ARTICLE / INVESTIGACIÓN

Evaluation of the operation of the stabilization pond for agricultural irrigation purposes

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Abstract: Improving the quality of residual water and increasing agricultural production is necessary to achieve food sovereignty in water deficit conditions. The research was carried out to evaluate the operation of the precision lagoon for agricultural irrigation purposes by determining the geometric and hydraulic parameters, kinetic coefficients and dissolved Oxygen using the Streeter & Phelps model. The main results indicate the presence of a facultative lagoon with a hydraulic retention time of 6.7 days, flow rate of 1 641,6 m3 day^{-1} contributed by 41 312 inhabitants, solar penetration of 0.20 m, presence of green algae, 0,36 day^{-1} deoxygenation coefficient, 0,60 day^{-1} reaeration coefficient, 0,09 day^{-1} sedimentation coefficient, 0,45 day^{-1} total removal coefficient, dissolved Oxygen of the effluent of 2 mg L^{-1}, initial dissolved oxygen deficit of the influent and effluent of 8,4 mg L^{-1} and 2,43 mg L^{-1} respectively. These indicate that the effluents can be used as wastewater reuse for irrigation of cooked food crops according to the recommendations of the World Health Organization.

Key words: Wastewater, kinetic coefficients, dissolved Oxygen, hydraulic parameters, reuse.

Introduction

Water quality depends on its use and is linked to various physical, chemical and microbiological parameters, with concentration limits established in its natural state or altered by humans. The problems derived from the contamination of bodies of water, such as the reduction of the supply of fresh water, health risks, the uselessness of water for various uses and the negative impact on aquatic life, are some of the associated effects to water quality[1].

Water quality depends on several natural factors, although human activities influence the decline in quality. It is necessary to look for tools such as mathematical modeling that improve the management of water resource quality[2].

Water is a crucial component of the environment where rivers have historically been considered a source of wealth; providing essential water for the subsistence and subsequent development of living beings favors soil fertility for obtaining food. However, the continuous growth of the human population and the presence of unsustainable development models have resulted in the contamination of rivers and the loss of the availability of these resources[3,4].

One of the elements that can affect the self-purification process of rivers is their length between two points, being adapted in principle to treatment systems in stabilization ponds. To describe this capacity, Streeter & Phelps5 developed a mathematical model that considers the main mechanisms of contaminant transport, natural purification through degradation by microorganisms present in the river, and reaeration[4].

Mathematical models are widely used tools that allow us to understand and describe the behavior of the variations of specific parameters that influence the quality of water bodies associated with the discharge of pollutants changes in land use. This tool is essential since it allows environmental authorities to understand cause-effect relationships associated with pollutant discharges into the river and lake streams. They can also be used to assess the benefits of installing wastewater treatment plants, environmental impact studies and sanitation plans[6].

The growing contamination of water bodies requires ever more significant efforts to study and determine the self-purification capacity of the water body, with the deoxygenation coefficient of degradation of organic matter (k1) and the atmospheric re-reaction coefficient (k_2) used in the Streeter & Phelps self-cleaning model. Where the dissolved Oxygen (DO) along the longitudinal profile of a particular body, once the Biochemical Oxygen Demand (BOD) has been consumed, the dissolved Oxygen decreases, the organic matter being biologically degraded until the DO takes its initial value[7,8].

The first model proposed by Streeter & Phelps assumes, among other hypotheses, that there are two predominant processes related to Dissolved Oxygen in water: biodegradation and reaeration, both occurring according to first-order reactions. In this model, the process for the deoxygenation coefficient k_1 and the reaeration coefficient k_2 depend on the water temperature. Subsequently, Streeter & Phelps water quality models use the same equations to obtain the spatial distribution of DO in river streams[9].

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Cuba has a sanitation infrastructure comprising more than 300 stabilization ponds, 5,442 kilometers of sewerage networks, 163 waste pumping stations and 12 treatment plants to achieve adequate final disposal of effluents[10].

The Ciego de Ávila province has an urban wastewater treatment system comprising ten facultative lagoons with removal efficiencies of chemical oxygen demand and biochemical oxygen demand that range between 35-55%, which is why they cause impacts negatively in surface water bodies.

The objective of the work was to evaluate the functioning of the stabilization lagoon for agricultural irrigation purposes in the municipality of Morón, Cuba, through the evaluation of geometric and hydraulic parameters, estimation of dissolved Oxygen using the Streeter & Phelps model and its kinetic coefficients. , as essential aspects in the removal of organic load[6, 7,11,12].

Materials and methods

The research was carried out in the stabilization lagoon of the municipality of Morón in the province of Ciego de Ávila, Cuba, located between the planar coordinates Cuba Norte X = 744367 m and Y = 257166 m.

The stabilization pond comprises three fundamental parts: the discharge work comprising three registers and a 350 mm discharge collector, the optional stabilization pond treatment system and the outlet work with three distribution registers towards two canals, one master and the other for agricultural irrigation. This structure allows the collection of liquid waste originating in the municipality, reducing the organic load and producing an effluent that does not cause negative impacts on the environment.

The information required consisted of evaluating the quality of the residual water by applying the following techniques: direct observation, evaluation of the geometric and hydraulic parameters, modeling of dissolved Oxygen in the lagoon and analysis of total coliforms (TC). And thermo tolerant (TTC). For the TC, the recommended limit value of 1 000 mg L^{-1} by the World Health Organization for crop irrigation and for the TTC, the value is lower than the limit of 2 000 mg L^{-1} recommended by several countries of America America for irrigation with wastewater. Depending on the evaluation of each indicator, retention time and coliforms are the main parameters that define the type of irrigation to be used, being their classification as raw food crops, cooked food crops and industrial[13].

Total (TC) and thermotolerant (TTC) coliforms were determined using the multiple tube technique[14,15].

Direct observation was used to determine the current situation of the community's wastewater treatment system through visual inspections and measurements with specific instruments.

The evaluation of the geometric and hydraulic parameters, estimation of dissolved Oxygen and kinetic coefficients of the stabilization pond are explained below:

The flow was determined based on the continuity equation, multiplying the cross-sectional area using a tape measure by the average current speed using the float method whose transfer time was measured with a clock in a length of co -A uniform current of 10 meters[12]. The average rate of the water[16,17] was determined with the float method over a distance of 10 meters using the following equation:

$$Q = A.v \tag{1}$$

Where A is the cross-sectional area of the discharge duct (m2), and v is the mean velocity of the water (m s^{-1}).

The surface area and length of the lagoon were determined with a GPS of the GARMIN model[18].

The average depth and thickness of the mud were determined by employing a limnimetric ruler graduated with a precision of one centimeter. Measurements were made at numerous points within the predetermined lagoon using a rectangular network[19].

Sunlight penetration was determined using the standard 20 cm diameter Secchi disk[20].

The volume and hydraulic retention time were determined using the Yánez surface charge empirical design method for dispersed flow facultative lagoons[21,22], using the following equations:

$$\lambda_s = 250.(1{,}085)^{T-20} \tag{2}$$

$$A_S = \frac{10.L_i.Q}{\lambda_s} \tag{3}$$

$$V_L = A_S.H \tag{4}$$

$$T_{rh} = \frac{V_L}{Q} \tag{5}$$

Where λs is the superficial organic load (kg BOD5 m^{-3} ha^{-1} day^{-1}), T is the minimum monthly air temperature (°C), AS is the surface area of the facultative lagoon (ha), Li BOD5 of the concentrated tributary in (mg. L^{-1}), VL is the volume of the lagoon (m^3), H the average depth of the residual water in the lagoon (m), Trh the hydraulic retention time (day), Q flow rate of the tributary (m^3 day^{-1}), Li the BOD5 concentration of the influent (mg L^{-1}).

The water quality was evaluated by applying the Streeter & Phelps mathematical model and the values obtained in field and laboratory work of the physical, chemical, microbiological and hydraulic parameters reflected in (table 1) to simulate the self-purification capacity of the organic matter in a length of 210 m distance between the influent and effluent. The mass transport equations describe the variation of the dissolved oxygen concentration and the BOD concentration at different spaces in the direction of the surface current path[4,6,11].

The evaluation of the deoxygenation and reaeration coefficients[2,9,12,24] and the dissolved oxygen concentration[7,23] were determined from the difference between the dissolved oxygen saturation concentration and the dissolved oxygen déficit[6,11], using the equations 6-16.

Where Qaverage balance of the average water flow (m^3 s^{-1}), Qeffluent effluent water flow (m^3 s^{-1}), Qafluent tributary water flow (m^3 s^{-1}), ODm average dissolved oxygen balance of the water (mg L-1), *T*S dissolved oxygen saturation concentration (mg L-1), T water temperature (oC), DDO initial dissolved oxygen deficit (mg L^{-1}), BODm biochemical oxygen demand balance average in the water (mg L^{-1}), v average velocity of the water transformed into (m d^{-1}) (0.20 m s^{-1}= 17 280 m d^{-1}), L length of the lagoon (m), t the travel time of the float for the specified length (s), k1 deoxygenation coefficient (day^{-1}), DBOD biochemical oxygen demand deficit at the specified distance (mg L^{-1}), L_o the BOD modeled on the

	T °C	OD mg L^{-1}	DBO$_5$ mg L^{-1}	CT mg L^{-1}	CTT mg L^{-1}	Caudal m^3 s^{-1}	H m	V m s^{-1}
Affluent	26	0	176	60 000	92 000	0,019	1.52	0.2
Effluent	26	2	112	1 200	1 200	0,016	1.52	0,2

Table 1. Physical, chemical, microbiological and hydraulic parameters for modeling.

$$Q_{half} = Q_{effluent} + Q_{affluent} \qquad (6)$$

$$DO_m = \frac{\left(DO_{effuent} \cdot Q_{effluent} + DO_{affluent} \cdot Q_{affluent}\right)}{Q_{halt}} \qquad (7)$$

$$O_S = 14,652 - 0,41022.T + 0,0079910.T^2 - 0,000077774 \quad (8)$$

$$D_{DO} = O_S - DO_m \qquad (9)$$

$$BOD_m \frac{\left(BOD_{effuent} \cdot Q_{effluent} + BOD_{affluent} \cdot Q_{affluent}\right)}{Q_{halt}} \qquad (10)$$

$$v = \frac{L}{t} \qquad (11)$$

$$k_1 = 0,3 \left(\frac{H}{2,4}\right)^{-0,434} \qquad 12)$$

$$D_{BOD} = L_o . e^{\left(-k_1 . \frac{x}{v}\right)}; \text{ Where } L_o = BOD_m \qquad (13)$$

$$k_2 = 5,13 \left(\frac{v}{H^{1,33}}\right) \qquad (14)$$

$$D_x = D_{DO} . e^{-k_2 . \frac{x}{v}} + \frac{k_1 . L_O}{k_2 - k_1} \left(e^{-k_1 . \frac{x}{v}} - e^{-k_2 . \frac{x}{v}}\right) \qquad (15)$$

$$DO_x = O_S - D_x \qquad (16)$$

lagoon (mg L^{-1}) where L_O = BODm, x specific distance (m), k_2 the reaeration coefficient (day^{-1}), *D*x is the total dissolved oxygen deficit or estimation of the dissolved oxygen deficit at a distance downstream (mg L^{-1}), ODx estimate of dissolved Oxygen at the total distance from the lagoon (mg L^{-1}).

The sedimentation coefficient of organic matter[25] and the total removal coefficient[24] were determined using the following equations:

$$V_S = 0,033634. \alpha(\rho_S - \rho_W). d_p{}^2 \quad (17)$$

$$k_3 = \frac{v_S}{H} \qquad (18)$$

$$k_r = k_1 + k_3 \qquad (19)$$

Where vs the sedimentation rate of organic matter (m day^{-1}) from the Stokes equation, α reflective factor approximately 1, ρs density of the particle (1.93 g cm^{-3}), ρw density of the water, dp diameter of the particle[24] of (1 to 2 μm), k_3 the coefficient of sedimentation of the organic matter (day^{-1}), kr the coefficient of total removal (day^{-1}). The sedimentation coefficient of organic matter (k_3) was estimated based on the average depth, the sedimentation rate of organic matter, the size of the particle and its density[25].

Dissolved Oxygen (DO) analysis was also determined using the Winkler[26] method for a range of 2 to 7 mg L^{-1} and was carried out by the laboratory staff of the National Technical Services Company of the province of Ciego de Ávila.

Results and discussion

Evaluation of geometric parameters

The geometric parameters that evaluate the lagoon are the length of 210 m, width of 100 m and depth of 1.52 m. The value of this depth indicates that it is a facultative-type lagoon for a range of 1,5 – 2,2 m, compared to results from (Treviño & Cortés, 2016)[21], which are potentially more efficient in removing of the organic load and are those recommended for the use of its effluents for agricultural purposes[13]. The shallowness of the facultative lagoons favors sunlight penetration and photosynthetic activity during daylight hours[27].

Evaluation of hydraulic parameters

The results of the direct observation method identified the presence of a stabilization lagoon composed of three fundamental elements: the discharge structure, the facultative lagoon and the outlet work.

The results of the field measurements and analytical calculations determined that the lagoon has a flow of 1 641,60 m^3 d^{-1}, an area of 7 083 m2 (0.70 ha), a volume of 10 767,44 m^3, retention time hydraulics 6,7 days, average speed of the water 0,20 m s^{-1}, penetration of sunlight 0,20 m and thickness of the mud variable between 0,20 and 0,40 m. The behavior of the thickness of the mud indicates the presence of an essential organic charge that influences the solar penetration to be 20 cm. Studies carried out by Cortés *et al.* (2017)[28] and Treviño & Cortés (2016)[21] demonstrated the usefulness of analyzing the hydraulic parameters of stabilization ponds in understanding their operation and decision-making.

The tributary is contributed by 41 312 inhabitants with an average flow of drinking water consumption of 600 L inhabitants^{-1} day^{-1}, which generates a surface organic load of 345 kg BOD$_5$ m^{-3} day^{-1} with a concentration of BOD5 of tributary of 176 mg BOD$_5$ L^{-1} and effluent BOD5 concentration of 112 mg BOD$_5$ L^{-1}.

Dissolved Oxygen Assessment

The dissolved Oxygen concentrations in the influent and effluent carried out by the water quality laboratory were 0 mg L^{-1} and 2 mg L^{-1}, respectively, lower results about the range (2 to 7 mg L^{-1}) . These values are common due to the low penetration of sunlight, as well as the abundance and activity of specific groups of microorganisms[4,6,26,29].

The tributary Streeter & Phelps mathematical model analysis presented an initial dissolved oxygen deficit of [8,40] mg L^{-1} to assume the decomposition of organic matter by bacteria that are mainly dependent on dissolved Oxygen. The effluent presented a total dissolved oxygen deficit of 2,43 mg L^{-1} and a biochemical oxygen demand deficit of 1,85 mg L^{-1}. The behavior obtained from the estimation of dissolved Oxygen in the lagoon effluent by the mathematical model was 6,87 mg L^{-1} compared to the analyses carried out in the laboratory of 2,00 mg L^{-1}. Similar studies were carried out by (Menéndez *et al.*, 2022)[11]; (Quiñones *et al.*, 2020)[6]; Pazmino *et al.* (2018)[12].

In (figure 1), the results of the coefficients of deoxygenation (k_1), reaeration (k_2), sedimentation (k_3) and total removal of BOD_5 (kr) are presented. It can be seen that the highest values corresponded to the reaeration coefficient with 0,60 day^{-1} and the complete removal coefficient with 0,45 day^{-1}. The sedimentation coefficient is very low, a parameter closely related to the short hydraulic retention time of 6,7 days (less than the range of 20 days for facultative lagoons).

The deoxygenation coefficient k_1 is related to the degradation produced by the bacteria at the bottom of the stabilization pond, reaching a result of 0,36 day^{-1}, which is within the established range ($0{,}10 < k_1 \leq 0{,}60$ day^{-1}) for shallow currents ($0 < H \leq 2{,}40$ m)[12, 25]. Similar results were found in Chile and Colombia[9,24].

The reaeration coefficient k_2 is linked to the renewal process of Oxygen and other gaseous components of the air in the body of water. In this research, the result achieved was 0,60 day^{-1}, a value within the range of ($0{,}30 < k_2 \leq 0{,}60$ day^{-1}) for wastewater streams[11,30,31]. These values are sensitive in shallow bodies of water[7].

The sedimentation coefficient k_3 was 0,09 day^{-1} for a sedimentation rate of organic matter of 0,14 m day^{-1}. A similar result was obtained by Cesar & Coelho (2014)[25].

The total removal coefficient of the BOD5 kr reached a value of 0,45 day^{-1}. This kinetic coefficient responds to the conditions of the lagoon and can be used in other facultative types in similar situations[24].

The observation technique showed that the lagoon had a green color, indicating good functioning due to the green algae of the genus Chlorella, Scene-desmus and Chalamydonomas, which are significant oxygen producers. The photosynthetic activity of these algae and surface reaeration favor oxygen production necessary for the purification process[32]. The existence of typical odor, absence of foam, floating material and weeds was also verified.

Analysis of microbiological characteristics

The values of thermotolerant coliforms were 92 000 mg L^{-1} and 1 200 mg L^{-1} in the influent and effluent, respectively. The effluent value is lower than the limit established of 2,000 mg L^{-1} used in several Latin American countries for irrigation with wastewater[13,14,15,33].

Total coliform values were 1 60 000 mg L^{-1} and 1 200 mg L^{-1} in the influent and effluent, respectively. The effluent value is slightly higher than the limit value of 1 000 mg L^{-1}, recommended by the World Health Organization for crop irrigation[13-15]. Thus, the effluent obtained is not suitable for irrigation. of food crops that are eaten raw, but yes, for cooked food crops.

Conclusions

The stabilization lagoon of the municipality of Morón is of the facultative type with an average depth of 1,52 m, average velocity of 0,20 m s^{-1}, hydraulic retention time of 6,7 days and solar penetration of 0,20 m.

The calculated kinetic coefficients showed values of 0,36, 0,60, 0,09, and 0,45 day^{-1} for the coefficients of deoxygenation (k_1), reaeration (k_2), sedimentation (k_3) and total BOD5 removal (kr) respectively.

The dissolved Oxygen concentration in the effluent was low, with a value of 2,00 mg L^{-1}, due to the low penetration of sunlight.

The Streeter and Phelps, mathematical model analysis showed an initial dissolved oxygen deficit of 8,40 mg L^{-1} in the influent and a total dissolved oxygen deficit of 2,43 mg L^{-1} in the effluent, indicating a tendency to decrease.

The effluent obtained is not suitable for irrigation of raw food crops, but yes, for cooked food crops.

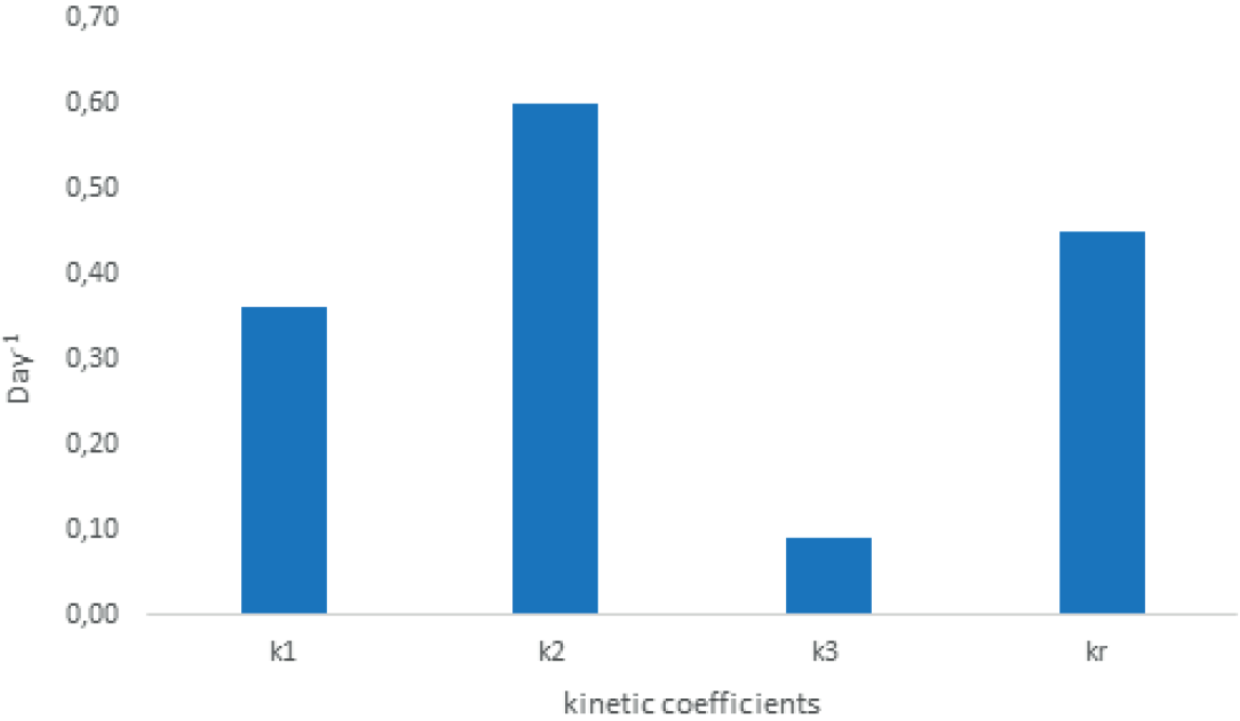

Figure 1. Values of the coefficients of deoxygenation (k_1), reaeration (k_2), sedimentation (k_3) and total removal of BOD5 (kr).

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Conflicts of Interest

The authors declare no conflict of interest.

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