The Current Water Balance in Syria

Evaluating the potential contribution of Constructed Wetlands as a treatment plant of municipal wastewater in Al-Haffah

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Abstract

The future projection of climate change suggests the strong need of improved systems to the resource management systems. In Syria, the current water resource management systems are weak, and the country has no resilience to the scarcity of water resources in the region. In 2007 a drought has crippled the Syrian economy and impacted the life of millions of Syrian People, the devastating occurrence of the drought had larger impacts due to the lack of water resource management systems and irresponsibility of use. This study investigates the current management systems that Syria has, and the supply and demand of the country, of which is aimed for with the term (water balance) that refer to the flow of water in and out of the system. Furthermore, a constructed wetland design is introduced as a system to treat municipal wastewater of the town Al-Haffah, located east of Latakia city of which is situated at the Mediterranean coast, on the Costal basin. All the data available relevant to the investigation has been used in the case study, nevertheless some assumptions has been made due to lack of available data. The introduced system is later evaluated in regards of water need for agricultural purposes in Al-Haffah. The design with the assumed current value, in worst case scenario could save annually (48.57%) of the groundwater abstraction for agricultural purposes, Or (29.14%) of the total water demand for the agricultural practices in Al-Haffah. Whilst, in best case scenario, if two third of the required water for agriculture is met with rainfall the system saves (145.7%) of the assumed groundwater abstraction, Or (87.43%) of the total annual required water.

Keywords: Water balance, constructed wetlands.
Abbreviations and Symbols

\[ \text{km}^3 \quad \text{Cubic Kilometre (1 km}^3 = 1 \times 10^9 \text{ cubic metre (m}^3) \]

VF \quad \text{Vertical Flow}

Q \quad \text{Daily Wastewater Flowrate}

HRT \quad \text{Hydraulic Retention Time}

SAR \quad \text{Sludge Accumulation Rate}

P \quad \text{Population}

DI \quad \text{De-sludging Interval}

AVFWW \quad \text{Available Volume for Wastewater in Septic Tank}

BOD_5 \quad \text{Biological Oxygen Demand in Wastewater}

A_h \quad \text{Surface area of wetland bed (m}^2) \]

Q_d \quad \text{Average daily flow rate of sewage (m}^3/d) \]

C_i \quad \text{Influent BOD}_5 \text{ concentration (mg/l)} \]

C_e \quad \text{Effluent BOD}_5 \text{ Concentration (mg/l)} \]

K_{BOD} \quad \text{Constant of Temperature dependent process of BOD}

K_T \quad \text{Constant of Operational Temperature of the System}

d \quad \text{Depth in Water Column in metre}

n \quad \text{Porosity of Wetland Substrate Medium}
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Preface

Lives of millions worldwide are affected on everyday basis, by environmental impacts and anthropogenic practices that impacts our environment and in return impacts us as humans with its trans-boundary effects to the world systems. In some part of the world, some argues that even conflicts are resources driven. This investigation has been initiated based on the future projection of climate change and its impacts to the hydrological cycle in the middle east, and especially in Syria and the necessity of technologies that sustain essential human needs. The current conflict and the poor existing management systems in Syria, puts the lives of millions of Syrian people under great pressure in regard to the natural resources. Nevertheless, this investigation has no solid prove whether the conflict was ignited by the environmental induced chain of events in Syria.

Furthermore, the lack of information and relevant data regarding many scientific fields and on ground scientific measurements, made the basis of the investigation rely on many assumptions. Such an approach could generate great room of error even with the attempt to assume close to reality values. Nevertheless, such attempts in this field could be useful for further studies and investigation.

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1. Introduction

The challenges to our societies caused by environmental issues and climate change stretch their vicinity into many fields. One of those impacted areas of most importance is the availability of water. The impacts on the water cycle are generated due to many social, economic, and poor management conditions in many regions of the world. The future projection of climate changes indicates that the water cycle will undergo harsh conditions due to various climatic and management factors (Stocker, Alexander & Allen 2013), of which will impact the livelihood of people worldwide. On July 28th, 2010, the United Nations recognized (The human right to water and sanitation) under its international law of human rights treaties (Human right to water and sanitation 2020). Furthermore, the role that water plays in the big complex of systems around us is vital to every life form, and the research of solutions to the problems within its availability is a priority to the world. Arid and Semi-arid regions are most vulnerable to the climate change induced impacts on water resources; therefore, early implementations of management systems and adaptive strategies are needed in order to sustain the circular water supply systems of those regions (Sowers, Vengosh & Weinthal 2010).

Based on the climate change scenarios introduced by the IPCC (The Intergovernmental Panel On Climate Change) in 2013, The Mediterranean region with 7% of the world’s population and approximately 2% of the available freshwater, is expected to have an increase in temperature and decrease in participations, the mix of those impacts will most likely to affect the balance of the water cycle in the region, with its growing demand and consumption of water in various sectors (Sowers, Vengosh & Weinthal 2010). According to studies, the Middle East is undergoing severe water scarcity, and conflicts caused by water availability, whilst most of its countries exploited more than 50% of freshwater resource, and some countries exploited up to 100% (Mourad 2012). According to FAO, by 2025, 1800 Million people will be living under “absolute” water scarcity (less than 500 m³ per Year per Capita), whilst, two third of the global population will be living under “stress” conditions (between 500 m³ and 1000 m³ per year per capita) (Water Scarcity | Food and Agriculture Organization of the United Nations 2020). Furthermore, the latter information, along with many studies, suggests the strong need for new sustainable systems for the water resource use and management in the Middle East region.
1.1 Background

The Syrian Arab Republic, has an area of about 185,180 Km\(^2\) and current population of about 16.9 million, with annual population growth of (-1 and -4.5% between 2011 and 2019) and the decline in population was caused by the current conflict (World Development Indicators | Databank 2020). Classified as a lower middle-income country, as of 2009 statistics showed, the most important sectors in the economy were industry with 25%, retail with 23%, agriculture with 22%, tourism with 12% (Zwijnenburg & te Pas 2015). Over the past decade the rapid development in all sectors has pressured natural resources and overall management systems, whilst only agriculture accounted for around 87% of the water withdrawn from the region’s aquifers, rivers, and lakes to feed its roughly 5.7 thousand hectare of cultivated land (Aw-Hassan, Rida, Telleria & Bruggeman 2014). From the early 1970s the Syrian government-initiated policies such as (land redistribution, irrigation projects, diesel fuel subsidies). Taken to improve and boost the agricultural production under no sustainable framework or any regard to the environment, those actions led to water scarcity and exploitation of land and water resources in rural areas (Kelley et al. 2015). Two thirds of the cultivated lands are fed by rain, whilst the remaining cultivated land depends heavily on groundwater. Furthermore, studies have shown that between 1985 and 2004, the total area of irrigated lands by groundwater has increased from 49% to 60% (Asmael et al. 2015). The exploitation of groundwater by farmers has reached to up to 60% of the total irrigation water, therefore, the government tried to solve the problem with a law in 2005, of which requires farmers to have a permit to dig a well, nevertheless the law was never enforced (Kelley et al. 2015). The beginning of 2007, has brought the region the worst drought in 40 years, causing the agricultural share of the Syrian GDP to drop from around 25% to 17%, the northern parts of the country has faced wheat production failures, whilst small and medium scale farmers and herders went through near zero production, and lost of almost all livestock (Kelley et al. 2015). Furthermore, by 2010, prices increased, while the country’s self production went down, import was a neccisity. The impacts to human health were also significant, due to the fact that many farmers used untreated water from gravity sewers canals for irrigation, especially in the northeast provinces that faced increase in nutrition related diseases among children, and it even affected the school enrollments as it dropped to up to 80% due to migration from agricultural/rural areas (Grungier, Qadir & Singh 2012). The drought’s impact on agriculture has affected roughly 1.5 million people, leading to
displacement and internal migration in pursuit of better life quality (Over a million people affected by drought 2010). An increase in the urban population in Syria by almost 40%, caused by both internal migration and (1.2-1.5 million) Iraqi refugees of which came into the country at the same period of time, the growth in urban Syria caused even higher pressure on natural resources (Kelley et al. 2015).

1.2 Study Aim

This study Aim is to investigate the water balance in Syria, and the current used management systems. Furthermore, a constructed wetland system will be introduced as a possible solution to mitigate the environmental impacts caused by the current management systems. The constructed wetland design will be evaluated as a treatment approach for wastewater in a small town on the coastal basin as a case study.

1.3 Research Question

Can constructed wetlands as a wastewater treatment technology, contributes to the water balance in a small Syrian town, and what is the magnitude of the contribution if the effluent water of the system is used for agricultural purposes.

2. Methodology

2.1.1 The Approach

The water balance in Syria has been investigated. The coastal basin and its hydrological systems have been under focus since that the intended case study is situated on it. Constructed wetlands is chosen as a technology to mitigate the environmental impacts of the current water system in Syria and evaluate its contribution to the Syrian water balance. The design of the constructed wetland
system will follow a manual produced by (The United Nations Human Settlements Programme), the manual has been introduced as a guideline based on examples from various Asian cities to inspire sustainable and affordable wastewater management systems (UN-HABITAT 2008). The choice of the manual was due to the similarity in climate and the feasible economical approach to the manual itself. The constructed wetland design will be introduced as a case study in Al-Haffah, the system will be a used as a wastewater treatment technology, the effluent water is subjected after the primary treatment to irrigation. The calculations and formulation of the design itself has been executed in a fashion to evaluate the technology and its contribution to water savings and overall water balance in Syria.

It has been decided that, the constructed wetland will be a subsurface flow with vertical flow constructed wetland, a system where a basin is filled with substrate and vegetation and wastewater is fed from the top, where eventually it drains to the bottom to the system drainage network that collect the effluent water. Subsurface vertical flow wetlands proved its greater removal of pathogens and it dose not attract mosquitoes or produce odorous, whilst in the winter season its functions are not affected by the climate. The choice of the vertical flow is due to the geographic characteristics of Al-Haffah (sloping lands), and the smaller size requirement compared to horizontal flow, and to its ability to remove organic pollutants due to the limited oxygen transfer (UN-HABITAT 2008). Moreover, the placement of the constructed wetland is to be in a suitable place that is down stream from Al-Haffah. Studies showed significant environmental impact caused by untreated wastewater outlet from up stream populations (Faour & Fayad, 2014).

2.1.2 The Approach parameters

Due to lack of recent data regarding the current population of Al-Haffah, (2%) annual population growth is assumed. Furthermore, calculations for required area and volume in the design has been rounded up as a safety measure, since that the population has been assumed. The number of produced wastewater per capita has been taken as an average from the existing studies regarding wastewater produced per capita in Syria of which ranged from 49 liter per day, to 96 liter per day (Elhadj 2004). For operational, aesthetic and safety reasons, the system in its different stages will have multiple facilities and components, such as (septic tanks, wetland beds).
It will be assumed that the existing system in Al-Haffah has a preliminary treatment facility, where the municipal wastewater goes through a simple treatment process before it ends up eventually in lakes and the sea. Furthermore, the lack of data and costs in Syria, and since that the design is executed to come up with numbers and evaluate the benefits of such system to the Syrian water balance, the details concerning the construction of the design are excluded. The choices regarding detailed construction process are only feasible when the design is set to be executed on the ground, same goes for maintenance protocols.

Furthermore, choices regarding technical and mechanical items within the design are excluded as well, for the fact that it will depend on the availability and cost of which it was not possible to obtain. Therefore, the technicality of the mentioned aspects of the design will be excluded from the design in this paper due its relevancy to the aim of the investigation. A sludge drying bed is presented in the design due to its importance and benefits to the system, nevertheless, its large extent technicality is excluded since that it is irrelevant for the intended calculation.

The arable area size of Al-Haffah has been assumed using QGIS tools, and based on literature research of the agricultural practices in the area, it has been assumed that AL-Haffah arable area, consists mainly of Olives around (80%), and the rest (20%) with various vegetables, and the required water for irrigation has been estimated accordingly. A cost analysis was not possible to perform; therefore, two cases are presented with an estimation of the possible per capita cost of such system.

Later on, the introduced constructed wetland system will be evaluated with two different estimation approaches. The first estimation assumes that two thirds of the cultivated lands are fed by rain, and (60%) of the remaining one third is met with groundwater. The second estimation exclude the rainfall contribution to irrigation. Both estimations present values in regard to groundwater abstraction and the total water requirement with all resources taken in consideration.

2.1.3 Motivation behind the choice of the case study area
The environmental impacts of pollution caused by the uncontrolled discharges of wastewater as a whole from all sectors, into water bodies is present in downstream areas in the coastal basin (Faour & Fayad 2014). According to (Faour & Fayad 2014), between 2000 and 2010 most of the discharged wastewater into the environment was reused for agricultural purposes without treatment, of which caused pressure on the available water resources in the coastal region. Thus, the existing collection network in most cities and smaller towns are the same network for runoffs and wastewater.

3. Results

3.1 The Syrian Water Balance

3.1.1 Water Resources & Management

Situated in Western Asia, along the eastern coast of the Mediterranean, in an arid to semi-arid climatic zone, with two thirds of its land as Rocky Mountains (Syria 2020). Syria’s water supply depends on rainfall, groundwater, and surface water, and can be divided into seven main water basins, each with its unique characteristics, Barada & Awaj, Al-Yarmouk, Orontes, Dajleh & Khabour, Euphrates & Aleppo, Desert and Coastal Basin (Water Resources in Syria - Fanack Water 2019). In 2003, it was estimated by studies, that the annual water withdrawal of Syria stands at around 16.69 km$^3$, of which 87.9% was for agriculture (Frenken 2009). The total of renewable water resource in the country is roughly 14 km$^3$ (10 km$^3$ surface water, 4 km$^3$ groundwater) and the annual use is roughly 17.5 km$^3$, of which gives a 3.5 km$^3$ shortage, whilst only agriculture consumption is 15.5 km$^3$ (Al-Charideh & Kattaa 2015). Furthermore, (Figure 1) shows the Syrian map with the coastal basin highlighted.
3.1.2 Precipitation & Evaporation

Precipitation starts between October and May, the average annual rainwater is around 46 km$^3$, with more than (1000mm) in the coast region, with more than 60% of the country receiving less than 250 mm/year. The country could be seen in five different climatic zones (Mourad 2012):

- Wet with more than 600mm
- Semi-wet 300-600 mm
- Semi-arid 200-300 mm
- Arid 100-200 mm
- Dry with less than 100mm

Syria has potential evaporation rate of 1300mm/year, 3000mm/year, in the western parts, and in the eastern to the south-eastern parts of the country (Kaisi, Al Chayeb & Al Zoughbi 2006).

3.1.3 Ground & Surface Water

Groundwater inflow is estimated at roughly 1.33 km$^3$ per year, with 1.2 km$^3$ and 0.13 km$^3$ from Turkey and Lebanon respectively, and an outflow of 0.25 km$^3$ and 0.09 km$^3$ per year to Israel and Jordan respectively (Mourad 2012). With 16 rivers that create the surface inflow in Syria of which
corelates to 75% of the controlled surface water, and 45% of the total available water resources, with totality of around 10 km$^3$ per year (Water Resources in Syria - Fanack Water 2019). Furthermore, Syria has 8 lakes, and around 150 surface dams with capacity of around 19.6 km$^3$ (Frenken 2009).

### 3.1.4 Water Reclamation & Current Wastewater Treatment

Syria has 26 operational wastewater plants scattered across the country with only 4 plants centralized in major cities and the rest are decentralized with some plants not working to their full capacity. The annual capacity of the operational plants is around 0.30 km$^3$ (Water Resources in Syria - Fanack Water 2019). Furthermore, the sewer system in a big part of the country is an old gravity system that in most regions directed to close water bodies with no treatment. The total annual production of wastewater in Syria was estimated around 1.364 km$^3$ (Frenken 2009). The reused drainage water from agriculture was estimated in 2004 to be around 2.24 km$^3$ (Frenken 2009). Furthermore, according to studies done in 2008, the reclaimed water from various sectors were as follow, 2.3 km$^3$ from agriculture (15% of total consumption), 0.67 km$^3$ from domestic use (55% of total consumption) and 0.4 km$^3$ from industry (65% of total consumption) (Mourad 2012).

### 3.1.5 Water Demand

According to the Syrian Ministry of housing and construction, the domestic water production in 2008 was 1.18 km$^3$ with a population of 19.9 million inhabitants, of which corresponds to annual consumption per capita of 59.45 m$^3$, which gives a 163L on daily basis per capita, including the potential loss the number represents the total production divided by population (Mourad 2012). For the industrial sector, there was few information available, nevertheless the demand has been estimated to be around 0.62 km$^3$. Furthermore, the agricultural sector as the biggest consumer of water it reached 15.4 km$^3$ (Mourad 2012). To sum it all up, according to the available studies and gathered information the total water demand in Syria (domestic total of 1.18 km$^3$ “not including water loss” + industrial 0.62 km$^3$ + agricultural 15.4 km$^3$) is roughly around 17.2 km$^3$/year.

### 3.2 The Area of The Case Study
The study area is located on the coastal basin, 33 kilometres east of Latakia on the Mediterranean coast of Syria (Figure 2), within AL-Haffah district that has 23,357 inhabitants and divided into 24 small villages, and mainly are agricultural lands of olives and some other vegetables and fruits. Our case study will be in the biggest town (Al-Haffah) with a population of 4298 as of 2004 statistics (Central Bureau of Statistics 2004). Due to conflict and lack of available information of the real time population growth/decline, it is hard to establish a correct number of the current population, therefore the number of the village is rounded up to (4500) inhabitants as of 2004 statistics, for simplicity of calculations.

The coastal basin has a single hydrologic unit (Figure 1), with 28 rivers discharging into the sea, of which most are seasonal and less than 50 km in length, and many streams and springs in the basin, of which end up in the sea via lower plain penetration. 21 dams situated on major rivers to store water for irrigation, the annual storage capacity is estimated around 0.85 km$^3$ (Kaisi, Al Chayeb & Al Zoughbi 2006). The coastal basin has a Mediterranean humid or subtropical climate and receives around 5.6 km$^3$/year of precipitation averaging between 2000-21000mm, nevertheless the loss via evapotranspiration has an average of 45-60%. According to the available data the ground water resources are estimated to be around 2.2 km$^3$/year in dry years, 2.9 km$^3$/year in wet years (Faour & Fayad, 2014). It was estimated that the total usable water resources in the coastal basin is roughly around 2.3 km$^3$ including storage from dams (Kaisi, Al Chayeb & Al Zoughbi 2006). Furthermore, the totality of the water sources calculation of the coastal basin has included well abstraction of around 0.15 km$^3$/year that correlates to 45% of the groundwater resources usable water, whilst surface water supply was estimated around 0.50 km$^3$/year that correlates to around 25% of its usable water (Faour & Fayad, 2014). The management of water resources in the governates situated in over the coastal basin, are 70% governmental and 30% private (Faour & Fayad 2014).
3.3 Wastewater Treatment by Constructed Wetlands

Recognised in recent years as a reliable wastewater treatment process, an artificial wetland is a technological solution has been used to treat municipal wastewater or stormwater runoffs (Albalawneh, Chang, Chou & Naoum 2016). And since the 1990s, has been used in ecological engineering solution (Zhang et al. 2012). Whilst for centuries, natural wetlands have been used for disposal wastewater, wetlands had easier access and were closer than rivers, and it has been referred too as “wastelands” (Vymazal 2010). This technology is a design that imitates natural wetlands process, to filter and improve water quality, with a variety of components such as gravel, sand, microorganisms, and vegetation, of which purify wastewater by chemical, biological and physical process. This sanitation technology is used as a biofilter to remove pollutants, infectious agents (pathogen), suspended solids, organic matter, and nutrients from the wastewater before its reused or released into the environment (Maiga 2017). The system of constructed wetlands as a wastewater treatment technology, consists of three steps, preliminary treatment, where all solids and floating materials are filtered out, primary treatment, where wastewater undergo processes of further sedimentation and fine filtration for suspended solids, and finally the wetland, where the wastewater is introduced to the basin. The wastewater undergoes many removal mechanisms in the wetland basin. The microbial growth in the substrate is responsible of the removal of soluble organics, of which its compounds are degraded biologically, aerobically, where the required oxygen is transferred into the rhizosphere through vegetation, and anaerobically (Maiga 2017). Adsorption to the vegetation surfaces and roots and its biotic assimilation are responsible of
phosphorus removal in the wastewater, whilst the removal of Total Nitrogen in wetlands is mainly caused due to the microbial nitrification and denitrification, filtration, sedimentation and adsorption by biomass trap pathogens within the wetland system and eventually natural process eliminate them (UN-HABITAT 2008).

3.4 The Design parameters

With a population of 4500 inhabitants Al-Haffah, with an average of annual water use of 50m$^3$ per capita, and an average daily wastewater generation of 70 liter per capita (Elhadj 2004). Furthermore, to be on the safe side with the design capacity, and due to the fact that the population number goes back to statistics from 2004. An annual population growth of 2% assumed rate based on (Mourad & Alshihabi 2015), has been taken into consideration to come up with the following numbers.

Annual population growth in Al-Haffah:

\[
4500 \times (2\%) = 90
\]

\[
90 \times (2004 \text{ till } 2020 = 16 \text{ years}) = 1440
\]

adding it to 4500, gives us a population of (5940 inhabitants in 2020).

Furthermore, the latter values give an estimation of the annual consumption of water in Al-Haffah:

\[
5940 \times 50 \text{ m}^3 = 297000 \text{ m}^3
\]

And Daily wastewater flow (Q) of:

\[
5940 \times 70 \times 1000 = 415.8 \text{ m}^3
\]

Due to the fact that the wastewater flow per day per capita has been assumed as well, it has been decided that the total daily wastewater flowrate will be rounded up to (Q = 500 m$^3$). According to the research done on the Syrian water management system, it has been found that in most rural areas the sewage system is an old fashion gravity system that in most cases follows canals across
the residential area and ends up in a small rivers and water body of which in its turn ends up in bigger lakes or rivers with no treatment (von Münch, Ingle & Mohamed 2009).

3.2.1 Preliminary treatment

In this stage the influent wastewater goes through a preliminary treatment process to protect the functionality of the wastewater plant. The wastewater goes through processes where it removes solids and coarse materials, after it goes into a grit chamber where it removes inorganic materials by simple gravity, the grit generated is cleaned once the chamber reach 40% of its capacity with grit. It has been assumed that Al-Haffah has a preliminary treatment facility that could be utilized for the design.

3.2.2 Primary treatment

3.2.2.1 Septic tank

A two-compartment septic tank, where the first compartment is two thirds of the total volume. The septic tank will be used to remove solids with retention time of 1.5 days. The influent wastewater accumulates sludge in the septic tank; therefore, the tank needs to be de-sludged once the accumulated material exceeds 30% of the tank volume, with desludging interval of 1 year (UN-HABITAT 2008). To establish the size of the septic tank the following equation was used, where (Q) is the wastewater flowrate per day, and (HRT) is the hydraulic retention time of the wastewater in the tank.

Septic tank Volume:

\[ Q \times HRT = 500 \text{ m}^3 \times 1.5 \text{ days} = 750 \text{ m}^3 \]

Due to its large Volume it has been decided to have two separate identical septic tanks with the Volume of 400 m³ each, for both the magnitude of such build and for maintenance. Furthermore, the sizing of the compartment gives the following values.

A tank with 400 m³ volume will have the following dimensions, 20 meters length, 10 meters width, and 2 meters depth (with 0.5 open space to the depth for free flow).

1\textsuperscript{st} compartment Volume:
\[ \frac{2}{3} \times 400 = 266.66 \text{ m}^3 \text{ with length of } \frac{266.66}{(5 \times 10)} = 13.33 \text{ Meters} \]

2\text{nd} \text{ compartment Volume:}

\[ \frac{1}{3} \times 400 = 133.33 \text{ m}^3 \text{ with length of } \frac{133.33}{(2 \times 10)} = 6.66 \text{ Meters} \]

To check the hydraulic retention time of the wastewater after the sludge maximum accumulation the following calculations are used, where (SAR) is Sludge accumulation rate, as the manual presented an annual accumulation rate of 70 litres per capita, the number has been estimated based on various case studies (UN-HABITAT 2008). (P) population, (DI) is desludging interval (1 year), whilst (AVFWW) is Available Volume for wastewater in the Septic Tank.

Sludge Volume:

\[ \text{SAR} \times \text{P} \times \text{DI} / 1000 \text{ (to get m}^3\text{)} = \frac{(70 \times 5940 \times 1)}{1000} = 415.8 \text{ m}^3 \]

AVFWW:

\[ \text{total volume – sludge volume = } 750 – 415.8 = 334.2 \text{ m}^3 \]

HRT after accumulation:

\[ \frac{\text{AVFWW}}{\text{Q}} = \frac{334.2}{500} = 0.668 \text{ Days} = 16 \text{ hours} \]

According to the followed manual (UN-HABITAT 2008), since that HRT is greater than 12 hours then the design with the giving parameters is operational according to the criteria. (Figure 4) shows a schematic view of the design of one of the two identical septic tanks.
3.2.2.2 Sizing of the wetland & depth, sealing and slope of the bed

To establish the size of the wetland the (Kickuth) equation could was used

\[ A_h = \frac{Q_d (\ln C_i - \ln C_e)}{K_{BOD}} \]

Where.

- \( A_h \) = Surface area of bed (m\(^2\))
- \( Q_d \) = Average daily flow rate of sewage (m\(^3\)/d)
- \( C_i \) = influent BOD\(_5\) concentration (mg/l)
- \( C_e \) = Effluent BOD\(_5\) Concentration (mg/l)
- \( K_{BOD} \) = Rate constant (m/d), of which is determined with the expression \( K_T dn \)
  - \( K_T = K_{20} (1.06)^{(T-20)} \)
- $K_{20}$ = Rate constant at 20 C (d$^{-1}$)
- $T$ = operational temperature of system (°C)
- $d$ = depth of water column (m)
- $n$ = porosity of the substrate medium (percentage expressed as fraction)

$K_{BOD}$ is temperature dependent process of BOD degradation rate of which increase 10% to every °C, of which is greater in the summer and increase with the age of the system. According to studies with the following parameters (40g BOD/pe.d, 30% BOD removal in the primary treatment, 30 mg/l concentration of BOD in the effluent water, with 0.20 of $K_{BOD}$ for VF wetlands) it has already been calculated that the average area needed per capita for VF constructed wetlands is estimated around (0.8 - 1.5m$^2$/person) (UN-HABITAT 2008).

An area of (1 m$^2$) is decided, the decision is taken due to the fact that on ground testing are unfeasible, and if utilized at some point, tests could conducted with the BOD$_5$ and other vital parameters and the size of the wetlands bed could be adjusted. The total area needed for the wetlands beds is ($A_h = 5940$ m$^2$), it will be divided into four identical beds to prevent bad circulation or retention in bigger beds and in cases of maintenance, illustrated in (Figure 5), the design of one of the four identical wetland beds. Each bed will be 100 meters in length, 20 meters in width, with 75 cm in depth, the choice of the depth has been as recommended in the manual due its efficiency in comparison to shallower or deeper systems in subtropical climate (UN-HABITAT 2008). The bed will have a level surface and a (1%) slope at the bottom with the direction of the water inflow for better drainage of the system, as shown in (Figure 6), and the linear to prevent loss and contamination of groundwater could be a traditional pond seal such as PVC or PE, nevertheless such decision could be taken upon execution of the design, depending on the cost and availability of substitutes in the area.
3.2.2.3 Media selection

The media and substrate in the wetland bed serve multiple functions, helps rooting for plants, distribution of water in inlet and outlet, helps microbial growth with available surface and filter particles. The media in this design will consist of, two variation of gravel mixes, (5-10mm), (20-40mm), and the substrate of a mixture of (1-4mm) sand. the bed is order in layers as follow starting from the bottom of the wetland bed, 20 cm of gravel (20-40mm) followed by 5 cm of (5-10mm) gravel mixture, 45cm layer of sand mixture (1-4mm), and the top layer with gravel (5-10mm) mixture, which follow the recommendation of the manual. All of which are illustrated in the following figure to understand the distribution of the substrate (Figure 6).

Figure 5 Wetland and influent water system

Figure 6 Wetland Substrate
3.2.2.4 Inlet and outlet

To achieve a uniform flow, and avoid dead zones in the wetland beds, an even distribution is essential. The *inlet system* for each bed will consist of a feeding tank with a distribution pipe system, shown in (Figure 5). The feeding of the wetlands will be regulated via the feeding tank with a volume system, where the pipes will receive water at an adjusted point of volume in the feeding tank, a hydromechanical system (sinking bucket) could be used as the volume regulator (Figure 7). The piping system will have one main feeding pipe along the wetland bed edge, and smaller distribution pipes over the bed (Figure 5). The inlet system will have the explained structure for maintenance and easy access purposes. The *outlet system* has to have an adjusted system of which allow the wetland to have controlled flooding, the hydraulic gradient in the bed plays a big role to the maintenance of the wetland. depending on the location of each bed, the collection pit for the outlet will have a depth leveled to the wetland 1% slope, with an elbow pipe system that have has an opening with manual mechanic of such could be opened and closed. The outlet water goes through a steel screen that is inserted under the outlet pipe inside the pit to filter debris out of it, after that each pit will have a connection to a one collection tank connected to all wetlands (Figure 8). The collection tank volume will be around 500 m$^3$. 

![Figure 7 Wetland Inlet Design](image)

![Figure 8 Wetland Outlet design](image)
3.2.2.5  Vegetation

According to the followed manual, the vegetation and its litter are essential for a successful wetlands function and the aesthetics of the wetland. And the following criteria has been suggested in the manual. The use of local dominant macrophyte species, that has deep root penetration with strong rhizomes and fibrous roots, the high density of the stem to achieve maximum translocation of water and the assimilation of nutrients, the availability of surface for microbial growth and an efficient oxygen transport to the root zone for oxidation of toxic metals and the support of the rhizosphere (UN-HABITAT 2008). The used vegetation will be common reed (Phragmites karka and P. australis), due its availability and productiveness, climatic tolerance, and rapid growth.

3.2.2.6  Maintenance, Technicalities and Construction

The maintenance of the plan will be following the criteria of the constructed wetlands manuals. According to the research, VF wetlands could take up to 2 years before they could be fully operational, the main reason is the vegetation population that needs time to adjust to the environment and have full growth. Nevertheless, the population of the reed is self maintained, meaning that the vegetation grows and dies and regrow, cleaning of dry reeds is required. Furthermore, the technicalities of this part are excluded.

3.2.2.7  Sludge Drying

A wetland bed for drying the produced sludge from the septic tank could be used. By dewatering using draining, evapotranspiration, and the mineralization of the organic solids in the sludge. The accumulation of the sludge could be for multiple years, the produced sludge could later on be used as agricultural fertilizers. The design of the sludge drying wetland bed substrate is similar to the VF wetland bed, with roughly half of the depth. It consists of three layers starting from the bottom with a gravel mixture of (20-40mm) that fills roughly 50% of the bed, followed by another gravel
mixture (5-10mm), and then a sand mixture (1-4mm), the latter two shares the remaining 50% equally.

3.5 The cost of the Design

With this investigation fashion, and due to current situation in Syria, it is hard to identify precise or close estimation of the cost of the design. Nevertheless, two cases have been investigated. The first case study was done by Khaldoon A. Mourad (2011), showing the potential of water saving in Sweida, Syria, had an estimation of the cost of an artificial wetland system for a building of 50 people (Mourad, Berndtsson, J & Berndtsson, R 2011). The estimation suggests that a in 2009 a constructed wetland with land requirement of 0.8 m² per capita, and water consumption of around 94 liter per day per capita, the block system will of which treat the wastewater of 50 persons. The calculation has been based on lump sum assumptions and it gave a total of (1330 US $), with a per capita cost of 26.5 $ (Mourad, Berndtsson, J & Berndtsson, R 2011).

The second case study is a pilot project of a constructed wetland in Haran Al-Awamied, Syria. The project was a cooperation pilot between Damascus university, Ministry of Housing and Construction, German embassy in Syria and the German ministry for economic cooperation and development (von Münch, Ingle & Mohamed 2009). According to the project parameters, the area used for the plant was 0.5 m² per capita, with a daily flowrate of wastewater of 600 m³ per day, the total cost of the plant done between the year 1999 and 2000 was (95900 €) of total cost, and based on a population of (7000) people, it was 13.7 € per capita. Furthermore, the annual operation cost of the plant was around (9000 €) (von Münch, Ingle & Mohamed 2009). An average could be taken from the different costs per capita in the two cases, and it could be established as an estimation cost per capita for the design in this paper. Although, it is not reliable for the fact that both costs estimation has been done before the current conflict, and the inflation and the Syrian Pound fluctuation were not taken into consideration. Therefore, it has been decided that the cost analysis is only feasible with more data or in case of the execution of the design.
3.6 Evaluation of The System

The needed area for the design is around 7000 m² which is roughly the size of a football field, the design will have flow capacity of 750m³ per day and 273 750 m³ per year. The system will produce effluent water that is safe to discharge back into the environment or used for irrigation. The estimations were buffered due to lack of data regarding the current population and flowrate. Furthermore, it was not possible to obtain data regarding the exact irrigated area and demand for Al-Haffah. With Using the mapping tools in the QGIS Software (Figure 9), an estimation has been made of the possible arable area of which has been assumed to be 40% of the total area, between open fields and back gardens. Of which gives us around 1.7 km² of land.

According to a study done on the agricultural production in Syria it has been estimated that water requirement of crops per hectare per year, the study included four categories, cereals & dry legumes (wheat, barley, maize etc), industrial crops (Cotton, tobacco, sugar beet, etc), fruit trees (grapes, olives, apples, etc) and vegetables (Tomato, potato, onion & Garlic, etc) (Mourad and Berndtsson, 2012).

It has been assumed that the agriculture practice in AL-Haffah consists mainly of Olives around 80% and the rest is a variety of vegetables, due to the fact that 72% of Olive farming in Syria is located in the coastal area (El Ibrahem, Abdine & Dragotta, 2007). According to Mourad and Berndtsson analysis, olives require (4 000 m³/ha/year) in Syria, whilst an average of the introduced vegetables crops in the study has been taken and it gives around (6 100 m³/ha/year) (Mourad & Berndtsson, R. 2012).
With the previous assumptions an estimation could be taken to the required water for the assumed crops in Al-Haffah, with 80% of the land being cultivated with olives it gives:

\[1.36 \text{ km}^2 = 136 \text{ hectare}\]

And an area for other vegetables of:

\[0.34 \text{ km}^2 = 34 \text{ hectare}\]

When we substitute the numbers, it gives us the following numbers of water requirement:

- **Olives:**
  \[136 \times 4000 = 544000 \text{ m}^3 \text{ per year}\]

- **Vegetables:**
  \[34 \times 6100 = 207400 \text{ m}^3 \text{ per year}\]

Furthermore, the latter assumptions give us a total of water requirement for the agriculture in Al-Haffah of

\[544000 + 207400 = 751400 \text{ m}^3 \text{ of Water per year}\]

### 3.4.1 First Estimation

As two thirds of the cultivated lands are fed by rain (Asmael et al. 2015), and farmers use of groundwater for irrigation has reached around 60% of total irrigation water in Syria (Kelley et al. 2015), it can be assumed that the same applies for AL-Haffah. If it is assumed that the precipitation over Al-Haffah, of which is considered to be in the wet-coastal region, of (1000mm) of which is the minimum estimation that has been given (Mourad 2012). With an average loss of 55% via evapotranspiration according to (Faour & Fayad 2014),

Subtracting two third of the water demand for agriculture in Al-Haffah, which is met by rainfall, Require annual water for agricultural purposes in Al-Haffah:

\[751400 \text{ m}^3 - (2/3 \times 500933) = 250467 \text{ m}^3 \text{ per year}\]
If 60% of the required water was abstracted from groundwater it gives, required annual water from groundwater resources in Al-Haffah:

\[
250\ 467\ m^3 \times (60\%) = 150\ 280\ m^3\ per\ year
\]

The constructed wetland system is assumed to produce 273 750 m³ effluent water per year, if 20% loss is assumed to happen in the system, it gives a yearly effluent water of 219 000 m³ of which is potentially safe to use for agriculture. Furthermore, according to the previous calculations and assumptions.

The effluent water from the constructed wetland system covers:

\[
(145.7\%)\ of\ the\ assumed\ groundwater\ abstraction\ in\ Al-Haffah.
\]

Or, if all sources of water are taking in consideration, it Covers:

\[
(87.43\%)\ of\ the\ total\ required\ annual\ water\ for\ agricultural\ purposes\ in\ Al-Haffah.
\]

3.4.2 Second Estimation

The calculation in the first estimation, included the precipitation parameters, the lack of resource management systems in Syria, backed the decision that the calculation in the second estimation will not include it, rather excluding rainfall and focusing on groundwater and surface resources as the only available resources for agricultural water needs, due to the exploitation that those resources are facing. And due to the future projection of the environment and hydrological cycle, that precipitation might face 50% reduction in the coming years (Faour & Fayad 2014). Therefore, the second estimation is more of a worst-case scenario, where resources are limited.

Plugging in the numbers, excluding the rainfall parameters it gives, required annual water for agricultural purposes in Al-Haffah:

\[
751\ 400\ x\ 60\% = 450\ 840\ m^3
\]

of which is assumed to be obtained from groundwater resources. With 219.000 m³ annual effluent water of the constructed wetland system, the introduced design could cover:
(48.57%) of the required groundwater resources for agricultural purposes in Al-Haffah.

Or, if all sources of water are taking in consideration, it Covers:

(29.14%) of the Total required annual water for agricultural purposes in Al-Haffah.

4. Discussion

4.1 The current situation

March 2011 was the beginning of the Syrian conflict, of which turned into an armed conflict between rebels and governmental forces. The armed conflicts displacement tool that affected more than 13 million people in within Syria and in neighbouring countries. It has been estimated that around 1.4 million people of the displaced with Syria, has moved to the coastal region (Faour & Fayad 2014). The combination of the mismanagement of the resources in Syria, and the pressure caused on resources to meet the needs of the rapid growing population in the region, is causing decrease of resource availability and production, while prices of potable water and food keep increasing. According to the findings of the investigation, it has been found that the Syrian water resource management system, is weak and unreliable. As it caused devastating impacts to the economy, environment, and wellbeing of the Syrian people when the drought happened in 2007. The vulnerability and scarcity of the water resources are imminent according to the future projections of climate change, of which will cause much more severe impacts if accompanied by the current management systems in Syria. Due to political and conflict driven factors for the past 40 years, there has been a lack of availability of research regarding water resources and its management in the scientific field. To mitigate the current situation, and even post-conflict, new measures are needed in the current system. Guidelines and awareness for users are of most importance to have a functional system. As it has been shown previously that the lack of awareness led to the use of untreated wastewater for irrigation. A combination of better systems for the sewage and run-offs, and civil awareness, is needed to mitigate the water contamination and the environmental impacts accompanied with it. The use of technologies such as Constructed wetlands to treat domestic wastewater, will be beneficial for the agricultural sector in rural areas. The high
consumption and exploitation of water resources caused by agricultural practices, could be mitigated by the allocation of wastewater, of which in the current state in Syria ends up in the sea.

4.2 The constructed wetland system in AL-Haffah

The used method had some assumptions when data was unavailable, which could have had great impact on the liability of the produced numbers. Furthermore, all assumptions have been made in correlation and relativity to conducted studies in the same sphere of investigations. The assumptions in the methodology of the investigation is meant to be as close to reality as possible. Some parts of the constructed wetland design, has been excluded or touched upon briefly, due to the fact that such parts of the design either require on ground testing, or are irrelevant to the investigation approach (the focus of water resource). Nevertheless, the method with the used assumptions has produced the information that the investigation thrived for. The Constructed wetlands has proved worthiness in treating various types of wastewater through its development in the past decades. The low energy input that the system needs, and low cost of maintenance compared to conventional systems (Vymazal & Kröpfelová 2008). All of which makes it an adequate approach to our case study for various reasons, the existing sewage system in most of the country is a gravity driven collection system that is usually connected to run-offs and end up in water bodies, along with the elevation of AL-Haffah, makes it possible to utilize these two aspects and place a treatment plant to mitigate the system.

Al-Haffah, as an agricultural area, access to land is possible of which exclude one of the downsides of constructed wetlands, which is the needed area. The system will mitigate the contamination of water resources in the downstream areas, which are heavily affected due to the lack of proper sanitation facilities of wastewater upstream and overall, in rural Syria. As water availability has decreased significantly in the region, due to the increased demand and the degradation of the water capacity. Between year 2000 and 2010 it has been estimated that the average availability of renewable water resources in the coastal basin are between 750 m$^3$ and 1000 m$^3$ per year per capita, in dry and wet years respectively, and are expected to decrease to around 550 m$^3$ per year per capita, due to climatic changes and conflict, of which cause poor management of resources (Faour & Fayad 2014). Which is considered living under water stress according to FAO (Water Scarcity | Food and Agriculture Organization of the United Nations 2020).
Whether the effluent water has been used for irrigation or discharged back into the environment, either ways, the impact of the system is significant. The lack of primary treatment of pollutants in rural areas in Syria suggest the strong need of such a solution, and the exploitation of water resources for irrigation is mitigated with such circular system. The introduced design is a desktop study to show the potential of implementation of such systems. As of one part of the introduced design, of which is (Sludge Drying) could be utilized in the agriculture sector in Al-Haffah, although it has not been the focus of this investigation due to the fact that the main focus is water. Nevertheless, the investigation is missing concrete numbers and therefore is only valid as a principle.

### 4.3 Further Studies

The produced constructed wetland design and the evaluation of it regarding water use and the scarcity that the country is facing, is one of the many possible solutions to the water management systems in small scale Syrian towns. As it has been found how vital the management of resources is, and how significant its impacts are, further investigations are needed to produce a circular system. It is of great interest to further investigate technologies, where an integrated system could be produced, of which sustain the availability on a larger scale, and meet the demand of the population with regards to climate change and the projected scarcity of water resources.

### 5. Conclusion

The current Water resource management systems in Syria are weak, the lack of proper solutions to the circularity of the hydrological system in Syria could impact the livelihood of its inhabitants significantly in the future. With 14 km$^3$ of renewable water resources, and 17.5 km$^3$ annual use, Syria is facing a shortage of 3.5 km$^3$. The drought in 2007, has showed how the lack of sustainable management systems in the water sector could lead to devastating impacts. Many parts of Syria have no wastewater treatment, untreated wastewater ends up in the environment. The introduced design of constructed wetlands as a treatment plant for municipal wastewater of a small town of around (5940) inhabitants, and daily wastewater flowrate of (500 m$^3$). The design area requirement
is around (7 000 m$^2$). The effluent water of the constructed wetland could play significant role first and foremost in decreasing the environmental impacts of the existing system (discharge of untreated wastewater in the environment), and in water savings in agricultural practices.

Two estimations have been done, the first including the precipitation parameters, and rainfall as a source meeting two thirds of the required annual water for agricultural purposes in Al-Haffah. The estimation gave, savings of (145.7%) of the assumed groundwater abstraction in Al-Haffah, or (87.43%) of the Total required annual water for agricultural purposes in Al-Haffah if all sources are combined.

Whilst the second estimation, excluding rainfall and focusing on groundwater and surface resources as the only available resources for agricultural water requirements. It gave savings of (48.57%) of the required groundwater resources for agricultural purposes in Al-Haffah, or (29.14%) of the Total required annual water for agricultural purposes in Al-Haffah if all sources are combined.

Furthermore, an integrated supply system is needed in Syria as a whole, for both rural and urban areas, where appropriate technologies could be utilized according to the location and limitations. For not only current state, rather current and post-conflict, where the climate induced impacts will be accompanied by many anthropogenic factors caused by the conflict and will produce devastating combination of impacts on the wellbeing of the Syrian people.

References


