Sustainable Water management scheme for the Negin Safari Park

By : Priyadarshini Nanda

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Author

Priyadarshini Nanda

Student number

4738748

Supervisory Team

Ir. Frank Schnater

Ir. Christien Janssen

NGO Simba

External Examiner

Rein Have

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Abstract

Though the perils of climate change on our environment are common knowledge its mitigation through informed planning is widely absent. This research project aims to aid the architect in developing a design which has a comparatively lower ecological footprint and focuses on opportunistic utilization of renewable resources readily available in the context. Within the preview of this thesis the potential of developing a sustainable water management scheme for the Negin safari park located in the Fars province of Iran is studied.

Iran is facing a situation of drought for the past few years which has had an adverse impact on the region. One of the communities to have been affected by this are the Qashqai nomads of Iran, who have been threatened with deprivation of their freedom due to the economic woes brought by drought. The Negin safari park being developed in the region aims to uplift this community and provide a platform for them to be able to share their work and culture. However, the influx of tourists due to the development of a Safari park further increases the stress on the depleting water resources in the region. In turn development of water technologies facilitating the reclamation of waste water, conservation of water and mitigation of extreme withdrawal of resources needs to be studied and implemented.

In order to create a design which consciously uses the water resources and facilitates re-use of waste water, different water technologies have been identified and studied to understand its feasibility for installation in Iran. Once the ideal technologies were identified, a water management scheme was developed which facilitated water autarky in the park. Further on the relation of the built form with the technology was explored. The technologies which were shortlisted entailed requirements which had a direct impact on the design of the built form and its spatial organization. The final product of this thesis entails a customized set of design guidelines for the development of a Safari park in Iran. These guidelines have stemmed from the optimization strategy used in designing the Negin safari park with the intended water technologies.

Adhering to the concept of developing the park as an eco-tourist destination attention has been placed to propose sustainable technologies with lower energy requirement and maintenance. It is believed that through implementation of these technologies the added stress on water demand caused by the erection of a Negin safari park in a drought hit region can be reduced. The implementation of these technologies can also further help in educating the local community and lead to encouragement of widespread implementation of these systems. This graduation project is an attempt to develop an informed relation between resource flows and spatial design in order to enable an uninterrupted functioning of the Safari park leading to prosperity of the region and its people.

Acknowledgement

With this project I complete my masters in Building technology at the TU Delft. Studying in this university has been a great learning experience and has introduced me to several technological advancements that are being explored in the building industry. It has also strengthened my view point on approaching sustainability through technological intervention.

I would like to express my sincere gratitude to my mentors, Ir. Frank Schnater and Ir. Christien Janssen who guided me through this project. Our meetings have been fruitful in moulding the project and facilitated me in being thorough in my research process and final outcome. I would like to thank you for sharing your knowledge with me and showing confidence in me which also helped me in believing in my convictions.

I would also like to thank NGO Simba for giving me the opportunity to work on the Negin Safari park for my thesis and sharing with me their view point at every step of the project. Your input was valuable to this thesis and further gave me an insight into the challenges of implementing the project in Iran.

I owe my deepest gratitude to my parents who gave me this opportunity to explore my interests , your motivation has helped in fuelling my ambition and made me want to strive for more. Finally I would also like to thank my friends especially Jagbir for consistently sharing his perspective and inspiring me through the length of this project.

Priyadarshini Nanda

Introduction

Chapter Overview

This chapter introduces the context of the sustainable research project and its problem analysis. The context is first described by speaking about the Qashqai community, their living conditions and their occupation. Furthermore, the challenges faced by the community are addressed. This is followed by a study into the Fars province of Iran where the Qashqai tribe is situated and the potential of the region to contribute in upliftment of the community and preservation of their culture. The basic problem analysis is summarized in form of a clear problem statement.

Context

The Qashqai nomads are a major tribal confederation of the southern Iran. They played a big part in the economy and politics of the region in early 1900 (Cronin, 2006). At present a larger number of the Qashqai population are still pastoralist , they travel with their flocks twice yearly, from the summer highland pastures in the north of Shiraz to the winter pastures on the lower land near the Persian Gulf. The migration is organized and controlled by the Qashqai Chief (Mannaerts, 2016). The annual migration of the Qashqai and their flocks is the largest of any Persian tribe.

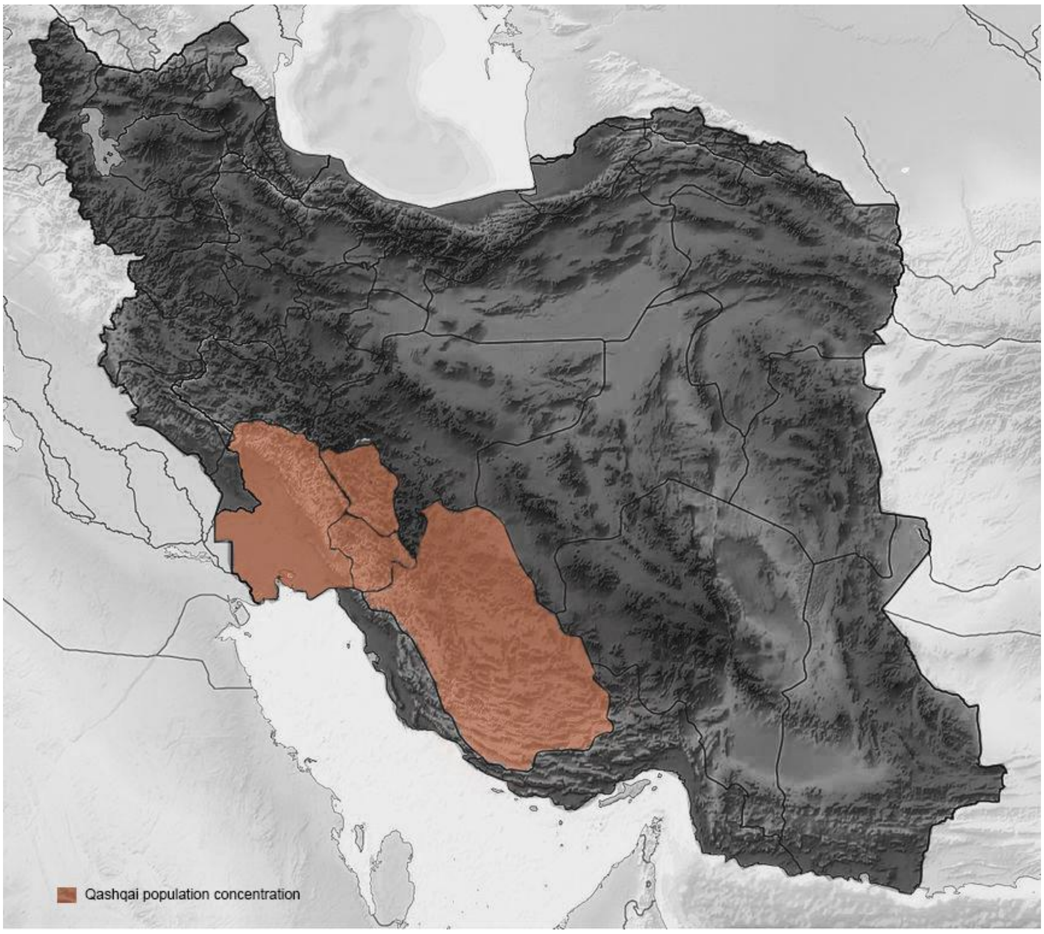


Figure 01: Map of Iran indicating location of Qashqai population (Wikimedia commons,2018)

In figure 01 the orange area indicates the region of Iran where the Qashqai are predominantly located. The total area of this region is 2,18,499 Km^2 which is 5 times the size of the Netherlands. The main occupations of the Qashqai people are animal husbandry of dairy animals, chickens and roosters, making handicrafts such as woven carpets which are generally made by the Qashqai women of the community and Agriculture. As per the 2016 census 40,000 Qashqai nomads live in the region. The Qashqai nomads migrate yearly and are known to live in temporary tent accommodations as shown in figure 02 (Mannaerts, 2016). The nomads heavily rely on the ground water through construction of wells to meet their daily water demands (NGO Simba, 2018).

Figure 02: Image of a Qashqai Tent (*Lovely* Persia, 2018)

Climate change has an adverse effect on the cultural heritage of Iran such as indigenous local knowledge , beliefs and value which have been acquired through centuries of trial and error in the natural environment and shared among the generations orally (Emadi and Amiri Ardakani, 2011). In recent times the Qashqai community of the Fars province is facing a challenge due to occurrence of Drought. This has increased the difficulty of the Qashqai community in finding grazing lands for their flocks and has forced the tribe into sedentism and jeopardized their freedom and independence (NGO Simba, 2018). The Qashqai community are unable to find a platform to promote their handicraft which has further led to a decline in sale. The production is further threatened by the machine woven rugs which are available in local markets for cheaper prices. Moreover, the Qashqai youth are seen moving to larger towns to find different mode of income. Leaving the community with a challenge of finding people to take care of the flocks and threatening the extinction of their culture (Mannaerts, 2016).

Figure 03: Qashqai Migration (*Lovely* Persia, 2016)

Figure 04: Qashqai flock (Mannaerts, 2016)

In an attempt to overcome this members of the Qashqai community who lived in Firoozabad, Fars province, Iran approached the Simba Nature Protection and Education Foundation .They asked for an environmental based project to improve their economic situation (NGO Simba, 2018).

The mission of the NGO Simba is to protect and preserve the Iranian wildlife and nature. In the past decade Iran has experienced an increase in the number of endangered species which has intensified due to the condition of drought. The NGO aims to improve this situation through establishment of a range of sustainable projects promoting an environmentally friendly lifestyle in the region (NGO Simba, 2018). Through extensive study and research the NGO proposed a sustainable Safari Centre which would run on environment friendly technologies. Further on they selected a multidisciplinary group of students from TU Delft and other Dutch universities to take care of the desk research and field study to develop a proposal for the Centre.

Problem Statement

A safari park was proposed in Kel Plein, Iran with the intention of conserving wildlife and habitat, providing jobs for the local population, generation of income, preservation of rural services like buses and shops and increasing the demand for local craft and food (NGO Simba, 2018). Kel Plein is located at a distance of 23.4 Km from the city of Firoozabad (as shown in Figure 05).

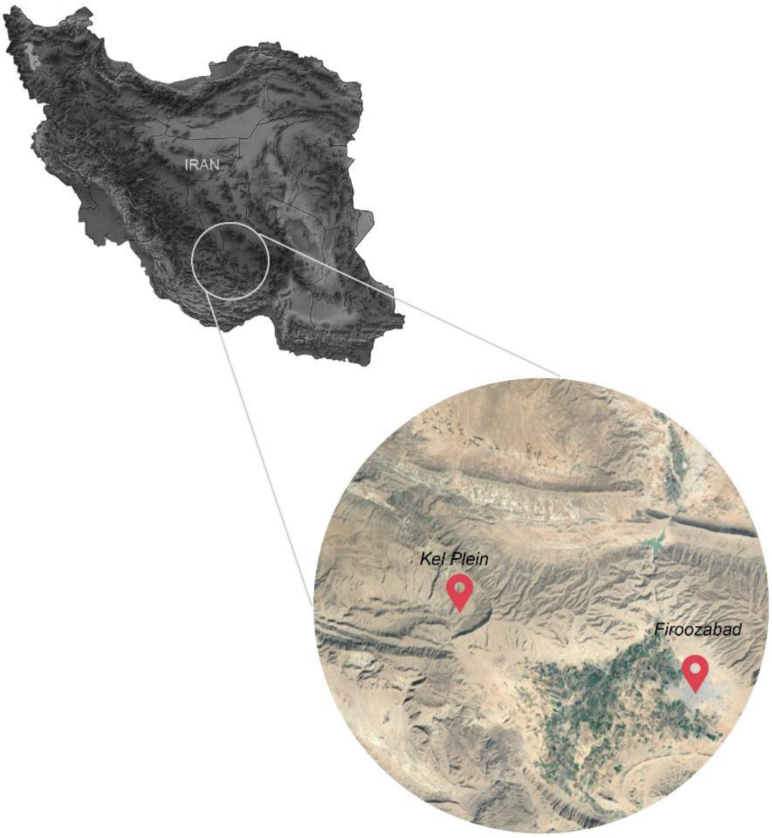


Figure 05: Location of Kel Plein and the city of Firoozabad (Google Maps, 2018)

The sites was characterized on the basis the social, political, engineering and environmental aspects by a team of management students from the TU Delft based on which a choice was made. The Development of the Centre needs to be carried out ensuring a least amount of impact on the flora and fauna of the region. Due to its distance from the main city and its utility grid, alternative solutions for provision of energy, water and waste disposal should be explored for efficient use of available resources.

Figure 06: Site at Kel Plein (TU Delft Management students, 2018)

Figure 06 shows an image of the site at Kel Plein. The total area of the site spans around 73.8 Km^2 roughly the total is of Zaanstad, Netherlands. It consists of a village on the periphery of the site boundary and several Qashqai settlements are also spread over in the region.

Impact of climate change

The Fars province of Iran is known to face extreme summer and winter leading to situations of Drought in recent times. The average annual rainfall experienced by the region in the period of 2009 and 2018 is 319.94 mm This is 70% lower than the worldwide average of 973mm. The annual maximum precipitation is experienced during the winter season, From late December through February. The Fars province has experienced several severe droughts in recent decades including 1999-2002 and 2007-2011. The World resource institute simulated with the help if climatic data what the water resource graph would look like in the next 20 years. They translated this information in the form of a map indicating the regions which could face high stress on water resources (Figure 07). As per the image NASA has claimed that 70% of Iran would become a dessert and the annual rainfall will also be severely impacted (NGO Simba,2018).

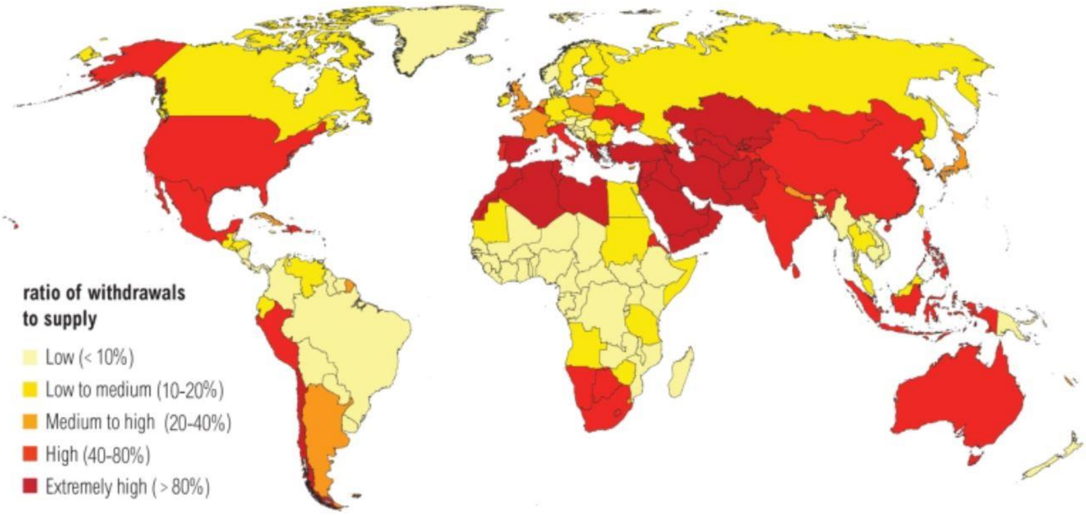


Figure 07: Map predicting the water stress regions by 2040 , (NGO Simba, 2018)

Drought brings with its severe environmental degradation, ground water level depression and water allocation controversies. In the case of the Fars province it has also resulted in migration of birds and animals. This has also led to the people of the region drinking the water resources that are meant for the cattle and are not up to the drinking water quality (NGO Simba,2018). The world business council for sustainable development has stated that business cannot survive in a society that thirsts and business is part of the solution and its potential is driven by its engagement (Pollalis, 2012). While developing a Tourist centre has the potential of generating economy in the region and promotion of the craft and culture of the community it also leads to further stress on the water needs in the region.

Objective

Chapter Overview

This chapter begins with addressing the general objective of developing a Safari Centre in the Fars province which can benefit the Qashqai people and the ecology of the region. In like manner the scheme of developing a sustainable water management cycle to address the problems are also talked about. Furthermore, the expected format of the final product is cited along its relevance for the graduation thesis and its use by the Simba Nature Protection and Education foundation. To begin the research work, the boundary conditions are itemized in the last section of this chapter.

Goals

The intention of this research project is to develop a model of sustainable water management cycle within the Safari Centre. The idea is to bring back the lost ecosystem and ensure uninterrupted functioning of the Centre. This might be achieved through opportunistic utilization of water where it is found, engineering storage and conveyance, ensuring fast conveyance of treated water, Addressing non-point sources available on site and integration of urban water management where possible.

Sub Goals

- Understanding the functional requirements of the safari park and translating them into built up areas based on which the water demand of the Safari Centre can be estimated.
- Researching relevant case studies and understanding the sustainable water management provisions made in them.
- Researching on the various technologies that can help in developing an array of sustainable water management cycle proposals.
- Studying the practicability of the sustainable water management schemes.

Final Product

The result of the report is going to be about the feasibility of a sustainable water management cycle concept and a design of the Centre which fits into this concept. The goal is to achieve partial or complete self-sufficiency about the water demand of the site.

This report will contain an advice towards the Simba Nature protection and education foundation about what technologies for a sustainable water management cycle are feasible to use. This will be based on the opportunistic utilization of water through its careful and informed distribution on site followed by conjectures on its optimum usage. Further on the result will also address the impact of these strategic technologies on the spatial organization and form of the building blocks. This will culminate into design guidelines for the development of the Safari Centre project for The NGO’s reference during the designing stage in future.

Boundary Conditions

The final product should satisfy NGO Simba and TU Delft. The Goal is to achieve partial or complete self-sufficiency. The boundary conditions are determined by the starting point, constraints and assumption.

Starting Point

The starting point of the research involves developing a program of requirements and its sizing for the estimation of the total water demand of the Safari Centre that needs to be met. The program requirements can further be visualized in form of a relativity chart. This will be followed by studying the different water technologies that can be incorporated in the built form.

Precondition

Feasibility of the solution is a pre-condition for NGO Simba to ensure successful implementation. The feasibility of the solution will be based on the physical and technical and aspects. While there is possibility of achieving the desired end goal through guaranteed techniques its impact on the built form also plays an important role in understanding its practicality. The decentralized water management cycle might have a higher set up cost it should also be able to meet the long term expected demand of the Centre.

Second pre-condition is ensuring that the flora and fauna of the region are not affected by the proposed water technologies on site. The Safari Centre aims to restore the ecology of the region through proposing solutions which would help in bringing back the animal and birds which have migrated out of the region. The sustainable water management scheme should also aid in the process.

As the attempt is to generate income through promotion of tourism the Safari Centre should meet a certain standard of luxury. The water management cycle should ensure it helps in meeting the water demands of the guests and the support staff.

Implementation of the technology on the built form should not lead to dissociation of the design from vernacular architecture of the region that illustrates the cultural facets of the Qashqai. The design should be humble yet meet the basic demands of the wide array of local and foreign tourists it expects to house.

Research questions

Chapter Overview

This Chapter starts by listing out the main, Sub and research question which are required to successfully carry out the research. This is followed by addressing the chronological methodology being followed to achieve the desired result. This chapter will end by sharing planning timeline in the period of which the goal is intended to be achieved.

Research Question

What sustainable water management scheme is possible for the Negin project, and what is its potential in the built environment?

Sub Questions

What is the estimated amount of potable and non-potable water required for uninterrupted functioning of the Safari Centre?

What is the amount of waste water expected to be generated within the site?

What technologies can facilitate the sourcing of water on site? What is the quality of the sourced water and its application?

What is the estimated quantity of the sourced water through these technologies?

What is its impact on the built form?

What technologies can aid decentralized water treatment? What is the quality of treated waste water and its application?

What is the estimated quantity of treated water generated through these technologies?

What is its impact on the built form?

What is the optimum sustainable water management scheme?

What is its impact on the water demand of the site?

How does the scheme impact the spatial organization of the centre?

How does the scheme impact the built form of the centre?

What impact does the scheme have on the surrounding environment and ecology?

What are the guidelines that can be derived from the design process?

Research Strategy

The thesis will be developed in 5 phases. The first 2 phases talk about the method of addressing the technology part of the thesis. The next 3 phases describe the method of developing guidelines through following the research by design process. These phases have been further elaborated below:

Research and literature review: This will be carried in three forms through the process of studying case studies, through research on novel and vernacular sustainable water management technologies and through gathering information from the TU Delft management student currently in Iran. The intention of re- searching case studies is to understand the state-of-the-art water technologies which have been put into application, the challenges they pose and their advantage. In addition to this the chosen case studies also need to give an idea of the functional requirements and functional relation for the development of a Safari park. To construct validity multiple sources of evidences will be researched and a chain of evidence will be developed. Further on, through pattern matching and use of replication logic information gathered from multiple case studies will be used to develop a database. While there are technologies which have been put to practice in tourist resorts, there are novel technologies which have been developed with an approach to mitigate the water crisis. The literature study on these technologies aims to tap into these ideas and understand their potential in the built environment. For e.g. Capturing water from air through a mesh is a rather recent technology which has been extensively researched and shows potential for the site. Iranians are also renowned for their age-old sustainable water management strategies which have helped their society strive in the difficult topography of Iran. Diving into these strategies can also be beneficial in developing a sustainable water management scheme. Methodologies of calculating the water flows of the site will also have to be researched to develop estimations on the water demand of the site. Thirdly to understand the physical parameters and the necessities of the site the author intends to closely work with the TU Delft management students.

Extracting inferences from the Research: From the literature research an inventory of water flows will be developed to understand the water demand of the project and predict the waste water generation. As the project aims to reduce its dependency on the central water network, schemes with varying water technologies will be developed to achieve a sustainable water management cycle within the site. The scheme that helps in achieving the final goal of partial or complete self-sufficiency of water will be shortlisted for further study and development

Study by Design: The intention of this stage is to study the impact of the sustainable water management scheme on the built environment. The developed scheme will be applied on the identified list of functional requirements. This will be done to understand its spatial impact, potential and challenges the water technology have on the built form.

Check the Design: The design and proposed technologies will be studied to understand their feasibility and potential. A chronological approach to re-search by design will be carried. Hence in the instance if the design is found to not meet all the requirements set at the earlier stage it will be challenged and changed to study the effects of the change to achieve the desired results.

Develop a set of Guidelines: Once an ideal option of design is achieved the gathered knowledge will be translated into a set of design guidelines which can be used as a base for further design development by the NGO. The final product will be delivered in forms of comprehensive advice which can be implemented on the design to achieve sustainable water management within the site to ensure uninterrupted functioning of the Safari Centre.

Throughout the process the guidance will be sought from the mentors. The approach will also be shared with the NGO from time to time to get their input and ensure their requirements are also met. The timeline has been further elaborated in form a Gant chart in the end of this section.

Relevance

The scientific relevance of the project lies in researching implemented techniques with successful outcomes as well as potential novel technologies and comparing it with the limiting parameters such as climate of Kel Plein. The Fars province of Iran is facing a serious climate change issue -Drought, conceptualization of distinctive features of water management in Kel Plein and providing an integrated analysis of water management through establishment of relationship between society, the infrastructure and biophysical environment can be valuable. Further the innovation of a park with limited water dependence can help in mitigating the impact of drought.

Though the perils of climate change on our environment are common knowledge its mitigation through informed planning is absent. This project aims to aid the architect in developing a design which consciously reduces its ecological footprint. The implementation of this project can act as a model design which could facilitate a larger impact on the perception of water management in the region and aid rural community autarky. Which means the local community is self-sustaining and does not need to rely on external resources for continued operation. As the park will be visited by a large number of people their interaction with the water technologies and exposure to conscious water saving techniques implemented in the park can have a larger societal impact and help in moving the community towards this change.

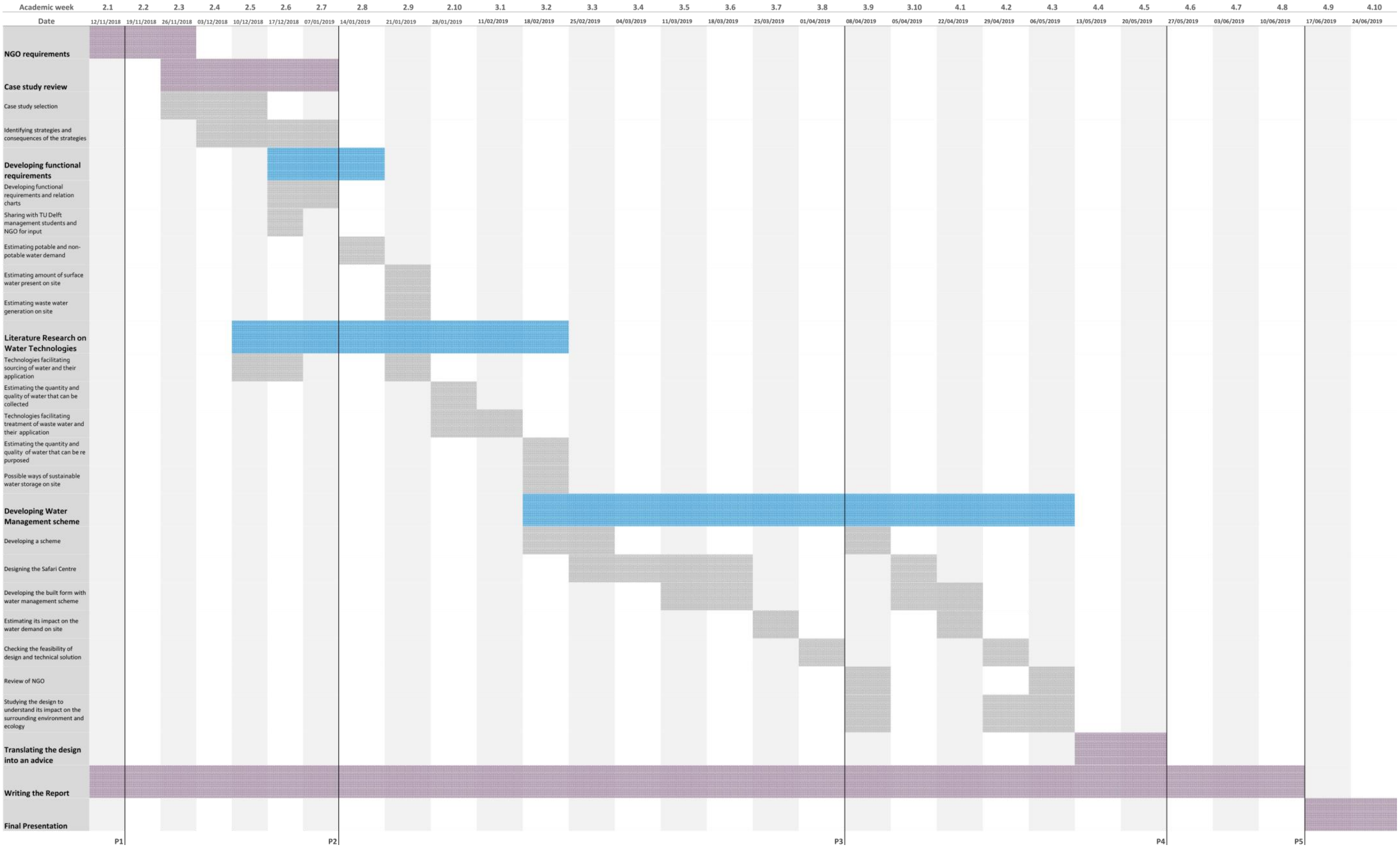


Chart 01 : Gant Chart

Literature Review

Chapter Overview

The following chapter starts by talking about the research done on water management and its challenges in the Safari Centre for tourists. Further on the chapter reviews the different case studies which have been researched to understand the technologies incorporated by them and the challenges they faced. This chapter ends by putting the inference derived from the case studies in a table form for future use.

Water Management

Challenges of water as a resource

"*Solving the water and sanitation crisis is today an urgent global priority with consequences far beyond water and sanitation, impacting inter alia economic development, food security, health, peace and security, and gender equality*." (United Nations, 2018)

Iran is facing a serious challenge in the water sector due to the rising water demand and shortage, declining groundwater levels, deteriorating water quality, water supply rationing and disruptions, forced migration, agricultural losses and increasing ecosystem loses. As the region becomes hotter and drier due to the effect of climate change the stress on the existing water resources is consequentially predicted to increase (Madani, 2014). The effects of this have also been witnessed by the Qashqai community which faces a cultural extinction due to the situation of drought in the region. While development of a Safari Centre shows potential of becoming an economic facilitator for the Qashqai population this also leads to an intensified water demand. Tourist demand is known to increase the water consumption which is well beyond normal and strenuous on the local water resources (Kelly & Williams, 2007). The extensive use of water intensive equipment's and technologies installed in tourist destination further magnifies the resource exploitation. Tourists are also known to consume more resources while on a holiday leading to increased water use and waste water generation. Eco -efficient strategies that do not rely on intensive use of natural resources can be applied to destinations which provide an experiential final product for the tourists (Madani, 2014). Consequently, there is a demand of proposing innovative eco efficient strategies to manage the water resources for conservation and uninterrupted function of the tourist destination (Kelly & Williams, 2007).

Table 01 indicates the statistics on the tourists entering the country in the period March 2016-March 2017 and March 2017 and March 2018. On comparing the precipitation chart with table 01 we can conclude that the months during which the Fars province experiences the highest amount of rainfall is also the months during which the least tourist numbers are witnessed. This results in an imbalance of when the resource is available and when the resource is required. This can be addressed through water management strategies.

Season	Iranian Month	From	Until	1395 (From March 2016 to March 2017)		1396 (From March 2017 to March 2018)		Balance	
				QTY	%	QTY	%	QTY	%
Spring	Farvadin-1	21-Mar	20-Apr	1.187.233	24,22	1.104.850	21,61	-82.383	6,94
	Ordibehesht-2	21-Apr	21-May						
	Khordad-3	22-May	21-Jun						
Summer	Tir-4	22-Jun	22-Jul	1.514.626	30,90	1.514.460	29,62	-166	-0,01
	Mordad-5	23-Jul	22-Aug						
	Shahrivar-6	23-Aug	22-Sep						
Autumn	Mehr-7	23-Sep	22-Oct	1.225.563	25,01	1.273.967	24,91	48.404	-3,95
	Aban-8	23-Oct	21-Nov						
	Azar-9	22-Nov	21-Dec						
Winter	Dey-10	22-Dec	20-Jan	973.662	19,87	1.220.247	23,86	246.585	-25,33
	Bahman-11	21-Jan	19-Feb						
	Esfand-12	20-Feb	20-Mar						

Table 01: Statistics on tourist influx (NGO Simba, 2018)

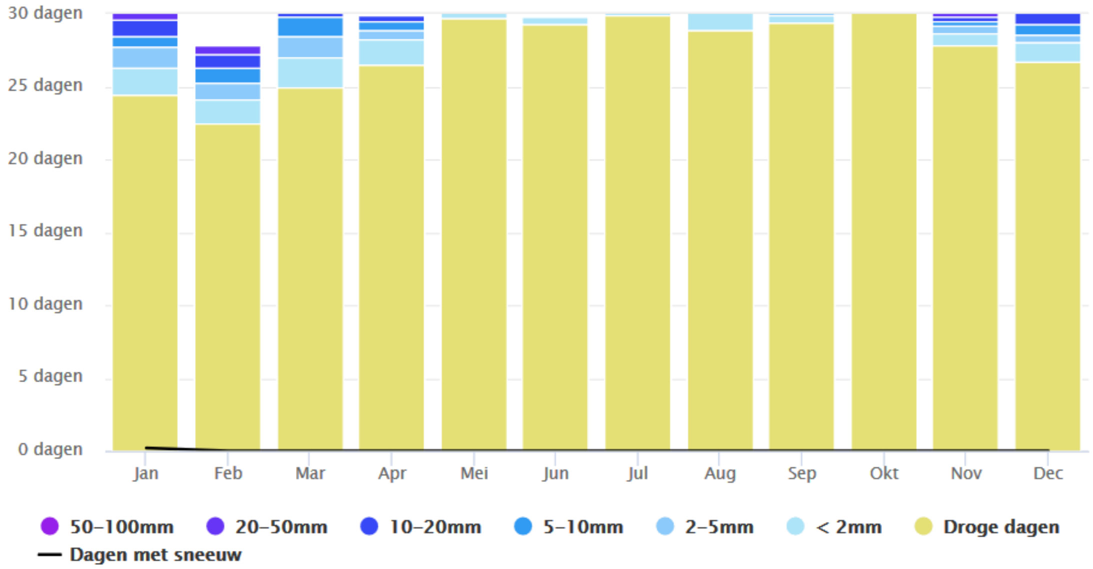


Figure 08 : Precipitation chart for the year 2018, (Meteoblue, 2019)

Challenge of urban water management

Urban water management involves massive investment for the procurement, treatment, storage, collection, re-treatment and discharge of water. Due to the singular supply point and treatment point these facilities fall short in addressing the non-binary water demand. The latent belief is that water quality is binary, either perfectly clean, or entirely dirty. A range of water qualities are required to fulfil the water demand however water once used is considered a waste and is referred to as sewage or waste water, its potential treatment and re-use is not widely considered. In a water scarce region rain water and grey water harvesting can potentially meet the non-potable water needs (Pollalis, 2012). Figure 09 indicates the quality the range of water qualities that are generated and their possible uses to meet the required current water demand. Eco efficiency in the tourist destination can be achieved through incorporation of innovative building design and landscaping options in built environments. The intention is to lower the demand of water from the central water infrastructure in the region through addressing non-point sources with an aim to meet partial or whole internal water requirement (Madani, 2014).

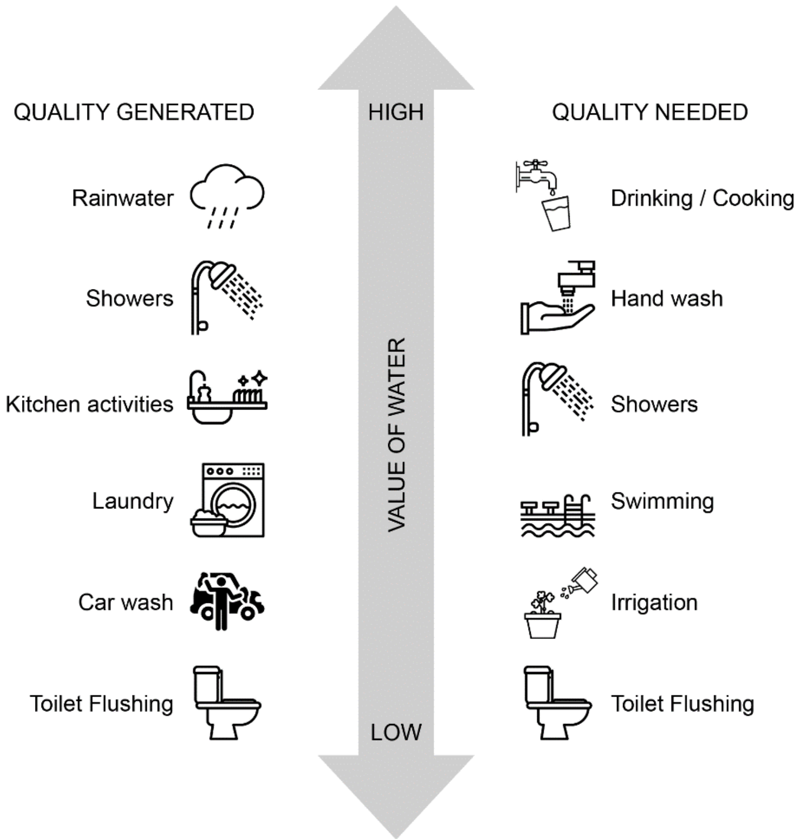


Figure 09: Range of water quality generated and demanded, (Pollalis, 2012 ; Author)

In this literature review the potential water supply methods, water storage and waste water treatment and re-use paradigms will be studied through case studies of existing buildings to understand their potential and application in the Negin project. This can help in developing a statistical model to understand how net zero design can be achieved through integration of a sustainable water management scheme. Integrated urban water management adopts a holistic, systems approach to the urban water shed, addressing the drinking water demand, sewage water generated, and storm water stored. Studies carried on potential fog technologies for water harvesting in Southern Iran also show potential and can be considered as reliable water sources (Davtalab, Salamat, & Oji, 2013).

Case studies

Case study of 4 different ecolodges and a veterinary clinic was carried out in order to identify the decentralized water management schemes used, the functions proposed in them and the area demand for each function. The results were shared with NGO Simba and the management students and subsequently modified according to their requirements. The case studies are elaborated below and their inferences are tabulated and added in the end of the section.

Negaar traditional guest house, Varzaneh, Iran

Negaar traditional guest house is a historic building which was restored for housing tourists. The guest house is in a dense region of Varzaneh, Isfahan province as visible from Figure 12. The guest house was visited by the management students of TU Delft as a case study. It consists of a restaurant, 12 private rooms with en-suite bathrooms and 1 dormitory with shared bathroom. This guest house has also been picked up as a case study to understand the existing provisions that have been made for a tourist resort.

The findings of this project can be used as model information based on which the minimum required provisions can be designed.

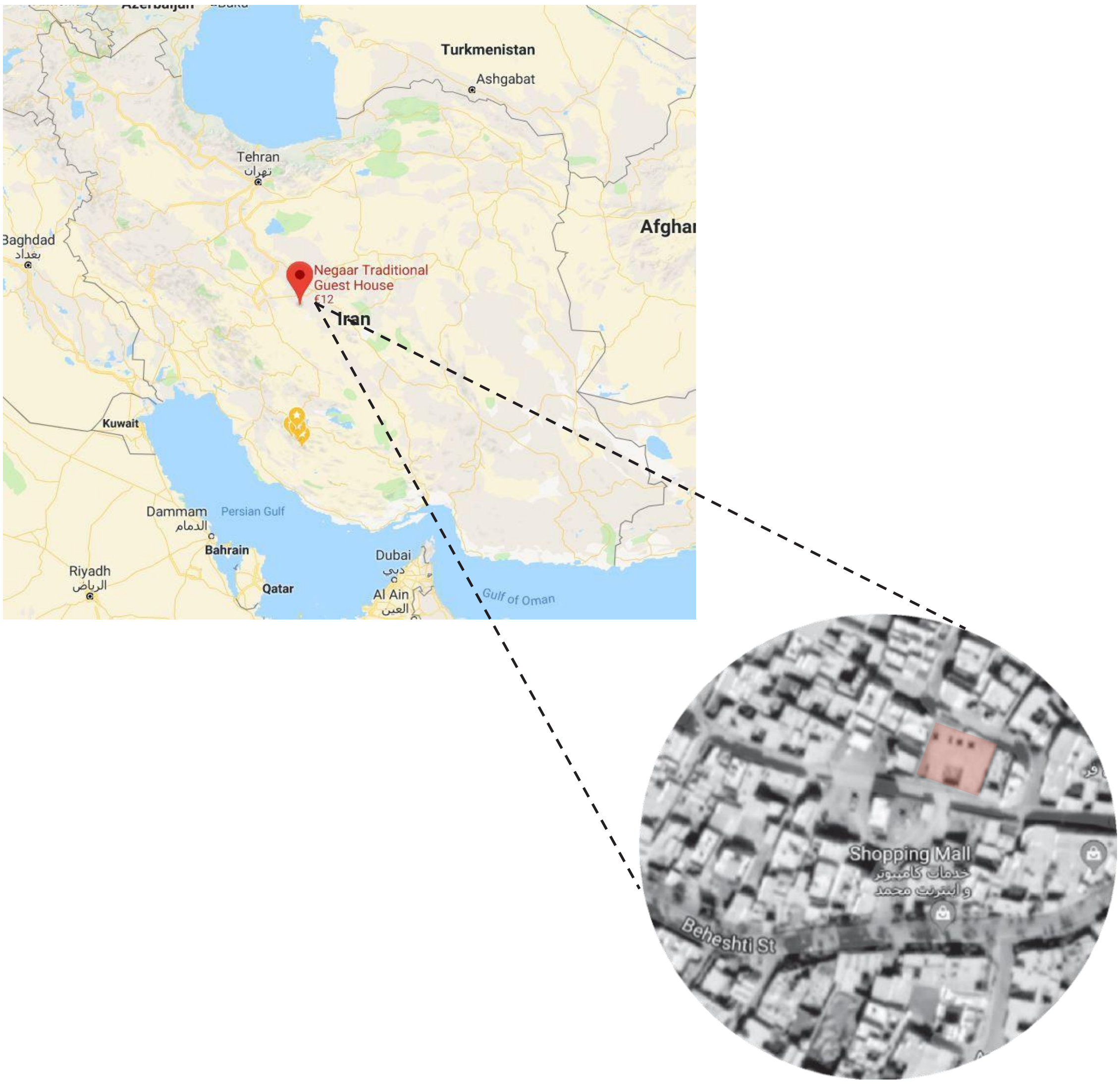


Figure 10: Location of Negaar traditional guest house, (Google Maps, 2018)

To acquire information regarding the water management scheme being followed in the guest house a list of questions was made which were shared with the management students. The management students during their visit to the guest house spoke with the owner of the guest house and in return reverted with answers to the queries in form of a report. The following paragraph mentions the questions asked to the owner of the guest house:

How is the potable and non- potable demand of water met?

Is the potable water treated at a local level?

How is the waste water treated?

Is the treated waste water re-used if not where is it discharged?

Is hot water supplied to the room? How is it heated?

Is rain water collected for use? Where is it used?

Approximately how many days in a year does the resort / guest house experience 100% occupancy?

What is the average occupancy Experienced throughout the year?

What is the total water demand in litres per day?

Figure 11: Image of the central courtyard of Nigaar guest house (left), image of the terrace(right), (Negaarhouse, 2018)

The potable water demand of the guest house is met by the central water network which collects water from a valley in Isfahan. Due to accumulation of salt the water pipes require replacement time to time. The water demand of cleaning the guest house is high due to which it is met through an existing well. The waste water from the washing of the guest house and the rain water is further re-used for gardening purposes. The waste water generated in the bathrooms and kitchen is discharged into the central sewage system where the water is treated and discharged in the wetlands (figure12). To ensure a comfortable, stay the guest house provides running hot water which is heated with the help of gas heaters. From the case study it can be concluded the lack of finances and infrastructure result in mismanagement of water resources. In this example opportunities of water treatment and local use for flushing and cleaning exist however they are not implemented. Despite government regulations barring locals from using wells as water supply leading to declining groundwater level these practices continue.

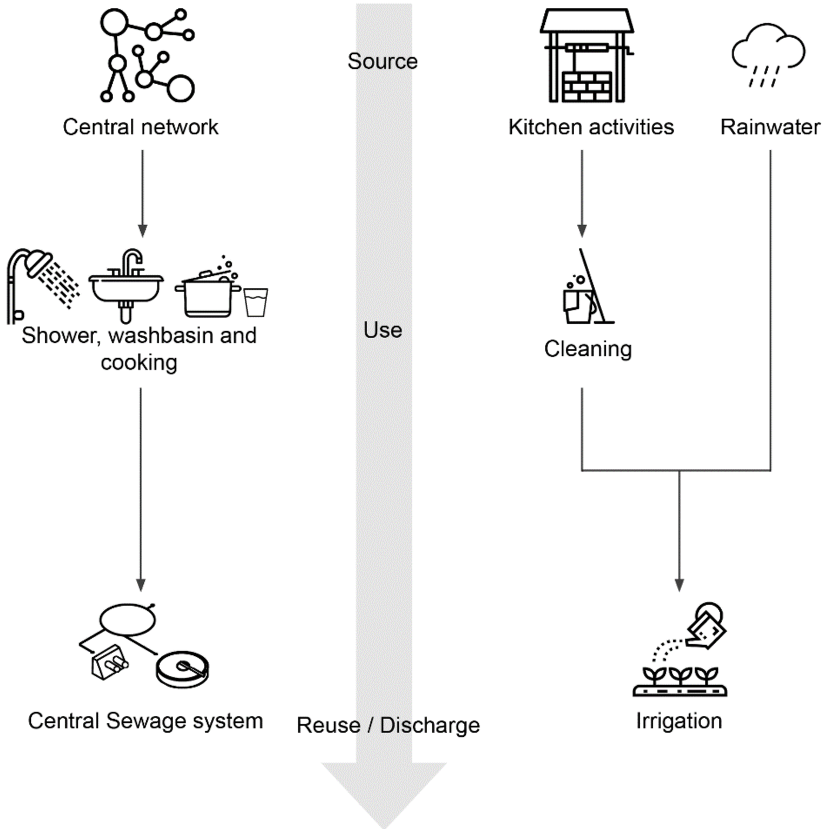


Figure 12: Water management scheme for Negaar guest house, (Author)

Al Karm Mountain Eco lodge, Egypt

The St. Kathrine protectorate was established in 1988 and is a unique high-altitude ecosystem with housing several rare species. The arid mountain supports a wide variety of flora and fauna. The principle of the region is to preserve the biodiversity of the fragile ecosystem and ensure that the growing tourism trend of the region does not have a damaging impact. Al Karm is the first Bedouin owned eco lodge built in the protected area which is owned and operated by the local community for generation of income and preservation of thecommunity's culture (Amara, 2017).

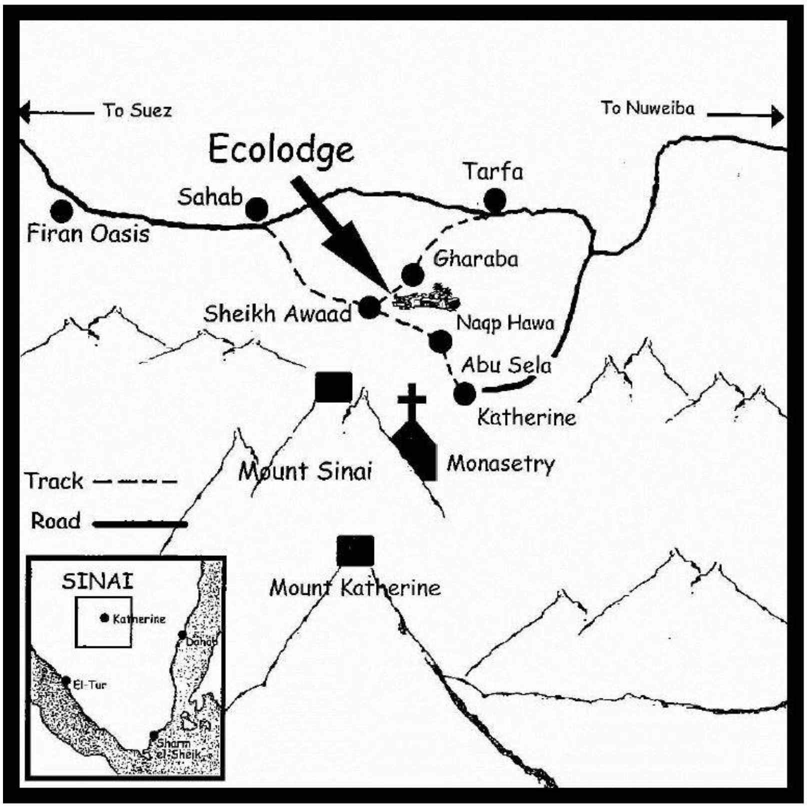


Figure 13: Location of lodge, Impression of Al Karm ecolodge (below), (El-borombaly, Yehia, & Khalil, 2014)

The lodge has been developed through the adaptive re-use of the vernacular architecture of an abandoned Bedouin mountain settlement by restoring and renovating it to turn it into an eco-lodge. The lodge has implemented sustainable low-technological techniques to minimize its environmental impact. This has been done through taking steps on saving water and energy, solid waste management techniques and waste water management and re-use techniques. The lodge consists of 8 bedrooms of double and triple occupancy which can accommodate 16-24 people. Additionally, the lodge also consists of a bakery, collective kitchen and restaurant, 2 showering areas, 2 toilets (1 for men and 1 for women), 2 main lounges and 1 Bedouin tent. No utility water supply network system or public utility sanitary sewage system exists on site.

Figure 14: Image of Al Karm Ecolodge, (Sheils, 2017)

The complete non-potable water demand of the household is supplied through gravity into an overhead tank from a nearby well located at a relatively higher altitude. The well is replenished by the rain in winter and flash floods water which is collected through the dams built for ground water recharge. To meet the potable water demand (drinking and cooking) bottled water is used. The waste water from showers, wash basins and kitchen sinks are collected in gravity lines to an isolated tank having a capacity of 2 days discharge. The tank treats the organic and biodegradable detergents and allows for the suspended solids to settle down. Further the water is filtered through a multi - level stepped trench covered in gravel following which it passes through the reed beds before it is used to irrigate the trees and shrubs in the orchard (El-borombaly, Yehia, & Khalil, 2014). The lodge consists of dry composting toilets. The composting tank is located under the toilet seat and is aerated by a solar powered fan inside a vent stake to keep the tank oxygen rich for aerobic decomposition. The cured compost is removed through a lower access door and used as a fertilizer for fruitless trees (El-borombaly et al., 2014). Figure 15 depicts the water management scheme used in this ecolodge. The Built environment of Al Karm follows the vernacular architecture of the traditional Bedouin settlement and makes use of the topography for transportation of the water within the lodge. The lodge incorporates sustainable techniques in-order to minimize the environmental impact and save the resources of the region.

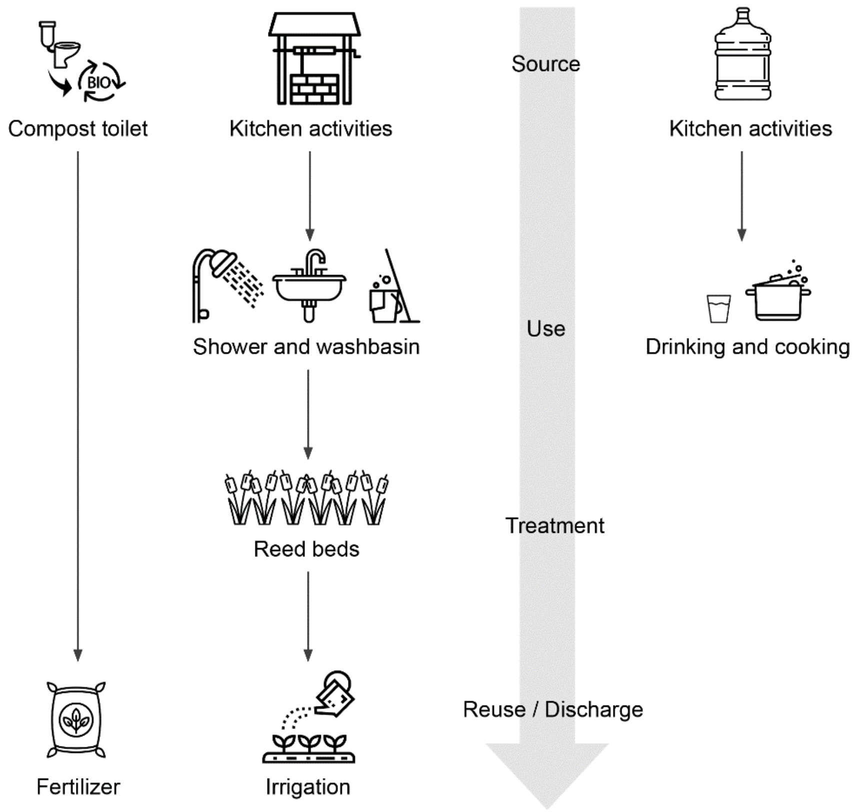


Figure 15: Water management scheme for Al- Karm ecolodge, (Author)

Matinabad Desert camp and organic Farm , Iran

The camp was established in 2008 45Km from Kashan , a touristic location in the central Iran. The Eco camp was developed with the principle of building sustainable tourism in Iran. The main building of the camp is built in the concept of a Caravanserai plan, a traditional style of Persian inn meant for tourists and merchants to rest after a long journey. The camp is built using local materials ensuring it has a minimal impact on its surrounding environment (Wei, 2013).

Figure 16: Location of Matinabad Desert camp, (Google Maps, 2018)

The Eco camp provides 4 types of accommodation – 40 small sized tents, 7 Large tents, 9 Caravanserai rooms, 1 luxury room and 13 Iranian cottages. All rooms consist of toilets apart from the tents which have public bathroom facilities. Additionally, the camp consists of a restaurant, kitchen and an organic farm. The can uses green technologies to reduce its impact on the surrounding fragile dessert (Matinaabd Eco Resort, 2016). The water drinking, cooking and irrigation is provided from a nearby Qanat. Qanat sloped underground aqueducts invented in Iran to help bring the underground water the surface mainly for irrigation (Matinaabd Eco Resort, 2016). The camp also makes use of solar and wind energy to heat the water used for shower and cooking covering the required amount for 100 people a day. 70 % of this energy is generated through solar panels. However, information on the waste water generation and treatment was not found.

Figure 17: Image of the camp built in Caravanserai (top) and Image of the tents (below), (Karimi, 2015; White, 2018)

Sossusvlei Lodge, Namib Desert

The Sossusvlei lodge is one of the mid-range lodges located in the periphery of the Namib - Naukluft National Park. The Namib sand sea is identified by UNESCO as a world heritage site and witnesses many tourists throughout the year.

The Lodge consists of 42 superior units and 3 junior suits consisting of a living area and king size bed with terrace and pool. In addition to this the lodge consists of a reception observation tower, dining, kitchen, swimming pool, souvenir shop and a conference centre with a seating capacity of 100 people (Sossusvlei Namibia - Travel site, 2018).

Figure 18: Location of Sossusvlei Lodge, (Google Maps, 2018)

The influx of tourists has increased the water demand and wastewater generation in the region which is a matter of concern for the private and public tourism industry of Namibia. The water demand of the lodge is met by using the groundwater which is accessed through boreholes. The water is pumped out using energy from the power line. The waste water is treated through simple septic tanks linked to French drain with an additional component of an evaporation pond. The treated waste water is disposed into the environment with the help of an evaporation pond which allow for the water to be evaporated rather than seeping into the ground and contaminating the ground water. In addition, the evaporation pond also allows oxidation of effluent for conversion of ammonia nitrate. The Lodge disposes of its grey water in evaporation ponds and does not put it to re-use. The waste water disposal site is located at a 500-800m distance from the fresh water source. However, a disposal system of this kind can act as a potential habitat for water borne disease vector and is not advisable (Amputu et al., 2014).

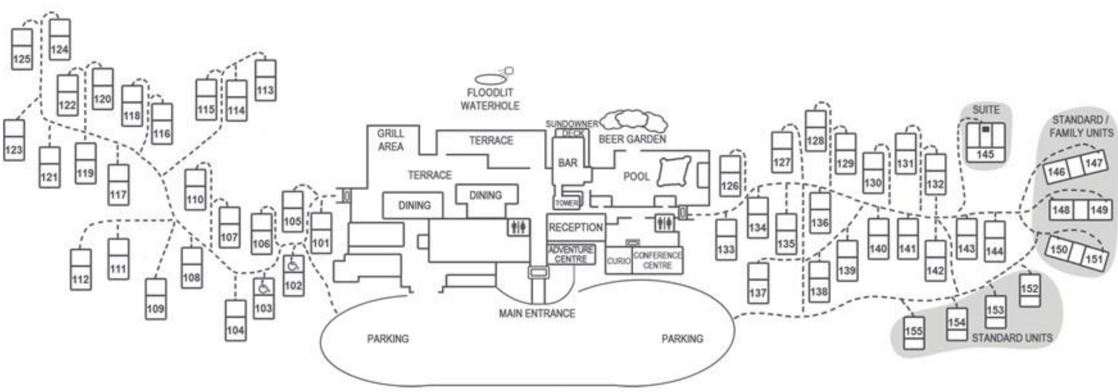
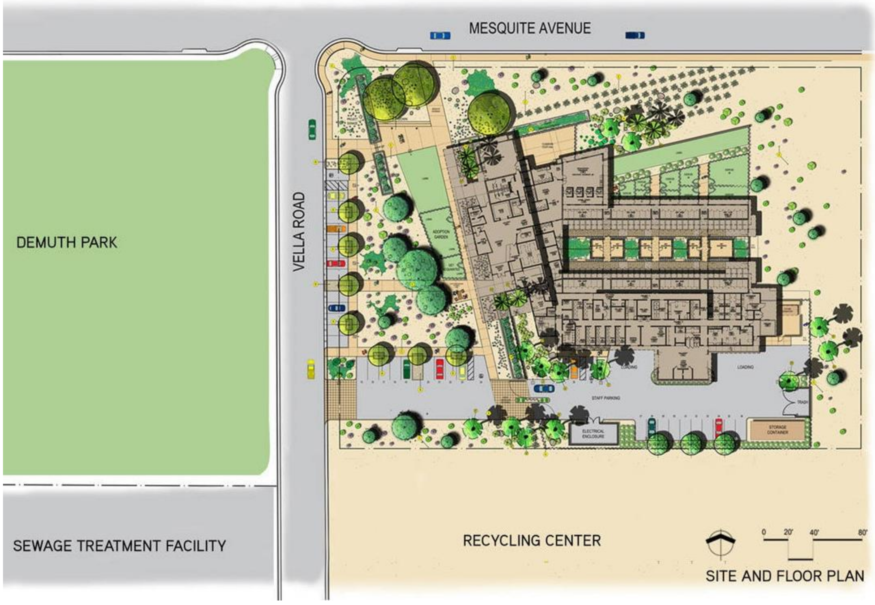


Figure 19 : Sossusvlei Lodge Layout (Sossusvlei Namibia - Travel site, 2018)

Figure 20: Image of a junior suite(left) and Image of evaporation pond (right), (Amputu et al., 2014; Sossusvlei Namibia - Travel site, 2018)

Palm Springs Animal Care facility, California

Apart from lodge facilities the NGO also wants to develop a dog centre and veterinarian clinic for the animals of the Safari park. Hence the Palm Springs Animal Care facility was picked up as a relevant case study to understand the functional demands and the water necessitates for such facilities. The project has been designed by the Swatt|Miers architects with an emphasis on water conservation. The total area of the project is 12,140 m^2. The potable water demand of the building is met through the central grid network. The waste water generated on site is treated in a sewage treatment facility and used for landscape irrigation and cleaning of animal areas this is further depicted in Figure 22. Portable hoses with quick coupler connections are then attached and used by staff. The plumbing system features a trap-less drain powered by flush controls to remove standing water in drains which helps avoid stagnation (Swatt | Miers Architects, 2012).



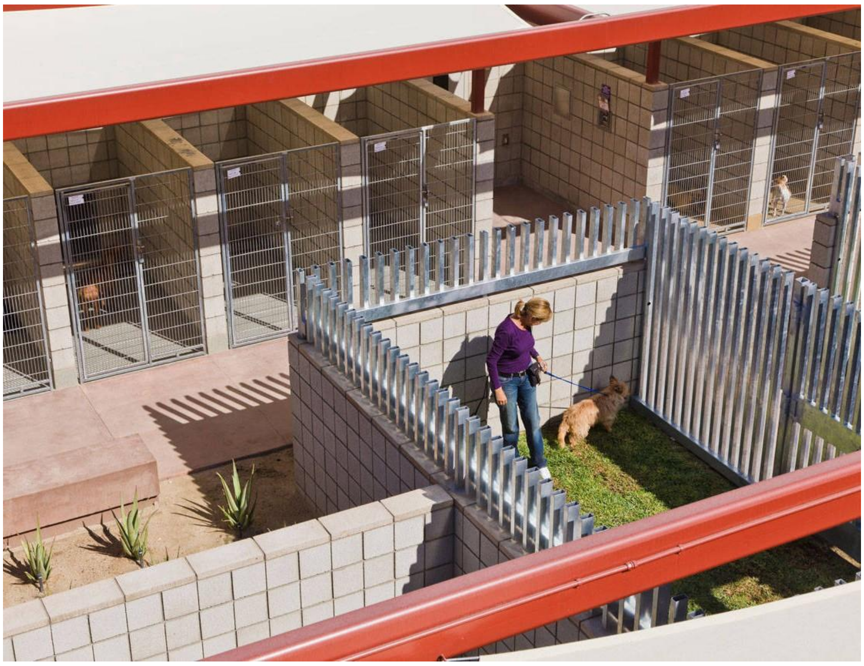


*Figure 21: Ground floor plan (top) and Dog shelter (bottom), (*Swatt | Miers Architects, 2012 ; *Archdaily, 2012)*

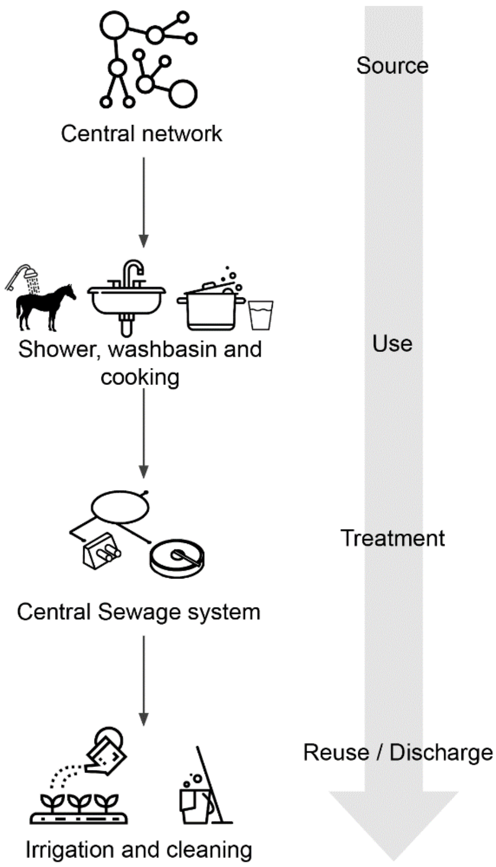


Figure 22 : Water management scheme at Palm Spring animal care facility, (Author)

Case study inference - water management

SNo.	Projects	How is the potable water demand met	How is the non-potable water demand met	How is the waste water treated	Is the water discharged or re-used	Is rainwater collected for re-use
1	Negaar Traditional guesthouse	Central water network	Local well and treated waste water	Waste water from kitchen and toilet discharged into main sewage system	the grey water from cleaning the guest house reused for gardening purposes	the rain water is reused for gardening purposes
2	Al Karm Mountains Ecolodge	Bottled water	Local well and treated waste water	grey water treated in isolated tank. Black water treated through dry composting	grey water used for irrigation purpose and by product of treated black water used as fertilizer	No
3	Matin Abad Desert camp and organic Farm	Qanat (underground water)	Qanat (underground water)	Information not available	Information not available	No
4	Sossusvlei Lodge	Groundwater accessed through borehole	Groundwater accessed through borehole	Septic tank and evaporation pond	Discharged through the evaporation pond	the rain water is harvested
5	Palm Springs Animal Care facility	Central water network	Treated waste water re-used	Treated in an adjacent sewage treatment plant	Re-used for cleaning animal areas and purpose of irrigation	No

Table 2: Comparison of different water management strategies use, (Author)

Case study inference – Bubble Diagram

The area chart for the functions has been tabulated and added in appendix I. Following this the area analysis has been grouped as per the functions, and their functional relativity is studied.

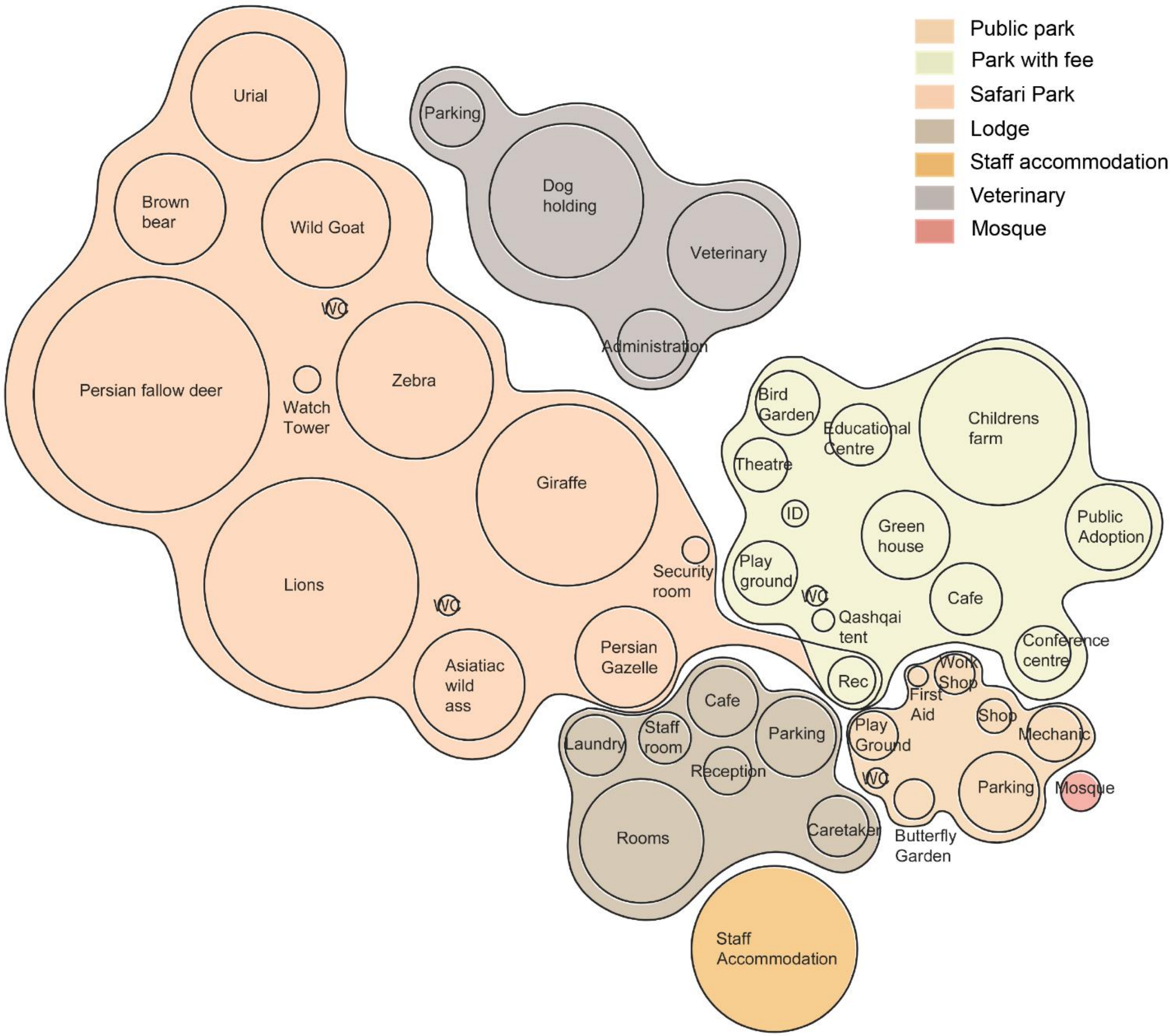


Figure 23: Bubble Diagram, (Author)

Initial Design

Chapter Overview

Prior to starting research on the water demand and water technologies a design was developed. This design was then used as a base for research on water technologies. This section begins with a site analysis to understand the impact the site and its surrounding environment have on the built form. It concludes by presenting a design on the basis of the area chart and bubble diagram developed in the earlier section.

Site analysis

The site is located at a distance of 23.4 Km from the city of Firoozabad. As per Iranian regulations the site needs to be placed 750m away from any village or establishment. The image below indicates the location of the site with relation to the nearby village further Figure24 indicates the features of the site.

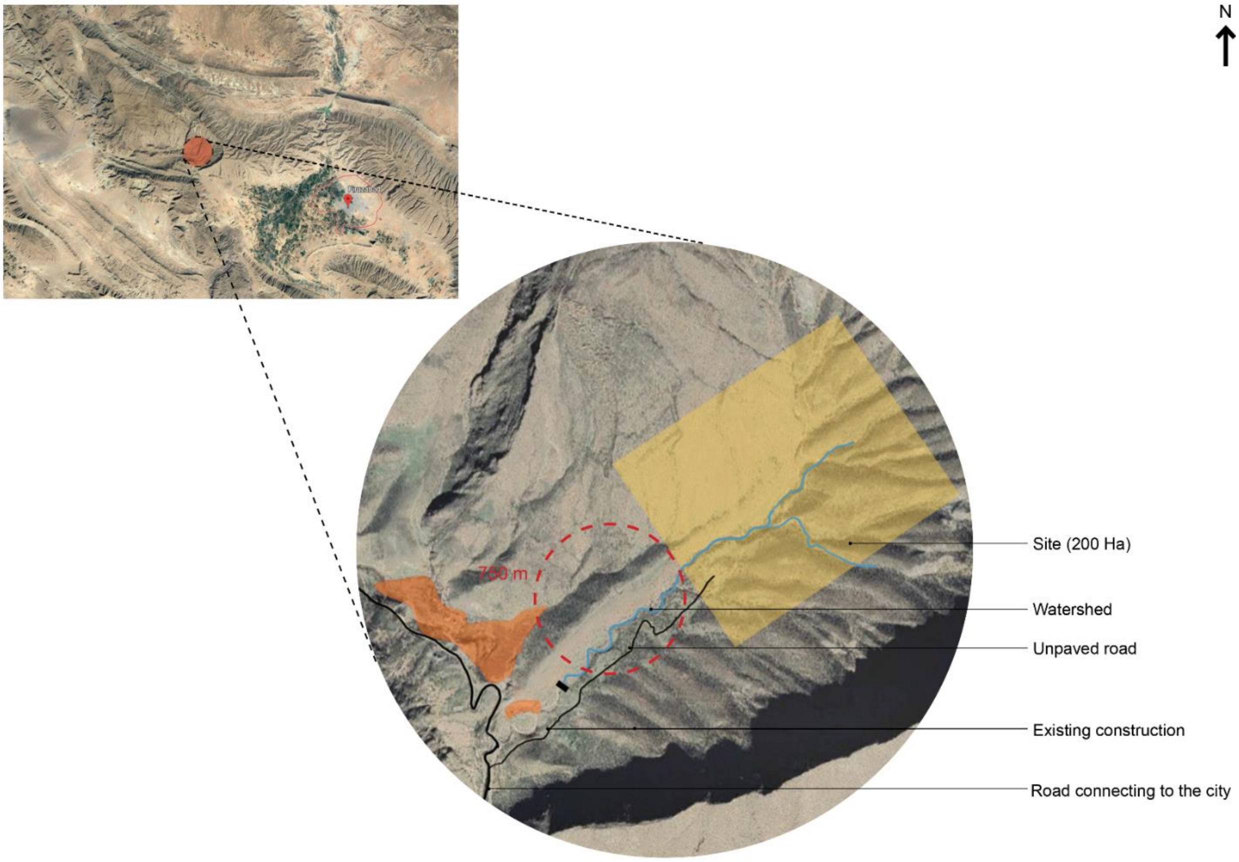
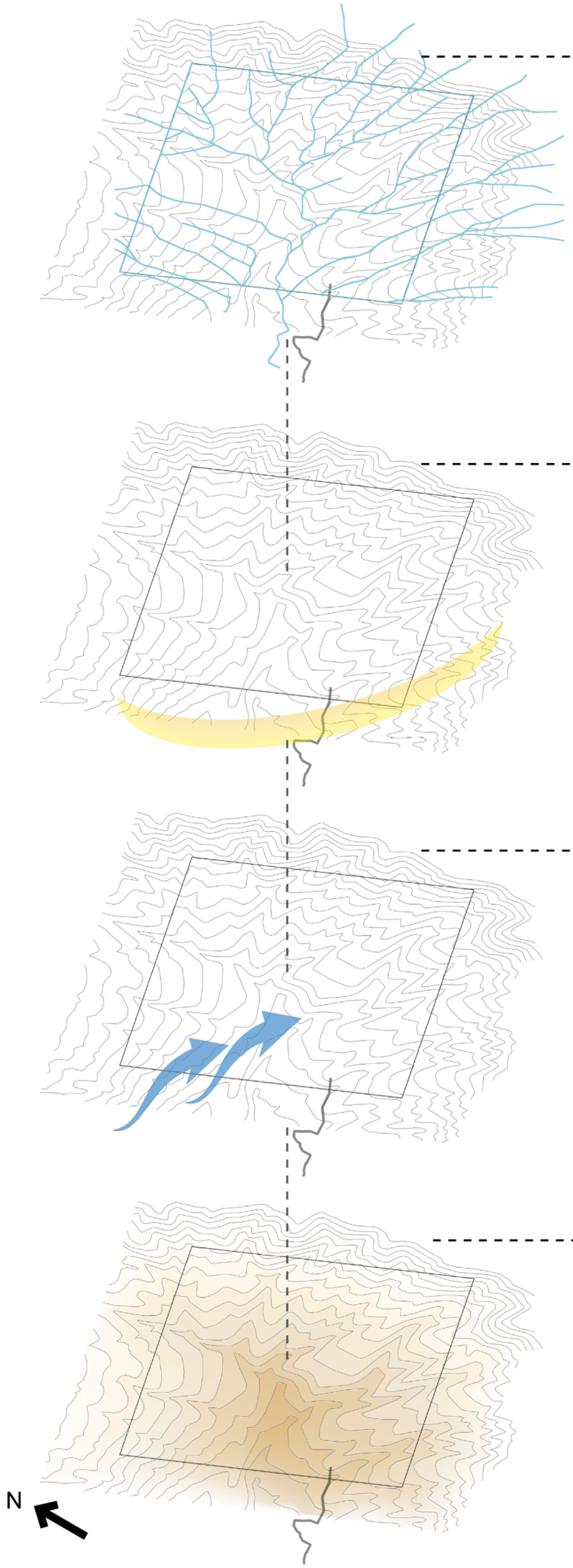


Figure 24: Site location with respect to surrounding, (Author)



Water

The ground water level is present at a depth of 200-300m. The rainy period lasts 5.1 months with a range of 50-100 mm. During these months a river is formed in the region however, the water quickly seeps into ground.

Sun Path

The length of the day in the region varies through out the year. In 2018, the shortest day was December 22, with 10 hours 18 minutes of daylight; the longest day was June 21, with 13 hours 59 minutes of daylight. The period during which the region is covered by clouds also varies. From May 17 to the following 5.3 months of the year Firoozabad faces the least amount of sky coverage.

Wind

The windspead in Iran varies from 5 km/h to 28 km/h. The prevailing wind direction in the region is South West to North East.

Site Topography

The site is slightly sloped over an area of 200 Ha. The highest point is on the East side of the site. Green vegetation is also scattered all over the site which is used as grazing lands for the Qashqai flocks.The soil is clayey soil.

Figure 25: Site analysis, (Author)

Design

The built form has been located on the lower region of the site as shown in figure 26.

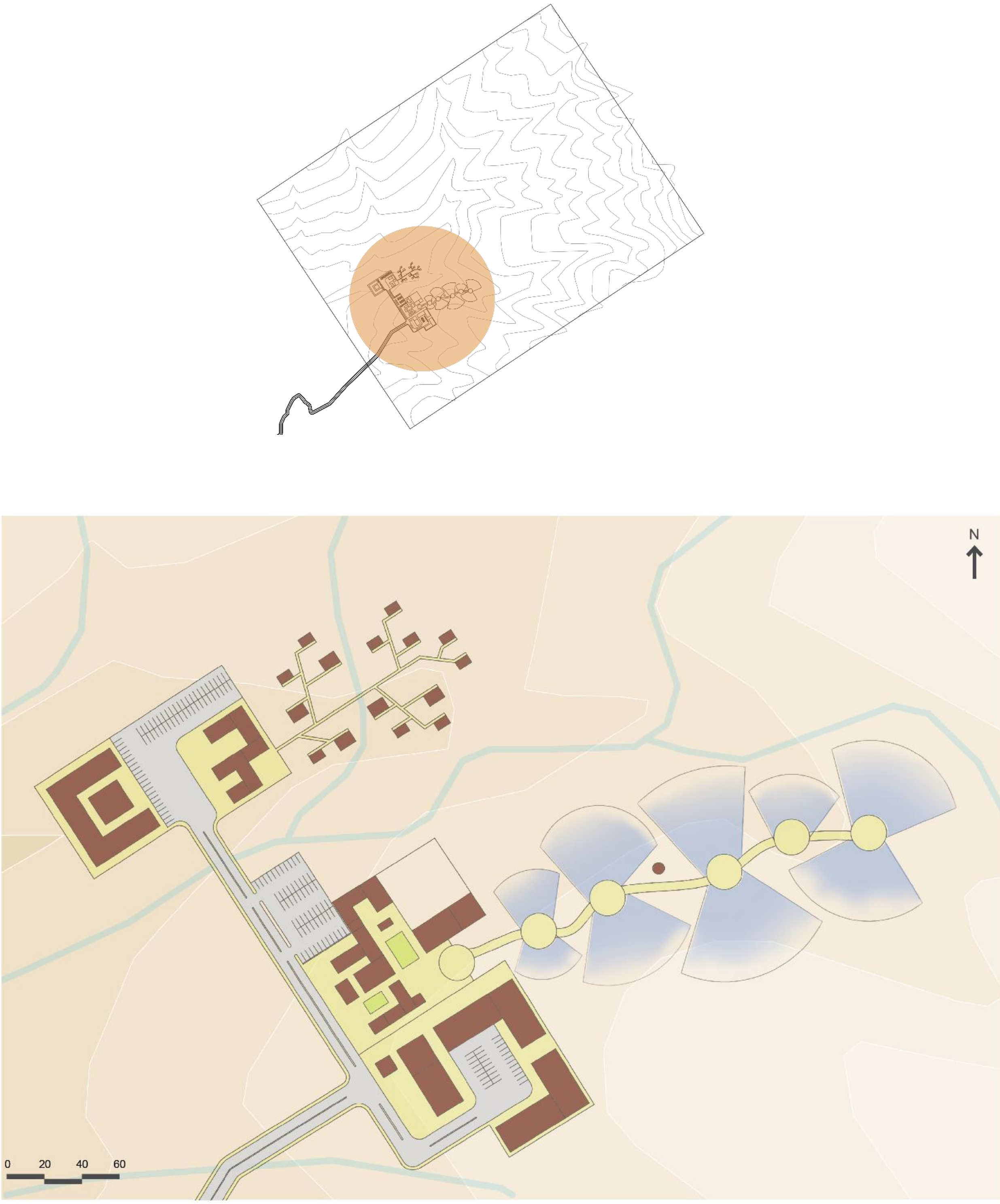


Figure 26: Location of built form on site (top) and Site plan (bottom), (Author)

The functions were placed on the site based on the grouping done while developing the bubble diagram. The public park was placed closer to the entrance with an intention to invite more visitors. While the park which would be accessed after paying a fee has been placed behind the public park. Vernerian facility has also been placed closer to the entrance so it has a direct and easy access to the main road. A designated parking area is provided for the veterinary for easy access for the ambulance. Additionally visitors coming to this park with a sole purpose of adopting an animal can also park their vehicles there. The lodging facility has been placed on the other side of the river watershed and is connected by a bridge. It is assumed that the visitors coming to the lodging facility would arrive by cars and coaches hence, a separate designated parking area has been provided. Staff accommodation has also been placed closer to the lodging facility.

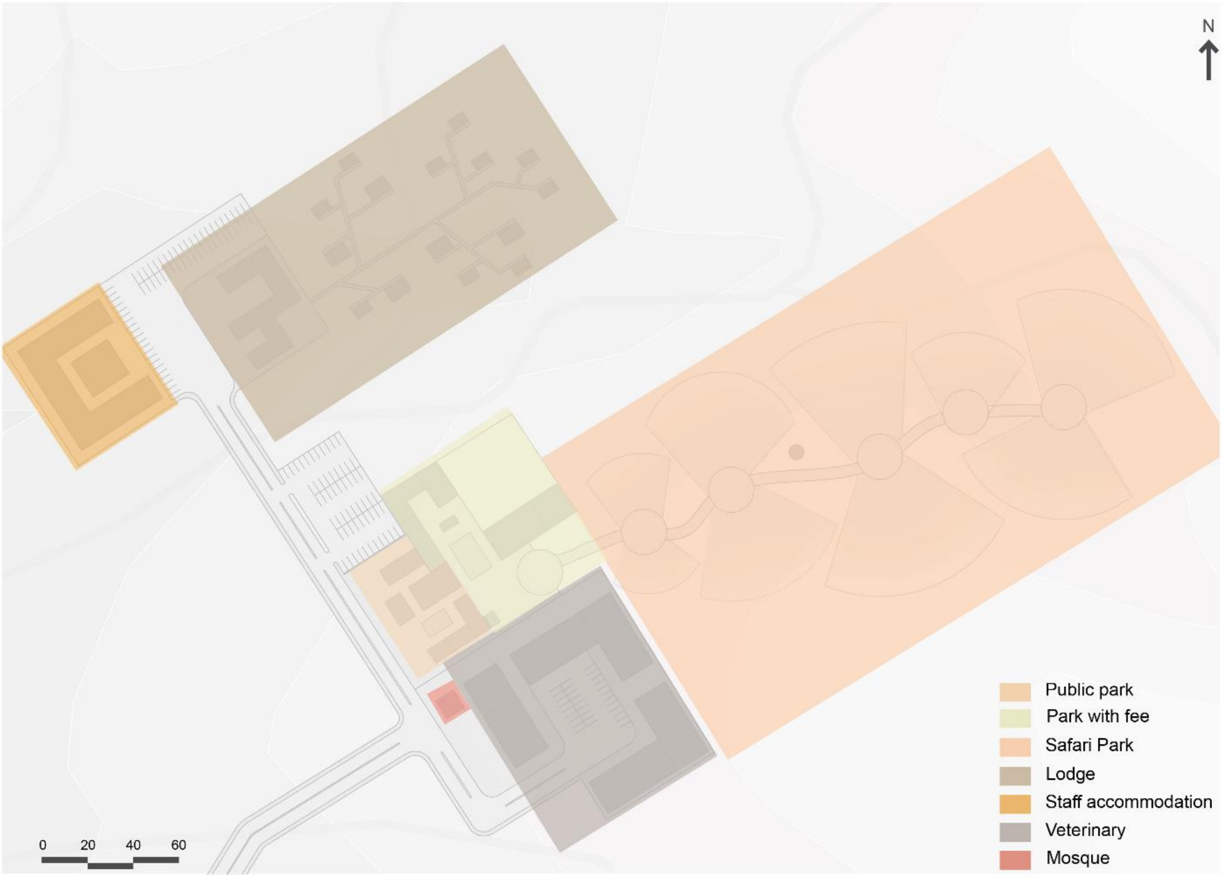


Figure 27: Site zoning, (Author)

Public Park

The playground has been placed in the centre to create a sense of liveliness as the visitors approach the public park. The built form is placed around the park with the butterfly garden and the shop placed at the entrance. The workshop and shop are grouped together as the products made in the workshop by the Qashqai women will be sold in the shop. The restaurant will be shared between both the parks and is placed at the cusp from where the park with fee would begin. The visitors will purchase the ticket from the reception counter and move towards the paid part of the park. The conference centre has been placed adjoining to the Restaurant on one end and the parking in the other so that it can operate as an independent function.

Figure 28: Public Park, (Author)

Park with fee

After entering the park with fee the visitor can choose to first visit the animal holding area or the rest of the park. The playground is located in the centre considering it will be the most liveliest function and would draw more visitors towards that area. The Qashqai tent is also centrally located as it acts as a fascinating function drawing people in to come and sit under the tent and enjoy traditional beverages while overlooking the playground. The animal farm is located on the far end to give the animals privacy and to allow for any future expansions.

Figure 29: Park with fee, (Author)

The animal holding area is accessed by the visitors through a foot bridge. The animal holdings are also developed with the concept to allow future expansion and addition of more animals. While the animals are confined in their zone a natural habitat for each animal holding is developed. The foot bridge has been developed with a concept that the visitor is always in the eye level of the animal to encourage positive engagement between the visitors and the animals. As this area is envisioned as an intersection of humans and animals wherein the visitors can educate themselves about the animals. This will ensure that the natural habitat is not disturbed by constant footfall and the visitors also get a better viewing angle of the animals.

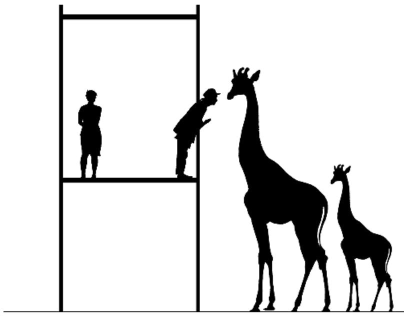


Figure 30: Concept of foot bridge   (Author)

Figure 31: Public Park, (Author)

Staff Accommodation and Tourist lodging facility

The lodging facility consists of a drop off zone from where the tourist can enter the reception from which they can proceed to their rooms.

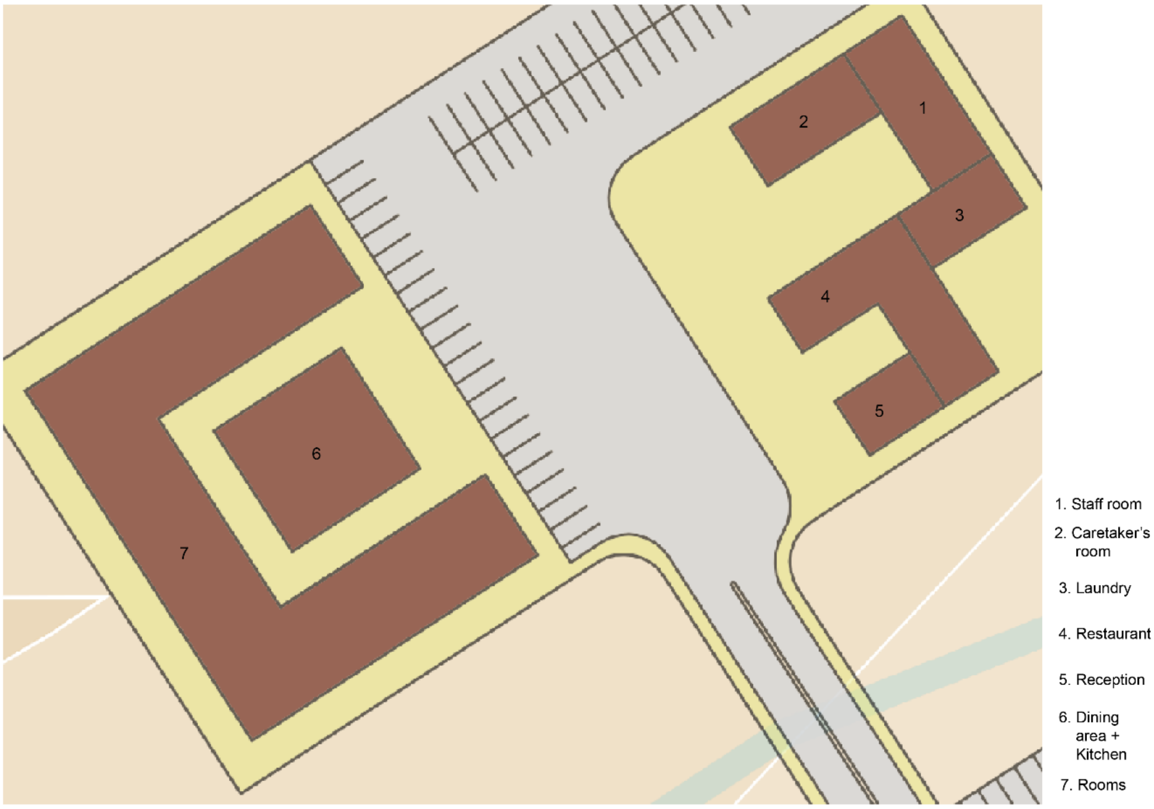


Figure 32: Staff accommodation and Tourist lodging facility, (Author)

The rooms are spread over the site to allow for a better viewing experience of the animal holding from the room and give privacy to each lodge as shown in figure 33. While the staff accommodation consists of double loaded rooms with attached toilets and a building block in the centre housing the kitchen and dining area.

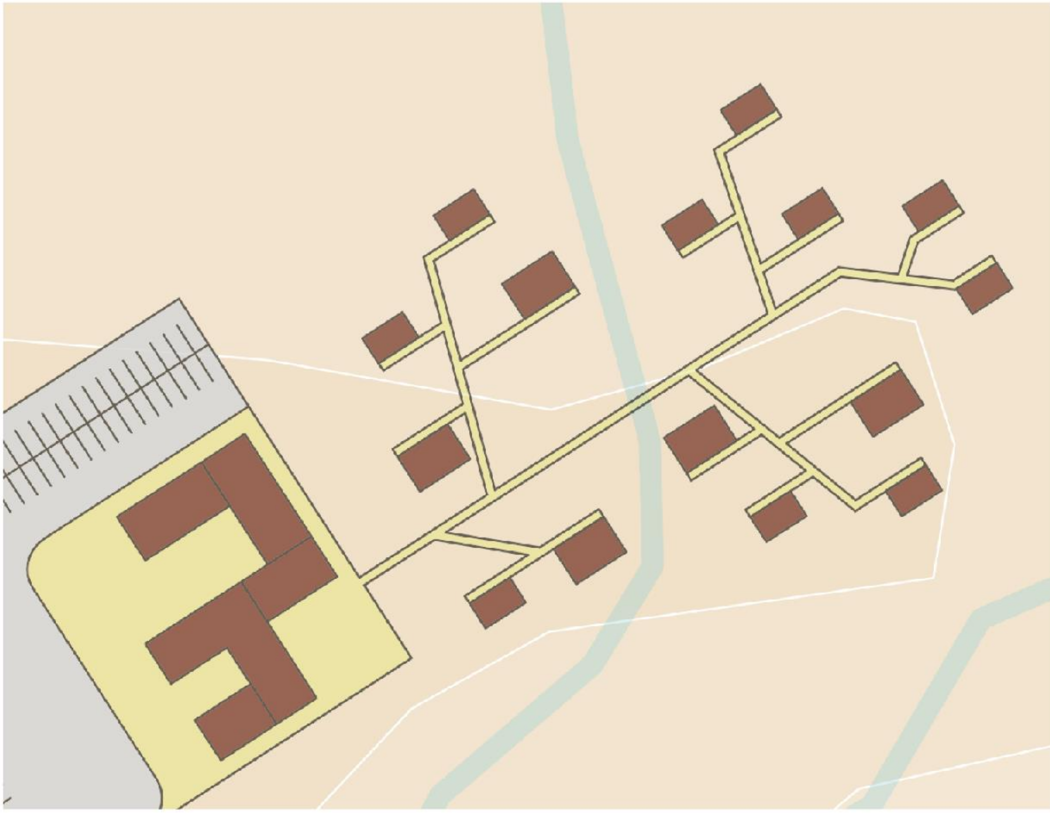


Figure 33: Lodge rooms, (Author)

Water demand

Chapter Overview

The following section addresses the first research question :

What is the estimated amount of potable and non-potable water required for uninterrupted functioning of the Safari Centre?

What is the amount of waste water expected to be generated within the site?

This is done by calculating the total water demand of the site on the basis of literature review and presenting it in a tabulated fashion for further reference . To calculate the water, demand the functions were divided into 9 categories. This was done based on the classification of different functions and their corresponding water demands found in the researched literature.

Lodge and Staff accommodation

The variability of domestic water consumption depends upon the availability of water and the cultural behaviour and habits of water consumers. While the indoor water demand remains fairly constant the outdoor water demand fluctuates greatly (Keshavarzi et al., 2006). Hence in this section only the indoor water demand was calculated while the outdoor water demand has been addressed in the following sections. For the calculation of the indoor water demand the water consumption has been further broken down into different utilities to get the final output, the total water consumption per capita per day was found to be 114 L during a period of maximum occupancy (AEE INTEC, 2005). The total number of people that will be using the facility daily are estimated as 48 guests and 58 staff members.

Public toilets

The water demand calculated for the fixtures installed in the toilet are based on the LEED baseline water consumption of fixtures and fittings. The total number of occupants was based on the area demand calculated in the earlier section. The water demand for the flushing is calculated separately for the men's and the women's toilet to address the water reduction due to use of urinals. The sex ratio of the visitors using the public facilities has been considered as 50:50.

Veterinary + Dog holding

Animal care facilities require a great deal of water for cleaning of kennel, animals, laundry and the floor. The water demand for these functions have been calculated separately per animal (Learned, 2014). The facility is considered as running on its maximum capacity hence the number of animals considered are 21 animals in the veterinary and 16 dogs which would be housed in the dog holding facility. The number of staff members required to run the facility are 7.

Gardening and Greenhouse

Keshavarzi et al., 2006 carried out a survey of 653 rural households in 33 vilages of Ramjerd area, Fars province to understand the daily water consumption patterns. This was done to address any deviations the statistics would have based on the location and household size. The water consumption for gardening , mainatianing a greenhouse and consumption of livestock was also measured. Based on the results the water consumption model for gardening and greenhouse was formulated:

Water consumption (LCD) = -0.882 garden area (m^2) + 0.872 garden watering time/ month + 1.6 green house area (m^2)

The garden watering time was considered as 9.4 times in a month for the garden and 13.7 times in a month for the greenhouse (Keshavarzi et al., 2006).

Restaurant

To calculate the water demand for the restaurant the utilities categorized are the drinking, food preparation, dishwashing and cleaning. For this calculation it is assumed a dishwasher will be used for washing dishes, in the case that the dishes will be washed by hand this demand can go up. The water demand for cooking is taken from the WHO standards and does not address the deviation in the water demand that may occur due to cultural differences in cooking. As the average number of daily visitors is 76.5 this value is considered to calculate the water demand of the restaurant (NGO, Simba).

Ablution

The water demand required for ablution in a mosque is 6-9L per person (Johari, Hassan, Anwar, Engineers, & Kamaruzaman, 2013) higher end of the value has been considered with an estimation of 50 people visiting the mosque.

Zoo animals and Children's Farm

The water demand for the animals was divided into two parts: water required for drinking and water required for cleaning and washdown of the animals. The drinking water demand for different animals has been researched and referenced in the table. Where the drinking water demand of the animal was not found an assumption was made based on its weight and similarity with other animals.

Conclusion

The breakup of the water demand on the basis of the utilities is tabulated and added in Appendix II. Total daily water demand of the Safari park was found to be 19364 L per day. The water demand was further divided in terms of potable and non-potable water consumption. The water required for drinking, cooking, bathing and washbasin was considered as potable water and the rest of the water demand was considered as non-potable water. Figure 24 shows the breakup of the potable and non-potable water consumption for the Negin Safari park.

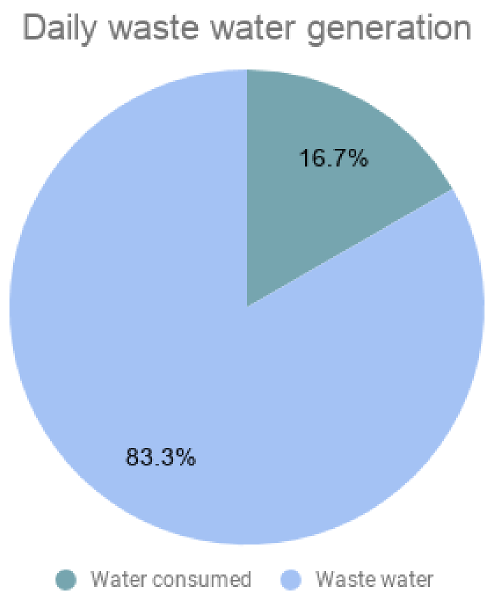


Figure 24: Daily water consumption at the Negin Safari Park, (Author)

Further the water being converted to waste water was also calculated as opposed to the water consumed this is shown in Figure 25.

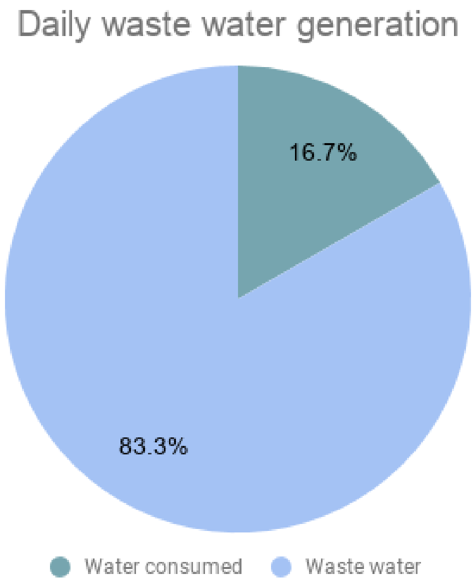


Figure 25: Daily waste water generation at the Negin Safari Park, (Author)

Hence a large part of the water demand turns into waste water, the upcoming sections will further the potential of treating this source for purpose of re-use to partly meet the water demand originating on site.

Sourcing of water

Chapter Overview

This section addresses the following research question :

What technologies can facilitate the sourcing of water on site? What is the quality of the sourced water and its application?

What is the estimated quantity of the sourced water through these technologies?

For the purpose of research this section was divided into two parts i.e. water collected through rainwater harvesting and moisture collection through atmospheric water generators. The potential of several technologies were studied in order to harvest water and their feasibility on site was verified by analysing its potential in Iranian climate.

Rainwater harvesting

Rainwater harvesting system are a decentralized method of collecting rainwater for storage and later use. The rainwater is generally stored at or near the location where the water demand arises (Kurian & Ardakanian, 2015). In a rainwater harvesting system rainwater is collected in a catchment area such as from the roofs of the building and transferred to a storage tank through a down pipe (Santasmasas, Rovira, Clarens, & Valderrama, 2013).

As per the data available on the precipitation of Firoozabad , the annual rainfall experienced for the past 30 years in the region was found to be 273mm (https://www.meteoblue.com , 2019).

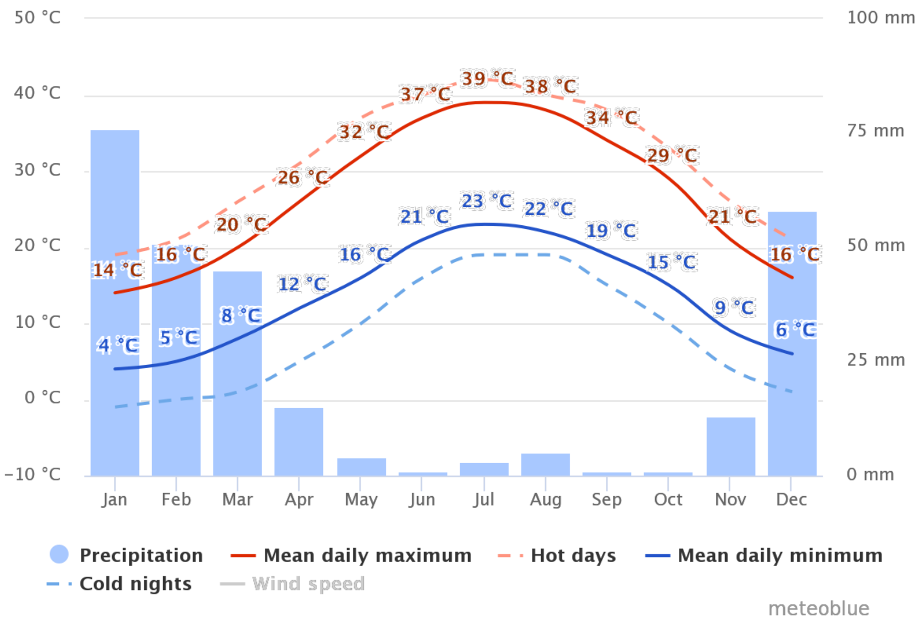


Figure 26: Average temperature and precipitation experienced in the Firoozabad city,(https://www.meteoblue.com , 2019)

The maximum amount of rainfall experienced in Firoozabad is during the winter months. While during the summer months the city faces below average rainfall. Hence to meet the water demand for the summer months water will have to be collected and stored during the winter months.

Rainwater Quality

While roof tops are considered as typical catchment surfaces, areas like patio surfaces, parking lots , pathways and channelled gullies can also serve as stormwater catchment surfaces. However water from these surfaces cannot be used for potable purposes without an accompanied treatment system installed (Kinkade-Levario, 2007).

Further the existence of desert has a considerable effect on the quality of rainwater , Iran is 85% desert due to which the rainwater runoff also has concentrates of sand dust similar to rainwater harvested in Jordan (Moore & Attar, 2011). A study done on the physical and chemical characteristics of the rooftop rainwater collected from cisterns of Jordanian homes (inclusive of first flush) showed that it met the drinking water standards put in place by WHO (Table 3). In order to ensure potability of water chlorine should be added to the cistern once a year so that the total coliform is eliminated as well and the rooftop catchment areas should be regularly cleaned (Abdulla, 2009).

Constituents	WHO standards	Min.	Max.	Average
Temperature, °C	—	16.3	0.197	18.6
pH	9.2–65	7.1	8.6	7.4
O_2 saturation, %	—	50.0	77.0	61.5
TDS, mg/l	200–500	76.38	681.1	270.2
EC, µs/cm	<250	114.0	1,017.0	402.6
Total hardness, mg/l	500	50.0	270.0	140.3
Total chlorine, mg/l	—	0.0	0.22	0.055
Total coliform counts/100 ml samples	0	11.0	56.0	33.0

Table 3: Water quality of rainwater collected from cisterns installed in Jordanian homes (Abdulla, 2009)

Hence it can be presumed that the rain water can be collected and used to meet the potable water demand of the site.

Rainwater Catchment

The water collection through a catchment area is calculated by the below mentioned formula (Thomas, 2008) :

Annual water collected = Catchment Area (m^2) X Average annual rainfall (mm) X runoff coefficient

The runoff coefficient is considered on the basis of the material of roof , its roughness and the angle of roof . Guisasola et al. in 2011 studied the 4 different roofs in Spain with an objective to develop a criteria for roof selection in order to maximize the rainwater collection. Each roof had a different material on its surface i.e. clay tile , metal sheet , polycarbonate plastic on sloped roof (30°)and a flat gravel roof. Their findings showed that sloping a roof with a smooth surface was able to harvest 50% more rainwater in comparison to a flat roof. Table 4 indicates the runoff coefficient for different slopes and roof materials.

Roof	RC	Reference
Roofs (in general)	0.7–0.9	Pacey and Cullis (1989)
	0.75–0.95	ASCE (1969), McCuen (2004), Singh (1992), TxDOT (2009), Viessman and Lewis (2003)
	0.85	McCuen (2004), Rahman et al. (2010)
	0.8–0.9	Fewkes (2000)
	0.8	Ghisi et al. (2009)
	0.8–0.95	Lancaster (2006)
Sloping roofs		
Concrete/asphalt	0.9	Lancaster (2006)
Metal	0.95	Lancaster (2006)
	0.81–0.84	Liaw and Tsai (2004))
Aluminium	0.7	Ward et al. (2010)
Flat roofs		
Bituminous	0.7	Ward et al. (2010)
Gravel	0.8–0.85	Lancaster (2006)
Level cement	0.81	Liaw and Tsai (2004))

Table 4: Review of runoff coefficient estimates (Guisasola et al., 2011)

The study also found that the rainwater collected from the flat roof had higher level of pollutants due to particle deposition , roof weathering and plant colonisation.

Rainwater Quantity

The total rooftop area as per the design was found to be 7907m^2 (Figure 27). For the purpose of calculation the roof runoff coefficient was considered as 0.95 and the annual rainfall 273mm.

Figure 27: Rooftop catchment area, (Author)

The annual water collection using the above mentioned data was found to be 2050m^3.

Storage of rainwater

Cisterns are used to store the harvested rainwater and are usually made of stone, Steel , concrete , ferro-cement, plastic or fibre glass. A tight cover over the cistern is essential to ensure water loss due to evaporation , mosquito breeding and entering of other insects in the tank. These tanks should also not allow sunlight to enter or this could lead to growth of algae inside the container (Kinkade-Levario, 2007). Further on rainwater storage tanks are more often also placed under the ground to avoid contamination and the adverse impact of the outdoor climate on the water (Abdulla, 2009). A cistern that is cool and a devoid of sunlight often helps in improving the water quality as photosynthesis cannot take place which leads to most organisms dyeing as their food source is eliminated (Kinkade-Levario, 2007).

Conclusion

Rooftop rainwater catchment systems can be concluded to be a reliable sources of potable water on the basis of the above research. However the water quality should also be tested on site periodically to ensure the standard drinking water requirement is met. On calculating the potential of rooftop rainwater harvesting for the Negin safari park the total harvested rainwater did not meet the complete potable water demand. Hence further research on alternative methods to source potable quality of water needs to be looked into.

Air to Water technology

The following section studies the potential of capturing atmospheric moisture for use. This has been done by studying five different technologies as mentioned below. In the final section of this chapter the different technologies have been tabulated and compared to propose an ideal technology for the Safari park.

Fog harvesting device

Cooling condensation device

Metal organic framework 801

Solar Hydro panel

Watergy greenhouse

Fog harvesting device

To investigate water harvesting from fog and air humidity Davtalab, Salamat and Oji in 2013 carried out a research through collecting data from 10 synoptic stations in the coastal region of Iran adjacent to the Persian Gulf and Oman Sea (Figure 28). Despite the average number of foggy days amounting to 41 investigation showed that the region had a potential to harvest moisture from the air for 160-360 days. Their findings showed that during summer a higher amount of water was harvested from the stations located near the coast while the station which were farther away from the coast experienced maximum collection during winters. Hence concluding that the moisture in the atmosphere could potentially be harvested for use (Davtalab et al., 2013).

Figure 28: positions of the synoptic station (Davtalab et al., 2013)

Figure 29: Image of an installed Fog harvesting device (Stenhouse, 2017)

The technology used to extract water from fog and atmospheric humidity is a simple device consisting of unidirectional rectangular nets of nylon supported by vertical poles at its lateral extremities and placed perpendicular to the pre-dominant direction of wind. The collectors can also be designed in complex forms , they can also be made of several collection panels for easy maintenance which can be joined together to form a more optimized structure. The number and size of the modules chosen are dependent on the limitation of the material chosen to build the structure and ease of mount ability (Calixto, 2018; Vittori, 2018). When the moisture in the air meets the mesh, it gets trapped and when the droplet becomes larger in size it trickles down the mesh due to gravity . These droplets are then collected in a storage tank placed below or adjacent to the mesh. The water collected through this system can be used for potable water purposes (Vittori, 2018).

The device is found to be only functional when the relative humidity of the region is above 69% (Davtalab et al., 2013). Hence the time during which the relative humidity of the city was above 69% was corroborated to study the potential of the device and the findings showed that the device would run for a period of 6.1% throughout the year. The annual water collected from this device amounted to 4548 l/m^2 of mesh.

Cooling Condensation

Another method through which atmospheric humidity can be extracted is through condensation of water vapour present in air. This is done by cooling the moist air below its dew point by bringing it in contact with a cool surface. Hence energy is required to create a cooled surface for this process to work (Gido, Friedler, & Broday, 2016). Several prototypes of atmospheric water generators using the concept of condensation have been developed and patented. The device also consists of a filtration processes which generates water of drinking water quality (GENAQ, n.d.; SKYH2O, n.d.; Watergen, n.d.). Figure 30 depicts the components of an atmospheric water generator.

Moist air is filtered through an electrostatic filter and passed through an evaporator and condenser and is driven out using an exhaust fan on the opposite end. While the air passes over the evaporator the moisture in the air condenses and is collected in a tank placed below the evaporator. The water is then treated through a UV filter and a multi stage filter system, so it can used for potable purposes.

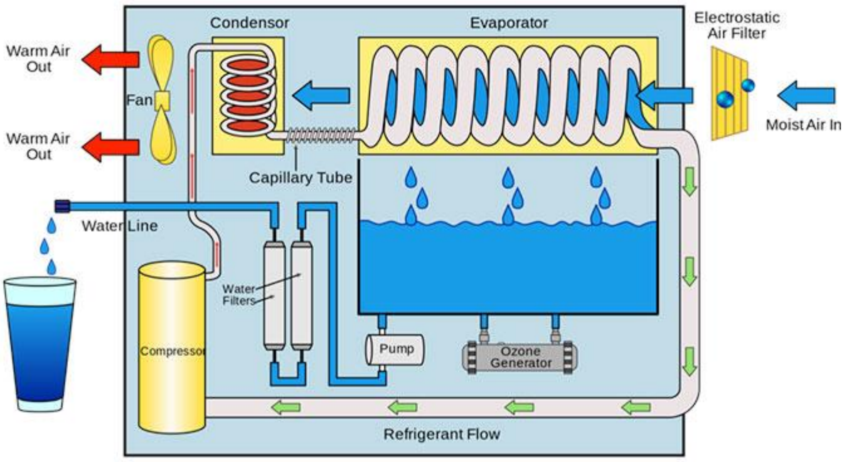


Figure 30: Diagram of a cooling condenser (Tripathi et al., 20160

As a rule of thumb these condensers do not work efficiently when the temperature is below 18^{o}C and the relative humidity is below 30% (Tripathi et al., 2016). The system can effectively run for 9.3 % period in the whole year. As the system is found to be ineffective during a large part of the year there are possibilities that the machine would malfunction (Gido et al., 2016)

Metal organic framework 801

The department of Mechanical engineering, MIT in collaboration with University of California Berkley developed a pilot project using a material which can take up and release water with a minimum amount of energy requirement and is powered by the sun's energy. The material is known as metal organic framework (MOF-801). The minimum relative humidity in which the material can adsorb water is 20%, minimum temperature requirement is 25^{o}C and a maximum solar flux of 1Kwm^{-2}. Hence the water is adsorbed during the night time when the solar flux is low. During the day with the help of the solar flux over 7KWhm^{-2}day^{-1} vapour desorption occurs.

This means that the material can absorb water 43.9% of the year. 2.8L of water is generated daily with 1Kg of MOF801 which amounts to 449L annually Per kg of MOF 801. Further research is being carried out by the university to find materials with higher absorption rates and lower cost investment (Fathieh et al., 2018).

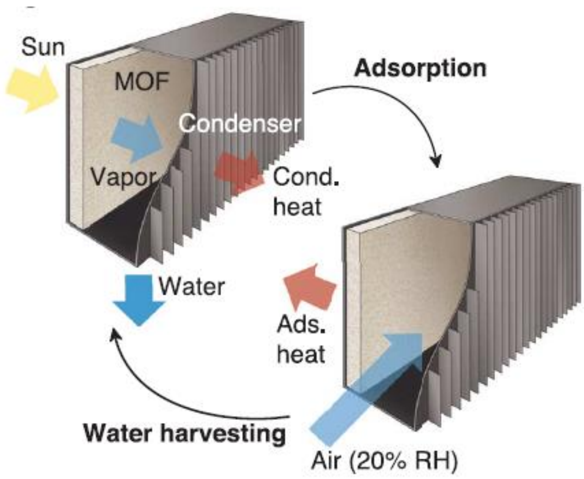


Figure 31: Diagram of MOF-801 prototype (Fathieh et al., 2018)

Solar Hydropanels

An Arizona based company called Zero Mass water has developed a novel solar hydropanels called Source to generate water from atmosphere. The technology uses solar energy to raise the dew point inside the panels that drives passive condensation and helps generate drinking water. The ambient air containing moisture is drawn into the panel wherein the advanced hygroscopic material adsorbs the water in the air. Following this the solar thermal power desorbs water from the hygroscopic material which is converted into large water vapour particles within the hydropanel resulting in formation of water that can be collected in a reservoir. Minerals are added to the collected water to improve its taste and provide optimal health so it can be used for drinking. Also the reservoir needs to be regularly cleaned to maintain the water quality.

The system claims to work when the Relative humidity is above 20% and the solar energy is above 13.7 Whr. Hence the device will function 30% of the time. The lifetime of each hydro panel is 15 years. Each panel can produce 2-5l of average water a day which amounts to 215L – 540L per panel annually considering only the period during which the panel is active (Zero Mass water, 2019).

Figure 32: Image of an installed solar hydropanel (Zero Mass water, 2019)

Watergy greenhouse

A closed greenhouse was developed with the concept of creating a closed environment for cultivation of crops which could lead to a reduction of water demand. Installation of such greenhouses increases the indoor air humidity resulting in the need for installing de-humidifiers. A Prototype of this greenhouse of area 200m^2 was installed in the arid region of southern Europe, Almeria , Spain during the year of 2004 – 2005 during the EU research project called Watergy. Cultivation of Green beans and Okra was successfully done in this greenhouse with an average water demand of 1.5 L/m^2. This water demand can also be met by impure water. The water collected due to the condensation process was found to be 75% of the total amount of water put into the greenhouse. 65% of this water was collected through condensation while the rest 10 % was collected through the drain of the greenhouse.

Figure 33: Image of the closed greenhouse (top) and section of the closed greenhouse indication airflow (bottom) ; (Buchholz, 2008)

The greenhouse consists of three elements a 10m high cylindrical cooling tower placed in the centre of the greenhouse, the vegetation area and the roof area which is placed above the vegetation area. A cooling tower is introduced in the centre of the greenhouse to reduce the total energy demand for cooling the greenhouse mechanically.

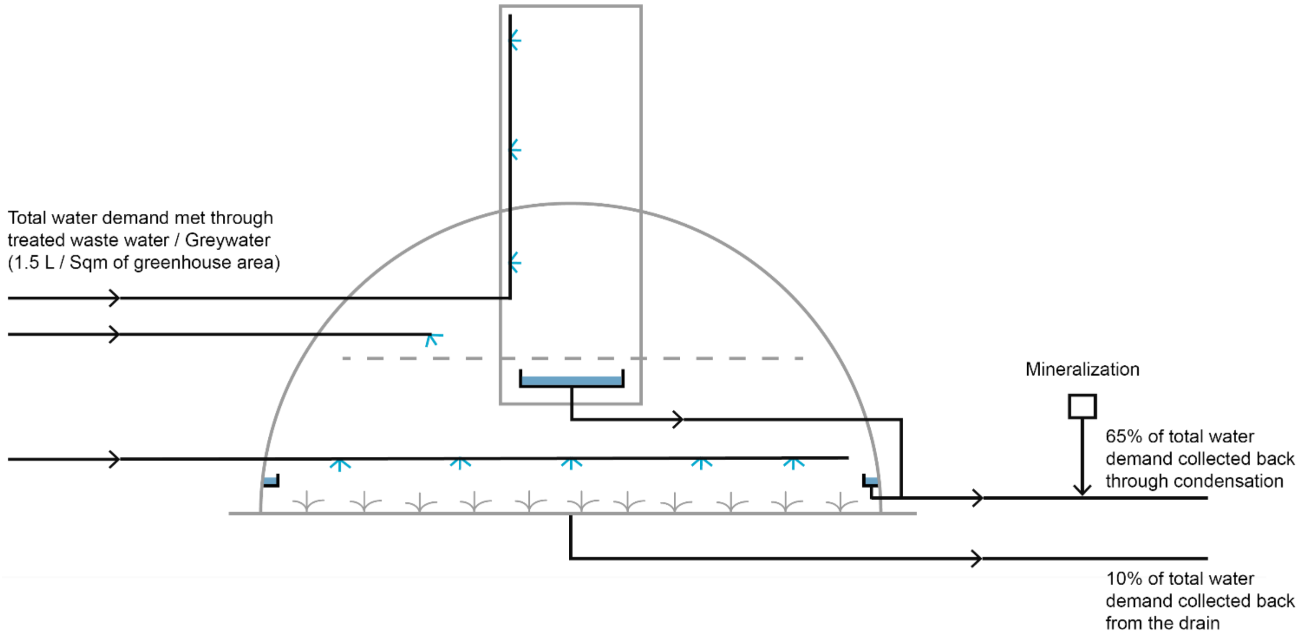


Figure 34: water distribution and collection within the closed greenhouse (Buchholz, 2008)

Through the day hot air carrying evaporated moisture travels from the vegetation area into the cooling tower. During this process water is sprinkled in the roof area to increase the number of water molecules present in the rising air. As the air reaches the top it is cooled by a heat exchanger due which it drops down. The cooling media used for this purpose is water which is stored in a tank outside. Due to the cooling process the humid air condenses on the cooler surface which is collected for the purpose of re-use.

While during the night in order to release the heat back into the greenhouse and cool down the storage the water flows in the reverse direction in the heat exchanger. In order to increase the heat release process the tower is humidified with the help of sprinklers. During this process the water is condensed on the walls of the greenhouse and can be collected for re-use. By installing this greenhouse condensed water can also be used for potable functions after mineralization (Bucholz, Bucholz, & Jochum, 2006).

Within the safari park the greenhouse which has been proposed has an area of 375m^2. The irrigation demand of this greenhouse would be 562.5 l/day. Hence, the amount of water which can be collected through evapotranspiration of plants and further condensation of moisture amounts to 366 l/day.

Conclusion

As the cooling condensation device functions for a limited amount of period which may increase its chances of malfunctioning this device is considered ineffective for the Negin Safari park. The MOF-801 and Solar hydropanels are required in a large quantity if they need to meet the drinking water demand for the park which renders these devices ineffective due to the high cost investment involved.

While the fog harvesting device works for a limited period of time the amount of water collected during that interval is found to be the highest. With a smaller mesh area and zero energy demand this device shows potential. The closed greenhouse also is a novel technology which can facilitate the growth of diverse vegetable due to the cool and humid indoor environment it can provide in an arid regions. The vegetables grown in this greenhouse can also be further marketed and the water collected can be mineralized and used to meet the potable water demand of the park. A further cost analysis has been carried out on these technologies for the reference of NGO Simba (Appendix IV,V and VI).

Technology	Minimum relative humidity	Minimum Temperature	Solar flux	% of the year technology is active	Area requirement	Average water generated annually	Reference
Fog harvester	69%	-	-	6.80%	6.8	4548 l/m^2 of mesh	(Davtalab et al., 2013)
Cooling condensation	30%	18.3	-	9.30%	9.3	-	(Gido et al., 2016)
Desiccant	20%	25	Adsorption < 1Kwm^{-2} Desorption 7 $KWhm^{-2}day^{-1}$>	43.90%	43.9	449L Per kg of MOF 801	(Fathieh et al., 2018)
Solar hydropanel	20%	-	<13.5Whr	30%	29.5	532L – 1329L per panel	(Zero Mass water, 2019)
Watergy Greenhouse	-	-	-	100%	375	133L	(Bucholz et al., 2006).

Table 5: Comparison between different atmospheric water generators (Author)

Treatment of waste water

Chapter Overview

This chapter will address the following research question :

What technologies can aid decentralized water treatment? What is the quality of treated waste water and its application?

What is the estimated quantity of treated water generated through these technologies?

Answers for these questions are researched through identifying different types of waste water and their quantities generated on site. Further the Iranian regulations for re-use of waste water are studied. This is followed by an extensive research on the different treatment processes which can be used to reclaim waste water. In order to study its feasibility in the context of Kel Plein existing examples of the installed treatment systems are studied. The chapter concludes by identifying the technologies which can ideally be inducted in the Negin Safari park .

Waste water characteristics and quantity

Waste water can be identified into 3 categories on the basis of the composition of waste water and the level of technology required to reclaim it. These categories include grey water, dark grey water, black water. Black water can be further divided into yellow water and brown water (Etter et al., 2016).

Greywater is defined as waste water which excludes the flow originating from toilet flushing. Greywater includes the streams generated from baths and showers , Laundry , washbasin , kitchen and dishwashing wastewater (Gross, Maimon, Alfiya, & Friedler, 2015). Further on water collected from bathroom showers, and tubs and laundry is termed as light greywater and has a low nutrient concentration , easily biodegradable organic content and relatively low pathogens. While kitchen waste water is known as dark grey water as it has a higher percentage of organic matter and grease (L. A. Ghunmi et al., 2011).In the instance that kitchen waste water is to be included with light greywater an additional degreaser needs to be added to the treatment system. (Friedler & Hadari, 2006; F Masi et al., 2010). The Royal Melbourne zoo in Australia also includes the water collected from washdown of animals, water ponds and swimming pools in the category of greywater (Victoria, n.d.). Black water is waste water that generates from water closets and urinals. Black water has a high organic load and can be combined with dark grey for treatment and re-use purposes. In certain instances wherein urine diverters are installed in the water closet the urine (yellow water) and solid waste (brown water) can be collected separately and re-used as nutrients for the plants and soil respectively. (F Masi et al., 2010)

The waste water generated in the Negin Safari Park is calculated and presented in Figure 35. The total amount of waste water generated at a maximum capacity amounts to $16m^3$ daily which has a potential of treatment and re-use.

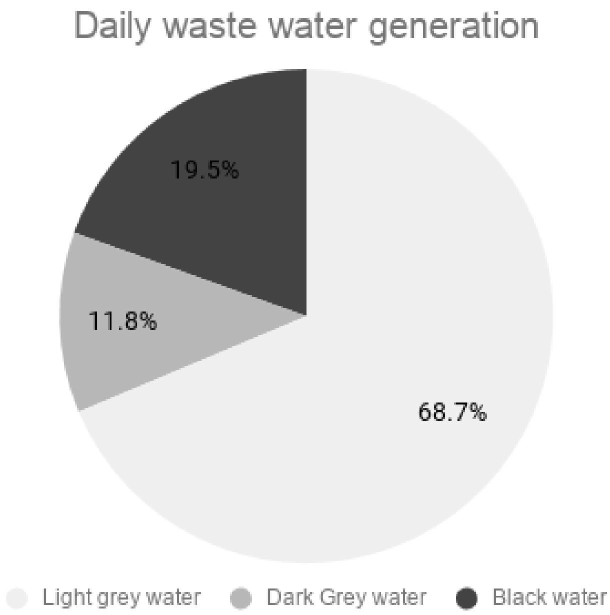


Figure 35: Quantity of greywater generation in the Negin Safari project (Author)

Waste water re-use standards

Waste water treatment systems do not aim to provide drinking water standards of treated water. The treated grey water is generally used for outdoor landscaping, irrigation purposes , washing of animals , indoor flushing of toilet and laundry (L. A. Ghunmi et al., 2011; F Masi et al., 2010; Victoria, n.d.). The water qualities required for these activities vary due to the composition of the treated waste water. The important parameters for the quality of recycled water for reuse based on International regulations and Iran IPEA regulations and standards are shown in Table 6.

Parameter		Unit		Reuse application	
		Laundry water	Sanitary toilet flushing	Landscape irrigation	Agriculture and Irrigation
pH	-	6.0-9.0	6.0-9.0	6.0-9.0	6.0-8.5
BOD5	mg/L	10	30	30	100
COD	mg/L	-	-	-	200
TSS	mg/L	10	30	30	100
Turbidity	NTU	2	NL	NL	50
TDS	mg/L	2000	1000	NL	-
TH	mg/L CaCO3	90	NL	NL	-
Fecal Coliform		25 max	200 ave: 800 max	200 ave: 800 max	400
(CFU/100 mL 75% ND)					
ND – Non-detect or below detection limit; NL – No limit					

Table 6 : Iranian and International standards for re-use of treated grey water (Gbagba, 2017)

Table 7 shows the water quality standards to be followed for washdown of animals. These guidelines are implemented by the Public health department, Government of Western Australia.

Parameter	Recycled water limiting criteria	Recommended monitoring frequency
E. coli	<10 MPN or cfu/100mL	Every six months
pH	6.5 – 8.5	Continuous online
Turbidity	< 5 NTU (95%ile)[1]	Continuous online
Disinfection	Cl[2]: 0.2 – 2.0 mg/L UV[3] UVT >75% UV intensity: drop <25% at 254nm UV dose: 40 70mJ/cm^2	Continuous online
Benzene, toluene, ethyl benzene, xylene (BTEX)	No more than ten times the guideline value of the Australian Drinking Water Guidelines	Every year

Table 7 : Australian standards for re-use of treated greywater for animal washdown (Western Australian Department of Health, 2011)

Greywater treatment technology

In order to store and re-use grey water it is essential to treat it (e.g., Erikssonet al., 2002; Jefferson et al., 1999). A greywater treatment system is considered effective only if they provide the effluent quality which meets the standards for waste water re-use , are easy to operate and require lesser skilled maintenance. A safe effluent has a lower pathogen re-growth as compared to raw grey water (L. A. Ghunmi et al., 2011).

A greywater treatment system consists of several steps that can be considered depending on the required quality of effluent. These technologies can be classified into three main steps being physical treatment, chemical treatment, biological treatment or a combination of these.

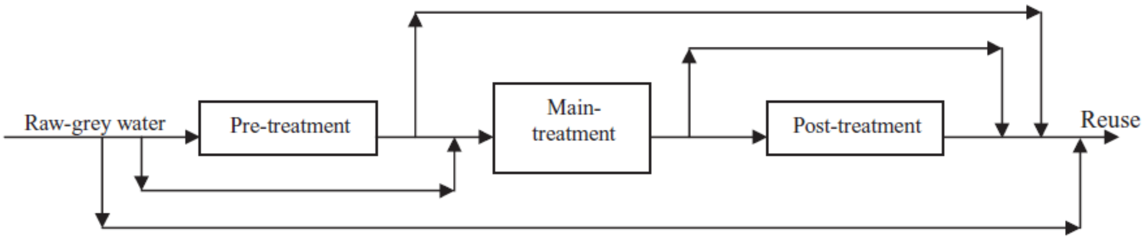


Figure 36: Steps involved in a greywater treatment system (L. A. Ghunmi et al., 2011)

The following Section talks about 5 grey water treatment systems and their application on projects. The treatment systems are as listed below:

- Filtration and physiochemical process
- Modified filter – Soil Filter
- Modified filter – Biofilter
- Aerobic biological treatment
- Anaerobic biological treatment

Filtration and physiochemical process

This process consists of several types of macro and membrane filtration units. The filters porosity and the waste water it is to treat have a direct impact on the efficiency of the filtration technique. The smaller the filters porosity the better the effluent quality obtained (L. A. Ghunmi et al., 2011). Macro filters aid in effectively reducing blockages in the recycling system through filtration of raw grey water (Christova-Boal et al., 1995; Jeffersonet al., 1999). However, the impact of macro filtration on the chemical nature of grey water is limited as the organic load and turbidity are not reduced. In addition, apart from sand filters all other filters are found to be unable to act as barriers for suspended pollutants. The effluent quality produced by these filters consists of primary unstable sludge that requires further treatment (L. A. Ghunmi et al., 2011).

To study the effectiveness of the treatment system two case studies have been referred to, water treatment system through sand filter installed in Mosques in Oman and a membrane filter installed in a hotel in Mallorca Island, Spain.

Ablution water treatment unit, Oman

A cost-effective low maintenance treatment system called the Wudhu water works system collects the ablution water from small and medium sized mosques and treats it for the purpose of re-use. To study the generated water quality from a mosque sample of Al Hail Mosque in Oman were collected and studied. The results are shown in table 8

					Standard		Acceptable
Parameter	Unit	*n*	Mean	SD	A	B	
pH		8	7.1	0.2	6–9	6–9	Yes
E.C.	m S cm-1	8	217.1	12.5	2000	2700	Yes
TDS	mg/l	8	119.4	6.9	1500	2000	Yes
TSS	mg/l	8	10.9	8.2	15	30	Yes
Turbidity	NTU	8	12	4.1	N.A.	N.A.	
BOD_5	mg/l	8	24.7	18.1	15	20	No
COD	mg/l	6	120.1	21.5	150	200	Yes
DO	mg/l	8	1.2	0.4	N.A.	N.A.	
Coliform	MPN/100 ml	6	>200.5		200	1000	No
E. Coli	MPN/100 ml	6	>200.5		N.A.	N.A.	

Table 8 : Quality of treated greywater (Prathapar et al., 2006)

Based on the obtained results the Wudhu water works was implemented. The filtration system consists of 6 steps as explained below and depicted in Image

Step 1: The collected grey water is passed through a sand trap (A) to allow for the settlement of soil. The sand trap is designed to be shallow to ensure periodic cleaning of the filter is made easy.

Step 2: After the water passes through the sand filter it is diverted to a storage tank (B) of size 1.5m X 1.5m X 1.7m considering the amount of ablution water produced in a day was 1.94 m^3. As the water moves into the tank with the help of gravity from a sub soil level to the water level which is 1m below, the water is aerated on the way. To ensure that the water is not stored for prolonged periods a submersible pump was installed which triggered operation when the water depth in the tank was 0.5 m, it stopped operation when the depth went below 0.2m.

Step 3: the pumped water was passed through a drip- irrigation filter (D) to ensure to floating mater proceeded further.

Step 4: Subsequently water entered the filter (E) which consisted of an activated carbon tray (10 cm deep), 0.2 mm washed beach sand (70 cm deep), gravel 1/8 (0.32 cm diameter gravel to a depth of 10 cm), gravel 1/4 (0.62 cm diameter gravel to a depth of 10 cm deep), and stones (10 cm deep)

Step 5: Once the water is treated in filter (E) the water was passed through a chlorination chute (F) packed with chlorine tablets.

Step 6: The water is then stored in a water storage tank of size equivalent to tank (B) before it is used for irrigation purposes.

Note: To ensure the un treated grey water does not become septic water from tank (B) needs to be emptied in time intervals of 24 hours.

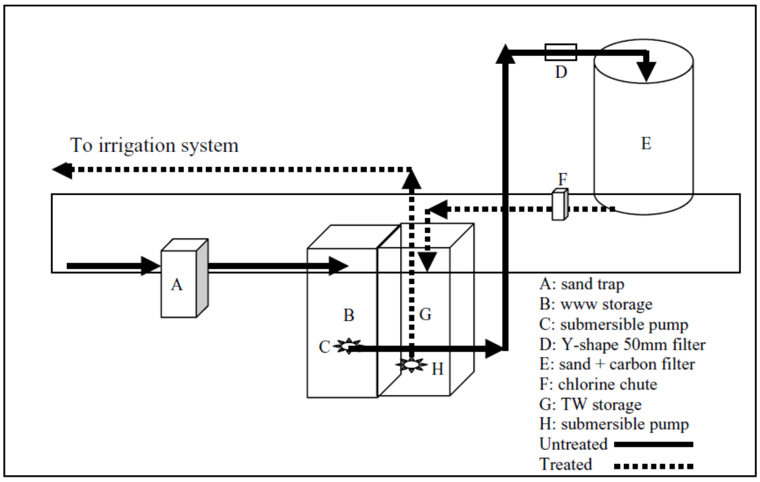


Figure 37 : Scheme of the treatment system (Prathapar et al., 2006)

Frome the below table we can conclude that the treatment system reduced the Turbidity, Chemical oxygen demand (COD) and Biochemical oxygen demand (BOD) values in the treated grey water rendering it useful for irrigation purposes(Prathapar et al., 2006).

Hotel, Mallorca Island, Spain

In a Hotel located in the Mallorca Island an indoor grey water recycling system was installed to re-use waste water for flushing of toilets. The hotel is a 3 -star apart hotel consisting of 81 rooms of which 63 rooms also have an attached kitchenette. The waste water was collected from bath tubs and had washing basins to meet the water demand for flushing during high occupancy periods. Settled matter was cleared out ever 15-16m^3 of treated water. The treatment consisted of 3 steps as shown below

Step 1: The water is passed through nylon sock type filter consisting of a 0.3mm mesh and 1 m^2 surface of filtration.

Step 2: The grey water is then allowed to go through a sedimentation tank and disinfected using sodium hypochlorite. The treated water is stored in a ground level tank of capacity 4.3m^3

Step 3: The water is then pumped to an overhead tank with the help of an automatic pump from where it is used to supply water for water closets through gravity.

Note: The maximum storage time recommended for treated and un-treated grey water was 48 hours. Hence all WC tanks of unoccupied room were flushed at least once a day.

As can be seen in Table 9 The resultant grey water was found to have a reduced percentage of Turbidity, COD , Total suspended solids (TSS)and nitrogen which rendered it acceptable for used in flushing of toilets (March & Gual, 2004).

	Type of water	Mean	*n*	*s*	Max.	Min.
pH	Raw grey	7.6	14	0.23	8.0	7.3
	Treated	7.5	14	0.32	8.1	7.1
	Tap	7.7	14	0.16	8.0	7.6
Suspended solids, mg/l^{-1}	Raw grey	44	12	31	126	20
	Treated	18.6	12	2.9	23.0	15.0
Turbidity, NTU	Raw grey	20	24	13	62	5
	Treated	16.5	24	7.5	42.0	5.6
TOC, $mg\ C\ L^{-1}$	Raw grey	58	18	42	186	18
	Treated	39.9	18	8.0	56.8	20.0
	Tap	0.15	13	0.14	0.5	—
COD, $mg\ O\ L^{-1}$	Raw grey	171	12	130	441	39
	Treated	78	12	30	118	24
	Tap	2.1	10	1.1	3.9	—
N total, $mg\ N\ L^{-1}$	Raw grey	11.4	12	9.4	40.0	4.7
	Treated	7.1	12	2.9	11.8	3.2
	Tap	4.3	12	1.7	6.8	1.2

Table 9 : Quality of treated greywater (March & Gual, 2004)

Modified filters - Soil filters and constructed wetland

Soil filters generate a better-quality effluent than a macro filter. It is found that the COD, BOD, SS , Turbidity and pathogen values are lower as compared to the effluent generated from a macro filter. However, these systems face several problems such an uneven distribution of waste water over the bed surface and selection of incorrect bed media. Careful attention needs to be paid to the climate composition , rainfall and waste water composition of the region when constructing a wetland (L. A. Ghunmi et al., 2011). Constructed wetlands are of two types horizontal flow and vertical flow , In arid climates such as Iran vertical subsurface flow constructed wetlands are preferred as the evaporation rate is found to be lower in those systems (Fabio Masi, 2013).

Constructed wetland, Gaza, Palestine

Oxfam Italy designed and constructed several constructed wetlands for treating grey water in the Palestinian villages. The waste water treatment system was installed for collection of grey water from households and re-used for irrigation and fodder production. To ensure that a constructed wet land could be effective in a dry and hot climate vertical flow beds were installed in place of horizontal flow beds to reduce evapotranspiration as they have a shorter hydraulic retention time in comparison to other constructed wetlands. The flow rate of the system 0.5-1 m^3 /day. Steps of treatment are mentioned below:

Step 1: The collected grey water is passed through mechanical pre-treatment process in a 3-chamber septic tank.

Step 2: The water is then passed through a vertical flow constructed wetland of a total surface area of $60m^2$.

Step 3: The treated waste water was further collected and re-used for irrigation purposes.

Note: During the initial commissioning phase the water level is kept high to ensure the plantation is allowed to grow (Fabio Masi, 2013).

The effluent obtained from the treatment system is used for olive tree irrigation.

Constructed wet roof, Van Heorot Groenprojecten facilities, Tilburg, Netherlands

In 2012 a constructed wet roof was built by the company ECOFYT. The CWR was divided into four identical beds of size (3.0 x 25.5 m) with a depth of 9cm horizontal flow (HF). These beds were installed on a roof having an angle of 14.3 degrees. Appropriate hydraulic retention time for treatment of waste water in combination with long term stability and the limitation of load bearing capacity of the roof were driving factors for the selection of the CWR matrix. A mixture of two types of sand, light expanded clay aggregate and polylactic acid beads was used in the substratum (Thickness 7.5cm). This was followed by a layer of stabilization plates of height 3.5 cm to help provide appropriate hydraulic retention time for the treatment of waste water. The top layer comprised of a 1.5 cm high turf mat (sod of grass). The different layers of the CWR are also shown in figure 38 (Pereyra, 2015). The treatment consisted of 3 steps as shown below:

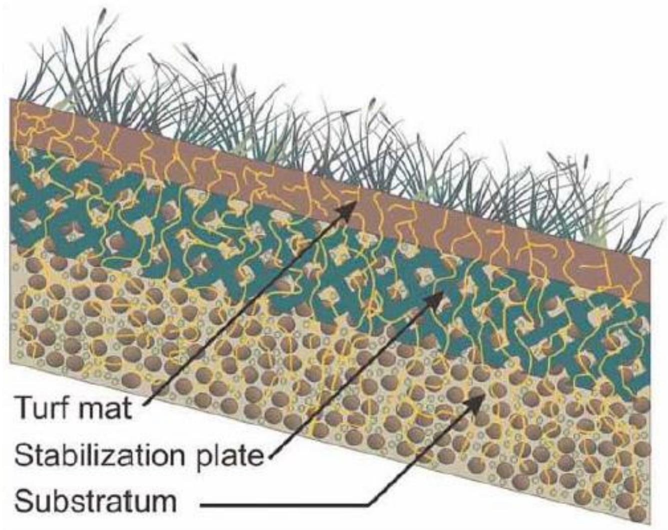


Figure 38: Section of the constructed wet roof

Step 1: The waste water is collected from kitchen sink, toilet, shower and hand wash basins of the office and pre-treated in a septic tank

Step 2: The grey water is further pumped to the overhead constructed wet roof. The grey water is passed into the upper end of the wet roof through pipes consisting of holes (6cm diameter) in intervals of 1m.

Step 3: The treater waste water is collected in an effluent tank through random holes made at the bottom of each constructed wet roof bed. The treated water was used for flushing purposes.

Note: Of the total grey water collected 38% of the water was obtained post treatment, the rest of the water was lost due to evapotranspiration.

Parameter	Influent	n	Effluent	n	% removal
pH	7.4-8.7	6	7.4-8.4	5	-
Dissolved oxygen (mg L^{-1})	0.3 ± 0.1	6	3.2 ± 1.8	5	-
Electric conductivity (μS cm^{-1})	2162 ± 161	6	1438 ± 344	5	-
Total suspended solids (mg L^{-1})	186 ± 22	11	26 ± 5	8	86
Chemical oxygen demand (mg L^{-1})	859 ± 76	11	129 ± 31	9	85
NH_4^+-N (mg L^{-1})	187 ± 9	12	0.2 ± 0.1	9	99.9
NO_3^--N (mg L^{-1})	0.08 ± 0.02	4	8.05 ± 3.28	7	-
Total nitrogen (mg L^{-1})	225 ± 8	4	7 ± 2	2	97
Total phosphorus (mg L^{-1})	27 ± 3	5	8.7 ± 2.7	6	68

Results are mean ± standard error, except for pH.

Table 10 : Quality of treated greywater (Pereyra, 2015)

The challenge faced in the project was that the constructed wet roof bed was found to be shallow due to which the water froze during winter while during summer the water was lost due to evaporation. While designing the roof structure of the building the load of the soil must also be taken into consideration which adds to an extra cost to the construction. This system is preferred in instances when the space for installation of a grey water treatment system is limited (Pereyra, 2015).

Modified filter - Biofilters

Biofilters are categorised into two macro biofilters and membrane biofilters. Macro bio filters consists of depth filtration through a porous media bed with fixed film biological reactor. Membrane biological reactor combine membrane filtration with an activated sludge system. The micro biofilters produce a better effluent quality as compared to macro bio filters. The effluent quality of both the filtration systems is dependent on the porosity of the filtration system and hydraulic retention time. Biofilters have problems with cleaning, membrane fouling and operational cost. Over 20% of the total flow is required for backwashing of the filter. This filtration system was found to be more effective on a larger scale. On a smaller scale it showed lesser fouling problems with laundry water however showed problems in treating grey water containing suspended solids.

Pilot project, Spain

The prototype system was installed in REMOSA facility in Spain to study the effluent quality of treated grey water using a submerged Membrane bioreactor with a bio reactor volume of 1200L and a chlorination tank of 500L.

Step 1: The grey water produced from shower and bathroom sinks was collected from a production plant facility and stored in a 500L tank under ambient temperature conditions.

Step 2: The grey water is separated through membranes with a mesh size of 1mm in the screening process.

Step 3: Then the waste water is passed through a bio reactor to allow for decomposition of organic matter

Step 4: The treated grey water is passed through a fine filtration system to ensure solid / liquid separation. This is done through a suction system which applies vacuum pressure in the membrane to create an inward flow.

Step 5 : Sodium hypochlorite is added to the treated water allowing the sanitary properties of the treated water to be conserved and subsequently stored in a chlorination tank (Santasmasas et al., 2013).

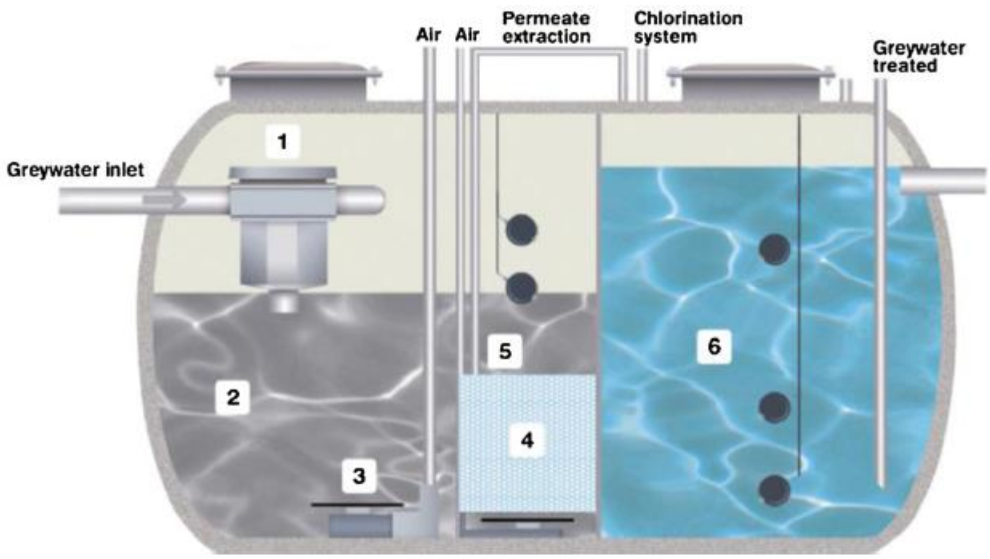


Figure 39: Schematic of the biofilter (1.Filter, 2.Bioreactor, 3.Air diffusers, 4.membranes, 5.Extraction pump, 6.Chlorination Tank) (Santasmasas et al., 2013)

Parameter	Number of samples	Recycled water		
		Min.	Average	Max.
pH	50	7.5	7.9	8.3
Conductivity (μS/cm)	50	931	1244	1633
MES (mg/L)	50	<1	1.3	5
Turbidity (UNT)	50	0.2	1.2	4.3
DBO_5 (mgO_2/L)	50	1	6	16
DQO (mgO_2/L)	50	5	29	74
Surfactant (mg LSS/L)	25	0.06	0.1	0.6
E. coli (CFU 100 mL^{-1})	25	<5[a]	<5[a]	100
Nematode eggs (egg/10 L)	25	<1	<1	<1
P total (mg/L)	25	2	3	8
N total (mg/L)	25	14	22	30

[a] Detection limit.

Table 11 : Quality of treated greywater (Santasmasas et al., 2013)

Aerobic Biological treatment

Aerobic treatment systems use oxygen which is utilized by microorganisms for the degradation of organics. The energy consumption in this system can be high as they require mechanical aeration or forced aeration equipment. As this system requires semi-skilled personnel it is a preferred choice of treatment system in developing countries. Issue faced with this system are often plugging of aeration device, mechanical failures and difficulty in scaling up (L. N. A. A. Ghunmi, 2009; Singh, Kazmi, & Starkl, 2015).

Apartment house, Kreuzberg, Berlin

The apartment house consists of a grey water treatment plant in its 15 m^2 basement. The apartment building houses 70 people.

Step 1: The grey water produced from shower, bath tubs and bathroom sinks are collected and stored in a sedimentation tank.

Step 2: Prior to the sedimentation process the grey water is passed through a rotating biological contractor as shown in image

Step 3: The treated grey water goes through a further screening to ensure the biomass is removed from the grey water

Step 4: This treated grey water is further made re-usable through disinfecting it is using a UV system.

Step 5: The effluent is stored in a tank and used for flushing purposes

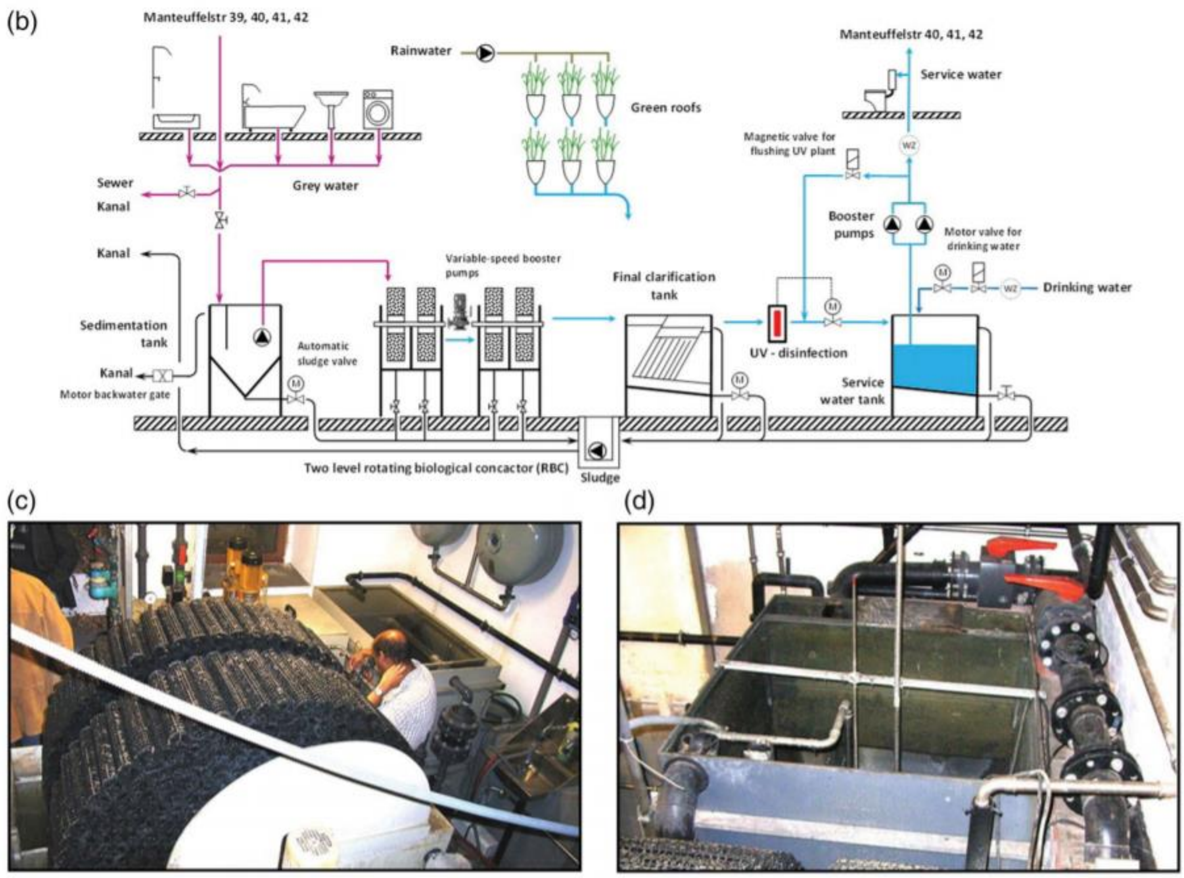


Figure 40 : (b) greywater treatment scheme ,(c) image of the rotating biological contractor, (d) sedimentation tank (Gisi, Casella, Notarnicola, & Farina, 2016)

Anaerobic biological process

This treatment needs to be operated at 30ºC to produce a stable effluent. This system is recommended when the grey water concentration is as high as 74 % of the pollutants found in the grey water are anaerobically biodegradable , The effluent is found to be deficient in Nitrogen and phosphorous which sustains microorganisms growth in the treatment and does not allow it to grow , The sludge produced through this system is found to be relatively lesser, The by-product of this system (methane) can also be further used as an energy source (L. A. Ghunmi et al., 2011). However the effluent produced cannot be used directly and requires further treatment which may require a large amount of energy (Kujawa-roeleveld & Zeeman, 2006).

Pilot project, Hamburg University of Technology, Germany

The treatment system was installed in a temperature-controlled environment. The temperature was set at 30 º C.

Step 1: The grey water was collected in a 1m^3 storage capacity tank.

Step 2: The grey water is pumped through an up flow anaerobic sludge blanket.

Step 3: The treated grey water goes through a further screening to ensure the biomass is removed from the grey water

Step 4: This treated grey water is further made re-usable through disinfecting it is using a UV system.

Step 5: The effluent is stored in a tank and used for flushing purposes

(Elmitwalli & Otterpohl, 2007)

Conclusion

To select a grey water treatment ideal for Negin Safari park the information obtained on the different greywater treatment systems from case studies was tabulated. The treatment systems were compared based on the effluent quality generated, locational challenges faced, Operation and maintenance requirements and water treatment period. This is shown in table 12.

In both the examples considered for the filtration and physio chemical process the water was only collected from the washbasins and the showering area and hence did not have a high pollutant concentration. While the effluent produced meets the outdoor re-use requirement as per the standards it fails to meet the indoor requirements due to a higher turbidity value due to which it was ruled out. The constructed wetland built in Palestine provided an effluent quality which only met the Iranian re-use standards for agriculture when the entire waste water was considered as an effluent. While in the case of the constructed wet roof the treated effluent was used for flushing of toilets as well however showed a higher water loss due to evaporation. The modified biofilter gave a high effluent quality and showed effective installation even in arid climates though 20% of the system was used for backwashing of the membrane. The aerobic biological treatment system provided an effluent quality which could be used for indoor non-potable purposes however it required forced aeration or natural aeration leading to a large energy demand. The anaerobic biological treatment system was ruled out as it required a controlled environment for successful operation.

A modified biofilter such as the membrane bioreactor was considered as an appropriate choice as it had a lower energy demand and provided a higher quality effluent. The system would require a pre filtration of the influent to ensure the suspended solids in the water are removed and do not damage the membrane. A constructed wetland is also considered as an effective and energy efficient way of treating the waste water for indoor restricted use. However the limitation arises due to its high evapotranspiration rate. The feasibility of this system can be studied during the development of the water management scheme.

Treatment system	Grey water collection	COD	BOD	PH	TSS	Turbidity	Comparison with Iranian standards	Operational and maintenance requirements	Locational challenges	Water treatment period (HRT)	Reference
Filtration and Physiochemical process											
Al Hail Mosque, Oman	Ablution water	120.1	24.7	7.1	10.9	12	Water can be used for toilet Agriculture	The sand trap requires periodic cleaning	All pumps need to be replaced in 6 years	-	(Prathapar et al., 2006)
Hotel Mallorca Island, Spain	Bath tubs and hand wash basin	78	-	7.5	18.6	16.5	Water can be used for Agriculture	requires high maintenence.The system needs to cleaned after 15-16 cubic metre of grey water is treated	-	-	(March & Gual, 2004)
Modified Filters - Soil filter											
Constructed wetland in SEKEM farm , Egypt	100% domestic waste water from school and administrative buildings	174	103	7.1-8.3	89.8	-	water can used for agricultural irrigation	Requires maintenance of the plants	The system is striving in the hot and dry climate of Egypt	2.3 days	(Masi, 2013)
Constructed wet roof , Van Hevorirt Groenprojecten facilities , Tilburg , Netherlands	kitchen sink, toilet, shower and hand was basins	160	-	8.4	31	-	water can used for flushing	Requires maintenance of the plants	The vegetation may dry up, A vertical flow treatment system is preferable as in the horizontal system chances of evaporation are higher	2.1 days	(Pereyra, 2015)
Modified Filters - Biofilters											
Pilot project, Ben-Gurion University Sports Centre, Israel	Shower	16.56	3.64	-	0	-	Values found to be lesser than the permissible value for toilet flushing	-	-	1.5 days	(Liberman, Shandalov, Forgacs, & Oron, 2016)
Pilot project, Spain	Toilet and wash basin	-	-	7.9	-	1.2	Values found to be lesser than the permissible value for toilet flushing	Waste removal required once a year	-	19.5 hours	(Santasmasas et al., 2013)
Aerobic Biological treatment											
Pilot project, Northern border university , Saudi Arabia	shower, bath tubs and bathroom sinks and Kitchen	-	4.19	-	4.59	-	Values found to be lesser than the permissible value for toilet flushing	-		-	(Abdel-kader, 2013)
Apartment house, Kreuzberg, Berlin	shower, bath tubs and bathroom sinks	-	5	-	-	-	Data is insufficient as per (Gisi, Casella, Notarnicola, & Farina, 2016) the system is still functioning and the water is being used for flushing	Operational ease and low technical personnel requirement		-	(Nolde, 2000) and (Gisi, Casella, Notarnicola, & Farina, 2016)
Anaerobic biological treatment											
Pilot project, Hamburg University of Technology, Germany	shower, bath tubs and bathroom sinks and Kitchen	106	-	-	-	-	COD value found to be lesser than the permissible value for landscape irrigation		The system can be installed in a controlled environment and requires energy to maintain the temperature	10 hours	(Elmitwalli & Otterpohl, 2007)

Table 12: Comparison between different grey water treatment systems, (Author)

Blackwater treatment

In this section two technologies are discussed for the treatment and re-use of concentrated black water where it is not diluted with grey water. Black water is waste water that generates from toilets. Black water has a high organic load and is usually combined with waste water generating from kitchens for treatment and re-use purposes (F Masi et al., 2010). In the first technology black water is treated in a constructed wetland to be re-used for irrigation and in the second technology the potential of installing a dry compost toilet for production of fertilizers and compost is explored.

Constructed wetland

This treatment process can be considered as the secondary treatment step while treating blackwater. Larger particles such as organic matter, toilet paper and other rubbish are required to be removed in the primary process before the waste water is treated in a subsurface constructed wetland.

Pilot study ,Cairo, Egypt

The National Research Centre , Cairo , Egypt collected the domestic black water originating from 5 households

Step 1: The collected black water is passed through mechanical a 3-chamber septic tank to remove larger particles and suspended solids. The septic tank chambers are made of polyvinyl chloride tank with an effective volume of $0.7m^3$.

Step 2: The effluent was then passed through a horizontal subsurface flow constructed wetland in order to remove the organic load.

Step 3: The water collected from the horizontal flow constructed wetland was further treated in a vertical flow constructed wetland for oxidation of the waste water and removal of any other suspended solids and further nitrification without having any clogging problems (Abdel-shafy, El-khateeb, & Shehata, 2017). A schematic representation of the treatment system is shown in figure 41.

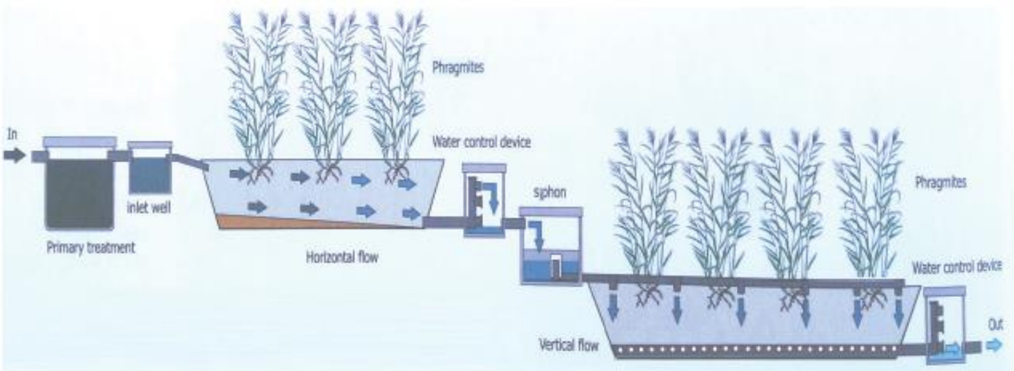


Figure 41: schematic representation of the treatment system , (Abdel-shafy et al., 2017)

The table below shows the effluent quality of the black water collected at different treatment levels. It can be concluded that the water collected from the vertical subsurface flow constructed wetland meets the Iranian standards for waste water re-used for landscaping and agricultural practices.

Parameter[a]	N	ST effluent	Sed. %R	HF effluent	HF %R	VF effluent	%R	Overall cumulative removal %
pH	18	7.9 (0.35)		8.2 (0.32)		7.8 (0.3)		
Turbidity	18	110 (38.5)	27.8	28 (14.9)	73.7	10.79 (6.9)	61.5	92.9
TDS	18	800 (80.7)	4.9	833 (66)	−2.1	868 (112)	−4	−3.2
TSS	18	126 (30.5)	56.8	21.5 (3.4)	82.9	7.6 (2.1)	64.7	97.4
BOD	18	321 (75.7)	64.8	38.4 (12.8)	88.0	18.0 (8.2)	53.1	98.0
COD	18	495 (226)	58.0	64 (14.4)	87.1	18 (5.1)	52.8	98.5
Oil and grease	18	43 (2.4)	36.8	9 (5.5)	79.1	4 (3.8)	55.6	94.1
TKN	18	109 (12.1)	23.0	23.6 (2.7)	78.3	23.6 (2.72)	28.2	83.3
NH_3	18	5.9 (1.44)	16.9	1.5 (0.24)	74.6	0.5 (0.17)	66.1	93.0
Nitrates	18	0.02	87.5	6.2	–	1.9 (0.68)	69.4	–
Nitrites	18	0.004	80.0	0.0	–	0.01 (0.01)	–	50.0
Organic nitrogen	18	103.2	23.0	25.0	75.8	21.6 (2.9)	13.6	83.9
TP	18	22.4 (5.8)	13.8	13.6 (2.6)	39.3	8.9 (1.1)	34.6	65.8
Fecal coliform	10	3.5×10^8 (2.4×10^8)	90.2	1.1×10^5 (2.2×10^5)	99.4	1.4×10^2 (1.1×10^2)	97.5	–

Table 13: Effluent characteristics of each effluent process, (Abdel-shafy et al., 2017)

Dry Sanitation

In this type of sanitation dry toilets are used with urine diversion so that the yellow water (urine) and the solid waste (brown water) can be collected separately for treatment and re-use. These toilets can be used without a connection to a direct water supply and are a safe and hygienic alternative. Composting toilets are dry toilets where in solid waste is collected separately and allowed to degrade in a chamber located below the toilet under ambient conditions. The toilet consists of 4 parts the squatting space, a chamber to collect solid waste for composting , a ventilation system to ensure favourable conditions for the composting as well as for trapping any odour and yellow water collection tank as shown in figure 42 (Berger, 2005). The collected yellow water can be used directly as a fertilizer for gardening while the compost is mixed with the soil to improve the nutritional requirements (Berger, 2005; Schönning, 2001).

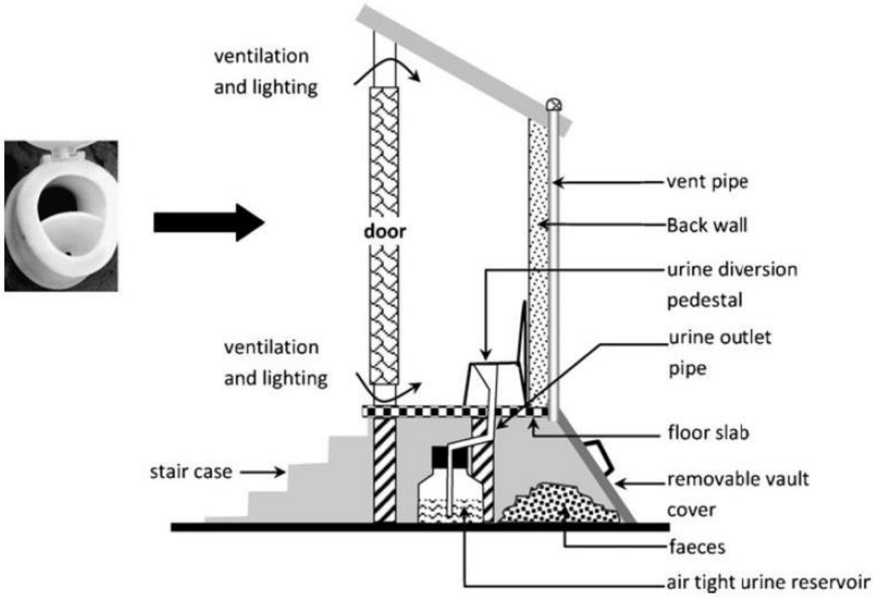


Figure 42: Dry composting toilet with a urine diverter (Karak & Bhattacharyya, 2011)

Conclusion

Both technologies show potential of being successfully implemented in the Negin Safari park. While the first technology addresses the use of water closet generating an effluent which can be treated through natural systems for re-use. The composting toilet completely eliminates the use of water for flushing. While the system requires a wider acceptance by the users it generates compost and urine which can effectively be used as nutrients for the soil and plants.

Water management

Chapter Overview

In the following chapter the below mentioned research questions are answered:

What is the optimum sustainable water management scheme?

What is its impact on the water demand of the site?

The water management schemes were developed by identifying the technologies which help in harvesting the best quality of water and matching it with the demand that required the highest quality. This step was sequentially carried out for all the different categories of water demand originating in the park. For the purpose of the report two schemes were elaborated and compared on the basis of the boundary conditions developed in the earlier section.

Water Management scheme

Three different sources of water were identified which would aid in meeting the water demand of the safari park i.e. Rainwater, Atmospheric water and Waste water. Two schemes have been developed based on the ideal technology and the water use on the site. Both the schemes were developed for an annual basis to consider the yearly rainfall and moisture collected for use and storage. The highest quality of water is used to meet the potable water demand for the visitors and animals while the water demand for laundry, flushing, landscaping and cleaning is met by treating waste water for re-use as shown in figure 43. Values of water demand and waste water generation are based on the average water demand calculated in the earlier section. Also, within the water management scheme water loss due leaks, backwashing of treatment systems and evapotranspiration of reed beds has been considered. These calculations have been tabulated and presented in Appendix III. While several schemes were developed to meet the water demand of the site for the purpose of the report two schemes which can successfully result in the off grid operation of the park have been presented for the purpose of comparison. The following section describes both water management schemes and addresses the advantages and disadvantages of incorporating them.

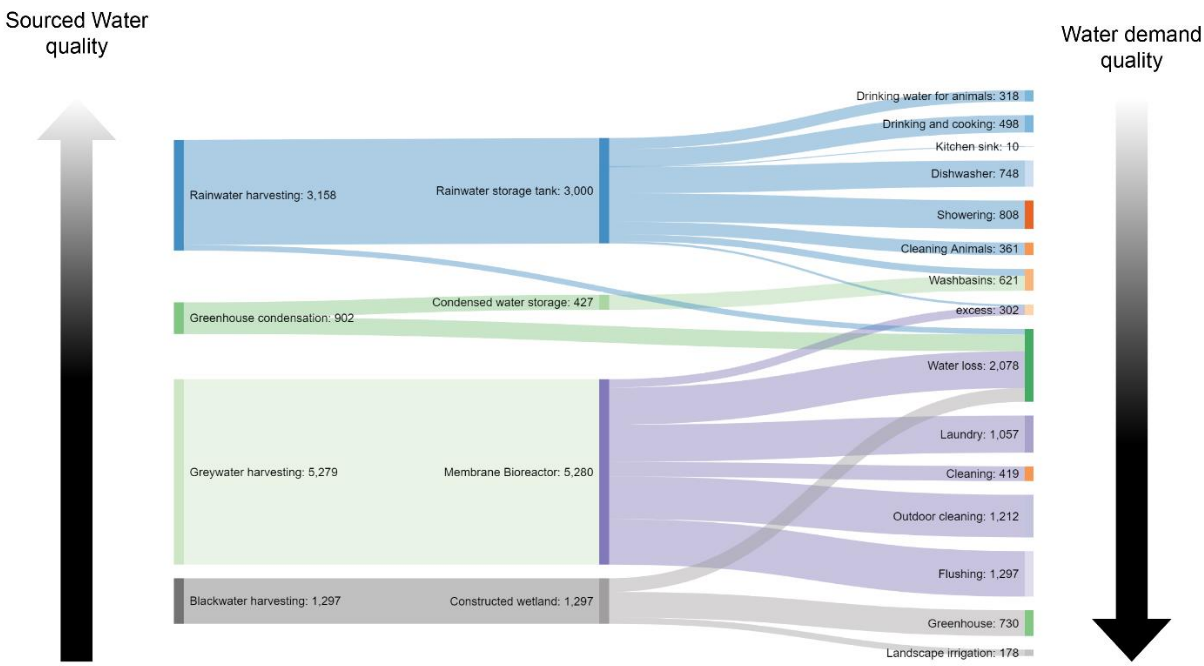


Figure 43: Sankey diagram depicting the hierarchy of sourced water quality and its subsequent water usage, (Author)

Water management scheme 01

In this scheme the water is sourced through rainwater harvesting, Atmospheric moisture collection of closed greenhouse, Reclaimed light grey water inclusive of kitchen water and reclaimed black water. The waste water was divided into two categories as grey water requires lesser energy to treat the water to better quality as compared to black water. The Rainwater is harvested from the roofs of the building and in order to meet the complete potable demand the roof area has to be increase by. Waste water originating from the kitchen sinks passes through a de-greaser before being combined with the rest of the grey water originating from showers, washbasins and animal wash downs. grey water is treated through a membrane bio reactor as the loss of water in the treatment process is 20% due to backwashing and maintenance of the membrane, this is lower as compared to the constructed wetland. Additionally the effluent quality of water provided through this system meets the Iranian waste water re-use standards for laundry. Black water is passed through a combination of Horizontal subsurface flow constructed wetland and vertical subsurface flow constructed wetland to meet the water re-use quality. However in the process 30% of the water is lost due to evapotranspiration. While the water quality generated meets the Iranian standards for re-use in flushing the water obtained from treatment of black water usually has a brownish colour which can stain the pots and add to higher and regular maintenance (Hoffman, Platzer, Winker, & Muench, 2011). Hence the effluent is only used for agricultural and landscape purposes.

Figure 44 depicts the water management scheme proposed for the Safari park while figure 45 elaborates the scheme with help of values in the Sankey diagram.

Advantages

- As the light grey water is treated with the help of a membrane bio reactor it generates a high quality effluent. This technology can also be further combined with a biological/chemical treatment process to give a potable quality effluent in the future (Pronk, n.d.)
- There is ample amount of water from the treated black water which can be used for irrigation purposes such as meeting the water demand for green house which can further lead to generation of potable quality of water in addition to vegetables.

Disadvantages

- In order to meet the potable demand the roof surface area needs to be increased.
- Installation of a membrane bioreactor requires a higher level of know-how and cannot be installed by the local community .

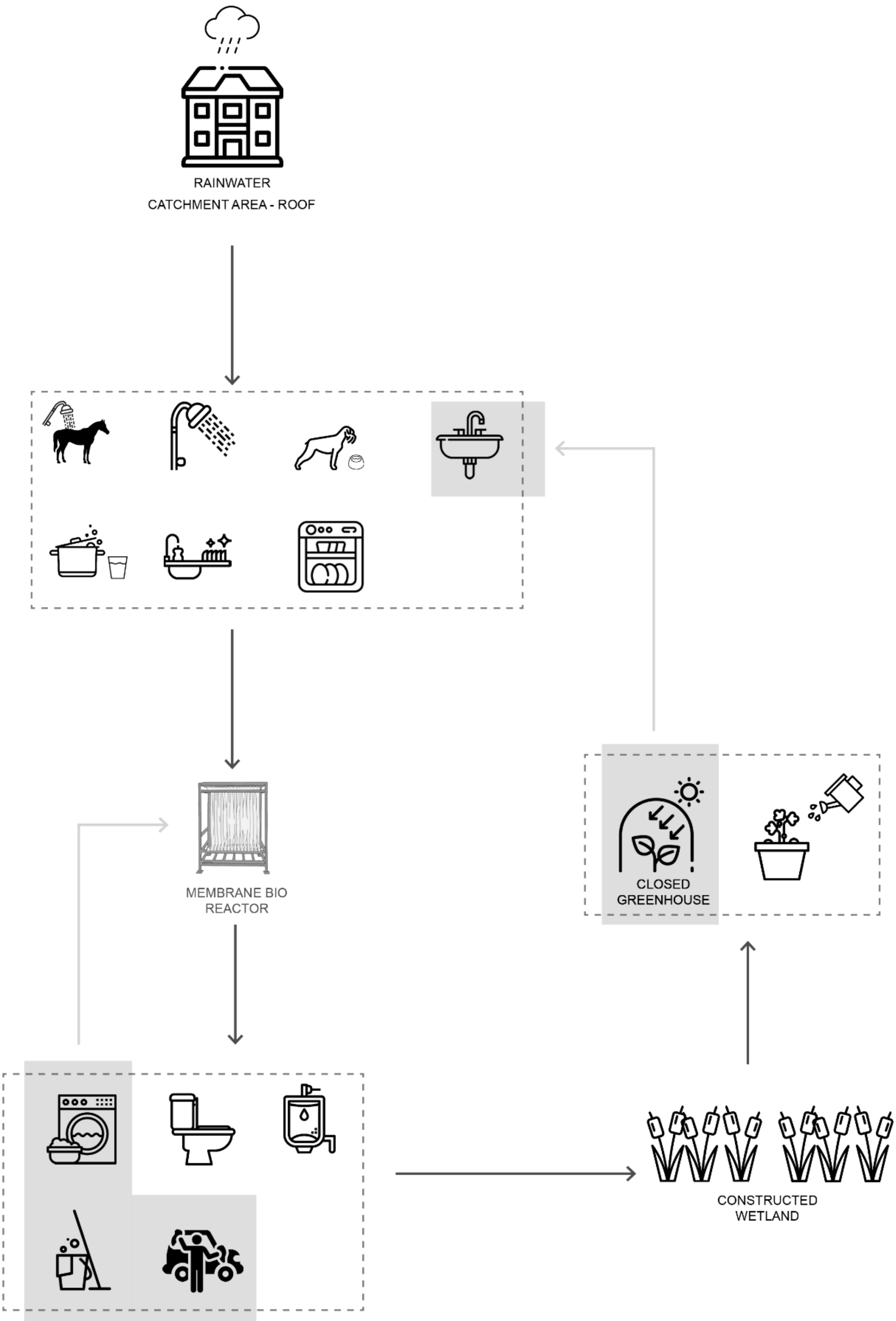


Figure 44: Water management scheme 01, (Author)

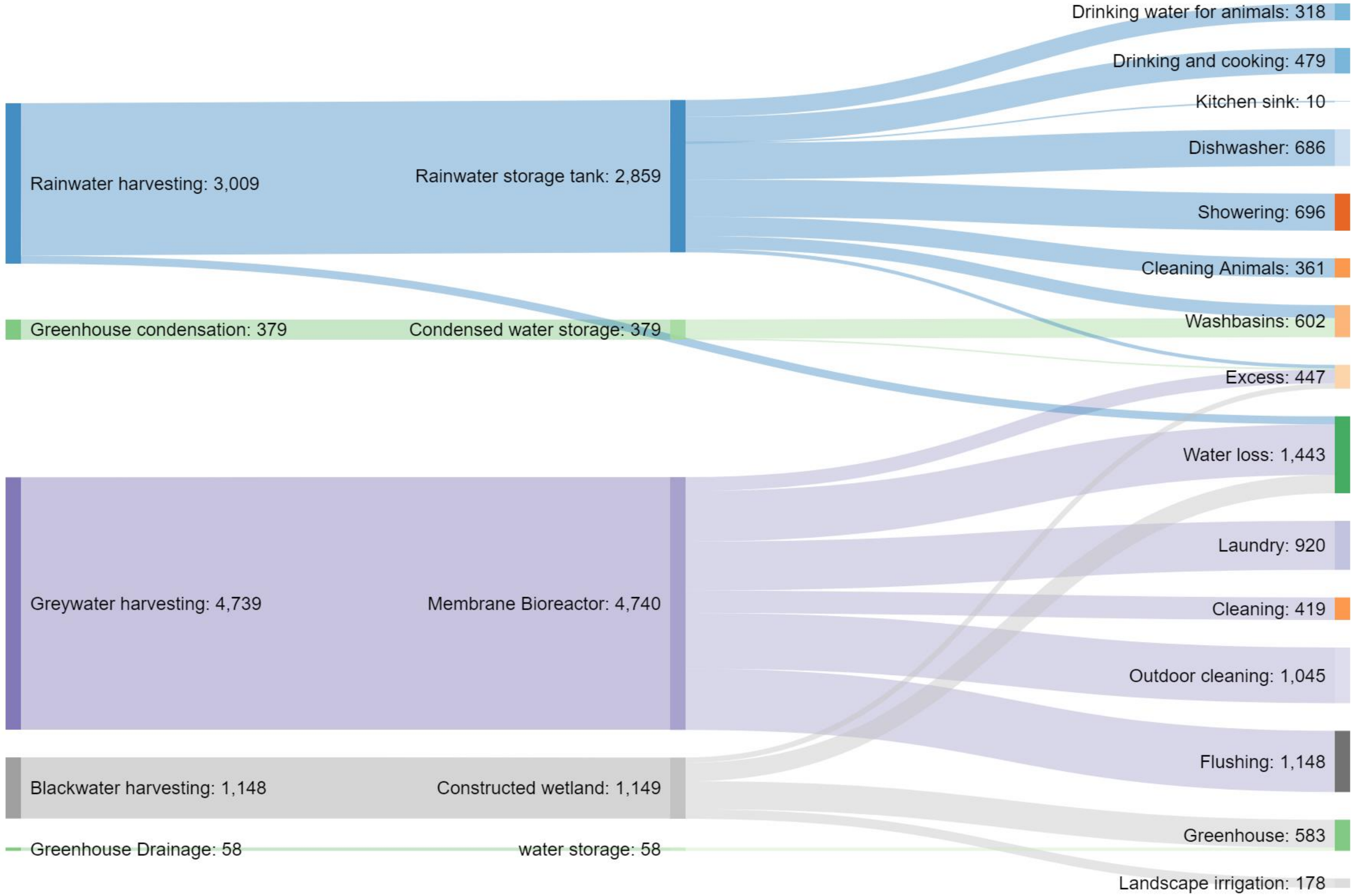


Figure 45: Sankey diagram depicting the hierarchy of sourced water quality and its subsequent water usage , All values in m^3 , (Author)

Water management scheme 02

In this scheme the water is sourced through rainwater harvesting, Fog harvesting device, Atmospheric moisture collection of closed greenhouse, Reclaimed light grey water and reclaimed black water. This scheme was developed with the idea of maximizing the use of natural and passive techniques as well avoiding roof enlargement through consideration of alternative sources. As a substitute the fog harvesting device was recommended to meet the drinking water demand. A larger are for greenhouse is also proposed which further generated better quality water. A constructed wetland was proposed for treatment of grey water which was combined with kitchen water. However the constructed wetland does not produce an effluent which meets the laundry water re-use standard therefore it was only used for flushing , landscaping and irrigation. The water demand for laundry was met by potable water. Flushing also results in a high water demand which was tackled by induction of compost toilet which eliminated this demand and helped in producing nutrients for the plants and soil.

Figure 46 depicts this water management with the help of icons while figure 47 further elaborates the scheme with the yearly water cycle shown in form of a Sankey diagram.

Advantages

- No additional increase in roof area required to meet the potable water demand.
- All proposed technologies can be developed by the help of local community.
- Through induction of a compost toilet nutrients for the plant and soil are generated which can be used within the park or sold to nearby villages.

Disadvantages

- Tourists may have reservations on using composting toilets.
- A separate chamber has to be built below every composting toilet and the compost within the chamber needs to be moved to a secondary chamber occasionally which means it requires higher maintenance.
- Collected fog water requires larger storage tanks due to its limited yearly functionality.
- Water loss due to evapotranspiration is high due to the arid conditions of the region.

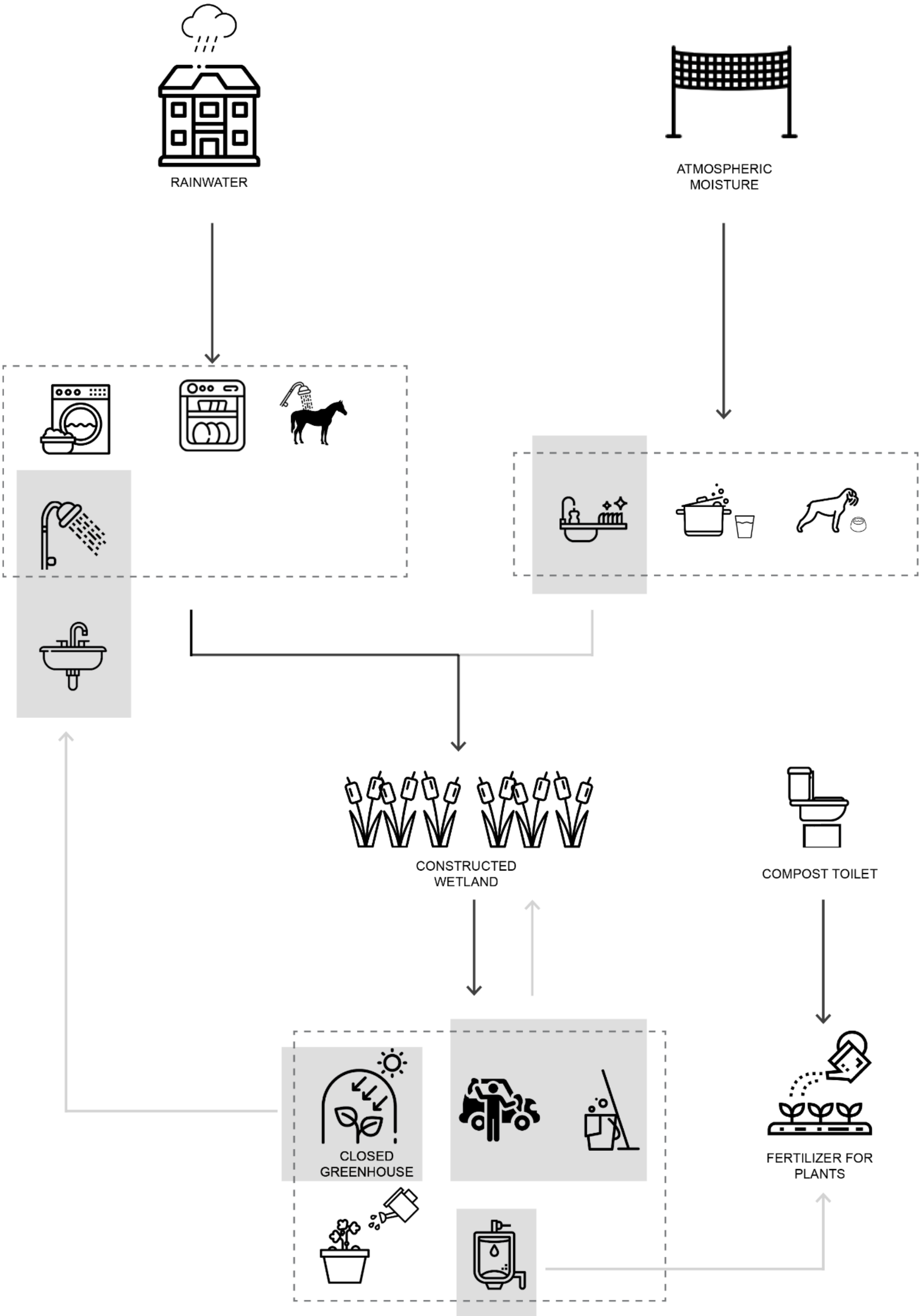


Figure 46: Water management scheme 02, (Author)

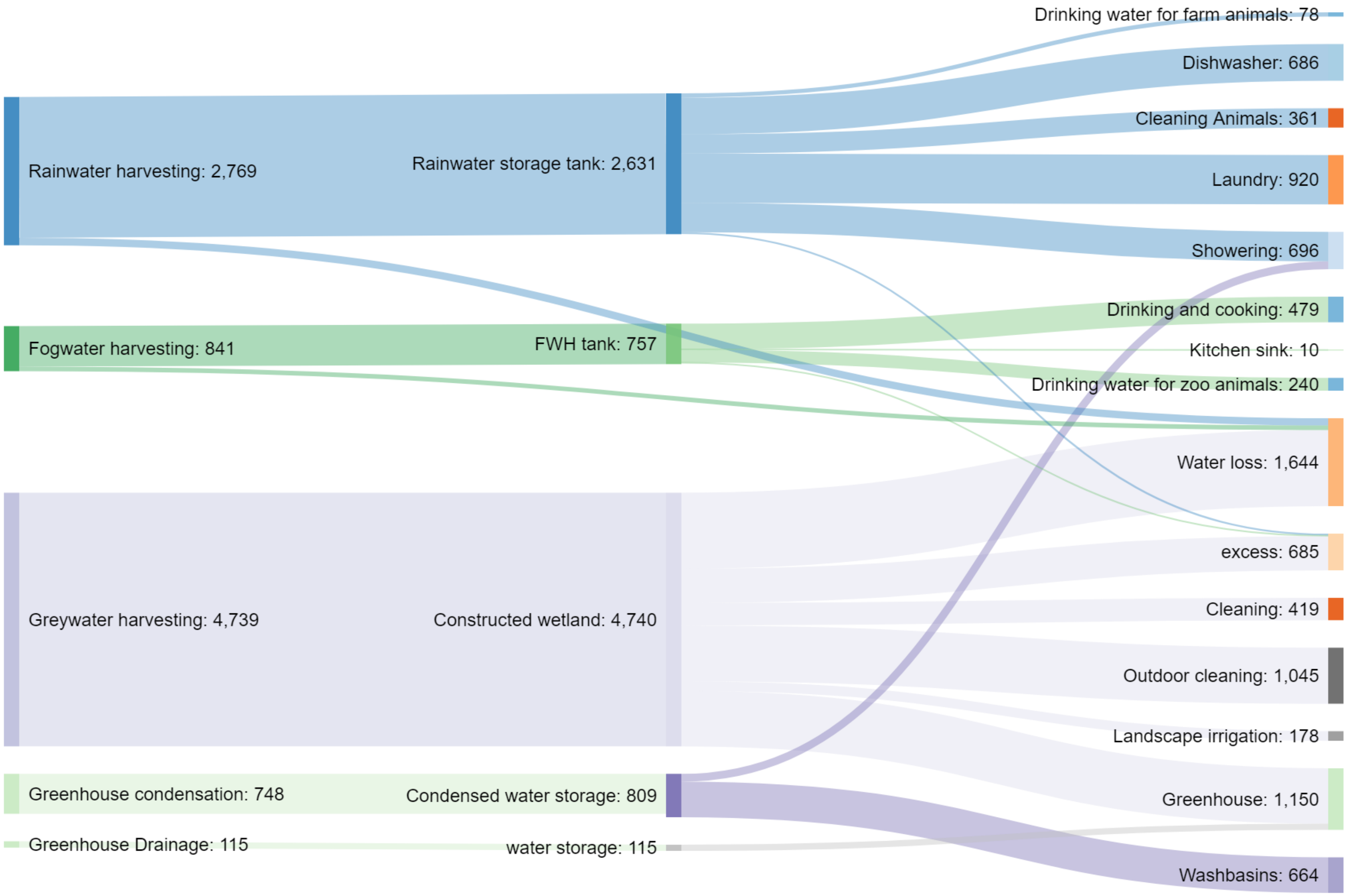


Figure 47: Sankey diagram depicting the hierarchy of sourced water quality and its subsequent water usage , All values in m³ , (Author)

Conclusion

Water loss in management scheme 02 due to the selected technologies was found to be higher. While a membrane bioreactor proposed in water management scheme 01 requires a higher level of expertise it results in lesser water loss , provides better quality of water and can be coupled with other treatment systems to also provide potable water. Though a large amount of water is produced by treating the grey water with the help of a constructed wetland the limited use of the effluent renders it less effective. In order to meet the increased potable water demand a larger area of the greenhouse is considered to upgrade the grey water into potable water as well installation of fog harvesting devices which means an added level of operation and maintenance.

Finally, it can be concluded that water management scheme 01 effectively meets the entire water demand of the site at a maximum capacity and can positively reduce the stress on the existing resources and promote self-sufficiency. Its further implementation on the design can help in understanding its consequence on the Safari park.

Revised Design

Chapter Overview

This chapter will address the following research question :

How does the scheme impact the spatial organization of the centre?

How does the scheme impact the built form of the centre?

What impact does the scheme have on the surrounding environment and ecology?

In order to address the following research questions the initial design was revised and optimised to incorporate the technologies suggested in the earlier chapter. The impact of each technology on the spatial organization and the built form is separately explained. The chapter concludes by discussing the impact of the changes on the environment and ecology of the surrounding.

Design

On the basis of the water management scheme the Design of the park was revised and recommended technologies were incorporated. While the location of the cluster of built forms with respect to the site remained the same the functions within the built form were moved as shown in figure 49. The veterinary which harvested largest amount of rainwater and generated a large amount of waste water daily was moved onto a higher level in order to make use of the natural slope of the site. The same was done with the staff and lodging facilities to ensure water could be transported to the storage tank with the help of gravity. The layout of the park with fee and the staff accommodation was modified to incorporate a larger area for the greenhouse.

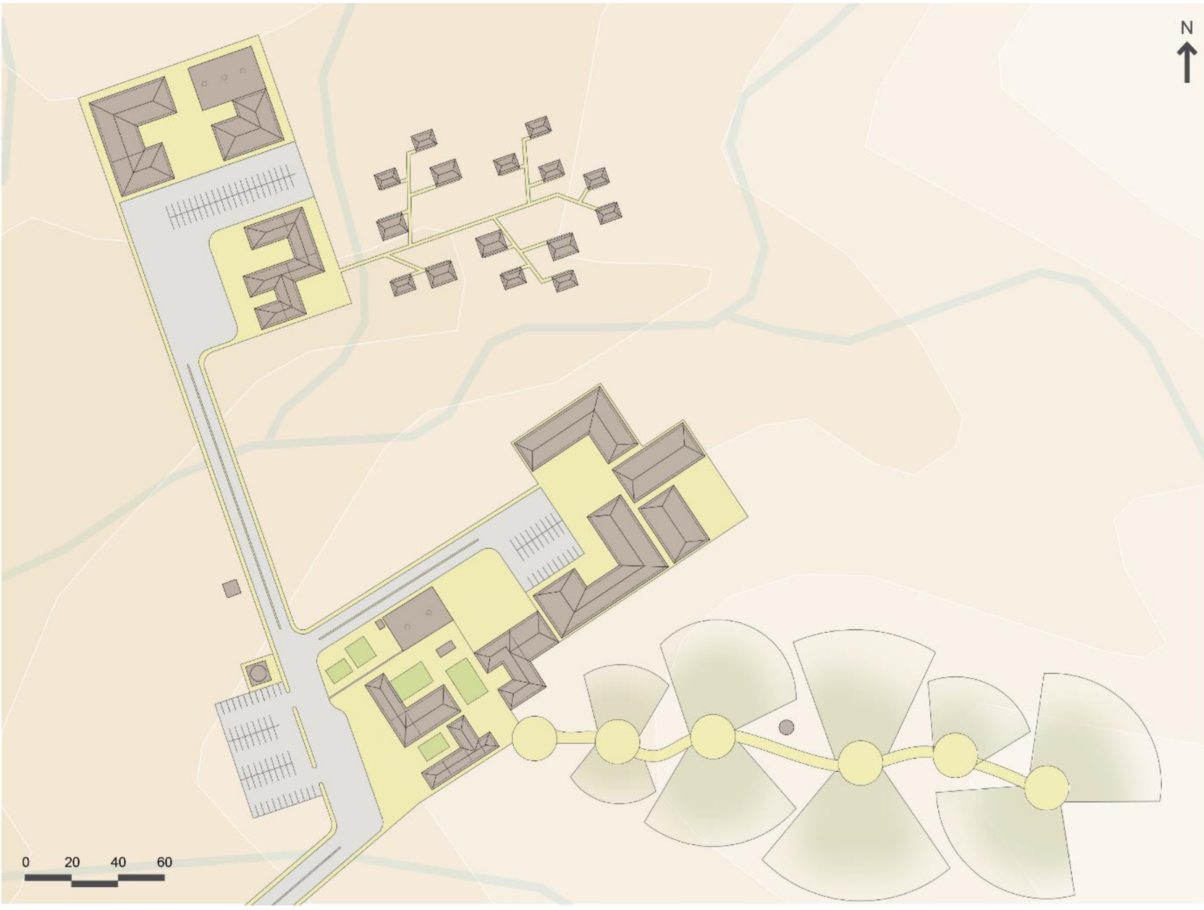


Figure 48: Revised site plan, (Author)

Figure 49: Site zoning, (Author)

The following section will further describe the impact of technologies on the design.

Greenhouse

Within the water management scheme a proposal to increase the area of greenhouse has been made. This has been done with a goal to further the concept of circularity by re-using the available treated waste water to grow vegetables in the greenhouse. Which can then be consumed by visitors in the restaurant and by locals residing in the staff accommodation. The installation of this greenhouse can also potentially facilitate the economic development of local communities as the produce from this greenhouse can be sold in the nearby city. The closed greenhouse concept makes possible the cultivation of vegetables and herbs which would not be possible to grow in the outdoor environment of Iran due to the climatic conditions. Additionally as opposed to the 1.7 L/m^2 water demand required for a standard greenhouse in Firoozabad, a closed greenhouse requires 1.5 L/m^2 (Bucholz et al., 2006; Keshavarzi et al., 2006).

Figure 50: Location of greenhouse, (Author)

A greenhouse of area 600 sqm has been proposed close to the staff accommodation with the intention of promoting local volunteering in the greenhouse to inform the local community of the possibilities a closed greenhouse has to offer. Additionally the condensed water generated in the greenhouse can be used to meet the water demand for the washbasin of the staff accommodation. Also a greenhouse of area 465 sqm is proposed in the park which can be visited by the tourist while the condensed water produced in this greenhouse can be used as shown in Figure 50.

The temperature within the greenhouse needs to be regulated between the range of 20-35 °C throughout the year (Bucholz et al., 2006). On studying the climate graph of Firoozabad (Figure 51) we can conclude an active cooling and heating system would be required to meet this demand. This has been met with the help of a heat exchanger in the Watergy project as explained in the earlier section (page 60). The heat exchanger uses 15m^3 of water to cool a 200m^2 closed greenhouse (Bucholz et al., 2006). On the basis of this study the number of heat exchangers required for the closed greenhouse are estimated and shown in Figure 52 for e.g. in the greenhouse adjacent to the staff accommodation 3 heat exchangers have been proposed at equal distance as opposed to 1, this is done to avoid a disproportionately large heat exchanger and allow for uniform cooling by reducing the distance between the heat exchanger and the edge of the greenhouse. Furthermore the water for the heat exchanger is stored in a room adjacent to the greenhouse. This information is further used to calculate the hydraulic power required to pump the water to the heat exchangers.

Appendix IV addresses the calculation for hydraulic power of the pump followed by the cost estimate for installing the closed greenhouse on site. While Appendix VI presents a comparative study of the cost of installing this technology as opposed to other alternative options.

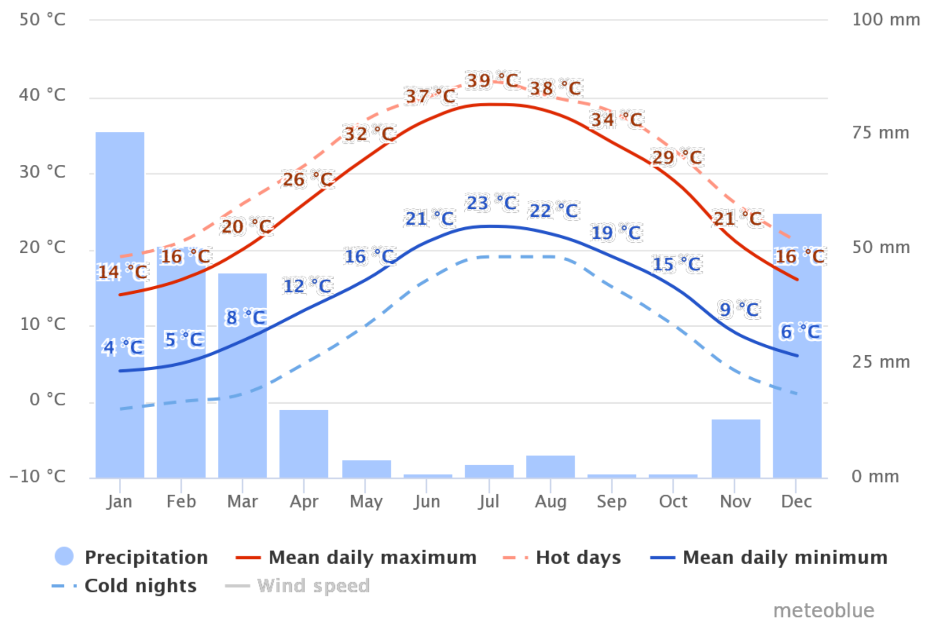


Figure 51: Average temperature and precipitation experienced in the Firoozabad city,(https://www.meteoblue.com , 2019)

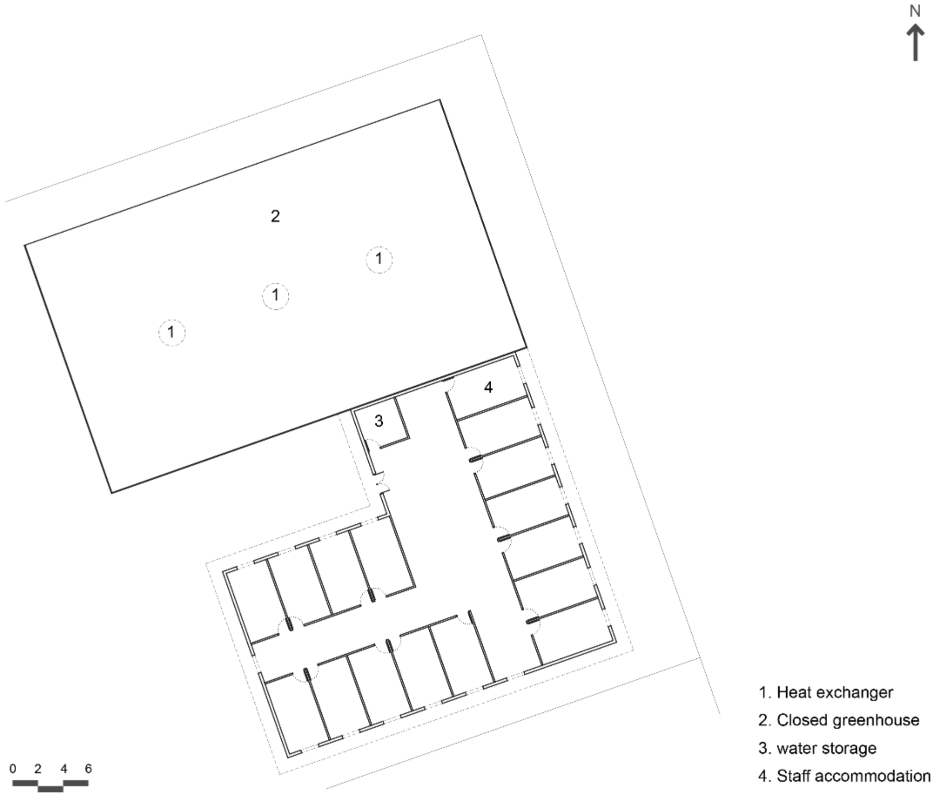


Figure 52: Closed greenhouse adjacent to the staff accommodation (above) and Closed greenhouse in the public park (below), (Author)

Rainwater harvesting

In order to collect rainwater the total catchment area needs to be 11,025m^2, this was calculated using the formula below.

Area = Annual water demand / (Annual rainfall X run-off coefficient)

For the purpose of this calculation the run-off coefficient was taken as 0.95 which is based on the design elaborated below (Guisasola et al., 2011). The annual average rainfall in city of Firoozabad was found to be 273mm (https://www.meteoblue.com,2019).

Area = 2859 / (0.273 X 0.95) = 11,025m^2

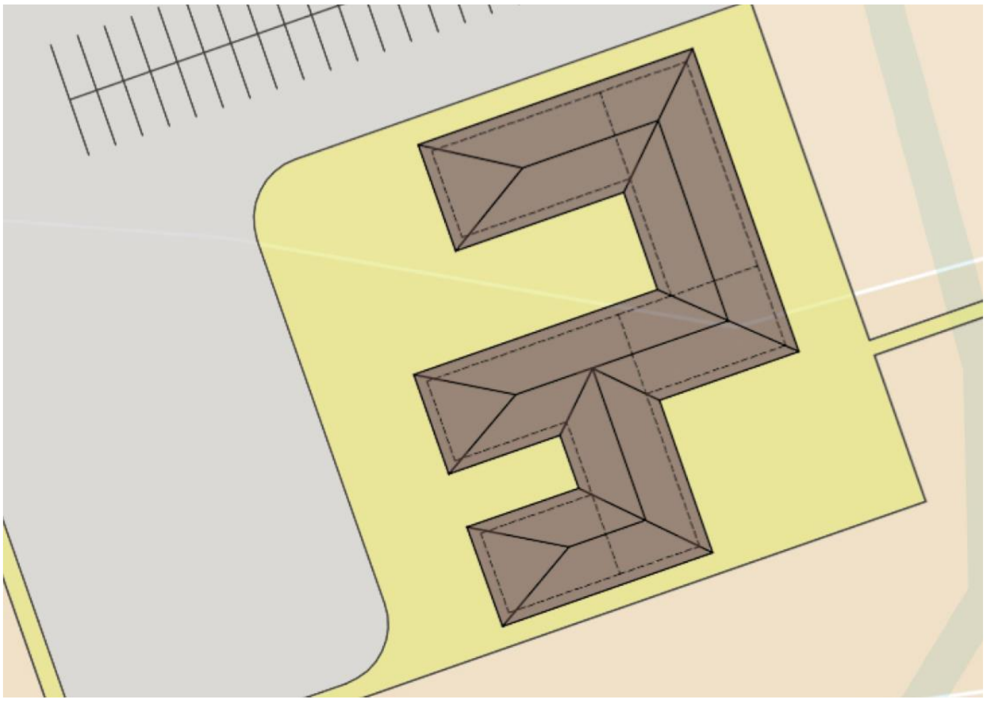


Figure 53: Lodging facilities reception block , (Author)

The roofs of the buildings were extended by 1200mm on all sides which helped in increasing the roof surface area to meet the required demand. In order to further work out the roof detail the lodging facilities reception block is considered. Figure 53 shows the impact of extending the roof while Figure 54 is the internal planning of the complex which was required for further development of the building block.

Figure 54: Internal planning of Lodging facilities reception block, (Author)

Design of the roof

Roofing material and its angle have a direct impact on the quality and quantity of collected rainwater. Installing a smooth and sloping roof implies a higher rainwater harvesting potential (greater runoff coefficient) as compared to flat and rough roofs. Hence metal was considered as the ideal roofing material because the runoff coefficient of metal was found to be the highest in comparison with concrete, asphalt or gravel (Guisasola et al., 2011) . However, as metal roofs would lead to the heating up of the internal building, the roof has been detached from the main roof structure and placed on a truss system (figure 55). This allows for a gap between the main roof and the metal roof through which air can pass. In order to facilitate internal ventilation perforations can also be introduced in the main roof structure to allow for the hot air to escape.

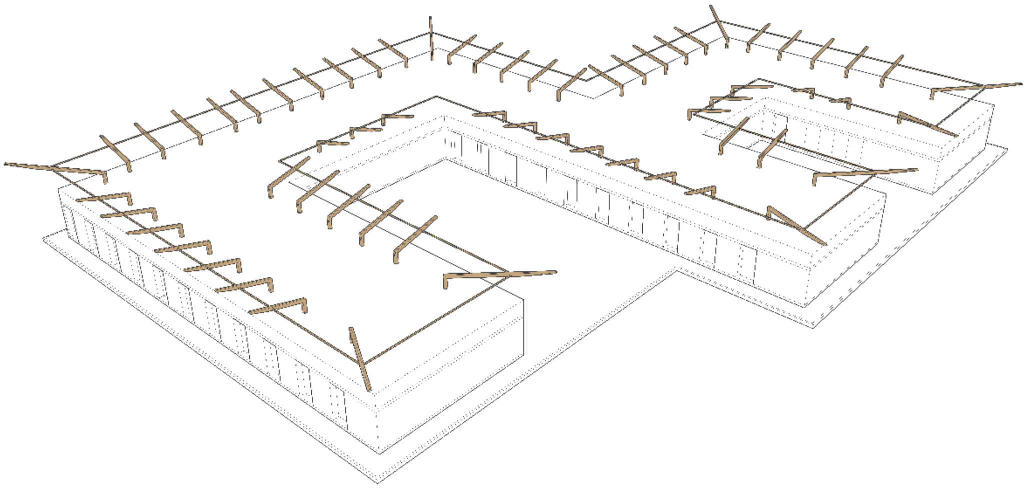


Figure 55: Roof structure , (Author)

Figure 56 indicates the impact of creating a 1200mm overhang over the building in order to increase the roof surface area.

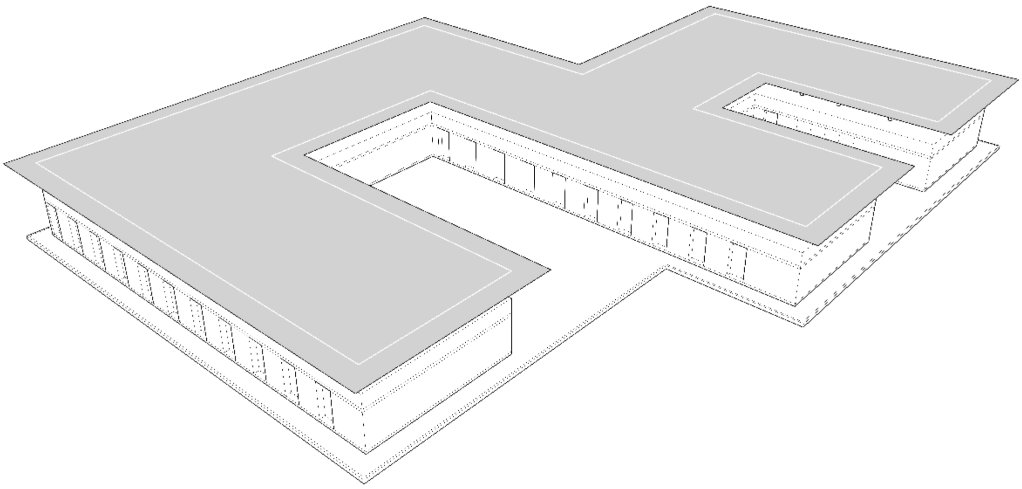


Figure 56: 1200mm overhang of the roof, (Author)

To capture the water quickly without allowing it to travel a long distance the number of gutters are reduced by proposing them in the centre of the roof as shown in figure 57.

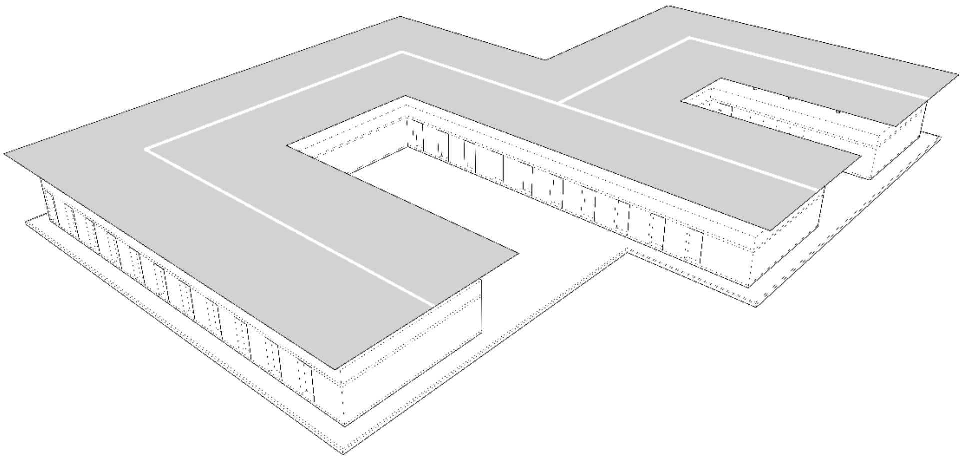


Figure 57: Location of gutter, (Author)

The roof angle was considered as 15° in order to facilitate rainwater collection. This is done by angling the roof towards the gutters to allow for quicker collection of the rainwater.

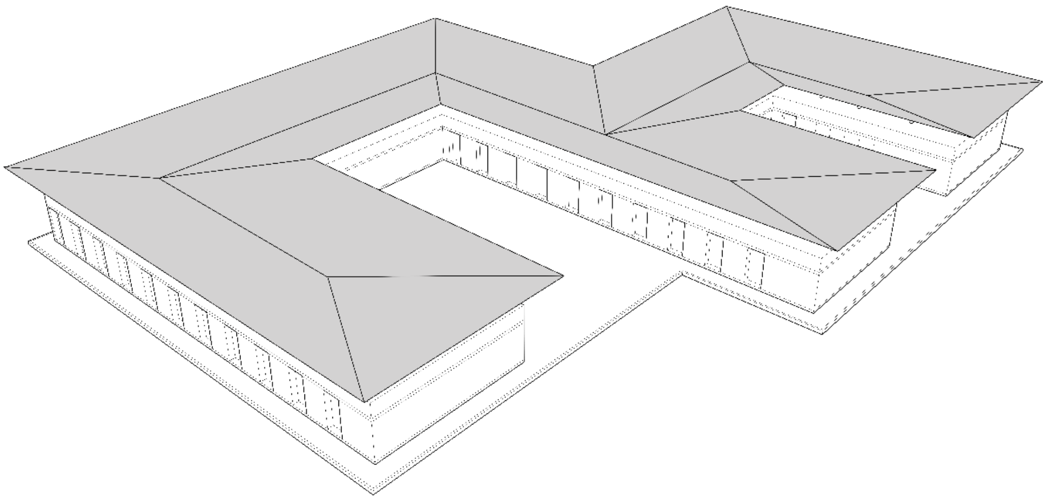


Figure 58: Tilting of roof , (Author)

While the built form has been developed with the concept of courtyards which is prevalent int the architecture of Iran, The roof has been designed to ensure that the induction of a metal roof does not lead to disassociation of the built form from the vernacular architecture of the region (figure 59).

Figure 59:3-D view of the reception in lodging facility depicting the water collection roof, (Author)

Figure 60 indicates the buildings taken into account to calculate the water catchment area which amounts to 11025m^2 post expansion.

Figure 60: rooftops considered as catchment areas, (Author)

Rainwater storage tank

Further on the size of the storage tank was also calculated. To meet the storage demand for the excess water the difference between the cumulative rainfall and cumulative water demand was calculated (Table 14). The storage capacity requirement was found to be 1483m^3 with the tank experiencing its full capacity in the month of march. To meet the complete potable water demand originating in the buildings 2792m^3 amount of water needs to be collected annually.

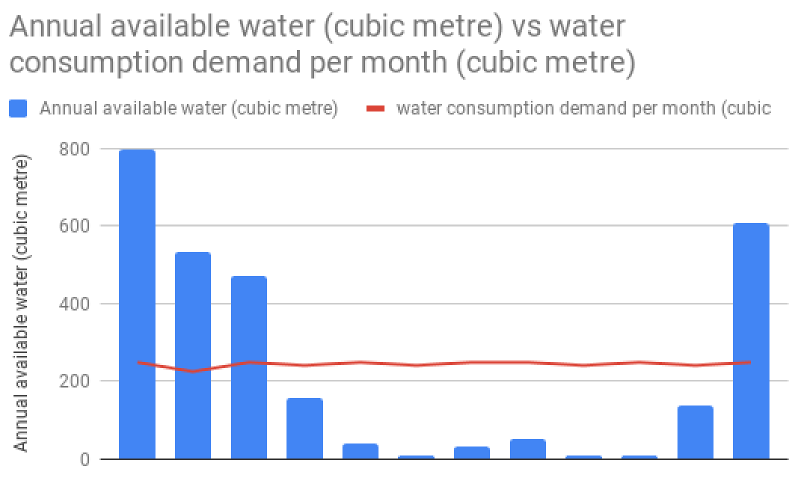


Figure 61: Annual available water (cubic metre) vs consumption demand (cubic metre), (Author)

Month	**Rainfall harvested (m^3)**	**Cumulative rainfall**	**Water demand (m^3)**	**Cumulative demand**	**Difference**
December	607	607	237	237	370
January	796	1403	237	474	929
February	534	1938	214	688	1249
March	471	2409	237	925	1483
April	157	2566	229	1155	1411
May	42	2608	237	1392	1216
June	10	2618	229	1622	997
July	31	2650	237	1859	791
August	52	2702	237	2096	606
September	10	2713	229	2325	387
October	10	2723	237	2562	161
November	143	3000	241	2937	63

Table 14: Calculation of storage tank requirement, (Author)

The large water tank also needs to be stored on the site in an ideal location. The ideal location of the water tank was found to be in the area between the lodging facilities and the park as shown in figure 62. This has been done with the idea that the water from all the roofs can be easily collected in the tank with the help of gravity (figure 63). While when the need for potable water arises it can be collectively pumped to smaller overhead tanks located closer to each functions. Further it is proposed that the water tank be placed underground so it is not adversely affected by the extreme climatic conditions.

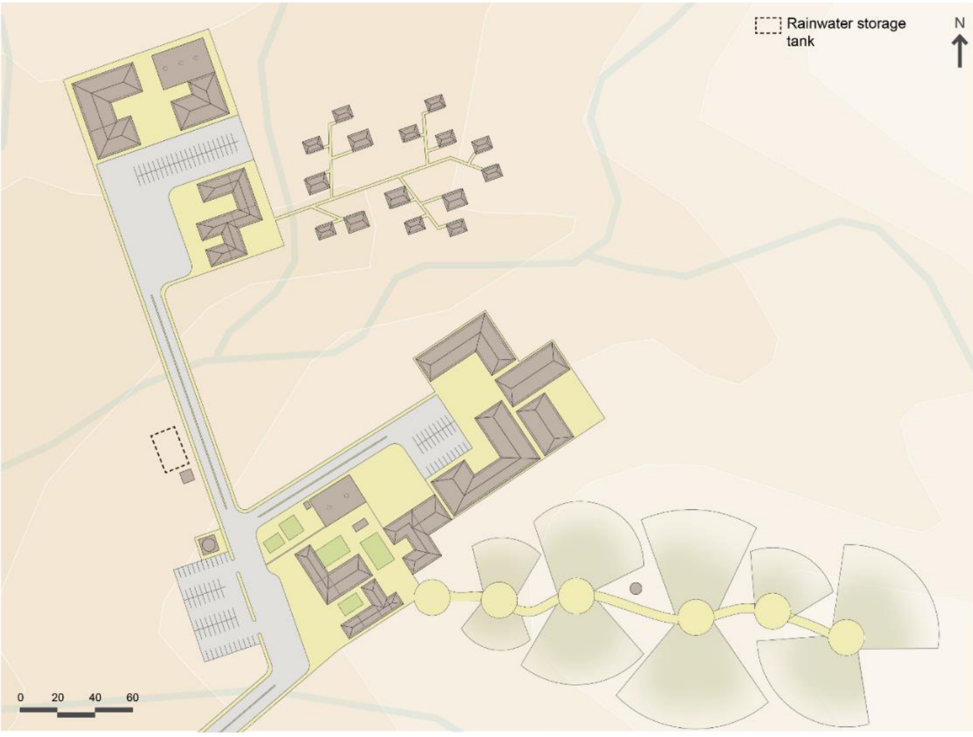


Table 62: Location of storage tank on site, (Author)

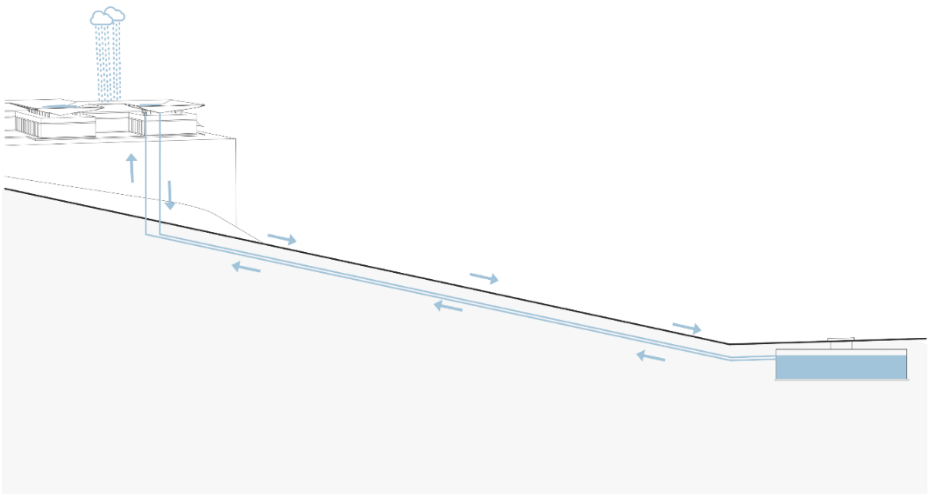


Table 63: using the natural slope to transport water into the storage tank, (Author)

Membrane Bioreactor

The membrane bioreactor is being used to treat the light grey water generated in the park. This treatment process consists of a three steps.

- Primary treatment : Screen chamber
- Secondary treatment : Membrane bioreactor
- Post treatment : Chlorination

The primary treatment removes large solids and grit which can interfere with the treatment process and cause mechanical wear leading to higher maintenance needs . While the membrane bioreactor biologically treats the waste water to produce a high quality pathogen free effluent which can be used for indoor potable purposes. As the effluent is going to be used for flushing and laundry purposes which have a fluctuating diurnal water demand a chlorination tank has been proposed as a post-treatment to get an effluent which can be stored (Aranda, Bribián, & Magno, 2015).

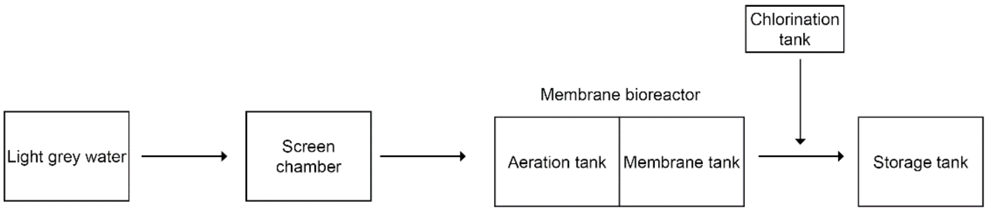


Figure 65: Steps of grey water treatment , (Author)

The area of the membrane bioreactor is calculated as 0.2m^2 / pe which amounts to 36m^2 (180 people). Hydraulic retention time of the membrane system is considered as 19.5 hours.

The water will be stored in a tank of volume 10.4m^3 post chlorination. This is calculating considering a hydraulic retention time of 0.8 days to take into account the volume of 1cycle of treated water. Assuming the width of the tank as 4m and the height as 2m the length of the tank will be 1.3 m. The system is housed above ground in a separate room so it is not tampered by miscreants and can be easily be accessed during maintenance. The maintenance of cleaning out the system has to be carried out twice a year by a sufficiently trained personnel (Aranda et al., 2015; Santasmasas et al., 2013) . The proposed location of the MBR is indicated in the Figure 66 below.

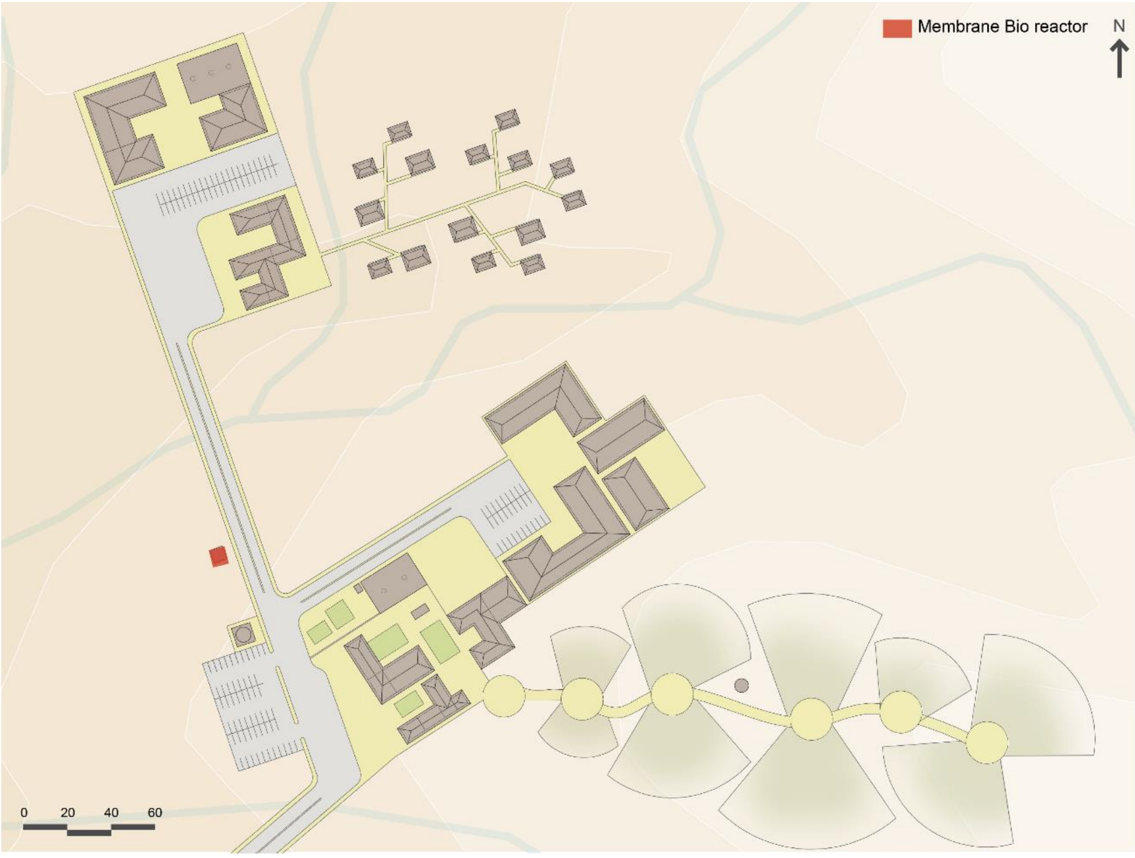


Figure 66: Proposed location of membrane bioreactor , (Author)

Constructed Wetland

The constructed wetland is used to treat the black water generated on site. The treatment process consists of 3 steps (Abdel-shafy et al., 2017):

- Primary treatment : 3 chamber septic tank
- Secondary treatment : Horizontal flow constructed wetland
- Tertiary treatment : Vertical flow constructed wetland

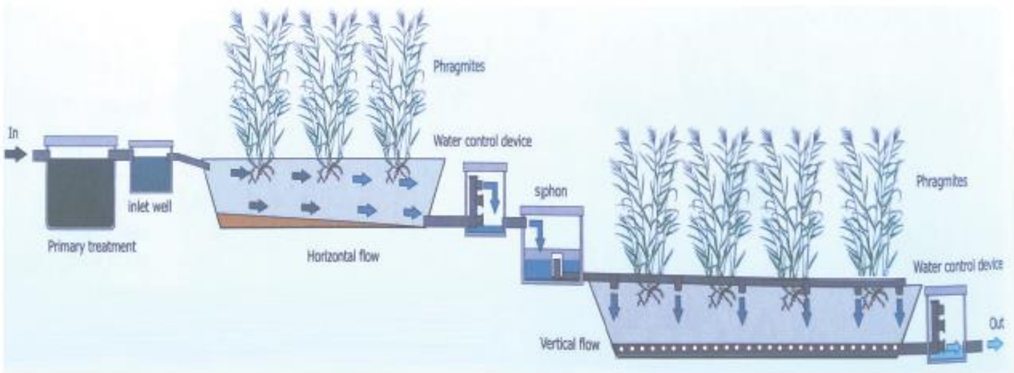


Figure 67 : schematic representation of the treatment system (Abdel-shafy et al., 2017)

A horizontal subsurface flow constructed wetland consists of sand and gravel planted with wetland vegetation. The waste water is released from one end and allowed to move in the bed horizontally. As the waste water moves the roots of the plant filter out particles and material and the microorganism degrade the organic material in the waste water (Wei, 2013).

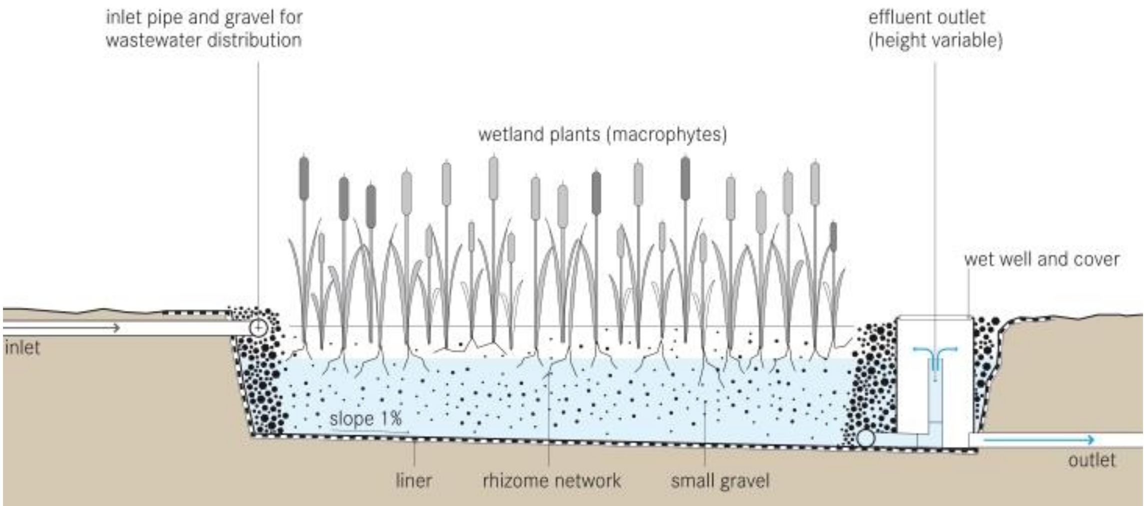


Figure 68: Horizontal subsurface flow constructed wetland (Wei, 2013)

A vertical flow constructed wetland consists of a flat bed of sand and gravel. The waste water is fed from the top through a network of pipes with openings towards the soil. The water percolates downward through the bed and is collected by a drainage network in the base as shown in (Wei, 2013) figure 69.

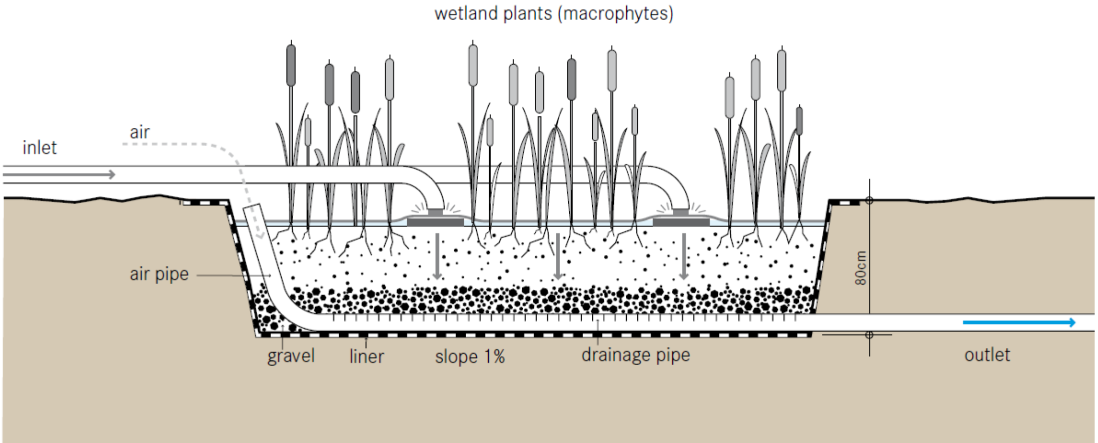


Figure 69: Vertical subsurface flow constructed wetland (Wei, 2013)

The following section addresses the size requirements of different treatment steps involved in the management scheme.

Primary treatment : 3 chamber septic tank

Primary treatment separates the physical matter through sedimentation. The most commonly used device for primary treatment is a septic tank (UN-HABITAT, 2008). A three compartment septic tank has been considered with a hydraulic retention time of 1.5 – 2.5 hours required for the settlement of the total suspended solids (Elizabeth Tilley, Lukas Ulrich & Zurbrügg, 2014).

Sizing of the septic tank:

Average volume of waste water (Q) = 3.1 m^3/day (calculated)

Hydraulic retention time (HRT) = 2.5 day (assumed)

Required volume of septic tank = 6.7 X 2.5 = 7.75 m^3

Depth of Septic tank = 2m (assumed)

Width of Septic tank = 3m (assumed)

Length of first compartment = 0.9 m

Length of second compartment = 0.4 m

These tanks usually require maintenance when 30% of the tank is filled with sludge to continue running effectively.

Sizing of a constructed wetland

Horizontal subsurface flow constructed wetland

Volume of dark grey water(Q) = 3.1 m^3

Population = 327

Per capita black water volume = 9.5L

As a rule of thumb BOD_5 contribution can be considered as 40g BOD/pe.d (UN-HABITAT, 2008)

BOD_5 concentration = 40X 327/ 3.15 = 4157.4 mg/l

It is assumed that 30% of the BOD_5 concentration is removed during the primary treatment process (UN-HABITAT, 2008)

BOD_5 concentration in the influent (C_i) = 2910.2 mg/l

Required BOD_5 concentration in the effluent (C_e) 30 mg/l (Gbagba, 2017)

K_{BOD} = 0.15m/day for a vertical flow wetland (UN-HABITAT, 2008)

Area = $Q (\ln (C_i) – \ln (C_e)) / K_{BOD}$ = 96 m2

The effluent collected from the horizontal subsurface wetland is further treated in a vertical subsurface flow wetland. An evapotranspiration rate of 30% is taken into account before the effluent is treated in the second constructed wetland (Abeer Albalawneh , Tsun-Kuo Chang, 2016).

Volume of black water	**Volume (m^3)**	**Population**	**BOD concentration**	**30% BOD removal in primary treatment**	**K_{bod}**	**Area (m^2)**	**effluent volume (m^3/day)**
Horizontal sub surface flow constructed wetland	3.15	327.0	4157.4	2910.2	0.15	96.0	2.7
Vertical sub surface flow constructed wetland	2.7	327.0	4891.1	3423.7	0.2	63.3	2.3

Table 15: Area calculation for subsurface flow constructed wetlands, (Author)

The depth of the constructed wet land is dependent on the type of plantation used to develop the constructed wetland as the roots must be in contact with the waste water for effective treatment. The Plants considered for the treatment process is cattail which is a local plant of Iran (Shahamat, Dadban, Yousef ;Asgharnia, Hosseinali ; Kalnkesh, R. laleh ;Hosanpour, 2017).

As the root depth of Cattail is 450 the constructed wetland should also have a similar depth. To ensure the waste water does not percolate into the ground and mix with the groundwater the wetlands should be lined. Liners used for wetlands are usually like the ones used for ponds in certain cases native soils can also be used as a liner if the clay content is high. The water will be stored in a sump of volume $4.2m^3$ post treatment.

As this waste water is high in pathogen content and can be harmful for health if it comes in human contact the treatment process is placed in a location with constricted accessibility as shown in Figure 70 (Hoffman et al., 2011). The maximum amount of black water generated originated from the lodging and staff accommodation followed by the restaurants and public toilet. The constructed wetland has been placed in a location where the natural slope of the site can be used to transport the waste water. The treated water will be used for irrigation and greenhouse purposes and can be pumped to the location.

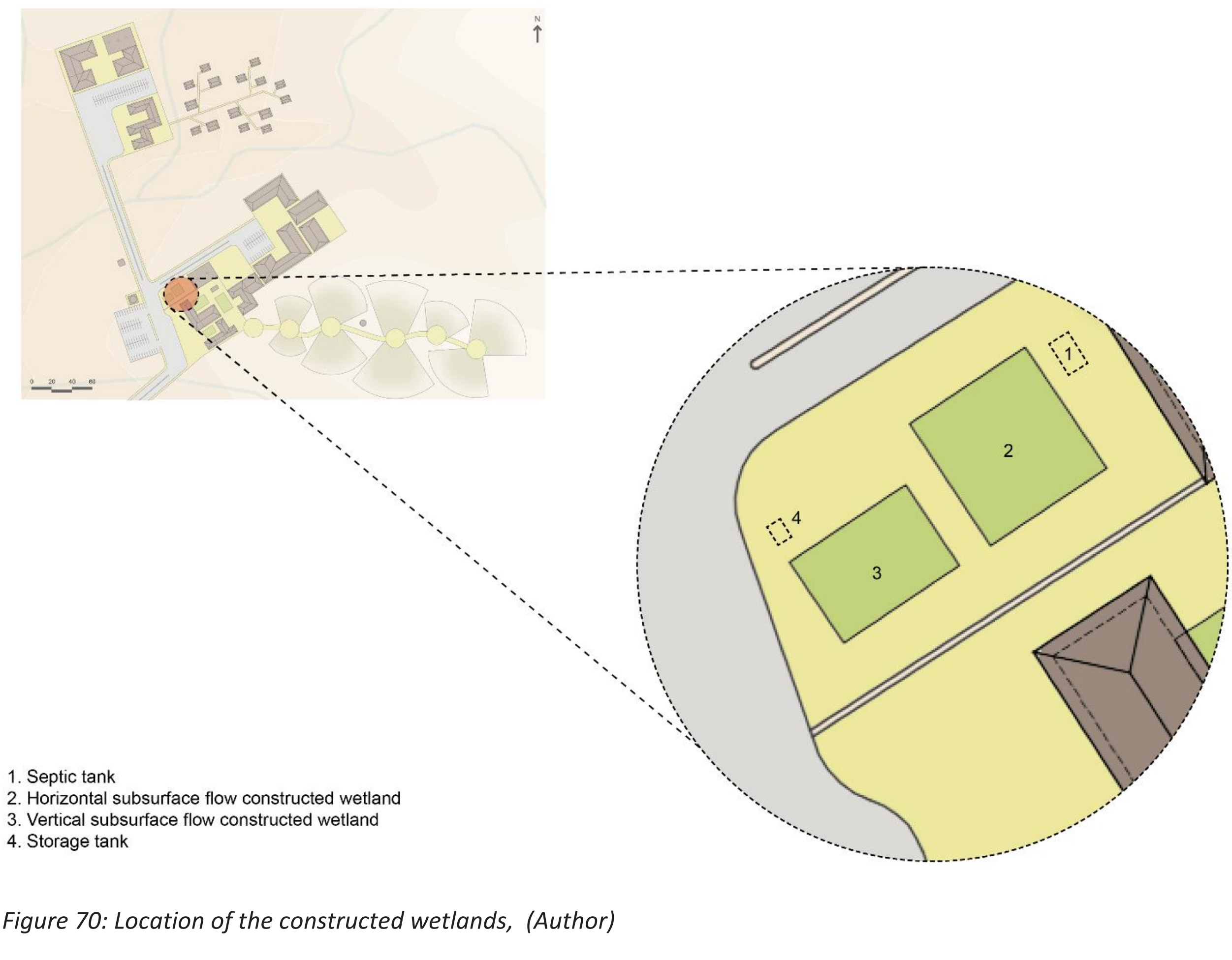


Figure 70: Location of the constructed wetlands, (Author)

Conclusion

While the impact of the water management scheme on the built form and spatial organization has been addressed above, the impact of design on the surrounding environment and ecology needs to be discussed. The design was developed with sustainability as the starting point, with consideration being given to reduce the stress on natural water resources. Through the decentralized treatment of waste water for re-use on site, the stress on the potable water reduces considerably. This also reduces the stress on the natural resources of the site and ensures there is no damage caused to the environment due to discharge of untreated waste water. Through induction of greenhouse and constructed wetland the fauna play an important role to provide clean water. The greenhouse also provides vegetables which further promote circularity within the site and help in mitigating the adverse effect of drought. The project addresses water saving through induction of water efficient fixtures and reduction of over exploitation of resources all at once also providing novelty and luxury to its tourist in a beautiful unspoilt space of Kel Plein. The autarky of the park is successfully achieved through the management scheme resulting in a positive impact on the flora and fauna of the region.

Design guidelines

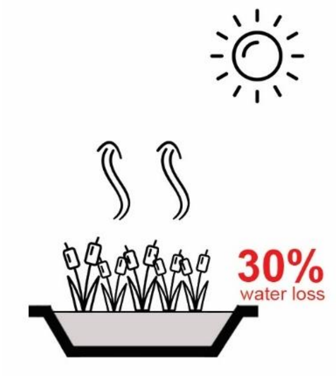
Chapter Overview

This chapter will address the following research question :

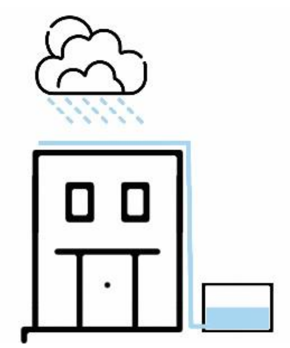
What are the guidelines that can be derived from the design process?

On the basis of the water management scheme and revised a set of design guidelines have been developed. The purpose of these guidelines are to facilitate the designer of the Negin Safari park in taking conscious actions to develop a design incorporating sustainable water technologies. The implementation of these guidelines would not only reduce the exploitation of natural resources but also act as a model project on the basis of which several optimized scheme can be developed and implemented in the region.

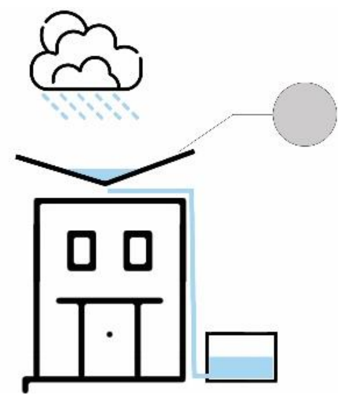
- Technologies which minimize the amount of water loss resulting in maximization of treated water for use should be selected.



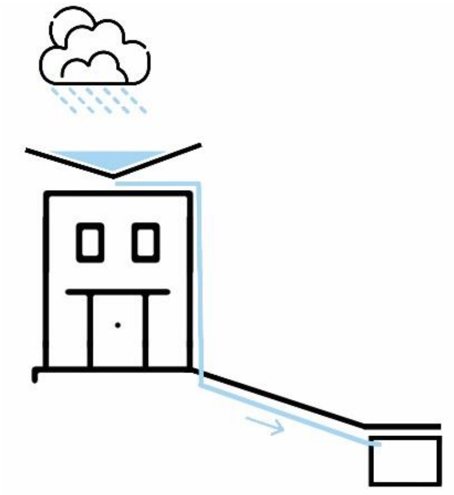
- Benefit should be taken from the rainy season.



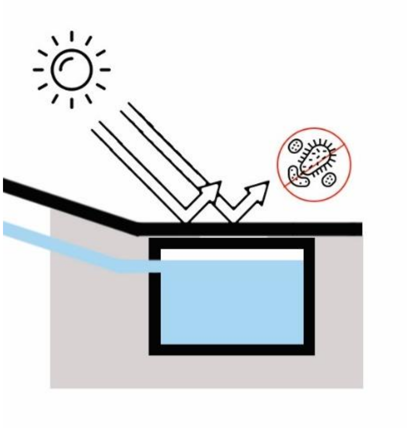
- In order to optimize the rainwater harvesting system the roof should be made of metal and should be placed at an angle between 15^o – 30^o



- The rain water storage should be located in a central location and at the lowest point so that the water can collect through gravity.

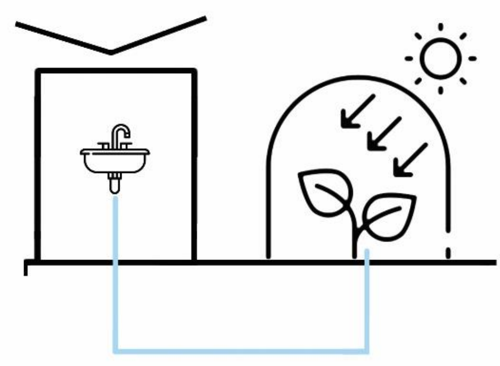


- The water tank should be placed underground to mitigate the adverse effect of outdoor climate on the water.

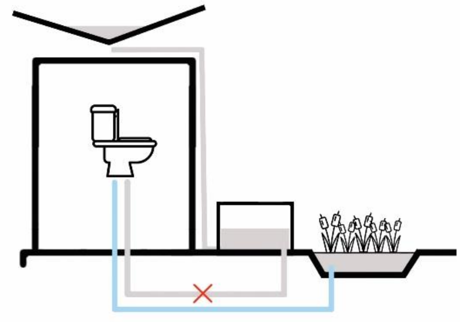


- The veterinary , staff accommodation and lodging should be placed at a higher point on the site as compared to the technologies to utilize the natural slope of the site.

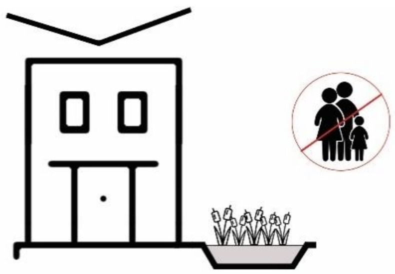
- The design should help in reducing the travel time of water to mitigate water loss. For e.g.: The greenhouse should be placed adjacent to the built form where the collected water will be used.



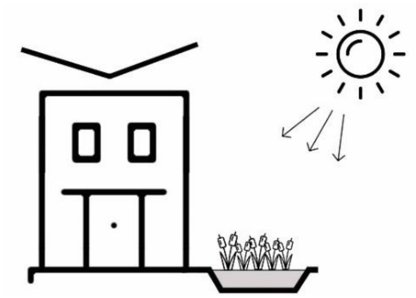
- Through reclamation of waste water, the stress on the natural resources can be reduced.



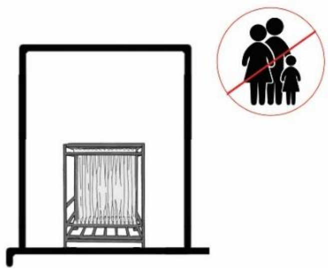
- The constructed wetland and membrane bioreactor need to be located at a lower point on the site so the natural slope of the site can be utilised for collection of water and the treated water can then be pumped back to the location.
- The constructed wetland can be placed in the vicinity of built form however public access to the constructed wetland should be limited.



- It should be ensured that the constructed wetland is exposed to direct sunlight and is not shaded by the built form.



- The membrane bio reactor needs to be located in an enclosed space with easy access for maintenance.



- Water should be conserved using water rated fixtures. For e.g. the toilet fixtures for flushing should only use 4.8L of water per flush and have a provision of dual flush to preserve water.

Conclusion

The Negin Safari park was proposed with the aim to preserve Iranian wildlife and nature and uplift the economic condition of the local Qashqai community. In order to attract the tourist to the park a diverse set of functions were proposed with varied water demands. While functions such as staff accommodation , lodging facility and veterinary had a high water demand the park was found to have comparatively lower demand. Air to water technology has a limited impact on meeting the water requirement whereas rainwater harvesting and waste water harvesting show the potential of meeting the complete water demand of the site. With the help of the membrane bio -reactor as the active technology treating grey water and the constructed wetland as the passive technology treating black water a circular waste water scheme has been effectively developed. While the natural resource of the site, rainwater can be efficiently managed by means of limited energy input. This eliminates the dependence on alternative water connection from external sources. The implementation of these technologies also does not have an adverse impact on the flora and fauna of the region but rather facilitates their growth and sustenance.

It can be concluded that through a combination of passive and active technologies the complete water demand of the site can be met and effectively result in lowering the stress on the natural resources of the surrounding environment.

Reflection

Through understanding the application of technology from an early design stage the project aims to strike a balance between the spatial needs , site limitations and possible sustainable technical solutions. This has been done by identifying different water technologies which could help source water, treat and re-use waste water and rainwater followed by studying their feasibility for Kel Plein, Iran. Several technologies were found which had existing applications on built form. However the warm and dry climate of the region rendered certain technologies irrelevant for Kel Plein. The technologies which were shortlisted entailed certain requirements which had a direct impact on the design of the built form and its spatial organization. The intention of the research was to focus on real time projects with successful application of the technology which would help justify its applicability in the Negin project. Attempting to reduce the stress on the water demand and developing a water management scheme is still a novel concept and has not been widely implemented in developing regions facing water shortage. The positive impact of implementing water management scheme entailing decentralized water technologies leading to a decline in the overall water demand of the project has been studied.

Adhering to the concept of developing the park as an eco-tourist destination attention has been placed to propose sustainable technologies with lower energy requirement and maintenance. It is believed that through implementation of these technologies the added stress of water demand caused by the erection of a Safari Park in a drought hit region like Kel Plein can be reduced. The implementation of these technologies in the Negin park can also further help in educating the locals and lead to encouragement of widespread implementation of these systems. This graduation project is an attempt to develop an informed relation between resource flows and spatial design in order to enable an uninterrupted functioning of the Safari park leading to prosperity of the region and its people.

Reflection Priyadarshini Nanda and Naftany van Zwaaij

In this reflection some conclusions will be drawn from Priya and Naftany's reports and presented as design guidelines for the Negin Safari park.

Roof

In Naftany's report the energy demand of the Negin Safari Park is calculated, It is found that 2500 solar panels are needed. The solar panels can be placed on the roof like shown in Figure 7. The optimal angle is 29°, which is very steep for a roof. The angle can be less, however the performance of the solar panels will than decrease in the winter months (Figure). According to Priyadarshini's work the optimal roof shape consist of two tilted plates with a gutter in the middle. (Figure 7) The plates have an angle of 15°- 30° to optimize the runoff coefficient for the collection of rainwater. This roof shape is however not optimal for the solar panels as only one plate is oriented towards the sun. In this case the solar panels can be placed in the desert outside the park. (Figure) The cost of the solar panel system will in this case increase, because more support elements should be placed for the panels.

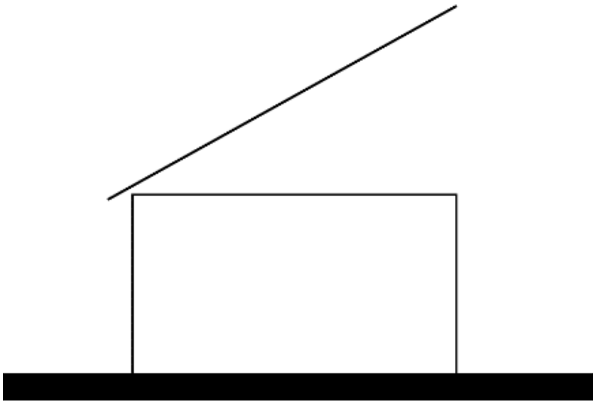


Figure 71: Solar panels on roof

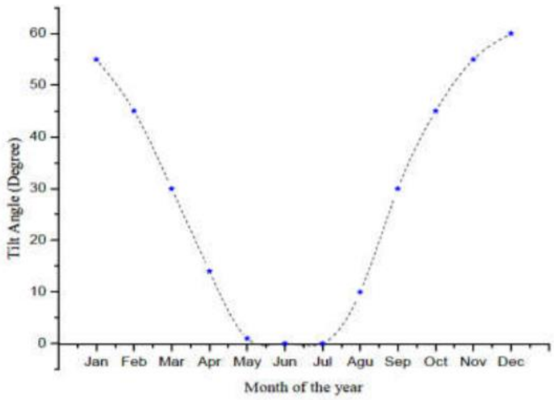


Figure 72: Optimal tilt solar panels Iran

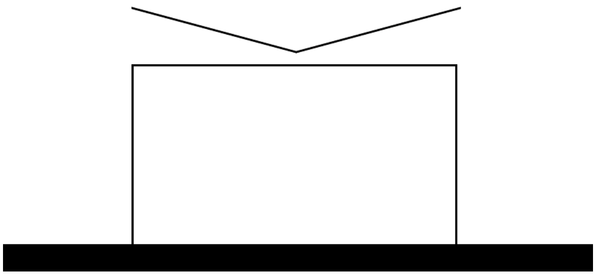


Figure 73: Optimal roof for rainwater

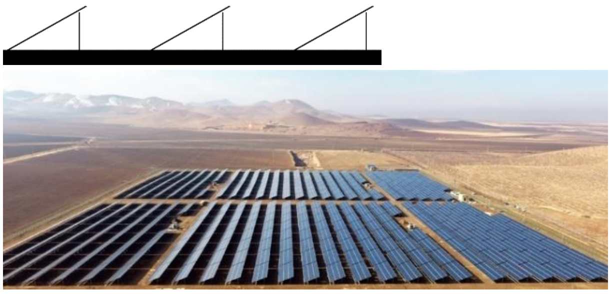


Figure 74: Solar panels placed on the ground

Constructed wetland to decrease the building from heating up

In Priyadarshini's report the constructed wetland is mentioned as a method to filter the black water. The constructed wetland was intended to be placed at a lower level on the site so it is easily visible to the tourists but limits accessibility. (Figure 7) However, since the plant used in the constructed wetland is cattail which can grow up to 3 meter, the plants present an opportunity to reduce direct solar heat gain by the built form if placed adjacent to it. When the constructed wetland is placed at the south or west façade of the building the sun will not be able to heat up the building. (Figure 76)

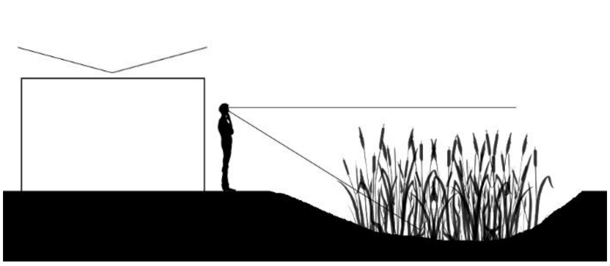


Figure 75: Optimal roof for rainwater

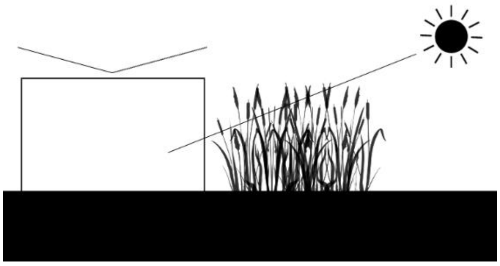


Figure 76: Solar panels placed on the ground

Greenhouse connected to the building

Priyadarshini has also proposed a closed greenhouse which also collects water for reuse. This greenhouse will have an internal temperature range of 20 - 35°C all year round. The greenhouse can therefore be connected to the buildings to prevent them from heating up during the summer and help them heat up during the winter. The greenhouse should ideally be located on the west side of the built form to shade the wall from direct solar heat gain.

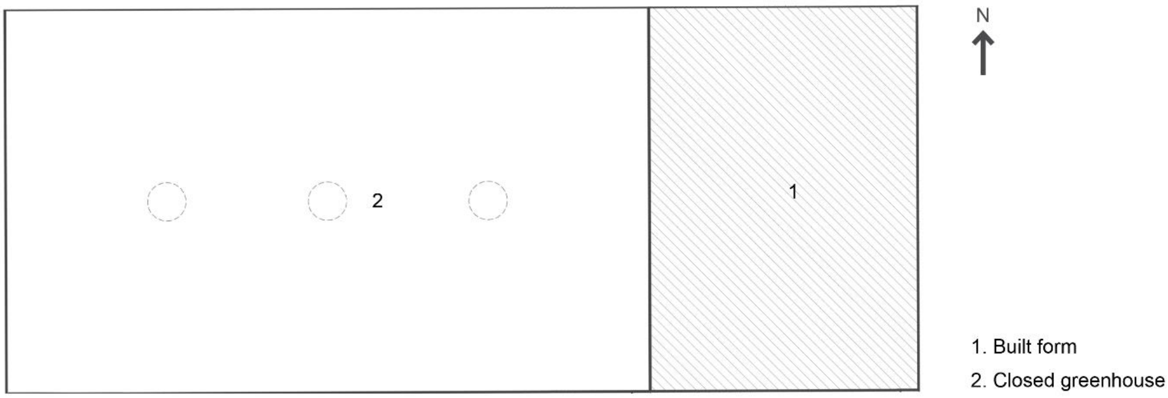


Figure 77: Optimal location for greenhouse

Appendix I

Based on the requirements set by the NGO an area analysis of the Safari park is tabulated below. The area requirements were established on the basis of the case study mentioned in the literature review section and Neufert, 2000.

SNO.	Function	Count	Area (Sqm)	Total Area (Sqm)
A	**Public area , No Fee**			**2225.5**
1	Butterfly Garden			80
2	Restaurant	50 Guest Capacity		243
	Kitchen		0.7X50= 35	
	Dinning		2X50= 100	
	Storage room and personal rooms		0.8X135=108	
3	Playground			120
4	Parking area	for 80 cars	19.2 (60 degree angle)	1536
5	Shop	1 Shop		60
	Display area		20	
	Counter		5	
	Office		35	
6	Weaving Workshop	1 room	76	76
7	Reception	50 Guest		110.5
	Entrance hall		20	
	Counter		20	
	Sitting		40	
	Storage space		10	
	Toilet (2 urinal + WC + WB , women 2 WC and WB)		18	
	Toilet for Disabled		2.5	
8	Prayer room	50 people		85
	Prayer room	50	1.5	75
	Ablution Space	1	10	10
	Shoe rack space	1	5	5

SNO.	Function	Count	Area (Sqm)	Total Area (Sqm)
B	**Negin Safari Park , Fee**			**2743**
1	Bird Garden			200
2	Facilities of restaurant shared			
3	First aid Post			20
4	Qashqai Tent			25
5	Toilets			20.5
	Toilet (2 urinal + WC+ WB , women 2 WC and WB)		18	18
	Toilet for Disabled		2.5	2.5
6	Children's farm			1145
	Goat	5	100	500
	Rabbit	5	9	45
	Peacock	1		0
	Chicken	5		0
	Camel	2	300	600
	Horse	2		0
7	Conference centre (event area)	100 people	1.5 / pp	150
8	Playground			200
9	Greenhouse	1	375	375
10	Parking			212
	Jeep	10 jeeps	20 (45 degree angle)	200
	Segway	1 room		12
11	Information desk	1	35	35
13	Educational Centre			185
	Workshop photography / Mosaic		65	
	Cooking Class + Dining area + cold and dry store		75+20+30	
	Classroom		50	
	Classroom		50	
	Store		20	

SNO.	Function	Count	Area (Sqm)	Total Area (Sqm)
B	**Negin Safari Park , Fee**			
14	Theatre			140
	Outdoor			70
	Indoor			70
15	Security room	2 guards		35
C	**Ancillary Functions**			**3048**
1	Clinic/Medical Area			677
	Intake cages and exam	4 cages	60	240
	Feral room	5 cages	14	70
	Bird room	5 cages	14	70
	Large animal holding	2 cages	14	28
	Exotic	5 cages	16	80
	Registry of cages		18	18
	Exam room		15	15
	Preparation room		25	25
	Surgery room		25	25
	Isolation Ward		30	30
	Euthanasia holding		8	8
	Euthanasia room		21	21
	Freezer		24	24
	General store		23	23
2	Administration (medical area)			235
	Staff lounge		30	
	Staff workstation		10	
	Lockers		13	
	Showers		2	
	Dressing		4	
	Chemical cleaning store		10	
	Food preparation		15	
	Food Pantry		5	
	Food store		32	

SNO.	Function	Count	Area (Sqm)	Total Area (Sqm)
C	**Ancillary Functions**			
	Storage		6	
	Grooming room		30	
	Laundry		23	
	Ablution		10	10
	Prayer room	30	1.5	45
3	Public adoption/rehabilitation			362
	Public intake lobby		35	
	Reception		97	
	Filing room		10	
	Dispatch Copy		18	
	Adoption lobby + Counselling		21	
	Volunteers		21	
	Toilets		45	
	Store		15	
	Classroom		100	
4	Dog holding			1165
	Dog ward	7	70	490
	Puppies	5	36	180
	Canine enclosure	4	45	180
	Socialization enclosure (for canine)	1	100	100
	Get acquainted	1	15	15
	Outdoor exercise area	1	200	200
5	Circulation			609.75

SNO.	Function	Count	Area (Sqm)	Total Area (Sqm)
D	Lodge			3488
1	Staff Accommodation	58 people		1211.65
	Entrance hall	1	14	14
	Laundry room	1	14	14
	Common room	1	23	23
	Dining room	58	0.7	40.6
	Kitchen	1	16	16
	Larder	1	9.3	9.3
	Washing in kitchen (2 sink)	1	11	11
	warden's room (attached toilet)	2	18	36
	Blanket store	1	3.75	3.75
2	Reception			110.5
	Entrance hall		20	
	Counter		20	
	Sitting		40	
	Storage space		10	
	Toilet (2 urinal+ WC+WB , women 2 WC and WB)		18	
	Toilet for Disabled		2.5	
3	Restaurant	50 Guest Capacity		243
	Kitchen		0.7X50= 35	
	Dinning		2X50= 100	
	Storage room and personal rooms		0.8X135=108	
4	Staff room	inn w/ <200 rooms	0.1X40X15	115
	staff changing room			
	Staff dining			
	Staff WC			
	Ablution		10	10

SNO.	Function	Count	Area (Sqm)	Total Area (Sqm)
D	**Lodge**			**3488**
5	Personal room ,supervision and caretaker	inn w/ <200 rooms	0.3X40X15	180
6	Laundry	inn w/ <200 rooms	0.3X40X15	180
7	Room for guests	15 rooms		750
	Suite	12	45	540
	Bedroom (Bed ,Refreshment station with fridge, Lazy chair, Study table, Closet)		30	
	Bathroom (shower + WC + WB)		10	
	Patio (lounge)		15	
	Luxury Suite	3	70	210
	Bedroom (Bed ,		25	
	Living(Refreshment station with fridge, Lazy chair, Study table, Closet)		25	
	Bathroom (Shower + bathtub + WC+WB)		15	
	Patio (lounge)		30	
8	Circulation			697.5
E	**Safari Park (animal holding)**	**64**		**13150**
1	Lion	15	150	2250
2	Brown Bear	2	300	600
3	Asiatic wild ass	9	300	2700
4	Persian fallow deer	9	300	2700
5	Urial	8	100	800
6	Wild Goat	8	100	800
7	Persian gazelle	5	100	500
8	Giraffe	4	400	1600
9	Zebra	4	300	1200
D	**Total built-up**			**24654**

Appendix II

The water demand based on the different functions has been calculated.

S No.	Function	Litres per capita per day	Number of people	Water consumption Litres per day	References
1	Lodge + Staff accommodation	114		12084	(AEE INTEC, 2005)
	Flushing	24	106	2544	
	Bathing	18	106	1908	
	Drinking	3	106	318	
	Dishwashing	10	106	1060	
	Washing	10	106	1060	
	Laundry	22	106	2332	
	Cleaning	15	106	1590	
	Others	12	106	1272	
2	Public toilet	25.85		1285.7	(AEE INTEC, 2005; Alliance for Water Efficiency, n.d.; LEED v4, n.d.)
	Water closet (men)	4.8	23	110.4	
	Water closet (women)	14.4	22	316.8	
	Urinal Washbasin	3.8 2.85	23 45	87.4 128.25	
3	Veterinary + dog holding	92.93		1265.36	(Learned, 2014)
	Water closet (men)	4.8	4	19.2	
	Water closet (women)	14.4	3	43.2	
	Urinal	3.6	7	25.2	
	washbasin	2.85	4	11.4	
	Kitchen sink	3.4	7	23.8	
	Janitor's sink	0.38	7	2.66	
	Pressure wash	12.1	37	447.7	

S No.	Function	Litres per capita per day	Number of people	Water consumption (Litres per day)	References
	Washing machine	37.8	5	189	
	Dishwasher	1.5	37	55.5	
	Trench wash down	12.1	37	447.7	
4	Gardening			487	(Keshavarzi et al., 2006)
5	Green house			634	(Keshavarzi et al., 2006)
6	Restaurant	38	76.5	2907	(AEE INTEC, 2005)
	Drinking and cooking	3	76.5	229.5	
	Dishwashing	10	76.5	765	
	Food preparation	10	76.5	765	
	cleaning	15	76.5	1147.5	
7	Ablution	9	50	450	(Johari et al., 2013)
8	Animals drinking water			728.96	
	Lion	3.8	15	57	(Broad, 2015)
	Brown Bear	15.14	2	30.28	assumption
	Asiatic wild ass	18	9	162	(Kaczensky & Walzer, 2010)
	Persian fallow deer	4.2	9	37.8	assumption
	Urial	11.4	8	91.2	assumption
	Wild Goat	11.4	8	91.2	(Ontario Goat, 2015)
	Persian gazelle	4.2	5	21	(Williamson & Delima, 1991)
	Giraffe	38	4	152	(San Diego Zoo Global, 2019)
	Zebra	3.7	4	14.8	assumption
	Washdown of animals	1.12	64	71.68	(Learned, 2014)

S No.	Function	Litres per capita per day	Number of people	Water consumption (Litres per day)	References
9	Children's farm			236.9	
	Goat	11.35	5	56.75	(Ontario Goat, 2015)
	Rabbit	0.5	5	2.5	(Ward & McKague, 2019)
	Peacock	0.5	1	0.5	assumption
	Chicken	0.5	5	2.5	(Ward & McKague, 2019)
	Camel	38	2	76	assumption
	Horse	38	2	76	(Parker & Brown, 2015)
	Washdown of animals	1.12	20	22.4	(Learned, 2014)
10	Total			19364.32	

Appendix III

The following tables show the water management scheme calculations made to study different ways water can be sourced and its quantity, followed by matching it with the water demand of different functions .

Water management scheme 01

	Rainwater	Condensed water	Treated grey water	Treated black water
Initial water source quantity (m3)	3010	583	4739	1148
water loss (%)	5%	35%	20%	30%
Water source quantity (m3)	2859	379	3792	804

Table 16 : Source and quantity of water, (Author)

water demand type	**Water demand quantity (m3)**	**water source type**	**Remainder sourced water (m3)**
A		Rainwater	2859
Potable water for farm animals	78		2781
Potable water for zoo animals	240		2541
water for drinking and cooking	479		2062
Water for kitchen sink	10		2053
Water for dishwashing	686		1366
Water for showering	696		670
Water for cleaning animals	361		309
Water for wash basin	241		68
B		Greenhouse condensed water	379
Water for wash basins in staff accommodation and mosque	361		18
C		Treated grey water	3792
Laundry	920		2871
Water for restaurant cleaning	419		2452
Water for outdoor cleaning	1045		1408
Flushing	1148		260
D		Treated black water	804
landscape irrigation	178		626
closed greenhouse	525		101
E		Greenhouse drain water	58
closed greenhouse	58		0

Table 17: Water demand quantities and its water balance calculation, (Author)

Water management scheme 02

	Rainwater	Fog water	Condensed water	Treated grey water
Initial water source quantity (m3)	2769	841	1150	4739
water loss (%)	5%	10%	35%	30%
Water source quantity (m3)	2631	757	748	3318

Table 18 : Source and quantity of water, (Author)

water demand type	**Water demand quantity (m3)**	**water source type**	**Remainder sourced water (m3)**
A		Rainwater	2631
Potable water for farm animals	78		2552
Water for dishwashing	686		1866
Water for showering	551		1315
Water for cleaning animals	361		954
Laundry	920		34
B		Fog water	757
Potable water for zoo animals	240		517
water for drinking and cooking	479		38
Water for kitchen sink	10		29
C		Greenhouse condensed water	748
Water for wash basin	602		145
Water for showering	145		0
D		Treated grey water	3318
Water for restaurant cleaning	419		2899
Water for outdoor cleaning	1045		1854
Flushing	0		1854
landscape irrigation	178		1676
closed greenhouse	1035		641
E		Greenhouse drain water	115
closed greenhouse	115		0

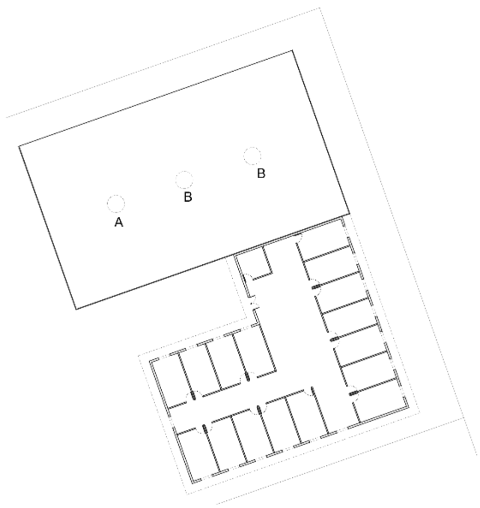
Table 19: Water demand quantities and its water balance calculation, (Author)

Appendix IV

Energy calculation of the water pump

In order to calculate the hydraulic power required to push the water through the heat exchanger the following formula is used (Engineering ToolBox, 2003) :

$P_h = q \times p \times g \times h / (3.6 \times 10^6)$



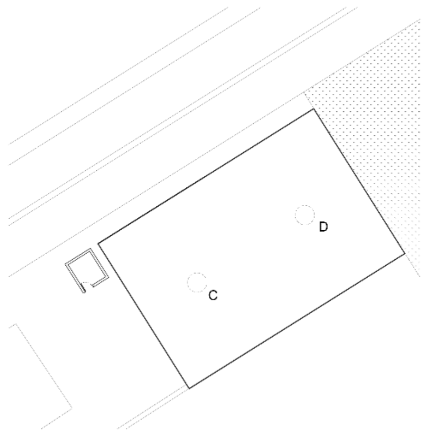


Table 78: Location of the heat exchangers in the closed greenhouse located adjacent to the staff accommodation (left) and the closed greenhouse located in the public park (right), (Author)

		Unit	Heat exchanger A	Heat exchanger B	Heat exchanger C	Heat exchanger D	Source
P_h	Hydraulic power of the pump	kW	0.18	0.13	0.11	0.23	Calculated
q	Volume flow rate	M3/h	1.25	1.25	1.25	1.25	(Bucholz et al., 2006)
p	Density of the fluid	Kg/m3	1000	1000	1000	1000	Standard
g	Gravity	m/s	9.81	9.81	9.81	9.81	Standard
h	Head of the pump	m	1.4	1	0.9	1.8	(Pump World, 2016)
E	Differential elevation	m	0	0	0	0	(Fluid Flow, 2018)
L	Pipe length	m	17.4	12.6	12	23	Design
D	Pipe diameter	mm	35	35	35	35	Assumption
M	Pipe material		New steel	New Steel	New Steel	New Steel	Assumption

Table 20: Calculation of the hydraulic power of the pump, (Author)

However, this calculation does not take into account does not take into the pump and motor efficiency. The impact of the efficiencies is calculated on the basis of the formula mention below.

$P_s = P_h / \eta_p$

		Unit	heat exchanger A	heat exchanger B	heat exchanger C	heat exchanger D
P_s	Shaft Power of the pump	kW	0.22	0.16	0.14	0.29
P_h	Hydraulic power of the pump	kW	0.18	0.13	0.11	0.23
η_p	Pump efficiency	%	0.8	0.8	0.8	0.8

Table 21: Calculation of the shaft power of the pump, (Author)

$P_m = P_s / \eta_m$

		Unit	heat exchanger A	heat exchanger B	heat exchanger C	heat exchanger D
P_m	Shaft Power of the motor	kW	0.28	0.20	0.18	0.36
P_s	Hydraulic power of the shaft	kW	0.22	0.16	0.14	0.29
η_m	Pump efficiency	%	0.8	0.8	0.8	0.8

Table 22: Calculation of the motor power of the pump, (Author)

Hence , The energy requirement for the heat exchangers to be installed in the closed greenhouse adjacent to the staff accommodation is 0.68kW and the energy demand for the other closed greenhouse is 0.54kW .

Cost of energy in Firoozabad (on-grid system) : 0.01€/kwh (NGO, Simba)

Cost of energy in Firoozabad (off-grid system) : 0.44€/kwh (NGO, Simba)

Assuming the pump runs 24 hours a day for 365 days the energy cost calculated is :

Cost of running heat exchanger over a year : 0.68 X24 X 365 X 0.01 = 60€

Cost of running heat exchanger over a year : 0.54 X24 X 365 X 0.01 = 47€

Or in case of an off grid design,

Cost of running heat exchanger over a year : 0.68 X24 X 365 X 0.44 = 2621€

Cost of running heat exchanger over a year : 0.54 X24 X 365 X 0.44= 2081€

Appendix V

Fog water harvesting calculation :

For the purpose of calculating the potential of collecting atmospheric water, the hourly Dry bulb temperature, Relative humidity, Wind speed and Wind direction for Shiraz was used. The formula used for this calculation is as below (Davtalab et al., 2013):

$$M_t = \frac{217\ X\ e}{T + 273.3}$$

$$e_s = 6.11 \exp \frac{17.27\ X\ T}{T + 273.3}$$

$$RH = \frac{e_s}{e}\ X\ 100$$

If RH >= 69% , $WH_3 = M_t\ X\ U_2\ X\ E_{eq}\ X\ 3.6$

M_t = absolute humidity (gm^{-3})
e = air vapour pressure (mbar)
T = air temperature (C°)
e_s = air saturated vapour pressure
RH = relative humidity (%)
WH_3 = Potential water harvested through air humidity (l/m^2)
U_2 = Windspeed (m/s)
E_{eq} = efficiency of the device (10-30% range)

As the Water harvested each day varies as per the climate conditions the calculation was summarized as water harvested each month (Table 23). The yearly water collected amounts to 4548 L/m^2 of mesh area. Hence, In order to meet a water demand of 379m^3/year, a mesh area of 85m^2 is required after accounting for 10% water loss.

MONTH	Potential water harvested 10% efficiency	Direction
JANUARY	765	ESE
FEBRUARY	1033	SE
MARCH	1010	SSE
APRIL	280	SSE
MAY	0	
JUNE	0	
JULY	0	
AUGUST	0	
SEPTEMBER	10	ESE
OCTOBER	30	ESE
NOVEMBER	67	ESE
DECEMBER	1353	ESE

Table 23 : Water harvested in L/m^2 per month with a mesh of 10% efficiency

Appendix VI

Cost comparison of sourcing 379m^3/year of water on site after 1 year, 5 years and 10 years.

Cost of one water bottle 1.5L : 0.37€ (Numbeo, 2019)

Cost of building a fog harvester of 40sqm : 1337€ (FogQuest, 2018)

Cost of transporting 10000L water using a water tanker : 55€ (NGO, Simba)

Cost of building a greenhouse : 279 €/m^2 (NGO, Simba)

Cost of energy to run the greenhouse : 107 €/year

Source	First year	Five years	10 years
Closed greenhouse	€297,242.00	€1,486,210.00	€14,862,100.00
Fog harvester	€2,841.00	€2,841.00	€2,841.00
Water truck	€2,085.00	€10,425.00	€20,850.00
Water bottles	€93,487.00	€467,435.00	€934,870.00

Table 24: Cost comparison of different methods of sourcing water, (Author)

The Fog harvesting device is found to be the cheapest method of sourcing water on site. While the close greenhouse is found to be the most expensive in comparison to the other methods mentioned in the table. However, sourcing water bottles to meet the water demand cannot be considered as an eco-friendly option as it results in a large amount of plastic waste. Transporting water through trucks appears to be an economically feasible option but falls short of being termed as a sustainable option due to the recurrent carbon emission this process may cause.

It should also be taken into account the current cost estimation of the closed greenhouse does not take into account the funds that can be obtained from selling the produce grown in the greenhouse. This should be further evaluated before making an informed decision on the ideal method of sourcing water.

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