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# Feasibility study on SWMED solutions for the project target areas in Tunisia

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# 1. Analysis and selection of the target areas

## 1.1 Summary

This document aims to present the feasibility study developed by CERTE, partner of the project SWMED – Sustainable Domestic Water Use in Mediterranean Regions in order to support the integration of ad-hoc sustainable strategies into the Mediterranean local/regional policies applied in Tunisia.

During the development of this study, the specific characteristics of urban and rural settlements in Tunisia were analysed in order to allow the identification of the best suite of measures which can be considered for optimising the management of water demand and wastewater treatment and reuse in the country. This also with a view of developing national and regional policies aimed at improving the wastewater treatment needs and the reuse practices, and thereby contributing to the sustainable use of water resources.

The identification of these characteristics was enabled through the collaboration of the National Water Services, SONEDE and ONAS. This analysis was undertaken on three specific representative localities that can be easily used as model for replication of similar approaches in several comparable situations in the country.

## 1.2 Selection criteria of the target areas

The criteria used by CERTE to identify the settlement typologies for the project was discussed with CERTE partners: SONEDE and ONAS during different meetings. The criteria are organized according to their importance. Criteria are organized starting with the more important (see box below). The Cr7 is important but in the seventh position as the main stakeholders (ONAS, SONEDE) are already involved in the project with CERTE, as well as their local teams. High weight is given to criteria from 1 to 4.

Cr1. Eligibility region for the project
Cr2. Fitting with national priorities
Cr3. Fitting with EU-MED priorities
Cr4. Representative of Tunisian existing Settlement
Cr5. To build on previous experience
Cr6. Synergy with other projects if possible
Cr7. Adherence of target groups and stakeholders to the objectives of SWMED

Basing on presented criteria, three target areas are selected:

**Rural settlements having in-house water distribution systems but with no sewage system (individual sanitation).**

Cr1. Eligibility region for the project: Governorate of Ariana
Cr2. Fitting with national priorities: National strategy for sanitation for rural area
Cr3. Fitting with EU-MED priorities: H2020, Depollution of Med Sea
Cr4. Representative of Tunisian existing Settlement: Small rural agglomeration without sanitation network and WWTP
Cr5. To build on previous experience: Local water management approach applied to the primary school, the population are already informed and followed the implementation of this approach.
Cr6. Synergy with other projects if possible: Project Zer0-M, Medawater program
Cr7. Adherence of target groups and stakeholders to the objectives of SWMED:
Target group: Habitants, Water and Sanitation actors in rural area
Stakeholders Involved: ONAS, SONEDE, Local authority

**Rural villages with in-house water distribution systems and a partial sewage system but with no treatment plant.**

Cr1. Eligibility region for the project: Governorate of Nabeul
Cr2. Fitting with national priorities: National strategy for sanitation for rural area, City on the top of the list of priority: Zaouet El Mgaeis (ZEM)
Cr3. Fitting with EU-MED priorities: H2020, Depollution of Med Sea
Cr4. Representative of Tunisian existing Settlement: Rural small city with partial sanitation network and without WWTP
Cr5. To build on previous experience: Local initiatives for sanitations
Cr6. Synergy with other projects if possible: No
Cr7. Adherence of target groups and stakeholders to the objectives of SWMED:
Target group: Habitants, Water and Sanitation actors in rural area
Stakeholders Involved: ONAS, SONEDE, Local authority, NGO

**Urban areas with prevalence of multi-floor buildings: in house water distribution systems and sewage systems and treatment plant.**

Cr1. Eligibility region for the project: Governorate of Tunis
Cr2. Fitting with national priorities: National strategy for management of the Grand Tunis: Vertical building
Cr3. Fitting with EU-MED priorities: H2020, Depollution of Med Sea
Cr4. Representative of Tunisian existing Settlement: Vertical construction, high density but without sustainable and local management of water (part of sustainable city)

Cr5. To build on previous experience: Local water management at urban level: Technical demonstration centre
Cr6. Synergy with other projects if possible: Project Zer0-M, Medawater program
Cr7. Adherence of target groups and stakeholders to the objectives of SWMED:
Target group: Habitants, Water and Sanitation actors in rural area, architect
Stakeholders Involved: ONAS, SONEDE, Local authority, NGO, syndicates.

## 1.3 Description of the sites

### 1.3.1 Chorfech 24: Rural settlements having in-house water distribution systems but with no sewage system (individual sanitation).

#### 1.3.1.1 Presentation, localization, generalities

Chorfech 24 is a rural agglomeration located in the low valley of Medjerdah, in the northwest of Tunis. Its naming « Chorfech 24 » corresponds to its location on the kilometric point 24 of the GP8 road linking Tunis to Bizerte and its appellation is used to make the difference between it and the other places having the same name (Chorfech1, Chorfech2, and Chorfech8) which are situated mostly in the west (figure 1).
Agriculture and breeding are the main activities of Chorfech region: the agriculture, which is intensive, is centered on the truck and fodder farming and it is often associated to breeding, particularly the dairy farming.
Chorfech 24 is divided into two parts: the first one contains about fifty fields on the highway A4 and it is named "Chorfech settlement", the other part is on the national road P8 which contains about thirty fields and represent the locality of our study (figure 2). In the rest of this document, Chorfech 24 will be named simply "Chorfech".
The two parts, even though related by a bridge, are separated by the highway. Thus, Chorfech settlement has been the object of an experimental project of a rural sanitation by CERTE and its partners. However, with regard to this separation, it was not possible to connect the study locality to this project.

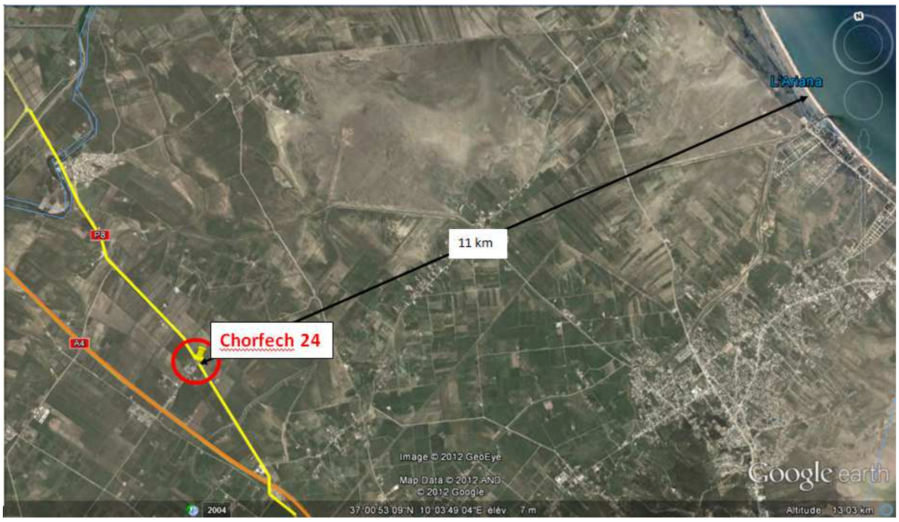



**Fig. 1: Localization of Chorfech 24 with regard to the national roads and the sea (36°57'33.91''N 10°04'40.12''E)**


**Fig. 2: Division of Chorfech 24 into 2 parts**

The Figures 3 presents specific public building (Police office (red)and primary school (green)) as well as Late collection cooperative. The Figure 4 presents the village and the target houses during the socio-economic study undertaken by CERTE in the frame of this project.


**Fig 3 : General view, public utilities**

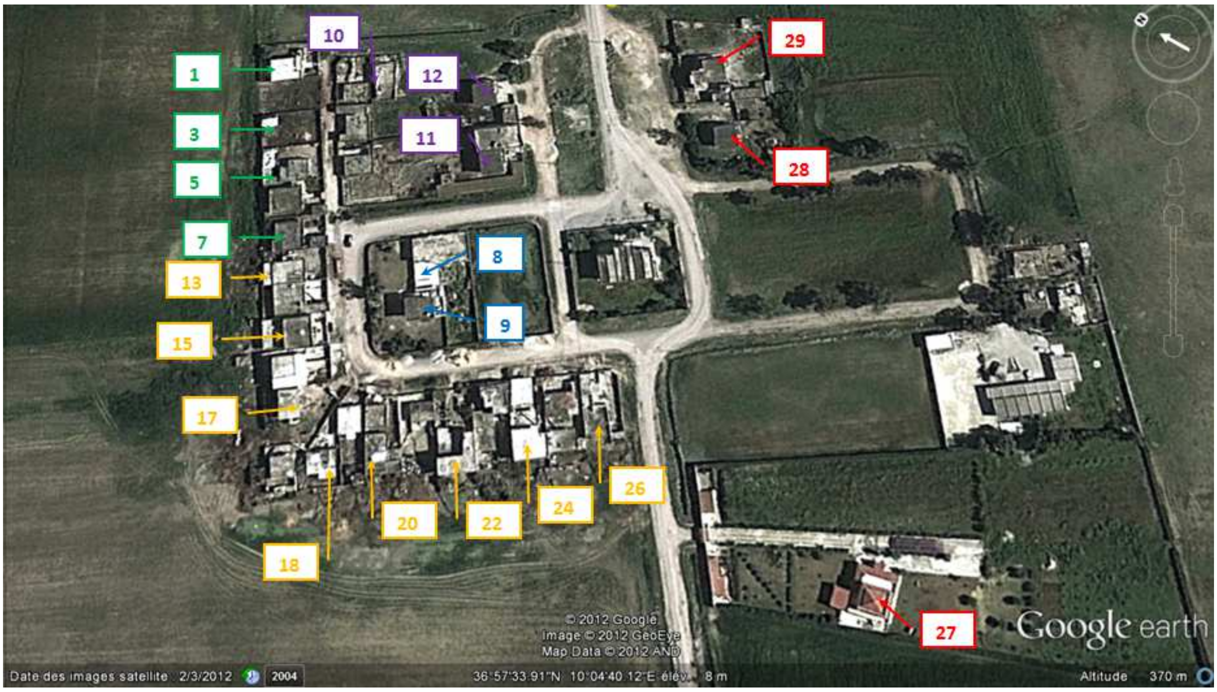



Figure 4: Detailed view of the village (socio-economic study, CERTE)

The urbanization of the region is 90,8% (2011). In the studied area, the inhabitant number is 180 and expected to reach 262 in 2020. House number is 39.

### 2.3.1.2 The wastewater treatment plant Chorfech

The wastewater treatment plant was set up by the CERTE/IRIDRA and ONAS in the frame of "Zer0-M" project. The flow rate is 17 m3/day. The process was the treatment by constructed wetland

The constructed wetland system of WWTPP presented by figure 2 consists of three stages in series:

- a first, horizontal flow stage, for carbon and suspended solids removal
- a second vertical flow stage, for nitrification
- a third horizontal flow stage, for remove the nitrogen in case of release of the wastewater into the aquatic environment.
- Sludge composting bed.

A pre-treatment by an Imhoff tank is installed before the system of constructed wetland. A "sludge treatment constructed wetland" allows the treatment and composting of the primary sludge accumulated in the Imhoff tank. This example is implemented as a demonstration action and a best practice example for rural settlements in Tunisia with low operation costs (Ghrabi et al., 2011). The preliminary results show the feasibility of the system and this Pilot Plant appears to be a powerful combination coupling the horizontal and vertical submerged flow CW after an Imhoff tank (Figure 5). Regarding the high removal rates obtained, the final quality of treated wastewater is sufficient compared to the national norms authorizing the discharge of treated wastewater into receiving water or reuse.

**Figure 5 : General layout of WWTPP, Chorfech 24**

1: Imhoff Tank; 2: 1st stage HF-CW; 3: 2nd stage VF-CW; 4: Reservoir of treated wastewater; 5: 3rd stage HF-CW; 6: Wastewater treated discharged in drainage channel; 7: Sludge Composting bed CW.

#### 2.3.1.1 Water supply

The water supply of the region is 99,9%. Regional SONEDE provided the subscribers' number evolution of the last four years and the total annual consumption. These statistics concern Chorfech village, they include both parts (interior/high way and exterior/high way).

Table 1 : SONEDE subscribers' data of Chorfech 24

| | Subscribers' number | Total annual consumption m3 |
|---|---|---|
| **2008** | 140 | 48390 |
| **2009** | 148 | 52340 |
| **2010** | 151 | 52380 |
| **2011** | 160 | 52740 |

Source: SONEDE Ariana

Regarding wastewater, as we have mentioned before, the network was realized only in the "Chorfech settlement". In the studied part, there is no collective sanitation and there are no planned connections to the network.

The only exception is the primary school of Chorfech (Figure 6), with a local water management designed and realized by IRIDRA/CERTE in the framework of the Zero-m project. This system will be used to collect data in purpose of design in this project. It is composed by:

- Implementation of several equipments to save water
- Set up of waterless on the place of conventional urinal;
- Implementation of push-button taps for toilet flush;
- Equipment of others taps by push-button (drinking and washing taps);
- Construction of reservoir to collect rainwater from school roof  which is used for flushing toilet;
- Treatment of wastewater by CW and reuse for landscaping.


**Figure 6 : Primary School of Chorfech**

### 1.3.2 ZAOUIET EL MGAIEZ (ZEM): Rural villages with in-house water distribution systems and a partial sewage system but with no treatment plant.

The Zaouiet EL Mgaiez town is situated on a hill's top, where the agriculture is the dominant activity, and it is situated in Tunisian Cap bon. Zaouiet Mgaiez belongs to El Haouaria's delegation, in Nabeul governorate.
It is surrounded by Oued Laabid-Dar Chichou zone which is made up of two natural spaces mainly forested; these two zones have the following respective surfaces of 5950 hectares and 6041 hectares. Zaouiet Mgaiez town is located in 22 km in the Southeast of El

Houaria. In the south, ZEM is limited by Tazoghrane-west and by Tazoghrane-east and in the north by the sea and Boukrim town.


Figure 7 : ZEM, geographic situation

### 1.3.2.1 Population

Zaouiet EL Mgaiez town has 4021 inhabitants in 2004 (which represents 10 % of El Haouria delegation total population) and 1700 inhabitants in 1994. The average annual increase rate of the Zaouiet Mgaiez population is 5 % during the period 1984-1994 to 9 % in the period 1994-2004.
According to the population survey of 2004, Zaouiet Mgaiez town (Zaouiet Mgaiez and Bir El Jedey) contains 978 housing occupied by 4021 inhabitants what gives an average of 4.11 inhab/ house. To calculate the current population of Zaouiet Mgaiez without Bir El Jedey, based in google map (house number) and the occupation rate of 4.11 inhab/housing, thus, at present Zaouiet Mgaiez contains approximately 3186 inhabitants.
According to the El Haouria delegation, Zaouiet Mgaiez houses density is about 14 housing per Km2.

### 1.3.2.2 Economical activities

The agriculture constitutes the main activity of Zaouiet Mgaiez population regarding to the availability of vast agricultural fields and the water availability. Breeding is also practiced, essentially the cattle and ovine breeding. The agricultural activity is essentially concern the truck and cereal, fruit trees as citrus fruits could be found.

The commercial activity is essentially based on the trade of the Sidi Daoued water, the small market and the weekly market. The only industrial activity in this area is the foam cut factory. Despite the beautiful landscape and the beach, there is no tourist activity in Zaouiet Mgaiez.

Zaouiet El Mgaiez town contains the mainly public utilities as primary and intermediary school and health office.

### 1.3.2.3 Drinking water supply and wastewater

According to SONEDE, the total number of connection to the network is 63 connections in 2011, what presents only 6 % of the housing of the locality.
During our visit and according to CERTE survey, the connection rate to the SONEDE's network is about 60 %.
Regarding sanitation, Zaouiet Mgaiez is currently served by a network of 7400 meters linear in PVC 250, a transfer network of 1180 meter shelf spaces and 613 connection boxes.
The ONAS asserts that the current consumption in drinking water is about 221 m3/d with a discharge rate of 50 %. The annual flow of waste water is about 40 330 m3/year.
According to our investigation, the existing network concerns about 35 % of the houses of and the rest uses pits. Administration buildings are equipped by septic tanks. The majority of pits volume is between 5 and 20 m3. The final discharge point is Oued Mgaiez.

The existing rainwater's network is limited to a collector draining both sides of the main street which appears not functional due to fouling by the solid waste.

### 1.3.2.4 Hydraulic system

The hydraulic system presents a strong connection between surface waters and ground waters.
The river system of Zaouiet Mgaiez town is relatively dense. The river system is relatively new and formed by three main Oueds: Ain Saada, Ennagr et Errabta, the three of them connected to Oued Mgaiez which is divided in the direction of Tunis Golf in the north of Zaouiet Mgaiez. Oued Mgaiez, generally dry in summer, is used for the irrigation of the neighborhood's fields.

The ground water resources in the region are from two superposed water tables (surface and deep). Tazoghrane groundwater with global reserves of 10,5 Mm3 and the deep groundwater of Tazoghrane with an exploitation of 0.07 Mm3 in 2008.
The groundwater, essentially used for the irrigated agriculture, is over-exploited today. Most of the houses have wells used for the irrigation as well as for domesticate uses. According to our investigation, the average daily consumption of groundwater is about 50 L/inhab/day. Rainwater is unexploited.

### 1.3.3 Bardo Center: urban settlement

#### 1.3.3.1 Presentation, localization, generalities

Bardo city is part of Tunis governorate which contains 43% of Grand Tunis population and 10% of the national population.

The demographic entity formed by the north west delegations around Bardo and El Omrane, is a quite ancient regrouping of 195139 inhabitants.

In 2004, the observed density in the governorate of Tunis varies between 115 and 62000 inhabitants per km², whereas the average densities are between 839 and 21059 inhabitants per km². The west zone of Grand Tunis, to which belongs Le Bardo, is a residential basin grouping 37% of the capital's population but only 10% of the employments.

#### 1.3.3.2 Bardo delegation

Grouping a population of approximately 106000 inhabitants, Bardo and Ezzouhour delegations, which are located in the northwest of Tunis governorate, have a residential vocation and in their North part (Bardo), they play a role of national sovereignty (chamber of parliament members and councilors). Both delegations are characterized by a natural environment characterized by its proximity to sebkha of Séjoumi, rich cultural character (Bardo museum…) and a small demographic dynamics marked by a permanent decrease of the local population.

Table 2: Bardo City data

| | |
|---|---|
| Population | 68 976 |
| Rate of Growth | -0,34% |
| Nb of household | 177999 |
| Average household size | 3,95 |
| Water supply rate | 99,90% |
| Connection rate to sanitation system | 98,40% |
| Bath room rate | 67,10% |
| Average density habitants/km² | 10011 |
| Nb Household | 19594 |
| Water consumption per activity (mille m3) | |
| Domestic | 2743,4 |
| Industry | 5,1 |
| Sanitation system | |
| Nb Subscribers | 18837 |
| WWTP(charguia) | - |

| | |
|---|---|
| Pumping station | 0 |
| Network | 87965 |
| Rain water (sabket Sejoumi) | |

### 1.3.3.3 Bardo Center

Bardo Center was constructed in 1995 to create an urban center which includes activities, businesses, services, accommodations and parking places.

Bardo Centre is a cluster of ten buildings organized in a circle in the center of the city of Bardo. The ground floor consists of various shops and businesses as well as the center. Each building has six floors and a mezzanine sometimes depending on the building (figures 8 et 9). Bardo is occupied by residents (80 apartments) but also used by different professions such as doctor, insurance, lawyer, etc. a total of 70 offices.

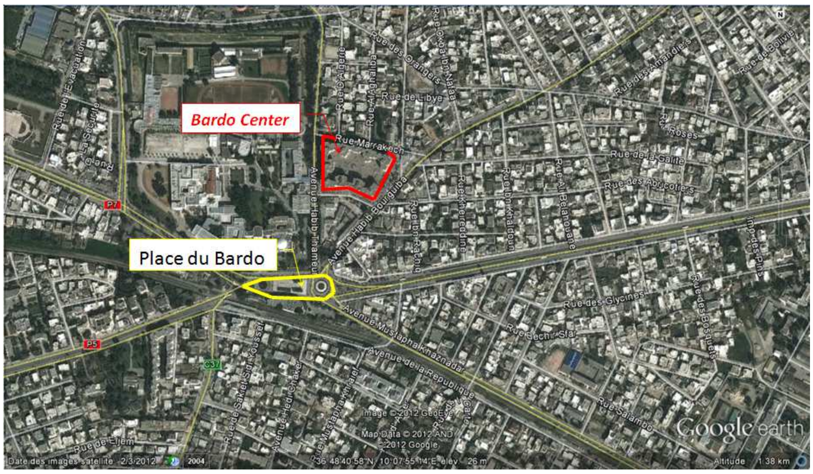



**Figure 8: Localisation of Bardo Center in Le Bardo city. (36°48’34.40’’N10°08’16.43’’E)**


**Figure 9: Le Bardo Center, aerial view.**

#### 1.3.3.4 Water Supply and wastewater:

As Tunisian urban city, Bardo is totally supplied by water by SONEDE. Bardo has a separated network. Thus, the wastewater is treated in the wastewater treatment plant (WWTP), where all the wastewater of Tunis governorate is treated (in case there is an excess, the treatment takes place in Chotrana WWTP). Rainwater is directly discharged in the natural environment (Khaznadar canal or sebkha of Séjoumi).
Both the 10th block and halves of the 1st and the 9th blocks are directly linked to the network. All the remaining part of Bardo Center is connected to an added collector which is linked to Bardo network. The roof rainwater and neighboring streets are evacuated via the Habib Thameur street.

Table 3 summarizes the characteristic of Bardo Centre apartment obtained via the socio-economic study conducted by CERTE. The average Water consumption during the summer based on our survey is from 300-700 L/day per apartment (household) and 70 to 300 L/day for doctor offices. The average consumption is from 120 to 170 L/inhab.day.

Table 3: Bardo Centre apartment characteristics.

| **Repartition according to the size of the house** (%) | | **Average number** | |
|---|---|---|---|
| 3 rooms | 37,5 | Tap | 4,2 |
| 4 rooms | 50 | shower | 1 |
| 5 rooms | 12,5 | WC ( all with flushing) | 1,4 |
| average | 3,8 | | |

**Figure 10 : Part of the Bardo centre building, view from the first floor**

# 2 Draft feasibility evaluations

Analyzing the data collected during the survey on the three case studies by CERTE, it's clear that these isolated areas face many infrastructural problems related to water and wastewater systems, with a particular attention on the abundant cases of not appropriate treatment that are still present in the country. In all the areas the promotion of the water saving kits, as water diffusers, dual flush button for the WC and also rainwater harvesting practices should be planned and encouraged.

Taking into account the 3 cases study, the following solution can be proposed:

- concerning Urban Residential areas, the recommended solutions are to be addressed to rainwater harvesting and the grey water separation system for improving the reuse at domestic level;
- having to do with the Rural Agglomerations the main problem to tackle is related to limited network and treatment system that should be solved building a constructed wetland plant in order to improve the adoption of more sustainable solutions and reuse of water, also in agriculture, the main activity around the village;
- the rural agglomeration without network have to face the problem due to the absence of connection to the WWTP due to highway separation, thus, a water saving campaign is proposed for supporting the adoption of sustainable solutions for domestic water reuse, as water saving kits, storage of rainwater and grouped CW system.

An adequate system of water recovery and reuse could help competent authorities and citizens to tackle the problem of wastefulness of drinking water, saving a quantity of water abundant enough for avoiding the periodical deficit, for example during the summer.

Here below a brief list of the possible tools suitable for the selected cases studies, with some essential explanation and clarifications in order to understand better the selection of the various tools in the proposed alternatives.

**Water Saving devices**

A wide range of fittings and equipment able to reduce water consumption is available on the market. Most effective products are taps aerators and low flow shower-heads. Among the different tap types are lever taps, taps with timers with electronic shutoff, etc. There are also devices which can be adapted for different tap systems like reduced flow, and Tap aerator. Many models of new taps have these devices already incorporated. In addition, these devices are almost always compatible with each other. You can find mixer taps that have a built-in aerator.

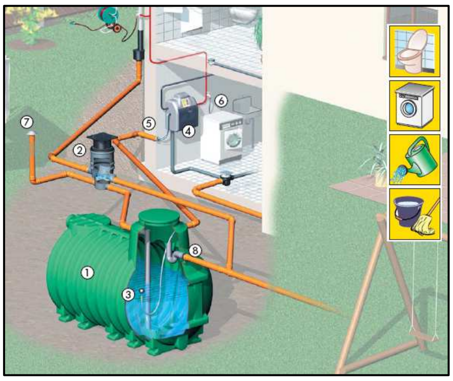
| | Savings for supply point |
|---|---|
| Flow restrictors | 30-40% |
| Tap aerator | 30-70% |
| Water pressure limiter | 10-40% |
| Water saving showers | 50% |
| Mixer  taps | 30-40% |
| Automatic taps | 30-40% |
| Electronic taps | 40-50% |
| Thermostatic taps | 50% |

The flush toilet can be adapted in order to use significantly less water than a full-flush toilet. Low-flush toilets use a special design of the cistern and the siphon in order to allow the removal of faeces and excreta with less water. Most often, they also include a dual flush system, with one flush being designed for urine only, using even less water than the other designed for faeces. Today, there exist many suppliers of different models of low-flush toilets all over the world.

**Rainwater Harvesting (Urban) and (Rural)** realized in a rooftop is the most common technique of rainwater harvesting (RWH) for domestic consumption. It can be done easily, doesn't cost much and is applicable at small-scale with a minimum of specific expertise or knowledge; or in more sophisticated systems at large-scale (e.g. a whole housing area). Rainwater is collected on the roof and transported with gutters to a storage reservoir, where it is either used for groundwater recharge or provides water at the point of consumption. Rainwater harvesting can supplement water sources when they become scarce or are of low quality like brackish groundwater or polluted surface water in the rainy season. However, rainwater quality may be affected by air pollution, animal or bird droppings, insects, dirt and organic matter. Therefore regular maintenance (cleaning, repairs, etc.) as well as a filtration treatment before water consumption are very important.
The main components of a system for rainwater harvesting are:

- The collecting surface: only connect suitable roof surfaces if the system does not include a treatment. Take into consideration possible erosion of hazardous matter from the roof. With an appropriate treatment water from pavements can also be used.
- Gutters and downspouts (gullies and rainwater drains)
- Filter – mechanical or natural (as raingarden)
- Tank below ground
- A distribution system for reuse in irrigation or for WC flush

The treatment could be a simple mechanical filter; there are several models on the market, generally they are very simple and permit a basic filtration, due to the presence of mesh grid and/or exploiting forced hydraulic patterns to separate the coarse solids from the water. Generally the models on the market can cover roof surface until 3-400 m2.

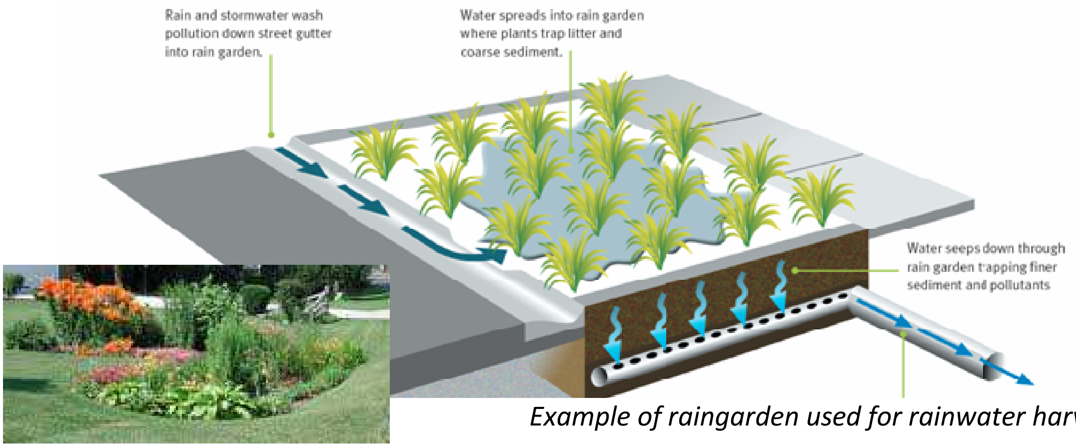


1)tank
2)stormwater mechanical filter
3) suction pipe with floating filter
4) control panel and external pump for reuse
5) dual network for WC
6) emergency connection to potable network in case of empty tank
7) emergency overflow with check valve connected to stormwater network
8) ventilation pipe (optional)

*Example of rainwater harvesting at household level with mechanical filter.*

If there is available space, the surface of the roof is higher and a higher purification capacity is required, natural treatment systems permit to achieve better results.
Vegetated natural filters (rain gardens) are intended to be landscaped areas that treat stormwater runoff. Homeowners or custodians can treat these gardens, giving them significant attention, or they can blend them into the landscape and make them look "natural." Whatever the context, a rain garden should look like part of the landscape: plants—particularly shrubs and trees—surrounded by mulch. However, the true nature of a rain garden is to treat stormwater. Water is directed into them by pipes, swales, or curb openings. The garden is a depression or bowl that temporarily holds and treats water.
The treated stormwater can be collected by a drainage system for the reuse or infiltrated for groundwater recharge.

- Help alleviate problems associated with flooding and drainage.
- Enhance the beauty of individual yards and communities.
- Provide habitat and food for wildlife including birds and butterflies.
- Allow reuse of treated stormwater




*Example of raingarden used for rainwater harvesting*

**SUDS**

Sustainable Urban Drainage Systems constitute a relatively new approach to water management in urban areas. The objective of SUDS is to maintain or replicate the pre-development water cycle. When urban development occurs, the natural water cycle is altered to the extent that stormwater runoff from individual properties and roads intensify, flows usually increase and potential contaminants from residential and commercial activity and associated vehicle use flow into the streams and watercourses. Traditionally stormwater generated from urban areas is conveyed efficiently to designed trunk drainage systems to reduce stormwater ponding and flooding risk.

SUDS aim to limit the negative impacts of urban development on the total urban water cycle:

• trying to more closely match the pre-development stormwater runoff regime, in both quality and quantity;
• reducing the amount of water transported between catchment, both in water supply import and wastewater export;
• optimising the use of rainwater that falls on the urban areas.

The key principles of SUDS are:

1. Protect natural systems (creeks, rivers and wetlands) within urban catchments.
2. Protect water quality by improving the quality of stormwater runoff draining from urban developments.
3. Integrate stormwater treatment into the landscape by using stormwater treatment systems in the landscape that incorporate multiple uses providing a variety of benefits such as water quality treatment, wildlife habitat, public open space, recreational and visual amenity for the community.
4. Reduce runoff peak flows from developments by on-site temporary storage measures (with potential for reuse) and minimise impervious areas.
5. Add long-term value while minimising development costs.
6. Reduce potable water demand by using stormwater as a resource through capture and reuse for non-potable purposes.

SUDS can be sized to suit most individual sites from residential house blocks through to whole subdivisions. However, appropriate planning and design are required to ensure successful outcomes. The range of applications available may be applied in the following areas:

• new road/street in large or small development areas;
• existing streets and roadways;
• upgrade of drainage systems or pavements;
• publicly owned land;
• new residential developments;

- existing residential developments, redevelopments and infill areas;
- commercial or industrial developments; and
- carparks/driveways/access ways on public or private property.

It is desirable to treat runoff and associated pollutants generated from impervious areas by SUDS located as close as possible to its source, thereby minimising the requirement for end-of-pipe or downstream catchment treatment measures. Pollutant removal mechanisms associated with these measures involve physical, biological and absorption processes. Treatment methods based on physical processors are often used first in the treatment train. The selection of the most appropriate SUDS depends on:

- the style of development and the type of pollutants likely to be generated;
- pollutant reduction objectives;
- location within the development catchment (i.e. allotment, subdivision or catchment level);
- role, function and effectiveness of the treatment measure;
- individual site assessment, physical constraints and design issues (such as soils, slopes, salinity,
groundwater and space);
- operation and maintenance issues;
- life cycle cost considerations.

**Stormwater ponds** are constructed stormwater retention basins that have a permanent (dead storage) pool of water throughout the year. Stormwater ponds are designed to control both stormwater quantity and quality. The primary removal mechanism is settling while stormwater runoff resides in the pool. Nutrient uptake also occurs through biological activity in the sediment and water. Wet ponds differ from constructed wetlands in that they are typically deeper, ranging from 1 to 2 m, and have less vegetative cover. Wet ponds are among the most cost-effective and widely used stormwater treatment practices.

**Bioretention areas** are engineered facilities in which runoff is conveyed as sheet flow to the "treatment area," which consists of a grass buffer strip, ponding area, organic or mulch layer, planting soil, and vegetation. An optional sand bed can also be included in the design to provide aeration and drainage of the planting soil. Bioretention systems can be designed as infiltration-based systems if the native soils beneath the facility are sufficiently permeable and there are no other constraints to infiltration such as soil or groundwater contamination. If infiltration is not feasible, they can be designed as flow-through systems that are contained within an impermeable liner and use an underdrain to direct treated runoff back to the collection system.
There are numerous design applications, both on and off-line, for bioretention areas. These include use on single-family residential lots (rain gardens), as off-line facilities adjacent to parking lots, along highway and road drainage swales, within larger landscaped pervious areas, and as landscaped islands in impervious or high-density environments. If designed properly, they can be an aesthetic and habitat amenity as well as a stormwater treatment facility. Bioretention areas are designed primarily for stormwater quality, i.e. the removal of stormwater pollutants. Bioretention can provide limited runoff quantity control, particularly for smaller storm events.

**Infiltration trenches** are excavations typically filled with stone to create an underground reservoir for stormwater runoff. This runoff volume gradually exfiltrates through the bottom and sides of the trench into the subsoil over a 2-day period and eventually reaches the water table. By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Due to this fact, infiltration systems are limited to areas with highly porous soils where the water table and/or bedrock are located well below the bottom of the trench. In addition, infiltration trenches must be carefully sited to avoid the potential of groundwater contamination.
Infiltration trenches are not intended to trap sediment and must always be designed with a sediment forebay and grass channel or filter strip, or other appropriate pretreatment measures to prevent clogging and failure. An infiltration trench is presumed to be able to remove 80% of the total suspended solids load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications.

**Vegetated infiltration swales** are conveyance channels engineered to capture and treat stormwater. They differ from a normal drainage channel or swale through the incorporation of specific features that enhance stormwater pollutant removal effectiveness. Vegetated infiltration swales are designed with limited longitudinal slopes to force the flow to be slow and shallow, thus allowing for particulates to settle and limiting the effects of erosion. Berms and/or check dams installed perpendicular to the flow path promote settling and infiltration. The bed of the swale consists of a permeable

soil layer, above a fine gravel layer (that represents the filtration layer) and a coarse gravel layer in which is inserted a perforated PVC pipe.
Vegetated infiltration swales are mainly used in moderate to large lot residential developments, small impervious areas (parking lots and rooftops), and along roads and highways.

*Bioretention area, infiltration trench and vegetated infiltration swales*

**Green Roofs**

Vegetated roofs are roofs that are entirely or partially covered with vegetation and soils. A typical vegetated roof has been found to retain 50 to 65 percent of annual rainfall and reduce peak flows for large rain events by approximately 50 percent. Vegetated roofs fall under two categories: intensive or extensive. Intensive roofs, or rooftop gardens, are heavier, support larger vegetation and can usually be designed for use by people. Extensive vegetated roofs are lightweight, uninhabitable, and use smaller plants. Vegetated roofs can be installed on most types of commercial, multifamily, and industrial structures, as well as on single-family homes, garages, and sheds.
Benefits

- Provides insulation and can lower cooling costs for the building.
- Extends the life of the roof – a green roof can last twice as long as a conventional roof, saving replacement costs and materials.
- Provides noise reduction; lowers the temperature of harvested (or drained) rainwater
- Creates habitat and increases biodiversity, provides aesthetic and recreational amenities.

*Extensive and intensive green roofs*

**Grey water reuse**

Any water that has been used in the household, excluding faecal water from toilets (black water), is called greywater. Shower, sink, laundry, and dishwashing effluents represent up to 70 % -80% of residential and touristic wastewater and as it is relatively clean, it is easier to treat. As drinking water is constantly used, domestic greywater is available in a constant quality and quantity. This is an important advantage for the reuse of greywater for toilet flushing, indoor and outdoor irrigation of plants and cleaning purposes. Major benefits of greywater reuse are the reduction of need for fresh water supply and sewage treatment. Especially in areas with low precipitation rates and water supply deficiencies, reuse for landscaping also has a benefit in reducing demands on high quality water supply.

Grey water are collected by a separate sewer, pre-treated by simple static degreaser, piped into a treatment system to reach the reuse limits and then stocked in a reservoir from which come out depurated water that can be inserted again into house pipes. Constructed wetland and compact precast plant (most of them based on SBR technology, but in some case also simplified MBR (membrane bio reactor) and MBBR (mobile bed biological reactor) are the most diffused as treatment tools.

**Constructed Wetland**

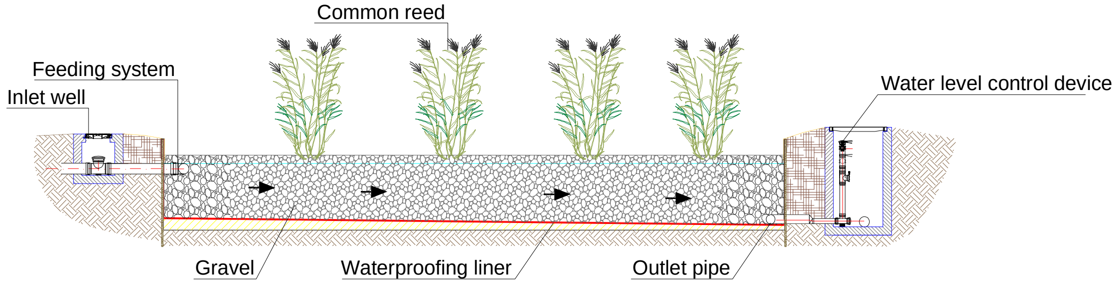
Constructed Wetland are nowadays one of the most worldwide diffused technology for the wastewater treatment; their functioning principles are based on the biological, physical and chemical processes that occur in natural wetland, even if the CWs (especially subsurface types) are engineered systems studied and monitored since the end of '70.

The most diffused are the submerged filters (horizontal and vertical flow type) where the wastewater is filtered by a medium (composed by gravel and/or sand) planted with aquatic macrophyte plants (generally Phragmites Australis or Typha latifolia); these systems require less area than free water systems (more similar to natural wetland) and permit both secondary and tertiary treatment of wastewater (e.g. greywater or blackwater). Because the water is not exposed during the treatment process, the risk associated with human exposure to pathogenic organism is minimized. Generally they require a primary treatment for coarse solids (a manual or automatic grid) and suspended solids removal (a septic tank or imhoff tank). The water is treated by a combination of biological and physical processes. The effluent of a well-functioning constructed wetland can be used for irrigation and aquaculture (in these cases a combination of horizontal flow and vertical flow could be suggested for blackwater and mixed water, considering the low capacity of ammonia reduction of HF) or safely been discharged to receiving water bodies. If the design requires expert knowledge, the implementation is very easy because it requires only a basic knowledge of simple hydraulic and civil works (earthmoving, waterproofing, hydraulic connection, small concrete structures); for the littler plants sometimes it is possible also the self-construction. Moreover CWs are relatively inexpensive to build where land is affordable and can be maintained by the local community as no high-tech spare parts, electrical energy or chemicals are required.

***Horizontal Flow Constructed Wetland***

HF constructed wetlands consist of waterproofed beds planted with hydrofite vegetation tipical of swamps and marshes (generally common reed - Phragmites Australis - is the most used, but to improve aesthetic amenity we could use together also other ornamental essence as Iris pseudacorus) and filled with gravel. The wastewater is fed by a simple inlet device and flows slowly in and around the root and the rhizomes of the plant and through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone. The filling material (coarse gravel, fine gravel and coarse sand) has to offer an appropriate hydraulic conductivity but also a large surface for the biofilm growing. Because the water is not exposed during the treatment process, the risk associated with human exposure to pathogenic organism is minimized. Properly designed HF beds do not provide suitable habitat for mosquitoes or other vector organism and permit public access in wetland area.

HF beds are typically comprised of inlet feeding system, a synthetic liner, filter media, emergent vegetation, berms, and outlet piping with water level control.




***HF wetland schematic longitudinal section***

Advantages/Benefits

- High treatment efficiency;
- Excellent environmental integration;
- Low investment cost and low maintenance requirements;
- No Energy consumption;
- The final effluent can be reused;

• High tolerance to seasonal and daily variation of fluxes and dry periods.

Disadvantages/Limitations

• Land requirement;
• High evapotranspiration at high temperatures
• Constrains on geometry (rectangular, ratio between Lenght and Width)

Operation and maintenance

• Management of primary sludge (periodic emptying of primary treatment)
• Annual mowing of emerging macrophytes.

The performance of HF systems are influenced by the wastewater temperature and the hydraulic retention time (HRT): HRT must be minimal 1 day for greywater (3 days for black water) to permit removal performances of organic matter over 60-70%. High temperatures positively influence the natural purification processes.

| | |
|---|---|
| $BOD_5$ | 85-95% |
| Suspended Solids | 70-95% |
| Total Nitrogen | 55-75% |
| Ammoniacal Nitrogen | 50-70% |
| Phosphorus | 50-90% |
| Pathogen micro-organisms | 97-99,999% |

*Typical removal of a well designed HF system*

The horizontal flow system is well suitable to treat greywater that contain low content of ammonia and bacteria compared to mixed wastewater and a fast biodegradable organic content; usually 2-3 days of HRT are enough to ensure a safe reuse of greywater.

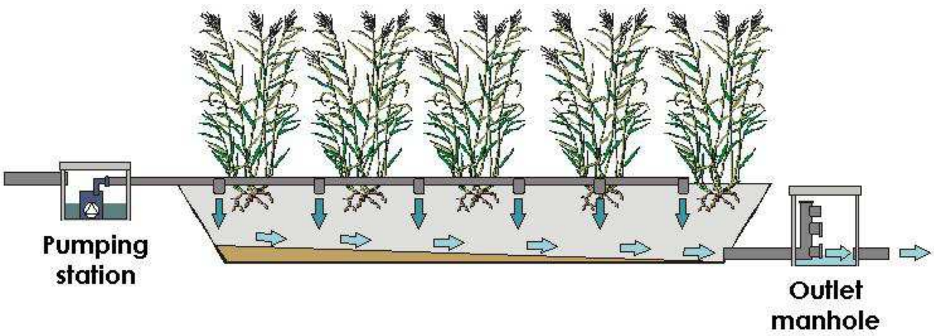
*HF system fro greywater reuse in Preganziol (TV) for 240 a.e.*

***Vertical Flow Constructed Wetland***

In the vertical flow systems (VF) the wastewater is applied through a distribution system on the whole surface area and passes the filter in a more or less vertical path. The pre-treated wastewater is dosed on the bed in large batches (intermittent feeding), thus flooding the surface. During the time between the feedings the pores within the filter media can fill up with air which is trapped by the next dose of liquid. Thus oxygen requiring nitrifying bacteria are favored and full nitrification can be achieved, but only a small part of the formed nitrate is denitrified under aerobic conditions. The treated water is collected in a bottom drainage system to be discharged.

The loading of Vfs normally happens intermittently by pumps, or by gravity using special self-priming siphon devices if there is enough difference of level between the primary treatment and the wetland basin.

This kind of CW is particularly efficient in nitrification, carbon and suspended solids removal. Due to its prevalently aerobic conditions denitrification is poor.




Advantages/Benefits
- High treatment efficiency;
- Excellent environmental integration;
- Low investment cost and low maintenance requirements;
- Low Energy consumption;
- The final effluent can be reused
- High tolerance to seasonal and daily variation of fluxes and dry periods.

Disadvantages/Limitations
- Land requirement (generally a little bit less than HF);
- Constrains on geometry (to permit uniform distribution on the surface)

Operation and maintenance
- Management of primary sludge
- Annual mowing of emerging macrophytes;
- Periodic inspection of the feeding system (usually centrifugal submerged pumps).

The performance of VF systems are influenced by the Hydraulic Loading Rate (m3/m2 per day) and the Organic Loading Rate (grCOD/m2 per day). The typical removal efficiency are listed below:

| | |
|---|---|
| $BOD_5$ | 85-95% |
| Suspended Solids | 80-95% |
| Total Nitrogen | 55-75% |
| Ammonium Nitrogen | 80-90% |
| Phosphorus | 50-90% |
| Pathogen micro-organisms | 2-3 log |

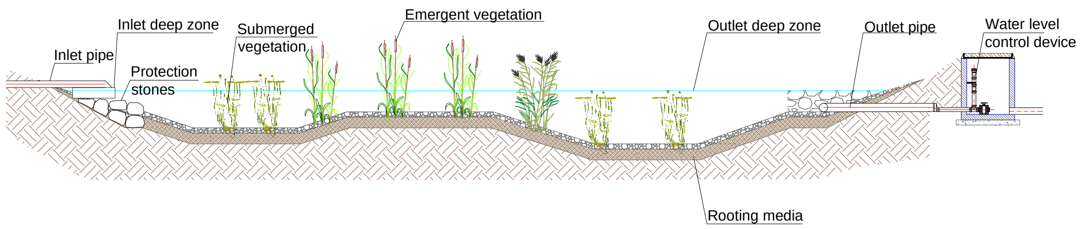
***Free Water System (FWS)***

Generally surface flow wetlands are densely vegetated basins that contains open water, floating vegetation and emergent plants. They need of soil or another suitable medium to support the emergent vegetation. When the FW systems are applied for the control of diffusion pollution, they don't need of waterproofing with plastic liner, due to the low risk of groundwater contamination.

The main components of a FW wetland are:

- An inlet distribution system, followed by an inlet deep zone to allow the removal of heavier sediments;
- Shallow marsh areas with varying depths (0,4 - 0,6 m) with wetlands vegetation;
- An outlet deep zone to clarify the final effluent;
- An outlet device to control the water level.

The most common application of these systems is the tertiary treatment due to their power of denitrification and pathogens removal (due to the high exposure of the wastewater to the UV component of the sunlight). FW systems are also largely used to control diffuse pollutions: these systems are one of better choice for the treatment of agricultural, urban and industrial stormwater, because of their ability to deal with intermittent flows and low concentrations




Advantages/Benefits

• Environmental restoration;
• Provides aesthetic amenity and increases biodiversity;

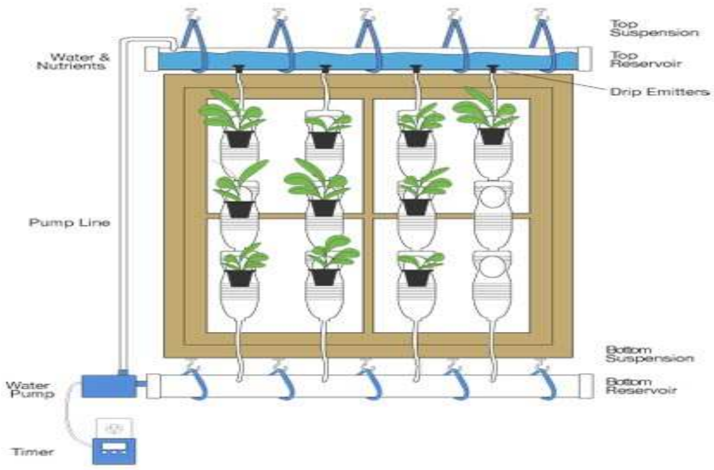
• Buffer effect when used as tertiary treatment;
• No energy consumption.

Disadvantages/Limitations
• High land requirements.
• Risk of mosquitoes diffusion.
• High evapotranspiration rates
• not indicated for secondary treatment (large area and bad odor diffusion)

Operation and maintenance
• Examine the functioning of the system;
• Annually mow emergent vegetations.

***Vertical gardens***

The Vertical Garden is a stackable planter made for indoor and outdoor use. The vertical garden or plant wall, green wall, bio wall is a light framed, mostly self –supporting plant community where the necessary water, light and liquid plant food are provided by a highly automatized system. The system is based on the principles of hydroponics that is the plants are rooted in a porous material soaked in fertilizer instead of soil. In particular cases, adapting its construction to improve the filtration capacity, a vertical garden can be used also as greywater treatment, permitting to reuse the treated water.




The design of vertical garden depends on the available material, space and local preferences as well as on the creativity and imagination of the users. There are very simple designs like tray models similar to nursery flats, where rectangular, plastic trays are divided into planting cells — all slanted at a 30-degree angle, with bottom holes that promote drainage and aeration. Each tray comes with a bracket for mounting. Complicated structures like green wall can be also there where the structure itself is a 10 mm-thick humidity-proof plastic panel fitted on a stainless metal frame, which is covered in a special, rot-free, absorbent synthetic felt in layers. This felt serves as pockets for

planting. The entire width of the structure is 4-20 cm, with the larger for greywater treatments. The supporting frame includes a water-tank and an automatic drip irrigation system. A properly adapted green wall can receive greywater instead of normal water, ensuring a good level of treatment; greywater have to be pre-treated (degreaser and a pre-filter are suggested to avoid obstruction of the drip irrigation system and of the vertical filters. There are very few applications in the world with treatment purpose; even these experience are successful and interesting, currently it is difficult to list precise construction principles: generally they use different panel types and various filling material (Leca and other lightweight granular material seem the most adaptable). The choice of plants applied is a technical criterion of utmost importance because determines the texture, color-combination, shape variety and life span of the wall and in case of treatment also the removal efficiency The loading often happens on two panels in series. A pilot system recently developed in Germany (Rousseau & Baumer, 2013), with a hydraulic loading rate of 35 l per m2 of vertical wall (2 m2/p.e.), the unit shows removal of 96% for COD, 91% for N, 67% of P, 97% of foam, whereas the disinfection is limited to 2 log. The same authors have estimated a cost of a 4 p.e. greywater treatment by green wall in 2600 € (650 €/p.e.) including disinfection (excluding labor).
A relevant case is constituted by the 2500 m2 vertical garden at the Tabacalera Space in Tarragona (Spain): completed in December 2011, the green wall is made by Babylon type modular pieces 50 x 100 cm and 14 cm thick substrate and it constitutes in this case the tertiary treatment after an horizontal flow system. The process is developed and patented by Vivers Ter-Asepma as proven gray water treatment by biofiltration using the architectural element of the vegetable walls, and permits the regeneration of greywater from shower and sink for different uses such as irrigation of green areas or supply the toilets.

*Babylon Green wall for greywater treatment*

Advantages

- Local reuse of wastewater from household wastes
- Low energy cost and Minimal area required

- Temperature insulation by growing plants on the walls of houses
- Simple and easy to understand

Disadvantages

- Unpleasant odors may appear during the irrigation with grey water if not well designed
- A certain amount of labor required

***SBR:***

A technological and compact sewage treatment systems that permit to clean the sewage water permitting to discharge the outflow in a water body or to reuse the treated water.
In the Sequencing Batch Reactors (SBR) the process is the same of classic activated sludge plants: oxygen is bubbled through the waste water to reduce pollutants by oxidation processes.
While there are several configurations of SBRs the basic process is similar. The installation consists of at least two identically equipped tanks with a common inlet, which can be switched between them, or of an equalization tank followed by one SBR tank. The functioning is based on a "batch mode", permitting to release the various stages of the treatment process (loading, oxidation, sedimentation, discharge) in a single tank (whereas in a Activated sludge plant, sedimentation and aeration are carried on in different tanks). These sequential phases are controlled by a automatic control panel; the conditions of mixing and equalization are normally better than a classic activated sludge plant and also the management is a little bit more simple; for this reason this particular process is well indicated for small and medium agglomerates and generally where a fluctuation of the inlet hydraulic and organic loads are expected. However the system requires skilled labor for its management and maintenance.
Simplified compact SBR systems are also commercialized for the greywater treatment and reuse.

Advantages/Benefits

- High treatment efficiency;
- low space required;
- affordable investment cost
- The final effluent can be reused with an additional disinfection unit
- High tolerance to seasonal and daily variation of fluxes and dry periods.

Disadvantages/Limitations

- high energy consumption;
- high surplus sludge production
- skilled labor maintenance requie
- higher maintenance cost compared to natural and other low-tech treatment

Operation and maintenance

- Management of surplus sludge
- weekly analytical control of sludge and wastewater characteristics
- Periodic inspection and maintenance of E&M equipment

| Tool | Applicability in the region | Diffusion in the region | Remarks/comments |
|---|---|---|---|
| ***CASE 1 BARDO*** | | | |
| Water saving devices | ++ | ++ | |
| Vertical garden for greywater | ++ | - | |
| SBR/MBR for greywater | + | - | |
| SUDS (infiltration trenches, rain garden) | ++ | - | |
| Green roofs | ++ | - | |
| ***CASE 2 CHORFECH*** | | | |
| Water saving devices | ++ | - | |
| CW for wastewater | ++ | + | |
| Rainwater harvesting | ++ | - | |
| Treated wastewater infiltration | - | - | |
| Treated wastewater reuse for irrigation | + | - | |
| SUDS (infiltration trenches, rain garden) | ++ | - | |
| ***CASE 3 ZEM*** | | | |
| Water saving devices | ++ | - | |
| Centralized approach (connection to existing WWTP) | ++ | - | |
| Constructed Wetland | ++ | - | |
| SUDS (infiltration trenches, rain garden) | ++ | - | |

++ applicable without constraints / very diffused
+ applicable with constraints / used in some cases
- not applicable / not used

## 3 Elaboration of alternative options

**BARDO CENTER**

**Alternative 0**

Alternative zero means "no intervention" and in this case the situation about sanitation and water management remains acceptable; Bardo is a quarter in the centre of Tunis and both the water supply than the wastewater and stormwater collection are managed by the public authorities.

Nevertheless, it has to be noticed that in this neighborhood, well representative of an urban context, the good life conditions and the presence of public services have leaded to an increase in the water consumption and therefore any action to favor the water saving is suggested. As showed in the table below, we have tried to imagine several alternatives focused on water saving and reuse, starting from the application of water saving devices until the reuse of greywater and rainwater, even if these kind of interventions are often much expensive and difficult to apply in existing buildings and agglomerations in comparison to the new constructions.

| | **ALT 0** (all in the sewer) | **ALT 1** SBR in the basement (reuse for gardening) | **ALT 2** MBR in the basement (reuse for gardening) | **ALT 3** vertical treatment by green walls (gardening) | **ALT 4** MBR in the basement (reuse for flushing toilets) |
|---|---|---|---|---|---|
| Water saving devices | NO | Yes | Yes | Yes | Yes |
| Greywater treatment for toilet flushing by MBR | NO | NO | NO | NO | Yes |
| Greywater reuse for gardening by SBR | NO | Yes | NO | NO | NO |
| Greywater reuse for gardening by MBR | NO | NO | Yes | NO | NO |
| Greywater vertical treatment by green walls (gardening) | NO | NO | NO | YES | NO |
| Rain trenches for street drainage | NO | Yes | Yes | Yes | Yes |
| Greenroofs | NO | Yes | Yes | Yes | Yes |

The Bardo Center is constituted by 10 building 5 floors each, with at the ground level a commercial area with small stores, cafés and a supermarket; the apartment are occupied by household or by several offices (doctor, lawyer, etc). Water consumption according to CERTE survey is summarized in the following table:

| | n°unit | procapita consumption (m3/year x unit) | consumption (m3/day) | greywater (m3/day) | WC flushing (m3/day) |
|---|---|---|---|---|---|
| apartments (3 persons) | 80 | 189 | 41 | 29 | 12 |
| Stores | 26 | 227 | 5,9 | 4,1 | 1,8 |
| Offices | 46 | 68,5 | 3,2 | 2,2 | 0,9 |
| | | | 50 | 35 | 15 |

In a preliminary way, we have divided the consumption for each building as an average value (apartment number versus offices number is different from one building to another), as in the table below.

| x building | consumption (m3/day) | greywater (m3/day) | WC flushing (m3/day) |
|---|---|---|---|
| apartments (3.5 person per apartments) | 4,1 | 2,9 | 1,2 |
| Stores | 0,6 | 0,4 | 0,2 |
| Offices | 0,3 | 0,2 | 0,1 |

The greywater production could cover the consumption of the WCs and give further availability of water for other type of reuse, i.e. irrigation

**Alternative 1**

Alternative 1 provides:

- the segregation of greywater and their treatment in SBR system to be realized underground at ground level for the urban irrigation reuse and other external reuse (i.e. road cleaning);
- The realization of some demonstrative green roofs with the purpose of rainwater harvesting and stormwater peak reduction
- The application of water saving device to all the household in the Bardo Centre
- Demonstrative SUDS in some street around the Bardo Centre

About the implementation of a SBR system for greywater reuse, in our preliminary evaluation we have considered to install a system each 2 building, principally to contain the installation costs.

Considering that the implementation of WSD could guarantee a reduction in the consumption of about 30%, we obtain the consumptions represented in the following table.

| x couple of building | consumption (m3/day) | greywater (m3/day) | WC flushing (m3/day) |
|---|---|---|---|
| apartments (3.5 person per apartments) | 5,8 | 4,1 | 1,7 |
| Stores | 0,8 | 0,6 | 0,2 |
| Offices | 0,4 | 0,3 | 0,1 |
| Total | 7,1 | 4,9 | 2,1 |

In the table below, several models of SBR (differentiating for maximum volume per day treated) are showed; in our case we should select a model to treat 6 m3/day (SBR 30).

SBR MODELS 10 UP TO 100 P.E.

| | SBR MODEL | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Operating Specifications | Volumen total (m3) | 5,4 | 10,8 | 18,6 | 22,3 | 27,8 | 33,5 | 37,8 | 43,1 | 48,9 | 54,1 |
| | Daily flow rate (m3/d) | 2,0 | 4,0 | 6,0 | 8,0 | 10,0 | 12,0 | 14,0 | 16,0 | 18,0 | 20,0 |
| | Peak flow Rate (m3/h) | 0,2 | 0,4 | 0,6 | 0,8 | 1,0 | 1,2 | 1,4 | 1,6 | 1,8 | 2,0 |
| | People equivalent | 10,0 | 20,0 | 30,0 | 40,0 | 50,0 | 60,0 | 70,0 | 80,0 | 90,0 | 100,0 |
| | BOD5 concentration (ppm) | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 |
| | SS concentration (ppm) | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 |
| | BOD5/Day loading (Kg) | 0,6 | 1,2 | 1,8 | 2,4 | 3,0 | 3,6 | 4,2 | 4,8 | 5,4 | 6,0 |
| | SS/Day loading (Kg) | 0,8 | 1,5 | 2,3 | 3,0 | 3,8 | 4,5 | 5,3 | 6,0 | 6,8 | 7,5 |
| SBR Tank | Diameter (mm) | 1,70 | 1,70 | 2,12 | 2,12 | 2,12 | 2,45 | 2,45 | 2,45 | 2,45 | 2,45 |
| | Length (mm) | 2,61 | 4,99 | 5,71 | 6,71 | 8,30 | 7,49 | 8,41 | 9,54 | 10,78 | 11,87 |
| Aeration system | Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Electrical specs. kW | 0,1 | 0,37 | 0,37 | 0,4 | 0,75 | 0,75 | 0,75 | 1 | 3 | 3 |
| | Air filter | Included | Included | Included | Included | Included | Included | Included | Included | Included | Included |
| | Microbubble air difussers | Assembled | Assembled | Assembled | Assembled | Assembled | Assembled | Assembled | Assembled | Assembled | Assembled |
| SBR automatic feed system | Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | kW | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,75 | 0,75 | 0,75 | 0,75 | 0,75 |
| Sludge recirculation pump | Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | kW | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,75 | 0,75 | 0,75 | 0,75 | 0,75 |
| Treated water discharge pump | Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | kW | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,75 | 0,75 | 0,75 | 0,75 | 0,75 |
| Homogenization system | Quantity | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| | kW | 0 | 0 | 0 | 0 | 0 | 0 | 0,6 | 0,6 | 0,6 | 0,6 |
| Control panel | Electrical Characteristics | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 400/3/50 | 400/3/50 | 400/3/50 |
| TOTALS | Total system price (€) | 7.600 € | 8.600 € | 10.100 € | 11.350 € | 12.950 € | 15.250 € | 18.800 € | 19.650 € | 21.100 € | 23.200 € |
| | Total (kw) | 1,75 | 2,02 | 2,02 | 2,05 | 2,4 | 3,0 | 3,6 | 3,85 | 5,85 | 5,85 |

The cost of the system considered in our estimation includes the installation, the pump to load the dual irrigation system and a storage of the treated water.

| | |
|---|---|
| Hp 1 | |
| SBR (including transport) | € 12.000,00 |
| optional devices for remote control | € 800,00 |
| civil engineering works | € 1.000,00 |
| installation costs | € 2.500,00 |
| greywater segregation | € 1.200,00 |
| pump for reuse | € 2.000,00 |
| storage tank 60 $m^3$ | € 10.500,00 |
| Total | € 30.000,00 |
| **Total per 10 building (excluding VAT)** | **€ 150.000,00** |

The yearly operational cost are substantially due to energy consumption and periodic ordinary maintenance, generally conducted by skilled workers; the sludge can be periodically discharged in the sewer.

| | |
|---|---|
| power consumption | € 1.000,00 |
| chemicals | € 500,00 |
| periodic maintenance | € 2.000,00 |
| extraordinary maintenance | € 1.500,00 |
| Total | € 5.000,00 |
| **Total per 10 building** | **€ 25.000,00** |

The quantity of recovered water is about 25 m3/day (about 9000 m3/year), that could be used for the irrigation of more than 6000 m2 of grass area. Considering a payback time of 20 year, it means that the cost per cubic meter of treated water is 3.5 €/$m^3$.

**Alternative 2**

Alternative 2 provides:

- the segregation of greywater and their treatment in MBR system to be realized underground at ground level, for the urban irrigation reuse and other external reuse (i.e. road cleaning);
- the realization of some demonstrative green roofs with the purpose of rainwater harvesting and stormwater peak reduction
- the application of water saving device to all the household in the Bardo Centre
- demonstrative SUDS in some street around the Bardo Centre

In the table below, several models of MBR (differentiating for maximum volume per day treated) are showed; in our case we should select a model to treat 6 m3/day (MBR 30).

| | MBR MODEL | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| System operating Specifications | Total Volume (m3) | 1,5 | 2,5 | 3,5 | 4,5 | 5,5 | 6,5 | 7,5 | 8,5 | 9,5 | 11,1 |
| | Daily flow rate (m3/d) | 2,0 | 4,0 | 6,0 | 8,0 | 10,0 | 12,0 | 14,0 | 16,0 | 18,0 | 20,0 |
| | Peak Flow Rate (m3/h) | 0,2 | 0,4 | 0,6 | 0,8 | 1,0 | 1,2 | 1,4 | 1,6 | 1,8 | 2,0 |
| | PE | 10,0 | 20,0 | 30,0 | 40,0 | 50,0 | 60,0 | 70,0 | 80,0 | 90,0 | 100,0 |
| | BOD5 Concentration (ppm) | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 | 300,0 |
| | SS Concentration (ppm) | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 | 375,0 |
| | BOD5/Day Loading (Kg) | 0,6 | 1,2 | 1,8 | 2,4 | 3,0 | 3,6 | 4,2 | 4,8 | 5,4 | 6,0 |
| | SS/Day Loading (Kg) | 0,8 | 1,5 | 2,3 | 3,0 | 3,8 | 4,5 | 5,3 | 6,0 | 6,8 | 7,5 |
| Reactor | Standard Configuration | Vertical | Vertical | Vertical | Vertical | Vertical | Vertical | Vertical | Vertical | Vertical | Vertical |
| | H (mm) | 1600,00 | 2100,00 | 1600,00 | 2000,00 | 1700,00 | 1700,00 | 1700,00 | 2000,00 | 2000,00 | 2000,00 |
| | L (mm) | 1200,00 | 1200,00 | 1200,00 | 1500,00 | 2900,00 | 3200,00 | 3500,00 | 3000,00 | 3200,00 | 4000,00 |
| | W (mm) | 800,00 | 1000,00 | 800,00 | 1500,00 | 1700,00 | 1700,00 | 1700,00 | 2000,00 | 2000,00 | 2000,00 |
| Membrane module | Quantity | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| | No. of elements | 1 | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 4 |
| | Total membrane surface area (m2) | 3,5 | 7 | 7 | 15 | 15 | 30 | 30 | 30 | 30 | 30 |
| | Filtration Pressure (bar) | 0,25 | 0,25 | 0,25 | 0,25 | 0,25 | 0,25 | 0,25 | 0,25 | 0,25 | 0,25 |
| Aeration system | Quantity | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | kW | 0,1 | 0,1 | 0,1 | 0,75 | 0,75 | 2,2 | 2,2 | 2,2 | 2,2 | 2,2 |
| | Diffussers Prefitted | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Permeate pump | Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | kW | 0,25 | 0,25 | 0,25 | 0,25 | 0,35 | 0,35 | 0,35 | 0,45 | 0,45 | 0,45 |
| Sludge recirculation pump | Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | kW | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 |
| Mbr recirculation pump | Quantity | OPTIONAL | | | | | 1 | 1 | 1 | 1 | 1 |
| | kW | | | | | | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 |
| Homogenization system | Quantity | OPTIONAL | | | | | 1 | 1 | 1 | 1 | 1 |
| | kW | | | | | | 0,6 | 0,6 | 0,6 | 0,6 | 0,6 |
| Sludge monitoring and discharge automatizacion | Quantity | OPTIONAL | | | | | | 1 | 1 | 1 | 1 |
| | Type of Device | | | | | | | SS Sensor 4-20 mA | SS Sensor 4-20 mA | SS Sensor 4-20 mA | SS Sensor 4-20 mA |
| | Control System | | | | | | | | | | |
| Control panel | Electrical Characteristics | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 | 230/1/50 |
| TOTALS | Total system price (€) | 8.300 € | 9.400 € | 10.100 € | 11.150 € | 12.950 € | 16.300 € | 22.150 € | 23.150 € | 23.800 € | 24.800 € |
| | Total kW | 1,00 | 1,00 | 1,00 | 1,55 | 1,65 | 4,25 | 4,25 | 4,35 | 4,8 | 4,8 |

In MBR option, additional tools has to be considered to reach a proper automation and to preserve the membrane during the operational phases, considering that the substitution of this element represents the main maintenance cost in this kind of process.

### 4.3.2 Solids Monitoring and Discharge Automation

The Solids Monitoring and Discharge Automation in only an option up to MBR model 60. For larger systems it is a standard element.

The optimization of processes is a key issue for Bioazul. By automatizing and monitoring sludge discharge it achieves the best performance for the MBR system, in both biological and economical ways

| MBR MODEL | 10 | 20 | 30 | 40 | 50 | 60 |
|---|---|---|---|---|---|---|
| Type of device | SOLITAX | SOLITAX | SOLITAX | SOLITAX | SOLITAX | SOLITAX |
| Control element | SC200 | SC200 | SC200 | SC200 | SC200 | SC200 |
| Units | 1 | 1 | 1 | 1 | 1 | 1 |
| Total price (€) | 4.147,00€ | 4.147,00€ | 4.147,00€ | 4.147,00€ | 4.147,00€ | 4.147,00€ |

### 4.3.3 MBR Recirculation System

The MBR Recirculation System is only an option up to MBR model 50. For larger systems it is a standard element.

The MBR Recirculation System promotes a higher rate of reaction within the MBR system by increasing microbial was-tewater contact time. Bioazul recommends this option for all systems. Installations in places where very high or low temperatures are experienced, this option is strongly recommended to promote process performance.

| MBR MODEL | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|
| Units | 1 | 1 | 1 | 1 | 1 |
| kW | 0,55 | 0,55 | 0,55 | 0,55 | 0,55 |
| Total price (€) | 364,500€ | 364,500€ | 364,500€ | 364,500€ | 364,500€ |

The cost of the system considered in our estimation includes the installation, the pump to load the dual irrigation system and a storage of the treated water. The cost are very similar to the alternative with SBR.

| | |
|---|---|
| Hp 2 | |
| MBR (including transport) | € 16.000,00 |
| optional devices for remote control | € 800,00 |
| civil engineering works | € 1.000,00 |
| installation costs | € 2.500,00 |
| greywater segregation | € 1.200,00 |
| pump for reuse | € 2.000,00 |
| storage tank 60 $m^3$ | € 10.500,00 |
| Total | € 34.000,00 |
| **Total per 10 building (excluding VAT)** | **€ 170.000,00** |

The yearly operational cost are substantially due to energy consumption and periodic ordinary maintenance, generally conducted by skilled workers; the sludge can be periodically discharged in the sewer. The energy consumption is lower than in SBR, considering the presence of the ultrafiltration membrane (the nominal power is 1 KW, against 2 KW for SBR). The frequency of the membrane substitution depends by the yearly loading and the proper maintenance of the system and it is difficult to forecast; considering that we are working on greywater, the frequency of substitution is however lower than in the case of blackwater treatment.

| | |
|---|---|
| power consumption | € 600,00 |
| chemicals | € 500,00 |
| periodic maintenance | € 2.500,00 |
| extraordinary maintenance | € 3.000,00 |
| Total | € 6.600,00 |
| Total per 10 building | € 33.000,00 |

**<u>Alternative 3</u>**

Alternative 3 provides:

- the segregation of greywater and their treatment in vertical garden to be realized on the wall of the buildings , for the urban irrigation reuse and other external reuse (i.e. road cleaning);
- the realization of some demonstrative green roofs with the purpose of rainwater harvesting and stormwater peak reduction
- the application of water saving device to all the household in the Bardo Centre
- demonstrative SUDS in some street around the Bardo Centre

This option of the vertical garden should be verified on the base of the max loads supported by the wall structure.
Cost of the vertical garden depends on design chosen. The required surface to treat approximately 6 $m^3$/day is 120 $m^2$; the cost depends by the type of installation and averagely could be estimated in about 40.000 €.

*Possible solutions for a vertical garden*

| Hp 3 | |
|---|---|
| Vertical garden | € 45.000,00 |
| optional devices for remote control | € 800,00 |
| greywater segregation | € 1.200,00 |
| pump for reuse | € 2.000,00 |
| storage tank | € 10.500,00 |
| Total | € 59.500,00 |
| **Total per 10 building** | **€ 297.500,00** |

| | |
|---|---|
| power consumption | € 100,00 |
| periodic maintenance | € 1.500,00 |
| extraordinary maintenance | € 1.000,00 |
| Total | € 2.600,00 |
| Total per 10 building | € 13.000,00 |

**Alternative 4**

Alternative 4 provides:

- the segregation of greywater and their treatment in MBR system to be realized underground at ground level, for the reuse of the treated water to flush the WC;

- the realization of some demonstrative green roofs with the purpose of rainwater harvesting and stormwater peak reduction
- the application of water saving device to all the household in the Bardo Centre
- demonstrative SUDS in some street around the Bardo Centre

For the reuse in WCs, it is enough to recover 2 $m^3$/day per couple of building. The total reusable volume is 10 $m^3$/day. Considering the higher quality of the reclaimed water, we consider to use in this case MBR systems (model MBR10).

| | |
|---|---|
| Hp 4 | |
| MBR (including transport) | € 13.000,00 |
| optional devices for remote control | € 800,00 |
| civil engineering works | € 1.000,00 |
| installation costs | € 2.000,00 |
| greywater segregation | € 1.200,00 |
| pump for reuse | € 2.000,00 |
| storage tank | € 4.200,00 |
| Total | € 24.200,00 |
| **Total per 10 building** | **€ 121.000,00** |

| | |
|---|---|
| power consumption | € 200,00 |
| chemicals | € 200,00 |
| periodic maintenance | € 2.000,00 |
| extraordinary maintenance | € 2.000,00 |
| Total | € 4.400,00 |
| **Total per 10 building** | **€ 22.000,00** |

**Considerations on green roofs**

The max loading for the Tunisian standards is 120 kg/m2, therefore extensive green roofs seem instead feasible, considering that in this case the increase of load is max 115 kg/m2. Extensive vegetated roofs are lightweight, uninhabitable, and use smaller plants; they however provide benefits in terms of building insulation, reduction of cooling costs, decrease in maintenance costs for the roof, noise reduction.

The effect on rainwater, also in the case of extensive green roofs, is positive in terms of hydraulic peak reduction and in terms of quality: the surplus filtered rainwater could be collected and reused.

Instead is impossible to imagine a constructed wetland system able to treat greywater integrated in the green roof, whereas this solution is feasible on intensive green roofs.

The cost of the installation of an extensive green roof on a flat existent roof should be around 100 €/m$^2$. Generally the 30% of the rainwater drainage by the green roof can be recovered and reused for several use as irrigation, road and pavement washing. The suggested volume for the storage tank should be 5-10 m$^3$/100 m$^2$ of green roof.

*Possible solution for extensive greenroofs*

**Application of SUDS in the nearby traffic roads**

In the nearby area of the Bardo Center there are several spaces that, even if limited, where a natural urban drainage system could be integrated.

These systems can improve the quality of the runoff water and the quantity of infiltration water in the ground; the effect in terms of hydraulic protection and minimization of the rainwater collected to the sewer will be probably very limited. In any case these kind of interventions could have a demonstrative value to improve the applications of these systems in the urban context on a larger scale.

*Possible locations for SUDS*

Rain trenches or rain garden for street drainage can be sized at 0,5-1 m$^2$ each 100 m$^2$ impervious surface, whereas the cost Is approximately 40-50 €/m$^2$.

**Summary of the alternatives**

In the following table a resume of the 5 alternative is shown. The costs are presented only in the cases where there is a variation in the proposed solution and therefore also in the cost of investment and maintenance: to better compare the various hypothesis, the cost per m$^3$ of treated water is shown, estimated considering a payback time of 20 years.

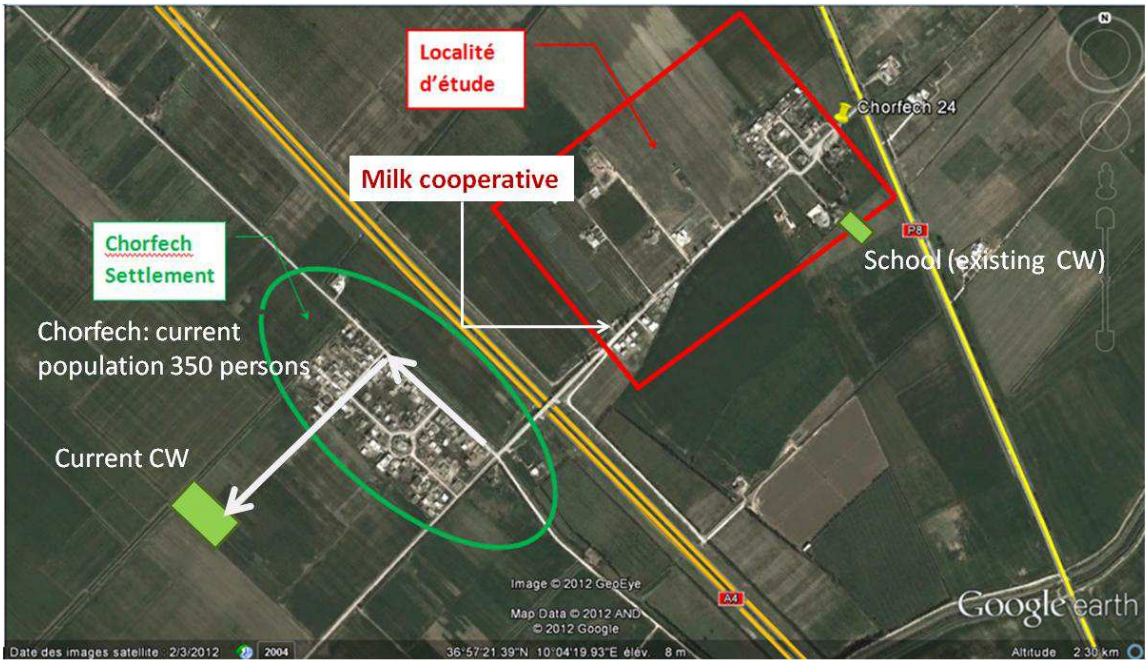
| | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
|---|---|---|---|---|---|
| | (all in the sewer) | SBR in the basement (reuse for gardening) | MBR in the basement (reuse for gardening) | vertical treatment by green walls (gardening) | MBR in the basement (reuse for flushing toilets) |
| Water saving devices | NO | Yes | Yes | Yes | Yes |
| Greywater treatment for toilet flushing by MBR | NO | NO | NO | NO | € 190.000,00 |
| Greywater reuse for gardening by SBR | NO | € 150.000,00 | NO | NO | NO |
| Greywater reuse for gardening by MBR | NO | NO | € 200.000,00 | NO | NO |
| Greywater vertical treatment by green walls (gardening) | NO | NO | NO | € 240.000,00 | NO |
| Rain trenches for street drainage | NO | Yes | Yes | Yes | Yes |
| Raingardens / Greenroofs | NO | Yes | Yes | Yes | Yes |
| Investment cost | | € 150.000,00 | € 170.000,00 | € 297.500,00 | € 121.000,00 |
| Operational yearly costs | | € 25.000,00 | € 33.000,00 | € 15.000,00 | € 22.000,00 |
| Cost per m$^3$ of reused greywater | | € 2,97 | € 3,79 | € 2,55 | € 6,99 |

## CHORFECH

### Alternative 0

Alternative zero means "no intervention" and in this case, if we analyze the wastewater management of the area, it means that the upper part of Chorfech is not collected to any kind of treatment, whereas the south part is connected to a Constructed Wetland system realized in 2009. The plant was designed for two qualities of treated wastewater allowing the discharge in the natural system (drainage system and oueds) and the reuse for irrigation, but the nearby lands are included in the restricted area for wastewater irrigation and the reuse has never been in practice.
The pumping station that permits the arrive of the sewage to the plant was damaged during the Tunisian Revolution in 2011; also the plant reports several damages of minor entity, mainly to the connection pipes. CERTE is signing an agreement with ONAS in order to conduct a diagnosis and mission and an optimization action plan. Currently the south part of Chorfech is without an operating sewage treatment system.

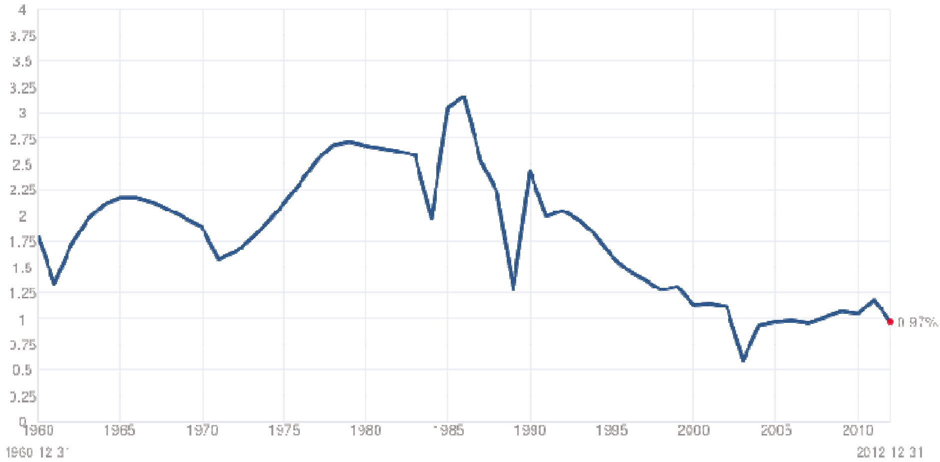
The school is equipped with several sustainable water management devices, such a little constructed wetland for irrigation reuse, urine segregation and rainwater harvesting for toilet flushing. It is considered as pilot action for demonstration and multiplication.



**Alternative 1a**

Alternative 1a provides the realization of a sewer to connect the north part to the Constructed Wetland in the South part, rehabilitating the constructed wetland and the final pumping station.

Firstly we evaluated the quantity and quality of the additional flow to be treated. According to World Bank Data, the 2012 population growth rate was 0.97 and the trend is to decrease.




*Population growth rate in Tunisia (source: WB)*

Currently there are 180 persons in the study area; assuming a 20 year projection and a fixed growth of 0.97%, we obtain 216 persons. The potable water consumption for domestic activities is 129 liter/day per person, according to the CERTE survey (164 l/day the overall consumption, considering also irrigation and animal needs).

There is a cooperative where the milk is processed; the consumption is about 360 $m^3$/trimester.

| **characterization of the north-part sewage** | | |
|---|---|---|
| residents | 180 | |
| residents in 2030 according to official growth rate | 216 | |
| water consumption | 129 | l/person |
| average wastewater flow | 28 | m3/day |
| organic production | 60 | grBOD/day |
| BOD concentration | 465 | mg/l |
| N-NH4 concentration | 78 | mg/l |
| ***industrial activities*** | | |
| milk processing cooperative | 5,5 | m3/day |
| assumed BOD concentration | 1300 | mg/l |
| assumed N-NH4 concentration | 30 | mg/l |
| ***others*** | | |
| school | already treated | |
| police station (estimated number of person) | 5 | |

| | | |
|---|---|---|
| police station wastewater production | 0,5 | m3/day |
| **Total wastewater production** | 34 | m3/day |
| **BOD concentration** | 600 | mg/l |
| **N-NH4 concentration** | 70 | mg/l |

The south-part characterization is showed in the table below; the monitoring consumption during the design phase was lower than 50 l/day, but considering the improvement of the life conditions also in this area (even if the socio-economics conditions are different in this part compared to the north part) we have assumed a pro-capita consumption of 80 l/day.

| **characterization of the south-part sewage** | | |
|---|---|---|
| residents | 350 | |
| current water consumption | 50 | l/person |
| average wastewater flow | 18 | m3/day |
| organic production | 60 | grBOD/day |
| BOD concentration | 1200 | mg/l |
| N-NH4 concentration | 200 | mg/l |
| residents in 2030 according to official growth rate | 420 | |
| assumed water consumption | 80 | l/person |
| **average wastewater flow** | 34 | m3/day |
| **BOD concentration** | 750 | mg/l |
| **N-NH4 concentration** | 125 | mg/l |

These estimates are quite according to the monitoring results of Chorfech CWTP, that indicates high concentrations of pollutants in the inflow, due to the low hydraulic load.

The total inflow in case of connection of the north part is therefore the following.

| | | |
|---|---|---|
| average wastewater flow | 67 | m3/day |
| BOD concentration | 675 | mg/l |
| N-NH4 concentration | 97 | mg/l |

Then we have analyzed the capacity of the plant, based both on the design data than on the monitoring data collected before the damages. The system was designed for a maximum capacity of 500 p.e. and a pro-capita consumption of about 50 l/day; currently there are about 350 residents connected to the sewer and the average flow was about 17 $m^3$/day before the stop of operation.

The treatment system is constituted by an Imhoff tank followed by a multistage constructed wetland with a first horizontal stage (200 $m^2$), a vertical flow second stage (850 $m^2$) and a horizontal flow third stage (750 $m^2$) to be used in case of river discharge (whereas in case of reuse the second stage is enough, considering that in Tunisian standards for irrigation (NT106-003) there are no limitations of fertilizers (nitrogen and phosphorus). For desludging, a sludge drying reed bed (100 $m^2$) is present too.

The table below shows a resume of the monitoring performed in 2009-2010. Note that the system substantially respects the limit for reuse (NT.106.03) even if the COD is a little higher than the permitted value; the inlet concentrations are very high for the low hydraulic consumption (the interval variation of the flow rate ranged between 14.14 and 21.60 $m^3$/day and the average value is 17 $m^3$/day corresponding to 48 L/d per person). Whereas the overall removal is very high (95-97% for COD and 71% for Ntot), it seems that the capacity of the treatment plant was not totally exploited; i.e. nitrification is in the range of 70-80%, but probably a better management of the feeding (the setting of the siphon was quite problematic due to some construction defections) could increase it. The early stop of the plant due to the damages doesn't permit to do further evaluation, but it has to noticed that the plant has operated for little more than one year and it didn't probably reach its best capability.

For river discharge, the bigger constraint seems to be the limit on NH4 (1 mg/l) that is very stringent for any biological treatment; this limit will be probably revised to 2 mg/l.

| | N[a] | Min. | Average | Max. | Standard deviation | Removal (%) Each stage | All system | Standards NT.106.02[(a)] | NT.106.03[(b)] |
|---|---|---|---|---|---|---|---|---|---|
| COD (mg $O_2$/L) | | | | | | | | | |
| Raw wastewater | 5 | 2300 | 3072 | 5040 | 1112 | | | | |
| Imhoff tank | 8 | 2150 | 2876 | 5052 | 941 | 6.4 | | | |
| 1st HF-CW | 8 | 384 | 1647 | 5204 | 1586 | 42.7 | | | |
| VF-CW | 6 | 102 | 234 | 410 | 123 | 85.8 | | 90 | 90[(c)] |
| 2nd HF-CW | 10 | 124 | 167 | 214 | 30 | 28.6 | 94.6 | | |
| BOD (mg $O_2$/L) | | | | | | | | | |
| Raw wastewater | 3 | 1000 | 1620 | 2300 | 652 | | | | |
| Imhoff tank | 4 | 120 | 1350 | 2900 | 1392 | 16.7 | | | |
| 1st HF-CW | 4 | 25 | 197 | 600 | 271 | 85.4 | | | |
| VF-CW | 3 | 20 | 26 | 35 | 8 | 86.8 | | 30 | 30[(c)] |
| 2nd HF-CW | 4 | 40 | 45 | 50 | 6 | (−)73.1[b] | 97.2 | | |
| N total (mg N/L) | | | | | | | | | |
| Raw wastewater | 3 | 50 | 125 | 256 | 113 | | | | |
| Imhoff tank | 5 | 4 | 70 | 264 | 110 | 44.0 | | | |
| 1st HF-CW | 5 | 9 | 65 | 128 | 51 | 7.1 | | $NO_3$ : 50 | No |
| VF-CW | 3 | 28 | 69 | 98 | 37 | (−)6.2[b] | | $NO_2$ : 0.5 | Limitation |
| 2nd HF-CW | 7 | 13 | 36 | 90 | 30 | 47.8 | 71.2 | Org. + $NH_4$: 1 | |
| P-PO4 (mg P/L) | | | | | | | | | |
| Raw wastewater | 5 | 30.23 | 33.35 | 35.12 | 2.15 | | | | |
| Imhoff tank | 5 | 24.60 | 29.51 | 34.09 | 3.40 | 11.51 | | | |
| 1st HF-CW | 5 | 16.50 | 18.28 | 21.80 | 2.07 | 38.08 | | | No |
| VF-CW | 6 | 0.50 | 4.22 | 14.57 | 5.65 | 76.91 | | 0.1 | Limitation |
| 2nd HF-CW | 7 | 0.80 | 5.95 | 11.11 | 4.55 | (−)40.99[b] | 82.2 | | |
| *E. Coli* (log FU/100 mL) | | | | | | Log removal | | | |
| Raw wastewater | 5 | 6.45 | 6.67 | 7.08 | 6.64 | | | | |
| Imhoff tank | 8 | 6.20 | 5.73 | 7.08 | 6.52 | 0.94 | | FC: 3.30/100 mL | |
| 1st HF-CW | 8 | 5.32 | 5.38 | 7.48 | 7.04 | 0.35 | | FS: 3.00/100 mL | |
| VF-CW | 7 | 4 | 4.66 | 5.26 | 4.76 | 0.72 | | N < 1/l[(d)] | N < 1/l[(d)] |
| 2nd HF-CW | 9 | 2.48 | 4.23 | 5.18 | 4.74 | 0.43 | 2.45 | | |

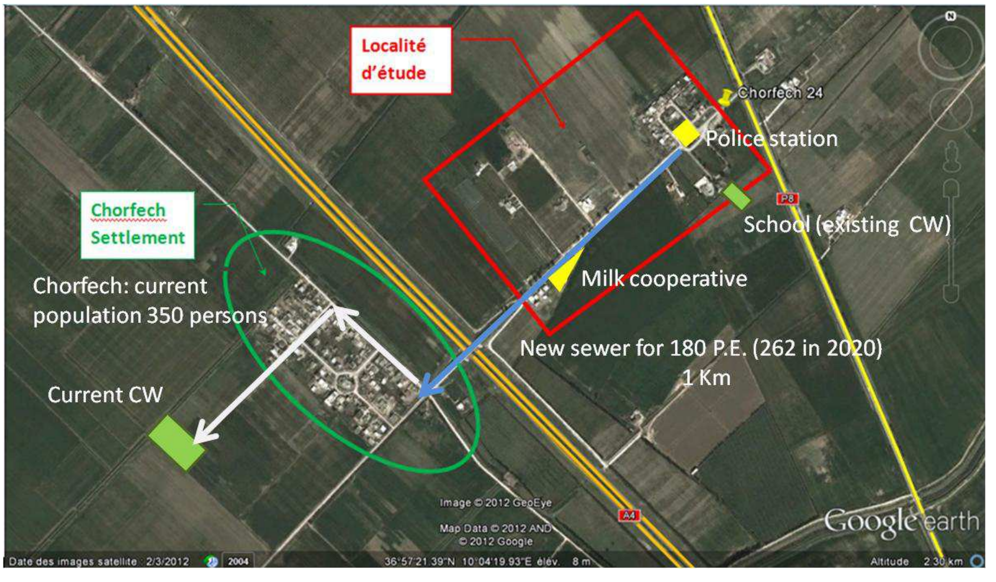
[a]N: number of samples; [b](-): negative removal, i.e., increase; (a) Tunisian standards into receiving waters; (b) Tunisian standards for reuse; (c): derogation can be obtained by authority; (d): 1 Nematode per liter.

*Performances of Chorfech WWTP*

Assuming that the system is capable to respect the limits for reuse and for the discharge in superficial bodies in the current condition, we have estimated using the mathematic models recognized by scientific literature for process calculation of constructed wetland.
With the total inflow of 67 $m^3$/day the system with the current configuration can't respect the limits for river discharge because the organic removal in the first stage is not enough to exploit the capacity of nitrification proper of Vertical flow systems; probably it will respect reuse limits, but the organic loading rate of the first stage is too high and the bed could clog rapidly and the Vf second stage could be consequently overloaded and reduce its performance. Considering that the system requires a rehabilitation due to the suffered damages, it could be possible to intervene on the hydraulic connection and change the overall configuration in this way:

- Pre-treatments: add of a sand removal pre-treatment;
- Imhoff tank: add another Imhoff tank in parallel to manage better the higher flows)
- 1st stage Horizontal flow 950 $m^2$ (connecting the current third stage directly after the Imhoff tank by gravity);
- 2nd stage Vertical Flow 850 $m^2$: add a pumping station to feed the system with the ouflow of the current 3rd stage, increasing the regulation capacity of the system and the oxygen transfer rate;
- Transformation of the current HF 1st stage in a second sludge drying reed bed to improve the capacity of desludging.

The cost of these interventions could be estimated in about **40.000,00 €**, including the required repairs.
The sewer length to connect the north part to the existing sewer is approximately 1 Km; the cost for sewer connection could be estimated in 90 €/m, therefore the total cost is about **90.000,00 €.**



**Alternative 1b**

Alternative 1b provides:

- the realization of a sewer to connect the north part to the Constructed Wetland in the South part, rehabilitating the constructed wetland and the final pumping station;
- The application of water saving device to all the household.

Assuming a reduction of 30% on the north part, and 20% on the south part applying simple water saving devices as flow restrictors and dual flush toilet 3/6 liter, the total sewage inflow could be reduced to 50 $m^3$/day. This have a positive influence on the overall performance of the constructed wetland system and on the sedimentation processes in the Imhoff tank (probably in the first 5-10 years of functioning, the current Imhoff tank could be sufficient to ensure an adequate sedimentation. Also the power costs for pumping will be reduced, even if the power consumption is already limited.

The cost of WSD for all the households could be about 8.000 €, considering to replace also the WC flushing system with a dual new one.

**Alternative 2**

Alternative 2 provides:

- the realization of a sewer to connect the north part to a new Constructed Wetland, allocated near to areas where reuse is permitted;
- The application of water saving device to all the household;
- Rainwater harvesting for all the household in the north-part;
- Reuse of Treated Wastewater for land irrigation and for soil infiltration

Assuming a reduction of 30% due to the presence of the WSD, the wastewater can be characterized as in the following table.

| **characterization of the north-part sewage** | | |
|---|---|---|
| residents | 180 | |
| residents in 2030 according to official growth rate | 216 | |
| water consumption | 90,3 | l/person |
| average wastewater flow | 20 | m3/day |
| organic production | 60 | grBOD/day |
| BOD concentration | 664 | mg/l |
| N-NH4 concentration | 111 | mg/l |
| ***industrial activities*** | | |
| milk processing cooperative | 3,85 | m3/day |
| assumed BOD concentration | 1300 | mg/l |
| assumed N-NH4 concentration | 30 | mg/l |
| ***others*** | | |
| school | already treated | |

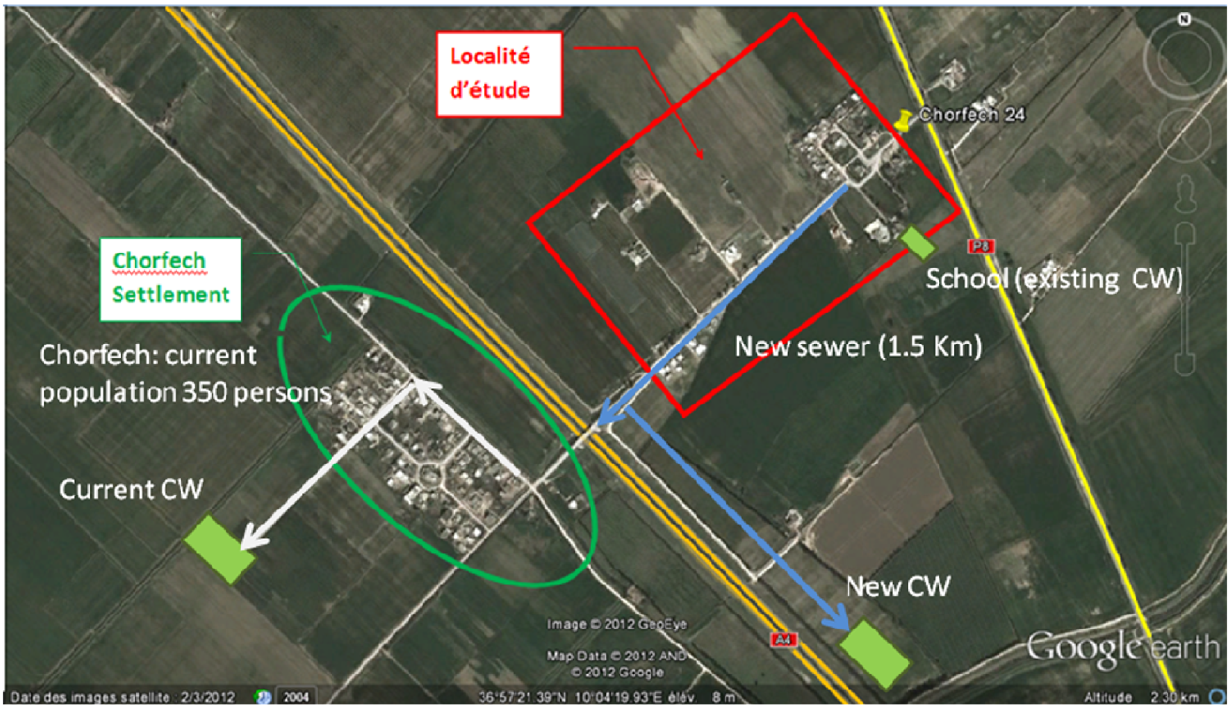
| | | |
|---|---|---|
| police station (number of estimated person) | 5 | |
| police station wastewater production | 0,5 | m3/day |
| **Total wastewater production** | 24 | m3/day |
| **BOD concentration** | 761 | mg/l |
| **N-NH4 concentration** | 97 | mg/l |

Considering the objective of the reuse, the limit to be observed is limited to organics, suspended solids and bacteria. However especially in the case of infiltration of the treated wastewater, a good nitrification and a good removal of N is suggested.

The treatment scheme could be the following:

- Manual grid
- Imhoff tank
- 1st stage Horizontal flow 250 $m^2$
- 2nd stage Vertical Flow 200 $m^2$
- Emergency disinfection and storage for land irrigation reuse

With this configuration the gross area required for the realization is about 800 $m^2$; the system can guarantee an outlet with BOD < 20 mg/l, COD < 90 mg/l, N-NH4 < 15 mg/l, N-NO3 < 30 mg/l.




The cost of the system can be estimated starting from the costs of the Chorfech CW plant.

| | |
|---|---|
| Sewer connection | € 86.000,00 |
| manual grid | € 2.000,00 |
| imhoff tank 20 m3 | € 6.000,00 |
| CW horizontal flow | € 12.500,00 |
| CW vertical flow | € 16.000,00 |
| pipe connections and special fittings | € 3.000,00 |
| E&M works | € 4.000,00 |
| Emergency disinfection | € 3.000,00 |
| ancillary work (fencing, maintenance roads) | € 5.000,00 |
| Storage tank | € 10.000,00 |
| | **€ 147.500,00** |

Rainwater harvesting is provided for all the buildings; the total roof surface is 2500 $m^2$ and considering to install a 5 $m^3$ tank each 100 $m^2$ roof, the total cost could be around 50.000,00 €. Rainwater will be reuse for irrigation, limiting the overall potable consumption that amounts to 164 l/day per person.

Roadside infiltration trench are also provided on the main roads of the village to limit flooding events and regulate better the stormwater drainage in a natural way; the sizing of this system could be 0,5-1 $m^2$ each 100 $m^2$ of impervious surface.

**Alternative 3**

Alternative 3 provides:

- the realization of two separate sewer: one to connect the upper part to a new Constructed Wetland, the second to connect the lower part to another new constructed wetland (3.a) or alternatively to the old Chorfech CW plant (3.b).
- The application of water saving device to all the household;
- Rainwater harvesting for all the household in the north-part;
- Reuse of Treated Wastewater for land irrigation

Assuming a reduction of 30% due to the presence of the WSD, the wastewater of the upper part and the lower part can be characterized as in the following table.

| **characterization of the lower part sewage** | | |
|---|---|---|
| residents | 60 | |
| residents in 2030 according to official growth rate | 75 | |
| water consumption | 90,3 | l/person |
| average wastewater flow | 7 | m3/day |
| organic production | 60 | grBOD/day |
| BOD concentration | 664 | mg/l |
| N-NH4 concentration | 111 | mg/l |
| ***industrial activities*** | | |
| milk processing cooperative | 3,85 | m3/day |
| assumed BOD concentration | 1300 | mg/l |

| | | |
|---|---|---|
| assumed N-NH4 concentration | 30 | mg/l |
| **Total wastewater production** | 11 | m3/day |
| **BOD concentration** | 895 | mg/l |
| **N-NH4 concentration** | 81 | mg/l |

| **characterization of the upper part sewage** | | |
|---|---|---|
| residents | 120 | |
| residents in 2030 according to official growth rate | 150 | |
| water consumption | 90,3 | l/person |
| average wastewater flow | 14 | m3/day |
| organic production | 60 | grBOD/day |
| BOD concentration | 664 | mg/l |
| N-NH4 concentration | 111 | mg/l |
| ***others*** | | |
| school | already treated | |
| police station (number of person) | 5 | |
| police station wastewater production | 0,5 | m3/day |
| **Total wastewater production** | 14 | m3/day |
| **BOD concentration** | 655 | mg/l |
| **N-NH4 concentration** | 110 | mg/l |

Considering the objective of the reuse, the limit to be observed is limited to organics, suspended solids and bacteria. However especially in the case of infiltration of the treated wastewater, a good nitrification and a good removal of N is suggested.

The treatment scheme could be the following:
CW n°1 lower part

- Manual grid
- Imhoff tank
- Horizontal flow 250 $m^2$ ,considering the presence of the milk industry and a low number or inhabitants, the main goal is to reduce the organic load in the simplest way; horizontal flow systems are very effective in dairy and milk industries wastewater and they are very simple to realize and to conduct because there aren't any pumping system.
- Emergency disinfection and storage for land irrigation reuse

CW n°2

- Manual grid
- Imhoff tank
- $1^{st}$ stage Horizontal flow 130 $m^2$
- $2^{nd}$ stage Vertical Flow 150 $m^2$
- Emergency disinfection and storage for land irrigation reuse

With this configuration the gross area required for the realization is about 800 $m^2$; the system can guarantee an outlet with BOD < 20 mg/l, COD < 90 mg/l, N-NH4 < 15 mg/l, N-NO3 < 30 mg/l.

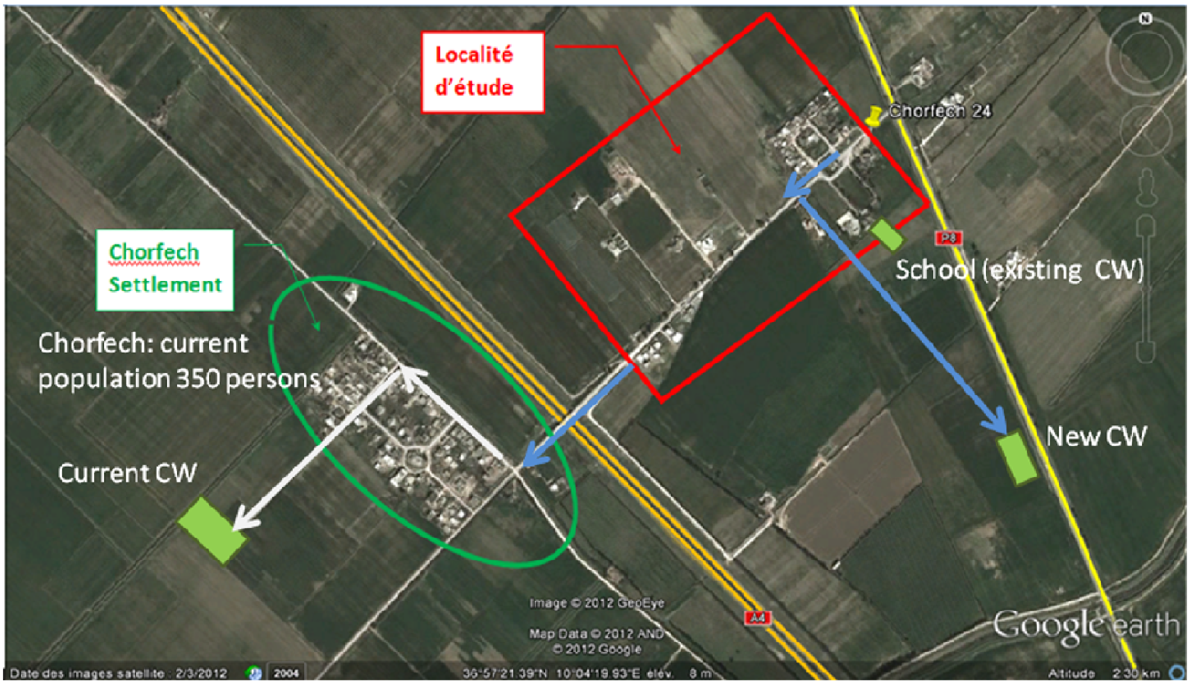
The cost of the system can be estimated starting from the costs of the Chorfech CW plant.

**ALTERNATIVE 3A**

| | |
|---|---|
| **lower part** | |
| Sewer connection | € 32.000,00 |
| manual grid | € 2.000,00 |
| imhoff tank 8 m3 | € 2.000,00 |
| CW horizontal flow | € 12.500,00 |
| pipe connections and special fittings | € 1.000,00 |
| Emergency disinfection | € 3.000,00 |
| ancillary work (fencing, maintenance roads) | € 2.000,00 |
| Storage tank | € 4.000,00 |
| | **€ 58.500,00** |
| **upper part** | |
| Sewer connection | € 19.000,00 |
| manual grid | € 2.000,00 |
| imhoff tank 16 m3 | € 4.000,00 |
| CW horizontal flow | € 7.150,00 |
| CW vertical flow | € 10.500,00 |
| pipe connections and special fittings | € 3.000,00 |
| E&M works | € 4.000,00 |
| Emergency disinfection | € 3.000,00 |
| ancillary work (fencing, maintenance roads) | € 3.000,00 |
| Storage tank | € 6.000,00 |
| | **€ 61.650,00** |

**ALTERNATIVE 3B**

| | |
|---|---|
| **lower part** | |
| Sewer connection | € 27.000,00 |
| rehabilitation of Chorfech CW | € 40.000,00 |
| | **€ 67.000,00** |
| **upper part** | |
| Sewer connection | € 19.000,00 |
| manual grid | € 2.000,00 |
| imhoff tank 16 m3 | € 4.000,00 |
| CW horizontal flow | € 7.150,00 |
| CW vertical flow | € 10.500,00 |
| pipe connections and special fittings | € 3.000,00 |
| E&M works | € 4.000,00 |
| Emergency disinfection | € 3.000,00 |
| ancillary work (fencing, maintenance roads) | € 3.000,00 |
| Storage tank | € 6.000,00 |
| | **€ 61.650,00** |




Rainwater harvesting is provided for all the buildings; the total roof surface is 2500 $m^2$ and considering to install a 5 $m^3$ tank each 100 $m^2$ roof, the total cost could be around 50.000,00 €. Rainwater will be reuse for irrigation, limiting the overall potable consumption that amounts to 164 l/day per person

Roadside infiltration trench are also provided on the main roads of the village to limit flooding events and regulate better the stormwater drainage in a natural way; the sizing of this system could be 0,5-1 $m^2$ each 100 $m^2$ of impervious surface.

**Summary of the alternatives**

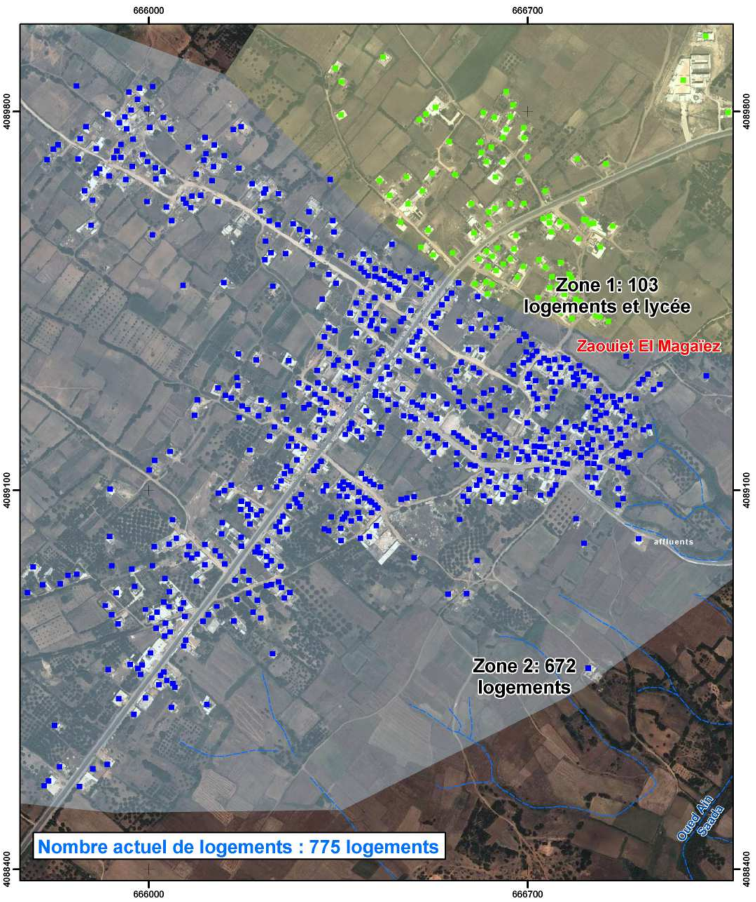
In the next table the figure with the calculated costs for the various option is presented.

| | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
|---|---|---|---|---|---|---|
| WSD | NO | € 8.900,00 | € 8.900,00 | € 8.900,00 | € 8.900,00 | € 8.900,00 |
| Rainwater harvesting | NO | NO | Yes | Yes | Yes | Yes |
| Sanitation interventions | NO | € 130.000,00 | € 130.000,00 | € 147.000,00 | € 120.000,00 | € 128.000,00 |
| Wastewater reuse | NO | NO | NO | Yes | Yes | Yes |
| infiltration trenches | NO | Yes | Yes | Yes | Yes | Yes |
| Treated wastewater infiltration | NO | NO | NO | Yes | Yes | Yes |

# ZEM

Zaouiet EL Mgaeiz (Zem) is a small town of approximately 4000 persons; the wastewater is not connected to any treatment. In the table below the main data on population and water consumption are showed.

| | |
|---|---|
| persons | 4021 |
| lodgement | 775 |
| person x lodgement | 5,19 |
| green zone lodgement | 103 |
| blue zone lodgement | 672 |
| green zone persons | 534 |
| blue zone persons | 3487 |
| water consumption (liter per person per day) | 129 |
| Green zone WW (m3/day) | 69 |
| Blue zone WW (m3/day) | 450 |



**Alternative 0**

Alternative zero means that all the wastewater is discharged in the environment without any treatment (mostly in a water body located approximately 1 Km East of the village. About the water consumption, we can assume a value similar to the upper part of Chorfech, that is relatively high for the Region.

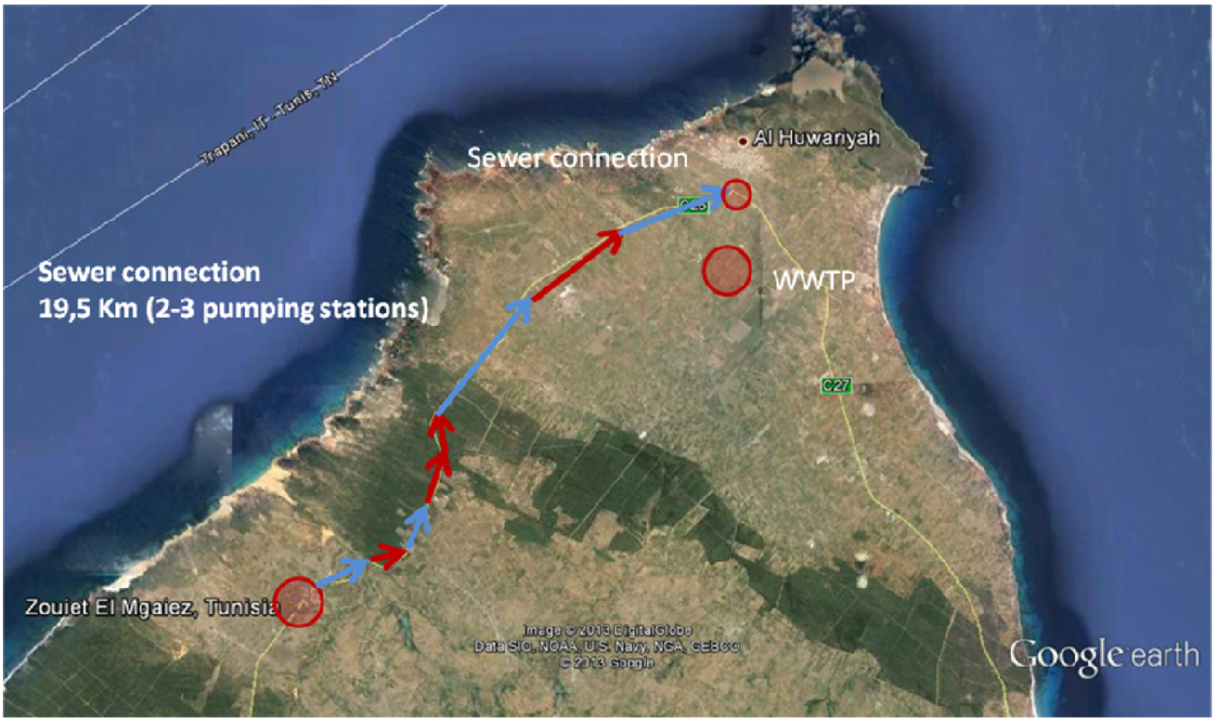
**Alternative 1**

There is a WWTP (activated sludge plant) about 18 Km in the north, near Al Huwariyah.

Alternative 1 provides:

- the realization of a sewer to connect the north part to the Constructed Wetland in the South part, rehabilitating the constructed wetland and the final pumping station;

About the application of water saving device to all the household, this could have a positive influence on the power costs for pumping, even if the expected consumption is quite limited.




| investment costs | € 2.420.000,00 |
|---|---|
| sewer (19,5 Km, 120 €/m) | € 2.340.000,00 |
| pumping station n°1 | € 40.000,00 |
| pumping station n°2 | € 40.000,00 |

| **operational costs** | **€ 39.725,76** |
|---|---|
| pumping electric power costs (0,1 €/KW) | € 2.920,00 |
| pumping system maintenance cost (0,3% capital costs) | € 240,00 |
| sewer maintenance cost (0,1% capital costs) | € 1.620,00 |
| ww treatment costs (0,2 €/m3) | € 37.865,76 |

**Alternative 2**

Despite of the connection to the existing WWTP, that for the long distance is very expensive, we have considered to realize a decentralized treatment by Constructed Wetland.

Alternative 2 provides:

- the realization of a sewer to connect the north part to the Constructed Wetland in the South part, rehabilitating the constructed wetland and the final pumping station;
- The application of WSD in the "green" northern part

About the application of water saving device to all the household, assuming a reduction of 30% applying simple water saving devices as flow restrictors and dual flush toilet 3/6 liter, the total sewage inflow could be reduced to 90 $m^3$/day. The cost of WSD for each the households could be about 100 €, considering to replace also the WC flushing system with a dual new one.

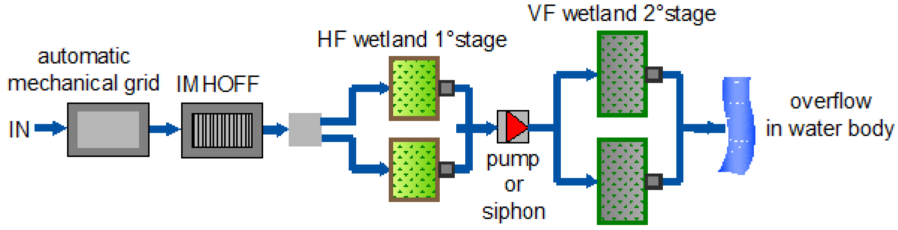
In this case the total flow to be treated is reduced to 500 $m^3$/day.

In the evaluation of the alternative we have considered the connection to the CW by a pumping station realizing the sewer along the public roads (red line in the figure); probably it could be possible also to provide the connection of the green part by gravity (as indicated in the figure): this last option needs lot of private land acquisition which has to be considered and economically evaluated).

Considering the objective of the discharge in a water body, the limit to be observed are reported in NT.106.02 and they required a high removal of organics, suspended solids, bacteria and an high nitrification (NH4 < 1 mg/l, even if this limit will probably updated to 2 mg/l). The treatment scheme could be the following:

- Manual grid
- Sand removal
- Imhoff tank
- 1st stage Horizontal flow 4500 $m^2$
- 2nd stage Vertical Flow 4500 $m^2$
- 100% Recirculation in the Imhoff tank to enhance denitrification
- Discharge in water body

The sludge of the Imhoff tank will be periodically extracted and treated in a sludge drying reed bed (composed by 4 beds with a total surface of 300 $m^2$), where they will stabilize and dewatered and they will be extracted after 8-10 year to be reused as soil conditioner in agriculture.




With this configuration the gross area required for the realization is about 15.000 m$^2$; the system can guarantee an outlet with BOD < 20 mg/l, COD < 90 mg/l, N-NH4 < 2 mg/l, N-NO3 < 30 mg/l.
The cost of the system are estimated starting from the costs of the Chorfech CW plant; in the cost the land acquisition and the technical services are not included.

| ***constructed wetland*** | |
|---|---|
| earthmovings (3 €/mc) | € 54.000,00 |
| primary treatment (300 m$^3$) | € 84.000,00 |
| preliminary treatment (automatic grid) | € 15.000,00 |
| procurement and placing of gravel/sand for CW beds (25 €/m$^3$) | € 231.875,00 |
| waterproofing of the basins | € 94.500,00 |
| plants | € 26.600,00 |
| pumping stations and electromechanical works | € 30.000,00 |
| pipelines, feeding, drainages | € 40.478,00 |
| ancillary works (fence, maintenance roads, etc) | € 28.822,65 |
| | **€ 605.275,65** |

In the following table, the investment cost and the maintenance for the sewer and the CW are showed; both are sensibly lower than in alternative n°1; in case of elimination of the pumping station and the selection of the gravity connection, the cost could be more reduced (about 30.000), even if the cost of land acquisition are to be considered in the comparison.

| **investment costs** | **€ 755.000,00** |
|---|---|
| sewer (1 Km, 120 €/m) | € 120.000,00 |
| pumping station n°1 | € 30.000,00 |
| constructed wetland | € 605.000,00 |
| **operational costs** | **€ 11.785,62** |
| pumping electric power costs (0,1 €/KW) | € 1.245,62 |
| pumping system maintenance cost (0,3% capital costs) | € 180,00 |
| sewer maintenance cost (0,1% capital costs) | € 755,00 |
| CW maintenance | € 9.605,00 |

**<u>Alternative 3</u>**

In this alternative we have considered a more decentralized approach, in order to reduce more the cost of the sewer and to permit in all the connections to operate by gravity. Each treatment is focused on Constructed Wetland systems. The application of WSD in the “green” northern part is included also in this option.

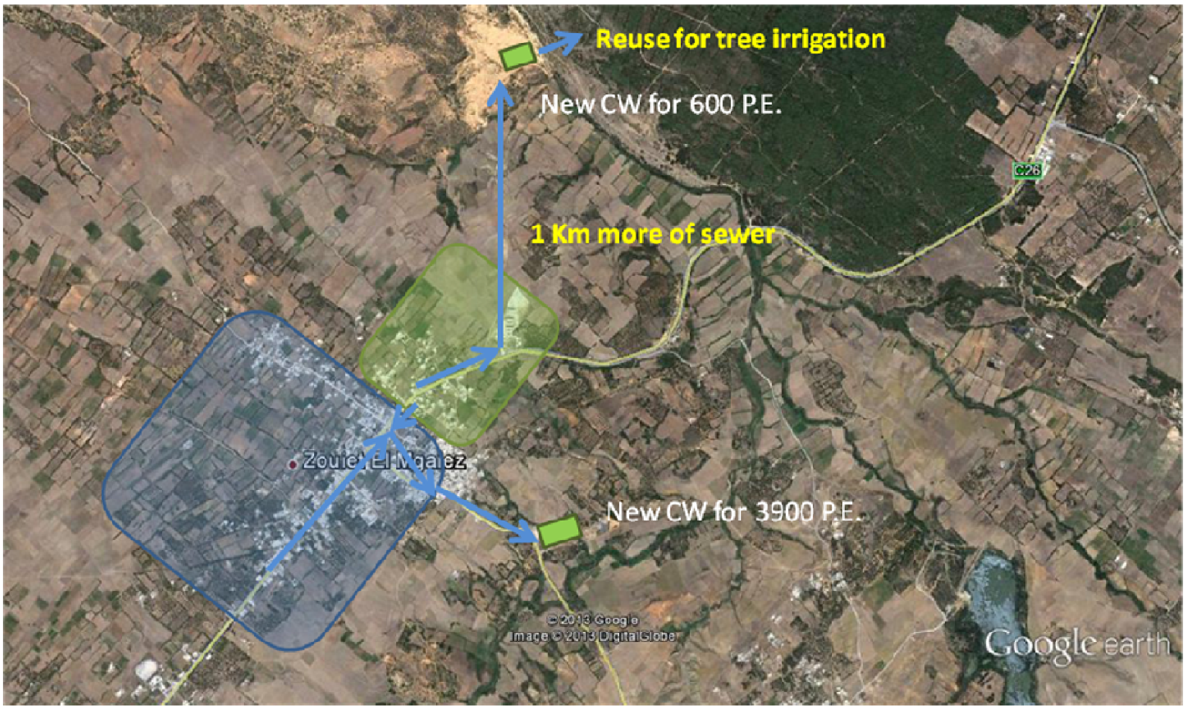

The treatment scheme could be the same of alternative n°1 in case of the new CW in the lower part; it will treat about 450 m$^3$/day and it will be composed by:

- Manual grid
- Sand removal
- Imhoff tank
- 1$^{st}$ stage Horizontal flow 4100 m$^2$
- 2$^{nd}$ stage Vertical Flow 4100 m$^2$
- 100% Recirculation in the Imhoff tank to enhance denitrification
- Discharge in water body

Also in this case the sludge of the Imhoff tank will be periodically extracted and treated in a sludge drying reed bed (composed by 4 beds with a total surface of 270 m$^2$), where they will stabilize and dewatered and they will be extracted after 8-10 year to be reused as soil conditioner in agriculture.
With this configuration the gross area required for the realization is about 14.000 m$^2$; the system can guarantee an outlet with BOD < 20 mg/l, COD < 90 mg/l, N-NH4 < 2 mg/l, N-NO3 < 30 mg/l.

In case of the littler CW in the upper part, it could be possible to provide the reuse for tree irrigation in the north part; this kind of reuse could happen for all the year and therefore the limits to be respect are less stringent than in case of water body discharge.

The system could be realized about 500 m from the buildings, but in this case the cost of the land could be high; as secondary option (alternative 3b), we could think to realize the system nearer to the reuse area (as showed in the next picture), where the land is not used for agricultural practices. The cost of the connection are similar because in case of reuse a connection with the tree land is however to be provided.




In the following tables the cost of the two Constructed wetlands are detailed. The cost are not including the acquisition of the land.

| | |
|---|---|
| ***constructed wetland 600 a.e.*** | |
| earthmovings (4 €/mc) | € 10.400,00 |
| primary treatment (60 m3) | € 21.000,00 |
| manual grid | € 3.000,00 |
| procurement and placing of gravel/sand for CW beds (25 €/m3) | € 35.140,00 |
| waterproofing of the basins | € 16.830,00 |
| plants | € 5.200,00 |
| pumping stations and electromechanical works | € 15.000,00 |
| pipelines, feeding, drainages | € 9.157,00 |
| ancillary works (fence, maintenance roads, etc) | € 9.258,16 |
| | **€ 124.985,16** |

| | |
|---|---|
| ***constructed wetland 3900 a.e.*** | |
| earthmovings (3 €/mc) | € 46.800,00 |
| primary treatment (260 m3) | € 70.000,00 |
| preliminary treatment (automatic grid) | € 15.000,00 |
| procurement and placing of gravel/sand for CW beds (25 €/m3) | € 200.958,33 |

| | |
|---|---|
| waterproofing of the basins | € 81.984,00 |
| plants | € 23.072,00 |
| pumping stations and electromechanical works | € 30.000,00 |
| pipelines, feeding, drainages | € 35.025,15 |
| ancillary works (fence, maintenance roads, etc) | € 25.141,97 |
| | **€ 527.981,45** |

In the following table costs of realization and maintenance of alternative n° 3a/b are showed.

| | |
|---|---|
| **investment costs** | **€ 855.000,00** |
| sewer (1 Km, 120 €/m) | € 120.000,00 |
| Sewer (1 Km) or reuse pipeline (1 Km) | € 80.000,00 |
| constructed wetland 3900 a.e. | € 530.000,00 |
| constructed wetland 600 a.e. | € 125.000,00 |
| **operational costs** | **€ 13.382,77** |
| pumping electric power costs (0,1 €/KW) | € 1.012,77 |
| pumping system maintenance cost (0,3% capital costs) | € 135,00 |
| sewer maintenance cost (0,1% capital costs) | € 120,00 |
| CW maintenance | € 12.115,00 |

**<u>Summary of the alternatives</u>**

In the next table the figure with the calculated costs for the various option is presented.

| | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
|---|---|---|---|---|
| WSD | NO | NO | € 10.000,00 | € 10.000,00 |
| Sanitation interventions | NO | € 2.420.000,00 | € 755.000,00 | € 855.000,00 |
| Wastewater reuse | NO | NO | NO | Yes |

# 4 Definition of sustainability criteria for evaluation

BARDO - URBAN RESIDENTIAL AREA

| **Health issues** | | weight (1-5) |
|---|---|---|
| Don't causes any risk of | additional mosquitoes (or other insects) growth | 4 |
| | illness | 5 |
| Reduced exposure to pathogens | of users | 5 |
| | of waste workers | 3 |
| | of resource recoverers /reusers | 5 |
| | of "downstream" population | - |
| **Impact to environment / nature** | | |
| use of natural resources | Minimize water use | 5 |
| | Low land requirements | 5 |
| | Low energy requirements | 3 |
| | Uses mostly local Construction material | 4 |
| low emissions and impact to the environment | Surface water | 2 |
| | Ground water | 4 |
| | soil/ land | 3 |
| | Air | 1 |
| | Noise and vibration | 1 |
| | aesthetic | 4 |
| | odours | 5 |
| good possibilities for nutrients recovering resources | energy | 2 |
| | Organic matter | 2 |
| | Water | 5 |
| | Landscape integration | 3 |
| **Technical issues** | | |
| allows simple construction | | 4 |
| low level of technical skills required for construction | | 4 |
| High level of efficiency (wastewater input/depurated/timing) | | 4 |
| Purification capacity (wastewater depurated/soil used by the plant) | | 4 |
| has high robustness and long lifetime/high durability | | 5 |
| enables simple and low operational procedures | | 5 |
| Low maintenance and low skills required | | 5 |
| not reliant on a continuous supply of a resource (such as water or energy) | | 3 |
| adaptable to unexpected future changes (adaptability) | | 3 |
| Good quality of effluent (according to the receiving environment) | | 5 |
| Amount and quality of generated sludge | | 2 |
| reduction of the imbalance water at the basin level | | - |
| **Economical and financial issues** | | |
| Provides benefits to the local economy (business opportunities, local employment, etc.) | | 3 |
| provides benefits or income generation from reuse | | 4 |
| **Social, cultural and gender** | | |
| Improves quality of life | | 5 |
| requires low level of awareness and information to assure success of technology | | 4 |

| | |
|---|---|
| requires low operation & maintenance and little involvement by the user/workers | 5 |
| high level of satisfaction of the local people regarding the implemented technology | 4 |
| requires low policy reforms at local, regional or national level. | 4 |
| educational impacts | 4 |
| **Costs** | |
| Investment cost (€) | 4 |
| Maintenance cost (€/year) | 4 |

Weight definition: number from 1 to 5, 5 is the max score, 1 is the minimum score

CHORFECH

| **Health issues** | | weight (1-5) |
|---|---|---|
| Don't causes any risk of | additional mosquitoes (or other insects) growth | 4 |
| | illness | 5 |
| Reduced exposure to pathogens | of users | 5 |
| | of waste workers | 3 |
| | of resource recoverers /reusers | 5 |
| | of "downstream" population | 2 |
| **Impact to environment / nature** | | weight (1-5) |
| use of natural resources | Minimize water use | 5 |
| | Low land requirements | 5 |
| | Low energy requirements | 4 |
| | Uses mostly local Construction material | 4 |
| low emissions and impact to the environment | Surface water | 4 |
| | Ground water | 4 |
| | soil/ land | 4 |
| | Air | 2 |
| | Noise and vibration | 2 |
| | aesthetic | 3 |
| | odours | 4 |
| good possibilities for nutrients recovering resources | energy | 3 |
| | Organic matter | 3 |
| | Water | 5 |
| | Landscape integration | 3 |
| **Technical issues** | | weight (1-5) |
| allows simple construction | | 4 |
| low level of technical skills required for construction | | 4 |
| High level of efficiency (wastewater input/depurated/timing) | | 4 |
| Purification capacity (wastewater depurated/soil used by the plant) | | 4 |
| has high robustness and long lifetime/high durability | | 5 |
| enables simple and low operational procedures | | 5 |
| Low maintenance and low skills required | | 5 |
| not reliant on a continuous supply of a resource (such as water or energy) | | 3 |
| adaptable to unexpected future changes (adaptability) | | 3 |
| Good quality of effluent (according to the receiving environment) | | 5 |
| Amount and quality of generated sludge | | 3 |
| reduction of the imbalance water at the basin level | | 3 |

| Economical and financial issues | |
|---|---|
| Provides benefits to the local economy (business opportunities, local employment, etc.) | 3 |
| provides benefits or income generation from reuse | 4 |
| **Social, cultural and gender** | |
| Improves quality of life | 5 |
| requires low level of awareness and information to assure success of technology | 4 |
| requires low operation & maintenance and little involvement by the users | 5 |
| high level of satisfaction of the local people regarding the implemented technology | 4 |
| requires low policy reforms at local, regional or national level | 5 |
| educational impacts | 4 |
| **Costs** | |
| Investment cost (€) | 4 |
| Maintenance cost (€/year) | 4 |

ZEM

| Health issues | | weight (1-5) |
|---|---|---|
| Don't causes any risk of | additional mosquitoes (or other insects) growth | 5 |
| | illness | 5 |
| Reduced exposure to pathogens | of users | 5 |
| | of waste workers | 2 |
| | of resource recoverers /reusers | 4 |
| | of "downstream" population | 3 |
| **Impact to environment / nature** | | weight (1-5) |
| use of natural resources | Minimize water use | 5 |
| | Low land requirements | 4 |
| | Low energy requirements | 4 |
| | Uses mostly local Construction material | 4 |
| low emissions and impact to the environment | Surface water | 4 |
| | Ground water | 5 |
| | soil/ land | 3 |
| | Air | 1 |
| | Noise and vibration | 1 |
| | aesthetic | 2 |
| | odours | 4 |
| good possibilities for nutrients recovering resources | energy | 1 |
| | Organic matter | 3 |
| | Water | 5 |
| | Landscape integration | 2 |
| **Technical issues** | | weight (1-5) |
| allows simple construction | | 5 |
| low level of technical skills required for construction | | 3 |
| High level of efficiency (wastewater input/depurated/timing) | | 4 |
| Purification capacity (wastewater depurated/soil used by the plant) | | 5 |
| has high robustness and long lifetime/high durability | | 3 |
| enables simple and low operational procedures | | 4 |

| | |
|---|---|
| Low maintenance and low skills required | 3 |
| not reliant on a continuous supply of a resource (such as water or energy) | |
| adaptable to unexpected future changes (adaptability) | 3 |
| Good quality of effluent (according to the receiving environment) | 3 |
| Amount and quality of generated sludge | 4 |
| reduction of the imbalance water at the basin level | 4 |
| **Economical and financial issues** | |
| Provides benefits to the local economy (business opportunities, local employment, etc.) | 4 |
| provides benefits or income generation from reuse | 4 |
| **Social, cultural and gender** | weight (1-5) |
| Improves quality of life | 5 |
| requires low level of awareness and information to assure success of technology | 4 |
| requires low operation & maintenance and little involvement by the users | 5 |
| high level of satisfaction of the local people regarding the implemented technology | 5 |
| requires low policy reforms at local, regional or national level | 5 |
| educational impacts | 4 |
| **Costs** | 5 |
| Investment cost (€) | 4 |
| Maintenance cost (€/year) | 4 |

**The “weights” will be multiplied for the specific indicator “measures” in order to obtain a final value that will contribute to the calculation of an aggregated and normalised index for each macro-indicator.**

# 5 Evaluation of the proposed scenarios based on a multi-criteria analysis

The kind of procedure to be applied is essentially the same used for a cost-benefit analysis and an environmental risks assessment (like in a EIA), considering not only the direct effects but also the most important indirect effects; the effects/impacts can be both material or immaterial, and so some of them can be measured while some others will need to be quantified by indicators. At the end of every evaluation of possible alternatives, simple and objective indicators should be the results of the multi-criteria analyses, so to provide the stakeholders with proper and "easy to understand" instruments for choosing the most appropriate alternative considering all the environmental, economical and social contexts for every case.

The economic evaluations will have to include the O&M costs for all the lifespan of the realizations and some recommendations in each feasibility study about the locally available fund raising options could be highly welcome from the stakeholders and considered as a very important contribution for the future application in real scale of the proposed solutions

**BARDO**

| **Health issues** | | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
|---|---|---|---|---|---|---|---|
| Don't causes any risk of | additional mosquitoes (or other insects) growth | 4 | 4 | 3 | 4 | 4 | 4 |
| | illness | 5 | 4 | 3 | 5 | 4 | 5 |
| Reduced exposure to pathogens | of users | 5 | 4 | 4 | 4 | 3 | 4 |
| | of waste workers | 3 | 4 | 3 | 4 | 4 | 5 |
| | of resource recoverers /reusers | 5 | 4 | 4 | 4 | 4 | 4 |
| | of "downstream" population | - | - | - | - | - | - |
| **Impact to environment / nature** | | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
| use of natural resources | Minimize water supply use | 5 | 2 | 4 | 5 | 4 | 5 |
| | Low land requirements | 5 | 5 | 1 | 1 | 2 | 2 |
| | Low energy requirements | 3 | 1 | 3 | 3 | 4 | 3 |
| | Uses mostly local Construction material | 4 | 1 | 4 | 4 | 4 | 4 |
| low emissions and impact to the environment | Surface water | 2 | 1 | 1 | 1 | 1 | 1 |
| | Ground water | 4 | 2 | 4 | 4 | 4 | 4 |
| | soil/ land | 3 | 1 | 3 | 3 | 3 | 3 |
| | Air | 1 | 1 | 3 | 3 | 3 | 3 |
| | Noise and vibration | 1 | 1 | 2 | 2 | 4 | 3 |
| | aesthetic | 4 | 1 | 3 | 3 | 5 | 5 |
| | odours | 5 | 1 | 2 | 1 | 2 | 3 |
| good possibilities for nutrients recovering resources | energy | 2 | 2 | 2 | 3 | 4 | 4 |
| | Organic matter | 2 | 2 | 3 | 3 | 4 | 4 |
| | Water | 5 | 1 | 3 | 3 | 4 | 5 |
| | Landscape integration | 3 | 1 | 4 | 4 | 4 | 5 |

| Technical issues | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
|---|---|---|---|---|---|---|
| allows simple construction | 4 | 5 | 4 | 4 | 4 | 4 |
| low level of technical skills required for construction | 4 | 5 | 4 | 4 | 3 | 3 |
| High level of efficiency (wastewater input/depurated/timing) | 4 | 4 | 3 | 3 | 3 | 3 |
| Purification capcity (wastewater depurated/soil used by the plant) | 4 | 1 | 4 | 5 | 4 | 5 |
| has high robustness and long lifetime/high durability | 5 | 1 | 4 | 4 | 4 | 5 |
| enables simple and low operational procedures | 5 | 5 | 3 | 3 | 3 | 3 |
| Low maintenance and low skills required | 5 | 4 | 3 | 3 | 4 | 3 |
| not reliant on a continuous supply of a resource (such as water or energy) | 3 | 4 | 3 | 3 | 4 | 3 |
| adaptable to unexpected future changes (adaptability) | 3 | 3 | 4 | 5 | 5 | 5 |
| Good quality of effluent (according to the receiving environment) | 5 | 1 | 4 | 5 | 5 | 5 |
| Amount and quality of generated sludge | 2 | 1 | 2 | 2 | 2 | 2 |
| reduction of the imbalance water at the basin level | - | - | - | - | - | - |
| **Economical and financial issues** | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
| Provides benefits to the local economy (business opportunities, local employment, etc.) | 3 | 2 | 4 | 4 | 5 | 5 |
| provides benefits or income generation from reuse | 4 | 2 | 4 | 4 | 5 | 5 |
| **Social, cultural and gender** | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
| Improves quality of life | 5 | 1 | 4 | 4 | 5 | 5 |
| requires low level of awareness and information to assure success of technology | 4 | 2 | 4 | 4 | 4 | 4 |
| requires low operation & maintenance and little involvement by the user/worker | 5 | 2 | 3 | 3 | 3 | 3 |
| high level of satisfaction of the local people regarding the implemented technology | 4 | 2 | 4 | 4 | 5 | 5 |
| requires low policy reforms at local, regional or national level. | 4 | 1 | 5 | 5 | 5 | 5 |
| educational impacts | 4 | 1 | 5 | 5 | 5 | 5 |

| Costs | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
|---|---|---|---|---|---|---|
| Investment cost (€) | 4 | 0 | 150.000,00 | 170.000,00 | 297.500,00 | 121.000,00 |
| Maintenance cost (€/year) | 4 | 0 | 25.000,00 | 33.000,00 | 15.000,00 | 22.000,00 |

**CHORFECH**

| Health issues | | weight (1-5) | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
|---|---|---|---|---|---|---|---|---|
| Don’t causes any risk of | additional mosquitoes (or other insects) growth | 4 | 3 | 5 | 5 | 4 | 5 | 4 |
| | illness | 5 | 3 | 5 | 5 | 4 | 5 | 5 |
| Reduced exposure to pathogens | of users | 5 | 3 | 5 | 5 | 4 | 5 | 5 |
| | of waste workers | 3 | 3 | 4 | 4 | 4 | 4 | 3 |
| | of resource recoverers /reusers | 5 | 3 | 5 | 5 | 4 | 5 | 5 |
| | of “downstream” population | - | - | - | - | - | - | - |
| **Impact to environment / nature** | | weight (1-5) | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
| use of natural resources | Minimize water supply use | 5 | 3 | 4 | 5 | 5 | 5 | 5 |
| | Low land requirements | 5 | 5 | 5 | 5 | 5 | 4 | 4 |
| | Low energy requirements | 4 | 5 | 3 | 3 | 3 | 3 | 3 |
| | Uses mostly local Construction material | 4 | 5 | 4 | 5 | 5 | 5 | 5 |
| low emissions and impact to the environment | Surface water | 4 | 5 | 4 | 3 | 5 | 5 | 5 |
| | Ground water | 4 | 1 | 5 | 4 | 5 | 4 | 5 |
| | soil/ land | 4 | 2 | 5 | 5 | 4 | 4 | 4 |
| | Air | 2 | 5 | 4 | 4 | 4 | 4 | 4 |
| | Noise and vibration | 2 | 5 | 4 | 4 | 4 | 4 | 4 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | aesthetic | 3 | 4 | 3 | 4 | 4 | 4 | 4 |
| | odours | 4 | 3 | 4 | 4 | 4 | 4 | 4 |
| good possibilities for nutrients recovering resources | energy | 3 | 5 | 1 | 3 | 3 | 3 | 3 |
| | Organic matter | 3 | 1 | 3 | 3 | 4 | 5 | 5 |
| | Water | 5 | 1 | 1 | 2 | 4 | 4 | 5 |
| | Landscape integration | 3 | 1 | 4 | 4 | 5 | 5 | 5 |
| **Technical issues** | | weight (1-5) | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
| allows simple construction | | 4 | 5 | 5 | 3 | 3 | 3 | 3 |
| low level of technical skills required for construction | | 4 | 5 | 4 | 4 | 4 | 3 | 4 |
| High level of efficiency (wastewater input/depurated/timing) | | 4 | 1 | 4 | 4 | 5 | 5 | 5 |
| Purification capcity (wastewater depurated/soil used by the plant) | | 4 | 1 | 5 | 5 | 5 | 5 | 5 |
| has high robustness and long lifetime/high durability | | 5 | 5 | 4 | 5 | 5 | 5 | 5 |
| enables simple and low operational procedures | | 5 | 4 | 5 | 4 | 4 | 4 | 4 |
| Low maintenance and low skills required | | 5 | 5 | 5 | 4 | 4 | 4 | 4 |
| not reliant on a continuous supply of a resource (such as water or energy) | | 3 | 5 | 4 | 5 | 5 | 3 | 3 |
| adaptable to unexpected future changes (adaptability) | | 3 | 1 | 3 | 5 | 5 | 5 | 5 |
| Good quality of effluent (according to the receiving environment) | | 5 | 1 | 5 | 5 | 5 | 5 | 5 |
| Amount and quality of generated sludge | | 3 | 5 | 3 | 3 | 3 | 3 | 3 |
| reduction of the imbalance water at the basin level | | 3 | 5 | 4 | 5 | 5 | 5 | 5 |
| **Economical and financial issues** | | weight (1-5) | weight (1-5) | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a |
| Provides benefits to the local economy (business opportunities, local employment, etc.) | | 3 | 1 | 3 | 5 | 5 | 4 | 5 |
| provides benefits or income generation from reuse | | 4 | 1 | 3 | 3 | 3 | 5 | 5 |

| Social, cultural and gender | weight (1-5) | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
|---|---|---|---|---|---|---|---|
| Improves quality of life | 5 | 4 | 5 | 5 | 5 | 5 | 5 |
| requires low level of awareness and information to assure success of technology | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| requires low operation & maintenance and little involvement by the user/worker | 5 | 4 | 4 | 4 | 4 | 4 | 4 |
| high level of satisfaction of the local people regarding the implemented technology | 4 | 2 | 5 | 5 | 5 | 4 | 5 |
| requires low policy reforms at local, regional or national level. | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| educational impacts | 4 | 1 | 1 | 2 | 3 | 3 | 4 |
| **Costs** | weight (1-5) | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
| Investment cost (€) | 4 | 0 | 138.900,00 | 138.900,00 | 155.900,00 | 128.900,00 | 136.900,00 |
| Maintenance cost (€/year) | 4 | 0 | 3.200,00 | 3.200,00 | € 4.500,00 | 5.000,00 | 4.500,00 |

**ZEM**

| Health issues | | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
|---|---|---|---|---|---|---|
| Don’t causes any risk of | additional mosquitoes (or other insects) growth | 5 | 1 | 5 | 4 | 4 |
| | illness | 5 | 1 | 4 | 5 | 5 |
| Reduced exposure to pathogens | of users | 5 | 1 | 5 | 4 | 4 |
| | of waste workers | 2 | 5 | 5 | 4 | 4 |
| | of resource recoverers /reusers | 4 | 3 | 3 | 3 | 4 |
| | of “downstream” population | 3 | 2 | 4 | 4 | 3 |
| **Impact to environment / nature** | | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
| use of natural resources | Minimize water supply use | 5 | 2 | 4 | 4 | 4 |
| | Low land requirements | 4 | 4 | 5 | 2 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Low energy requirements | 4 | 5 | 1 | 4 | 5 |
| | Uses mostly local Construction material | 4 | 3 | 4 | 4 | 4 |
| low emissions and impact to the environment | Surface water | 4 | 1 | 4 | 5 | 5 |
| | Ground water | 5 | 2 | 5 | 4 | 4 |
| | soil/ land | 3 | 1 | 5 | 4 | 4 |
| | Air | 1 | 4 | 4 | 5 | 5 |
| | Noise and vibration | 1 | 3 | 2 | 2 | 3 |
| | aesthetic | 2 | 1 | 4 | 4 | 4 |
| | odours | 4 | 1 | 5 | 4 | 4 |
| good possibilities for nutrients recovering resources | energy | 1 | 3 | 3 | 3 | 3 |
| | Organic matter | 3 | 3 | 4 | 3 | 3 |
| | Water | 5 | 1 | 2 | 4 | 5 |
| | Landscape integration | 2 | 1 | 3 | 5 | 5 |
| **Technical issues** | | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
| allows simple construction | | 5 | 3 | 5 | 4 | 4 |
| low level of technical skills required for construction | | 5 | 3 | 4 | 4 | 4 |
| High level of efficiency (wastewater input/depurated/timing) | | 5 | 1 | 3 | 4 | 4 |
| Purification capacity (wastewater depurated/soil used by the plant) | | 4 | 1 | 5 | 4 | 4 |
| has high robustness and long lifetime/high durability | | 5 | 1 | 4 | 4 | 5 |
| enables simple and low operational procedures | | 5 | 3 | 2 | 5 | 5 |
| Low maintenance and low skills required | | 5 | 3 | 2 | 5 | 5 |
| not reliant on a continuous supply of a resource (such as water or energy) | | 4 | 3 | 1 | 4 | 5 |
| adaptable to unexpected future changes (adaptability) | | 3 | 3 | 4 | 4 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| Good quality of effluent (according to the receiving environment) | 3 | 1 | 5 | 5 | 5 |
| Amount and quality of generated sludge | 3 | 3 | 4 | 5 | 5 |
| reduction of the imbalance water at the basin level | 1 | 3 | 3 | 4 | 4 |
| **Economical and financial issues** | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
| Provides benefits to the local economy (business opportunities, local employment, etc.) | 4 | 1 | 4 | 5 | 5 |
| provides benefits or income generation from reuse | 4 | 1 | 4 | 5 | 5 |
| **Social, cultural and gender** | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
| Improves quality of life | 5 | 1 | 4 | 5 | 5 |
| requires low level of awareness and information to assure success of technology | 4 | 3 | 5 | 4 | 4 |
| requires low operation & maintenance and little involvement by the user/worker | 5 | 3 | 3 | 5 | 5 |
| high level of satisfaction of the local people regarding the implemented technology | 5 | 3 | 5 | 5 | 5 |
| requires low policy reforms at local, regional or national level. | 5 | 3 | 5 | 5 | 4 |
| educational impacts | 4 | 1 | 3 | 5 | 5 |
| **Costs** | weight (1-5) | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
| Investment cost (€) | 4 | 0 | € 2.420.000,00 | € 765.000,00 | € 865.000,00 |
| Maintenance cost (€/year) | 5 | 0 | € 39.725,76 | € 11.150,62 | € 13.382,77 |

Altenative 0 = no intervention
++ or 5 the criterion is very fulfilled by this alternative
+ or 4 the criterion is fulfilled by this alternative
0 or 3 the criterion is neutral to this alternative
- or 2 the criterion does not fulfilled well by this alternative
-- or 1 the criterion does not at all fulfilled by this alternative
(the + and – can be substituted by numbers in the range 1-5 as specified above)

# 6 Conclusions

In the following section we report the results of the multi-criteria analysis, based on the scores and weights previously assigned for each case study, accompanied by some technical comments.

## 6.1 Definition of the optimal "tailor-made" alternative

Legenda

| | |
|---|---|
| 5 | the criterion is very fulfilled by this alternative |
| 4 | the criterion is fulfilled by this alternative |
| 3 | the criterion is neutral to this alternative |
| 2 | the criterion does not fulfilled well by this alternative |
| 1 | the criterion does not at all fulfilled by this alternative |

**BARDO**

| | | ALT 0 | ALT 1 | ALT 2 | ALT 3 | ALT 4 |
|---|---|---|---|---|---|---|
| **Health issues** | | 4,0 | 3,5 | 4,2 | 3,8 | 4,4 |
| **Impact to environment / nature** | | 1,7 | 2,9 | 2,9 | 3,5 | 3,8 |
| **Technical issues** | | 3,1 | 3,5 | 3,8 | 3,8 | 3,8 |
| **Economical and financial issues** | | 2,0 | 4,0 | 4,0 | 5,0 | 5,0 |
| **Social, cultural and gender** | | 1,5 | 4,1 | 4,1 | 4,5 | 4,5 |
| **Investment cost (€)** | | 0 | € 150.000,00 | € 170.000,00 | € 297.500,00 | € 121.000,00 |
| **Maintanance cost (€/year)** | | 0 | € 25.000,00 | € 33.000,00 | € 15.000,00 | € 22.000,00 |
| | WEIGHT | ALT 0 | ALT 1a | ALT 2 | ALT 3 | ALT 4 |
| Investment cost (€) | 4 | 3,0 | 4,5 | 4,0 | 2,0 | 4,5 |
| Maintanance cost (€/year) | 4 | 3,0 | 4,0 | 3,5 | 5,0 | 2,0 |
| **COST** | | 3,0 | 4,3 | 3,8 | 3,5 | 3,3 |
| | | | | | | |
| **TOTAL SUM** | | **15,3** | **22,2** | **22,8** | **24,0** | **24,6** |

In the case of Bardo Center all the alternatives reach good scores, compared to the alternative 0 that is almost neutral; in fact the current situation in Bardo doesn't lead to health issues or particular environmental impacts because there is a sewer that collect the wastewater and the general level of sanitation is acceptable.

The introduction of Suds or Green roofs can lead to a positive reduction of rainwater collected to the sewer or to a limitation of flooding events in the streets, but these strategies has to be planned at a larger scale to reach significant result. However we have also to consider the "secondary effects" of these kind of techniques:

- the educational impact of these measure in order to promote the adoption of these strategies, considering that the Bardo Center is located in the center of an important city as Tunis;
- the aesthetic improvement of semi-abandoned areas along the street, or building walls and roofs: in these last cases, the positive impact on the energy performance of the building has also to be considered.

Water saving devices and the segregation and recovery of used greywater have a positive effect on the resident people, that can count on more available water for different use and at the same time they can reduce the water consumption (and consequently also the wastewater discharged into the sewer).

The best alternative is the n°4, where MBR is applied for the reuse of greywater only for WC flushing; this is also the less costly alternative because the amount of treated water reused is lower compared to alternative n°1-2-3. It has to be underlined that the cost per $m^3$ of recovered water is higher in alternative 4 than in the other alternative. However, the availability of larger volumes of treated water to be reused for irrigation of public green areas doesn't really concern resident people, that are mainly interested in the "in house" reuse of treated water for WC flushing, that allows a significant reduction of water consumption and, consequently, a "measurable" money saving.

On the other hand more available water could give more possibilities to improve the quality of local green spaces. The need of green areas seems in fact to emerge from the MCA analysis, considering that the second ranked alternative is the one that includes, besides green roofs and the "green" suds, the creation of a green wall for greywater treatment, despite that this has to be still considered an experimental technique and the construction cost and the uncertainties on their operation are quite high.
It has also to be considered the advantages of green walls in terms of energy cost reductions and aesthetic potential; the educational potential could be strong and a pilot installation on a part of the produced greywater could have a good impact and allows further investigation on its functionality, operational reliability and adaptability to Tunisian context (where as already evidenced the roofs are enough only to permit installation of extensive green roofs and a greywater roof wetland could be difficult and very costly on existing structures).

**CHORFECH**

| | | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
|---|---|---|---|---|---|---|---|
| **Health issues** | | 2,6 | 3,7 | 4,1 | 4,1 | 4,1 | 4,1 |
| **Impact to environment / nature** | | 3,3 | 3,6 | 3,9 | 4,3 | 4,1 | 4,2 |
| **Technical issues** | | 3,6 | 4,4 | 4,3 | 4,4 | 4,2 | 4,3 |
| **Economical and financial issues** | | 1,0 | 3,0 | 3,9 | 3,9 | 4,6 | 5,0 |
| **Social, cultural and gender** | | 3,4 | 3,9 | 4,2 | 4,4 | 4,2 | 4,5 |
| **Investment cost (€)** | | 0 | € 138.900,00 | € 138.900,00 | € 155.900,00 | € 128.900,00 | € 136.900,00 |
| **Maintanance cost (€/year)** | | 0 | € 3.200,00 | € 3.200,00 | € 4.500,00 | € 5.000,00 | € 4.500,00 |
| | WEIGHT | ALT 0 | ALT 1a | ALT 1b | ALT 2 | ALT 3a | ALT 3b |
| Investment cost (€) | 4 | 3,0 | 4,5 | 4,5 | 3,5 | 5,0 | 4,0 |
| Maintanance cost (€/year) | 4 | 3,0 | 5,0 | 5,0 | 4,0 | 4,0 | 4,0 |
| **COST** | | 3,0 | 4,8 | 4,8 | 3,8 | 4,5 | 4,0 |
| **TOTAL SUM** | | **16,9** | **23,4** | **25,2** | **24,8** | **25,7** | **26,2** |

Also in the case of Chorfech all the alternatives reach good scores, except alternative zero where part of the village remains without any treatment.

The two best alternatives are 3a and 3b, the ones that envisage more decentralized solutions and that allow the maximum reuse of used water and the minimum length of sewer to be realized; in the 3a option the only pumping station remains the current one that collect the wastewater of the south part to the CW, whereas the other collectors are by gravity. The location of the new 2 CW permits also the local reuse, that is instead forbidden in the area of the old CW. The option 3b, that reaches the best ranking, envisages the collection of a small part of the wastewater on the old treatment system; even if less decentralized, this option seems to be more practical and acceptable considering also that the old system need some interventions for its rehabilitation.

**ZEM**

| | | ALT 0 | ALT 1 | ALT 2 | ALT 3 |
|---|---|---|---|---|---|
| **Health issues** | | 1,8 | 4,3 | 4,0 | 4,1 |
| **Impact to environment / nature** | | 2,2 | 3,8 | 3,9 | 4,1 |
| **Technical issues** | | 2,3 | 3,5 | 4,3 | 4,6 |
| **Economical and financial issues** | | 1,0 | 4,0 | 5,0 | 5,0 |
| **Social, cultural and gender** | | 2,4 | 4,2 | 4,9 | 4,7 |
| **Investment cost (€)** | | 0 | € 2.420.000,00 | € 765.000,00 | € 865.000,00 |
| **Maintenance cost (€/year)** | | 0 | € 39.725,76 | € 11.150,62 | € 13.382,77 |
| | WEIGHT | ALT 0 | ALT 1a | ALT 1b | ALT 3 |
| Investment cost (€) | 4 | 3 | 1 | 4 | 3,5 |
| Maintenance cost (€/year) | 5 | 3 | 2 | 4 | 3,5 |
| **COST** | | 3,0 | 1,6 | 4,0 | 3,5 |
| **TOTAL SUM** | | **12,7** | **21,3** | **26,1** | **25,9** |

For this case the Alt 2 has been ranked as the optimal one, even if the Alt 3 reaches similar results for most of the indicators and appears to be better performing for health issues, environmental impact and technical aspects, while it's only slightly lower for the social and cultural issues as also for the economic estimations. If the stakeholders can find coverage for the costs of Alt 3, this one should be chosen as the optimal one, having instead a second chance with Alt 2.

From a technical point of view these two alternatives are quite similar, both are applying water saving measures to reduce the amount of water to be treated and the treatment method is exactly the same, the only difference being the more decentralized approach by the splitting of the treatment in 2 different locations (alt 3) instead of a single one (alt 2).

A further alternative to be evaluated before to take a final decision about the future plans for the sanitation of the ZEM settlement has been announced in April 2014 by ONAS and the bureau (EGS) designated by ONAS to finalise the wastewater treatment strategy in the Governorate of Nabeul (Etude du plan directeur de l'épuration des eaux usées dans le gouvernorat de Nabeul): the objective is to regroup the rural settlements together and create a treatment pole (>4000 inhabitants) with one WWTP and for our case, the study proposes to regroup the ZEM and Boukrim and construct one centralized WWTP. The total population is about 8000 inhabitants for the two settlements.

For the evaluation of this other alternative, that is someway comparable to Alt1, is essential to consider the investment and maintenance costs for the sewer network and connections that are highly impacting in a negative way on a final ranking based on a MCA process, as it is evident by the comparison of the economic aspects for the Alt 1, 2 and 3.

Thus, for this new proposal also, the comparison must consider these investments and operational costs, putting into account the higher operational costs linked to the technology suggested by EGS/ONAS (low load activated sludge system). This centralized alternative should be compared to another alternative, completely centralized or mixed with Alt2, where also the Boukrim settlement has a local decentralized treatment by natural systems (CWs).