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WATER HYACINTH (*Pontederia crassipes*) BLOOM IN BENGAWAN SOLO RIVER, INDONESIA: AN AQUATIC PHYSICOCHEMICAL AND BIOLOGY PERSPECTIVE

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Abstract

This research aims to investigate the blooming phenomenon of alien invasive plants in the Bengawan Solo River using an aquatic physicochemical and biology analysis approach. This research method involves collecting water samples from locations impacted by the alien invasive plants. Sampling point 1 at 7°08'05.3"S 111°43'13.9"E; Sampling point 2 at 7°06'59.6"S 111°43'33.2"E; Sampling point 3 at 7°06'39.3"S 111°44'05.4"E; and Sampling point 4 at 7°06'58.5"S 111°44'54.2"E is near to rice field area. Physical parameters measured included turbidity (NTU) and water temperature (°C), while chemical parameters included pH, dissolved oxygen level (DO in ppm), oxygen saturation (%), nitrate (NO_3 in ppm), phosphate (PO_4 in ppm), total dissolved solids (TDS in ppm), total suspended solids (TSS in ppm), biochemical oxygen demand (BOD5 in ppm), and chlorophyll-a (µg/L). In addition, researchers also recorded the density of P. crassipes in terms of individuals per square meter (ind/m^2). The analysis was conducted to determine the Pollution Index (PI) and assess the water quality status using the NSF Water Quality Index (WQI) calculation method. The Pollution Index (PI) score categorizing the water quality as heavily polluted. The NSF-WQI analysis for the Bengawan Solo River at four sample points indicating moderate water quality. It can be concluded that the Bengawan Solo River at the study site is significantly polluted. The high density of P. crassipes, an alien invasive plant, has covered the entire water surface at all sampling locations. This phenomenon has negatively impacted water parameters. The data highlighting the urgency for more effective and sustainable management actions.

***Keywords**: Alien invasive plant; Non-native species; Pollution index; River; Water quality index.*

Introduction

Pontederia crassipes, commonly known as water hyacinth, is native to the Amazon basin in South America [1]. It is a free-floating perennial aquatic plant [2-4] that has become most dangerous invasive plant in many parts of the world, including more than 80 countries over outside of its native habitat [5-7]. Water hyacinth spreads primarily through vegetative

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reproduction [8-9]. Rapid growth is characteristic of *P. crassipes,* allowing it to cover the water surface densely [10]. It reproduces rapidly by forming daughter plants, also known as offsets or runners, which grow from the main plant. These daughter plants break off and float on the water's surface, where they take root and establish new colonies [11]. They are one of the invasive plants that have caused serious concerns in aquatic ecosystems around the world, including in the Bengawan Solo River, Bojonegoro, Indonesia. While the beauty of its blue-violet flowers may be alluring, the impact of *P. crassipes* has disrupted the balance of the ecosystem and hampered human activities in the vicinity.

In a short period of time, it can form a dense layer that blocks the access of sunlight into the water [12-13]. As a result, photosynthesis is inhibited, reducing oxygen levels in the water and affecting other aquatic life [14]. Human activities, such as fisheries, water transportation, and irrigation systems, are also hampered by the presence of this plant ([15-16]. In the context of the Bengawan Solo River, the presence of *P. crassipes* is not only a threat to the sustainability of the aquatic ecosystem, but also poses a serious challenge to local communities who depend on the river for their livelihoods and daily needs.

Physicochemical and biological analysis of waters are two important approaches used to understand the quality of aquatic ecosystems and monitor environmental changes to the organisms living in them ([17-18]. Physicochemical analysis of waters includes the measurement of various physical and chemical parameters, such as temperature, pH, dissolved oxygen concentration, nutrient content and the presence of certain chemical compounds [19-21]. Within this framework, this study aims to analyze the water pollution index, the status of water quality based on the physicochemical and biological perspectives of waters and its relation to the invasive plant water hyacinth *P. crassipes* bloom phenomenon in the Bengawan Solo River, Bojonegoro, Indonesia. With an in-depth understanding of the physicochemical characteristics and biological condition causes bloom of *P. crassipes,* it is hoped that this study will make a valuable contribution to the development of effective management strategies to address this plant invasion problem. Thus, appropriate conservation measures can be formulated to restore the disturbed aquatic ecosystem and support human life in the vicinity.

Experimental

Study area

This study was conducted in October 2023 in the Bengawan Solo River basin, Bojonegoro, Indonesia, which is affected by the presence of alien invasive plants. The sampling points were selected based on the variation in land use around the river. Four sampling points were carefully selected:

- Sampling point 1 (7°08'05.3 "S 111°43'13.9 "E): This location is close to tourism objects, rice fields, and residential areas. The presence of this invasive plant here can give an idea of its impact on tourism activities, agriculture, and people's daily lives.
- Sampling Location 2 (7°06'59.6 "S 111°43'33.2 "E): This location is adjacent to a pottery craft educational tourism object, catfish farming ponds, rice fields, and residential areas. The presence of invasive plants here allows researchers to assess their impact on the educational tourism, fish farming and agriculture sectors.
- Sampling point 3 (7°06'39.3 "S 111°44'05.4 "E): This site is located near the rice field area and the Malo bridge on the highway. Research at this site can provide insight into the impacts of invasive plants on agriculture and transportation infrastructure.
- Sampling point 4 (7°06'58.5 "S 111°44'54.2 "E): This site is adjacent to a paddy field. Research here could focus on the impact of invasive plants on agriculture and the sustainability of water resources.

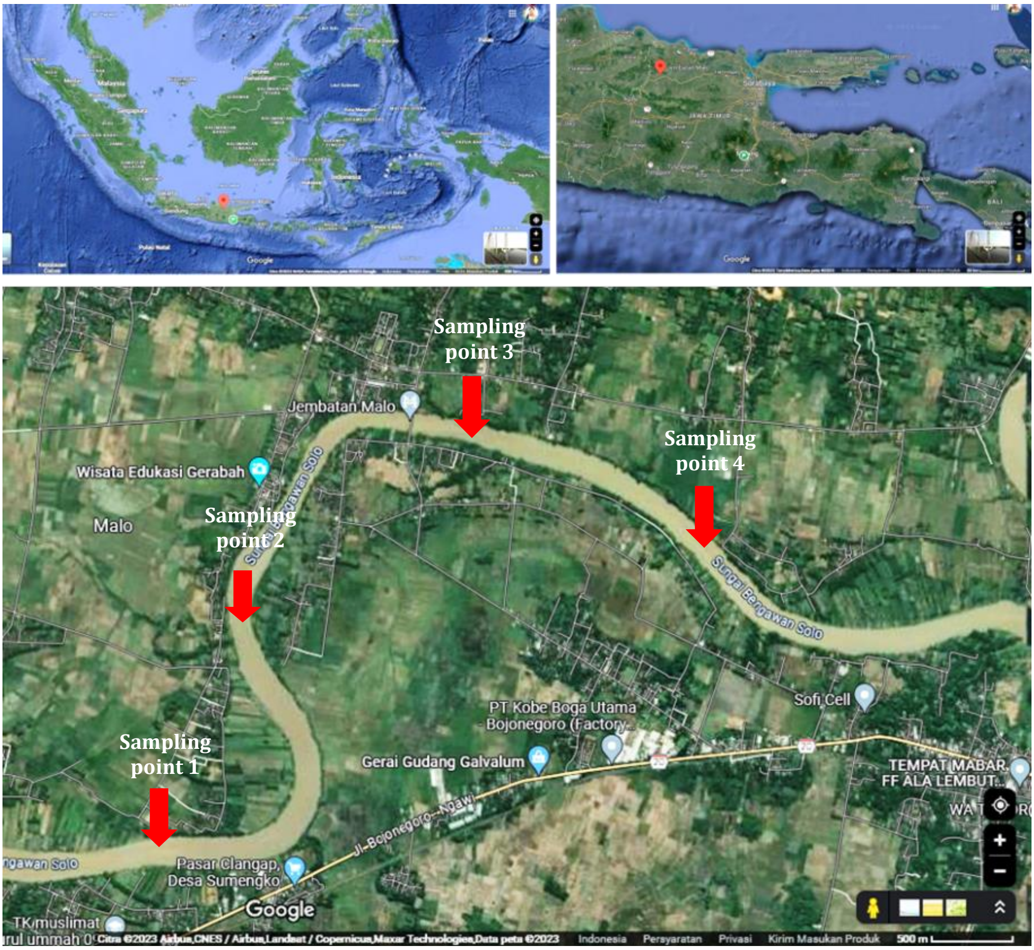

Fig. 1. Sampling location at Bengawan Solo River, Bojonegoro, Indonesia

The selection of these diverse sampling locations is designed to reveal the various factors that lead to the development of these invasive plants. By understanding the surrounding environment, this research will provide deep insights into the interactions between invasive plants, humans and natural ecosystems, which is crucial for planning effective and sustainable management strategies.

Sampling Collection

Samples were collected once a week during October 2023. Sampling at each sampling point was carried out at several site (both river banks area and in the middle of river) (figure 2) to gain an in-depth understanding of the aquatic conditions in the Bengawan Solo River affected by the presence of *P. crassipes*. The researchers selected various physical, chemical and biological parameters to identify significant changes in the aquatic ecosystem. Physical parameters measured included turbidity (NTU) and water temperature (°C), while chemical parameters included pH, dissolved oxygen level (DO in ppm), oxygen saturation (%), nitrate (NO_3 in ppm), phosphate (PO_4 in ppm), total dissolved solids (TDS in ppm), total suspended solids (TSS in ppm), biochemical oxygen demand (BOD5 in ppm), and chlorophyll-a (μg/L). In addition, researchers also recorded the density of *P. crassipes* in terms of individuals per square meter (ind/m^2).

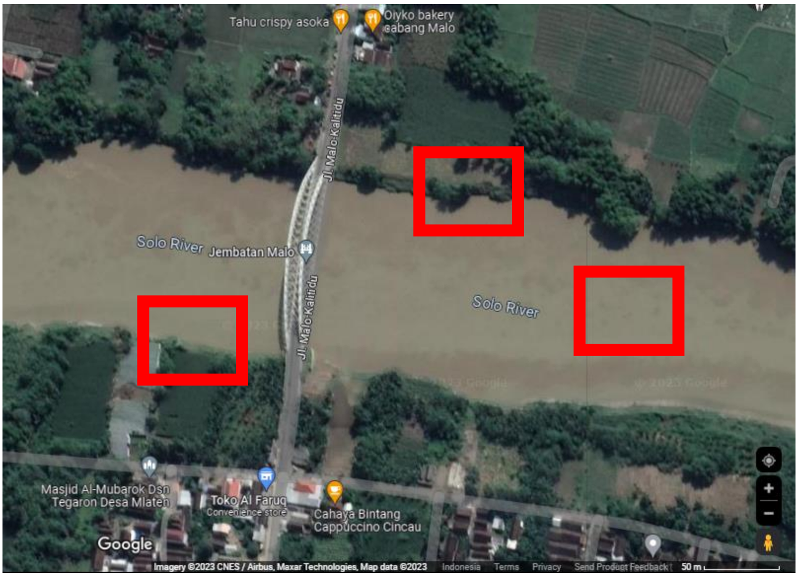

Fig 2. An illustration of several site (both river banks area and in the middle of river) for sampling collection at each sampling point.

Physicochemical Parameter

Turbidity

The turbidity of water, measuring the extent to which particulate matter interferes with the transmission of light in water. Turbidity measurements are made using a turbidity meter that uses Nephelometric Turbidity Units (NTU) [22]. This tool measures how much light is scattered or scattered by particles in water.

Temperature

The temperature of the water, reflecting the hotness or coldness of the water in the environment. Water temperature is measured using a water thermometer [23] immersed directly into the water to obtain the actual temperature.

pH

A measure of the acidity or basicity of water, indicating the chemical balance in the water. The pH measurement is done using a digital pH meter [24]. The use of a pH meter provides more accurate and precise results.

DO (Dissolved Oxygen)

Dissolved oxygen levels in water, essential for the sustainability of aquatic life. Measurement of dissolved oxygen levels in water (DO) using a digital oxygen meter [25].

DO Saturation

Percentage of dissolved oxygen saturation, indicating how much oxygen can be dissolved in water at a given temperature and pressure. Measurement of DO saturation using online convertion calculator from DO measurement result in ppm to % saturation at https://www.waterontheweb.org/under/waterquality/dosatcalc.html

NO_3 (Nitrate) and PO_4 (Phosphate)

Nitrate content in water, can affect plant growth and aquatic life. Phosphate content in water, essential for plant growth and aquatic ecosystems. Measurement of nitrate and phosphate levels using water test kits [26] that provide specific chemical reagents to detect the concentration of these substances.

TDS (Total Dissolved Solids) and TSS (Total Suspended Solids, ppm)

Total dissolved solids in water, including minerals, salts and other chemical compounds. Total suspended solids in water, measures the number of particles suspended in water. TDS and TSS levels are measured using a conductivity device or by the gravimetric method [27], where water samples are evaporated to dryness and then weighed.

BOD_5 (Biochemical Oxygen Demand, ppm)

Biochemical oxygen demand, measures the amount of oxygen required by microorganisms to decompose organic compounds in water. BOD_5 measurement involves incubating a water sample for five days under specific conditions [28], during which microorganisms decompose organic matter. After this period, dissolved oxygen measurements are used to calculate BOD5.

Chlorophyll-a (µg/L)

Chlorophyll-a content in water, giving an indication of the presence of phytoplankton and the biological productivity of waters. Chlorophyll-a sampling was conducted horizontally at each station, followed by filtration of 1 L water samples using a 42 µm milipore filter/Whatman GF/C filter paper assisted by a vacuum pump. The filter paper containing chlorophyll-a was folded four times to form small folds and then placed in aluminum foil. The folded chlorophyll-a samples were stored in a refrigerator at 4°C until the subsequent procedures. To extract chlorophyll-a from the filter paper, 5 ml of 90% acetone was added for thorough grinding of the filter paper until it was completely dissolved. An additional 3.5 ml of the same 90% acetone was added, and the grinding process was repeated until all filter parts were completely dissolved. Subsequently, 1.5 ml of 90% acetone was added to rinse the grinding container, ensuring no sample residue remained. The extracted samples were transferred to reaction tubes and stored in the refrigerator at 4°C for 1 hour. The extracted samples were then placed in a centrifuge machine and spun at 3000 rpm for 15 minutes. Afterward, the samples were analyzed using spectrophotometry at wavelengths of 665 nm, 645 nm, and 630 nm. Chlorophyll-a concentration was calculated using the published equation provided by *Rodríguez-López et al*. [29].

Biological parameter

Biological parameters in environmental science and ecology refer to the aspects related to living organisms within a specific ecosystem. These parameters are essential for understanding the biodiversity, ecological balance, and overall health of an ecosystem.

The density of P. crassipes (ind/m^2)

The population density of *P. crassipes*, measuring the number of individuals of this invasive plant per square meter of water area. The density of *P. crassipes* was determined using a modified belt transect method based on the techniques outlined in the study conducted by *Isroni et al.*, [30]. Three replications were performed for each sampling station. The selection of the belt transect method was influenced by the specific density of *P. crassipes* in the study area, taking into account its overall appearance. This approach aimed to ensure that the profile diagram generated would accurately represent the vegetation in that particular location. The transect belts were standardized to a size of 100x100 m^2 for systematic data collection. The results were quantified and expressed as individuals per square meter (ind/m^2).

Analysis Data

The analysis was conducted to determine the Pollution Index (PI) and assess the water quality status using the NSF Water Quality Index (WQI) calculation method.

Pollution Index (PI) Calculation

The Pollution Index (PI) was calculated based on the collected data for various parameters such as turbidity, temperature, pH, dissolved oxygen (DO), nitrate (NO_3), phosphate (PO_4), total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD_5), chlorophyll-a, and *P. crassipes* density. Each parameter's value was compared to the standard permissible limits, and a score was assigned according to the degree of deviation from the standard. The PI for each parameter was calculated, and the total PI for the study area was determined by summing the individual PI values. Water pollution categorized base on published criteria [31-32].

Table 1. Water pollution categorized [31-32]

Pollution Index (PI) Score	Criteria
0 ≤ PI ≤ 1.0	Fulfill quality standard (good)
1.0 < PI ≤ 5.0	Light Pollution
5.0 < PI ≤ 10.0	Moderate Pollution
PI > 10.0	Heavy Pollution

Based on the Pollution Index calculation, it is known that the value of the water parameter value (Ci) meets the established quality standards (LiX). Therefore, the obtained Ci/LiX value remains unchanged. If the pollutant parameter (Ci) does not meet the established quality standards, the new Ci/LiX value is calculated using the following formula:

$$\frac{Ci}{LiX}\,new = 1 + 5.log\,(Ci) \tag{1}$$

In this formula, log (*Ci*) refers to the base 10 logarithm of the pollutant parameter value (Ci). The newly calculated Ci/LiX value provides additional insights into the extent to which the pollutant parameter (Ci) exceeds the established quality standards (LiX).

Water Quality Index (WQI)

The Water Quality Index (WQI) at total 4 sample points in sampling location of Bengawan Solo River, Bojonegoro, Indonesia was calculated using National Sanitation Foundation Water Quality Index (NSF-WQI) online calculator which can be accessed on https://www.knowyourh2o.com/outdoor-3/water-quality-index-calculator-for-surface-water .

Water Quality Index (WQI) categorized base on published criteria by Tyagi et al., (2013) i.e. NSFWQI categorizes water quality into five ranks based on five score ranges: excellent (91-100), good (71-90), moderate (51-70), poor (26-50), and very poor (0-25). The Pollution Index and NSF WQI served as valuable tools to evaluate the overall environmental condition and determine the suitability of the water for different purposes, guiding future conservation and management strategies in the affected area.

Results and discussion

Pollution Index (PI)

Pollution Index (PI) is a numerical value used to assess the level of pollution in a specific area or environment. It is calculated based on the concentration of various pollutants or parameters in the environment, such as chemicals, particulate matter, or biological factors. The PI provides a quantitative measure of the degree of pollution and is often used in environmental studies to evaluate the environmental quality and health of ecosystems. A higher PI value indicates a higher level of pollution, while a lower value suggests better environmental conditions.

The provided data presents the median values of measured water quality parameters in a river, along with the corresponding quality standards set by the Indonesian government. The Pollution Index (PI) score, calculated from these values, is found to be 13.10, categorizing the water quality as heavily polluted according to the established criteria. These data provide an overview of the physical and chemical conditions of the waters, which can affect the biological processes in them. Data from biological analysis provides deep insights into the dynamics of aquatic ecosystems, including the response of organisms to changes in aquatic physicochemistry and their impact on food chains and other ecological webs. Research involving physicochemical and biological analysis is expected to provide a deeper understanding of the impact of *P. crassipes* on the aquatic ecosystem and the surrounding communities.

Table 2. Bengawan Solo River Pollution Index (PI) data at 4 sample points

Parameter	Pollution Index (PI)					
	Ci Min	Ci Max	Ci Med	LiX	Ci Med/LiX	Ci Med/LiX (new)
Turbidity (NTU)	6.40	14.80	10.60	5.0	2.12	2.63
Temperature (°C)	24.00	24.00	24.00	28.0	0.86	0.86
pH	6.00	7.00	6.50	7.0	0.93	0.93
DO (ppm)	51.08	67.71	59.40	100.0	0.59	0.59
DO saturation (%)	4.30	5.70	5.00	4.0	1.25	1.48
NO_3 (ppm)	0.78	1.53	1.16	1.0	1.16	1.31
PO_4 (ppm)	0.16	0.22	0.19	0.1	1.86	2.35
TDS (ppm)	177.00	294.00	235.50	1000.0	0.24	0.24
TSS (ppm)	75.00	109.00	92.00	50.0	1.84	2.32
BOD_5 (ppm)	6.32	17.70	12.01	6.0	2.00	2.51
Chlorophyle a µg/L	18.40	20.23	19.32	30.0	0.64	0.64
The density of *P. crassipes* (ind/m²)	22.00	36.00	29.00	0.0	2900.0	18.31
					(CiA/LiX) Average =	2.85
					(CiA/LiX) Maximum =	18.31
					PI Value =	13.10

Note: Ci Min= minimum value of measured water quality parameter; Ci Max= maximum value of measured water quality parameter; Ci Med= Median value of measured water quality parameter; LiX= Quality standards for river water quality parameters based on the Indonesian government regulation number 22 of 2021 concerning the implementation of environmental protection and management.

The analysis of water quality parameters in the river revealed critical disparities between measured values and the established standards set by the Indonesian government. The turbidity level, measured at 10.60 NTU, exceeded the permissible standard of 5.0 NTU. This elevated turbidity indicates the presence of suspended particles in the water, potentially obstructing light penetration and disrupting aquatic habitats [33-36]. Elevated turbidity in water indicates the presence of suspended particles, such as sediment, organic matter, and pollutants, which can cloud the water and reduce its clarity. This phenomenon has significant implications for aquatic ecosystems. When water becomes turbid, it obstructs light penetration, a crucial factor for aquatic plants and algae that rely on photosynthesis. Insufficient light hampers their ability to produce food, disrupting the entire food chain. Aquatic plants provide oxygen, food, and shelter for various organisms, and when their growth is hindered, it adversely affects the entire ecosystem.

Moreover, elevated turbidity poses challenges for fish and other aquatic animals that rely on sight to hunt for prey, avoid predators, and find mates [37]. Reduced visibility makes it difficult for these organisms to perform essential activities, leading to decreased feeding efficiency and reproductive success. Additionally, suspended particles can settle on the riverbed, smothering aquatic habitats like gravel beds and rocky substrates where fish spawn. This can significantly impact fish populations, leading to declines in their numbers and biodiversity. The pH level, recorded at 6.50, deviated slightly below the acceptable limit of 7.0, which, although not a severe deviation, might impact pH-sensitive aquatic species. Dissolved Oxygen (DO) saturation, at 59.40%, fell significantly below the ideal level of 100.0%, suggesting inadequate oxygen supply for aquatic organisms, which could lead to reduced biodiversity and fish kills.

Furthermore, nitrate (NO_3) and phosphate (PO_4) concentrations were measured at 1.16 ppm and 0.19 ppm, respectively, surpassing the standards of 1.0 ppm and 0.1 ppm. Elevated nutrient levels can lead to eutrophication, triggering excessive algae growth and potentially causing oxygen depletion, harming aquatic life [38]. Biochemical Oxygen Demand (BOD_5) was measured at 12.01 ppm, double the standard of 6.0 ppm, indicating an increased demand for oxygen due to organic pollutants. This signifies heightened organic pollution in the water, potentially leading to oxygen-starved conditions detrimental to aquatic organisms.

Chlorophyll-a, an indicator of algae abundance [39-40]. The result measured at 19.32 µg/L, slightly lower than the standard of 30.0 µg/L. The presence of invasive *P. crassipes* was noted, with a density of 29.00 ind/m^2. These findings underscore the urgent need for comprehensive management strategies. Failure to address these discrepancies could result in further deterioration of the aquatic ecosystem, posing risks to both aquatic life and the communities relying on the river for various purposes. Swift intervention is essential to mitigate these adverse effects, restore water quality, and preserve the delicate balance of the river ecosystem.

Biological pollution of water bodies is a serious problem that needs to be taken seriously. Bioremediation is one of the things that needs to be done so that the condition of river waters can be maintained [41]. Apart from water hyacinth plants, this problem also involves invasive fish species such as tilapia [42-43], arapaima [44] and alligator [45], which can threaten the sustainability of freshwater ecosystems in Indonesia. Future research needs to add biological parameters such as microalgae and some invasive fish species in the Pollution Index (IP) to make the data more complex. Recording and monitoring the transportation of live organisms is essential to prevent the spread of these invasive species. One effective way to address this issue is to implement strict regulations regarding the trade and transportation of live organisms, including potentially invasive alien fishes. Data collection on the diversity of non-fish freshwater species such as gastropods also needs to be done as has been done in seawater [46-47]. This is important because the pollution index data in terms of biological parameters can be presented in a more complex and broader scope. So that the data can be a reference in determining environmental sustainability policies, especially the waters of the Bengawan Solo River.

Table 3. NSF-WQI data for the Bengawan Solo River at 4 sample points with incomplete parameter variations

Parameter	Input Value	Weight	Weight Normalized	Q-Value	Sub Total
Turbidity (NTU)	10.6	0.08	0.1	79	7.9
Temperature (^oC)	24	0.1	0.12	17.68	2.1216
pH	6.5	0.11	0.13	71.65	9.3145
DO Saturation (%)	60.52	0.17	0.2	57.95	11.59
NO_3 (ppm)	1.16	0.1	0.12	92.03	11.0436
PO_4 (ppm)	0.19	0.1	0.12	94.48	11.3376
TDS (ppm)	235.5	0.07	0.08	1	0.08
BOD_5 (ppm)	7	0.11	0.13	45.47	5.9111
				NSF-WQI =	**59.2984**

The NSF-WQI analysis for the Bengawan Solo River at four sample points revealed a composite score of 59.2984, indicating moderate water quality. The parameters assessed include turbidity, temperature, pH, dissolved oxygen (DO) saturation, nitrate (NO_3), phosphate (PO_4), total dissolved solids (TDS), and biochemical oxygen demand (BOD5). Turbidity, representing the clarity of the water, scored 7.9, indicating a relatively low impact. Temperature, with a score of 2.1216, falls within an acceptable range, suggesting minimal influence on the overall water quality. pH, at 9.3145, indicates slightly acidic conditions, potentially affecting aquatic life. DO saturation, a crucial indicator of oxygen availability, received a score of 11.59, suggesting moderately favorable conditions for aquatic organisms. Nitrate and phosphate levels were relatively high (11.0436 and 11.3376, respectively), indicating nutrient pollution, which could lead to eutrophication. TDS scored 0.08, indicating low mineral content. BOD_5, reflecting organic pollution, received a score of 5.9111, suggesting a moderate impact on water quality.

Moderate water quality implies that while the river is not severely polluted, there are concerns that need attention. High nitrate and phosphate levels raise the risk of algal blooms, depleting oxygen levels and threatening aquatic life [48-49]. The slightly acidic pH may adversely affect certain species, disrupting the natural balance of the ecosystem. Additionally, the moderate BOD_5 score signifies the presence of organic pollutants, hinting at potential contamination from agricultural or domestic sources. If these issues are left unaddressed, the consequences could escalate. *P. crassipes* blooms phenomenon, driven by high nutrient levels, may lead to oxygen depletion, causing fish kills and impacting the entire aquatic food chain. Lower pH could harm sensitive aquatic organisms [49], affecting biodiversity. Moreover, organic pollutants might accumulate, rendering the water unsuitable for consumption and recreation.

Fig 3. View of the sampling location during the research

The phenomenon of almost the entire water surface at each sampling location being covered by *P. crassipes* indicates a significant problem with the spread and growth of this invasive plant in the Bengawan Solo River, Bojonegoro, Indonesia. With *P. crassipes* population densities ranging from 22.00 to 36.00 ind/m^2, these areas face a high risk of various ecological and environmental problems. In addition, the thickness of *P. crassipes* piles also restricts water movement, creating stagnant zones that are detrimental to aquatic organisms and native plants. The Bloom phenomenon of the invasive alien plant *P. crassipes* in the Bengawan Solo River, Bojonegoro, Indonesia (figure 2), has complex root causes. One of the main causes is the release of nutrients, especially nitrate (NO_3) and phosphate (PO_4), into the river. NSF-WQI data showed high concentrations of nitrate and phosphate, reaching 11.0436 ppm and 11.3376 ppm respectively, exceeding the set standards. These high nutrient concentrations provide a fertile substrate for the growth of *P. crassipes*, triggering an abundant bloom phenomenon. In addition, the relatively low TDS (177.00-294.00 ppm) indicates the lack of dissolved minerals in the water, which can actually be a favorable growth factor for aquatic plants such as *P. crassipes*.

In relation to Pollution Index (PI) data, high *P. crassipes* density values directly affect PI values. The dense growth of this plant can lead to increased organic matter in the water (including BOD5 levels), increased levels of nutrients such as nitrates and phosphates, and reduced dissolved oxygen levels. This in turn will worsen PI parameters related to organic (BOD_5), nutrient (NO_3 and PO_4) and dissolved oxygen. This complicates water management efforts and indicates significant levels of pollution at these sites.

In the context of the Water Quality Index (WQI), the presence of *P. crassipes* at high densities can inhibit the penetration of sunlight into the water, resulting in decreased photosynthetic activity by algae and other aquatic plants. This could potentially affect parameters such as turbidity and chlorophyll-a, which in turn will affect the overall WQI value. This invasive plant-covered environment can also hinder water circulation and oxygenation, worsening the values of DO (Dissolved Oxygen) and DO saturation parameters, which are critical for the health of aquatic ecosystems.

When nitrate and phosphate levels are also high, mainly due to nutrient accumulation from human activities and agricultural effluents, *P. crassipes* utilizes them as a source of nutrients, triggering rapid and mass growth. Therefore, the presence of this invasive plant creates an environment that favors algal blooms and other aquatic vegetation, impairing water quality and causing a decrease in WQI status.

Conclusions

Based on the data analysis and discussion, it can be concluded that the Bengawan Solo River at the study site is significantly polluted. The high density of Pontederia crassipes, a foreign invasive plant, has covered the entire water surface at all sampling locations. This phenomenon has negatively impacted water parameters, including increased nitrate and phosphate levels, decreased dissolved oxygen, and disrupted other water quality parameters such as turbidity and pH. The Pollution Index (PI) and Water Quality Index (WQI) also show values that reflect moderate pollution, highlighting the urgency for more effective and sustainable management actions. Pontederia crassipes prevention and control measures, along with nutrient management and ecosystem restoration efforts, are key in restoring the water quality of the Bengawan Solo River and maintaining the sustainability of its aquatic environment.

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