Low-cost natural wastewater treatment technologies in rural communities using Instream Wetland, Moringa Oleifera, and Aeration Weirs – A comparative study

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Low-cost natural wastewater treatment technologies in rural communities using Instream Wetland, Moringa Oleifera, and Aeration Weirs – A comparative study

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Abstract: Low-cost natural wastewater treatment technologies are very useful in developing communities that lack investment and technologies. Wetland technologies prove excellent results for wastewater treatment. The objective of this study is to compare and propose a new wastewater technologies using wetland, weirs as an aeration source, finally add Mouringa Oleifera seeds which proven effective in removing: suspended substances, turbidity, chemical oxygen demand (COD), color, and other organic pollutants. To cover the objectives, several studies have been carried out, and can be summarized as follows: two study areas were investigated that used instream wetland as a natural treatment and compare the hydraulic design and efficiency for two case studies both in Egyptian drainage systems. Secondly, studied a field aeration weir that already exists in one of the rural drains and studied its ability to improve water quality after aeration system, finally represent a laboratory analysis using Mouringa Oleifera seeds for drainage water treatment. Removal efficiency for the first wetland study area ranged from 35% to 75% for removal of suspended solids, from 58% to 30% for BOD, 57–44% for COD, and 99% for fecal coliform. While in the second instream wetland is 50% for EC, 83.3 for bicarbonate, 44.2% for TDS, 20% for TSS, 60% for BOD, 85% for COD, 63% for calcium, 88% for potassium, 20% for magnesium, 90% for lead, 99% for total and fecal coliform. The removal efficiency when using M. Oleifera is 85.1% for turbidity, 96.1% for total coliform, 82.8% for total coliform, 60% for arsenic, 85% for cadmium, and 90% for nickel. The efficiency for weir as an aeration source is 77.1%
for EC, 98% for TDS, 92.9 for bicarbonate, 95.8% for chloride, and 83.3% for phosphate. The studied technologies offer a cheaper alternative to conventional treatment methods without using any chemical substances for treatment and provide minimum operation and maintenance needs. The instream wetland could be replicated to cover a larger percentage of drains recommend using M. Oleifera beside native plants in wetland especially in sedimentation zone, also study weirs as an aeration source.

**Subjects:** Wastewater Treatment; Water Resources management; Environmental Sciences; Civil and Hydraulic Engineering

**Keywords:** drainage water; natural treatment; constructed wetland; aeration weirs; Mouringa Oleifera

1. Introduction

Low-cost technologies for water and wastewater treatment are developed to assist small communities without technical staff and limited financial support. Rural communities obliged to investigate unconventional treatment technologies lead to treatment at low cost.

In this research three natural techniques will be studied: the first technique is a wetland treatment system on existing drains that provides an efficient, inexpensive, and simple alternative to treatment and improve the quality of wastewater. The total efficiency expected of wetlands in the watercourse, including the sedimentation area, can reach 50–80% depending on the permissible retention time.

The second technique is to use Moringa Olivera MO as a coagulant and absorber in the drainage system. It is growing in Egypt, its leaves are very nutritious and can be eaten either fresh or cooked. Humans can eat leaves because it contains 15–25% digestible protein, Fe, Ca, K, and vitamins. The use of natural coagulants to clarify water is of environmental importance, because it is a simple technique that can be applied in development of societies. Several studies showed the effect of natural blood clotting obtained from M. Oliveira seeds to clarify and purify wastewater. Results showed removal efficiencies of 70.9% and 85.1% for apparent color and turbidity, respectively, and removal efficiencies of 96.1% and 82.8% for total coliforms and E. coli, respectively, indicating the potential use of M. Oliveira coagulant and absorber for auxiliary in wastewater treatment systems (Munirat et al., 2016).

**M. Oleifera** as Coagulant: M. Oleifera in its various extracted and purified forms have proven effective in removing suspended substances and removing turbidity, chemical oxygen demand (COD), color, and other organic pollutants (Beltrán & Sánchez, 2009; Bina et al., 2010; Katayon et al., 2006; Noor et al., 2013). It has been concluded that the coagulation efficiency of M. Oleifera seeds can be greatly enhanced by extracting its active agents with a saline solution containing a single valence electron such as NaCl, KCl, etc. (Okuda et al., 2001). The coagulation capacity was significantly increased to about 7.4 times when the coagulation factor was extracted using 1 M NaCl from those extracted with distilled water. This improvement has apparently been suggested due to the salting mechanism in proteins where salt increases the separation of proteins, leading to increased protein solubility while increasing the strength of the ionic salt (Okuda et al., 1999).

It was reported the performance of M. Oliveira seeds as a coagulant or alternative coagulant for various water treatments such as turbidity, alkalinity, dissolved organic carbon (DOC), humic acid, and dehardening in the raw water (Ali et al., 2010; Leo, 2010). Other studies recommended using M. Oleifera seed extracts as a coagulant for water treatment to remove pollutants such as orange 7 dye and alizarin violet dye in wastewater (Marandi & Bakhtiar, 2012).
M. Oleifera as Adsorbent: Heavy metals are most of the critical pollutants that have an effect on water quality. It has a tremendous toxic impact on human and aquatic species and consequently, its elimination is sincerely necessary. Many heavy metals observed their way to our bodies of water due to industrial activities along with mining, fossil gasoline combustion, tanning, etc. Studies have proven that M. Oleifera seeds have a brilliant adsorbent property that has been used to dispose of accompanying materials such as minerals, natural materials, and pesticides. Studies conducted revealed that nun shelled M. Oleifera seeds incorporate about 37% protein. The absorptive capacity of the seed is due to the presence of proteins, some fatty acids, and carbohydrates with lignin-containing cellulose certain in its structure. Lignin is a bipolar heterogeneous molecule with exclusive functional companies together with methoxyl, hydroxyl-oliphatic, carboxyl, and phenolic companies. It additionally has a three-dimensional fragrant polymer shape with infinite molecular weight and as a result chooses organic absorption as a promising method for eliminating heavy metals. Sharma et al. (2006) concluded that the capacity of seeds to do away with heavy metals becomes verified by the use of the Fourier Transform Infrared (FTIR) spectrometer which highlighted the bonding interactions between amino acids and the minerals responsible for the absorption phenomenon. Minerals removed from the water with the seeds of M. Oleifera consist of arsenic, cadmium, zinc, and nickel (Acheampong et al., 2012; Sharma et al., 2007).

Oleifera seeds have been proven to cast off arsenic from water in step with a study (Kumari et al., 2006), and absorption research within the batch test has shown that the optimum circumstance for putting off arsenic (III) and arsenic (V) changed into 60.21% and 85.06%, respectively. For cadmium, nickel 85.10%, 90%, respectively, elimination turned into achieved.

The Third Technique using aeration weirs as a source of dissolved oxygen (DO). The concentration of dissolved oxygen (DO) in river and stream water is very important to the quality and existence of aquatic life. Hydraulic structures increase the amount of DO in the river system, although the water comes into contact with the structure for only a short period of time. The same amount of oxygen transportation that usually occurs several kilometers away in a river can occur in a single hydraulic structure. The oxygen transport that occurs in a specific structure is sensitive to water temperature, water quality, tail depth of water, drop height, dam drainage, and DO deficit.

Several studies were conducted to find the relationship between quality, and specification of weir structures in both laboratory and infield represented in Table 1 that represents Weirs and its geometries used in the laboratory and their comparison, Table 2 shows the Works on factor affecting aeration performance and relating equations, and Table 3 represents the Works on use of weirs in the field.

2. Materials and methods

2.1. Research problem
Rural communities need untraditional wastewater techniques thus in this research four rural communities in Egyptian drainage areas were studied using three low-cost wastewater technologies and compare the efficiency using these techniques in order to choose the suitable technologies in the Egyptian drainage system. These techniques summarized in using instream wetland, treatment using M. Oleifera as its seeds proved its ability for wastewater treatment as it is used as a coagulant and an Adsorbent, finally using aeration weirs increasing Do in the stream that is good for increasing water quality.
Table 1. Weirs and its geometries used in the laboratory and their comparison (Arvind et al., 2019)

| St. no. | Reference           | Weir shape                        | Discharge (Q) | Height of Drop (H) | Conclusion                                                                                                                                                                                                 |
|---------|---------------------|-----------------------------------|---------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1       | Van der et. al. (1969) | Rectangular, and semicircular     | 0-80 m³/hr    | 0.2-0.9 m        | a) As the probability of Q and H aeration potential increases with no. of split nappe, up to a limit and then starts decreasing in rectangular weirs.                                                       |
|         |                     |                                   |               |                   | b) When the probability of constant Q and H aeration potential decreases with no. of split nappe in rectangular weirs.                                                                                         |
|         |                     |                                   |               |                   | c) Weir shows increase in aeration potential.                                                                                                                                                              |
|         |                     |                                   |               |                   | d) All weir aeration potential increases with increase in H and decreases with increase in Q at fixed H.                                                                                                 |
| 2       | Baylar et al. (2001)| Triangular notch weir            | 3.6-14.4 m³/hr| 0.15-0.90 m      | A 90° triangular notch weirs are better than that of the other weirs type.                                                                                                                                |
| 3       | Baylar et al. (2002)| a) Sharp crested weir             | 3.6-18 m³/hr  | 0.15-0.90 m      | A) A 30° triangular sharp crested weir is better than other sharp crested weirs.                                                                                                                          |
|         |                     | b) Rectangular, trapezoidal, semicircular, and triangular |               |                   | b) A 30° triangular sharp crested weir with two V notches has a higher values than other variations in number of V notches.                                                                           |
| St. no. | Author names(s) Year | Weir shape | Discharge (Q) | Height of Drop (H) | Conclusion |
|---------|----------------------|------------|---------------|-------------------|------------|
| 4       | Emiragla et. al. (2003) | a) Broad Crested Weirs Triangular weir angles as 30°, 45°, 90°, and 135° | 3.6–18 m³/hr | 0.15–0.90 m | a) A 30° triangular sharp crested weirs are better than that other sharp crested weirs. b) Empirical relation for broad crested weirs given was \( Q_a = 2.160 \cos (\alpha/2) Q^{1.030} H^{0.782} \) where, \( Q_a \) = air entertainment rate, \( Q \) = weir discharge, \( H \) = weir height |

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### Table 2. Works on factor affecting aeration performance and relating equations (Arvind et al., 2019)

| Sr.no. | Author name(s), Year       | Weir Shape       | Methodology                                                                 | Conclusion                                                                 |
|--------|-----------------------------|------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| 1      | kahil, M. et.al. (2014)     | Weirs and cascades | Developed an equation deals with a fall height, discharge, and tail water depth | $\text{Ln} 20 = A(D^{1.5}H_c^H)Bq^C$  
Where: $A, B, C$ are constants depends on $D, H_c, H$ and $q$ |
| 2      | Gulliver et al. (1993)      |                   | Worked on the relationship for a transfer efficiency from the mass transport  | a) The transport of oxygen from a specific structure is sensitive to head loss and temperature but little when discharging and tail water depth  
b) In a certain structure, head loss and tail water depth are relatively constant, so this is usually not a concern.  
c) The water temperature can vary greatly, and there are relationships for accurately indexing the transportation of oxygen to the common water temperature. |

### Table 3. Works on the use of weirs in the field (Arvind et al., 2019)

| Sr. no. | Authors name(s), Year       | Weir Shape       | Purpose of use                                                                 | Conclusion                                                                 |
|---------|-----------------------------|------------------|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| 1       | (Arvind Kumar, et al. (2019) | Conventional weir | Increasing the quality of drains .                                             | Conventional weirs efficient when used for the indirect aeration of water. |
| 2       | Bagatur (2009)               | Weir and stepped cascade | Alternative pre-aeration system in circular clarifiers                       | Weir and stepped cascade can be efficiently used as pre-aeration system    |
| 3       | Poommai et al. (2012)       | Rectangular weir | Increasing the efficiency by oxygen transfer into wastewater. Wastewater depths used in m are 0.03, 0.04, 0.05, 0.06, and 0.07 | Circular clarifiers with weir and stepped cascade can be efficiently used as pre-aeration system. |
2.2. Drainage treatment using in stream wetland in rural Area1- El Tellin Drain, Sharkya, Egypt

2.2.1. Study area
El Tellin drain length is 5.7 km, with an average area served of 2515 feddan. Figure 1 represents the layout of the study area. The drain is covered by culverts in 4 points. The sewage diameter is 1.5 meters. The main problems facing the population within the area are the lack of sewage collection networks and wastewater treatment systems, as well as inappropriate practices for solid waste management. Subsequently the main problems are: untreated wastewater which discharge directly into drains; drains pollution causes negative effects on the quality of the surrounding environment; increased soil salinity and thus loss of agricultural land; and the direct harmful impact on groundwater. Figure 2 shows El Tellin drain longitudinal layout and photos of the drainage wastewater discharged in drain. (Ministry of Water Resources and Irrigation (MWRI), Consulting Services for the Enhanced Water Resources Management Project (EWRMP), 2015)

There are four main sewage disposals in El Tellin drain. The disposal points are for draining sewage coming from five villages along the drain. The discharge of the drain in the inlet and outlet is 0.027 m³/s, 0.44 m³/s respectively. Figure 3(a) shows the Population 2015, Expected at 2025 for 5 villages discharged in El Tellin Drain, and Figure 3(b) shows the expected 2025 discharge m³/sec for 5 villages discharged in El Tellin Drain.

2.2.2. El Tellin in stream constructed wetland hydraulic design
The study is down year 2016 by Ministry of Water Resources and Irrigation, Egypt, and funded by World Bank, and GEF by project named Enhanced Water Resources Management Project—Project Environmental Management Plan Okda/Tellin Pilot Area. Design Elements consist of three main regions as follows: The first part is sedimentation zone that has been proposed to collect suspended particles. The length sedimentation zone is between (300–500) m. Two floating areas for native plants as shown in Figure 4 to take advantage of aquatic plants that use nutrients and to support microorganisms and...
**Figure 2.** El Tellin drain, Sharkya longitudinal layout and drainage wastewaters discharged in drain photos. (Ministry of Water Resources and Irrigation (MWRI), Consulting Services for the Enhanced Water Resources Management Project (EWRMP), 2015).

**Figure 3.** (a) Population 2015, expected at 2025 for 5 villages discharged in El Tellin Drain, and (b) Expected 2025 discharge m$^3$/sec for 5 villages discharged in El Tellin Drain.

**Figure 4.** (a) Represents the typical wetland design scenarios, Figure (b) A final design of the instream wetland along El Tellin Drain, and Fig. (c) A Layout of the final design in stream wetland along El Tellin Drain, Sharkya, Egypt.
convert them into less harmful forms. Each area is separated by internal weirs, and finally ends with end weir with height ranged from (0.7–1.0 m). Figure 4 represents the typical wetland design scenarios that should start to reach the final and best wetland scenarios that fit the drainage system in the study area. The measured velocities along the drain range from (0.02–0.1) m/s. The detention time over the drain is 55 hrs. The slope of the drainage bed ranges from (0.5–10) cm/km. (Ministry of Water Resources and Irrigation MWRI), World Bank, GEF. Enhanced Water Resources Management Project (EWRMP), 2016.

The design of wetlands is based on four main criteria: hydraulic load rate, detention time, plant density, entrance concentration. Therefore, the design will primarily depend on the increase detention time and use of native plants. Design steps include several HEC-RAS hydraulic modeling processes. Figure 4(a) represents the typical design scenarios that taken in HEC RAS model to calculate the designed scenario that reaches the longer detention time for the drain. Figure 4(b,c) represents a final design of the instream wetland along El Tellin Drain, and a Layout of the final design in stream wetland along El Tellin Drain, Sharkya, Egypt. The design included includes two weirs at 2850 m and 1050 m from the downstream. Each weir is preceded by an internal sedimentation zone as shown in Figure 4(b). Finally, the vegetation area extended in the last 1 km from the drain. The design decreases the velocities along the drain, therefore doubles the detention time. For the proper functioning of the specific in stream wetland, several checks were required: The velocity of the water should not exceed 0.05 m/s, the detention period must be at least 4 days, and different structures should not be close to culverts, villages, or sewage pipes. Based on the calculated detention time, average air temperature, wind speed, and solar radiation, the system’s removal efficiency has been estimated for different parameters.

2.3. Drainage treatment using in Stream Wetland Dakahlya Governorate—4th degree drain

2.3.1. Study area

The Wetland Study Area is located in the Faraa Al Bahwo Drain which is a fourth order agricultural drain, Dakahlia, Mansoura. Figure 5 shows the location of the site and photos of the drain site. The effective length of the drain is about 1710 m, and drains into the Al Bahwo Drain, a third order agricultural drain, which in turn drains partially into the Mit al Aamel Drain, and drains into the Al Nezam Drain. The Faraa Al Bahwo Drain contains mainly agricultural drainage water from the outlets of underground drainage collectors, some municipal wastewater from private house pipes, in addition to excess irrigation water from the outlets of some canals at its beginning. The width of the drain bed is approximately 5.0 m. The drainage area served is 1,269 feddans of agricultural land, with a drainage capacity of 30 m³/fed/day. The maximum flow rate of the drain is 0.44 m³/ sec at its end, which discharges into the Al Bahwo Drain (a third order drain, 2350 m long). The maximum flood level of the drain is 2.7 m AMSL (above mean sea level), the slope of the water along the drain is 25 cm/km, and the mean flood level in the drain is 2.59 m AMSL. The bed level of
the drain at its outlet is 2.0 m AMSL, with a bed slope of 35 cm/km and side slopes of 3 (horizontal): 2 (vertical). (CLEQM, 2001), (DRI & CLEQM, 2003).

2.3.2. System elements and hydraulic design scenarios
The optimum design should meet certain conditions related to minimum retention time, water surface elevation and costs. The typical channel system proposed for the in-stream wetland consists of a sediment trap zone, a floating aquatic plant zone, and an open water zone near the outlet boundary. Figure 6 shows the typical design scenarios that are used to determine the best scenario (El Gohary, 2006). In order to understand the hydrodynamic effect of each element in the typical PIW channel system, a group of 25 numerical runs have been proposed as listed in Table 4.

It has chosen retention time as a crucial design criterion for wetland systems instreams. The higher the retention time of the system, the better the water quality of the effluent. The study proposed different design scenarios. It was presented that retention time could be significantly increased from its typical present value of 6–8 hours to more than 68 hours (3 days), using simple elements (such as a sediment trap and weirs) forming a typical arrangement. After examining the importance of each element (sediment trap, spillway and baffles) in the typical arrangement, it was found that: The end weir plays the most important role in controlling detention time throughout the wetland system. The higher the crest of the weir, the longer the retention time produced by the system. Floating aquatic plants have little effect on the detention time produced. As the thickness of the floating aquatic plants increases and the air density of the plants is higher, the retention time increases.

It was also noted that flow variation has a non-linear response to retention time. For example, a 50% increase in Q results in a 36% decrease in retention time, while a 50% decrease in Q results in a 91% increase in retention time. It is proposed that the bed profile of the El-Bahwo Drain be gently reshaped to form the sediment trap. It is proposed that the sedimentation pit extends from the inlet of the drain over a length of 520 m. It should be mentioned that the sedimentation trap needs to be rehabilitated and maintained regularly (the minimum rate of reformation and excavation is bi-monthly). An area of approximately 0.5 feddan should be allocated to the wetland area to receive the sediment trap sludge. This mud will be transported out of the area after the drought.

As mentioned previously, the end weir plays the most important role in controlling retention time throughout the in stream wetland system. As the water level in the drain is expected to vary over time, it is proposed that an adjustable crested end weir be constructed. The weir consists of a concrete weir of 25 and a number of wooden logs (5 logs) each 10 cm high. If all the logs are fixed, the total height of the weir reaches 75 cm.

2.4. Drainage treatment using Moringa Oleifera

2.4.1. Laboratory procedures and case studies
M. Oleifera seeds were collected from the National Research Center. Dokki, Cairo, Egypt. Moringa seed husks were removed and dried. The white grains were crushed into a fine powder. An amount of 5 gm seed powder was dissolved in 1-liter sterile water and stored 7 days in the refrigerator at 3 ° C. The solution was shaken for one minute to extract and activate the coagulated proteins in the seed powder. Then different concentrations of M. Oleifera Seed solution (350–400– 450–500– 550-
Table 4. Instream wetland numerical runs for HEC RAS model

| Run   | Q%     | Weirs  | Weirs  | Vegetation |
|-------|--------|--------|--------|------------|
|       |        | A      | D      | B          | C          | A-B | B-C |
| Run 1 | 100%   |        |        |            |            |      |     |
| Run 2 | 100%   |        |        |            |            |      |     |
| Run 3 | 100%   |        |        |            |            |      |     |
| Run 4 | 100%   |        |        | 30 cm      |            |      |     |
| Run 5 | 100%   |        |        | 50 cm      |            |      |     |
| Run 6 | 100%   |        |        | 30 cm      |            |      |     |
| Run 7 | 100%   |        |        | 50 cm      |            |      |     |
| Run 8 | 100%   |        |        | 75 cm      |            |      |     |
| Run 9 | 100%   |        |        | 50 cm      | 50 cm      |      |     |
| Run 10| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      |      |     |
| Run 10A| 100%  | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.06, t = 5 cm |     |
| Run 10B| 100%  | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.06, t = 5 cm |     |
| Run 11| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.03, t = 5 cm |     |
| Run 12| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.03, t = 5 cm | n = 0.03, t = 5 cm |
| Run 13| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.02, t = 5 cm | n = 0.02, t = 5 cm |
| Run 14| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.01, t = 5 cm | n = 0.01, t = 5 cm |
| Run 15| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.03, t = 10 cm | n = 0.03, t = 10 cm |
| Run 16| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.03, t = 10 cm | n = 0.03, t = 20 cm |
| Run 17| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.03, t = 20 cm | n = 0.03, t = 20 cm |
| Run 18| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.02, t = 20 cm | n = 0.02, t = 20 cm |
| Run 19| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.01, t = 20 cm | n = 0.01, t = 20 cm |
| Run 20| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.02, t = 10 cm | n = 0.02, t = 10 cm |
| Run 21| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.02, t = 10 cm | n = 0.02, t = 10 cm |
| Run 22| 100%   | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.02, t = 10 cm | n = 0.02, t = 10 cm |
| Run 23| 50%    | 50 cm  | 50 cm  | 25 cm      | 25 cm      | n = 0.02, t = 10 cm | n = 0.02, t = 10 cm |

600) mg/L were prepared by adding (70–80-90-100-110-120) ml of M. Oleifera extract respectively to 6 cups containing 6 liters of raw water. The jars were then quickly stirred for 60 seconds and then slowly for 20 units using the VELP flocculator. Then allow raw water to stand for 30 minutes to settle down. Sewage water samples were collected from Giza Governorate to apply the physical chemical parameters test. The remedy used is M. Oleifera to be used as a coagulant and then clear the pottery used for filtration. An equipment was prepared as shown in Figure 7 to proceed the experiment. It was filled raw water in the first precipitation tank for 6 hours. Pass the water to the second tank and add the M.Oleifera solution at an appropriate concentration resulting from the 12-hour jar test. Then pass the treated water to the last tank containing pottery for 6 hours. We
collected 100 ml of supernatant from all solutions and filtered the solution with the help of filter paper and then the solution was tested to monitor changes in pH, EC, TDS, alkalinity, hardness and sulfate. All of these tests were also repeated 1 hour, 1.30 hours and 2 hours later. The collected water samples were analyzed to different criteria with the help of the WHO guidelines on drinking water quality. The parameters are: pH, electrical conductivity, total dissolved solids, alkalis, hardness and sulfate.

2.4.1.1. Aeration weirs in wastewater treatment a case study
2.4.2. Study area
The objective of this study is to investigate the feasibility of establishing weir structure in Egyptian drainage system that is capable of purifying water heavily polluted with sewage to reduce health risk associated with the reuse for irrigation or aqua system. This goal can be achieved by making changes in the hydraulic properties of open drains by putting weirs in the path of water. The main advantage of this technique lies in the fact that it doesn’t need any power to add oxygen and requires minimum labor for operation and maintenance. The studied area was lies in El Rahawy drain, which is situated between the city of El Ayat at south and Rosetta branch at the north with length of about 74 km and drain its water to Rosetta branch with discharge of 2.5 million m³/day at kilometre 9.60 and its area served is 145 feddans. El Rahawy receives drains “Al Ganabya al Yomna, El Moheet, al Ganabya al Yosra, and El Lbene” as well as primary or untreated sewage from Zeneen and Abou Rwash wastewater treatment stations with total disposal of 1.9 million m³/day in addition to the output of sewage treatment plants from five stations (Minshet el Kanater—Thormous—Al Hawamdy—Al Badrasheen—Shabramant). Moreover, wastewater from factories and industrial companies and local units “at about 14 polluted points” acted without authorization over the drain and its branches which are at end drains at Rosetta branch. Figure 8 shows the study area layout and photos from El Rahary drain and weir in the study area.

3. Results and discussion
3.1. Treatment efficiency for in stream Wetland Area1- El Tellin Drain, Sharkya, Egypt
Water quality parameters are measured every three months. Figure 9 shows water quality concentrations from August and October 2014, 2015 for EC, TDS, and oil& grease before and after wetland treatment. Figure 10(a) shows BOD (mg/l), COD (mg/l), and Coli form (CFU/I) concentrations for samples in the site location for year 2014 2015 and after wetland treatment. The measurements show an increase in electrical conductivity, TDS, BOD, COD, and fecal coli. The quality of the water measured along the drainage does not always correspond to the locations of the sewer pipes. Some factors that affect the quality of wastewater other than disposal of wastewater are the presence of culverts and hyacinths. The culverts are not well maintained, and therefore most culverts are expected to be blocked along the drainage more than 30%, therefore
increases the detention time at the waterways, and increases the efficiency. Moreover, the hyacinth-covered areas are expected to increase drainage water quality. This encourages farmers to reuse drainage wastewater in some locations. The removal efficiency ranged from 35% to 75% for total removal of suspended solids, from 58% to 30% for removal of BOD, from 57% to 44% for COD removal, and 99% for Fecal Coliform removal.

3.2. Treatment efficiency for in stream Wetland Area2- El Bahw Drain, Dakahlya Governorate

Water quality parameters are measured every month for year 2003, and 2004 before treatment and for year 2006 after treatment. Figure 11(a) shows that the bicarbonate ranges between 250 and 1600 mg/l all the monitoring period from 8/10/2003 to 12/6/2004 and the point source 81 has high records all the period this may be because it needs more public awareness to highlight the negative impact of this pollutant on the human health, and After In-Stream Wetland (From 19/1/2006 to 12/6/2006), the concentration ranges between 200 and 1000 mg/l and reaches to 1500 mg/l only in the construction period at 19/1/2006 and this increase may be due to winter closure period plus the construction period, the removal efficiency reaches to 83.33%. Figure 11(b) shows that EC concentration is relatively high at the beginning of the drain just downstream the point source of pollution, a reduction in EC concentrations while approaching the outlet of the drain was detected, the first monitoring location shows the highest values with a variation between 1.8 and 3.9 (ds/m), while after 200 m a considerable degradation occurs, and variation lies between 1.1 and 2.4 (ds/m), while a little increase appears due to adding loads from the subsurface agricultural drainage pipes allocated on the drain downstream the point source of pollution. After In-Stream Wetland, Concentration ranges between (2–4) mg/l, and peaks to 6 mg/l at the point source at construction period and this peak may be due to winter closure plus the effect of construction period, concentration ranges between (1.8–2) mg/l at operation period all the downstream points, and the removal efficiency could reach until 50%, and this removal
efficiency could be improved in the near future after the wetland process doing its role in eliminating the pollutant and improve water quality if it is operating well. Figure 11(c) shows that TDS is stable and varies in narrow range downstream reaches where more drainage water is mixed with the wastewater. The TDS upstream values vary between 2000 and 4000 mg/l and are reduced downstream varying between 900 mg/l to 1500 mg/l. The heavy metals present in drainage water samples are within allowable limits according to national law (48/82) and FAO recommended guidelines for reuse in agriculture. Stable and varies in narrow range downstream reaches where more drainage water is mixed with the wastewater. After In-Stream Wetland, concentration ranges between (0–2000) mg/l, and peaks to 4000 mg/l at the point source at construction period, ranges between (350–1200) mg/l at operation period. The removal efficiency could reach to 44.2% and this removal efficiency could be improved in the near future after the
wetland process doing its role in eliminating the pollutant and improve water quality if it is operating well. Figure 11(d) shows that TSS at the point source shows high levels as well as high variability, it varies between 200 and 1000 mg/l in all months except in the winter closure it rises to 5000 mg/l. Although, it is noticed that in other locations TSS records vary between 36 and 300 mg/l which are within allowable limits according to national law (48/82) and FAO recommended guidelines for reuse in agriculture. After In-Stream Wetland, concentration ranges between (0–9000) mg/l at construction period, ranges between (0–7000) mg/l at operation period. The removal efficiency could reach to 20% and this removal efficiency could be improved in the near future after the wetland process doing its role in eliminating the pollutant and improve water quality if it is operating well.

Figure 12(a) shows that BOD at 1.6 km upstream the outlet, just after the point source of pollution, it varies between 200 and 1800 in all months except in the winter closure until May it is noticed a high variation which rises until 11000 mg/l which of course higher than water quality slandered in law 84/1982 (not exceed 10 mg/l). While just 200 m downstream the source of pollution a considerable amount of degradation occurs, which is physically understood due to the water treatment along the drain until the outfall which is totally treated. After In-Stream Wetland (From 19/1/2006 to 12/6/2006), concentration ranges between (0–100) mg/l, and peaks to 1600 mg/l at the point source at construction period, ranges between (0–50) mg/l at operation period. The removal efficiency could reach to 60%. Figure 12(b) shows that COD records shown in figure indicate that a high level is obvious at the first location downstream the point source of pollution. Records around 2000 shown in the first location upstream are rapidly decreased by about 40% in the first 200 m after the point source, at the second location. Decreasing in the COD records by about 80% is clear at the third location, which is about 1 km upstream of the drain outlet, however records measured at the last location located 0.2 km from the outlet show that records still above the standard allowed of Law 48/1982 (not exceed 6). Also, it is noticed that the records from January till May at the point source have a dramatically pollutants as it is varying.
from 2000 to 25000 mg/l this may be due to winter closure in February, also due to human action. This will need a public awareness in this area as its bad affect downstream the point source where the in-stream wetland works in treating the drain. After In-Stream Wetland (From 19/1/2006 to 12/6/2006), concentration ranges between (0–2000) mg/l at construction period, ranges between (0–1500) mg/l at operation period. The removal efficiency could reach to 85%. Figure 12(c) shows that Calcium concentrations show relatively higher values in the first location than that in the downstream locations. Calcium concentration at the first location near the point source of pollution varies between 50 and 200 mg/l all months except from February till May it increases to 380 mg/l. All the station downstream the point source the records are varying between 10 and 50 mg/l. After In-Stream Wetland (From 19/1/2006 to 12/6/2006), concentration ranges between (20–120) mg/l at construction period, ranges between (10–120) mg/l at operation period. The removal efficiency could reach to 63%. Figure 12(d) shows that Potassium concentrations show relatively higher values in the first location than that in the downstream locations. Potassium concentration at the first location near the point source of pollution varies between 20 and 200 mg/l. All the stations downstream the point source the records are varying between 100 and 5 mg/l. After In-Stream Wetland (From 19/1/2006 to 12/6/2006), concentration ranges between (20–200) mg/l, and peaks to 200 mg/l at the point source at construction period, ranges between (5–160) mg/l at operation period. The removal efficiency could reach to 88%.

Figure 13(a) shows that Magnesium concentrations show relatively higher values in the first location than that in the downstream locations. Magnesium concentration at the first location near the point source of pollution varies between 50 and 300 mg/l. After In-Stream Wetland (From 19/1/2006 to 12/6/2006), concentrations between (0–70) mg/l at operation period. The removal efficiency could reach to 20%. Figure 13(b) shows that Lead concentration at all points varies between 0 and 1 mg/l, at the period of winter closure 2004 the concentration jump to 1 mg/l from around 0 mg/l, it is noticed that at the construction and operation period the concentration not exceeds .01 mg/l at all point. After In-Stream Wetland the concentration not exceeds .01 mg/l at all points. The removal efficiency could reach to 90%. Figure 13(c) shows that Total Coliform concentration at the point source varies between 0 and 3000000000 CFU/100 mg, at the other points it varies between 0 and 50000000 CFU/100 mg. The allowable limits according to national law (48/82) (Not exceed 5000 MPN/100 mg). After In-Stream Wetland, concentration ranges between (0–50000000) FCU/100 mg, and peaks to 30000000 FCU/100 mg at the point source at construction period, ranges between (80x10^3–25x10^3) mg/l at operation period. The removal
efficiency could reach to 99%. Figure 13(d) shows that Fecal coliform counts indicate significant difference between the first location and the other three locations, the first location shows also high variability. Presence of a sewage source of pollution at the beginning of the drain is the reason of high counts indicated at the first. Fecal Coliform is correlated to BOD records shown above. Fecal Coliform concentration at the point source varies between 0 and 35000000 CFU/100 mg, at the other point it varies between 0 and 10000 CFU/100 mg. After In-Stream Wetland, concentration ranges between (0–500000) FCU/100 mg, and peaks to 70000000 FCU/100 mg at the point source at construction period, ranges between (14x10^3–16x10^4) mg/l at operation period. The removal efficiency could reach to 99%.

Figure 14. Water quality analysis for the experiment after Mo treatment, and after Pottery as filtration.
3.3. Treatment efficiency for drainage system using Moringa Oleifera

Physico-chemical analysis of collected water sample was done before & after treatment with M. oleifera seed. Figures 14 and 15 show the water quality analysis for the experiment.

It was determined that once treatment with M. oleifera seeds, the pH scale worth decreases with increasing concentration of Moringa seed powder and conjointly decreasing with increasing hours of treatment. There’s a small decrease within the pH scale once half-hour of treatment, however the pH scale falls a lot of once an hour and continues to decrease till 2 hours of treatment. Similar results have already complete by other researchers (Hendrawati et al., 2016; Kumar & Trivedi, 2016). It was noticed that there is an inverse relationship between EC concentrations and M. oleifera seed powder doses. Similar results were concluded by other researchers (Hendrawati et al., 2016).

TDS decrease with increasing M. oleifera seed powder dose with time from 30 min to 3 hrs. This results that M. oleifera seed is effective as a coagulant for raw water purification. The raw water samples alkalinity decreases with increasing concentrations of Moringa seeds. All parameters were reduced with an hour, and the maximum was in wastewater with respect to pH, alkalinity. It is clear that M.oleifers is an environmentally friendly, cheapest, and simple treatment method to purify water. Therefore, it can be used in rural communities where there are no equipment available to treat drainage waste water.

3.4. Treatment efficiency using aeration weirs in drainage system

Data for Rahawy drain study area were obtained from the Drainage Agency and The General Management of Drainage in Giza and they are as follows: Agricultural drainage discharge of 894000 m³/day—Wastewater from Zenein treatment plant 430000 m³/day—Bottom width 18 m—Bottom slope 7 cm/km. Initial concentrations of the simulated water quality parameters were analyzed to the drain conditions for an agricultural open drain receiving sewage. This data was obtained from 4 locations along Rahawy drain (100 m before the existing weir—50 m before weir—just before the weir—50 m after the weir. The existing weir with a height of 60 cm at the end of

Figure 16. (a) PH concentrations for samples in the site location, (b) EC (mmhos/m) concentrations for samples in the site location, and (c) TDS (mg/L) concentrations for samples in the site location.
Figure 17. (a) Bicarbonate HCO₃ (mg/l) concentrations for samples in the site location, (b) Chloride Cl mg/l concentrations for samples in the site location, and (c) Phosphate PO₄ (mg/l) concentrations for samples in the site location.

Rahawy drain. It is clear that from Figure 16 that Ec decreased from 1.4 mg/l to 1.08 mg/l with removal efficiency 77.1%, TDS decreased from 754 mg/l to 743 mg/l with removal efficiency 98%. Figure 17 shows that Bicarbonate HCO₃ decreased from 356 mg/l to 331 mg/l with removal efficiency 92.9%, Chloride Cl decreased from 261 mg/l to 250 mg/l with removal efficiency 95.8%, Phosphate decreased from 138 mg/l to 115 mg/l with removal efficiency 83.3%.

4. Conclusion

The present study evaluated four rural communities in Egyptian drainage areas using three low-cost wastewater technologies by using instream wetland, using M. Oleifera, and finally using aeration weirs for increasing the water quality and the results showed that:

- The removal efficiency for El Telin wetland ranged from 35% to 75% for removal of suspended solids, from 58% to 30% for BOD, 57–44% for COD, and 99% for fecal coliform. While removal efficiency for El Bahwo instream wetland is 50% for EC, 83.33 for bicarbonate, 44.2% for TDS, 20% for TSS, 60% for BOD, 85% for COD, 63% for calcium, 88% for potassium, 20% for magnesium, 90% for lead, 99% for total and fecal coliform. Sediments can be used for the production of bricks, ceramics, etc. and the growing edges of plants free from toxic elements are used as fodder or fuel.

- The optimum design should meet certain conditions related to minimum retention time, water surface elevation and costs. The typical channel system proposed for the in-stream wetland consists of a sediment trap zone, a floating aquatic plant zone, and an open water zone near the outlet boundary.

- The design of wetlands is based on four main criteria: hydraulic load rate, detention time, plant density, entrance concentration. Therefore, the design will primarily depend on the increase of the detention time and use of native plants. The design decreases the velocities along the drain, therefore doubles the detention time. For the proper functioning of the specific in stream wetland, several checks were required: The velocity of the water should not exceed 0.05 m/s, the detention period must be at least 4 days, and different structures should not be close to culverts or any irrigation structure if any, villages, or sewage pipes. Based on the calculated detention time, average air temperature, wind speed, and solar radiation, the system’s removal efficiency has been estimated for different parameters. For El Tellin Drain the absence of four culverts has a negative impact on wetland efficiency as the selected reach of the drain must have no physical obstacles that prevent site accessibility and/ or equipment movement. Infrastructure facilities on the drain banks or side roads (e.g. irrigation aqueducts, any gas, water, electricity, telephone pipes or cables, etc.).

- The results showed a removal efficiency when using M. Oleifera of 70.9 for apparent color and 85.1% for turbidity, and 96.1 % for total coliform and 82.8% for total coliform. M. Oleifera seeds have an excellent adsorbent property that has been used to remove accompanying
substances such as minerals, organic materials and pesticides. Its removing efficiency was 60% for arsenic, 85% for cadmium, and 90% for nickel.

- Weir structure in Egyptian drainage system is capable of purifying sewage water in order to reuse for irrigation the results show that the weir efficiency could reach to 77.1% for EC, 98% for TDS, 92.9 for bicarbonate, 95.8% for chloride, and 83.3% for phosphate.
- The studied technologies offer a cheaper alternative to conventional treatment methods without using any chemical substances for treatment and provide minimum operation and maintenance needs which is suitable for rural communities.

5. Recommendations

- It should be mentioned that the proposed in-stream wetland requires at least a bimonthly removal of sludge deposition from the sediment trap, and sediments can be used for the production of bricks, ceramics, etc., and the growing edges of plants free from toxic elements are used as fodder or fuel.

- A reduction of the efficiency of the system might take place if the depositions are not regularly removed. During the monitoring period, it is recommended that the monitoring program includes the effects of the aquatic plants and the fecal decay coefficients. To minimize the failure risk, three elements should be considered; public acceptance and participation, dredging management of sediments and vegetation control.

- The in-stream wetland could be replicated to cover larger percentage of Egyptian drains and from the analysis done it highly recommend using M. Oleifera beside native plants in wetland especially in sedimentation zone which is the main element in wetland. Taking into consideration these terms Model and designs versus lessons learned and experience gained.

- Pollution type (agriculture, sewage, Industrial, mixed types).
- Design criteria (climate, soil type, native vegetation).
- Capacity, Land availability, required treatment stage/level.
- It is recommended to study the effect of changing of weir width and weir length on weir aeration process and its effect in wetland system as an aeration source that could increase the water quality thus increasing wetland efficiency. Also study the effect of sewage pollution concentration, discharge, and temperature on weir aeration process.

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References

Acheampong, M., Joana, P., Roel, J., & Piet, N. (2012). Kinetics modelling of Cu(II) biosorption on to coconut shell and Moringa oleifera seeds from tropical regions. Environmental Technology, 33(4), 409-417. https://doi.org/10.1080/09593330.2011.576765

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Disclosure statement

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Ali, E., Muhibi, S., Salleh, H., Alam, M., & Salleh, R. (2010). Production of natural coagulant from Moringa oleifera seed for application in treatment of low turbidity water. Journal of Water Resource and Protection, 2(1), 259–266. https://doi.org/10.4236/jwarp.2010.23030

Arvind, K., Krishna, R., & Ajay, B. (2019). Sustainable engineering-sustainable engineering (Vol. 30). Springer Nature Singapore Pte Ltd. https://doi.org/10.1007/978-981-13-6717-5

Bagatur, T. (2009). Evaluation of pre-aeration with V-notch weir and cascades structures in clarifiers. Journal of Environmental Engineering, 135(3), 176–184.

Baylar, A., Bagatur, T., & Tunca, A. (2001). Aeration Performance of Triangular Notch Weirs at Recirculating System. Water Qual. Res. J. Canada, 36(1), 121–132. https://www.cwqrc.ca/journal/temp/article205.pdf

Baylar, A., & Emirouglu, M. E. (2002). The effect of sharp-crested weir shape on air entrainment. Canadian Journal of Civil Engineering, 29(1), 375–383.

Beltrán, J., & Sánchez, J. (2009). Removal of sodium lauryl sulphate by coagulation/flocculation with Moringa oleifera seed extract. Journal of Hazardous Materials, 164 (2-3), 713–719. https://doi.org/10.1016/j.jhazmat.2008.08.053

Bina, B., Mehidinejad, M., Dalhammer, G., Rajoroo, G., Nikoone, M., & Movahedian, H. (2010). World academy of science, engineering and technology. International Journal of Environmental and Ecological Engineering, 4(7), 261–263. https://doi.org/10.5281/zenodo.1060399

Central Laboratory for Environmental Quality Monitoring CLEQM. (2001). A Passive wetland water quality management system incorporating the existing drainage canals (A Conceptual proposal for treating village drainage and irrigation return flow for reuse). pp. 40–56

Drainage Research Institute DRI & Central laboratory for Environmental Quality Monitoring CLEQM. (2003). Literature review of natural wastewater treatment systems (CLEQM Report). pp. 20–37.

El Gohary, R. (2006). In stream wetland water quality management system (PhD. Thesis). Faculty of Engineering Ain Shams University.

Emirouglu, M. E. & Baylar, A. (2003). The effect of broad-crested weir shape on air entrainment. Journal of Hydraulic Research, 41(6), 649–655. doi:10.1080/00221680390566897

Gulliver, J. S. & Rindels, A. J. (1993). Measurement of air-water oxygen transfer at hydraulic structures. Journal of Hydraulic Engineering, 119(3), 327–349. https://doi.org/10.1061/(ASCE)0733-9429(1993)119:3(327)

Hamza, W., Osman, A., & Elshiekh, F. (2016). Effect of Moringa seed powder on blue rille water purification as compared to poly aluminum chloride. International Journal of Science and Research (IJSR,Vol.5-Issue 12). 1574–1579. https://doi.org/10.21274/IJSR.2016.13753

Hendrawati, R., Yuliastri, N., Eti, R., Hefni, E., & Latfiah, K. (2016). The use of Moringa oleifera seed powder as coagulant to improve the quality of wastewater and ground water IOP Conf. Series: Earth and Environmental Science, 31 (2016) 012033, 1–10. https://doi.org/10.1088/1755-1315/31/1/012033

Kohl, M. & Seif, H. (2016). Mathematical Modeling of Wastewater Aeration Efficiency using Natural Stepped Cascades. Civil and Environmental Research, 6(5), 41–47. https://www.researchgate.net/publication/301286654

Kotayan, S., Megat, M., Amsa, M., Abdul Gani, L., Thamer, M., Azni, I., Ahmad, B., Khor, C., & Suleyman, A. (2006). Effects of storage conditions of Moringa oleifera seeds on its performance in coagulation. Bio-resource Technology, 97 (13), 1455–1460. https://doi.org/10.1016/j.biotech.2005.07.031

Kumar, K., & Trivedi, L. (2016). Moringa oleifera seeds: An efficient & cost effective bio alternative for water waste treatment. International Journal of Botany Studies, 2(5), 40–45. http://www.researchgate.net/publication/301298887

Kumari, P., Sharma, P., Srivastava, S., & Srivastava, M. (2006). Biosorption studies on shelled Moringa oleifera Lamark seed powder: Removal and recovery of arsenic from aqueous system. International Journal of Mineral Processing, 78(3), 131–139. https://doi.org/10.1016/j.minpro.2005.10.001

Lea, M. (2010). Bioremediation of turbid surface water using seed extract from Moringa oleifera Lam (drumstick tree). Current protocols in microbiology Chapter 1: Unit1G2. https://doi.org/10.1002/9780470772925.mcl012016

Marandi, R., & Bokhtiar, M. (2012). Removal of orange 7 dye from wastewater by natural adsorbent of moringa oleifera seeds. American Journal of Environmental Engineering, 1(1), 1–9. https://doi.org/10.5923/j.ajee.20110101.01

Ministry of Water Resources and Irrigation (MWRI), Consulting Services for the Enhanced Water Resources Management Project (EWRMP). (2015). Environmental assessment study - Okda and Telin Pilot Scheme/Volume 1: Main report. Arnhem, Netherlands: Euroconsult Mott MacDonald Ameerstudoomsegw. http://pubdocs.worldbank.org/en/1581061522152747710/EA-Volume-1-OKDA-TELIN-Final.pdf

Ministry of Water Resources and Irrigation (MWRI), World Bank, GEF. Enhanced Water Resources Management Project (EWRMP). (2016). Egypt Okda and Telin Pilot Project Environmental Management Plan Okda/Telin Pilot Area. Grant No TF 012592. Project No 325837. Arnhem, Netherlands: Euroconsult Mott MacDonald Ameerstudoomsegw in association with Altera, Deltares, Capacity Building International, Chemonics Egypt Consultants. http://documents.worldbank.org/curated/en/409514972871308045/I1-纪录-Document-P118090-2017-06-01-13-59-FINAL-06072017.pdf

Munirat, I., Mohamed, J., Ademola, H., & Parveen, J. (2016). Moringa Oleifera seed extract: A review on its environmental applications. International Journal of Applied Environmental Sciences, 11(6), 1469–1486. 0973-6077. http://www.researchgate.net/publication/312069731

Nag, M., Mohammeh, H., Mohammad, T., & Ghazoli, H. (2013). Effect of the packaging and storage conditions on the coagulation activity of spray-dried salt-extracted Moringa oleifera Desealination and Water Treatment, 51(7–9), 1947–1953. https://doi.org/10.1080/19943994.2012.715428

Okuda, T., Boes, U., Nishijima, W., & Okoda, M. (1999). Research note: improvement of extraction method of coagulation active components from moringa oleifera seed wastewater. Research, 33(15), 3373–3378. https://doi.org/10.1002/s0043-1354(99)00046-9

Okuda, T., Boes, U., Nishijima, W., & Okoda, M. (2001). Isolation and characterization of coagulant extracted from Moringa oleifera seed by salt solution. Water Research, 35(2), 405–410. https://doi.org/10.1016/S0043-1354(00)00290-6

Poommai, S., Chunkao, K., & Bualerd, S. (2012). Variation of oxygen transfer along the rectangular weir crest distance of wastewater treatment pond. Proceedia Environmental Sciences, 13, 498–512. doi:10.1016/j.proenv.2012.01.041

Sharma, P., Kumari, P., Srivastava, M., & Srivastava, S. (2006). Removal of cadmium from aqueous system by shell Moringa oleifera Lam. seed powder. Bio-resource
Sharma, P., Kumari, P., Srivastava, M., & Srivastava, S. (2007). Ternary bio-sorption studies of Cd(II), Cr(III) and Ni(II) on shelled Moringa oleifera seeds. Bio-resource Technology, 98(2), 474–477. https://doi.org/10.1016/j.biortech.2005.12.016

Vanderkooi, G. T., & Schram, A. H. (1969). Weir aeration—part I: single free fall. Water, 2(22), 528–537. https://edepot.wur.nl/405313

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