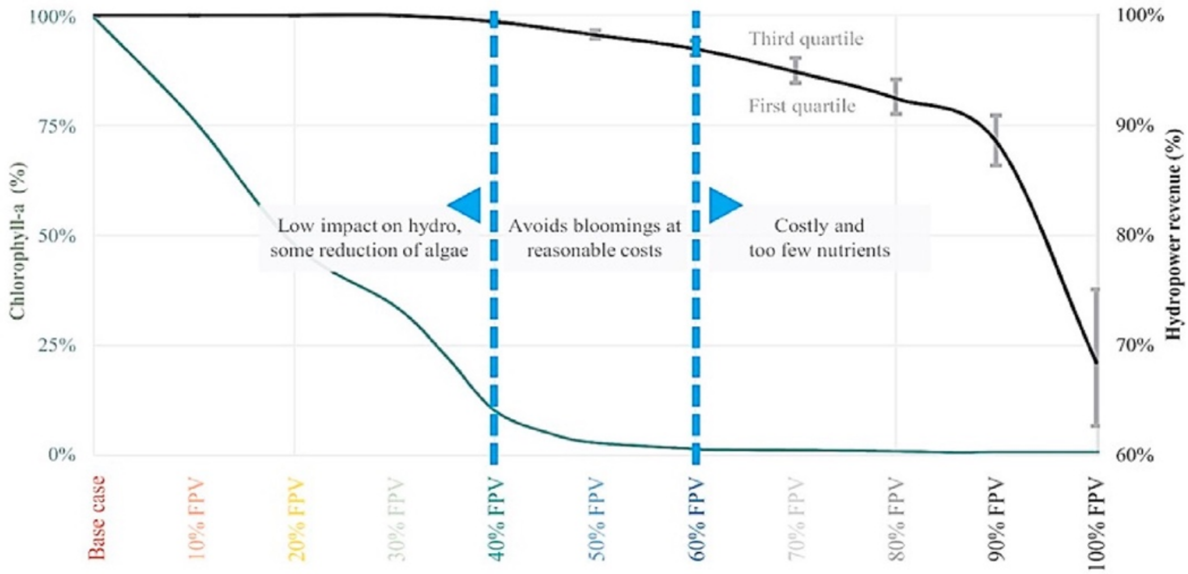
The water quality of reservoirs which have a FPS must be carefully evaluated, many studies present numerous conclusions regarding algae growth and eutrophication control, but they do not analyze in depth the chemical, physical and biological aspects related to this process.

Excessive algae growth can cause eutrophication, which is the unrestrained growth of algae and is usually caused by the enrichment of nutrients such as phosphorus and nitrogen, which are introduced into the water mainly by the dumping of industrial and domestic sewage, as well as by the leaching of agricultural pesticides. Eutrophication causes negative effects such as the reduction of available oxygen, the death of fish, it adds odor and taste to the water and in some cases, depending on the algae that proliferate, it can make the water toxic for human consumption, which is the case with cyanobacteria (KOSTEN; HUZAR, 2012). Therefore, the control of algae growth and eutrophication is of both public and private interest, in addition to being of interest to sanitation companies, as with the large presence of algae, filters, used in filtration units of water treatment plants, can become clogged, requiring frequent cleaning and replacement (REC, 2018).

Many aspects can interfere in eutrophication, such as shading in reservoirs, because it can reduce algae growth and it can also interfere in aquatic life (GORJIAN *et al*. 2021). Moreover, it can reduce local photosynthetic activity, causing an imbalance in the trophic chain, which can cause the appearance or disappearance of certain species (COSTA, 2017; SAHU *et al.* 2016).

Haas *et al.* (2020) investigated the effects of a FPS installed in the Rapel hydroelectric reservoir, in Chile, with the interest of analyzing the microbial growth. They studied different percentages of reservoir surface cover ranging from 10% to 100%. They came to the conclusion that a very extensive FPS drastically reduces the presence of algae, eliminating them, which is not interesting for the maintenance of the ecosystem. In addition, they evaluated the hydropower production operation together the presence of the FPS. The Graph 25 was obtained by them comparing the amount of *chlorophyll a* available in the reservoir and the capacity to generate hydroelectric energy. Thus, it can be seen that up to 40% of the surface covered by the FPS there were no major impacts on the operation, but there was already a reduction in the presence of algae. Between 40 and 60% was what they determined as the ideal rate, as it significantly reduced the amount of algae and reduced the hydroelectric plant's operation by around 5%, being considered an acceptable cost. However, above 60% coverage there was a very significant reduction in the operation and also in the presence of algae. Low algae concentration is critical for the reservoir food chain, with algae being the primary producers. The literature indicates a minimum concentration of 0.4 µg/L *chlorophyll a* for healthy oligotrophic reservoirs in this same study region of Chile (PIZARRO *et al*. 2016).

Graph 25 – *Chlorophyll a* concentration and hydropower revenues for different FPV scenarios



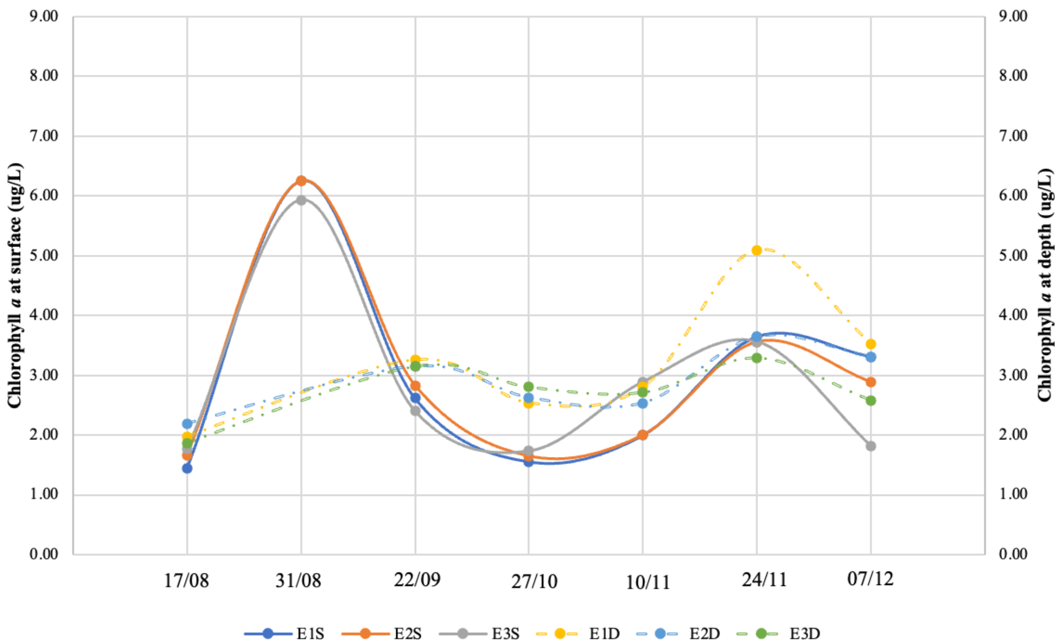
Source: Haas *et al*. (2020)

It is important to emphasize that the ecology of the reservoirs is individual, that is, it depends on numerous factors that interfere not only with the water quality but also with the aquatic life, factors such as the climate, the insertion and concentration of nutrients, the concentration of sediments, etc., interfering with chemical, physical and biological issues specific to each reservoir. Therefore, results obtained by different authors, such as the one of Hass *et al.* (2020) can indeed guide other studies, but specific studies for each region must be carried out.

In this way, this work presents the interference of the FPS installed in the Passaúna reservoir on the water quality. Analyzes were performed to compare water quality results at internal and external points of the system. The parameters analyzed were pH, turbidity, *chlorophyll a*, nitrate nitrogen and ammonia nitrogen. The nutrients for algae, nitrogen and phosphorus, are important to be analyzed because they are responsible for the enrichment of nutrients in the water, one of the aspects that facilitates the eutrophication of a water body, however at this research only the nitrogen was analyzed. In addition, *chlorophyll a* is a pigment responsible for capturing light and enabling photosynthesis and all algae have this pigment, so this is a good parameter for determination of the presence of algae in the reservoir or not (RUDORFF, 2006).

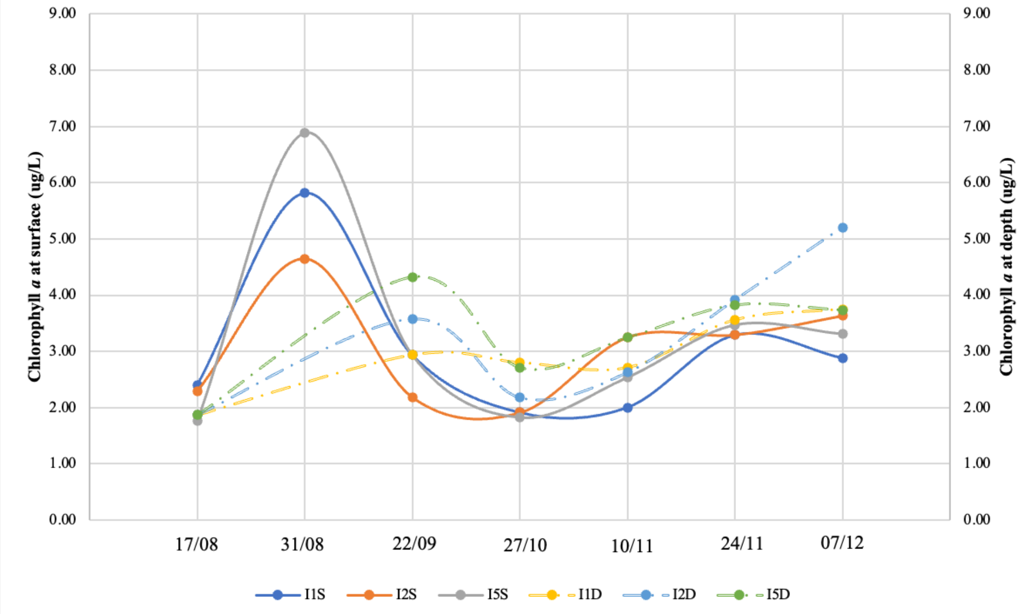
In Brazil, according to CONAMA resolution 357 (2005) for water bodies classified as class II, the limit concentration for *chlorophyll a* is up to 30 µg/L. The results obtained in this research were far below this limit, the highest value being equivalent to 6.889 µg/L for a surface point internal to the FPS and only on one winter day (08/31/2022), and the lowest result obtained was 1.442 µg/L for a surface point external to the FPS. The mean of the values for the internal points was 3.126 µg/L and for the external points, 2.944 µg/L. Demonstrating that the reservoir is in the mesotrophic trophic state according to the classification of Pavluk and Bij de Vaate (2013). Graphs 26 and 27 demonstrate *chlorophyll a* results.

Graph 26 – External points results for *chlorophyll a*



Note: E: external points; I: internal points; D: depth points; S: superficial points.
Source: Author, 2022.

Graph 27 – Internal points results for *chlorophyll a*



Note: E: external points; I: internal points; D: depth points; S: superficial points.
Source: Author, 2022.

As can be seen by comparing the results of the external and internal points, in general both showed the same behavior, thus indicating that the FPS installed in the Passaúna reservoir does not significantly influence the *chlorophyll a* parameter, indicating that the presence of algae is not lower due to this system.

The pH results ranged from 7.2 to 8.4 and are within the range specified by CONAMA (2005) which allows a variation from 6.0 to 9.0. The pH indicates the acidity or alkalinity of the water, and in relation to the results obtained, Passaúna reservoir is in alkaline conditions. In addition, no results were presented that indicated the interference of the FPS in this parameter.

For the turbidity, the maximum limit of CONAMA (2005) for this water body is 100 NTU, and the values obtained were extremely lower, ranging from 0.99 NTU to 4.567 NTU on days with higher rainfall, indicating low presence of suspended solids. There was a variation of values referring to the days with rain or not, but for this parameter the FPS also did not interfere significantly.

Finally, regarding the nitrogen present in this reservoir, two distinct forms of this nutrient were analyzed, being ammonia nitrogen and nitrate nitrogen CONAMA (2005) establishes the limit of ammonia nitrogen depending on the pH of the water. For the average of pH (7.7) observed in the analyses, the limit for ammonia nitrogen is 2.0 mg/L N, and for nitrate is 10.0 mg/L N. The results obtained were much lower than the established limits, with the highest result raised for nitrate nitrogen was 0.436 mg/L N and for ammonia nitrogen 0.185 mg/L N, this indicates that in the studied of Passaúna reservoir and for the period of the water quality monitoring, there were no significant concentrations of nitrogen. Therefore, the FPS did not interfere in the nitrogen concentrations, during the period studied.

5.4 CONCLUSION

This work aimed to carry out a bibliographic review about the aspects related to the FPS on its installation and mainly on its operation phase. Furthermore, analyze the possible interferences, mainly related to water quality, taking into account the results obtained in a study in the Passaúna reservoir.

The installation of FPS can still be considered a new technology, so many of its characteristics still need to be analyzed, but it is already known that the efficiency of this system when compared to the ground-mounted system is higher, which can vary according to the region and its temperatures. It is also known that FPS interferes on the water evaporation rates of lakes and reservoirs, which can vary depending on the type of structure and modules installed. However, the influence of the FPS can reach expressive levels of evaporation rate reduction and contributing to the hydric balance.

In addition, aspects as possible changes in the aquatic biota are a possibility due to the change in the characteristics of the water bodies. On the other hand, a relevant point is the possibility of installing FPS in hydroelectric reservoirs, thus using the surface of the water not requiring the opening of new areas, avoiding deforestation. Moreover, the installation of FPS at water supply reservoirs is also good for the sanitation companies that can generate its own energy using the available area of water surface.

The most relevant point of this study regarding water quality is the influence of the FPS in reducing the presence of algae in lakes and reservoirs. Numerous studies have pointed out this aspect as being positive for the reduction of eutrophication and raised the alert that a very drastic decrease is also not interesting because it will affect the aquatic ecosystem and its food chain. However, in the Passaúna reservoir it was not possible to verify modifications at *chlorophyll a* levels, meaning that the presence of algae did not changed due to the installation of the FPS.

It is clear that the interference of the FPS depends on its proportion in relation to the area of the reservoirs, and a small system, such as the one installed in the Passaúna reservoir, which covers less than 1% of the surface of the reservoir, did not present any influence on water quality, to the parameters analyzed.

Another relevant point is that the FPS is installed close to the water pumping system and thus there is constant water agitation, causing mixing of the water layers not presenting relevant differences of results between internal and external points of the FPS or even between the surface and depth points.

To conclude, all the parameters analyzed, especially *chlorophyll a* had variations of results due to the rainfall precipitation and temperature, reinforcing that these variations did not occur because of the presence of the FPS.

Therefore, in this study in the Passaúna reservoir, the installed FPS does not influence the water quality, although this study analyzed only some parameters and some aspects related to the installation and operation of FPS, but it is suggested to carry out more studies focused on the aquatic life of the reservoir.

6 FINAL CONSIDERATIONS

Floating Photovoltaic Systems is a relatively new technology and many efforts are being made to understand its behavior in front of the ground-mounted system. Besides that, as it is installed at a water body other significant aspects such as water quality, water ecosystem and aquatic life should be taken in consideration.

This work had as objective to evaluate the influence of the floating photovoltaic system on the water quality of the Passaúna Reservoir, especially when it comes to algae growth and it was accomplished.

At the first chapter it was possible to resume that the FPS did not show significant influence on pH, turbidity, nitrate nitrogen, ammonia nitrogen and *chlorophyll a.* It was due to the size of the FPS installed in the Passaúna Reservoir that has an area of 1200 m², which represents less than 0.5% of the total area of the reservoir. Besides that, the FPS is very close to the water intake of SANEPAR's water collection system and there is great agitation in the pumping system, so there are no significant variations in water quality, both in the samples of the internal and external points and also in the surface and depth samples. Moreover, the low mean concentrations of nitrogen and *chlorophyll a* suggest that the classification of the reservoir is oligotrophic not presenting eutrophication.

At the second chapter as overview of FPSs around the world showed that this system has more positive than negative aspects as it increases the efficiency of the photovoltaic modules, decreases water evaporation rates, reduces the algae growth, has the convenience of water to be used to the cleaning and maintenance process.

To conclude, under the conditions evaluated at Passaúna Reservoir, the FPS do not influence the water quality neither its parameters significantly, however its research did not evaluate the aquatic life neither the FPS interference on it. Furthermore, this study analyzed only some of the aspects related to the installation and operation of FPS's, but it is suggested to carry out more studies focused on the aquatic life of the reservoir.

REFERENCES

AHLERT, V.S.C. **Aplicação de sistemas fotovoltaicos flutuantes em reservatórios de hidrelétricas:** Estudo de caso em uma hidrelétrica brasileira. Thesis (Postgraduate Program in Environmental Engineering) - Polytechnical School, Federal University of Rio de Janeiro, Rio de Janeiro, 2017.

APHA – AMERICAN PUBLIC HEALTH ASSOCIATION. **Standard Methods for the Examination of Water and Wastewater**, 22st Edition, 2017.

ANEEL – National Agency of Electric Energy. **Resolution 482.** 2012

BARRETO, N. P. **Avaliação do grau de trofia e variação de fitoplânctons em reservatório de abastecimento de água:** estudo de caso Passaúna/PR. Dissertation (Postgraduate Program in Water Resources and Environmental Engineering) - Federal University of Paraná, Curitiba. 2020.

BERMANN, C. Crise ambiental e as energias renováveis. **Cienc. Cult.**, São Paulo, v. 60, n. 3, p. 20-29, 2008.

BRASIL. Ministry of the Environment. National Environment Council. **Resolution nº 357.** Resolution n˚ 357, 2005. Provides for the classification of bodies of water and environmental guidelines for their framing. Ministry of the Environment, Brasilia, 2005.

BRAGA, B. *et.al*. Introdução à Engenharia Ambiental. 2. ed. São Paulo: **Pearson Prentice Hall**, 2005.

BROOKE, D. *et al.* **Algas e seus impactos em sistemas de tratamento de águas para abastecimento:** estudo de caso sistema Guarapiranga. Thesis (Postgraduate Program in Sanitary and Hydraulic Engineering) - Polytechnical School, University of São Paulo, São Paulo, 2008.

BUZELLI, G.M., CUNHA-SANTINO, M.B. (2013) Análise e diagnóstico da qualidade da água e estado trófico do reservatório de Barra Bonita, SP. **Ambi-Água**. Taubaté, v.8, n.1, p.186-205.

CARVALHO, T. F. QUIROZ JÚNIOR, I. S. **Estudo sobre usinas solares flutuantes em reservatórios de água no Brasil:** Estudo de caso no Rio Mossoró. 2020

CAZZANIGA, R., *et al.* Floating photovoltaic plants: performance analysis and design solutions. **Renewable Sustainable Energy Rev**. n. 81. p. 1730-1741. 2018.

CETESB - ENVIRONMENTAL COMPANY OF SÃO PAULO STATE. **Relatório de Qualidade de Águas Interiores do Estado de São Paulo 2006**. São Paulo: CETESB, 2007. 327 p.

CETESB - ENVIRONMENTAL COMPANY OF SÃO PAULO STATE. **Relatório de qualidade das águas superficiais do estado de São Paulo:** significado ambiental e sanitário das variáveis de qualidade. São Paulo: CETESB, 2014.

CHOI, Y. K. A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact. **International Journal of Software Engineering and Its Applications**, v. 8, n. 1, p. 75-84, 2014.

CIOTTI, A.M. *et al.* **Clorofila a, Medida Bio-ópticas e Produtividade Primária**. In: VALENTIN, J.L. Características hidrobiológicas da região da Zona Econômica Exclusiva brasileira. Brasília: Ideal Gráfica e Editora. p.61-72, 2006.

CONAMA - National Environment Council. Ministry of the Environment. **Resolution N. 357**, 2005. Provides the classification of water bodies and environmental guidelines for their classification. Ministry of the Environment, Brasilia, 2005.

COSTA, S.G. **Impactes ambientais de sistemas fotovoltaicos flutuantes**. Dissertation (Master's), University of Lisbon, 2017.

CURITIBA. City Hall. **Waters of Tomorrow Project**: a critical look at the Alto Iguaçu watershed. n.1: report. Curitiba: 2011.

DA SILVA, G. D. P. **Large-scale solar photovoltaic impact assessment in the context of the Brazilian environmental and energy planning.** 89 p. Dissertation (Master's) – UFRJ/ COPPE/ Energy Planning Program, 2019.

DA SILVA, G. D. P. BRANCO, D. A. C. **Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts, Impact Assessment and Project Appraisal**. 2018.

DE LIMA,R.L.P. *et al.* In-Situ Water Quality Observations under a Large-Scale Floating Solar Farm Using Sensors and Underwater Drones. **Sustainability**. n. 13. 2021.

DULLIUS, D. J. **Estudo da utilização de sistemas fotovoltaicos flutuantes no lago da UHE Luís Eduardo Magalhães.** Monograph (Graduate Program in Electrical Engineering) - Federal University of Tocantins, Palmas 2019.

EPE. Energy research company. **Análise da Inserção da Geração Solar na Matriz Elétrica Brasileira**, Rio de Janeiro, 2012.

EPE. Energy research company. **BEN 2022 - Relatório Síntese: ano base 2021**, Rio de Janeiro, 2022.

EPE. Energy research company. **Plano Decenal de Expansão de Energia 2029**, Rio de Janeiro, 2019.

ESTEVES, F.A. Gêneros dos Ecossistemas Lacustres. **Fundamentos de Limnologia**. n. 3. Rio de Janeiro: Editora Interciência. 2011.

ESTRADA, A. *et al*. Determination of biogeochemical parameters in eutrophication models with simultaneous dynamic optimization approaches. **Computers and Chemical Engineering**. v.33. p. 1760 – 1769. 2009.

GODOY, R. F. B. **Dinâmica da qualidade da água em reservatório de abastecimento público: estudo de caso do Passaúna – PR**. Dissertation (Postgraduate Program in Water Resources and Environmental Engineering) - Federal University of Paraná, Curitiba, 2017.

GOOGLE EARTH, 6.0. 2022. Passaúna reservoir 25º30'45” S and 49º22'07” W. 3D map, Buildings data layer.

GORJIAN, S. *et al*. Recent technical advancements, economics and environmental impacts of floating photovoltaic solar energy conversion systems. **Journal of Cleaner Production**, n. 278. 2021.

HAAS, J., *et al*. Floating photovoltaic plants: Ecological impacts versus hydropower operation flexibility. **Energy Conversion and Management**, n. 206, 2020.

IEA. International Energy Agency. **Snapshot of global photovoltaic markets.** PVPS, 24 p. 2022.

INSTITUTO AMBIENTAL DO PARANÁ (IAP). **Qualidade das águas dos reservatórios do estado do Paraná**. IAP, Curitiba. 2017.

JAGERWALDAU, A. Photovoltaics and renewable energies in Europe. **Renewable and Sustainable Energy Reviews**, v. 11, p. 1414–1437. 2007.

KERSKI, J. **Water Quality**. v14, n.1, p. 36-41. 2017.

KIRK, J. **Light capture by aquatic plants**. In Light and Photosynthesis in Aquatic Ecosystems. Cambridge: Cambridge University Press. n.3. p. 308-329. 2010.

KOSTEN S.; HUSZAR V. Warmer climates boost cyanobacterial dominance in shalow lakes. GWF Discussion Paper 1213, **Global Water Forum**, Canberra, Australia. 2012.

KUO J.T, *et al*.Eutrophication modelling of reservoirs in Taiwan. **Environment Modell Software**. v. 21, p. 829 – 844, 2006.

LEAL, L. **A influência da vegetação no clima urbano da cidade de Curitiba – PR**. Thesis (Postgraduate Program in Forest Engineering) - Federal University of Paraná, Curitiba, 2012.

LIBÂNIO, M. Fundamentos de Qualidade e Tratamento de Água. Campinas, São Paulo: **Átomo**, 2005. 444p.

MARIANI, C.F. **Reservatório Rio Grande: Caracterização limnológica da água e biodisponibilidade de metais-traço no sedimento**. Dissertation (Postgraduate Program in Ecology and Terrestrial and Aquatic Ecosystems) - University of Sao Paulo, Sao Paulo, 2006.

MAROTTA, H.; SANTOS, R. O.; ENRICH-PRAST, A. Monitoramento limnológico: um instrumento para a conservação dos recursos hídricos no planejamento e na gestão urbano-ambientais. **Ambiente & Sociedade**, Campinas, v. 11, n. 1, p. 67-79, 2008.

McCRACKIN, M. L. *et al*. Recovery of lakes and coastal marine ecosystems from eutrophication: A global meta-analysis. **Limnology and Oceanography**. v.62. p. 507 – 518. 2016.

METCALF & EDDY. **Wastewater engineering**: treatment and reuse. n.4. New York: McGraw-Hill International edition, 2003.

MOBLEY, C. D. **Light and water**: radiative transfer in natural waters. San Diego: Academic Press. 593 p., 1994.

NAIME, R.; FAGUNDES, R.S. Controle da qualidade da água de Arroio Portão-RS. **Pesquisas em Geociências**, v.32, n.1, p. 27-35, 2005.

NARDINI M. J.; NOGUEIRA I. S. O processo antrópico de um lago artificial e o desenvolvimento da eutrofização e florações de algas azuis em Goiânia. **Estudos**, Goiânia. v.35, n.1/2, p23-52, 2008.

OLIVEIRA, L. G. F. **Processos oxidativos avançados** – utilização do sistema TiO_2/O_2/UV na remoção de NH_3 em águas residuais. Dissertation (Postgraduate Program in Chemistry) - Fluminense Federal University, Niteroi, 2017.

ONS. National Electric System Operator. **O que é o Sistema Interligado Nacional**, 2021.

PAERL H. W.; Otten T. G. Harmful Cyanobacterial Blooms: Causes, Consequences and Control. **Microb. Ecol**.v.65, n.4, p. 995-1010, 2013.

PAVLUK, T.; BIJ DE VAATE, A. **Trophic index and efficiency**. Reference Module in Earth Systems and Environmental Sciences, Elsevier, 2013.

PEREIRA, E. B. *et al.* **Atlas Brasileiro de Energia Solar**. n. 2. São José dos Campos. 2016.

PEREIRA, E. B.; MARTINS, F. R. Energia Solar - O potencial brasileiro. **Renováveis - Energias Complementares**, Perdizes , p. 42-69. 2018.

PINHO, J. T., GALDINO, M. A. Manual de Engenharia para Sistemas Fotovoltaicos. **CEPEL-CRESESB**. 2014.

PIZARRO, J., *et al.* Cooling and eutrophication of southern Chilean lakes. **Sci Total Environment** n. 541. p. 683–691. 2016.

REC, 2018. **Riding the wave of solar energy**: Why floating solar installations are a positive step for energy generation. 2018.

REISMANN, H. *et al.* **Remoção de nitrogênio e fósforo em efluentes**: principais técnicas existentes, características, oportunidades e desafios para o tratamento terciário de efluentes. Congress of Brazilian Association of Sanitary Engineering. 2017

RIBEIRO FILHO, R.A**. Relações tróficas e limnológicas no reservatório de Itaipu: Uma análise do impacto da biomassa pesqueira nas comunidades planctônicas**. Thesis (Postgraduate Program in Environmental Engineering Sciences) - University of Sao Paulo, Sao Paulo, 2006.

RICHTER, C.A. **Água:** métodos e tecnologia de tratamento. São Paulo: Blucher. 340p. 2009

ROSA-CLOT, et al. Floating photovoltaic plants and wastewater basins: an Australian project. **Procedia Engineering**, n. 134. p. 664-674. 2017.

ROSA-CLOT, P.FPV and environmental compatibility. **Floating PV Plants.** Elsevier, p. 101-118. 2020.

RUDORFF, C. M. **Estudo da composição das águas da Planície Amazônica por meio de dados de reflectância do sensor Hyperion/EO-1 e de espectrômetro de campo visando à compreensão da variação temporal dos seus constituintes opticamente ativos.** Dissertation (Postgraduate Program in Remote Sensing) – National Institute for Space Research, São José dos Campos, 2006.

SACRAMENTO, E. M. D. *et al.* Scenarios for use of floating photovoltaic plants in Brazilian reservoirs. **IET Renewable Power Generation**, 2015.

SAHU, A., *et al.* Floating photovoltaic power plant: A review. **Renewable And Sustainable Energy Reviews**, v. 66, p.815-824. 2016.

SALES, G. G. N. **Water Quality Modeling in a Subtropical Water Supply Reservoir.** Dissertation (Postgraduate Program in Environmental Engineering) - Federal University of Paraná, Curitiba, 2020.

SAMPAIO, P. G. V.; GONZÁLEZ, M. O. A. Photovoltaic solar energy: Conceptual framework. **Renewable and Sustainable Energy Reviews**. v.74. p. 590 – 601. 2017.

SANEPAR - Water and Sanitation Company of Paraná State. 2019

SANTOS, F. R, *et al*. Effects of a floating photovoltaic system on the water evaporation rate in the Passaúna reservoir, Brazil. **Energies.** n. 17. v. 15. 2022.

SHARMA P, Muni B, Sen D. 2015. Design parameters of 10kw floating solar power plant. **International Advanced Research Journal in Science, Engineering and Technology** (IARJSET). n. 2. p.85–89.

SIMEPAR - Paraná’s Environmental Technology and Monitoring System. 2022.

SPERLING, M. V. **Introdução à qualidade das águas e ao tratamento de esgotos**. Belo Horizonte: UFMG, 2005. 452 p.

STRANGUETGO, K.M. **Estimativa do potencial brasileiro de produção de energia elétrica através de sistemas fotovoltaicos flutuantes em reservatórios de**

hidroelétricas. 47 p. Thesis (Postgraduate Program in Mechanic Engineering) – State University of Campinas, Campinas, 2016.

SUREHMA – Superintendence of Water Resources and the Environment. **Ordinance number 02**: Iguaçu River Basin. 1992.

TOLMASQUIM, M. T. **Energia Renovável:** Hidráulica, Biomassa, Eólica, Solar, Oceânica. Rio de Janeiro: Empresa de Pesquisa Energética (EPE), 2016.

TRAPANI, K.; SANTAFÉ, M. R. A review of floating photovoltaic installations: 2007-2013. **Program Photovoltaic** n. 15, p. 659–676, 2014.

TUNDISI, J.G. *et al.* **Reservoirs**: Functioning, Multiple Use and Management. NEGOWAT. 2005.

TUNDISI, J.G., MATSUMURA-TUNDISI, T. **Limnologia.** São Paulo: Oficina de Textos. 631p. 2008

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC). **Decisions taken at the Sharm El-Sheikh Climate Change Conference - Advance unedited versions.** 2022.

WALSTON LJ. *et al.* A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States. **Renewable Energy**. n. 92. p. 405–414. 2016.

WIRTH, H. Recent Facts about Photovoltaics in Germany. **Fraunhofer ISE**. 2017.

WORLD BANK GROUP, ESMAP, SERIS. **Where Sun Meets Water**: Floating Solar Market Report. Washington, DC: World Bank. 2019

WENJUN, L. *et al*. Enclosure Experiment for Influence on Algae Growth by Shading Light. **Procedia Environmental Sciences**. Beijing, v. 10, p. 1823 – 1828, 2011.

ZHANG, D. *et al*. Modeling and simulating of reservoir operation using the artificial neural network, support vector regression, deep learning algorithm. **Journal of Hydrology**. n. 565. p. 720-736. 2018.