

DETERMINE THE REQUIRED LOG REDUCTIONS OF HUMAN INTESTINAL HELMINTH EGGS BY WASTE STABILIZATION POND: A SIMULATION FOR WASTEWATER RECYCLING IN AGRICULTURE

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Abstract: This paper investigates the determined the required log reductions for human intestinal helminth eggs by waste stabilization ponds as simulation as assessing of mitigating health risk to satisfy practice WHO, 2006 guidelines for the safe use of wastewater in agriculture (≤ 0.1 helminth egg/L) to protect the health of children under 15 years was the development of MATLAB, a computer program based waste stabilization ponds design based on parameter uncertainty and 10,000-trial Monte Carlo simulations were developed for a series of anaerobic, facultative and maturation ponds based on 95%-ile of effluent (≤ 0.1 helminth egg/L) which the result in a health-based target. Whereas the influent of the helminth eggs (Nematode) was (932.500 eggs/L). While the treatment provided (100 % reduction/removal) for the overall treatment process with total hydraulic retention time in climatic conditions of Libya it took 36.207 days in the anaerobic pond, facultative pond, first maturation pond and one of the subsequent maturation pond.

Keywords: Safe re-use wastewater practices; Nematode eggs removal in climatic conditions of Libya; PC-based Monte Carlo simulation.

1. Introduction

About 173 million people in the Eastern Mediterranean Region, 35% of the entire Region, have less than the threshold level of 1000 cubic meters per capita per year. These include the countries of Bahrain, Djibouti, Egypt, Jordan, Kuwait, Libya, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, the United Arab Emirates, and Yemen. Countries of the Eastern Mediterranean Region which may be considered below the water poverty line of 500 cubic metres per year total about 73 million people, 15% of the total population, and include Bahrain, Jordan, Kuwait, Libya, Oman, Qatar, Yemen, Saudi Arabia, Tunisia, and the United Arab Emirates [1].

Water for irrigation and food production constitutes one of the greatest pressures on fresh water resources. The daily drinking water requirement per person is 2-4 litres, but it takes 2,000 to 5,000 litres of water to produce one person's daily food. Agriculture is by far the largest consumer of fresh water resources, currently accounting for over 70 per cent of global withdrawals and 86 per cent of the world's total fresh water consumption [2].

It is clear that wastewater is increasingly being used worldwide, both in developing and industrialized countries, particularly in rapidly growing urban areas with large wastewater production volumes. It is important to note, however, that there is a range of types, categories and uses of wastewater, depending on its composition, its treatment, and the planned or unplanned forms of its utilization [3].

The main advantages of domestic water reuse are: (a) provision of nutrients; (b) reliability in water supply; (c) contribution to the urban food supply; (d) income generation; and (e) livelihood sustenance. These aspects are especially important for small-scale farmers who can obtain enhanced water and food security by using recycled or even raw wastewater for irrigation [4 – 6].

Municipal wastewater contains a variety of pathogens, reflecting the carrier state and infection levels in the community [7,8]. The contamination of surface water with untreated or partially treated wastewater may as a consequence lead to adverse health implications [9 – 11].

1.1. Organisms pathogens in raw sewage

Raw sewage contains a variety of excreted organisms and pathogens from human and animal origin, with numbers that vary depending upon the background levels of disease in the population. Disease outbreaks in affected populations result in increased concentrations of the causative agents in the wastewater. Table 1 shows ranges of concentrations for different excreted organisms that can be found in wastewater, and are related to bacteria, intestinal helminths, protozoa and viruses [12].

Table 1

Typical numbers of excreted organisms in raw sewage

Organism	Numbers in wastewater (per L)
Bacteria	
Thermotolerant coliforms	$10^8 - 10^{10}$
Campylobacter jejuni	$10 - 10^4$
Salmonella spp.	$1 - 10^5$
Shigella spp.	$10 - 10^4$
Vibrio cholerae	$10^2 - 10^5$
Intestinal helminths	
Ascaris lumbricoides	$1 - 10^3$
Ancylostoma/Necator	$1 - 10^3$
Trichuris trichiura	$1 - 10^2$
Protozoa	
Cryptosporidium parvum	$1 - 10^4$
Entamoeba histolytica	$1 - 10^2$
Giardia intestinalis	$10^2 - 10^5$
Viruses	
Enteric viruses	$10^5 - 10^6$
Rotavirus	$10^2 - 10^5$

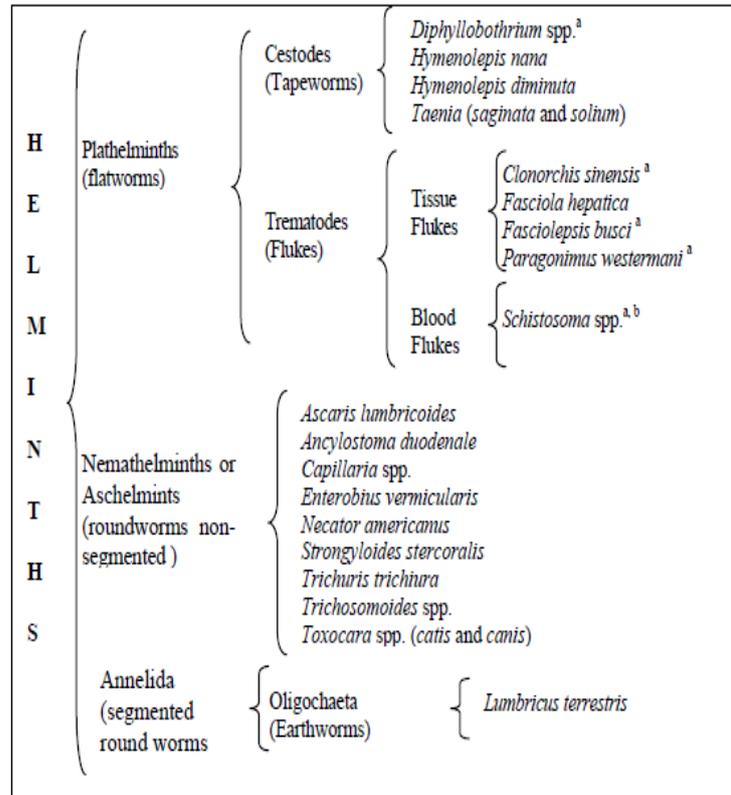
Source: [13–16].

1.1.1. Helminths

Helminths are worms causing a wide variety of diseases globally called helminthiases. Helminthiases almost only occur in developing countries, particularly in areas where sanitation is low sanitation. Although helminths are not microscopic animals, their eggs, which are the infective agents, are. Helminth eggs are discharged to the environment in faeces and the oralfaecal route is the main dissemination pathway of the disease [17].

1.1.2. Classification of the Helminths

There are three different kinds of helminths (a) Plathelminths or flat worms, (b) Nemathelminths (Aschelminths) or non-segmented round worms, and (c) Annelida or segmented round worms (Figure 1). Those infecting humans through wastewater, sludge or faecal sludge belong only to the first two groups. Helminths are pluri-cellular worms with sizes varying from 1 mm to several m in length; thus, they are not microbes although their eggs are microscopic [17].



^a Reported in wastewater or sludge from some countries in Asia.

^b Reported in wastewater or sludge from North Africa and Far East

Fig. 1- Helminth classification and common genera found in wastewater and sludge [17].

1.1.3. Helminth eggs

A common characteristic of helminths is that they reproduce through eggs. The eggs are different in shape and size depending on the genera (Figure 2). The helminth eggs of importance in the sanitary engineering field frequently measure between 20 and 80 µm, although some are as long as 185 µm (schistosomonas). The density of the eggs is greater than that of the water (1.056-1.237) and their structure is gelatinous making them very sticky [17,18].

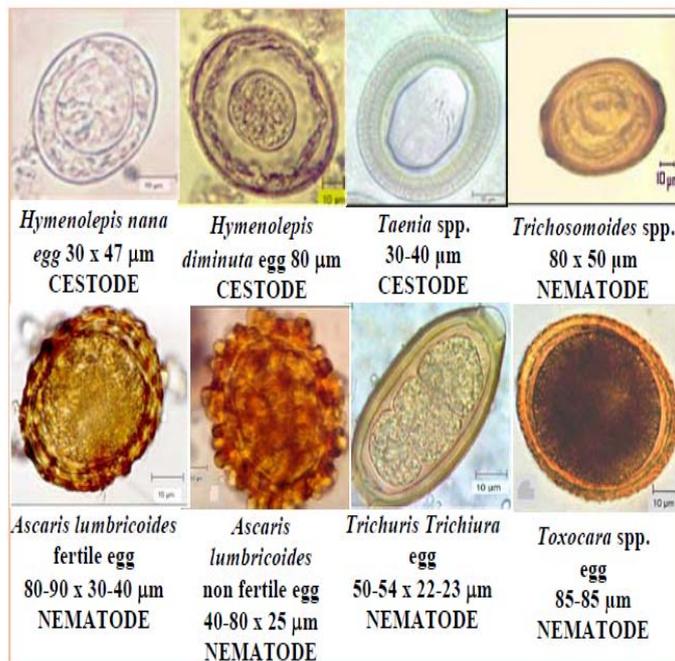


Fig. 2- Helminth eggs observed in wastewater and sludge[17,18].

1.2. The basic mechanism of helminth eggs removal in waste stabilization ponds

Removal of pathogens is considered a major advantage in using waste stabilization pond (WSP) systems for wastewater treatment [19, 20]. Over the last decade, an increasing number of studies conducted in different countries have shown waste stabilization pond systems to be a suitable method of wastewater treatment, especially with regard to the removal of helminth parasites [15, 21–27].

The basic mechanism of egg removal in all wastewater treatment processes is by sedimentation (plain or enhanced by adsorption to solids). This implies that all factors influencing this process will affect helminth egg removal. For effective helminth egg removal, the most important design parameters are probably the number of ponds in series and the mean hydraulic retention time of each pond [28].

1.3. Guidelines for the safe use of wastewater in agriculture

The World Health Organization has adopted a tolerable burden of waterborne disease from consuming drinking water of $\leq 10^{-6}$ DALY per person per year (WHO, 2004). This level of disease burden can be compared with mild diarrhea at an annual disease risk of 10^{-3} , which is equivalent to 1 occurrence in a population of 1000, during a lifetime. Such a high level of health protection has been adopted by (WHO,2006) [29], as a tolerable burden of disease for wastewater use in agriculture, by assuming that food crops irrigated with treated wastewater, especially those eaten uncooked.

1.3.1. Health Based -Targets for treated wastewater use in agriculture

The health-based targets define a level of health protection that is relevant to each hazard a health-based target can be based on an appropriate health outcome, such as the prevention of the transmission of vector-borne diseases resulting from exposures to wastewater use in agricultural practices. To achieve a health-based target, health protection measures are developed. Usually, a health-based target can be achieved through a combination of health protection measures targeted at different components of the system. Figure 3 illustrates different combinations of health protection measures that can be used to achieve the 10^{-6} DALYs health-based targets for excreta-related diseases.

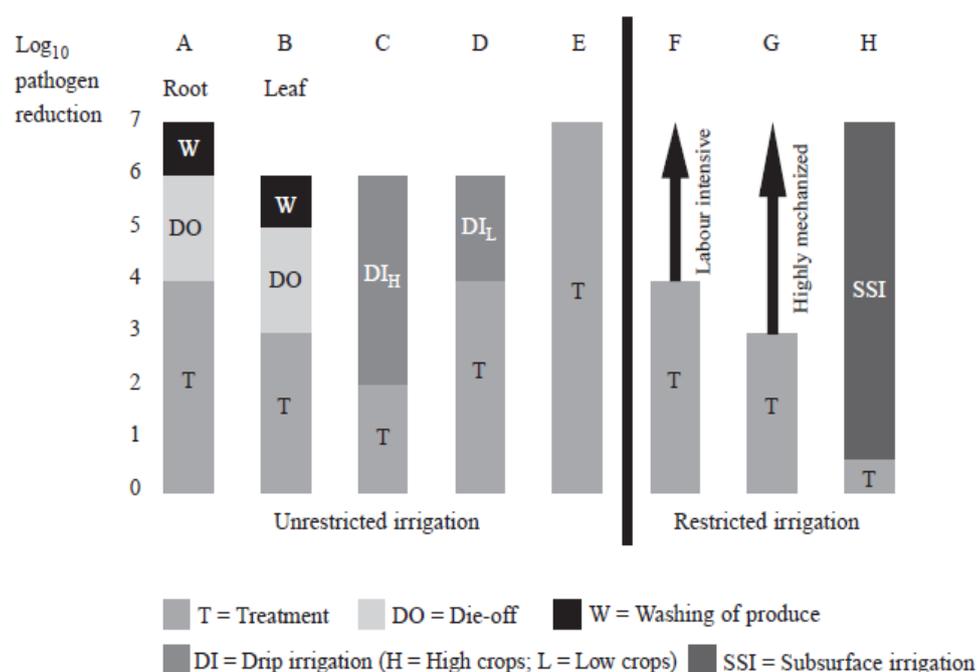


Fig. 3- Examples of options for the reduction of viral, bacterial and protozoan pathogens by different combinations of health protection measures that achieve the health-based target of $\leq 10^{-6}$ DALYs per person per year [29].

Table 2 describes health-based targets for agriculture. The health-based targets for rotavirus are based on QMRA indicating the \log_{10} pathogen reduction required to achieve 10^{-6} DALY for different exposures. To develop health-based targets for helminth infections, epidemiological evidence was used.

Table 2

Health-based targets for wastewater use in agriculture

Exposure scenario	Health-based target DALY (pppy)	Log10 pathogen reduction needed	Number of helminth eggs per liter
Unrestricted irrigation: Lettuce Onion	$\leq 10^{-6}$	6	≤ 1
		7	≤ 1
Restricted Irrigation: Highly mechanized Labor intensive	$\leq 10^{-6}$	3	≤ 1
		4	≤ 1
Localized (drip) irrigation: High-growing crops Low-growing crops	$\leq 10^{-6}$	2	No recommendations
		4	≤ 1

Source: [29].

This evidence demonstrated that excess helminth infections (for both product consumers and farmers) could not be measured when wastewater quality of ≤ 1 helminth egg per litre was used for irrigation. This level of health protection could also be met by treatment of wastewater or by a combination of wastewater treatment and washing of produce to protect consumers of raw vegetables; or by wastewater treatment and the use of personal protective equipment (shoes, gloves) to protect workers. When children less than 15 years old are exposed in the fields. Either additional wastewater treatment (to achieve a wastewater quality of ≤ 0.1 helminth egg per litre) or the addition of other health protection measures (e.g. anthelmintic treatment) should be considered [29].

2. Materials and method

2.1. Location and Climate

This study was carried on climatic conditions of Libya, where Jalu is a place of wastewater sampling. Jalu is a small municipality with a population of 18873 in 2006. Located in the central South-East of Libya, as shown in Figure 4. The climatic conditions as showing in table 3. The main economic activity in Jalu municipality is agriculture.

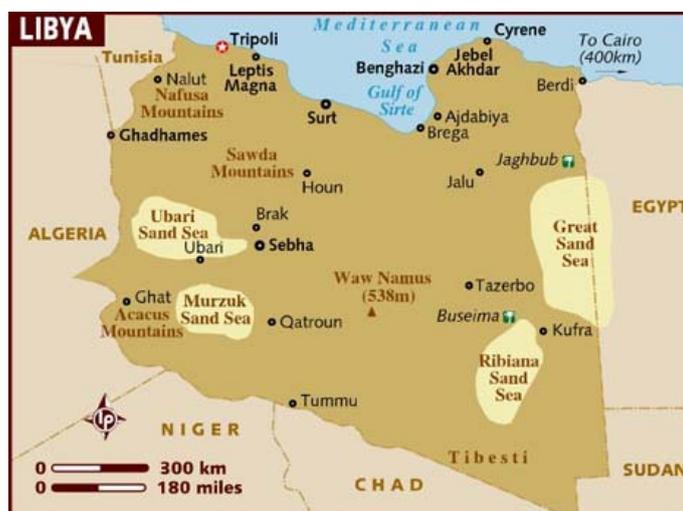


Fig. 4 - a map Jalu municipality in Libya

Table 3

The climatic conditions at Jalu, Libya

Parameters	Lower value	Upper value
temperature	1 °C	48 °C
evaporation	0.43 mm/day	23.1 mm/day
Net evaporation	- 3.9 mm/day	23 mm/day
Average Rainfall	18.4 mm/day	

Source: Libyan national meteorological center [30].

2.2. Sample collection

The sampling was stored in a cooler during the transfer to the laboratory. When the samples arrived at the laboratory, sample preparations for the pathogen tests were performed immediately to minimize changes in the microbiology of the samples. Examination the samples were as the American public health association standard methods for the examination of water and wastewater [31]. Wastewater analyzed included (See table 4) biological oxygen demand (BOD), chemical oxygen demand (COD), coliform bacteria (MPN/100 ml).

Table 4

Wastewater composition at Jalu, Libya

Parameters	Median value
BOD (mg L-1)	225
COD (mg L-1)	249
Coliform bacteria (MPN/100 mL)	11×10 ⁷
Nematode eggs (eggs/L)	Range
	100 - 1000

Note: MPN stands for: most probable number.

Source Nematode eggs content in wastewater by Ayres and Mara [32].

2.3. A computer program using Monte Carlo simulation methods

Banda and Banda et al. Have suggested that using modern methods for designing waste stabilization ponds WSP whose final effluent is to be used for the irrigation in developing countries [33, 34]. There is commonly some degree of uncertainty about the values of the parameters used to determine required log pathogen reductions. According to Von Sperling, that Monte Carlo simulation should be used when designing WSP because it is an efficient way to manage the uncertainty of the input design variables and coefficients. [35]. In this way, was the development of MATLAB a computer program for design waste stabilization ponds (See flowchart).

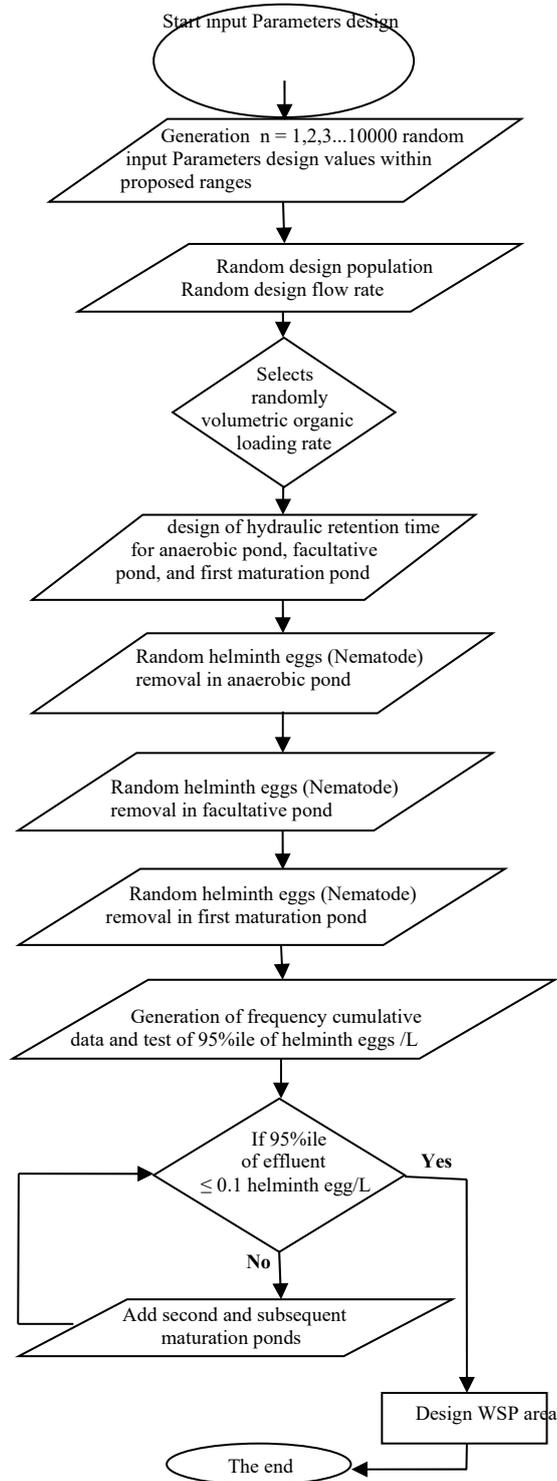


Fig. 5- Flowchart for the Monte Carlo simulation

The Monte Carlo simulation methods work by selecting at random a value of each input design parameter and the coefficient of the models within a specified range, the ranges from (100 to 1000 eggs/L) for human intestinal helminth eggs. Other parameters based on ($\pm 20\%$) from median value. The procedures, based on parameter uncertainty and 10,000-trial. PC-based was developed for a series of anaerobic, facultative and maturation ponds. Finally, the output data were statistically analyzed as frequency cumulative data. The 95-%ile value of effluent helminth eggs is selected from the frequency cumulative data and is compared with WHO, 2006 guidelines. If the effluent helminth eggs (Nematode) concentration is more than (0.1 helminth egg/L) the computer program adds subsequent maturation ponds until to satisfy the WHO, 2006 guidelines for the safe use of wastewater in agriculture.

2.3.1. The design equations

Generation the input design range: Monte Carlo simulation uses a uniform probability distribution to generate a range of the input design parameter. Vose [36], suggested that the cumulative probability distribution function for a uniform distribution of any range that has known end values could be expressed as an equation:

$$F(x) = \frac{x - A}{B - A} \quad (1)$$

where

x = any random input design value within a range.

A = the lower input design value of a range.

B = the upper input design value of a range.

Monte Carlo simulation utilizes the inverse function of the cumulative density function, which according to Vose [36], is given in equation as follows:

$$F^{-1}(xi) = A + (B - A)vi \quad (2)$$

$$xi = A + (B - A)vi$$

where

vi = any random number value (0 - 1).

The input range of the design parameters: Von Sperling [35], recommends that the lower and upper design values of the proposed range be determined by assuming a percentage value, which reflects the level of uncertainty of the average deterministic single value. the equations as follows:

$$X_{min} = \bar{X} - a \bar{X} \quad (3)$$

$$X_{max} = \bar{X} + a \bar{X} \quad (4)$$

where

X_{min} = lower end value of the input design range.

X_{max} = upper end value of the input design range.

\bar{X} = average value of the input design parameter.

a = any assumed percentage value based on the level of the uncertainty.

Design population: The design population is established by using equation as follows:

$$P_d = P_o (1 + r)^n \quad (5)$$

where

P_d = design population of the served community.

P_o = initial population of the served community.

r = population growth rate.

n = design period of waste stabilization ponds.

Design flow: The values of the population range are then used in equation for establishing the design flow range as follows:

$$Q = \frac{P_d q}{1000} \quad (6)$$

where

Q = design flow rate (m³/day).

P_d = design population.

q = per capita wastewater production (l per person per day).

Volumetric organic loading: At every run of a simulation, the computer program selects randomly the temperature from the proposed range and the selected temperature is compared with the four temperature conditions as suggested by Mara and Pearson [37], and Mara et al. [38].

The first temperature condition is satisfied when the selected random temperature (T) <10°C as presented as follows:

$$\lambda_v = 100 \quad (7)$$

$$(L_i)_f = 0.6 (L_i)_a \quad (8)$$

$$(L_i)_{m1} = 0.3 (L_i)_a \quad (9)$$

where

λ_v = volumetric organic loading rate (g/m³ day).

$(L_i)_a$ = random design value of influent BOD in anaerobic pond (mg/l).

$(L_i)_f$ = influent BOD in facultative pond (mg/l).

$(L_i)_{m1}$ = influent BOD into first maturation pond (mg/l).

The second temperature condition is satisfied when the selected random temperature is between 10 and 20°C as presented as follows:

$$\lambda_v = 20 T - 100 \quad (10)$$

$$(L_i)_f = \frac{100 - (2 T + 20)}{100} \times (L_i)_a \quad (11)$$

$$(L_i)_{m1} = 0.3 (L_i)_a \quad (12)$$

where

T and $(L_i)_a$ are random design parameters.

The third temperature condition is satisfied when the selected random temperature is between 20 and 25°C as presented as follows:

$$\lambda_v = 10 T + 100 \quad (13)$$

$$(L_i)_f = \frac{100 - (2 T + 20)}{100} \times (L_i)_a \quad (14)$$

$$(L_i)_{m1} = 0.2 (L_i)_a \quad (15)$$

where

T and $(L_i)_a$ are random design parameters. The fourth temperature condition is satisfied when the selected random temperature is above 25°C as presented as follows:

$$\lambda_v = 350 \quad (16)$$

$$(L_i)_f = 0.3 (L_i)_a \quad (17)$$

$$(L_i)_{m1} = 0.2 (L_i)_a \quad (18)$$

where

$(L_i)_a$ is a random design parameter.

The hydraulic retention time: The determination of the random value of the hydraulic retention time for the anaerobic pond is calculated as follows:

$$\theta_a = \frac{(L_i)_a}{\lambda_v} \quad (19)$$

where

the design parameters L_i , and λ_v are random values selected from a proposed range in order to determine the random hydraulic retention time in anaerobic pond.

θ_a = hydraulic retention time (days).

L_i = influent BOD concentration (mg/l).

λ_v = volumetric BOD loading (g/m³ day).

The procedures for calculating the random hydraulic retention time for the facultative pond are presented as follows:

$$\lambda_{sf} = 350(1.107 - 0.002T)^{T-25} \quad (20)$$

$$A_f = \frac{10 (L_i)_f Q_f}{\lambda_{sf}} \quad (21)$$

$$\theta_f = \frac{2 A_f H_f}{(2 Q_f - 0.001e A_f)} \quad (22)$$

where

the subscript “ f ” refers to facultative pond.

the parameters T , $(L_i)_f$, Q_f , λ_{sf} , A_f and e are random design values.

θ_f = hydraulic retention time in facultative pond (days).

λ_{sf} = surface BOD loading (kg/ha day).

T = temperature (°C).

A_f = facultative pond area (m²).

$(L_i)_f$ = influent BOD concentration in the facultative pond (mg/l).

Q_f = mean flow (m³/day).

H_f = pond depth (m).

e = net evaporation (mm/day).

The procedures for calculating the random hydraulic retention time for the first maturation pond are presented as follows:

$$\lambda_{sf} = 350(1.107 - 0.002T)^{T-25} \quad (23)$$

$$\Theta_{m1} = \frac{10 (Li)_{m1} H_{m1}}{0.75 \lambda_{sf}} \quad (24)$$

where

the subscript “ $m1$ ” refers to first maturation pond.

the parameters T , $(Li)_{m1}$ and λ_{sf} , are random design values.

θ_{m1} = minimum hydraulic retention time in first maturation pond (days).

H_{m1} = design depth of the first maturation pond (m).

$(Li)_{m1}$ = influent BOD concentration in first maturation pond (mg/l).

λ_{sf} = surface BOD loading in facultative pond (kg/ha day).

The random design values of the hydraulic retention time in the second and subsequent maturation ponds is selected from the minimum retention time range of 3 to 5 days, as recommended by Marais [39].

Removal of human intestinal nematode eggs: The effluent helminth eggs concentration in the ponds is carried out by the design equation of Ayres et al. [40] as follows:

Removal of human intestinal nematode eggs in the anaerobic pond:

$$R_a = 100[1 - 0.41 \exp(-0.49\theta_a + 0.0085\theta_a^2)] \quad (25)$$

where

R_a = the percentage egg removal in the anaerobic pond.

θ_a = the retention time in the anaerobic pond (days).

Removal of human intestinal nematode eggs in the facultative pond:

$$R_f = 100[1 - 0.41 \exp(-0.49\theta_f + 0.0085\theta_f^2)] \quad (26)$$

where

R_f = the percentage egg removal in the facultative pond.

θ_f = the retention time in the facultative pond (days).

Removal of human intestinal nematode eggs in the first maturation pond:

$$R_{m1} = 100[1 - 0.41 \exp(-0.49\theta_{m1} + 0.0085\theta_{m1}^2)] \quad (27)$$

where

R_{m1} = the percentage egg removal in the first maturation pond.

θ_{m1} = the retention time in the first maturation pond (days).

Removal of human intestinal nematode eggs in the second and subsequent maturation ponds:

$$R_m = 100[1 - 0.41 \exp(-0.49\theta_m + 0.0085\theta_m^2)] \quad (28)$$

where

R_m = the percentage egg removal in the second and subsequent maturation ponds.

θ_m = the retention time in the second and subsequent maturation ponds (days).

Additionally, The equation is applied to the anaerobic pond, facultative pond and then to maturation ponds, to calculate the number of eggs per litre of the effluent, as follows:

$$E = E_{rw} (1 - r_{an}) (1 - r_{fac}) (1 - r_{matu1}) (1 - r_{matu}) \quad (29)$$

where

E = the effluent number of Nematode eggs per litre.

E_{rw} = number of Nematode eggs per litre in the raw wastewater.

$r = R/100$ with the subscripts 'an' 'fac' 'matu1' 'matu' referring to the anaerobic pond, facultative pond, first maturation pond and the second and subsequent maturation ponds.

3. Results and Discussion

As a result of Monte Carlo simulations models for the design of waste stabilization pond based on parameter uncertainty and 10,000-trial. A summary of the major types and functions of each pond is described in Table 5. Where we can see the highest number of human intestinal helminth eggs was removed in the anaerobic pond which a total removal efficiency (88.709 %) (figure 6) with a hydraulic retention (2.855 days) but the effluent still contained (105.288 eggs/l) (figure 7). Reasons that can explain Because, In anaerobic ponds, despite the high removal rate of suspended solids, the release of methane, hydrogen sulphide and carbon dioxide from the sludge layers leads to the resuspension of some organic and inorganic solids. It is possible that the relatively poor rate of removal of intestinal parasitic helminth eggs in anaerobic ponds is due to their resuspension by gas [41, 28].

Also, the Table 5 shows that numbers of helminth eggs in the effluent from facultative pond was (0.571eggs/l) (figure 7). with a hydraulic retention (21.049 days) And the total efficiency removal which (99.938 %) (figure 6). The extremely the low efficiency Because anaerobic and facultative ponds are designed for removal of biochemical oxygen demand (BOD) and maturation ponds for pathogen removal. However, some BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds [42].

Table 5

Summary of data PC-Monte Carlo simulations for removal of human intestinal helminth eggs by waste stabilization ponds

Pond type	Area (ha)	Depth (m)	Design Retention time (d)	Total Efficiency (%)	Effluent eggs/L
Raw wastewater					932.500
Anaerobic Pond	0.418	4.00	2.855	88.709	105.288
Facultative Pond	9.942	1.00	21.049	99.938	0.571
First maturation Pond	6.986	0.65	7.453	99.999	0.008
First addition maturation Pond	4.754	0.65	4.850	100	0.000
The overall	22.1 ha		36.207 days	100 %	0.000 eggs/L

On the other hand, A series of anaerobic and facultative ponds can treat wastewater to a sufficient degree to allow it to be used in a restricted way for irrigating crops [19]. Anaerobic and facultative ponds only a relatively weak wastewater (up to 150 mg BOD/l). Maturation ponds are required only when the treated wastewater is to be used for unrestricted irrigation and when stronger wastewaters (BOD > 150 mg/l) [43, 44].

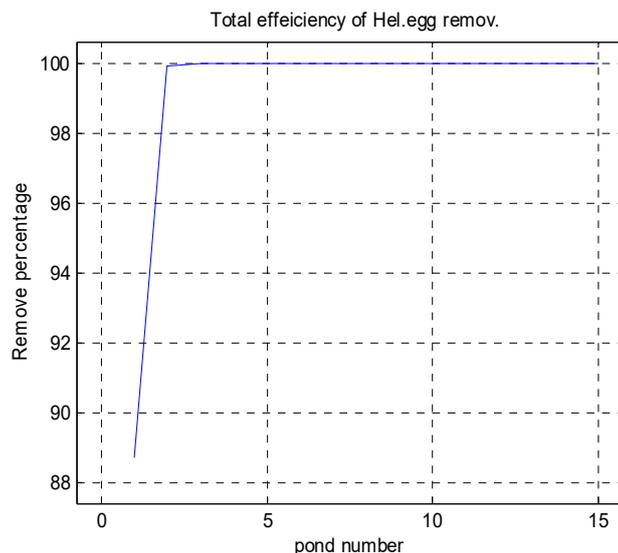


Fig. 6 - The total efficiency removal of helminth eggs in WSP

The extremely high removal of helminth eggs in maturation ponds is shown in Table 5. While in the first maturation pond (figure 6) a total removal efficiency (99.999 %) and the effluent helminth eggs concentration was (0.008 eggs/l) with a hydraulic retention time (7.453 days) (figure 7). Moreover, The total efficiency dramatically rose in the first addition maturation pond which (100 %) with effluent helminth eggs concentration (0.000 eggs/l). which the becomes less than WHO, 2006 guidelines for the safe use of wastewater in agriculture.

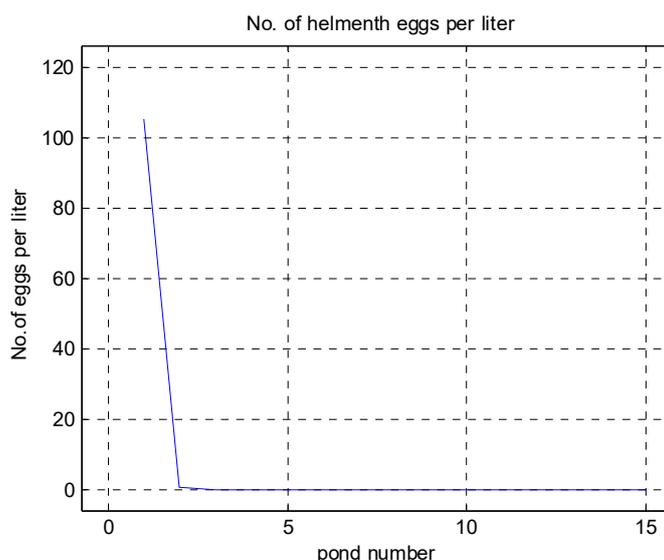


Fig. 7 - The effluent of helminth eggs from WSP

Possible reasons that can explain the high removal of helminth eggs in maturation ponds by the sedimentation Because the sedimentation is more effective in waste stabilization pond WSP with less turbulence. While the WSP systems have hydraulic retention times on the order of days, weeks, or even months, which allows particles to sedimentation [45]. Sedimentation is an important mechanism for the removal of those pathogens which can either settle on their own accord or attach to settleable particles. The degree to which pathogens adsorb onto settleable particles is influenced by both environmental conditions and the surface characteristics of the pathogens themselves through their influence on electrostatic, hydrophobic, and steric interactions [46]. This mechanism is considered to be important for both helminth eggs and protozoan cysts within WSPs, though recent studies have hypothesized that sunlight and physicochemical conditions of water could have a higher impact on cyst removal than previously thought [47, 48].

4. Conclusions

In conclusions, That 36.207 days waste stabilization pond WSP in climatic conditions of Libya at Jalu municipality (anaerobic pond, facultative pond, first maturation pond and the first addition maturation ponds) produces an effluent of helminth eggs concentration less than WHO, 2006 guidelines for the safe use of wastewater in agriculture. Finally, the recycling of wastewater for agriculture may result in too high economic benefits that can offset the operation and maintenance costs of the ponds. However, there are also negative aspects related to wastewater reuse which include soil salinity, the health of farmers and consumers, public acceptability, marketability of produce, economic feasibility and sustainability of wastewater irrigation.

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