Design and implementation of a small scale NBS – Constructed wetland to treat greywater in a selected case study in Jordan.

Final Report By

Climate Action Network Jordan (CAN)

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Acronyms list

BOD	**Biological Oxygen Demand**
BoQ	Bill of Quantities
CAN	Climate action Now
CFU	Colony forming unit
COD	Chemical oxygen demand
CSL	Cross-sectional organic loading rate
CW	Constructed Wetland
E. coli	Escherichia coli
FAO	Food and Agriculture Organization (FAO) is a specialized agency of the United Nations
HFCW	Horizontal Flow Constructed Wetland
FOG	Fat, Oil, and Grease
HLR	Hydraulic loading rate
HRT	Hydraulic retention time
JD	Jordanian Dinar
JS	Jordanian standards
JSMO	Jordan Standards and Metrology Organization
L/W	Length/Width
M.L	Mass loading rates
MPN	Most Probable Number
MWI	Ministry of water and irrigation
NbS	Nature based Solution
NGO	Non-governmental organizations
NTU	Nephelometric Turbidity unit
O&M	Operation and maintenance
pH	Potential hydrogen
SS	Suspended solid
TC	Total carbon
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solid
USD	US dollar
VF	Vertical flow
WASH	Water Sanitation and Hygiene
WWTP	Wastewater treatment plant

1. Introduction

Water scarcity in Jordan seriously affects the social and economic development of the country. The situation is likely to exacerbate as the population doubles in the coming decades and climate change scenarios indicate a significant reduction in water quantity and quantity. The threat of depleting water resources that can no longer meet the increasing demand might create instability in the kingdom and wreak havoc on future generations (Breulmann *et al.*, 2019). The reuse of greywater plays a major role in the agricultural sector as a key scenario to reduce the strain on water resources in Jordan (Breulmann *et al.*, 2019)

Jordan's Government investing in implementing projects for the reuse of greywater in agriculture using economic, effective, and environmentally friendly systems (Abdelhay and Abunaser, 2021). The government has also prepared a detailed standard to control the treatment and reuse of greywater mainly in cooked vegetables, parks, playgrounds, and roadsides within cities, food crops intended for human consumption including raw consumption, and toilet flushing (JSMO, 2013). Several greywater treatment and reuse projects have been widely applied in Jordan at different levels, such as households, institutional levels, schools, campuses, mosques, etc. (Al-Mashaqbeh, Ghrair and Megdal, 2012; Qdais, Abdulla and Kurbatova, 2019; Al Arni *et al.*, 2022; Masoud, Alfarra and Sorlini, 2022)

Greywater produced in Jordan is estimated up to 75% of the wastewater volume produced and is estimated to be 54 million m3 each year. Therefore, greywater reuse for irrigation and toilet flushing is endorsed by the government to conserve water. Based on previous studies and projects, Mosques for example, on average, produced greywater amounts between 1 to 10 m^3 per day, based on the number of worshipers, and pattern of use. Despite the considerable potential for greywater reuse in Jordan, the current state of implementation and management approaches is inadequate, and the existing market system faces several challenges, leading to missed opportunities and failing projects to recycle greywater (Breulmann *et al.*, 2021).

Several organizations in Jordan at the national and international levels worked together in scaling up the treatment and reuse of greywater to be used in agriculture, including research institutes in order to capacitate the Jordanians with the technical requirements for greywater treatment technologies and to raise awareness about the importance of reusing greywater. This opened innovation and new approaches to be piloted and adapted.

The signed Letter of Agreement between the Food and Agriculture Organization of the United nations, FAO and Climate Action Network, CAN is for the provision of services for "Feasibility assessment, design and implementation of a small scale Ecosystem-based solutions -

constructed wetland to treat greywater in a selected case study in Jordan" aims to assess the feasibility of integrating Ecosystem-based solutions – constructed wetland to treat greywater generated from a selected mosque in Jordan through implementing a pilot- scale constructed wetland and monitor the performance and treatment efficiency with referring to the treatment and reuse Jordanian standards for reclaiming wastewater JS 1776/2013 (JSMO, 2013)

2. Project Overview

Under the LoA, the services provided will focus on integrating Ecosystem-based solutions – Constructed Wetland as a low-cost sustainable solution for greywater treatment. Implementation of a greywater treatment system at the selected mosque has several benefits and can achieve several objectives. First, the mosque generates continuously a good amount of greywater from its ablutions. Moreover, mosques are known to have a good influence on Muslim communities to deliver key messages on the acceptance and reuse of treated greywater in gardening and agriculture. Mosques are not only used for religious purposes but also, they are known to be culture centres. People usually gather for praying and to have social discussions. Finally, the mosques are public facilities that are managed by Jordan Government, this can facilitate the implementation and adaption of new technology using constructed wetland (CW) to treat greywater and reuse it in agriculture.
The general scope of the project is to investigate the sustainability of Ecosystem-based solutions practice - constructed wetland as a treatment option for greywater. As well as providing a treatment system with low operation costs for a selected institutional building, aiming to provide a new source of water through reclaiming the greywater according to the local standards.

Following to the first submitted inception report, design report has been submitted and this final report summarises the overall project activities, main results, methodology utilised during selection and assessments period, final dimensions and technical specifications of the constructed wetland and guidelines.

3. Methodology

3.1 Assessment and site selection

To select a site for implementing the CW, several onsite assessments were carried out between September and December 2023.

The following criteria were considered in the assessment for the selection:

- WASH conditions in each of the potential mosques.
- Understand the Water Sanitation and Hygiene (WASH) practices at the potential mosques .
- Visit the mosques with a group of engineers, and assess key environmental features of the mosques such as availability of space/ land, , WASH infrastructure (pipes, water tanks, water meters) and document the features as photographs (not people)
- Note other key features related to the assessment.

For mosques sites, the assessments were carried out in one week by a group of engineers focusing on the features below:

- Distance from governorate
- Distance from Zarqa City
- Transportation and road conditions
- Presence of antiquities and caves
- Internal and the adjoining spaces to the institution
- Total area and availability of open spaces within the institutions

Institution characteristics, functionality, and key staff:

- Number of targeted beneficiaries and types in our case the community
- Working hours
- Key staff / Positions at institution number

Institution WASH infrastructure status analysis:

- Type, number, and general conditions of toilets
- Type of toilets flushing system
- Number and status of washing sinks in toilets.
- Evaluation for the Ablution Places
- The level difference between the Washbasin facilities and toilets in institution
- Cleaning equipment (bin, water pot, cleaning kits, soap holder, hand drier, etc…)
- WASH buildings/rooms infrastructure conditions: Tiles, leaking, paints, doors, etc…
- Piping location (external or internal connection) and conditions

3.2 Data collection

Different types of data have been collected for the selected mosque (Roqayya Bent Al Rasoul) such as:

- water bills;
- number of daily users;
- number of trees and irrigation area;
- greywater characteristics;
- possible reuse options;
- peak hour, peak day, peak month;

3.3 Design and preparation

Introduction

The collected flow data and the characteristics of the raw greywater have been used to design the treatment system. Subsurface Horizontal flow constructed wetland, HFCW was selected for this project due to the ease of implementation and operation, and the greywater has a minimal load of nitrogen. Several literature have illustrated the efficiency of HFCW in treating greywater. Plug flow k-C* method was selected to design the CW and calculate the CW's dimensions. According to (Dotro *et al.*, 2017a) several methods can be used for designing CW and plug flow k-C* has proved several successful examples and cases (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a).

The proposed simple treatment process for our case included:

Collection/Sedimentation tank >>> HFCW >>> Collection tank

Design specifications and recommendations from Jordanian standard for reclaim and reuse treated greywater JS 1776/2013 (JSMO, 2013) were considered in our design.

Usually, a preliminary step is being provided but, in our project, and treatment system preliminary treatment is not needed

Preliminary treatment mainly separates the coarsely dispersed solids out of the liquid phase. The preliminary treatment prepares wastewater influent for further treatment in wetland by reducing or removing wastewater characteristic that could otherwise delay operation or increase maintenance of the further treatment steps like pumps. The typical wastewater characteristics include large solids and rags; grit; odors etc. The preliminary treatment of wastewater comprises of mainly screen and grit chamber. A screen is a device with openings, generally of uniform size, that is used to retain solids found in the influent wastewater to the treatment plant, which removes coarse materials from the wastewater. Grit chambers remove grit: sand, gravel, or other heavy sold materials that have specific gravities much greater than those of the organic solids in the wastewater (Kadlec and Wallace, 2009). The project is treating greywater that is directly coming from sinks and ablution practices. During the feasibility and assessment phase, several samples were collected and tested in order to determine the necessity of the preliminary step. The outcome of this was having preliminary treatment wasn't needed.

Primary treatment

The primary treatment separates the suspended matter by physical processes mainly sedimentation. Raw greywater contains suspended particulate heavier than water; these particles tend to settle by gravity. Primary treatment reduces suspended solids, organic load to the CW and equalizes raw greywater quality and control the flow to the CW (UN-HABITAT, 2008; Dotro *et al.*, 2017a) .

In our treatment system collection tank has been used as a collection tank and septic tank. Septic tank is the most common primary treatment option used in small-scale CW worldwide. A single-compartment septic tank was used with a capacity of one cubic meter.

Septic tanks will generally need to be desludged, otherwise they produce very poor effluents with high suspended solids content, which can be unfavourable to the CW (e.g., clogging of beds). To ensure continuous effective operation, the accumulated material must therefore be emptied periodically. This should take place when sludge and scum accumulation exceed 30% of the tank's liquid volume (UN-HABITAT, 2008; Kadlec and Wallace, 2009).

Although the collection and septic tank can reduce the suspended solid and BOD (Biological oxygen demand), in the raw wastewater 50% and 30% respectively (Kadlec and Wallace, 2009), that removal percentage weren't considered in designing the CW for many reasons. First, to consider safety factor in designing and calculating the required dimensions of CW, and second, to consider lack of proper operation of the collection tank.

Horizontal flow constructed wetland (HFCW)

Plug-flow k-*C**

The HFCW has been designed based on the first-order Plug-flow k-C* approach proposed by (Kadlec & Wallace, 2009a; Nivala et al., 2017). This approach considers influent and effluent concentrations as well as background concentration but assumes ideal plug-flow hydraulics.

Background concentration (C*) is an irreducible effluent concentration that results from internal biogeochemical cycling within wetlands. For example, for organic matter, C* could represent the refractory or non-biodegradable fraction. The background concentration C*, which is often inferred from a large collection of data, effectively sets a lower limit to the effluent concentration of a CW (Co). This means that even for a wetland that has an infinitely long retention time, the theoretical effluent concentration, Co will never be less than C* (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a). Value of C* for different parameters are varied according to the treatment stage, for example for BOD removal for primary effluent C* = 10 mg/l, while for secondary effluent C* = 5 mg/l and for tertiary effluent C* = 1 mg/l (Kadlec and Wallace, 2009)

In this approach wetland area, A, can be calculated as follows (Equation 1):

$$A = -\frac{Q_{in}}{k_T}\ln\left(\frac{C_{in}-C^*}{C_{out}-C^*}\right) \qquad \text{Eq 1}$$

Where A [m^2] is the area of the CW

Q_{in} is the discharge [m^3/d]

C_{in} [mg/L] the inlet pollutant concentrations

C_{out} (mg/L) The target output concentrations

C* the background concentration.

K_T is the modified first-order areal rate coefficient, m/d measured at T °C, the coefficient can be modified according to the temperature based in equation 2:

$$k_T = k_{20}\vartheta^{(T-20)} \qquad \text{Eq 2}$$

Where k_{20} is the rate coefficient at water temperature at 20 °C temperature and its value varied according to each parameter while θ is the modified Arrhenius temperature factor (dimensionless) equal to 1.06 (average) and is T is the temperature of the liquid in the system [°C] (Kadlec and Wallace, 2009).

The required area for to treat each parameter (BOD, COD, TSS, etc.) has been calculated separate, and the largest areas has been selected for the final design and implementation.

Several design parameters have to be checked, such as hydraulic retention time, hydraulic loading rate, mass loading rate, and cross-sectional loading rate. All design checks are described below (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a):

For the hydraulic retention time (HRT) as

$$HRT = \frac{A*H*\varepsilon}{Q_{in}} \qquad \text{Eq 3}$$

Where HRT is the hydraulic retention time (days)

A is the area of CW (m^2)

H is the depth of CW (m)

ε is the porosity of the filter material (m^3/m^3)

and Q_{in} is the fixed discharge (m^3/d).

The depth of the HFCW is varied and depends on the application of CW, for secondary treatment the depth is between 0.35 to 0.7 m (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a).

For the hydraulic loading rate (HLR) is expressed as [m/d] and can be calculated according to the flowing equation

$$HLR = \frac{Q}{A} \qquad \text{Eq 4}$$

The mass loading rates M.L [kg/m^2d] represents the amount of mass loaded to the CW daily and can be calculated as:

$$M.L. = \frac{Q*C_{in}}{A} \qquad \text{Eq 5}$$

The check of cross-sectional organic loading rate (CSL) ($gBOD_5/m^2d$) is fundamental to avoid clogging problem during the operation. It is measured as:

$$CSL. = \frac{BOD_{5,in}}{C.S.} \qquad \text{Eq 6}$$

Where $BOD_{5,in}$ is the BOD_5 (g/d) which enters in the CW tank and C.S. (m^2) is the cross-sectional area determined as:

$$C.S. = W * H \qquad \text{Eq 7}$$

Where W is the width of CW (m), and H represents the saturated depth of the HF wetland (m). The CSL must not exceed 250 ($gBOD_5/m^2d$), otherwise clogging problem might occur (Dotro *et al.*, 2017a).

The recommended length-to-width ratio (L: W) for HF-CW should vary from 2:1 to 4:1. In order to maximize the cross-sectional area and reduce clogging potential with the higher hydraulic rates applied, HFCW systems are generally constructed with a longitudinal sloped base (1%) to facilitate draining of the bed if needed (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a). Several design guidelines and manuals have estimated and set design limits to guarantee an efficient performance of CWs. Table 1 below summarizes some design limits as adopted from different resources (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a)

Table 1. Design limits for CWs

Parameter	Free water Surface CW	Vegetated submerged CW
Organic loading rate, kg BOD/ha day)	5-110	10 - 200
Nitrogen loading rate, kg N/ha. day (Kg/ha day)	0.5-60	2-80
HRT (d)	3-10	2-7
HLT (cm/d)	2.5-10	2.5-20
water depth from the surface **(cm)**	20-50	2-10
L/W	4:1-6:1	2-1
bed depth (cm)	-	30-90

Finally, it is possible to estimate the efficiency of plant considering the different pollutants using the simplified equation:

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \qquad \text{Eq 8}$$

Where: η is the estimated efficiency, C_{in} is the concentration of raw greywater and C_{out} is the concentration of the treated greywater.

Media selection

The filter media perform several roles in CWs. They are rooting material for vegetation, they help to evenly distribute and collect flow at inlet/outlet, also they provide surface area for microbial growth, and they act as filter and trap particles (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a).

Very small particles have very low hydraulic conductivity and create surface flow. Very large particles have high conductivity but have little wetted surface area per unit volume of microbial habitat. Large and angular medium is inimical to root propagation. The compromise is for intermediate-sized materials generally characterized as gravels. It is recommended that the gravels are doubled washed to remove fines that could block the void spaces (Kadlec and Wallace, 2009; Stefanakis, Akratos and Tsihrintzis, 2014; Dotro *et al.*, 2017a).

For HFCW it is reported that the diameter size of media used varies from 0.2 mm to 40 mm (Kadlec and Wallace, 2009; Stefanakis, Akratos and Tsihrintzis, 2014; Dotro *et al.*, 2017a; Arias *et al.*, 2021). It is also recommended that the media in the inlet and outlet zones should be between 40 and 80 mm in diameter to minimize clogging and should extend from the top to the bottom of the system. For the treatment zone, it does not appear to be a clear advantage in pollutant removal with different sized media in the 10 to 60 mm range (Kadlec and Wallace, 2009; Stefanakis, Akratos and Tsihrintzis, 2014; Dotro *et al.*, 2017a).

4. Results

4.1 Assessment and mosque selection

Several mosques have been assessed during the onsite assessment activities, the assessment covered Amman and Zarqa city. The assessment focused mainly on i) available space for implementing the system, ii) potential of reuse of the treated greywater, iii) availability of local staff to operate the system in the long term.

Among the eleven mosques, Roqayya Bent AlRasoul Mosque in Zarqa was the most suitable mosque for the project, and the community in Zarqa showed high interest in the project.

Roqayya Bent AlRasoul mosque is in Zarqa city in the easter part of Jordan, Zarqa city considered as semi-arid – arid climate with less than 250 mm/year rainfall (I, 2017). The mosque is located in the eastern part of the city with harsh climate conditions, the area is considered as a desert with very limited rainfall. The city and the mosque receive fresh water from the drinking water network, which is mainly used for ablution and rarely for irrigation the green area within the mosque building. The water bill is paid by the Ministry of Awqaf and religious Affairs and that leads to increase the consumption rate. It is worth to mention that the water supply in Jordan is intermittent., The water is supplied only one or two times a week and people store the water into water tanks and use it until the next water supply. For drinking purposes, mosque attendees mainly use bottled water, and this practice is common practice in Jordan. The water demand is variable during the year and its peak is in the summertime (July – August – September). The peak month during the year is Ramadan time and Friday is the peak day during the week, especially at noon time.

The total number of beneficiaries is 1200 in the neighbourhood with an average of 100 persons attending each prayer. During the Friday prayers, more than 500 people usually attend.

The total available land area of the mosque is around 4,700 square meters, where 750 square meters is vegetated with different types of tress and crops, mainly olive trees and local herbs. The remaining area is not vegetated mainly due to the limitation of water availability. The estimated water consumption for irrigation is very limited, around 35 tress and other crops relay mainly on rainwater. Figure 1 shows the mosque compound while Figure 2 shows top view of the mosque's facilities.

Figure 1 Roqayyah Bent Al Rasoul mosque's vegetated and unvegetated area (Winter season)

The irrigation (when it happens) is done manually with drinking water from the tank connected to the public service. Drinking water is used for the plants and vegetation because is the only source of water available for the mosque. Due to the lack of water only half of the land area is vegetated while the other half of is empty, without trees nor vegetation. A possible reuse of the treated greywater is the irrigation of the existing garden, and it could be possible also to increase the green area with new plants and vegetation to irrigate with the new source of water.

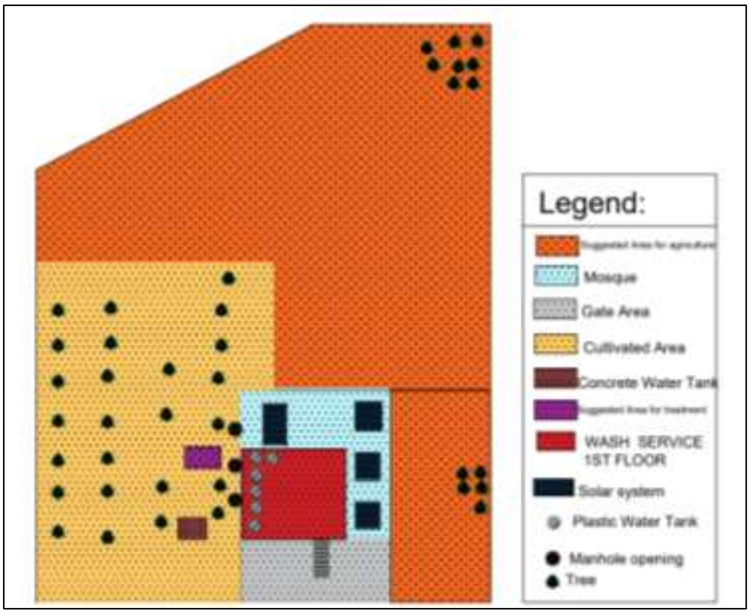

Figure 2 Roqayyah Bent Al Rasoul mosque Top view sketch

The WASH units are located within the main building with separated entrance. The general conditions are good, the wastewater is being disposed by gravity to the sewer network. The WASH units building is relatively new with internal plumbing. Figures 3 shows the general condition of the WASH units.

Figure 3 WASH unit – ablution area

Although the mosque receives electricity from the local electricity grid, the mosque has a solar system on the roof top to generate electricity and reduce the energy consumption costs.

The willingness of acceptance in the mosque staff is high, the staff is cooperative, guaranteeing the availability to follow the training, operating and the ordinary maintenance of the greywater treatment plant.

4.2 Data collections

Table 2 summarize the water consumption in the mosque for the last three years, the data has been collected from the water bills from Miyahuna water company in Zarqa City. As mentioned earlier the water is only being used for ablution practices, toilet flushing and very limited garden irrigation. For drinking water, the mosque provides bottled water for all users. The water consumptions considered relatively high and reusing treated greywater could reduce the water consumptions and can increase the green area with new plants and vegetation. The collected data will be used to calculate the water saving after the implementation and operation on the CW.
The mosque is located near a main road so many people stop by to rest, use the toilets, wash their hands and faces for refreshments especially during summer.

Table 2. Water consumption – Roqayyah Bent al Rasoul Mosque

Year	Duration	Water consumption (m^3)	Costs (JD)
2021			
	Second quarter	165	305.4
	Third quarter	155	275.2

2022	First Quarter	122	177.4
	Second quarter	178	344.6
	Third quarter	173	329.5
2023	First Quarter	235	515.8

4.3 Detailed design

Raw greywater Characterization,

As a first step for designing CWs, the characteristics of the raw greywater were identified thought two steps. First, samples were collected over three days and a composite sample was tested and analysed in the laboratories of Water Authorities of Jordan. The second step is from the collected previous tests that took place in different mosques in the same city and other cities in Jordan. This step was necessary to check if the greywater characteristics are within the regular limits and the water consumption practices and to be sure no critical parameters or illegal behaviours such as disposing industrial wastewater or slaughter wastewater in the mosque WASH units are exist for the selected mosque. Table 3 shows the raw greywater parameters that have been used for the design of the HFCW.

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Table 3. Raw greywater characteristics

Characterization of Raw wastewater		
Parameter	Unit	Raw greywater
BOD	mg/l	100
COD	mg/l	153
TSS	mg/l	200
NH_4	mg/l	less than 5
NO_3-	mg/l	13
Turbidity	NTU	16
Temperature	C	25

The main parameters considered for design the CW were TSS and the BOD.

The target effluent concentrations have been determined according to the Jordanian standards for reclaimed and reuse treated greywater JS 1776/2013. Table 4 shows the acceptable limits for reuse the treated greywater. For this project "Food crops intended for human consumption including raw consumption" reuse options has been considered. The daily greywater influent considered to 1 cubic meter daily, Although the mosque generates more greywater during the peak time, the flow has been selected due to the limited budget available. The system has been designed with a dosing pump which doses a specific amount in a specific time of greywater from the first collection tank to the constructed wetland. This means during the peak time if the greywater flow exceeds the system capacity, the system will not affected and the overflow of the greywater will go directly to the sewer system and not to the treatment system.

Jordanian standards

The Jordanian Government established a standard for reusing and treating greywater in 2013. The standards describe some obligatory conditions, for example to use the treated greywater for toilet flushing a chlorination is obligatory. Table 4 summarizes the main parameter and reuse limits for treated greywater for different reuse purposes.

Table 4. Jordanian standard for greywater reuse JS 1776/2013

Parameter	Cooked vegetables, parks, playgrounds, and roadsides within cities.	Food crops intended for human consumption including raw consumption	Toilets flushing
BOD_5 (mg/l)	60	60	<10
COD (mg/l)	120	120	<20
TSS (mg/l)	100	100	<10
pH	6 - 9	6 - 9	6 - 9
NO_3^- (mg/l)	70	70	70
TN (mg/l)	50	50	50
Turbidity NTU	undefined	undefined	< 5
E. coli (CFU/100 ml)	10000	1000	<10
Helminth eggs (egg/l)	<1	<1	<1
Fat, Oil, & Grease (FOG) (mg/l)	8	8	8

Area calculation

By using equation 1 mentioned earlier the area required to treat BOD from 100 to 60 mg/l, and the area required to treat TSS from 200 to 100 mg/l was calculated.

$$A = -\frac{Q_{in}}{k_T} \ln\left(\frac{C_{in}-C^*}{C_{out}-C^*}\right) \qquad \text{Eq 1}$$

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C* can be calculated for the BOD and TSS with the same equations but different constant values according to (Abdel Razik Ahmed Zidan and Mohammed Ahmed Abdel Hady, 2018) as

$$C^*_{BOD} = 3.5 + 0.053 * C_{BOD,in} \qquad \text{Eq 9}$$

$$C^*_{TSS} = 5.1 + 0.16 * C_{TSS,in} \qquad \text{Eq 10}$$

Therefore, C* for BOD = 3.5+.053*100 = 8.8 mg/l

C* for TSS = 5.1 + 0.16*200 = 37.1 mg/l

Where the value C* for BOD equal from 1 to 10 mg/l depending on the treatment stage and for TSS equal to 37 mg/l according to (Kadlec and Wallace, 2009; Stefanakis, Akratos and Tsihrintzis, 2014; Dotro *et al.*, 2017a; Merriman *et al.*, 2017). The value of the C* is affected by the temperature, initial concentration of the raw wastewater, and the treatment stage (primary, secondary, or tertiary) (Dotro *et al.*, 2017a).

For this design higher values of C* have been considered in order to maximize the required area. The removal coefficient rate K_{20} have been selected and adapted to the water temperatures according to (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a).

For BOD

- K_{20} = 36.5 (m/y)
- $K_T = K_{20}$ * 1^ 25-20 = 36.5 m/y
- C* = 8.8 mg/l
- C_{in} = 100 mg/l
- C_{out} = 60 mg/l
- Q = 1.1 m^3/day
- Area = 6.26 m^2

While for TSS

- K_{20} = 30
- K_T = 30*1.1^ (25-20)
- C* = 37.1 mg/l
- C_{in} = 200 mg/l
- C_{ou}t = 100 mg/l
- Q = 1.1 m^3/day
- Area = 7.91 m^2

Table 6 summarize the design parameters and the final calculated area for the selected parameter (BOD and TSS)

Table 1 Design parameters and the final calculated areas

	K_{20} (m/y)	Q (m^3/day)	T (°C)	K_t (m/y)	C_{in} (mg/L)	C* (mg/L)	C_{out} (mg/L)	A (m^2)	Expected η (%)
BOD	37	1.1	25	37	100	8.8	60	6.26	40
TSS	30	1.1	25	48.31	200	37.1	100	7.91	50

The depth of the filter material has been selected to be 50 cm, and the water depth below the surface with 10 cm in the inlet and 20 cm in the outlet. Jordanian tuff has been selected as a filter material, several studies have recommended tuff due to its texture which is a favourable location for microbial growth, tuff are available locally with low cost. The media selected for all the CW tank, have a porosity ε=0.60 (Al Dwairi *et al.*, 2018) and L: W has been selected equal to 2:1.

The final dimensions for the CWs have been selected and illustrated in Table. Free board is required, due to that 0.3 m has been added to the total depth of the CW (Dotro *et al.*, 2017b).

Table. 2 Final dimensions of HFCW

HF-CW tank size	
High (m) (including 0.3 m free board)	0.8
Width (m)	2.0
Length (m)	4.0
Area (m^2)	8.0
Volume (m^3)	6.4

The CSL determined is less than maximum value possible suggested by literature is equal to 250 [$gBOD_5/m^2d$].

The other design parameters such as HRT, HLR, ML, and CSL have been calculated and checked according to equations illustrated before. The results are summarized in Table 8.

Table. 8 Design parameter check

AREA (m^2)	**Saturated depth (m)**	**ε (porosity)**	**HRT (d)**	**HLR (m^3/d)**	**ML – BOD (kg/ha.d)**	**CSL rate (gBOD5/m^2d)**
8.00	0.4	0.6	1.8	0.14	13.75	**137.5**

The parameters are achieving the recommended limits in (Kadlec and Wallace, 2009; Dotro *et al.*, 2017a) for the HRT and based on the operation mechanisms of CW. A dosing system to be installed to supply the greywater from the collection tank to the CW during the day. The dosing system can be regulated in order to achieve the treatment efficiency. For the first operation it was selected to dose the CW with (0.1 m^3) every two hours, depending on the availability of greywater in the collection tank.

Prefabricated polyethene water tanks were used in this project. Three tanks with capacity of 1 m^3 each were also used. The first tank is used as a collection /sedimentation tank for the raw greywater, the second tank is used to collect greywater from the CW, and the third one is used for storing the treated greywater which is connected to an irrigation network. Figures 5 to 7 illustrate the detailed design for each tank.

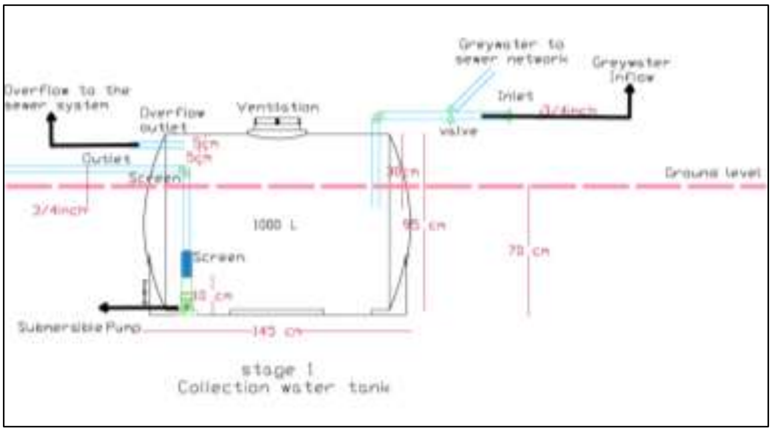

Figure 4 First collection tank

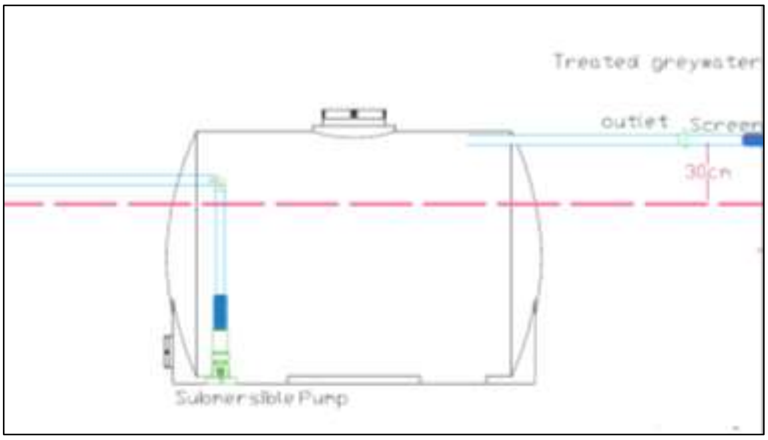

Figure 5 Second Collection tank

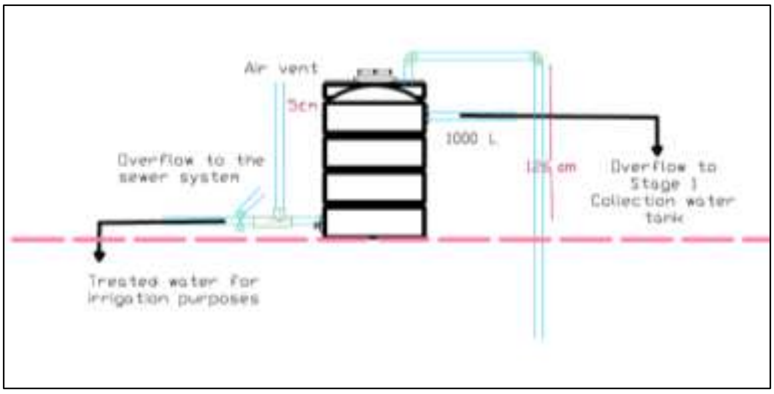

Figure 6 Treated greywater Storage tank

The HFCW was constructed using prefabricated galvanized steel water tank, with polyethylene isolation sheets as illustrated in Figures 8 and 9. The inflow and outflow within the HFCW bed have been designed in a way that guarantees to use all the CW bed without dead zones as illustrated in Figure 10. The filter material was distributed as follows: the first 40 cm and the last 40 cm of the tank length, course tuff with dimeter of 4 cm and for the remaining 3.2 meters, tuff was also but but with 2 cm diameter.

The inlet pipe was installed 10 cm below the tuff surface, while the outlet pipe was installed 20 cm below the tuff source in order to guarantee the flow direction. The slope of the bed is 1% towards the outlet.

Phragmites Australis and Arounda to be used in the wetland, distances of 25 cm to 50 cm between each reed were considered.

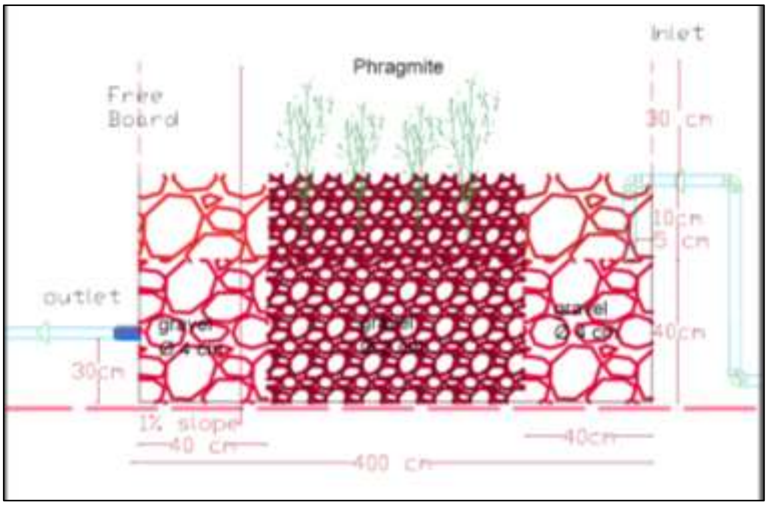

Figure 7 Side view HFCW

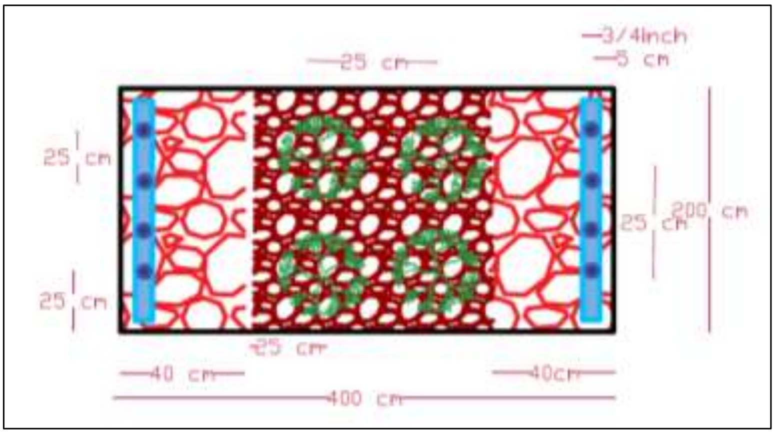

Figure 8 Top view of HFCW

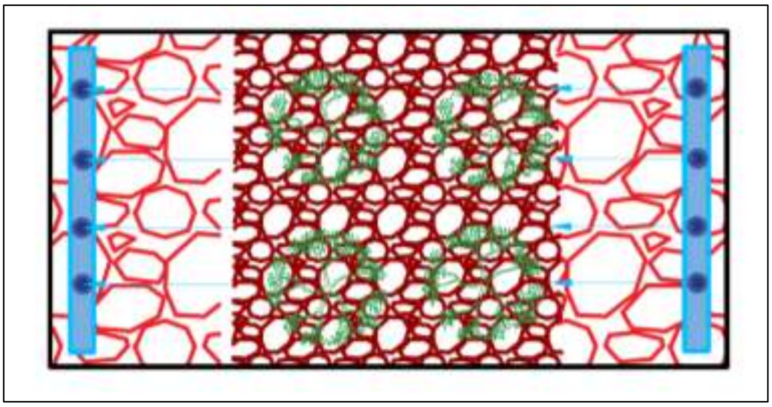

Figure 9 Flow within the HFCW bed

The design also contained a recirculation system which serves several benefits:

- to dilute the concentrations of the raw greywater with treated one
- to maximize benefiting of the treated greywater so the water can be stored and circulated within the system instead of discharge it to the sewer in case the reuse option is not needed,
- to assure that the CW has enough water inside.

The system contains an overflow to the sewer system from the first collection tank, so in case of overloading the system or in case of pump failure the greywater will flow by gravity to the sewer system smoothly.

Another overflow has been provided in the second tank which collected treated greywater from the CW, the overflow can go directly to the trees in the garden because the greywater considered to be treated in that stage.

The final collection tank in the roof (or steel tower) of the building has an overflow connected to the first collection tank (or to the horizontal contracted wetlands) to achieve the circulation mentioned before.

5. Implementation

After finalizing the design, several approvals and permits were required from the governmental authorities. Detailed explanations for the design and the components of the systems have been explained to the stakeholders. Technically, a bill of quantities (BoQ) was prepared and the treatment system implemented in collaboration with local contractor in Jordan/in house within the local NGO. The selected contractor has wide experiences in implementing greywater systems in Jordan. The implementation was completed within 13 calendar days starting from 17 Feb 2024 to 29 Feb 2024. Safety regulations were considered during the implementation. Daily monitoring was also considered to assure the quality of the implementation, and frequent tests were conducted to the pipes, tanks, and pumps.

Photos of the implementation are provided in annex A.

Monitoring

While sampling process has been carried out by local expert engineers who followed sampling procedures of “STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 23RD EDITION” (Rodger B. Baird, Chair Eugene W. Rice and Andrew D. Eaton, 2017), tests are being carried in laboratories of Water Authority of Jordan. The tests to be performed also according to “STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 23RD EDITION” (Rodger B. Baird, Chair Eugene W. Rice and Andrew D. Eaton, 2017).

The tables below summarize the performance of the CWs for the first three months of operation and according to the Jordanian standards.

Table. 8 Treated greywater vs Jordanian standards

Parameter	April	May	June	Cooked vegetables, parks, playgrounds, and roadsides within cities.	Food crops intended for human consumption including raw consumption	Toilets flushing
BOD_5 (mg/l)	20	15		60	60	<10
COD (mg/l)	43	23		120	120	<20
TSS (mg/l)	0	<10		100	100	<10
pH	7.38	7.4		6 - 9	6 - 9	6 - 9
NO_3^- (mg/l)		17		70	70	70
TN (mg/l)		33		50	50	50
Turbidity NTU	0	<0.2		undefined	undefined	< 5
E. coli (CFU/100 ml)	2300	400		10000	1000	<10
Helminth eggs (egg/l)		<1		<1	<1	<1
FOG (mg/l)		8		8	8	8

Table. 9 Treatment efficiencies

Parameter	**April**			**May**			**June**		
	Raw	Treated	Efficiency	Raw	Treated	Efficiency	Raw	Treated	Efficiency
BOD_5 (mg/l)	379	20	95%	411	15	96%			
COD (mg/l)	496	43	91%	523	23	96%			
TSS (mg/l)	23	0	100%	55	<10	82%			
pH	7.22	7.38		7.41	7.4				
NO_3^- (mg/l)				19	17	11%			
TN (mg/l)				35	33	8%			
Turbidity NTU	12	0	100%	15	<0.2	99%			
E. coli (CFU/100 ml)		2300		2800	400	86%			
Helminth eggs (egg/l)				<1	<1				
FOG (mg/l)				<1	<1				

Training and guidelines

Guidelines for operation and maintenance have been prepared. A full day of training was conducted to the responsible operator with explanation for the process and operation procedure. The training includes explanation about the regular daily operation and maintenance, while for major maintenance a focal point engineer from the local partner will be responsible to follow up on the major maintenance. The guideline has been prepared in Arabic language for local people. The guideline can be found in Annex B.

Commented [GA5]: The guidelines form an important component for the sustainability and capacity building for the project. If possible, please add the guidelines to this doc as an Annex

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Appendix A: Photos during implementation

Figure A.1 Excavation work

Figure A.2 Plumping works

Figure A.3 Plumping works

Figure A.4 Civil works

Figure A.5 Wetland works

Figure A.6 Wetland plumping works

Figure A.7 Filter material distribution

Figure A.8 Roof tank for irrigation

Figure A.9 Plumping finishing works

Figure A.10 Tanks installation

Figure A.11 Final system installation

Figure A.12 Electrical box

Appendix B: Operation and maintenance guideline

دليل التشغيل والصيانة

نظام معالجة المياه الرمادية باستخدام نظام الاراضي الرطبة المنشأة

الإصدار الأول

نيسان, 2024

فريق الإعداد

جمعية العمل المناخي الأردنية

المحتوى

المقدمة

هذا الكتيب يوضح الإجراءات الازمة لتشغيل وصيانة نظام معالجة وإعادة استخدام المياه الرمادية بواسطة الاراضي الرطبة التجريبي الذي تم تطبيقه في الأردن ضمن أنشطة مشروع "تنفيذ نظام المياه الرمادية في المساجد باستخدام حلول مبنية على أسس طبيعية في الأردن" ضمن اتفاقية التعاون المتبادل بين جمعية العمل المناخي الأردنية و منظمة الأغذية والزراعة للأمم المتحدة (الفاو) من أجل تحقيق الأهداف المحددة التالية:

1) توفير مصدر جديد من المياه التي يمكن استخدامها في المسجد لاستبدال المياه العذبة لأغراض الري (كمثال يمكن تكراره في مساجد أخرى في المجتمع)

2) رفع مستوى الوعي في المجتمع حول قبول مفهوم إعادة استخدام المياه الرمادية المعالجة، والحفاظ على المياه، والتكيف مع تغير المناخ.

تم انشاء النظام التجريبي في مسجد رقية بنت الرسول – صلى الله عليه وسلم – في محافظة الزرقاء حيث تم تزويد المسجد بمحطة معالجة صغيرة وبسعة هيدروليكية مقدارها متر مكعب واحد يوميا ليتم معالجتها باستخدام تقنية الاحواض الرطبة المنشأة, ويهدف النظام الى تزويد المسجد بمياه معالجة حسب المواصفات الاردنية لإعادة استخدام المياه الرمادية المعالجة لغايات الري.

الادوات والمكونات الرئيسية

1. انابيب لفصل المياه الرمادية من مسار الصرف الصحي
2. صمام رئيس عدد اثنان على الخط الرئيسي المغذي للنظام المعالجة
3. خزان تجميع ارضي رقم 1 ويهدف الى تجميع المياه الرمادية
4. مضخه رقم 1 غاطسة في الخزان رقم 1
5. مؤقت كهربائي للتحكم في تشغيل المضخة رقم 1
6. حوض الرطب المنشأ والمزروع بنبات القصب
7. خزان رقم 2 لتجميع المياه المعالجة من حوض الرطب المنشأ
8. مضخة رقم 2 غاطسة في الخزان رقم 2 والتي تضخ المياه للخزان رقم 3
9. خزان رقم خزان 3 مرفوع على سطح المسجد لتجميع المياه المعالجة
10. شبكة ري مشبوكة من خزان رقم 3 الى الشجر المتواجد في حديقة المسجد

1. قاطع الكهرباء للمضخة الغاطسة رقم 2 في الخزان رقم 2
2. قاطع الكهرباء للمضخه الغاطسة رقم 1 في الخزان رقم 1
3. المؤقت الزمني للمضخة رقم 1
4. القاطع الرئيسي للنظام كامل

تعليمات التشغيل اليومي

- يجب ان تتم عملية التفقد والصيانه من قبل شخص بالغ ومؤهل فنيا
- يجب ان يلتزم المسؤول عن عمليات التفقد والصيانة باجراءات ومعدات السلامة العامة (القفازات والكمامات وملابس وقية الخ)
- يجب ان يلتزم الشخص المسؤل عن عمليات التفقد والصيانة بتعلميات التشغيل المرفقة
- ضرورة تفقد وتنظيف خزان التجميع رقم 1 كل ثلاث شهور
- تفقد الخزانات وانابيب التوصيل والري بشكل دوري للكشف عن اية اضرار او تسريب ضمن الشبكة

هام جدا ضرورة تثقيف الاشخاص المستخدمين للوحدات والمرافق الصحية بضرورة عدم رمي النفايات الصلبة داخل المصارف

كيفية عمل النظام

يعمل النظام بشكل تلقائي حيث تتدفق المياه الرمادية عبر الانابيب الى خزان التجميع (خزان رقم 1) وعند الوصول الى المنسوب المطلوب وتوافق ذلك مع اشارة المؤقت فيتم الضخ التلقائي من الخزان الى حوض القصب المزورع من خلال المضخة الغاطسة رقم 1 (في حال عدم وجود اشارة من المؤقت او في حالة تعطل المضخه فان المياه الرمادية المتدفقة تخرج من الخزان 1 الى المنهل القريب من خلال انبوب تصريف الفائض)

يتم الضخ التلقائي من الخزان رقم 1 الى حوض القصب المزروع على شكل دفعات وتنساب المياه عبر مواد الفلترة وعبر القصب المزروع وتخرج بفعل فرق منسوب المياه والميلان الموجود في الحوض وتتجمع في الخزان رقم 2

يتم ضخ المياه من الخزان رقم 2 عبر مضخة غاطسة رقم 2 والتي تعمل بشكل تلقائي عند وصول الخزان لمنسوب معين وتتوقف ايضا بشكل تلقائي عند انخفاض المنسوب (في حالة حدوث اي خلل في المضخة رقم 2 فإن المياه تتدفق بشكل تلقائي خارج الخزان حيث ان المياه تعتبر مياه معالجة)

تضخ المياه المعالجة من الخزان رقم 2 الى الخزان رقم 3 والمتواجد على سطح المسجد

يتوفر ثلاث نقاط للتصريف من الخزان رقم 3:

1. الى شبكة الزراعة
2. نقطة تصريف الى شبكة الصرف الصحي وذلك لغايات التفريغ في حالة عدم الاستخدام
3. نقطة تصريف الفائض والتي تسمح للمياه بالتدفق الى الخزان رقم 1 مرة اخرى بما يضمن وجود مياه في النظام واستهلاك أكبر كمية للمياه المعالجة.

الصيانه الدورية

تفقد الخزانات وانابيب التوصيل بشكل يومي والتأكد من عمل المضخات وذلك من خلال ملاحظة استمرار تدفق المياه عبر النظام

تنظيف الخزان رقم 1 من خلال ادوات الكشط والتجميع بحيث يتم تجميع وازالة المواد الطافية على سطح المياه وتتكرر العملية كل ثلاث شهور او اقل حسب جودة المياه لذا ينصح باجراء العملية بشكل شهري

قص وحصد القصب المزروع بشكل سنوي في شهر 3 او 4 من كل عام مع ابقاء طول 40 سم من طول القصب الاصلي

يرجى توخي الحذر واستخدام الادوات المناسبة اثناء القيام بالصيانة الدورية للنظام

الصيانة المتخصصة

عند حدوث خلل او الحاجة الى صيانة اساسية مثل تعطل المضخات او عدم تدفق او انسياب المياه بشكل سلس او حدوث اغلاقات في النظام على المشغل فصل النظام من خلال اغلاق الصمام رقم1 و 2 فتح السدات الموجوده داخل المناهل والتواصل مع فريق الصيانة باستخدام معلومات الاتصال الواردة ادناه

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المهندس حمزة عوده 0785807773

حقوق النشر وعدم الافصاح