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Design Steps and Performance of Aerated Lagoon, Oxidation Ditch and Wetland Methods for Erbil Municipal Wastewater Treatment and Reusing

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A R T I C L E I N F O

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A B S T R A C T

The objectives of the current study were to investigate the characterization, treatment techniques and reuse of fresh municipal wastewater (MWW) from the east-south area of Erbil city, Kurdistan Region, Iraq. The collected wastewater samples were analyzed for 21 quality parameters. Some of the quality parameters such as color (146 Pt. Co and 337 Pt. Co), total solids (800 mg/L), suspended solids (400 mg/L and 1100 mg/L), nitrate (17.7 mg/L), nitrite (11 mg/L and 29 mg/L), and ammonia (2.09 mg/L and 2.64 mg/L) exceeded the standards for wastewater disposal. Accordingly, treatment was required before the wastewater could be discharged to the natural environment. Treatment techniques such as aerated lagoons, oxidation ditches, and wetlands were designed and investigated. Design procedures, calculations, and performance for each treatment method were explained. The total area designed for aerated lagoons, oxidation ditches, and wetlands was 72000 m^2, 17180 m^2, and 25200 m^2, respectively. In general, the wetland method was the most effective method with efficiencies of 91.6 % for biochemical oxygen demand, 90.4 % for chemical oxygen demand, 85.7 % for ammonia, and 91.8 % for suspended solids. Treated wastewater can be reused for irrigation purposes and is completely safe for irrigation. The use of treated wastewater from the east-south part of the city of Erbil for irrigation instead of drinking water is economical and leads to the conservation of drinking water sources.

1. Introduction

The expansion of urban populations and increasing attention to domestic water supply and sanitation are resulting in greater volumes of municipal wastewater (MWW). Given the importance placed on environmental health and water pollution, there is a growing awareness of the need to dispose of this wastewater in a safe and

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beneficial manner. The use of wastewater in agriculture could be an important issue when planning disposal in arid and semi-arid areas. However, it should be realized that the amount of wastewater available in most countries will be a small fraction of the total water demand for irrigation. However, the use of WW will lead to the protection of higher quality water and its use for purposes other than irrigation. Since the negligible cost of an alternative supply of good quality water is generally higher in areas of water scarcity, it makes sense to integrate agricultural reuse into water resource and land use planning (Pescod, 2013). Water reuse is a fundamental component of water demand management that promotes the protection of high-quality freshwater and reduces both pollution and overall supply costs (Shakir et al., 2017).

Increasing efficiency in crop management and continuous increase in crop yields have increased the demand for water resources for irrigation purposes. In many countries around the world, WW is reused for irrigation purposes (Toze, 2006; Al-Murshady et al., 2021; Kesari et al., 2021; Ramirez et al., 2021; Ortega-Pozo et al., 2022). In many countries, water is becoming an increasingly scarce resource and planners are forced to consider all sources of water that can be used economically and efficiently to support further development. At the same time, as the population is growing at a high rate, increasing food production appears to be critical. One of the first reasons for this problem is that the proportion of water available for human consumption in rivers and streams, lakes, reservoirs, and aquifers is not evenly distributed throughout the world (Sophocleous, 2004). The authors noted that agriculture has increased in recent decades, which has increased pressure on groundwater resources and the need for pumping energy, and has affected the North Western Sahara Aquifer System (NWSAS). The NWSAS is located in North Africa and covers large areas in Tunisia, Algeria, and Libya. It holds invaluable groundwater resources that are necessary for sustaining livelihoods in the area. Therefore, researchers have planned another source for irrigation instead of groundwater, through the treatment of wastewater and reuse for agriculture (Ramirez et al., 2021). Due to drought years and impact on water resources and direct use of raw wastewater for irrigation in Erbil, Babylon, Karbala, Diwaniya, and Najaf provinces in Iraq, wastewater has been treated to replace water sources and ensure acceptable water quality for irrigation (Aziz et al., 2019; Al-Murshady et al., 2021). Because there is not enough irrigation water available, many low-income countries in Asia. Africa, and Latin America use untreated WW as a source for irrigation. In contrast, middle-income countries, such as Jordan, Tunisia, and Saudi Arabia, use treated wastewater for irrigation (Kesari et al., 2021). In addition, China tops the list of Asian countries for wastewater reuse with an estimated $1.3 \cdot 10^6$ hectares, including India, Vietnam, and Pakistan (Kesari et al., 2021).

Consequently, 40 % of the total land area is arid and includes climatic zones classified as arid, semi-arid, and dry sub-humid (Koohafkan and Stewart, 2008). At the same time, the increasing demand for water resources is a result of population growth, economic development and raising the standard of living, climate change, and pollution (Mujumdar, 2013).

It is estimated that more than 40 % of the world's population will face water stress or scarcity in the next 50 years, providing a serious incentive to find sustainable management options for water resources (WHO, 2006). Reuse of treated wastewater (TWW) is a viable option that is being forced in some cases by the lack of viable alternatives. In addition to reducing the use and withdrawal of freshwater, wastewater reuse also helps reduce the discharge of wastewater into freshwater ecosystems. In this scenario, WW increasingly becomes a valuable resource rather than a waste product. Certainly, irrigation with treated wastewater is already practiced, mainly in agriculture and landscaping (Bixio et al., 2006; Aziz et al., 2019; Aziz, 2020; Al-Murshady et al., 2021; Ramirez et al., 2021; Ortega-Pozo et al., 2022).

Wastewater in Erbil city is composed of domestic, commercial, washing and industrial sources. On the other hand, irrigation with wastewater raises health problems (risks of viral and bacterial infections for both the farmer and the plants) and agronomic problems due to the presence of toxic substances. To avoid health risks and damage to the natural environment, wastewater must be treated before being used for agricultural and landscape irrigation.

Nowadays, as climate change is affecting water resources and droughts are becoming more frequent, measures to adapt to the effects of climate change are urgently needed. To solve this problem, water can be used for irrigation in agriculture.

The main goal behind reusing wastewater is to close the water cycle on a much smaller, local scale. In this way, once properly treated, wastewater becomes a valuable water resource rather than a waste to be disposed of. Water reuse is the most difficult decision to make because these water sources are the lowest quality and therefore require advanced treatment.

Rapid climate change can lead to long periods of drought that directly affect the availability and dependence on groundwater for irrigation. During long periods of drought, there is a greater risk that aquifers will dry up, especially if they are small and shallow. In this case, irrigation cannot depend on groundwater for this reason. Irrigation from groundwater should be reduced and more groundwater should be recharged by treated water. This can be done by two methods (1) surface application or infiltration and (2) direct injection into the aquifer (Asano, 2006).

The disposal of wastewater from the east-south part of

Erbil city causes problems for the natural environment. Therefore, the wastewater generated must be treated before it is discharged into the environment or used for irrigation. In addition, depletion of groundwater table and use of potable water for irrigation are other shortcomings in the water sector of Erbil city. The objectives of the present work were to 1) study the characteristics of raw wastewater from the east-south part of Erbil city, 2) present suitable treatment methods such as aerated lagoons, oxidation ditches, and wetlands, and 3) reuse the wastewater for irrigation purposes in Erbil city. In the literature, aerated lagoons, oxidation ditches and wetlands have been used to treat urban wastewater (USEPA, 2000; Gikas and Tsihrintzis, 2014; Hadisoebroto et al., 2014; INDITEX, 2015). To date, this type of study has not been conducted in Erbil City.

2. Material and Methods

2.1. Site description

Erbil is the capital of the Kurdistan Region of Iraq. It is located about 350 km north of the city of Baghdad. The population of Erbil City is about one million people. Its boundaries extend from longitude 43° 15' E to 45° 14' E and latitude 35° 27' N to 37° 24' N. The canal that carries sewage is located at 36° 08.780' N and 044° 04.203' E. Sewage from Zeelan City, Hawkary Q., part of Hasarok 5 Q., Alton City, Zagros Q., Zaiton City, Ala City and Awenae Shar City flows into the said canal. In addition, the discharge (Q) was measured at the site and was 0.5 m^3/sec.

2.2. Sample collection

Samples were collected in clean containers in the east-south area of Erbil city. Fresh wastewater samples were collected in commercial 1.5-L plastic containers. During this investigation, two water samples were collected on February 25, 2018 and March 27, 2018. In accordance with the Standard Method for Water and Wastewater Testing, American Public Health Association (APHA) (2005). Samples were immediately transported to the Sanitary and Environmental Engineering Laboratory and stored in a dark, cold room at 4 °C prior to experimental use to avoid biological activity and changes in the samples. Samples were collected from the surface at a depth of approximately 30 cm.

WW samples were analyzed for their chemical and physical properties. The experiments were performed according to (APHA, 2005). The following parameters were tested: pH, oxidation-reduction potential (ORP) (mv), total dissolved salts (TD salts) (mg/L), temperature (^{o} C), total solids (TS) (mg/L), total suspended solids (TSS) (mg/L), total dissolved solids (TDS) (mg/L), total volatile solids (TVS) (mg/L), total nonvolatile solids (TnVS) (mg/L), total acidity (mg/L), total alkalinity (mg/L), total hardness (mg/L), biochemical oxygen demand (BOD5) (mg/L), turbidity (FTU), chloride (mg/L), chemical oxygen demand (COD) (mg/L), color (Pt.Co.), dissolved oxygen (DO) (mg/L), electrical conductivity (EC) (µs/cm), ammonia (mg/L), nitrite (mg/L), and nitrate (mg/L). The experiments were conducted at the Sanitation and Environment Laboratory, Department of Civil Engineering, College of Engineering, Salahaddin College of Erbil, Erbil, Kurdistan Region, Iraq. The following equipment and procedures were used to measure WW properties. The water temperature of the samples was measured in the field using a clean mercury thermometer with an accuracy of 0.1 °C. Turbidity was measured in the laboratory using the Model WTW 550 Germany turbid meter. EC and pH were measured using the Combined CCMD 625. The total salt was determined mathematically from the EC values. Total acidity, total alkalinity, total hardness, and chloride were determined using titration methods in accordance with APHA Standard (2005). BOD5 values were determined based on values from DO at initial collection and after five days. TS TSS and TDS were determined using an oven, filter paper, evaporating dish, flask, and sensitive electric balance. Color, COD, ammonia, nitrite and nitrate were measured using spectrophotometer DR 3900. A multi-parameter instrument was used to measure the redox potential.

2.3. Treatment approaches

Aerated lagoons, oxidation ditches, and wetlands were proposed for treating Erbil's wastewater. Each method was designed based on the collected data or available data and equations in the references. Design procedures, calculations, details and drawings, separation efficiency, advantages and disadvantages were explained for each treatment technique.

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3. Results and Discussions

3.1. WW characteristics

Raw sewage from the east-south area of Erbil city is generally composed of: 1) domestic wastewater from households generated by dishwashers, washing machines, bathtubs and toilets, which may contain organic and inorganic substances in suspended, colloidal and dissolved forms, 2) commercial and institutional areas, and 3) rainwater that enters the sewer system during the rainy season and washing.

The experiments conducted are listed in Table 1. The parameters such as temperature, pH, BOD5, COD and chloride were within the permissible limits specified in the standards. However, the limits were exceeded for other parameters such as color, TS, TSS, nitrate, nitrate and ammonia. Consequently, the treatment of wastewater in the east-south part of Erbil city is necessary. The low BOD5 and COD values are due to the dilution of wastewater by other types of wastewater with low BOD values entering the sewer. Higher values of BOD5 and COD were reported in the literature for Erbil wastewater (Mustafa and Sabir, 2001; Aziz, 2004, Aziz and Ali, 2017; Aziz, 2020). Erbil MWW can be considered as weak WW (Metcalf and Eddy, 2014). From the documented data, parameters such as pH, temperature, and chloride were in accordance with the standards for wastewater disposal, while TSS and BOD5 exceeded the standards (Mustafa and Sabir 2001; Ali, 2002; Aziz, 2004; Shekha, 2008; 2013; Aziz and Ali, 2017; Aziz, 2020). In the literature, wastewater samples were analyzed at another site in Erbil City and some parameters such as BOD5, COD, ammonia, manganese, phenols, oil and grease, TS, TSS and TDS exceeded the standards for wastewater disposal (Aziz and Ali, 2017; 2018). Therefore, treatment of wastewater in Erbil city was proposed using different methods such as aerated lagoon, oxidation pit and wetland for wastewater reuse.

Table 1
Characteristics of raw Erbil municipal WW

No.	Parameter	Unit	Value Feb. 25th, 2018	Value March 27th, 2018	Standards*
1	Temperature	°C	13.4	23	40
2	pH		7.82	7.7	6.5-9.6
3	EC	µs/cm	580	573.65	-
4	Total Acidity	mg/L	24	40	-
5	Total Hardness	mg/L	160	160	-
6	Total Alkalinity	mg/L	192	252	-
7	Turbidity	FTU	12.7	11.3	-
8	Chloride	mg/L	38	52	750
9	Color	Pt. Co	146	337	Nil**
10	TDS	mg/L	200	400	-
11	TS	mg/L	200	800	500
12	DO	mg/L	7.9	7.2	-
13	BOD_5	mg/L	4.1	5.6	40**
14	COD	mg/L	8	10	100**
15	TSS	mg/L	400	1100	35
16	TVS	mg/L	200	700	-
17	TnVS	mg/L	200	400	-
18	Ammonia	mg/L	2.09	2.64	1
19	ORP	mv	-175	-189.7	-
20	Nitrate (NO_3-N)	mg/L	2.6	17.7	10
21	Nitrite (NO_2-N)	mg/L	11	29	1

* According to environmental protection regulation EPA (2003)
** Iraqi Environmental Standard (2011)

3.2. Treatment methods

3.2.1. Aerated lagoons

The aerated lagoon is one of the most widely used methods of wastewater treatment in the world, and also one of the simplest and least expensive systems. Lagoons are basins designed to receive, store and treat wastewater over a period of time. Lagoons are equipped with mechanical aerators to maintain an aerobic environment and prevent the settling of suspended biomass. Aerated lagoons can be divided into two types: Aerated lagoons with suspended growth (completely mixed lagoons) and facultatively aerated lagoons (partially mixed lagoons). The difference between these two types is the degree of mixing of the lagoon contents. Fully mixed lagoons provide sufficient aeration or mixing to keep solids in suspension, while partially mixed lagoons are designed so that settleable solids accumulate on the lagoon floor where they are anaerobically decomposed. Generally, lagoons are lined with materials such as clay that prevent effluent from leaching into the underlying groundwater. Wastewater in the lagoons undergoes a variety of treatment methods, including physical, biological, and chemical processes. Most of the treatment occurs naturally, but some systems are designed to also use aeration devices that increase oxygen levels in the wastewater (Kamyotra and Bhardwaj, 2011). An aerated lagoon is designed to have flow through it, an influent on one side and an effluent on the other, and to retain the effluent for a period of time. The treatment plant for MWW consists of a fine screen, two or three aerated lagoons in series or parallel, and a treatment lagoon.

i) Design of aerated lagoons

Each lagoon system must be individually designed for its particular location and use. The design of lagoons is based on several factors such as the type and amount of wastewater to be treated and the level of treatment required by law, the type of soil, the climate, the available land area, and the amount of sunlight and wind. After the wastewater leaves the lagoons, it usually must undergo an additional treatment called polishing. This treatment is used to remove pathogenic organisms or nutrients from the wastewater. After this stage, the wastewater is considered treated and can be returned to the environment. The depth of the polishing lagoon should be about 1.20 m (Qasim, 2017). There are two bases on which the design of aerated lagoons is based: volume loading and residence time.

There are different forms of lagoons. The most common shape for treatment plants is the rectangular shape, which allows good circulation and mixing with lower energy requirements. The corners of the lagoon should be curved and the slope should not exceed a 2:1 ratio (width to height).

The water depth is usually set at 2.5 m and the depth of the lagoon should be between 2 and 3 m. The slope angle depends on the type of soil on which the lagoon is built. As a rule, it is 1:1.5 to 1:2. A natural or clay lining should be used. If the soil is highly permeable, a plastic liner can be used to protect the areas and prevent water leakage. Another problem with lagoon design is the damage caused by muskrats and plants. The solution to this problem is to reinforce the embankments at the level of the normal water table.

In the range of 0.44 to 2.2 m^3/sec, four tanks are often provided to allow operational flexibility and ease of maintenance (Metcalf and Eddy, 2014).

Kinetic coefficients of interest in the design of an aerated lagoon:

Design procedure

Measured discharge at the site,

$$Q = 0.5\ m^3/s = 43200\ m^3/d$$

Assumed water depth = 3 m and width of basin = 4.5 m (Metcalf and Eddy 2014). In addition, the suggested depth for an aerated lagoon varies from 3 m to 4.5 m (Hill, 2015). The USEPA (2002) also indicated that the typical depth of an aerated lagoon is 3 m. Determine the area of the lagoon based on the SRT,

SRT=5 d (Metcalf and Eddy, 2014)

In addition, USEPA (2002) stated

$$\text{Volume (V)} = Q \cdot SRT = 43200 \cdot 5 = 216000\ m^3$$

Surface area of the lagoon

Area= Volume / Depth

$$Area = \frac{216000\ m^3}{3} = 72000\ m^2$$

Determination of lagoon temperature according to Eq. (Metcalf and Eddy, 2014)

$$Tw = \frac{AFTa + QTi}{AF + Q} \tag{1}$$

where:

Ti is the temperature of the inflowing wastewater, ˚C
Tw is the temperature of the lagoon water, ˚C
Ta is the air temperature, ˚C
A is the surface area, m^2
Q is WW flow rate, m^3/d

Two samples were collected on 25th February and on 27th March. The average of the two temperatures was taken.

$Ta = 23\ celsius,\ \ Ti = 18.2\ celsius, and\ A = 0.489\ m^2$
$Assume\ Q = 0.3\ m^3/s$
$Q = 25920\ m^3/d, F = \ 0.5\ in\ SI\ system$

$$Tw = \frac{0.489 \cdot 0.5 \cdot 17 + 43200 \cdot 13.4}{0.489 \cdot 0.5 + 43200} = 18.2\ °C$$

Estimation the soluble discharge (Metcalf and Eddy, 2014):

$$S = \frac{k_s \cdot [1 + (k_d)SRT]}{SRT \cdot (Y_k - k_d) - 1} \tag{2}$$

Kinetic coefficients (Metcalf and Eddy, 2014):

$K = 5\ g\ per\ g.d,\ \ Ks = 60\ g\ /m,\qquad Kd = 0.10\ g\ per\ g.d,$ $Y = 0.6\ g\ per\ g,$ For 20 ˚C

$$S = \frac{60 \cdot [1 + (0.10) \cdot 43200]}{43200 \cdot \left((0.6 \cdot 5) - 0.10\right) - 1} = 2.069\ g/m^3$$

1 - Estimation of the BOD of the waste water

a) Correct the removal rate constant for temperature effects using Eq. 3 (Metcalf and Eddy, 2014):

$$k_T = k_{20}\theta^{(T-20)} \tag{3}$$

where:

k_T is the BOD reaction coefficient at temperature T, 1/d
k_{20} is the BOD degradation rate at 20 ˚C, 1/d
θ is the temperature coefficient 1.06
$k_{18.2} = 2.5 \cdot (1.06)^{(18.2-20)} = 2.25\ /d$

b) Determine discharge values BOD using Equation 4 (Metcalf and Eddy, 2014):

$$S = \frac{s_0}{[1 + (k) \cdot SRT]} \tag{4}$$

$$S = \frac{200}{[1 + (2.25) \cdot 5]} = 16.32\ \ \mathrm{g/m^3}$$

2 - Estimate the concentration of biological solids according to Eq. 5 (Metcalf and Eddy, 2014):

$$X = \frac{Y \cdot (s_0 - s)}{[1 + (k_d) \cdot SRT]} \tag{5}$$

$$X = \frac{0.6 \cdot (200 - 16.32)}{[1 + (0.10) \cdot 5]} = 73.5\ g/m^3$$

An approximate estimate of biological solids produced is obtained by multiplying the assumed growth yield constant (BOD basis) by the removed BOD (Metcalf and Eddy, 2014).

3 - Estimate suspended solids in the lagoon effluent prior to settling (Metcalf and Eddy, 2014).

$$TSS = 200 + \frac{X}{0.85} = 200 + \frac{73.5}{0.85} = 286.47\ \mathrm{g}/m^3 \tag{6}$$

Estimate oxygen demand using equation 7 (Metcalf and Eddy, 2014).

$$R_0 = Q \cdot (S_0 - S) - 1.42 \cdot P_{x,bio} \tag{7}$$

a) Determine $P_{x,bio}$ the amount of biological solids wasted per day (Metcalf and Eddy, 2014).

$$\mathrm{P_x} = \mathrm{X} \cdot \mathrm{Q} \cdot \frac{1\mathrm{kg}}{1000\ \mathrm{g}} \tag{8}$$

$$P_x\ = 73.5 \cdot\ 43200 \frac{m^3}{sec} \cdot \frac{1}{1000} = \ 3175.2\ kg/d$$

b) The conversion factor for BOD to COD is 1/1.6 for determining oxygen requirements (Metcalf and Eddy, 2014).

$$R_0 = \frac{43200 \cdot (200 - 16.32)}{0.625 \cdot 1000\ g/kg} - 1.42 \cdot 3175.2 = 8187.2\ kg/d$$

4 - Calculate ratio of oxygen needed to BOD removed by Eq. 9 (Metcalf and Eddy, 2014).

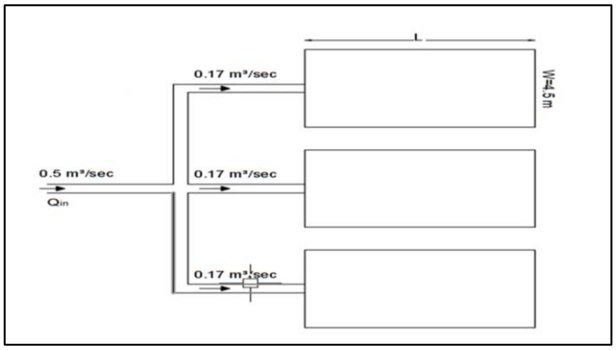
$$\frac{O_2 Required}{BOD\ removed} = \frac{R_o}{Q \cdot (S_o - S)\left(\frac{1kg}{1000g}\right)} \tag{9}$$

$$\frac{O_2 Required}{BOD\ removed} = \frac{8187.2}{43200 \cdot (200 - 16.32)\left(\frac{1kg}{1000g}\right)} = 1.03 \frac{kgO_2}{kgBOD}$$

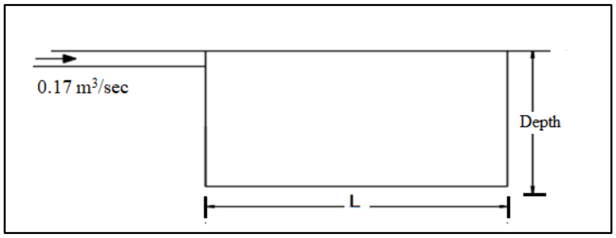
5 - Determine the surface aerated energy requirements, the aerators used are valued at 1.8 kg O_2/kWh. (Metcalf and Eddy, 2014). The details of the design are shown in Fig. 1.

Aerated lagoons are an efficient and cost-effective system for primary and secondary treatment of wastewater in small communities. They integrate very well with the surrounding landscape.

When appropriate aerators are used, the energy input is similar to that of a comparable activated sludge system. In addition to providing adequate oxygen transfer, the aerators must provide mixing and circulation.



(a)



(b)

Figure 1. Details of aerated lagoon (a) Plan and (b) Section

3.2.2. Oxidation ditch

An oxidation ditch is a modified biological activated sludge process that uses long residence times for solids (SRTs) to remove biodegradable organics. Oxidation ditches are classically complete mixed systems, but can be modified to approximate plug effluent conditions. Typical oxidation ditch treatment systems consist of single- or multi-channel configuration within an annular or oval basin. For this reason, oxidation ditches are also referred to as "racetrack" reactors, Figure 2.

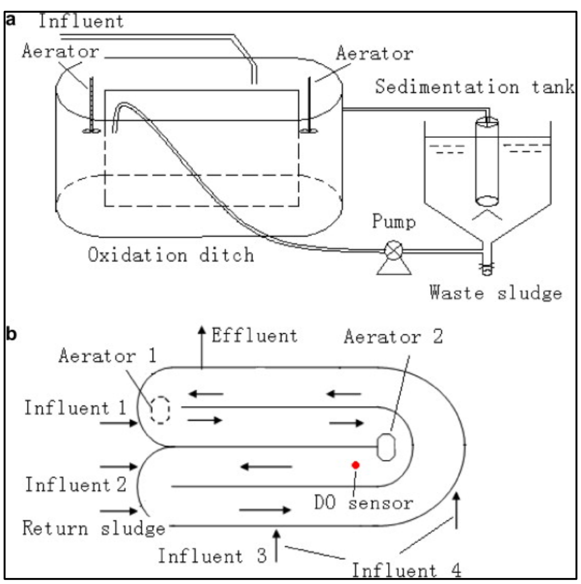


Figure 2. Schematic diagram of oxidation ditch (Liu et al., 2010)

Horizontally or vertically mounted aerators provide circulation, oxygen transfer, and aeration in the trench. The cross-sectional area of the trench is typically 1.2 m to 1.8 m deep and has 45° sloped sidewalls. Oxidation trench systems with a depth of 3 m or more with vertical sidewalls and vertical shaft aerators can also be used. Trenches can be made of a variety of materials, including concrete, asphalt, or impermeable membranes. Concrete is the most common. L-shaped and horseshoe-shaped structures have been built to maximize land usage (Davis, 2011).

i) Advantages

The main advantage of the oxidation ditch is its ability to meet separation performance objectives with low operational requirements, operating and maintenance costs. Specific advantages of oxidation ditches include (Xia and Liu, 2004):

a) An added measure of reliability and performance compared to other biological processes due to a constant water level and continuous discharge that lowers the weir above the discharge rate and eliminates the periodic surge of water common to other biological processes such as the Sequencing Batch Reactor.
b) Long hydraulic residence time and complete mixing minimize the influence of shock loading or hydraulic surge.
c) Compared to other biological treatment processes, less sludge is produced because biological activity is prolonged during the activated sludge process.
d) Energy-efficient operation results in lower energy costs compared to other biological treatment systems.

ii) Disadvantages

a) Compared to other modifications of the activated sludge process, the suspended solids concentrations in the Effluent are comparatively high.
b) This type of treatment requires a larger area compared to other activated sludge treatments. This can prove costly, limiting the feasibility of oxidation ditches in urban, suburban, or other areas where land acquisition costs are relatively high.

iii) Design criteria

Oxidation ditches are usually constructed of reinforced concrete, but asphalt, butyl rubber, and clay are also used.

Impervious materials are generally used to prevent erosion. The trenches are typically 1.2 m to 1.8 m deep and have 45-degree sloped or vertical sidewalls (Davis, 2011). The effluent enters the ditch after screening, is aerated, and circulates at a velocity of 0.25 to 0.35 m/s to keep solids in suspension (Metcalf and Eddy, 2014). The activated sludge recycle ratio ranges from 75 % to 150 %, and the suspended solids concentration in the mixed liquor (MLSS) ranges from 1500 mg/L to 5000 mg/L. The oxygen transfer capacity of oxidation ditches ranges from 2.5 to 3.5 lb/hp-h, 1.134 to 1.588 kg/hp-h (Process, 1999; Xia and Liu, 2004). The design criteria depend on the effluent content parameters and the required characteristics of the detergent, including the decision or requirement to provide a nitriding or denitriding effect and/or biological phosphorus removal. Specific design parameters for oxidation ditches include (Xia and Liu, 2004).

iv) Design procedure for oxidation ditch

Design an oxidation ditch for the treatment of the WW with the following parameters:

Average WW discharge= $\frac{m^3}{day}$ 43200 m^3/d (Measured from the site)
WW $BOD_5 = 4.85$ mg /L
WW SS = 400 mg /L
WW VSS = 200 mg /L
Total organic nitrogen concentration=30 mg/L
Total phosphorus concentration = 15 mg/L
Required effluent BOD_5 = 16.32 mg /L from Eq. 4
Required effluent SS≤ 10 mg/L (Davis, 2011)
Required underflow sludge concentration is 10,000 mg/L
WW temperature is 18.2 °C (Average temperature measured from the site)

The following parameters according to Wang et al. (2010):

1. Fraction of BOD synthesized, a = 0.73
2. Fraction of BOD oxidized for energy, a′ = 0.52
3. Endogenous respiration rate, $b = 0.075\ 1/d$ and $b' = 0.15\ 1/d$
4. Fraction of BOD_5 synthesized to degradable solids, $a_o = 0.56$
5. No biodegradable fraction of VSS in influent, $f = 0.40$
6. Mixed liquor suspended solids (MLSS) = Xa = 6000 mg/L
7. Mixed liquor volatile suspended solids (MLVSS) = XV = 4200 mg/L
8. Temperature correction coefficient, $\theta = 1.02$
9. Degradable fraction of the MLVSS, $f' = 0.53$
10. Food-to-microorganism ratio, $F/M = 0.06$

6 - Effluent soluble BOD_5, Se =10 mg/L

Adjust the BOD removal rate constant for temperature:

$$k_T = k_{20}\theta^{(T-20)} \tag{10}$$

$k_{18.2} = 2.25\ 1/d$. calculated previously for design of aerated lagoon.

a) Determination the size of the tank according to Eq. 11.

$$V = \frac{a_0(s_0 - s_e)Q_{avg}}{X_V \cdot f'b} \tag{11}$$

Parameters were used from Wang et al. (2010). Where:

V is aeration tank volume, million galloon
a_0 is fraction of BOD_5 synthesized to degradable solids=0.56
s_0 is influent BOD_5, 200 mg/L
s_e is effluent soluble (BOD_5 = 16.32 mg/L), calculated from design of aerated lagoon;
Q_{avg} = Average waste flow = 0.5 m^3/s = 9.50 MGD
X_V is MLVSS and it is equal to 4200 mg/L
f' is degradable fraction of the MLVSS = 0.53
b is endogenous respiration rate, 0.075 1/d

$$V = \frac{0.56 \cdot (200 - 16.32) \cdot 9.50}{4200 \cdot 0.53 \cdot 0.075} = 5.85\ MG = 25768.57 m^3$$

Suppose depth of the tank is 1.5 m (1.2 m to 1.8 m) (Davis, 2011). Total surface area = 25768.57 m^3/1.5 m ≈ 17180 m^2. Calculation of detention time using Eq. 12.

$$t = \frac{V}{Q} \cdot 24$$

$$t = \frac{25768.57 m^3}{43200\ m^3 \cdot sec^{-1}} \cdot 24 = 14.3\ hour \tag{12}$$

Obtained time coincided with the criteria (6 to 30 hours) published by USEPA (2000). Determination of the oxygen requirements allowing 60 % for nitrification from Eq. 13:

$$O_2 = a's_r Q(8.34) + b'x_v \cdot V\ (8.34) + 0.6\ (4.57)(TKN)(Q)(8.34) \tag{13}$$

Where:

O_2= oxygen required, Ib/d
a' is fraction of BOD oxidized for energy = 0.56

s_r is BOD5 removed $= So - Se = 200 - 16.32 = 183.68\ mg/L$
Q is average waste flow 9.50 MGD = 0.5 m^3/s
b' is endogenous respiration rate, 0.15 1/d
x_v is MLVSS, 4200 mg/L
V is aeration tank volume, 5.85 MG = $25768.57 m^3$
TKN is total Kjeldahl nitrogen, 30 mg/L

$$O_2 = 0.56 \cdot 183.6 \cdot 9.50 \cdot (8.34) + 0.15 \cdot 4200 \cdot 5.85 \cdot \cdot (8.34) + 0.6\,(4.57) \cdot (30) \cdot (9.50) \cdot (8.34) = = 40309.3 \text{ Ib day}^{-1} = 18283.99092 \text{ kg/d}$$

Calculation of oxygen requirement per Ib BODr from Eq. 14; (it should be ≥ 1.5) Ib O_2/Ib BODr

$$= \frac{Q_2}{Q} \cdot S_r \cdot (8.34) \quad (14)$$
$$= \frac{40309.3}{9.5} \cdot 1.83 \cdot (8.34) = 2.8 \ \geq \ 1.5 \ \ \text{OK.}$$

3.2.3. Wetland

Wetlands are typically used to treat wastewater and improve water quality for reuse. Wetlands use microorganisms, plants, and soil to treat wastewater. Plants such as sedges, cattails, reeds and bulrushes can grow in them as they can be filled with water up to 0.6 m deep. They mainly serve four functions, namely, landscape improvement, wastewater treatment, fish culture, and land aesthetics improvement. In some cases, constructed wetlands are the main and only wastewater treatment, in others they are just one step in a larger treatment process. Plants in constructed wetlands help philter wastewater and absorb solids, as well as transfer oxygen. Wetlands have many advantages, such as their good ability to remove pollutants (suspended solids and organic matter). In addition, wetlands do not require much energy or high maintenance costs and can be adapted to climate change (Vymazal, 2010).

There are several types of constructed wetlands: surface flow, subsurface flow, and hybrid systems that combine surface and subsurface flow. Constructed wetlands can also be combined with conventional treatment technologies, Figs. 3 and 4.

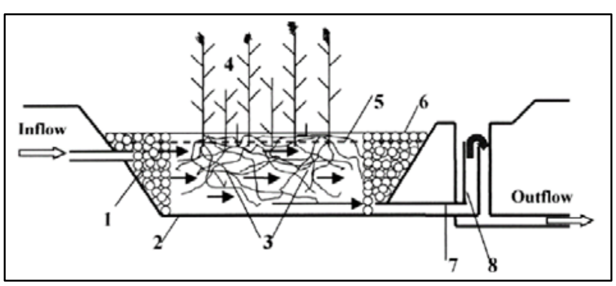


Figure 3. Schematic layout of a constructed wetland with horizontal subsurface flow. 1 inflow distribution zone filled with large stones; 2 impermeable layer; 3 filtration material; 4 vegetation; 5 water level in the bed; 6 outflow collection zone; 7 drainage pipe; 8 outflow structure with water level adjustment. (Vymazal, 2010)

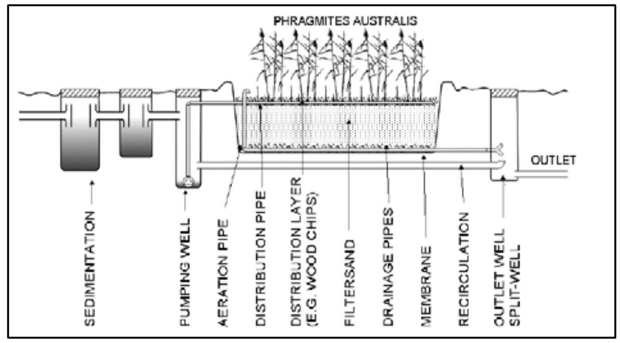


Figure 4. Layout of a vertical flow constructed wetland system for a single household (Vymazal, 2010)

Design procedure of wetland

BOD removal:

It is assumed that the removal of BOD follows first-order kinetics and that the continuous reactor formulation assumes complete mixing. Therefore, Eq. 7 is used as the kinetic model for the removal of BOD in the aerated lagoon, as shown in Eq. 15:

$$S_e = \frac{1}{1 + k_t} \cdot S_0 \quad (15)$$

where:

S_e is the outflow concentration, mg/L
S_0 is the inflow concentration, mg/L
k is the BOD coefficient at temperature T, 1/d
t is detention time, day.

$$S_e = \frac{1}{1 + 0.3} \cdot 200 = 153.85 \text{ mg/L}$$

Modification to temperature can be done using Eq. 3 (Zhang, 2012).

$$k_T = k_{20} \cdot \theta^{T-20}$$

where:

k_T is the BOD reaction coefficient at temperature T, 1/d
k_{20} is the BOD removal rate at 20 ˚C, 1/d
θ is the temperature coefficient 1.06

For normal sewage k_{20}= 0.3 1/d at 20 ºC (Shilton, 2006)

$$k_{18.2} = 0.3 \cdot \theta^{18.2-20} = 0.27 \text{ 1/d}$$

Area:
TKN surface area loading in wetland is 3 kg/ha. (Tousignant et al., 1999). Conservative estimates of effluent quality entering wetland:

TKN = 175 mg/L (Tousignant et al., 1999)

$$Daily\ TKN\ loading = 175\ \frac{mg}{L} \cdot Q\ \frac{m^3}{d} \cdot 10^{-3} = $$
$$= 7560\ kg/d$$
$$Total\ surface\ area = \frac{(7560\ kg/d \cdot 10m^2/ha)}{\left(3\ \frac{kg}{ha} \cdot d\right)} =$$
$$= 25200\ m^2$$
$$Wetland\ area = 50\%\ of\ 25200\ m^2 = 12600\ m^2$$

Designing two wetlands:

$$Area\ of\ each\ cell = \frac{12600\ m^2}{2} = 6300\ m^2$$

Overall size of wetland:
Aspect ratio: 4:1 (Tousignant et al., 1999). If width: 33 m then length: 132 m. Aspect ratio in the current design agree with the criteria mentioned by Wu et al. (2015).

3.3. Performance evaluation

The performances of aerated lagoons, oxidation ditches and wetlands for the treatment of wastewater from Erbil were studied. Parameters such as BOD5, COD, ammonia and TSS were used because they are widely used to study treatment methods (Renou et al., 2008; Abbas et al., 2009; Bashir, et al., 2015). In the literature, the values of BOD5, COD, ammonia and TSS for Erbil MWW were 13-110 mg/L, 20-188 mg/L, 3.25-11.4 mg/L and 200-400 mg/L, respectively (Mustafa and Sabir, 2001; Aziz, 2004; Aziz and Ali, 2017). BOD5, COD, ammonia and TSS parameters have been used in the study of wastewater treatment plants and the disposal standards due to their effect (EPA, 2003; Metcalf and Eddy, 2014; Bashir et al., 2015). Details of the inlet concentration, removal efficiency of the methods, outlet concentrations, and effluent standards are shown in Table 2. The results from Table 2 show that the common WWTP is the most efficient method for removing pollutants in the Erbil WWTP. Aziz (2020) studied the quality of wastewater of Erbil in the main sewer from 1994 to 2020 with possible treatment techniques and reuse. The results obtained in the present study are consistent with the work published by Aziz (2020). The removal of BOD5 and TSS in the aerated lagoons is in agreement with USEPA (2002).

3.4. Reusing Treated Municipal WW for Irrigation

The quality of untreated MWW and other types of WWs is different and it depends on the source of WW, for instance the quality of WW from dairy, steel, slaughterhouse, tannery, yeast, and paper factory are not the same (Aziz et al., 2019). Several treatment technologies are needed based on the pollutants in the WWs and should be treated to a level to qualify for the different types of irrigation, i.e. forest, greenbelt, wheat, fruits, vegetables, etc. (Mecalf and Eddy, 2014; Aziz and Ali, 2018; Aziz et al., 2019).

Table 2
Performance assessment for the Erbil MWW treatment using various techniques

Factors	Treatment Techniques			Discharge Standards
	Aerated lagoon	Oxidation ditch	Wetland	
Avg. inlet BOD (mg/L)	13-110 (61.5*)	13-110 (61.5*)	13-110 (61.5*)	40 mg/L (Iraqi Environmental Standard, 2011)
BOD removal (%)	70-95 (82.5*)	82-99 (90.5*)	90.8-92.3 (91.6*)	
Outlet BOD (mg/L)	10.76	5.84	5.17	
Inlet COD (mg/L)	20-188 (104*)	20-188 (104*)	20-188 (104*)	100 mg/L (Iraqi Environmental Standard, 2011)
COD removal (%)	62.5	61.5	89-91.7 (90.4*)	
Outlet COD (mg/L)	39	40	9.9	
Inlet ammonia (mg/L)	3.25-11.4 (7.3*)	3.25-11.4 (7.3*)	3.25-11.4 (7.3*)	1 mg/L (EPA, 2003)
Ammonia removal (%)	≈ 90	90-94 (92*)	83.8-87.5** (85.7*)	
Outlet ammonia (mg/L)	0.71	0.584	1	
Inlet TSS (mg/L)	200-400 (300*)	200-400 (300*)	200-400 (300*)	35 mg/L (EPA, 2003)
TSS removal (%)	60.3	69-97 (83*)	90.4-93.2 (91.8*)	
Outlet TSS (mg/L)	119.1	51	24.6	
References	INDITEX (2015)	USEPA (2000); Hadisoebroto et al. (2014)	Gikas and Tsihrintzis (2014)	

* Average Value
** Removal efficiency for NH4-N

Three key views should be measured for irrigation by treated WW, which cares about public health for farmers and users, the avoidance of atmosphere degradation, and removes the antagonistic that has an effect on the production of crops. Various organizations for using TWW for irrigation concentrated on, the amount of indicator organisms, biodegradable organic matter, TSS, turbidity, heavy metals, and residual chlorine that has an effect on public health (Paranychianakis, et al., 2011; Aziz et al., 2019).

In this study and based on the pH, EC, and TDS results, there are no limitations to the use of MWW (Aziz et al., 2019). The MWW is considered as water with medium salinity (Punmia and Lal, 1979). According to EC and chloride values, Erbil water is considered completely safe for irrigation (Abbas, 1986). The obtained results are in agreement with the data published by Aziz et al. (2019). Of course, treatment of wastewater from Erbil with different techniques reduces pollutants such as organic matter, TSS, nitrogen compounds, etc. in wastewater (USEPA, 2000; Gikas and Tsihrintzis, 2014; Hadisoebroto et al., 2014; GINDITEX, 2015). Consequently, treatment of wastewater improves the quality of Erbil's wastewater and it can be used for irrigation purposes.

4. Conclusions

The results showed that the wastewater from Erbil is considered to be low polluted and some quality parameters exceed the standards for wastewater disposal. The total planned area for aerated lagoons, oxidation ditches and wetlands were 72000 m^2, 17180 m^2 and 25200 m^2, respectively. The wetland design resulted in 91.6 % reduction in BOD5, COD, ammonia, and TSS. 90.4 %, 85.7 % and 91.8 %, respectively. Compared to the aerated lagoon and oxidation ditch methods, the wetland method was generally the most effective. Based on the above treatment methods, the treated wastewater can be reused for irrigation, and the wastewater has medium salinity and is completely safe for irrigation. In this way, drinking water is no longer used for irrigation in the city of Erbil.

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Postupak osmišljavanja i izvođenja metoda aerisane lagune, oksidacionog jarka i konstruisanja mokrih polja za tretman i ponovnu upotrebu otpadnih voda u Erbilu

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INFORMACIJE O RADU

Primljen 16 septembar 2022
Prihvaćen 30 mart 2023

Originalan rad

Ključne reči:
Aerisane lagune
Navodnjavanje
Oksidacioni jarak
Otpadne vode
Mokra polja

I Z V O D

Cilj ovog istraživanja je bio ispitivanje karakterizacije, tehnike tretmana i ponovna upotreba sveže komunalne otpadne vode iz jugoistočne oblasti grada Erbila koji se nalazi u oblasti Kurdistan u Iraku. Prikupljeni uzorci otpadnih voda analizirani su na 21 parametar kvaliteta. Neki od parametara kao što su boja (146 Pt. Co i 337 Pt. Co), ukupne čvrste materije (800 mg/L), suspendovane čvrste supstance (400 mg/L i 1100 mg/L), nitrati (17,7 mg/L), nitriti (11 mg/L i 29 mg/L), i amonijak (2,09 mg/L i 2,64 mg/L), premašili su standarde za odlaganje otpadnih voda. Shodno tome, bilo je potrebno sprovesti tretman pre nego što se otpadna voda ispusti u prirodno okuženje. Dizajnirane su tehnike za tretman kao što su earisane lagune, oksidacioni jarak i konstruisanje mokrih polja. Objašnjene su procedure osmišljavanja, proračuni i performanse za svaku metodu tretmana. Ukupna površina projektovana za aerisane lagune, oksidacioni jarak i mokra polja, iznosila je 72 000 m^2, 17 180 m^2 i 25 200 m^2. Metoda konstruisanja mokrih polja je bila najefikasnija metoda sa efikasnošću od 91,6 % za biohemijsku potrebu za kiseonikom, 90,4 % za hemijsku potrebu za kiseonikom, 85,7 % za amonijak i 91,8 % za suspendovane čvrste materije. Prečišćena otpadna voda može se ponovo koristiti za navodnjavanje i potpuno je bezbedna. Korišćenje prečišćenih otpadnih voda iz jugoistočnog dela Erbila za navodnjavanje umesto vode za piće predstavlja ekonomično rešenje i doprinosi očuvanju izvora pijaće vode.