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Economic Viability of Lake Interventions: A Benefit-Cost Analysis on Mitigating Kanduli (Arius manillensis) Fishkills in Sampaloc Lake, Philippines

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Jericho A. Trio[1], ORCID No. 0009-0002-8773-2054
Patricia Mae M. Clarino[2], ORCID No. 0009-0004-2939-3319
Chris C. Guevarra[3], ORCID No. 0009-0001-7457-6630

[1]Gtraduate Student, School of Environmental Science & Management, UP-Los Baños, Laguna, Philippines
[2]Graduate Student, Institute of Biological Sciences, University of the Philippines Los Baños, Laguna, Philippines
[3]Graduate Student, Institute of Weed Science, Entomology and Plant Pathology, UP-Los Baños, Laguna, Philippines

Abstract

The Manila Sea Catfish (Arius manillensis), or Kanduli, an endemic benthopelagic species in Luzon, faces severe threats in Sampaloc Lake, Philippines due to lentic overturn events. In Sampaloc Lake, San Pablo City, the Kanduli's survival is increasingly compromised by lake turnover events driven by the breakdown of thermal stratification. This study analyzes the economic viability of interventions designed to mitigate the anoxic conditions resulting from the mixing of the oxygen-depleted hypolimnion with the surface epilimnion. A Benefit-Cost Analysis (BCA) was conducted on three distinct intervention scenarios: (i) diffused aeration (reactive), (ii) destratification mixers (preventive), and (iii) lake restoration (nature-based). The economic evaluation reveals that Intervention 2 (destratification mixers) is the dominant strategy, yielding a Benefit-Cost Ratio (BCR) of 5.45 and an Internal Rate of Return (IRR) of 58.4%. This preventive measure addresses the root cause of anoxia, offering Pareto-efficient outcomes that benefit both fishery yields and the tourism sector by mitigating hydrogen sulfide odors. In contrast, diffused aeration proved only marginally viable (BCR 1.18; IRR 7.7%), functioning primarily as a short-term insurance policy against fishkill rather than a sustainable economic driver. Lake restoration demonstrated strong efficiency with a BCR of 2.69. The study recommends a hybrid economic approach framed through Pigovian principles. It proposes that the surplus value generated by the economically strategic destratification mixers be utilized to fund the public goods associated with lake restoration, such as native littoral flora conservation. This creates a closed-loop system where economic utility supports ecological preservation.

Keywords: economic viability, lake interventions, ariid catfish, Kanduli, benefit-cost analysis, fishkill, Sampaloc Lake

INTRODUCTION

Tropical lakes as in the case of Sampaloc Lake in San Pablo City, Laguna, exhibit thermal stratification, where a warm, buoyant upper layer (epilimnion) sits atop a cooler, denser bottom layer (hypolimnion) (Woolway et al., 2022). Temperature is the primary driver of lake structure as water density change is associated to sporadic spikes and troughs altering the lake epilimnion; this eventually breaks the thermocline resulting in rapid mixing of water layers, a process known as lake overturn (Rohman et al., 2023). Two critical water quality parameters are affected in such temperature anomalies, namely, biological oxygen demand (BOD) and dissolved oxygen (DO). It is important to acknowledge that BOD signifies the quantity of required oxygen for bacteria to decompose organic matter. Within lentic environments, BOD has a tendency to sink in the isolated hypolimnion (Pekarek, 2021). As for dissolved oxygen, the parameter serves as a fuel for aquatic life to thrive replenished through photosynthesis and surface atmospheric mixing (Stefan and Fang, 1994).

Within the tropical and subtropical regions, climate change (as evident in increased heat index and precipitation), has altered thermal behavior of lentic temperature regimes, amplifying the severity of overturn events and the odds of fish kill occurrence. Lake systems are transformed into ticking time bombs causing anoxic environments inhospitable to life (Nieves et al., 2020). During stratification, the high BOD in the bottom layer actively consumes limited oxygen. Since the thermocline prevents atmospheric oxygen from reaching benthic layers, the bottom water becomes anoxic (Lotfata et al., 2023). The higher the BOD the faster the lentic "dead zone" forms. When the lake overturns, the massive volume of anoxic bottom water is upwelled to the surface. This sudden behavior dilutes the surface DO to lethal levels and exposes fish to toxic byproducts of anaerobic decomposition (Ndebele-Murisa et al., 2011). The following diagram depicts the interplay between temperature, biological oxygen demand, dissolved oxygen, and ichthyofaunal kills in lentic systems:

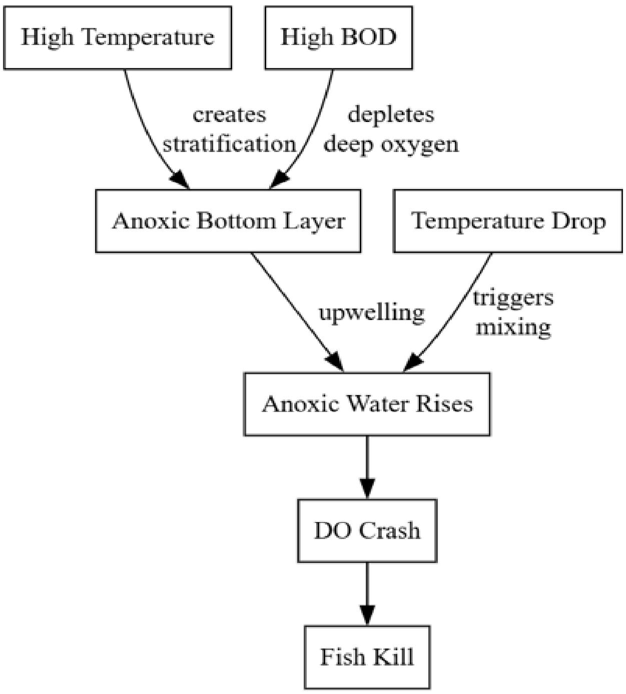

Figure 1
Interplay of temperature, BOD, and DO to fish kill occurrence (visualized using GraphViz)

The following research is anchored in providing a benefit-cost analysis on interventions to address Kanduli fishkill in the lentic environments of Sampaloc Lake, specifically this study aims to: (i) identify the net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (BCR) for each intervention, (ii) weigh negative and positive outcomes of each intervention scenario, and (iii) provide recommendations based on the results of the benefit-cost analysis. In implementing the benefit-cost model, although the primary focus is Kanduli, the economic analysis incorporates the avoided loss of the commercial Tilapia stock. This inclusion is based on the principle of joint production in ecosystem services where the proposed water quality interventions (aeration/mixing) are non-excludable public goods that benefit both endemic and aquaculture fisheries simultaneously. Excluding Tilapia monetary values would violate the total economic value (TEV) framework by ignoring a significant portion of the direct benefits generated by the investment (Randall, 1987; Baumgärtner et al., 2001).

The study is limited on three intervention scenarios, namely, (i) diffused aeration systems, (ii) destratification mixers, and (iii) lake restoration. Intervention 1 (diffused aeration) is structured as reactive (mitigates the consequences of an event rather than stopping the event itself); Intervention 2 (destratification mixers) as preventive (eliminates the conditions required for the event to occur); and Intervention 3 (as nature-based—since it considers natural processes and ecosystem services to address the issue). The intervention scenarios and its key assumptions will be thoroughly discussed in the methodological section of this article.

LITERATURE REVIEW

Kanduli biology and the duong. Historic fish kills in Sampaloc Lake known as “duong” typically occur during the colder months of December to February when the Northeast Monsoon (Amihan) brings cool winds, resulting to a drop of surface temperature in lentic environments (Vicoy, 2021; Briones et al., 2016). Significant fish kill events were recorded throughout the 1990s, leading to warnings of "imminent biological death" for the lake. A notable event occurred in January 2004, affecting six of the seven lakes in San Pablo. More recently, in January 2021, a massive fish kill destroyed approximately 12 to 13 tons of tilapia (Oreochromis niloticus), ayungin (Leiopotherapon plumbeus), and Kanduli (Arius manillensis) (Paller et al., 2017; Vicoy, 2021; LLDA, 2005).

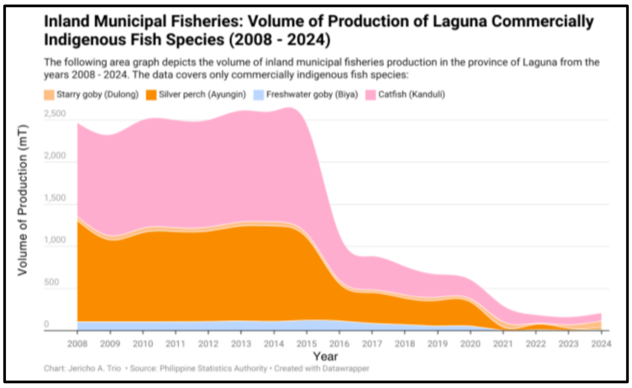

Figure 2
Volume of production of Laguna inland municipal fisheries in terms of commercially indigenous fish species (2008 - 2024); Source - Philippine Statistics Authority

The Kanduli, also known as the Manila Sea Catfish, is a species endemic to the island of Luzon, historically thriving in the Laguna de Bay basin and its interconnected waterways. The said arid catfish exists as a benthopelagic species that relies entirely on dissolved oxygen in the water column (Santos & Quilang, 2012; Jumawan et al., 2020). The benthic adaptations of Kanduli suffer within the margins of vulnerability in episodes of lake turnover as the lentic bottom region experiences anoxia. The Kanduli's physiology is ill-equipped for the boom-and-bust oxygen cycles of eutrophic lakes. In Sampaloc Lake, the duong phenomenon mixes the anoxic bottom water with the surface water. For a bottom-dweller like the Kanduli, there is often no escape. During the onset of stratification, the bottom water where they reside becomes hypoxic (<2 mg/L DO) (Santos and Quilang, 2012). As expressed in Figure 2, data obtained from the Philippine Statistics Authority, A. manillensis contributes a significant amount on indigenous volume production having an average of 724.94 mT from the years 2008 - 2024. A. manillensis falls under open water capture fisheries together with L. plumbeus (Comiso et al., 2023, p. 118). It is critical to consider how without any existing conservation efforts on A. manillensis, population trends between 2009 - 2018 fell approximately 72% (from 1198.04 metric tons to 338.61 metric tons) (Torres et al., 2021), such depressions are evident in the year 2016 (543.01 mT) where Kanduli production dropped half relative to its 2013 crest (1321.15 mT). The arid catfish species which is commercially important for Laguna fisheries has been flagged as an overexploited fisheries resource (Santos et al., 2017).

Photo 1
Kanduli specimen at a Sampaloc Lake talipapa; photographed by the researchers of the study

Intervention strategies. As emphasized in the previous section, lake overturn occurs as a natural process where the stratified hypolimnion becomes isolated from the atmosphere during dry season extremities resulting in anoxic environments as aerobic bacteria decompose organic matter (Jane et al., 2021). A sudden drop in temperature or high-wind event can trigger an overturn mixing anoxic bottom water with the oxygen-rich surface layer. The aftershock is that of a lentic environment characterized by near-zero dissolved oxygen levels throughout the entire water column, leading to rapid fish kills (Koutrakis et al., 2016; Caliro et al., 2008). Three intervention strategies were considered in the development of the benefit-cost analysis, namely, (i) diffused aeration systems, (ii) destratification mixers, and (iii) lake restoration.

Diffused aeration operates on the principle of airlift pumping and gas-liquid mass transfer. As fine or coarse bubbles are released at the lake bottom, they rise due to buoyancy, entraining the cold, dense, and typically oxygen-depleted water of the hypolimnion (Hasan et al., 2013). This upward movement creates a vertical circulation pattern that transports hypoxic bottom water to the surface, where it can interact with the atmosphere and undergo natural re-oxygenation. The efficiency of this process is significantly enhanced by the use of microporous diffusers, which generate smaller bubbles with a high surface-area-to-volume ratio, thereby increasing the oxygen transfer rate and residence time within the water column (DeMoyer et al., 2003). Diffused aeration addresses lake overturn by maintaining a state of continuous artificial circulation. By preventing the formation of a thermocline, the system ensures that the water body remains isothermal and isochemical (Gibbs et al., 2019). Continuous mixing prevents anoxic water buildup, eliminating the low-oxygen reservoir that could cause lethal shocks during weather-driven mixing.

Destratified mixers serve as a proactive engineering intervention designed to mitigate the risks associated with sudden lake turnover by maintaining continuous vertical circulation within the water column. These technologies are generally classified into two functional categories: mechanical surface mixers, which employ impellers to drive oxygen-rich surface waters downward, and bubble-plume aerators, which utilize compressed air released from the benthic zone to entrain and lift bottom waters toward the surface (Slavin et al., 2022). By facilitating a constant exchange between the atmosphere and the deep-water strata, these systems ensure the efficient transport of dissolved oxygen to the deepest regions of the basin, thereby preventing the development of an anoxic hypolimnion (Singleton & Little, 2006). From an ecological perspective, destratification significantly expands the viable habitat for fish populations. In naturally stratified systems, fish are frequently restricted to the narrow, oxygenated epilimnion, but artificial mixing renders the entire lake volume habitable, thereby reducing interspecific competition and physiological stress (Balangoda, 2017). Additionally, the maintenance of oxic conditions at the sediment-water interface serves to inhibit the internal loading of phosphorus. This suppression of nutrient cycling helps mitigate the formation of harmful algal blooms, which would otherwise contribute to excessive organic matter accumulation and subsequent oxygen depletion (Visser et al., 2016).

The strategic planting of native riparian flora, vegetation situated at the interface between land and a water body, serves as a critical nature-based solution for mitigating lake overturn events and subsequent fish kills. These botanical buffers regulate the physical, chemical, and biological stability of lacustrine environments by controlling thermal energy transfer and limiting nutrient loading (Dosskey et al., 2010). Native riparian flora, particularly woody species with dense overhanging canopies, mitigate this by providing thermal buffering (Xu et al., 2025). The shade provided by these plants reduces the amount of solar radiation reaching the lake's margin, which lowers the maximum surface water temperature and slows the rate of heat gain during the day. By stabilizing the thermal gradient, riparian vegetation reduces the severity of stratification, making the eventual turnover less volatile and preventing the rapid upward movement of toxic gases like hydrogen sulfide that often accompany sudden mixing. Unlike non-native or invasive species, native riparian plants have evolved to withstand local flood and drought cycles, providing consistent bank stabilization. This prevents excessive siltation, which can decrease lake depth and increase the frequency of rapid temperature fluctuations (Feng et al., 2025). By maintaining a balanced "light environment" and donating organic matter that supports a healthy food web, native flora ensures that aquatic ecosystem remains resilient against physical stresses of seasonal mixing (Zalewski, 2002).

METHODS

Study site. Sampaloc Lake (Table 3) is the largest of the Seven Lakes of San Pablo City, Laguna. The lentic environment exists as a volcanic maar formed by phreatic eruptions approximately 500-700 years ago. Bathymetric studies characterize the lake as having a circular surface area of 104 hectares with a maximum depth of 27 meters and a mean depth of 20 meters. The basin exhibits a shallow depression typical of its volcanic origin, yet recent hydrodynamic modeling indicates a stable stratification due to a slow water retention time of four years (Farofaldane et al., 2024).

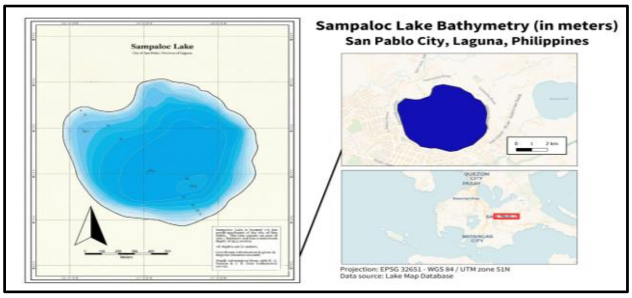

Figure 3
Sampaloc Lake Bathymetry (in meters)

Benefit-cost analysis scope and limitations. The primary scope of this research involves the comparative economic evaluation of three technical and ecological interventions: (i) diffused aeration systems, (ii) solar-powered destratification mixers, and (iii) wetland restoration through littoral zone management. Geographically, the analysis is localized to Sampaloc Lake, a 104-hectare volcanic crater lake in San Pablo City, Philippines. The model quantifies direct benefits, specifically the market value of ichthyofauna—primarily Tilapia and the endemic *A. manilensis* (Kanduli)—protected from fishkill events. Furthermore, the scope extends to indirect benefits, encompassing daily tourism expenditure, community willingness to pay (WTP) for enhanced water quality, and carbon sequestration potential. To ensure intergenerational equity and reflect the long-term ecological value of the lake, the temporal framework utilizes a social discount rate of 3%, deviating from standard commercial rates to prioritize ecosystem service longevity. Data synthesis is grounded in 2023-2025 benchmarks, integrating market standard prices from global aquaculture suppliers with institutional data from the Bureau of Fisheries and Aquatic Resources (BFAR) and the Department of Tourism (DOT), alongside 2025 electricity rate projections from MERALCO.

The model incorporates subjective risk factors of 10%, 15%, and 20% as friction costs to account for typhoons, technological failures, and institutional delays characteristic of the Philippine infrastructure landscape. While grounded in regional climate data, these percentages remain estimates of potential downtime rather than real-time measurements. Regarding tourism, the model assumes a direct causal link between lake aesthetics (odor and clarity) and visitor behavior, projecting a steady flow of 1,183 visitors per day. This assumption does not account for macroeconomic shocks or shifts in national travel trends that could fluctuate the PHP 300 daily expenditure rate. For the technical performance of destratification mixers, the model assumes the successful maintenance of an isothermal state across the entire 104-hectare area; however, the actual kinetic energy transfer required to overcome the density barriers of a deep crater lake may deviate from theoretical efficiency rates.

Price Assessment at Market Standard Price. The following research on economic analysis was limited on a market standard price and secondary literature in implementing the benefit-cost model. Online shopping hubs such as Sagar Aquaculture, Alibaba, and Shopee were evaluated to obtain the estimated price of aerators, control panels, concrete, and nylon ropes necessary for each implementation set-up. Institutional data was also considered both in the government and private sectors: for electricity rate, the 2025 price costs of MERALCO was considered; as for the market price of ichthyofauna species such as Kanduli and tilapia, the study took into account 2024 rates from the Bureau of Fisheries and Aquatic Resources (BFAR). Survey data on daily tourism volume (PHP 300/ day) was obtained from the 2023 Regional Visitor Survey of the Department of Tourism (DOT) Region IV-A.

Table 1
Price of variables for benefit-cost analysis based on secondary sourced data

Variable	Value	Secondary Source
Commercial-grade 2HP Paddlewheel (Diffused Air system)	PHP 40,000	Sagar Aquaculture. (2024). Product Catalog: Long Arm Paddle Wheel Aerators. (India-based company)
Tilapia market price	PhP 120/kg	Bureau of Fisheries and Aquatic Resources (BFAR). (2024). National Consolidated Price Monitoring Report. Department of Agriculture.
Kanduli market price	PhP 160/kg	Bureau of Fisheries and Aquatic Resources (BFAR). (2024). National Consolidated Price Monitoring Report. Department of Agriculture.
Fishkill volume avoided	≈ 50 MT/ event	LLDA. (2017). (Historical event data).
Ichthyofauna survival rate	25%	Boyd, C. E., & Hanson, T. (2010). Dissolved-oxygen concentrations in pond aquaculture. Ratio, 2, 42.
Tourism volume	≈ 1,183 visitors/ day	Brillo, B. B. C. (2016). Urban lake governance and development in the Philippines: The case of Sampaloc lake, San Pablo City. Brillo, BB (2016). Urban Lake Governance and Development in the Philippines: The Case of Sampaloc Lake, San Pablo City. Taiwan Water Conservancy Journal, 64(3), 66-81.
Willingness to pay	PHP 1,150 / day	Villaruel, S., & Jervis, M. (2024). Willingness to Pay Estimation for the Restoration of Water Quality of a Eutrophic Lake. *Environment & Natural Resources Journal, 22*(3).
Daily tourist expenditure	≈ PHP 300/ day	Department of Tourism (DOT). (2023). Regional Visitor Survey (Region IV-A).
Carbon sequestration	5 tC/ hectare/year	Lasco, R. D., Evangelista, R. S., & Pulhin, F. B. (2010). Potential of community-based forest management to mitigate climate change in the Philippines. Small-Scale Forestry, 9(4), 429-443.
Electricity Rate	PHP 13.5/ KWH	Meralco (2025).
Wetland restoration	PHP 400,000/ hectare	DENR-BMB. (2022). (Cost estimates for National Greening Program).

Methodological Framework

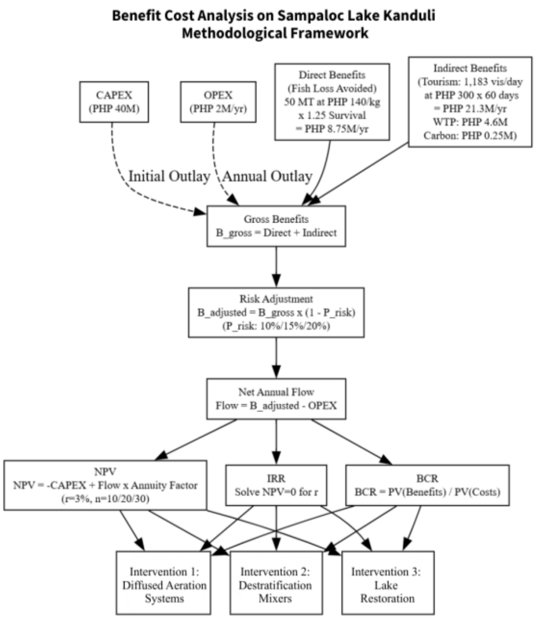

Figure 4.
Methodological framework for BCA on Sampaloc Lake Kanduli, created using GraphViz

Capital expenditure. Capital expenditure (CAPEX) refers to the long-term investment in physical assets. Within the context of this study, capital expenditure was implemented on three interventions, namely: (i) diffused aeration systems, (ii) destratification mixers, and (iii) lake restoration. The following tables seek to summarize the items considered to compute capital expenditure, prices were obtained via Shopee, Alibaba, and Sagar Aquaculture:

Table 2
Capital Expenditure computation for Intervention 1

Item	Value
Diffused aeration system unit cost (PHP 40,000); estimated 150 units for a 104 hectare lake	150 units x PHP 40,000 **= PHP 6,000,000**
Running waterproof cabling	≈ **PHP 10,000,000**
Partial solar setup (for OPEX reduction)	150 units x PHP 100,000 (Solar per station) **= PHP 15,000,000**
Installation and Anchoring (Concrete blocks and ropes)	**PHP 9,000,000**
TOTAL	**PHP 40,000,000**

Table 3
Capital Expenditure computation for Intervention 2

Item	Value
Solar circulator (unit cost is $ 35,000 USD); estimated 6 units for a 104 hectare lake	6 units x PHP 2,000,000 (converted from $ 35,000 USD) **= PHP 12,000,000**
Installation and Anchoring (concrete anchors for 6 units)	≈ **PHP 5,000,000**
Logistics (Shipping of solar circulator from US per Bureau of Customs 70% rule)	**PHP 3,600,000**
Tourism Infrastructure (building viewing decks/signage explaining the project_	**Assumed at PHP 19,400,000**
TOTAL	**PHP 40,000,000**

Table 4
Capital Expenditure computation for Intervention 3

Item	Value
Land preparation	PHP 500 per cubic meter. For a 1km shoreline buffer x 10m wide = **PHP 15,000,000**
Native flora campaigns (campaign materials and planting of native littoral flora such as kangkong and phragmites)	≈ **PHP 5,000,000**
Land Rights/Compensation (Paying informal settlers or land claimants to vacate the buffer zone)	Estimated 50 families x PHP 300,000 relocation assistance = **PHP 15,000,000**
Design and Permitting (Engineering land surveys and LLDA permits)	**Assumed at PHP 5,000,000**
TOTAL	**PHP 40,000,000**

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Operational Expenditure. Operational expenditures (OPEX) signify daily costs necessary to sustain a project once initial capital investment has been made. The following tables seek to compute operational expenditures in concordance to the computed capital expenditure costs; similarly, secondary data from online shopping hubs such as Alibaba, Shopee, and Sagar Aquaculture; together with rates from Philippine law and associated institutions were considered altogether.

Table 5
Operational Expenditure computation for Intervention 1

Item	Value
Power grid	225 kW x 12 hours x 90 days x PHP 13.5 KWH **= PHP 3, 280, 500**
Solar savings	Assumed at 40%
Net energy cost (considering power grid and solar savings)	≈ **PHP 1,900,000**
Maintenance (considering grease, bearings, rust, broken machinery)	**Assumed at PHP 100,000**
TOTAL	**PHP 1,900,000 + PHP 100,000 = PHP 2,000,000**

Table 6
Operational Expenditure computation for Intervention 2

Item	Value
Energy Cost	0 (brought by 100% solar powered)
Staffing (13 month-pay considered under the Philippine Labor Code)	Around 4 personnel x PHP 15,000/ month x 13 months **= PHP 780,000**
Maintenance and batteries (for 6 solar units to be replaced every 3 years)	≈ **PHP 1,220,000**
TOTAL	**PHP 1,220,000 + PHP 780,000 = PHP 2,000,000**

Table 7
Operational Expenditure computation for Intervention 3

Item	Value
Labor (removal of invasive hyacinth in Sampaloc Lake littoral) and tasked to maintain native flora	Around 10 laborers x PHP 10,000/ month x 13 months = **PHP 1,300,000**
Water quality monitoring (including testing fees at DOST-approved laboratories)	**PHP 700,000/ year**
TOTAL	**PHP 1,300,000 + PHP 700,000 = PHP 2,000,000**

Direct and indirect benefits. Direct benefits refer to immediate gains. In the context of your Sampaloc Lake economic analysis, these are the primary financial returns that have a clear market price (weighted average of Kanduli (PHP 160) and Tilapia (PHP 120) — this assumes a 50/50 mix for a conservative estimate of PHP 140/kg.). Such benefits are to be construed as the ichthyofauna population which was saved from fishkills during lake overturn events; the following formula was implemented:

$$B_{fish} = (\text{Volume Saved (kg)}) \times (\text{Market Price (PHP/kg)})$$

Plugging in the values of Table 1 for volume of fish saved (50 MT) multiplied to the conservative market price of Kanduli and tilapia (PHP 140/ kg) results in a direct benefit of PHP 8,750,000 per year for fisherfolk. On the other hand, indirect benefits refer to intangible gains that manifest from an intervention. Such benefits are to be construed as non-market goods. The following components were considered as indirect benefits, namely, (i) tourism, (ii) willingness to pay, and (iii) carbon credits. The following table seeks to summarize on how indirect benefits were computed in the conduct of this research:

Table 8
Computation of indirect benefits

Variable	Value
Tourism	1,183 visitors x PHP 300 (conservative lower-bound estimate for San Pablo Lake travel)
Willingness to pay	Assumed 4,000 households x PHP 1,150 = PHP 4,600,000
Carbon credit	50 ha x 10 tons x PHP 560 (voluntary carbon market rate) = PHP 250,000

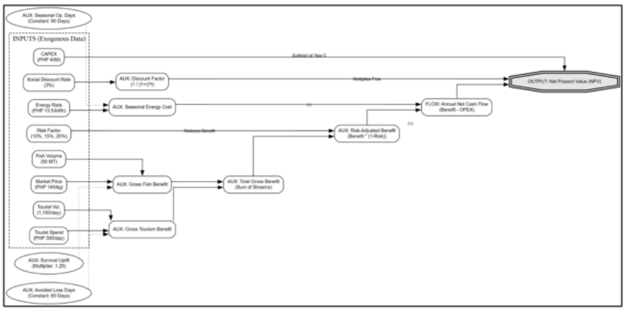

Figure 5
Auxiliary variables considered in the benefit-cost analysis, created using GraphViz

Risk factor. The risk factor implemented at each intervention is to be construed as an adjustment knob which exists to modify the gross benefit into the net benefit. The behavior of the risk factor is understood as instantaneous since it does not have an accumulative history. The assigned risk factor values are as follows: 10% (for the first intervention), 15% (for the second intervention), and 20% (for the third intervention). The risk factor acts as a scalar multiplier the benefit-cost analysis set-up:

$$B_{real} = B_{ideal} \times \underbrace{(1 - P_{risk})}_{\text{Auxiliary Calculation}}$$

For the first intervention (diffused aeration systems), the 10% deduction accounts for operational downtime caused by typhoons and grid instability. Located within the typhoon belt of the Western Pacific, the Philippines experiences an annual average of 20 tropical cycles with 3 - 5 directly impacting the Southern Tagalog region. Within these events, floating equipment must either be deactivated or transferred to lake littoral zones to prevent damage as a precautionary measure there is a cut for grid power. A 10% risk factor conservatively models this downtime (Cinco et al., 2016; DOE, 2023). For the second intervention, the 15% risk factor accounts for technological failure and revenue volatility (from tourism shocks). It is critical to acknowledge that unlike simple aerators which operate primarily through localized gas transfer (Boyd & Hanson, 2010), destratification mixers must manipulate the density of a lake gradient — to prevent an overturn, a mixer must generate sufficient kinetic energy to push the buoyant surface water down through a density barrier, forcing the entire lake to mix into an isothermal state (Chaaya et al., 2025). In the case of tourism, the author of this research affirms that such a commodity is classified as a luxury good (Income Elasticity > 1.0). Travel is to be construed as an expense consumers cut when the economy tightens or when the "quality" of the destination drops (Jones, 2020; Camillo et al., 2013). For the third intervention, a risk factor of 20% was implemented; this accounts for institutional risk particularly in infrastructure delays in Philippine settings. Infrastructure projects in the Philippines face an average delay of 2–3 years (Deep et al., 2019; Komatsuzaki, 2019). The 20% discount serves as a "friction cost" for these inevitable institutional delays.

Discount factor. The discount factor in this benefit-cost analysis is implemented under the following formula:

$$DF_t = \frac{1}{(1+r)^t}$$

**Where r refers to the social discount rate (3 %) and t to time.*

The discount factor subscribes to the principle of time preference—the concept that a unit of currency (or benefit) received in the present is worth more than the same unit received in the future due to its potential productive use or consumption value (Mishan and Quah, 2020). The social discount rate of 3% was applied rather than the standard NEDA 10% benchmark, to reflect intergenerational equity. This captures the intergenerational value of preserving the endemic A. manilensis and the long-term ecosystem services of Sampaloc Lake (Dasgupta & Treasury, 2022; ADB, 2017).

Gross annual benefit. Gross Annual Benefit (GAB) is an economic metric used to quantify the total monetary value or utility derived from a project or natural resource within a single fiscal year. GAB considers both direct provisioning services and indirect regulating services to reflect true economic worth (de Groot et al., 2012). GAB within the context of this research was implemented under the following arrangements:

$$B_{gross} = (Vol_{fish} \times Price) + (Visitors \times Spend \times Days) + WTP$$

GAB acts as a summing variable which aggregates the different benefit streams before the risk factor is applied.

Annuity factor (Cumulative discount). The annuity factory (cumulative discount) evaluates a "money's worth" of commercial annuity products (Davidoff et al., 2005). The annuity factor for the BCA is implemented under the following formula:

$$AF = \sum_{t=1}^{n} \frac{1}{(1+r)^t}$$

**Where r refers to the social discount rate (3 %), t to time, and n to total number of periods.*

Other auxiliary variables. For other auxiliary variables of the BCA, Table 9 provides a summary on how they were operationalized:

Table 9
Auxiliary variables and corresponding operations

Variable	Operation
Tourism loss avoidance	$B_{tourism}$ = $Daily_{visitors}$ + Avg_{spend} X 60 (assumed disruption days)
Survival rate uplift (yield bonus)	$B_{totalfish}$ = $B_{baseline}$ X 1.25
Seasonal energy cost	C_{energy} = kW_{load} X $hours$ X $rate_{kwh}$ X 90 (assumed season days)

Intervention 1. The air diffusion system of Intervention 1 works on the following assumptions, namely, (i) the absence of "spillover benefit" to wild fisheries outside the immediate radius of the diffuser as it assumes that Kanduli and tilapia within the aerated zone of fish cages will survive an overturn event even if the surrounding open water becomes anoxic, and (ii) aeration does not mitigate the sulfuric odor associated with lake overturns; this results to a zero recovery of lost tourism revenue, as the aesthetic quality of the lake remains degraded during the event despite the fish survival. The following flow chart seeks to summarize on how Intervention 1 operates:

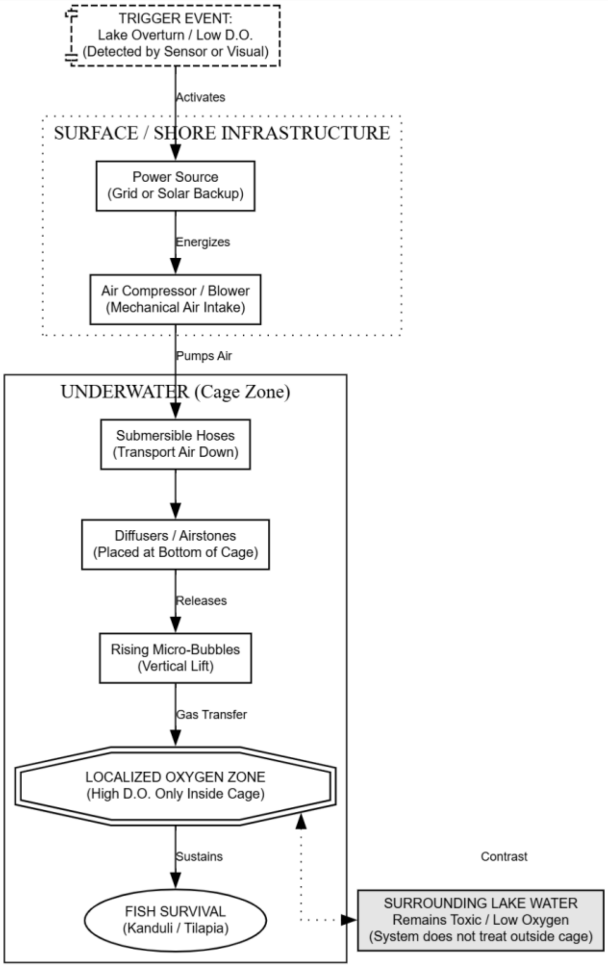

Figure 6
Intervention 1 operational framework, created using GraphViz

Intervention 2. The second intervention on solar-powered destratification mixers is governed by the following assumptions — (i) mixers can physically push buoyant surface water down through the thermocline to prevent stratification and sustain an isothermal condition, (ii) a direct causal link between tourism and lentic odor; should bad smell emitted from sulfur dioxide and associated pollutants be prevented, the assumed 1,183 visitors shall persist to visit Sampaloc Lake, and (iii) tourists are not deterred by the visual presence of the floating solar panels.

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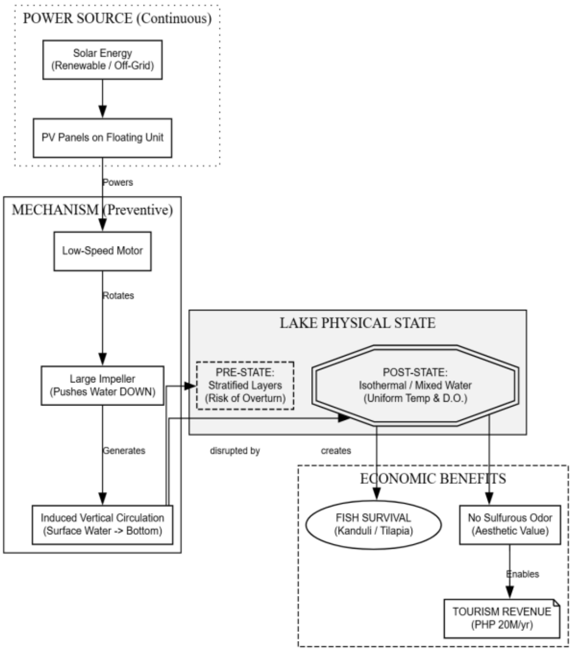

Figure 7
Intervention 2 operational framework, created using GraphViz

Intervention 3. The third intervention operates on the following set of assumptions: (i) assumes that the primary driver of the Sampaloc Lake anoxia is external loading (runoff from canals and groundwater) rather than internal loading (legacy sediments already at the benthic zone of the lake, (ii) native lentic riparian flora will reduce algal blooms by stabilizing regimes of dissolved oxygen and biological oxygen demand, and (iii) the City Government of San Pablo possesses the political will and legal capacity to implement the infrastructure without delays. Watershed in the operational framework is not to be construed as "river basins" but as urban canals and sewage draining towards the lentic environment of Sampaloc Lake.

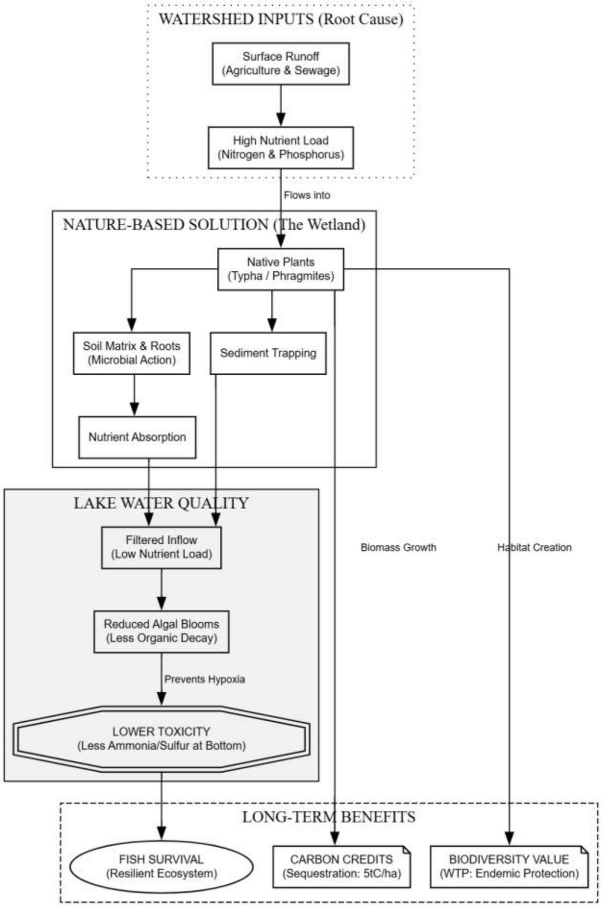

Figure 8
Intervention 3 operational framework, created using GraphViz

RESULTS

The result for the BCA is summarized in the following table per intervention, the operations were pursued in Google Sheets for each economic metric:

Table 10
Benefit cost analysis results for each intervention

BCA Metric	Intervention 1 (Diffused Aeration)	Intervention 2 (Destratification)	Intervention 3 (Lake Restoration)
Annual gross benefit	PHP 8,750,000	PHP 30, 044,000	PHP 13,600,000
Risk adjustment	PHP 7,875,000	PHP 25, 537, 400	PHP 10,880,000
Net annual flow	PHP 5, 875,000	PHP 23, 537, 400	PHP 8,880,000
Net present value	PHP 10,113,750	PHP 310,165,900	PHP 134,048,000
Benefit cost ratio	1.18	5.45	2.69
Internal rate of return	7.7%	58.4%	22.1%

**Decision Rule: if BCR > 1 and IRR > 3%, the project is economically viable.*

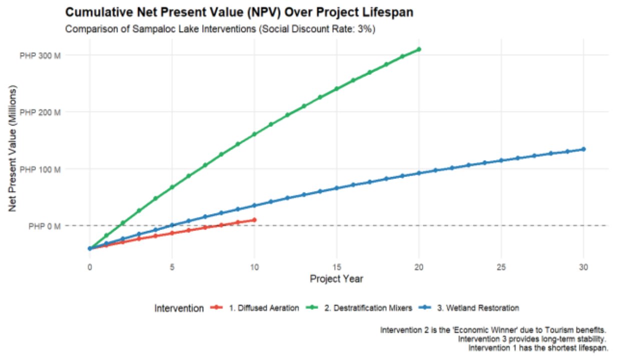

Figure 9
Cumulative Net Present Value over project lifespan of interventions

Utilizing the BCR and IRR as reference for evaluation, it can be observed that Intervention 1 has a BCR of 1.18 and an IRR of 7.7%, this project is marginally viable. The intervention exists as a "safety net" and acts as an insurance policy for fishkill episodes rather than an economic measure which sustains monetary gains for longer trajectories. With a positive NPV of PHP 10.11 million and a relatively short lifespan (10 years), this project is financially viable but economically modest. In the case of the second intervention, the BCR (5.45) and IRR (58.4%) suggest such a measure as an economically dominant strategy when compared to the economic metrics for Intervention 1 and Intervention 2. This indicates that for every peso invested, the City of San Pablo receives PHP 5.45 in economic value. Intervention 3 on the other hand is to be understood as a stable economic venture. A BCR of 2.69 is suggestive of strong efficiency.

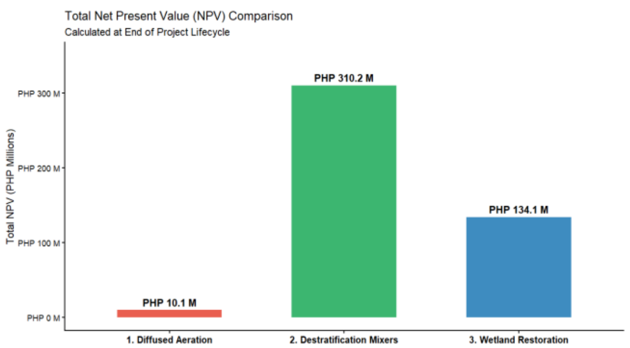

Figure 10
Total net present value comparison (calculated at the end of project cycle)

Negative and positive impacts. The following table provides a summary of the positive and negative impacts generated by each intervention relative to the results obtained from the benefit-cost analysis:

Table 11
Negative and positive impacts

Intervention	Negative impacts	Positive impacts
Diffused aeration system	-Surrounding lake water remains anoxic as the diffusion system only constrains aeration to Kanduli and tilapia fish cages within the lake littoral -Absence of the PHP 21M Tourism Benefit because the lake will likely still smell sulfurous during overturns, driving visitors away -acts as an insurance policy against total stock collapse but does not generate new value (**Low Allocative Efficiency**)	-Flagged as a safety net measure (project is financially viable but economically modest); applicable in the milieu of its 10-year lifespan -Saves the livelihood of the specific fisherfolk with cages (**High Social Equity**)
Destratification mixer	-Possible displaced fish cages brought by the construction of the floating solar panels	-By preventing stratification, the mixers ensure the lake remains odorless and clear year-round. This unlocks the PHP 21.3M annual tourism revenue -Despite a higher Risk Factor (15% vs 10% in Intervention 1), the volume of benefit obtained from tourism buffers the project against failure. Even if the system fails every other year (50% risk), the project would still yield a positive NPV. -Maximizes "Pareto Efficiency" since the fisherfolk get higher yields (survival rate 25% uplift) and the tourism sector gets a clean lake. (**Economically dominant strategy**)
Lake restoration	-Displacement of some 50 families residing near a lake littoral	-Biomass conservation by restoring the lake littoral zone

DISCUSSION

The management of common-pool resources (CPRs) as in the case of Sampaloc Lake in San Pablo City, Laguna, offers the classic macroeconomic challenge of balancing immediate industrial utility versus long-term ecological stability. The treatment of ecosystem services as free inputs is often associated with market failure characterized by negative externalities. Market failure is wrought into conception upon the failure of markets to allocate resources efficiently from a societal perspective. As noted by Farley et al. (2015), critical ecosystem services are non-excludable as one cannot prevent others from benefiting. Because markets typically require clear property rights and excludability to function, these ecosystem services are often treated as zero-cost inputs in production processes. When a firm utilizes an ecosystem service without paying for it produces a negative externality. This implies the cost of environmental degradation is flagged as external to the firm's decision-making and is instead borne by society at large (Tinch et al., 2019).

Applying a macroeconomic perspective, Sampaloc Lake must not be construed as a mere body of water; the lentic environment exists as a form of natural capital crucial for food production, waste assimilation, and aesthetic value. Depreciation of natural capital occurs when the rate of extraction supersedes the rate of regeneration. Elinor Ostrom (1990) in her management of the commons argued that this such a tragedy is not inevitable when local institutional arrangements provide clear boundaries and monitoring.

Under such circumstances, it can be inferred that the first intervention on a diffused aeration system represents a reactive approach to the commons problem. Marginal viability is expressed with the diffused system's BCR of 1.18 and IRR of 7.7%. From an Ostrom perspective of institutional economics, this intervention suffers from low as the aeration is constrained to specific cages, the surrounding lake remains anoxic. It treats the symptom (fish death) rather than the systemic failure of the commons. There exists a failure on reclaiming the PHP 21 million tourism benefit because the sulfuric smell of the degraded commons remains.

Arthur Pigou (1920) proposed that an efficient measure to respond to negative externalities is for a policy geared towards internalization. A Pigovian approach seeks to align private incentives with social costs. As expressed in the benefit-cost analysis, the second intervention boasts a BCR of 5.45 and an IRR of 58.4%. In macroeconomics, an outcome is Pareto Efficient if no one can be made better off without making someone else worse off (Stiglitz, 1987). The destratification mixer achieves a near-Pareto optimum as fisherfolk benefit from the increased 25% survival rate of tilapia and Kanduli and a projected boost in tourism brought by minimized sulfuric odor in the lentic environment. The destratification mixer is to be understood as a form of public infrastructure under Pigovian permutations where investments in the destratification mixer results in an effective buy back of improved water quality and clean air.

Nature-based solutions (NbS) involve the protection, restoration, and sustainable management of ecosystems to provide environmental and social benefits (Seddon et al., 2020). Lake restoration represents such a transition toward long-term biomass conservation. In terms of its economic performance, a BCR of 2.69 indicates strong efficiency and stability. While the destratification mixer in the second intervention is technically superior in immediate return of investment, lake restoration addresses the health of the littoral zone. However, the said intervention introduces a significant macroeconomic trade-off — the displacement of 50 families. The displacement of families is a social cost that must be weighed against the long-term gains of biomass conservation. While lake restoration is a stable economic venture, the high social equity seen in Intervention 1 is contested, highlighting the tension between environmental restoration versus social welfare.

Conclusion. Elizabeth Zott in "Lessons in Chemistry" once stated, "The only constant variable in the environment is change". The anomalies of lentic overturn events in Sampaloc Lake and consequences of Kanduli fish kill are testament to the inevitability of change; only by recognizing the reality of such changes can policymakers pursue context-based and evidence-driven pathways. Under the arrangements of the Local Government Code of 1991, city governments are given the mandate to pursue the general welfare of communities under their jurisdiction. The local government as an instrument of the state has its duty to pursue "a balanced and healthful ecology" as state principle. The City of San Pablo must recognize the intertwined relationship between economic ventures and water quality indices to the ichthyofaunal communities existing within the lentic environments of Sampaloc Lake. Considering that the study utilized secondary data, on-the-ground and expert-validation is necessary to verify the estimations provided. The Kanduli being data-deficient in its IUCN status does not equate the said fish as a least priority species. The very existence of the Kanduli serves as a living indicator measuring how healthy the Sampaloc Lake is, considering the foraging nature of Kanduli as a demersal fish is suggestive of an oxygenated lake bottom. While the waters for Kanduli remain uncertain, the challenge for government action is of utmost importance.

Recommendation. Based on the results of the Benefit-Cost Analysis, it can be observed how Intervention 2 (Destratification Mixer) is pareto-efficient, since fisherfolk within the area get higher yields (survival rate 25% uplift) brought by reduced anoxic events and the tourism sector has a lake environment whose hydrogen sulfuric smell is mitigated. It is critical to construe "economically dominant" not as an abandonment of other interventions. For instance, gains generated from Intervention 2 may be used to fund efforts for native flora conservation in Intervention 3. Within the lens of Pigovian economics, the utility of gains from Intervention 2 for Intervention 3 is a classic application of correcting the under-provision of public goods (Robertson, 2004). Under such arrangements, the City Government of San Pablo effectively internalizes the positive externalities of Kanduli fisheries in concordance to native littoral flora. This creates a closed-loop financial system where the tourism utilization of the lake pays for its ecological preservation. Intervention 1 must be understood as an insurance policy specific for fisherfolk owning fish-cages of tilapia and Kanduli. Pigovian economics treats Intervention 1 not as a public good, but as a private risk mitigation tool. Since the primary beneficiaries of aeration are the specific fisherfolk owning cages (a private good), the cost of this "insurance policy" should theoretically be borne by the private owners to avoid subsidizing high-risk behavior (Baumol & Oates, 1988).

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Artificial intelligence use. AI-assisted language editing was performed using Grammarly and Gemini; authors reviewed and approved all content. Such measure was pursued for grammar purposes and the restructuring of complex sentence structures. The other parts of the paper maintain full integrity in terms of originality.

Ethics approval statement. Ethics approval was not required for this study as it involved publicly available data. The study did not involve human participants. Secondary data was handled with due diligence.

Data availability statement. The dataset will be available upon request from the corresponding author of this study.

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