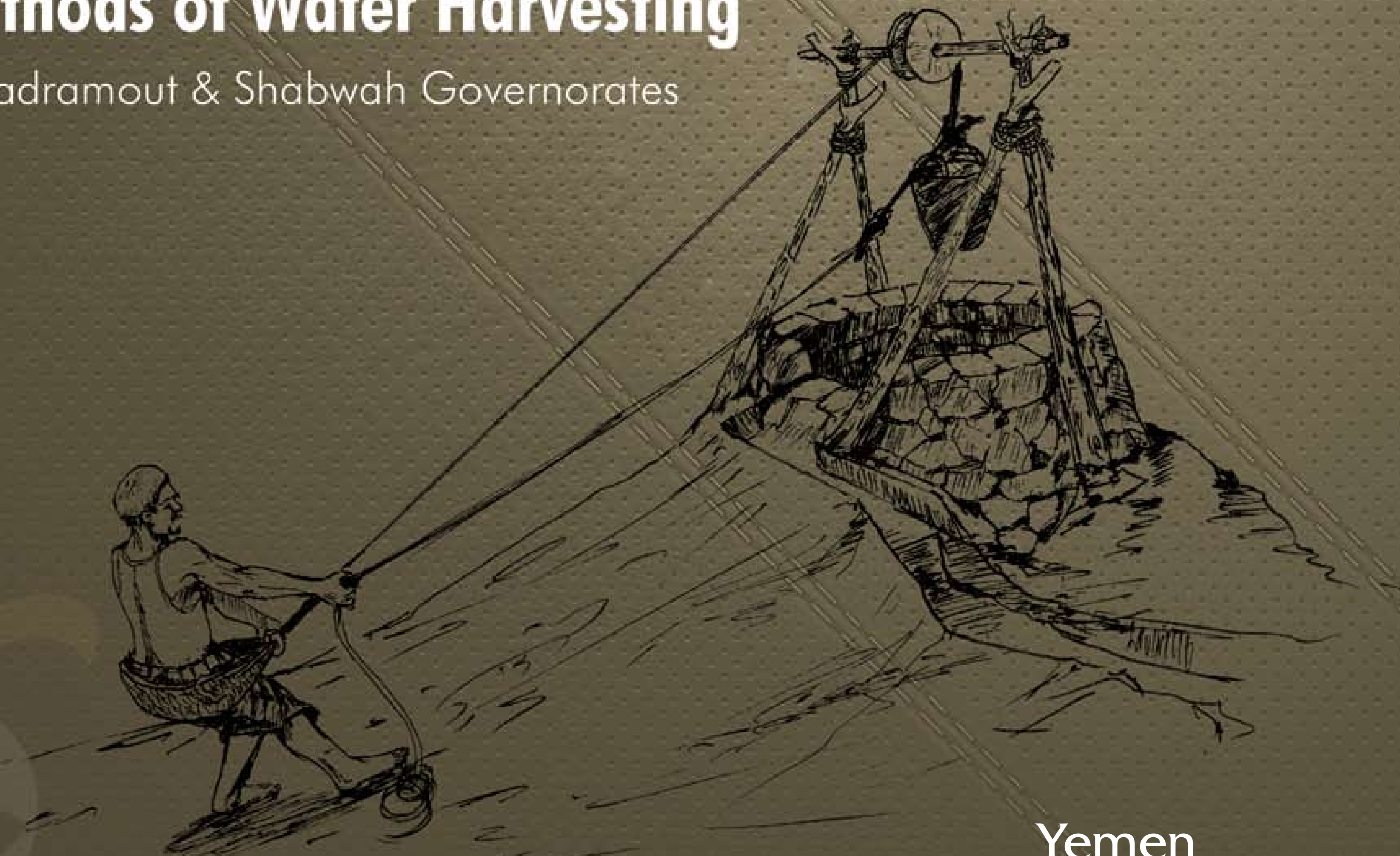
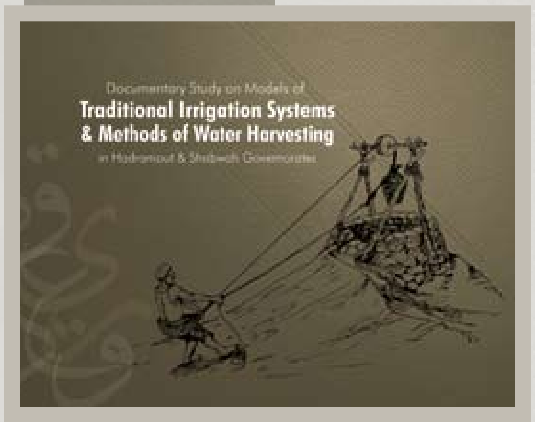
Documentary Study on Models of

Traditional Irrigation Systems & Methods of Water Harvesting

in Hadramout & Shabwah Governorates



Yemen



Documentary study on models of traditional irrigation systems & methods of water harvesting in Hadramout & Shabwah governorates

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In the name of God, the Merciful, the Compassionate

Verses from the Holy Quran:

The Almighty said:

“And from water we made all living things.”
(The Prophets, 21:30)

“He it is Who sendeth down water from the sky, whence ye have drink, and whence are trees on which ye send your beasts to pasture. Therewith He causeth crops to grow for you, and the olive and the date-palm and grapes and all kinds of fruit. Lo! herein is indeed a portent for people who reflect.”
(The Bee, 16:10-11)

“And We send down from the sky blessed water whereby We give growth unto gardens and the grain of crops, And lofty date-palms with ranged clusters, Provision (made) for men; and therewith We quicken a dead land. Even so will be the resurrection of the dead.”
(Qaf, 50:9-11)

Acknowledgement

We would like to present our deep gratitude to all those who contributed directly or indirectly to achieve this work by providing valuable information or references or direct contribution by accompanying us to the fields and smoothening difficulties. Also, we would like to extend our thanks and appreciation to all people who hosted us at their homes in remote areas and provided us with everything possible for them. Furthermore we would like to thank the Environment Protection Council and the project of the Dutch Support Program for Technical Secretariat for material and moral support to this study.

Foreword

Water is under severe stress in Yemen. Many blame inefficient water resource management or poor enforcement of the water law. This book focuses on the lessons that we can learn from the past to better tackle these issues.

It gives me great pleasure to write this foreword, especially as it gives me the opportunity to thank Job Kleijn, First Secretary Water and Environment of the Embassy of the Kingdom of the Netherlands for his initiative in publishing the following research by Eng. Salem Abdullah Baquhaizel, Eng. Ibrahim Ahmed Saeed, and Dr. Mohammed Salem bin Ghouth. Without his efforts, this vital study on traditional systems of irrigation in Hadramout and Shabwa would have remained shelved until today and would never have been given the importance it deserves. I am glad that this important work will now be readily available to students, researchers and other readers with an interest in Yemeni culture, water management, and community organization.

This study highlights Yemen's rich history in engineering and forming efficient organizational structures for water management. It shows the remarkable harmony that existed between communities and their environment, as well as their resourcefulness in achieving so much development with what little means they had available.

I hope that this book will inspire all those involved in the water sector to be as creative as our forefathers.

I also recommend it to all those interested in Yemeni culture as it gives an excellent insight into the water management structures and lives of our people.

Finally, I trust that this study will motivate others to start research in the water domain and encourage the younger generation to prepare themselves for their future leadership role in securing Yemens' water resources.

March 2011

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Content

Abstract

God said, “There was indeed a sign for Sheba in their dwelling-place: Two gardens on the right hand and the left (as who should say): Eat of the provision of your Lord and render thanks to Him. A fair land and an indulgent Lord!” (Sheba, 34:15)

The governorates of Shabwa and Hadramout have long been renowned for their agriculture and irrigation systems. In an arid climate, their people developed irrigation systems to best exploit scarce water resources, leading to green lands and civilized cities.

Today, the neglect of traditional techniques has led to soil erosion, an increase in water salinity, and the spread of drought and desertification. This work therefore aims to lead the way in documenting the traditional systems developed in selected areas of Shabwa and Hadramout as unique and effective systems to manage water and exploit land for agriculture.

Previous research into traditional irrigation and water harvesting systems has rarely addressed all social, economic, geological and geographical aspects of the topic. In general, these studies have not given the natural aspect - geography and geology- sufficient attention.

The first chapter of this work is therefore dedicated to geographical and geological data including rainfall, natural groundwater recharge, and water usage across the varied topography of the area.

In its second chapter, the study focuses on the traditional irrigation techniques that depend on different sources of water, for example spring water or floodwater, and on local topography. The first part of this chapter in particular focuses on the prevalent model of irrigation in the area of Ghail Bawazeer called the ma’aayeen system (Arabic plural of ma’yaan), where channels above and below the ground extend for kilometers from the water source to reclaim expansive areas of agricultural land. These systems are comparable to the qanat systems found in other parts of the world.

We have reviewed the customs of irrigation water distribution, according to the different systems of land ownership in the district, such as the private property systems of ajeez and fakhd. We point to the howam (Arabic plural of houma), or karst pools, as being important water sources, and to the khuwa’ (Arabic plural of khu’a), or cracks in the earth, as important in directing rainfall toward groundwater reserves. We explain the method of digging irrigation water channels through solid rock by hand, according to customs that cover both digging and maintenance of irrigation water conduits.

The second part of this chapter discusses the methods, structures and customs of spate irrigation. Because these are often similar from one area to another, the study will mainly focus on two models:

- The traditional flood irrigation system in the Baihan valley in Shabwa;
- The traditional flood irrigation system in the Do’an valley in Hadramout.

Through these examples, we review the system of the sawaqi (Arabic plural of saaqiyya), or irrigation water conduits, from how floodwater is directed into them, to how it is distributed to the fields and the surplus then drained off.

In the third chapter, we document water harvesting systems in areas of severe drought, especially on the Hadramout Plateau from the high valley of Jardan and Arma in Shabwa to Mahra, in an area locally called the Sitan, where different life and development-sustaining methods of water harvesting have been developed. These include the naqab (Arabic plural of naqba),

karfaan (Arabic plural of kareef), dams, and the jawaabi (Arabic plural of jaabiyya). The shurooj (arabic plural of sharj), or plots of land directly irrigated by rain water, are also discussed in this chapter.

In the fourth and last chapter, the study reviews some environmental aspects of traditional irrigation and water harvesting. It suggests recommendations to protect these systems as well as to study and develop them.

This documentation also includes drawings, photographs and parts of interviews with local experts, all to make a few steps towards maintaining these unique traditions, a wealth of knowledge inherited through generations from those who established the consecutive civilizations of Arabia Felix.

Water is the source of life on earth. The issue of looking for water sources and forms of its availability (surface and ground) received mankind's attention long time ago across the history of first civilizations. There have been many wonderful archeological witnesses which indicate the efforts of man for making water available for different life purposes. The best example we can mention here is the effects of surface water conduits in dry and semi-dry areas to which many areas are belonging in the world, especially in the Middle East. We shall mention, for example, Al Nubah desert, most of North Africa countries and areas of Arab Island, of which Yemen. The areas of field and documentary study (in Shabwah and Hadramout in Yemen Republic), belong to these areas which had human activity, embodying the conflict of man with nature in order to receive water for drinking, pasture and agriculture…etc. Many expertise, traditions, and standing systems have developed over time till this date. Such traditions and systems should be studied and maintained by this generation, especially as they are accumulated expertise across thousands of years which are threatened in our time by the factors of neglect and economic change. From here, the objectives of this documentary study which pays attention to the following themes come up as follows:

- Paying special attention to studying water transferring system that is known for "Al Ma'ayen' in the area of Ghail Ba Wazeer.
- To identify and determine the use and spread of traditional systems of irrigation by flood.
- To identify the methods and techniques of making water available for different purposes in driest areas (water harvesting).
- To identify the status quo of these systems and how they are affected by the use of techniques and modern methods, either negatively or positively.
- Scientific documentation by drawings, photographs and video footage of these systems.

This study has been carried out in a period not exceeding three months for information collection and field surveys and office works. It has ended by making this report and contains descriptions of irrigation systems and methods of water harvesting and supports them with drawings and photographs. Since water is the first aim, the study includes reviewing of natural factors which influence the cycle of draught in nature like topography, structural factors, rocky structure, climate,…etc. The study contains models of some customs and methods prevailing in dividing water which has been depending on accurate astrological calculations.

Introduction

Water is the source of life on earth, and man has long sought water out above and below ground. Archeological discoveries have attested to this, such as the remains of surface water conduits in the dry and semi-dry areas of the world, especially in the Middle East, in the Nubian Desert, most countries of North Africa and areas of the Arabian Peninsula including Yemen.

In the Yemeni governorates of Shabwa and Hadramout in particular, man has long struggled with nature to obtain water for drinking and agriculture. Over time, he has developed expertise in harvesting water, and draining surface water for irrigation. Our generation must study and preserve this expertise that has been accumulated over thousands of years but is now falling into neglect. Thus, the objectives of this study are:

- to describe the ma'aayeen system, in particular in Ghail Ba Wazeer
- to document the traditional spate irrigation models
- to document water harvesting methods in the most arid parts of the area
- to document the current status of these systems and the effects of modern techniques upon them
- to document these systems with photographs and drawings

Information gathering, field surveys, and office work for this study took less than three months. The result was a scientific description of traditional irrigation and water harvesting methods, supported by photographs and video footage. Since water is the main focus of this study, it contains a review of natural factors that influence drought such as topography, rock structure and climate. The study also describes irrigation water distribution systems based on the stars.

Chapter 1: Geology and geography of the area

1-1 Geographical location

The study focuses on areas of the Shabwa and Hadramout governorates between the longitudes of 45 30 and 51 00 E, or as delimitated according to the current administrative division of the governorates. The area studied extends from the Gulf of Aden in the south to the Empty Quarter in the north. (Figure 1).

1-2 Geological structure of the area

The geological structure of the area is the effect of both internal tectonic plate movements that form the greater elements of the topography and external water and wind erosion that form the valleys, hills, and sand dunes.

In the research area, we can distinguish different geological areas up to 2,500 m above sea level (Figure 2):

- Region of base rocks from the Precambrian era
- Region of sedimentary rocks from the Tertiary (Hadramout plateau, and east and southeast Shabwa)
- Region of sedimentary deposits from the Quarternary (Ramlat Al-Saba'atayn, Empty Quarter, Hadramout Valley, coastal plains)

1-2-1 Region of base rocks

These solid rocks are considered to be a part of the Arabian Shield. During the Precambrian era 600 million of years ago, such rocks were exposed to compressions that converted its primary rocks to metamorphic rocks like gneis and schist, granite, syenite and other kinds of rock like durite that appear on the surface. This region is considered to be part of a wide range that includes the areas of Sa'ada, Al-Jawf and Al-Baidha and Mukairas and extends to Hareeb, Bayhan and Al-Saeed. The structure of this base is considered to be related to broader tectonic events in the Arabian Peninsula and east of Africa, that the area as a whole was exposed to as a consequence of the rifting of the Red Sea. The exposed crust which extends from Sa'ada through Al-Jawf, Ataq and Balhaf along the Gulf of Aden is considered to be part of this structural process. One can see its effect on the topography in the western part of the research area. (Figure 2)

1-2-2 Region of sedimentary rocks

Due to the general elevation of the land in the west and southwest of Yemen, inland depressions developed, including a general depression in the eastern parts of the Arabian Peninsula in the area of research, where carbonate rocks can be dated back to the Higher Eurasian era in geology were recently discovered in the area around Al-Naqaba, south of Ataq.

Following this era, eras of tropical and semi-tropical conditions caused the deposit of sand rocks as discovered in the areas of Al-Khair east of Al-Mahfad and even in the areas of Azan. Their rocks can be found in hills down to the coastal plain between Erqa and Balhaf, and are from the Cretaceous era.

Figure 1: Map showing the rates of rainfall and valley network in Shabwa and Hadramout

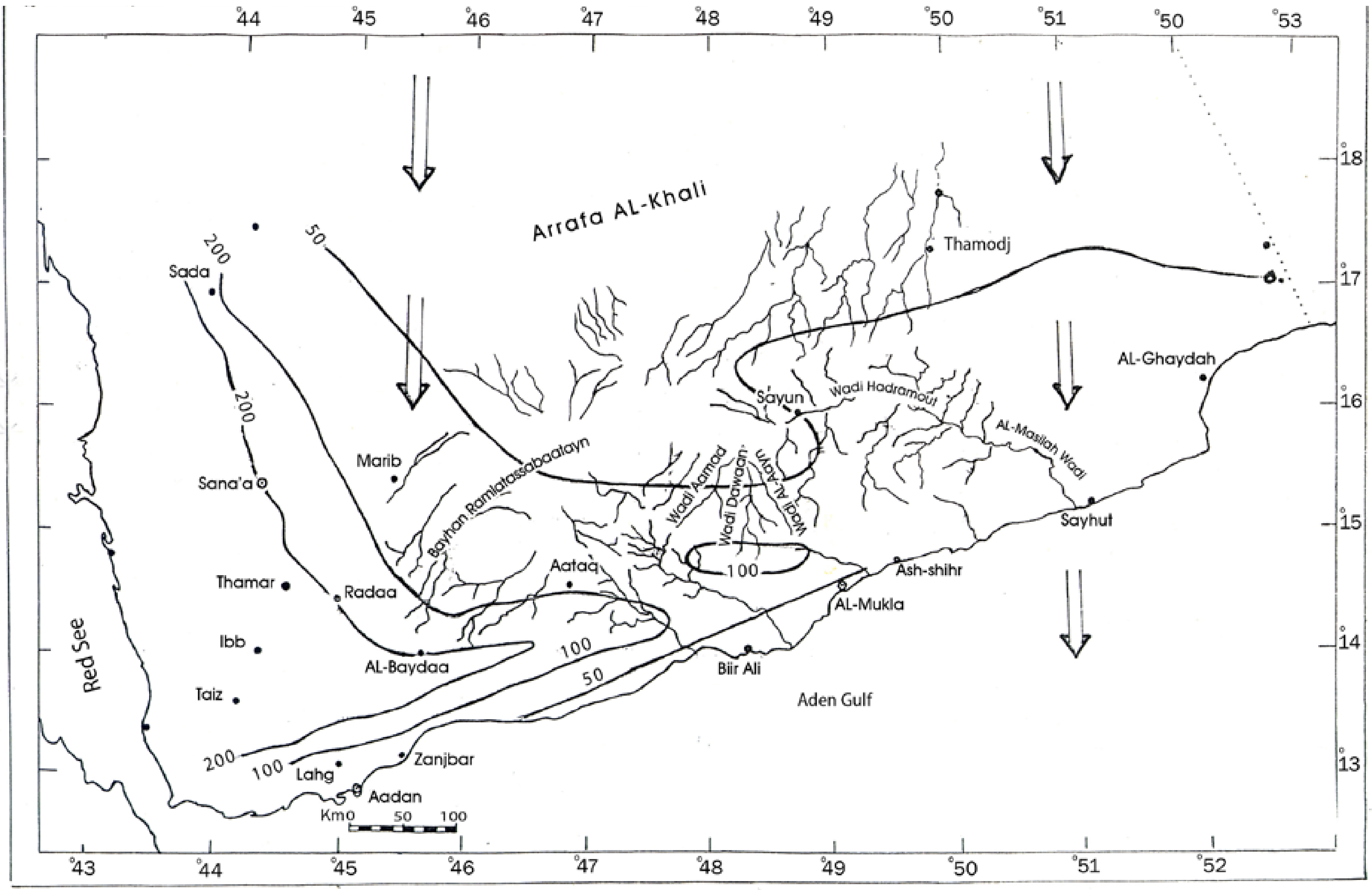
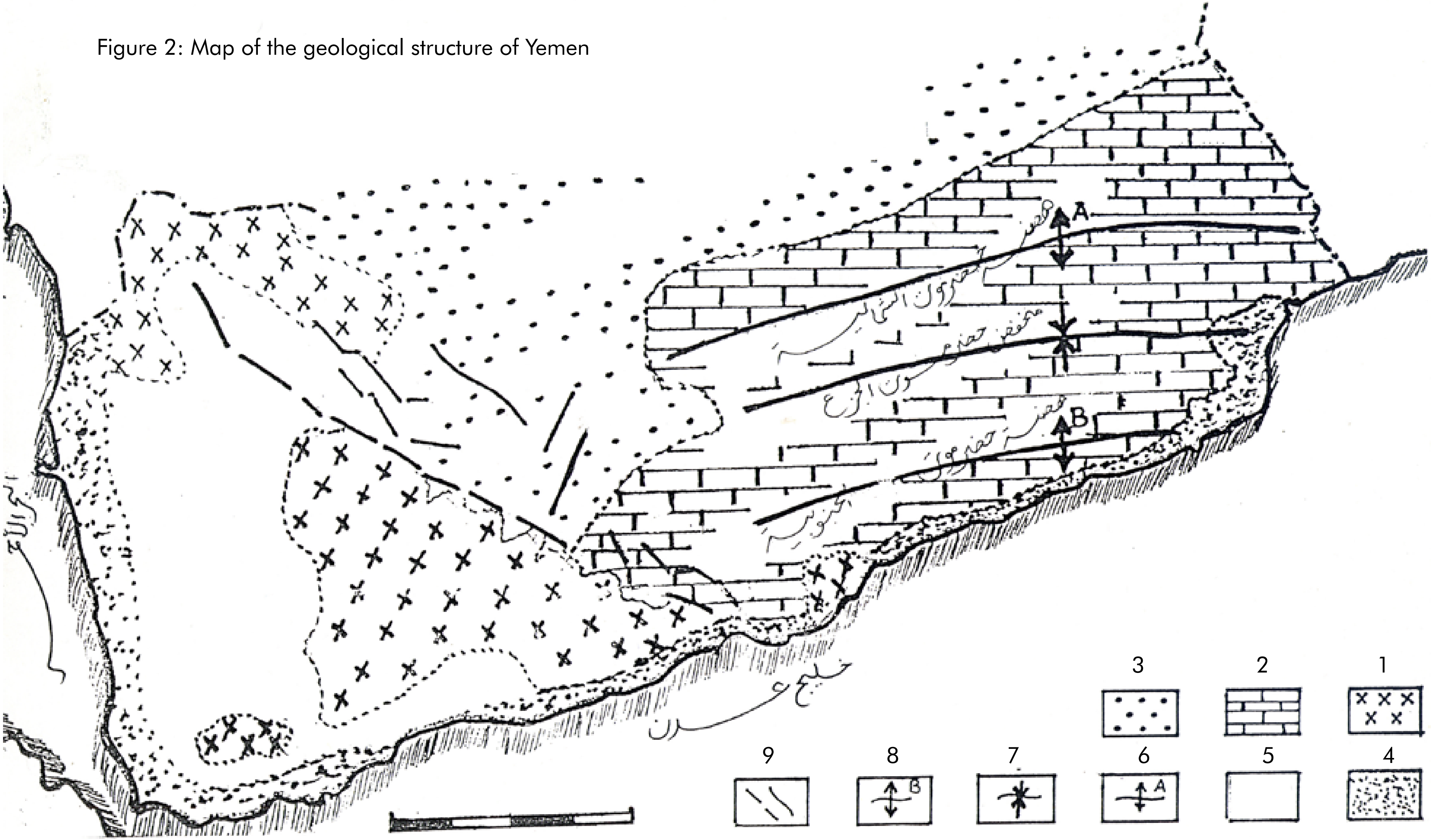


Figure 2: Map of the geological structure of Yemen



1. Region of sediment coverage
2. Region of base rocks
3. Region of deserts (Empty Quarter and Ramlat Al-Saba'atayn)
4. Region of sediment deposits and recent volcanic flows
5. Hadramaut Plateau
6. Jeza' Formation
7. Crack systems, Al-Jawf, Balhaf
8. Volcanic and sediment rocks
9. Limestone and anhydrite

During the Tertiary, the area was submersed in seawater that covered the Arabian Peninsula from the east. The shore then was around the area of Al-Mahfad, and ran up through the area of Ataq and toward Riyadh in Saudi Arabia to the north. In such marine conditions, sediment settled to form thick carbonate rocks: clay rocks in the middle part, carbonate rocks (limestone and anhydrite) above, and then finally sandstone.

At the end of the Tertiary, tectonic movement linked to the formation of the Gulf of Aden was at its maximum. The result was a regional movement upwards that broke the layer of sedimentary rock mentioned above in its coastal parts on the side parallel to the Gulf of Aden. Far away from the coast, the area suffered movements pushing the sedimentary rock layer upwards and downwards, something we can see today in the surface of the southern Hadramout Plateau (movement upwards), the Hadramout lowlands or Jeza' formation (movement downwards), the northern Hadramout Plateau (movement upwards), and the lowlands of the Empty Quarter (movement downwards) (Figure 2). This plateau today extends, in the east, from the area of Arma and the Jardan Valley east of Ataq to the areas of Mahara in the east of Yemen. The consequence of these tectonic movements upwards was the formation of depressions along adjacent coastal areas, as well as the formation of saline lakes and salt deposits after evaporation, now being discovered in the area of Ghail Bawazeer, the Ambakha Valley, the Ghabr Valley and others. As for other depressions, different kinds of rock and sediment accumulated to form what is called the Shihr Group.

1-2-3 Region of quarternary sedimentary deposits and recent volcanism

This region is part of the coastal plains of Hadramout and Shabwa, more exactly the valley depressions, and those between the plateau and the depressions of Ramlat Al-Saba'atayn and the Empty Quarter. Sediment carried by floodwater and wind settled on the slopes and on sand dunes.
This layer of sediment depended on the type of surface or depression, local topography, the nature of its rocks, and erosion. In the narrow valleys, the influx of rocky rubble was varied, while in the wider valleys, the fine sediment that was deposited often appears like loess. As for the coastal depressions, the Empty Quarter, and Ramalat Al-Saba'atayn, the sediment on the sand dunes varies.

Recent volcanism refers to the volcanic activity that accompanied the internal movements that led to the formation of the Gulf of Aden. It appeared on the surface as stratovocanoes or composite volcanoes. Lava emanated from the craters of many of these, such as Bir Ali in the southeast Shabwa, or, in southeast Hadramout, Qusair, Al-Musayna'a, and Wadi Badash whose basalt layers might be connected to the forming of the fissure in the rock.

1-3 Topography of area and valley network

The topography of the area is governed by the drainage network. Climate plays an important role in this respect. The area can be considered as a dry or semi-dry area. The area under study boasts different geographic elements in its topography, according to geological structure and rock structure, as mentioned in the paragraph 1-2 of this chapter.

These elements of the area's geography can be listed as follows:

1-3-1 The eastern slopes of Yemen's western highlands

These include the slopes to the west of Ramlat Al-Saba'atayn in Shabwa. They are base rocks and extend in the study area from Al-Naqoob and Hareeb in Marib in the north to the areas west of Ataq and Erqa in the south towards the coast. These slopes incline to the east to dive under the accumulated sediment in Ramlat Al-Saba'atayn, but can also reach 2,200 m above sea level, for example in the east of Al-Baida.
Within these slopes, there are many valleys like the Baihan Valley, Jubahh, Jafa'a, Markha, and Abdan which faces towards the northeast to flow into Ramlat Al-Saba'atayn. In the southern mass of these slopes, water courses run south and southeast. Valleys run through sedimentary rock in the area of Naqaba, like in the Yashbum Valley in the Shabwa governorate.

1-3-2 The Hadramout Plateau and its slopes

This is mainly made up of limestone walls. From the point of view of its topography, the Hadramout plateau is divided into three morphological elements, all linked to the rising movement in the plates that formed the Gulf of Aden (See paragraph 1-2-2). These three elements, the description of which follows below, are parallel to the coastline (Figure 2).

The southern Hadramout Plateau

In the south, this plateau is fragmented and in the north it is curved or bending. The southern part, with an altitude between 1,000 and 2,000 meters above sea level, is the feeding area for all the valleys and water tanks in their lower parts until the coastline. Many valleys slope down from the plateau, including the Huwaira Valley, Bouyish, Araf, Badash, Tamnoun, and many parallel valleys up to Seyhout and to its east.

The Hadramout depression. also called the Jeza'

This is in to the north of the southern Hadramout plateau. The Hadramout Plateau slopes very gently into it, and it is a feeding area for many tributaries that pour into valleys like that of Markha, Amad, Do'an, Al-Ain, Bin Ali, and 'Adam that all feed into the Hadramout Valley.

The northern Hadramout Plateau

This plateau is located to the north of the Hadramout depression or the Jeza' (that crosses the Hadramout Valley and surrounding areas in the south). The northern Hadramout plateau rises up gradually towards the north until the Empty Quarter. Its altitude reaches 600 to 900 meters above sea level, and it is considered to be a feeding area for valleys running to the south of the Hadramout Valley like Wadi Sir.

1-3-3 The coastal areas

These include all natural depressions along the coastline into which run many valleys from the southern Hadramout Plateau, rich in water sources like springs, hot springs, groundwater, and karst areas like Ghail Bawazeer.

1-3-4 The Empty Quarter desert

This is the desert that receives all the valleys sloping down towards the north from the northern Hadramout Plateau, as well as those on the slopes east of Sa'ada and Al-Jawf.

1-3-5 The Ramlat Al-Saba'atayn desert

This is the desert between the eastern side of the Hadramout Plateau and the Hadramout Valley on one side and the slopes northeast of the Jawf- Baihan- Markha area on the other. It is bordered on the north and northeast by the Empty Quarter.

Chapter 2: Traditional irrigation in the Hadramout and Shabwa governorates

Yemenis have long benefitted from the nature and environment that has surrounded them. Traces of ancient irrigation can be found in many valleys like those of Marib, Baihan, Markha, Jardan, Mayfa'a, Raikhaya and the large Hadramout Valley.

Yemenis were also good at building dams, canals and reservoirs which enabled them to establish prosperous civilisations along the edge of the desert in Shabwa and Marib and in the valleys. Still today, the descendants of those who built these structures benefit from them and use the same techniques to best utilize water from its different sources.

Within the scope of this work, we can mention three main types of traditional irrigation systems which are:

- 'Ma'aayeen' irrigation
- Spate irrigation
- Spring irrigation

2-1 Ma'aayeen irrigation (Ghail Bawazeer model)

The Almighty said, "Say: Have ye thought: If (all) your water were to disappear into the earth, who then could bring you gushing water?"
(The Kingdom, 67:30)

The study and definition of ma'aayeen irrigation constitutes one of the main objectives of this study. This is because of the unique system and its positive features and as it is not registered elsewhere in Yemen.

The ma'aayeen system transfers water from different sources (wells, springs, howam or karst pools) via open conduits or via underground tunnels with openings for ventilation and lighting, called naqab, to agricultural lands or to use it in rural and urban development.

This system is widespread in the area, from the east of Al-Mukalla to eastern Raida to the east along the coastal plain of the Hadramout governorate. It is encountered in the following areas:

1. Areas near Mukalla, like Al-Kirba and Al-Baqrain
2. Ghail Bawazeer and surrounding areas like Al-Suda', Habaayer, Al-Qara, Shaheer, Al-Naqa, Sahoot, and Katheeba
3. Areas belonging to the Shihr district, like Tibala, Me'yaan Al-Masaajida, Al-Habs, Al-Huwa, Al-Hami and Al-Waaset
4. Areas of eastern Dais like the ma'aayeen of Al-Saiq, Sana'a, Thawban, and Swaiber.

Ghail Bawazeer has been selected as a research model for this study, notably because it has abundant water sources (springs and howam or karst pools) and a unique irrigation system of underground water conduits extending for kilometers to irrigate agricultural lands, known as the ma'aayeen system.

The story of the ma'aayeen in Ghail Bawazeer starts more than 700 years ago, when Sheikh Abdul Rahim bin Omar Bawazeer came to the area in 706 AH. He was one of the wisest preachers to spread knowledge and culture on the Hadramout coast, and is also considered to be one of the founders of the town of Ghail Bawazeer and the engineer behind the first irrigation in the area.

The beginning of the ma'aayeen in Ghail Bawazeer is associated with the founding of its famous mosque. There was no source of water for ablution or washing as there was no source of water near the mosque. Bawazeer shot an arrow from the mosque and ordered men to dig where it landed. There, they found a source of water at modest depth. He ordered the construction of a conduit to the mosque and then to the agricultural lands of Habit Al-Amal to the south of the mosque. These were irrigated by the sinaawa or open well irrigation system (described below).

Some ascribe the overall development of the ma'aayeen system to the arrival of Sheikh Abdul Rahim Bawazeer, yet ma'aayeen with open water channels were known long before the sheikh's time although their precise history is unclear. During the Sheikh's time, Ma'yaan Al-Harth Al-Kafir and the Diwan Ma'yaan and other ma'aayeen were already present.

Some of those interested in the history of the area like Sheikh Mohammed Bin Hawi Bawazeer, nicknamed Abu Sirajeen, indicate that there were once more that 361 ma'aayeen in the area. They irrigated thousands of hectares ensuring food security, as well as economic and social prosperity.

The ma'aayeen system is similar to other systems known under different names in other countries:

The 'qanat' system

These so-called 'horizontal' wells carry water from underground springs through tunnels whose length varies between hundreds of meters to 70 kilometers. Usually, however, they are between 4 and 5 kilometers long. Manholes are developed at 30-40 meters distances to secure ventilation and light in the tunnels and to remove sand and rubble that has accumulated in them. The qanat system dates back more than 3,000 years and is thought to have originated in Iran although it has also been found in some desert areas of Asia, Africa and Southern Europe.

The 'aflaj' system

This system is similar. It exists in Oman where Omanis have developed irrigation systems through surface and tunnel conduits as deep as 50 meters underground extending over long distances to transfer water from its sources to agricultural land.

It is worth mentioning that these systems (the ma'aayeen, the qanat and the aflaj) are typically implemented in areas where water sources are naturally at a higher altitude than the areas to which water is delivered. The slope of the tunnels being less than the lay of the land helps the water to run by gravity to the area that needs it.

2-1-1 Geography and geology of Ghail Bawazeer

Location

For this study, Ghail Bawazeer refers to the area around the town of Ghail Bawazeer, including the villages of Al-Qarah, Habair, Al-Suda to the east, the villages of Duru', Al-Makhiba, Farja, Diwan, Naqa and Sahut to the west, and the village of Shahir to the south near the coast. The area of study is delimited by the coastline south of Shahir to the south, by the Jad and Yamballah valleys and the range of limestone mountains to the north, by the Shoughal and Shanqah valleys to the east, and by the Huwaira valley to the west. (Figure 3)

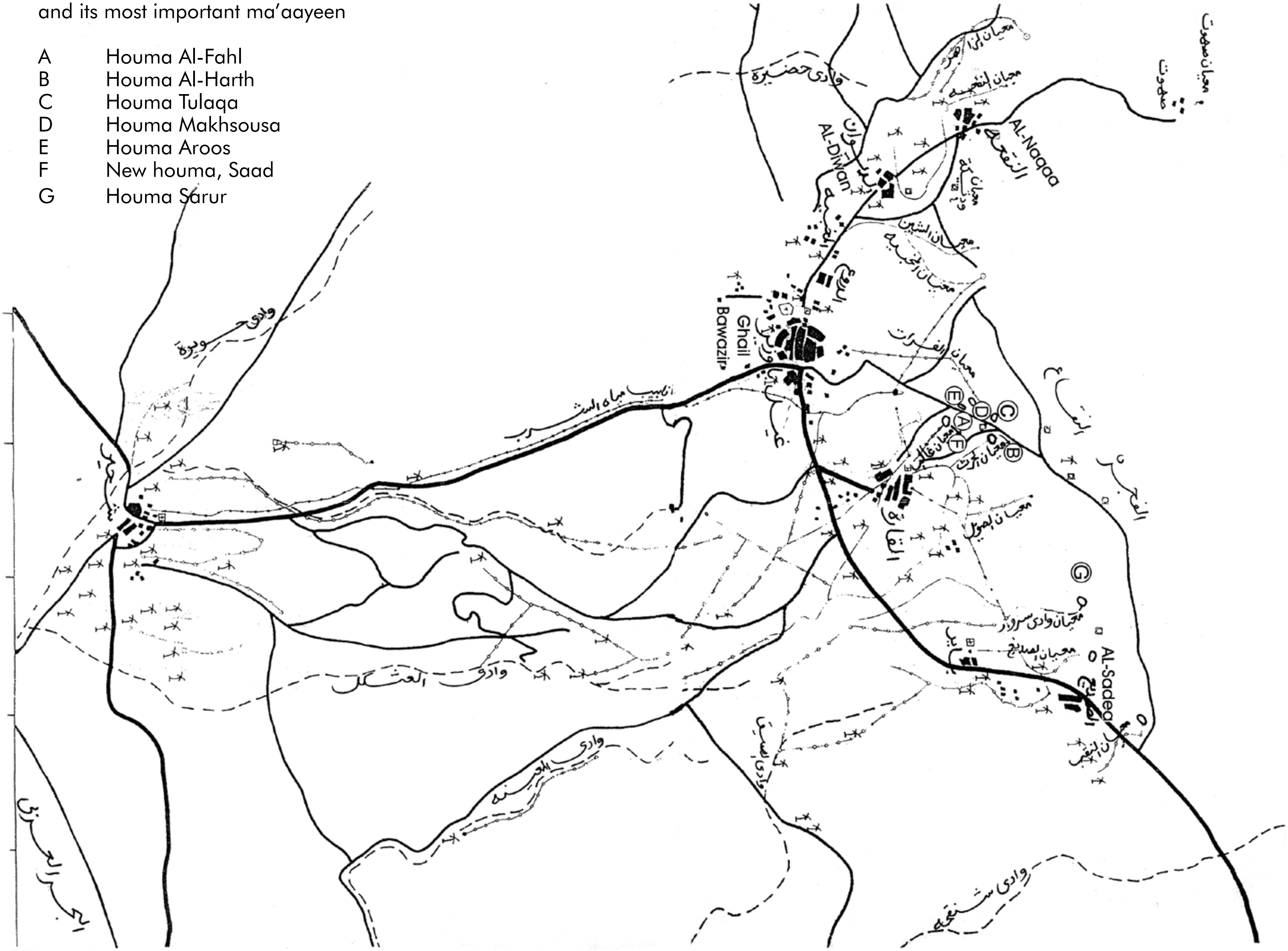
Geology and topography

The area consists of sedimentary rocks, mostly limestone. The thickness of the compact limestone formation reaches several meters. Under this layer, there are clay and loam layers believed to be rich in water. This limestone belt is a part of the rock formed by accumulation of shells and others during the Oligo-Miocene in the depression that existed at the time in the area at the time (see paragraph 1-2-2). This happened in a marine environment that had been isolated from the sea after the upward tectonic movement that led to the formation of the Hadramout Plateau and the mountain slopes along the north of the Jad and Yamaballah valleys, through the areas of Sahut and Abdullah Ghareeb. The high points of these two valleys are at about 1,000 meters altitude.

The top of the mountain range consists of limestone made of calcium carbonate. This is the Umm er-Raduma Formation, distinctive for widespread fissures. More recently, these fissures or cracks have caved in creating a sequence made up of clay layer and belts of carbonate rock called the Jeza Formation. This sequence is visible from the highlands north of Naqa'a to Al-Adeeba where it reaches 150 meters depth.

Figure 3: Map showing the depression of Ghail Bawazeer and its most important ma'aayeen

A	Houma Al-Fahl
B	Houma Al-Harth
C	Houma Tulaqa
D	Houma Makhsousa
E	Houma Aroos
F	New houma, Saad
G	Houma Sarur



To the northeast of these hilly highlands, there are limestone layers that appear in a range of small mountains that reach maximum 280 meters altitude. It extends 7 kilometers north to the area of Al-Niqaa', more exactly from the southeast of the Sahut area to the turn of the Jad Valley in the east.

To the south of this area, a narrow depression includes the areas of Al-Fajra, Al-Niqaa' and Al-Qif. Here fertile flood lands are flanked by a relatively high plateau of limestone that protects them and is locally called the Howam, after the Arabic plural of huma meaning karst pool. It extends from the village of Sidaa' to the northeast of Al-Qaara.

The Howam refers to a group of water pools that appear in a disorganized semi-circle containing water at depths of between 15 and 20 meters underground. These sinkholes can be found at an altitude of 110-125 meters above sea level and the level of the water depends on the degree of feeding from surface water.

Scientifically, these sinkholes are part of karst topography in regions notable for chemical weathering by dissolution. This happens in wet or semi-wet regions when rainwater causes cracks and holes in the rock, which leads to the collapse of rock near the surface. In general, karst topography is widespread in wet areas with soluble bedrock, but rare in dry and semi-dry areas that lack the conditions for dissolution.

In Ghail Bawazeer there has been no geological study of the phenomenon, but some factors are clear. From the observation of the shape of the sinkholes and the inspection of the area's rock structure, it is clear that the surface layer of limestone has been affected by dissolution, especially where it has been directly in contact with stored water. In a dry to semi-dry climate with little rainfall and no permanent rivers, cracks must have led to the formation of underground cavities or caves through rock collapses. This must have enabled surface water - and maybe ground water- to leak into the cavities or caves that grew over time. This has led to continued water storage, from where the formation of non-porous non-permeable limestone created semi-wet conditions in which dissolution was possible.

As both dissolution and collapse contributed to the formation of these howam or sinkholes, there are two types:

- Solution sinks
- Collapse sinks

In Ghail Bawazeer, some surface streams have been identified as feeding into the cracks, locally called 'khuwa'' (Arabic plural of khou'a), that lead to these natural water reservoirs. We cannot rule out that the formation of these karst sinks might have started in the rainy geological age that is known to have existed in the area. Chemical weathering was prevalent then and dwindled over time to cause the present day collapse.
These sinks constitute a main source of water for a group

of earth channels made by man to irrigate wide expanses of agricultural land around and downhill from this area, like the outskirts of Ghail Bawazeer and the surrounding villages, where the ma'aayeen system is well-known and altitude does not exceed 70-85 meters above sea level. Thus, lands have easily benefited from the water stored in the karst sinks through an effective traditional irrigation system using tunnels dug into the ground on the model of the aflaj system from Oman. All irrigated areas are however not dependent on these karst sinks as some ma'aayeen are irrigated from springs and other sources of water such as in the cases of Habit Al-Amal, Ma'yaan bin Jaber, and Ma'yaan bin Qasem.

Ghail Bawazeer and the above-mentioned agricultural areas sit on a solid limestone layer less than a meter to several meters thick and an earth layer appears on the surface where the limestone layer disintegrates. Here conditions are suitable for the formation of fertile soil near groundwater level. This is a phenomenon of geomorphology that contributes to both factors of the limestone's erosion and cracking (Figure 4). In these low areas, there is usually water infiltration and water springs that can irrigate large agricultural areas in these low lands.

When the thickness of the limestone is 1.5 meter or less, man has perforated holes in the limestone layer and planted palms in the earth layer. As for the areas where the limestone is thicker and where the terrain is ready for available irrigation (by sinaawa or ma'aayeen for example), man has transferred fertile soil locally called 'dubur' to these surfaces. Thus, agricultural land has been reclaimed around Ghail Bawazeer.

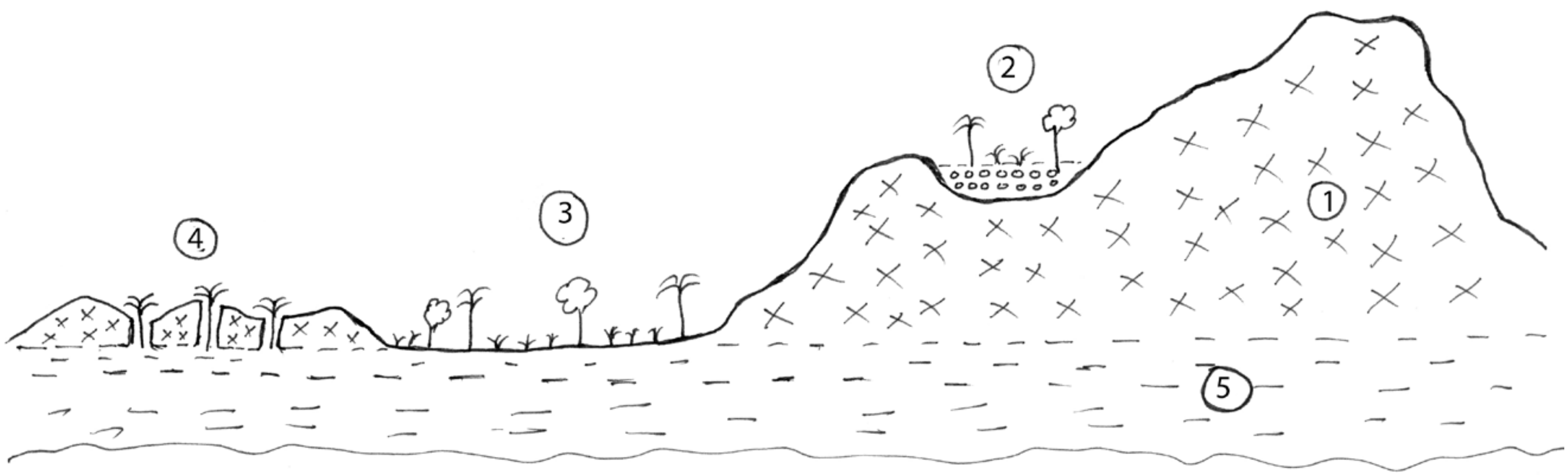
2-1-2 Origin and evolution of the ma'aayeen in Ghail Bawazeer:

2-1-2-1 Natural conditions behind the origin and evolution of the ma'aayeen system in Ghail Bawazeer and surrounding areas

The lowlands and hills along the coastline are covered with springs and other water sources. This is because local geomorphological and hydrological conditions have created, at the foot of the southern mountain slopes of the southern Hadramout Plateau, a water basin. This mountain range at the southern edge of southern Hadramout Plateau feeds water into the valleys and the lowlands at their feet until the coastline. The solid rock structure of these basins holds back large quantities of surface water and prevents it from flowing into the sea. The presence of limestone and limestone rocks have helped to store substantial quantities of water. Karst caves are considered to feed water to many springs and water sources like in Ghail Bawazeer. The water flow depends on the quantity of rainfall in these areas and the highlands that surround them.

Figure 4: Map showing the link between topography and land reclamation

1. Limestone layer
2. Transferred agricultural soil
3. Natural agricultural soil
4. Reclaimed pits to plant palms
5. Clay layer



It is believed that the ma'aayeen system started long ago when the level of water was near the surface. This water was used for agriculture and was transferred from the higher lands where the sources were. This was done by digging simple shallow open conduits through limestone and sandstone with locally-made tools. The area, however, was exposed to successive waves of drought that led to the declining of the water level at the source, causing the water flow to the agricultural lands to stop. The main conduit was then deepened to reach the water level at the source so that water could again be obtained by gravity flow. Over time the main conduit was dug deeper and deeper so that the ma'aayeen could still flow with water - until the water source reached its current level.

Continuous waves of drought and a low water level as deep as 15 meters under the surface meant that digging open conduits became undesirable as it demanded increasingly more money and effort.

Digging the ma'aayeen ('naqab' method) was seen as the easiest method and became widespread, especially in Ghail Bawazeer and surrounding areas. The length of the irrigation ditches varied between 4 and 5 kilometers. Their depth reached 6 to 10 meters or more especially in the area of the howam or sinks and over the elevated areas but decreased gradually to reach land levels where water ran through the distribution network to the agricultural land.

The ma'aayeen were not only dug for irrigation, but also to bring water to the mosques for ablution, to nearby houses for washing, bathing and watering animals, and to school and mosque gardens for irrigation (Figure 5). Special water canals passed through town in a precise system perfected to ensure the cleanliness of the water.
To distribute the water between the different users, farmers used an astronomical system depending on the shade of sun during the day and location of stars at night. This system will be explained further on.

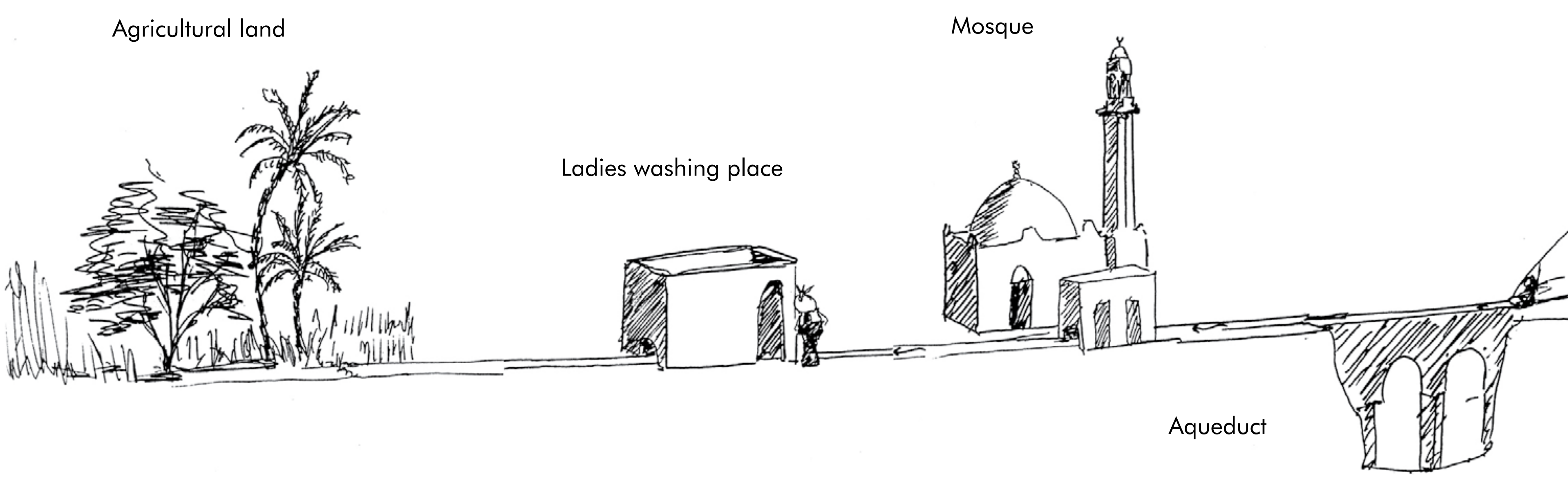
Apart from the ma'aayeen system, another widespread system was used in which water was taken from wells by bucket. It was called the 'sinaawa' system and will be briefly described so as to give the readers an overall view of outstanding irrigation techniques in the area.

2-1-2-2 Sinaawa or open well irrigation system

Sinaawa is a traditional irrigation system widespread in Shabwa and Hadramout. It is based on the extraction of water from a well using a leather bucket locally known as a 'gharab' by man, animal, or both. The water is then used for agriculture, household uses, and other purposes in urban and rural development.

This system was efficiently used for different purposes in Ghail Bawazeer before, during and after the digging of the ma'aayeen. The system was distinguished for taking maximum benefit from every drop. Water was collected in pools called 'jawaabi' or 'birak' on farms, mosques, or schools. There local inhabitants developed an outstanding tradition of re-use of water used for different purposes to irrigate new lands known as the 'heyout' (Arabic plural for 'hayt') that were palm tree gardens belonging to mosques as well as school gardens and gardens belonging to big merchants called ‘banaqil’. New house gardens called ‘duru’’ (Arabic plural for ‘dara’’) also appeared and grey water or water after household use was re-used for their irrigation to grow vegetables and fruit. This system has however now been neglected in many areas which has led to the waste of resources and created environmental problems such as the pollution of ground water.

Figure 5: Components of Al Mayean (qanat) and the course of Al Sawaqi (water course)



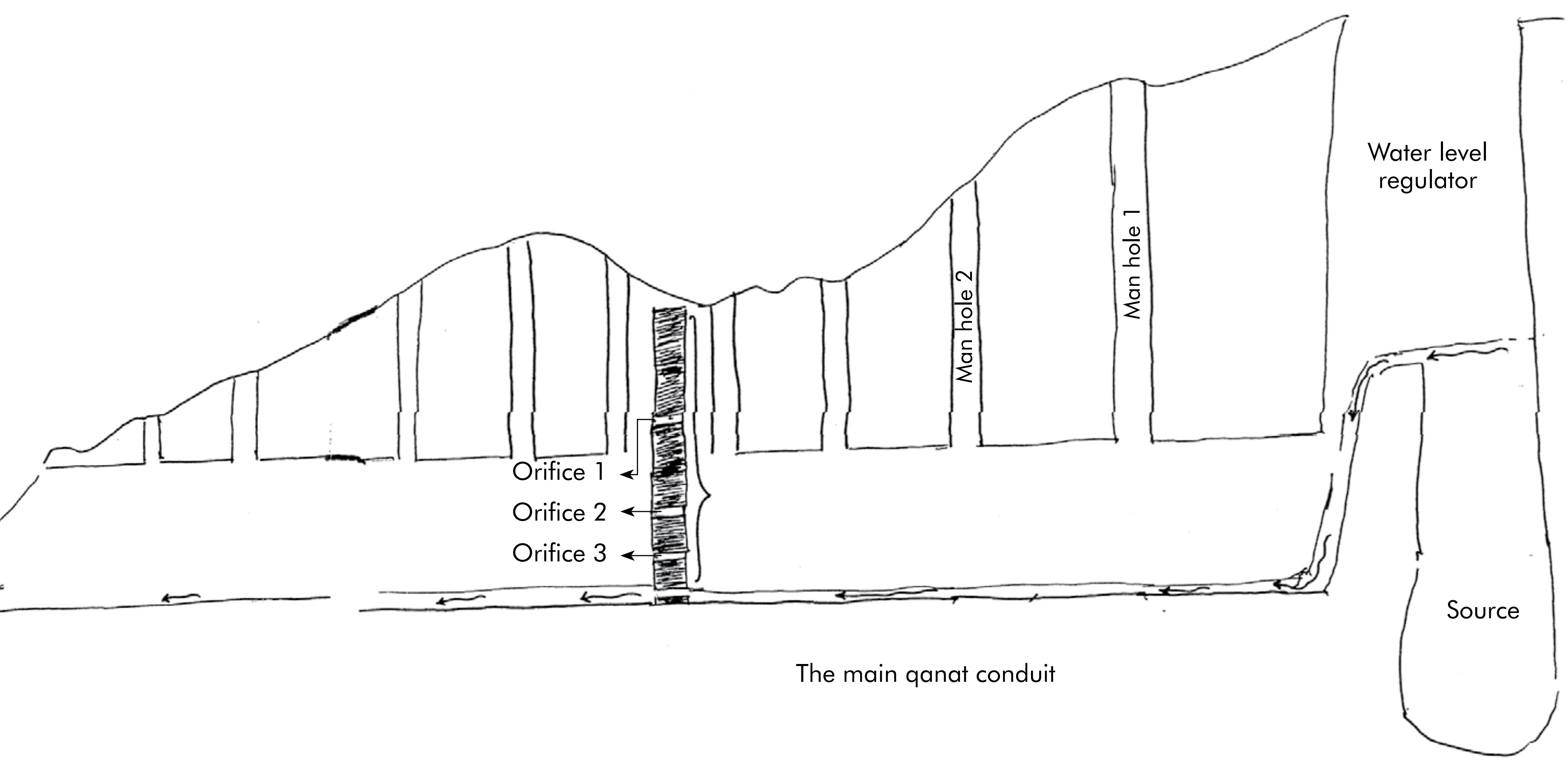
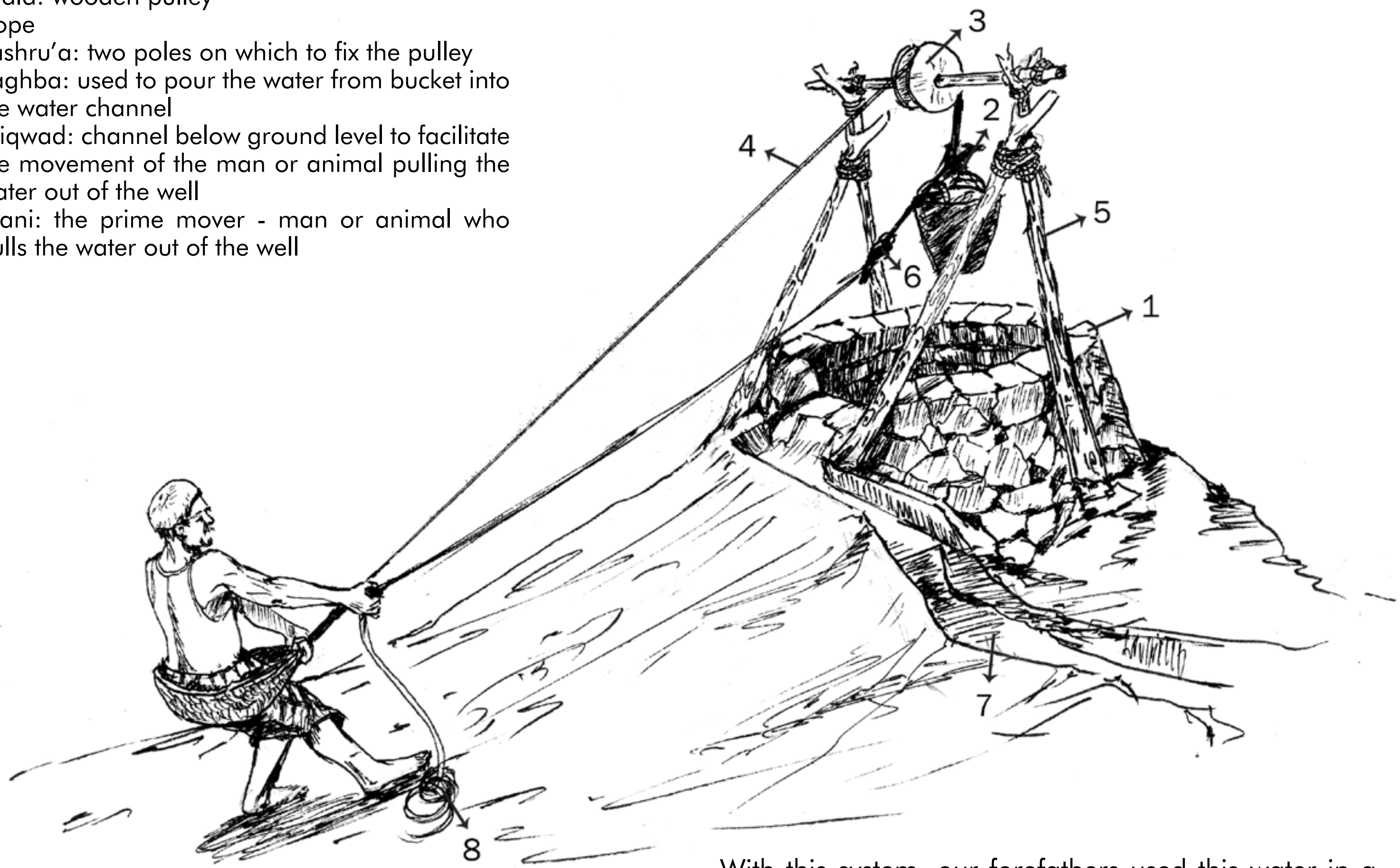

Water level
regulator
Man hole 1
Man hole 2
Orifice 1
Orifice 2
Orifice 3
Source
The main qanat conduit

Figure 6-a: Components of the sinaawa system

1 - Well
2 - Gharab: leather receptacle similar to a bucket
3 - Ajala: wooden pulley
4 - Rope
5 - Tashru'a: two poles on which to fix the pulley
6 - Laghba: used to pour the water from bucket into the water channel
7 - Miqwad: channel below ground level to facilitate the movement of the man or animal pulling the water out of the well
8 - Sani: the prime mover - man or animal who pulls the water out of the well



With this system, our forefathers used this water in a sustainable way, using every single drop whether on the farm, in the mosque, in the house or in the school in view of the effort exerted to obtain this water. No drop was wasted.

2-1-2-3 Stages of the ma'aayeen system

The three main elements of the system are:

1) The water source called the 'ab' (Arabic for father): usually a 'houma' or karst sink, a spring or a well;
2) The main water conduit called 'saqiyyat Al-ab': according to the nature of the area, a surface conduit, ditch or tunnel underground that connects the water source to the agricultural land;
3) The agricultural land: the water's final destination after sometimes having passed through the mosque, places of bathing and washing, and near houses.

First stage: the survey

Setting up a ma'aayeen system demands deep knowledge of the water sources and the ground through which the water canals are to run. Before digging, a comprehensive survey is required to determine the water source to be used, the land to be cultivated, and then the course of water channels to be dug.

Identifying the water source

This first step identifies the water source to be be used. Local experts find and evaluate potential water sources through theoretical and practical tests, for example by seeing if there is water infiltration on the ground in the early morning, moisture known locally as 'kahra' rising from the ground, or the existence of any fissures in the rock or khuwa' in the area, as all these indicate the possibility of the presence of water. Local water experts say that land that which takes water will also give it and the opposite is also true. In other words, there is a great likelihood of water presence under land that easily and rapidly absorbs water. Other indications of the presence of water include the presence of certain types of trees in a specific location or the internationally- known intuition of people with a special gift for finding water.

When a water source has been located, its depth and quantity are checked by extracting relatively large quantities of water from it. If the water level quickly returns to normal, then this means that the water source is deep and connected with others sources that feed it. (Water sources that run dry and are not replenished are called 'coconut water' like the milk of a coconut that vanishes in one gulp.) Thus, the water source is tested for sustainability.

Determining the location of the agricultural land

Once a good water source is found, the second step is determining what agricultural land it will irrigate according to the following conditions:

- The water level in the source is higher than that of the land to irrigate, part of the concept of 'wala' about the course of the conduit;
- The land is arable or, if it is not, fertile soil can be transferred to it;
- The land is situated in a large area where land reclamation might be possible in the future according to water availability.

Determining the course of the main water channel (saqiyyat Al-ab)

After the selection of the water source and the location of the land to be irrigated, comes deciding on the course of the main water channel. These can be far away from each other and the water conduit can be up to 3 or 4 kilometers long. A survey of local topography is made using a piece of wood called ‘tab’ and a water level.

This is how the method works according to one of the experts.

The depth of the water source, that we shall call X, is measured as the vertical distance between ground level and water level. A series of perforations are then made from the source in a straight line. Starting from the source, the distance between perforations is 15 feet or 4.5 meters. The length of the opening of each perforation is 3 feet or 0.90 meter and its width is 1.5 foot or 0.45 meters.

The depth of the first perforation, which we shall call X1, is then measured by placing the first end of the tab at ground level of the source and the other at ground level of the first perforation. The water level then measures the difference in level between the two points, which we will call Y1. Thus, the depth of the water at the first perforation is $X1=X+Y1$ if the difference is positive and $X1=X-Y1$ if the difference is negative. If the difference in level between the two points is nil, then $X=X1$. The location and depth of the first perforation are registered.

Similarly the depth of the second perforation, which we shall call X2, is measured by placing one end of the tab at ground level of the first perforation and the other at ground level of the second perforation. Using the water level, the difference in level between the two points, which we shall call Y2, is measured. The depth of the water at the second perforation will be $X2=X1+Y2$ if the difference is positive, $X2=X1-Y2$ if the difference is negative, and $X2=X1$ if the level between both points is the same. The location and depth of the water at the second perforation are then registered in the survey.
In this way, the depth of water at the different perforations is measured and the results are registered along with the location of the perforations in the survey. The measuring process is repeated twice to ensure accurate figures. If figures do not match, the process is repeated until they do. Finally, the volume of work and its costs is calculated and transmitted to the person who ordered the work.
The water conduit does not have to be entirely underground. It can be part underground tunnel and part surface channel according to the topography of the area through which it is to pass.

During the process of conduit survey, a very important matter should be considered, which is the matter of ‘wala’ (Arabic for allegiance). This involves ensuring that the level of the conduit is higher than the ground level of the land to be irrigated, even though the conduit is dug deeper than the level of the water at the source, a process known as ‘suqa’.

Ma’aayeen often run to the north or west. If, on the contrary, ma’aayeen are not built running to the north and west, they tend to be unsuccessful and to only last for short periods of time, as in the case of Ma’yaan Al-Diwan.

Second stage: digging the ma’aayeen

After finishing the survey, feasibility study and estimate for the cost of digging the ma’aayeen, local man-made tools are used to dig them (Figure 6-b). They are:

1. A ‘mizha’ to shovel up soil and broken down rocks;
2. A mountain adze used to break down solid rock;
3. A digging adze used to break down clay layers;
4. A palm basket called ‘hahmala’ and rope to lift out broken rock from the conduits to the surface

5. A makhla’ and a maqsa’ (literally, a crusher) used for breaking down the hardest rocks. The maqsa’ is fixed to the hard rocks and hit by the makhla’ until they are broken down

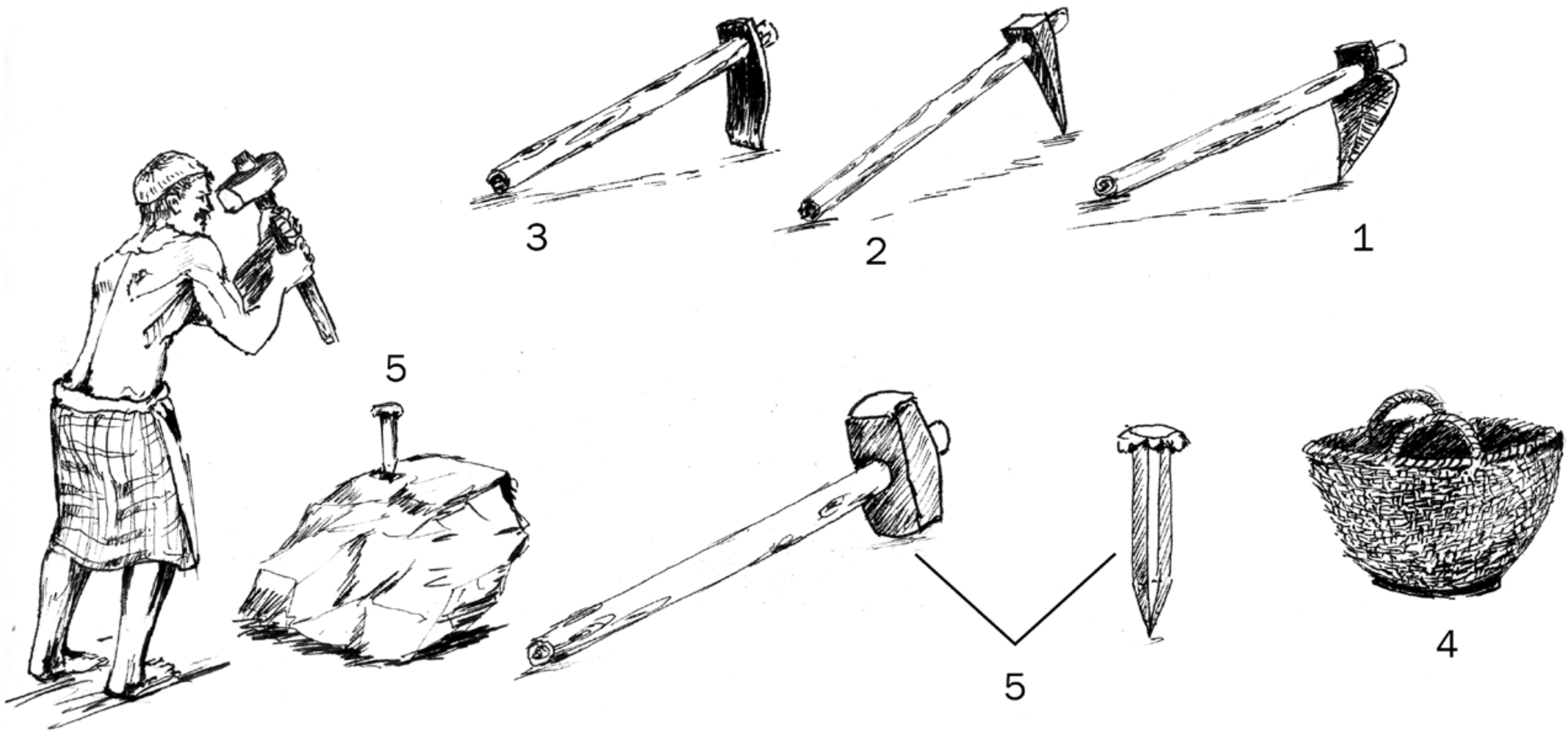
After digging at the water source or locating it if it is a spring or a houma perforations are dug vertically along the course of the underground channel according to the survey for the ma’aayeen. After that, the ‘shattat’ (Arabic plural of shatta) are dug out to connect each vertical perforation to the next underground and so that a man can easily move through them during digging and maintenance.

As the saqiyya or main water channel runs closer to ground level or runs through a clay layer that is easy to dig, it is dug out in what is locally called the ‘bat’ method as an open ditch – rather than an underground tunnel, leading to the land to be irrigated. After that, the saqiyya is levelled out so that it is smooth from the source to the land it is to irrigate, making sure that this water channel is always below the level of the water source. When large ma’aayeen are dug out, a team of blacksmiths assists the diggers by maintaining their tools so that work does not stop.

Technical measures are then taken to ensure good management under different circumstances including drought and heavy rainfall.

Figure 6-b: Tools used to dig out the ma'aayeen

1. A 'mizha' to shovel up soil and broken down rocks;
2. A mountain adze used to break down solid rock;
3. A digging adze used to break down clay layers;
4. A palm basket called 'hahmala' and rope to lift out broken rock from the conduits to the surface;
5. A makhla' and a maqsa' (literally, a crusher) used for breaking down the hardest rocks. The maqsa' is fixed to the hard rocks and hit by the makhla' until they are broken down.



The marda'

The marda' is a barrier constructed in the middle of the main water conduit in which are different openings called 'haraat' (Arabic plural of hara) at different levels and whose diameters measure 10 and 15 centimeters wide. (Figure 7)

The aim of these openings is to control water flow down the conduit. In the event of heavy rain and the water level rising at the source, all openings are closed off except for the highest. The lower the lever of the water at the source, the lower the level of the opening that is opened. More or less openings can be opened according to necessity. In the irrigation season, for instance in case of heavy demand at the end of the harvest, more water can be supplied. In this way, water is managed according to requirements.

The marda' is located at an appropriate distance between the water source and the nearest inhabited area to make it easy to close up its openings when water flow increases.

The mawhed

This is a small dam made out of what is left of the water conduit's original rocks adjacent to the water source. Its level is slightly below the level of the water in the water source. Its main task is to regulate water flow from the source to the main conduit according to need. When the water level in the source drops, a small part of the dam is removed to allow water to flow again according to demand. This is repeated when there is a drought until the water level at the source is the same level as the bottom of the saqiyya or main water conduit.

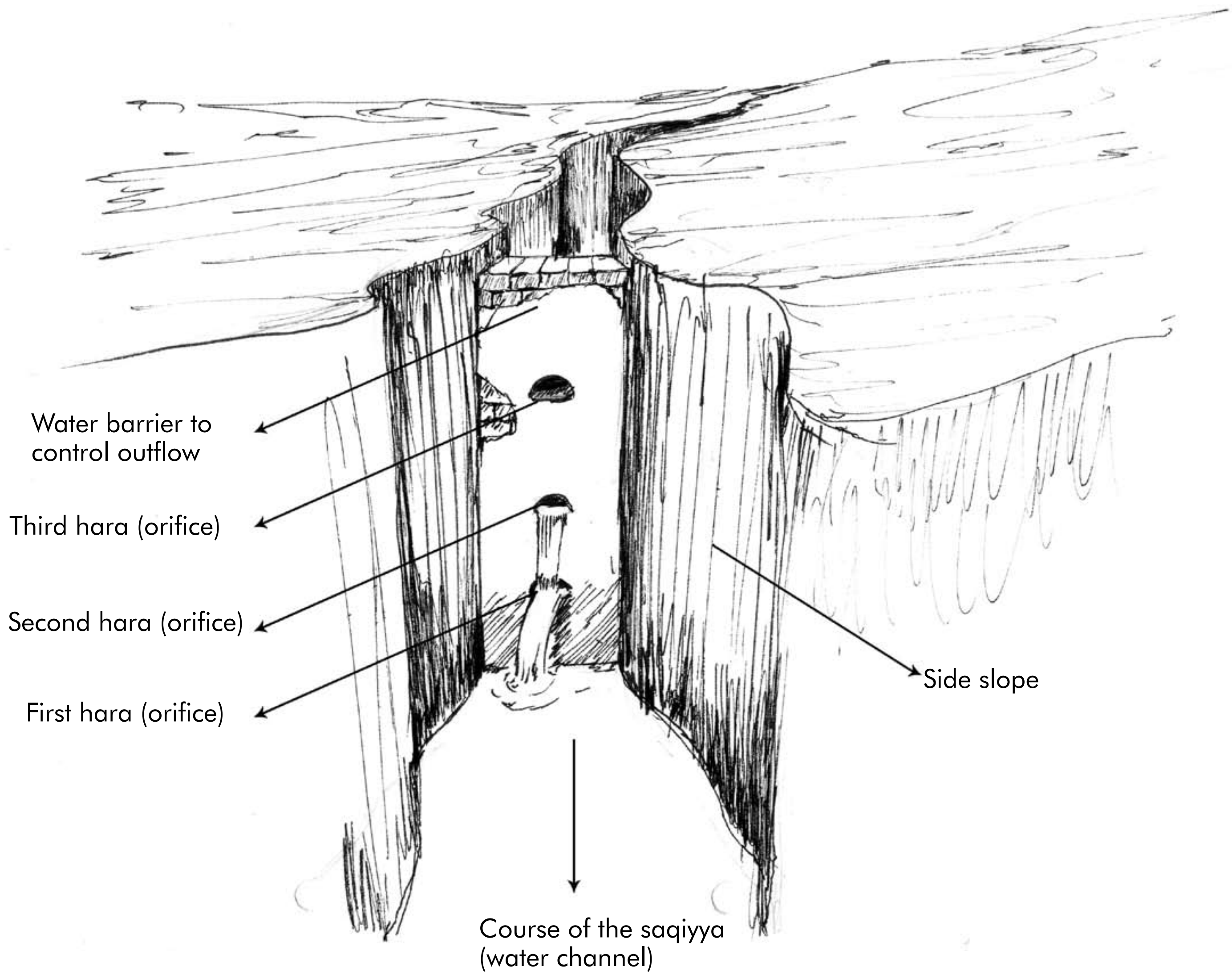
When drought persists and the water level descends below the level of the saqiyya or main water conduit, the latter is deepened so that the water flows down it naturally again. This is called 'suqa'. The best example of this is what happened in Ma'yaan Lashol (Ghaleb) at the beginning of the 1970s. The main water channel was dug deeper so that water would flow by gravity from the source into it and it has remained the same until today.

A second solution when the water level drops at the source is called 'taqduma'. It involves finding another water source nearby the water level of which is higher than that of the original. Water from the new source is then directed to the first source via a conduit which raises the water level there so that water flows again into the ma'yaan's main water conduit. This what happened at Ma'yaan Dhahban, for example. In general, more than one taqduma can me made according to the need.

The jawaabi (Arabic plural of jaabiyya)

In the smaller ma'aayeen where water flow is weak, pools called 'jawaabi' are dug out near the land to be irrigated. Water is then gathered during the night and used for irrigation during the daytime. This creates enough flow for water to travel to the channels and avoids small volumes that may not reach anywhere.

Figure 7: Location of the marda' (barrier) and its haraat (orifices - openings)



2-1-2-4 Challenges to digging the saqiyya

The workers who dig out the saqiyya or main water conduit often encounter challenges to their work. Here we review the most important difficulties and how they are handled.

- When workers hit a solid rocky layer in one of the vertical perforations planned along the course of the future water conduit, the perforations on either side of it are deepened until an easier layer is hit. These two perforations are then connected through digging, forgetting the one originally in its middle. As the distance between each perforation is 15 feet and the length of one is 3 feet, the two newly joined-up perforations are 33 feet or 10 meters apart which is a relatively long distance especially deep underground. There is however another solution which is to divert the course of the saqiyya far away from the layer of solid rock and then return to the course originally planned. (Figure 8-a).
- If a main conduit needs to flow over a valley or naturally lower lands, an aqueduct is built with rocks available in the area and lime mortar (instead of cement). The main water conduit or saqiyya runs along the aqueduct, whose height and length depend on the depth and width or the valley, while floodwater passes underneath (Figure 8-b).
- If a main conduit hits a road, a small bridge called a 'masha' is built out of rocks, wood, and earth over the water conduit so that the road remains without obstacles.
- When a main conduit intersects with that of another ma'yaan, one passes over the other.

Figure 8-a: Sketch of a saqiyya's course through a layer of solid rock

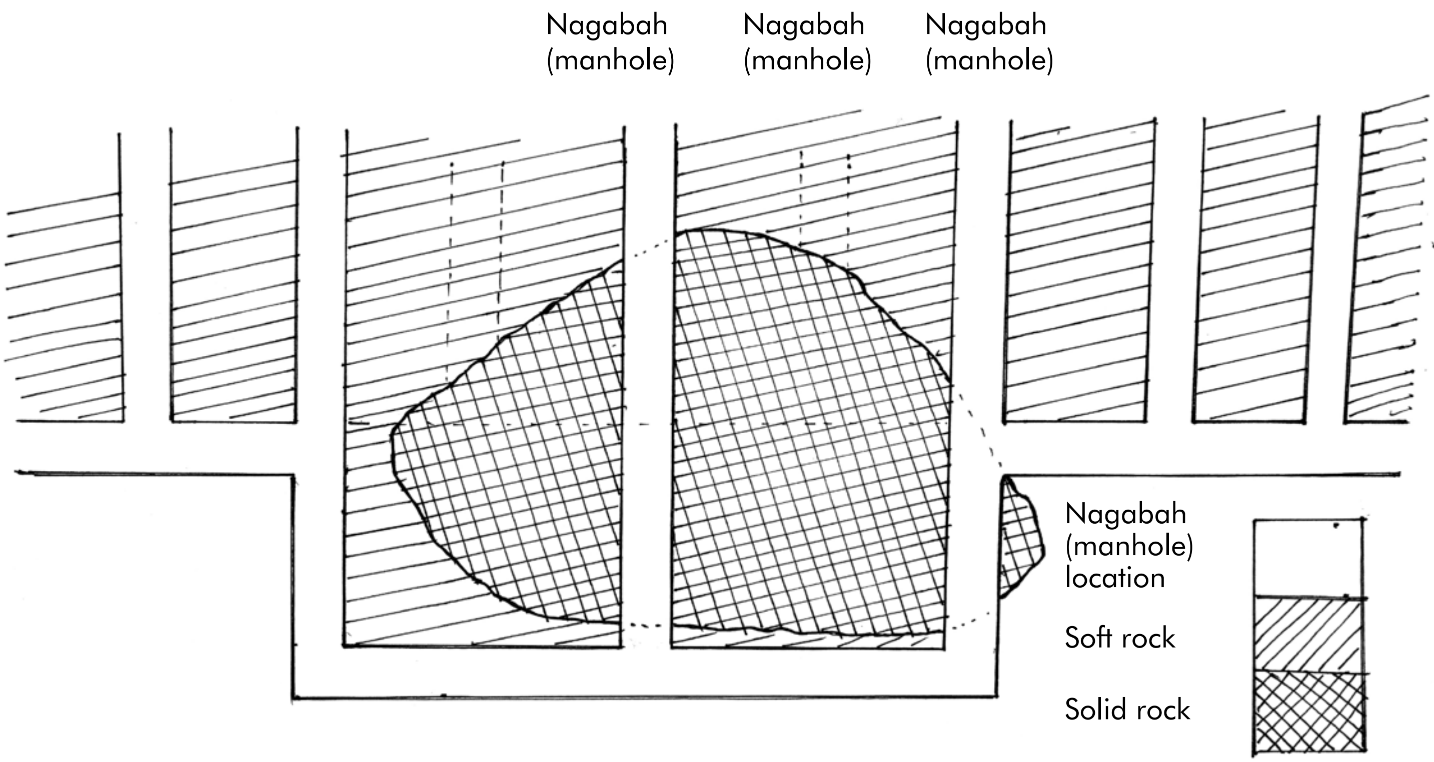
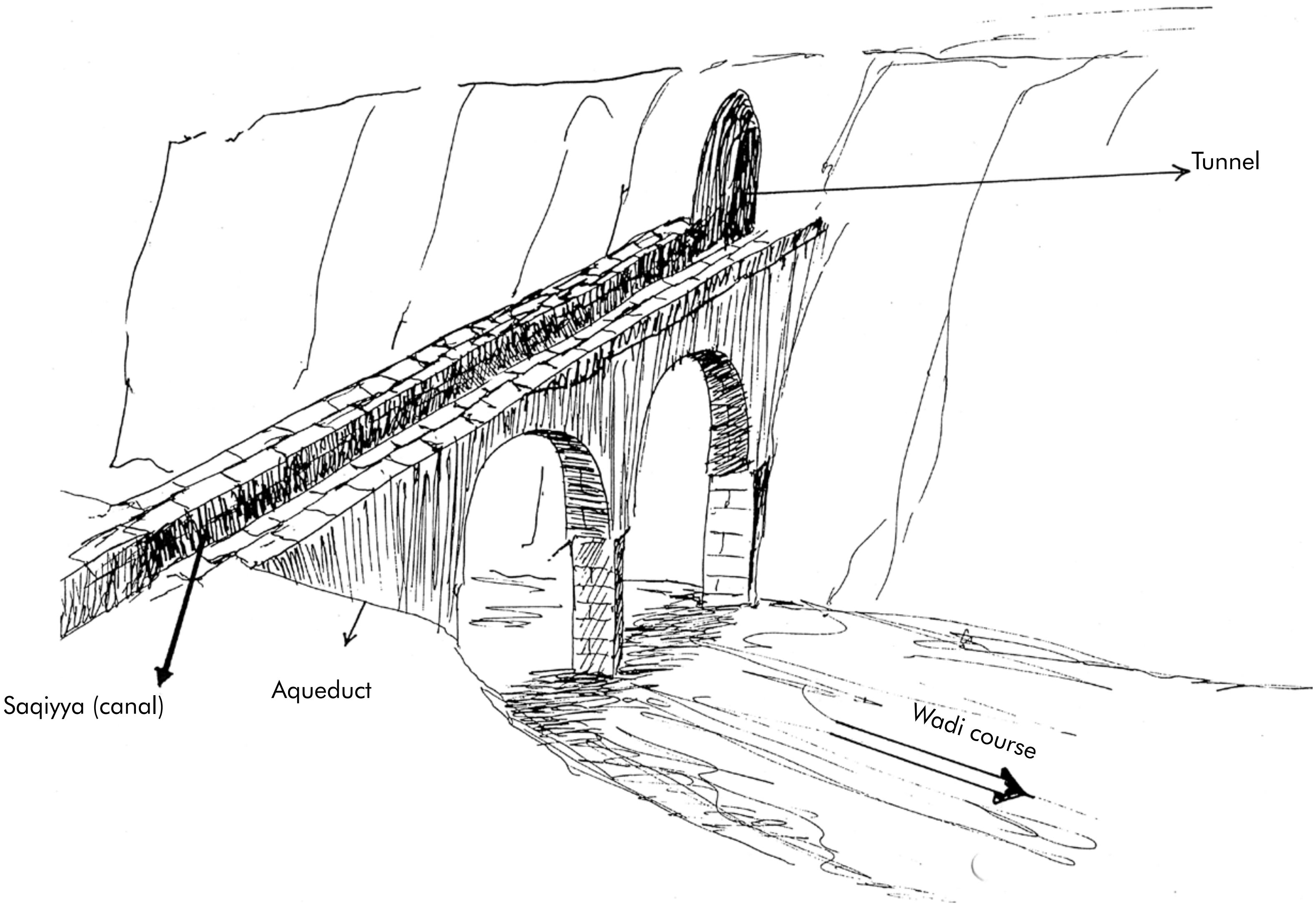


Figure 8-b Aqueduct across a valley



2-1-2-5 Management of the ma'aayeen system

The ma'yaan supervisor and his workers

For each ma'yaan, a person is appointed to be responsible for its management. This supervisor is assisted by a group of workers whose number depends on the size of the ma'yaan. For example, Ma'yaan Al-Harth, the largest and oldest ma'yaan in Ghail Bawazeer, has nine workers who help manage it in three shifts. The smaller and private ma'aayeen are managed by their owners or by those who pay for them. Some ma'aayeen are managed by committees that act as supervisor.

A ma'yaan supervisor must:

- Be one of the farmers owning land in the area of the ma'yaan;
- Be trustworthy, wise, honest, and able to take decisions;
- Have good knowledge of the star system governing times of harvest and irrigation.

In a state-owned ma'yaan, the municipal council appoints a supervisor and his fees are paid by the state. In the cases of a private ma'yaan, a public-private ma'yaan, or a ma'yaan owned by various private owners, a supervisor is appointed by secret ballot. Profit made from the 'surkal', ma'yaan, the communal water share set aside for sale, pays his fees as well as maintenance costs.

Tasks of the ma'yaan supervisor and his workers:

The supervisor gives out the instructions of the agricultural overseer and municipal council. He decides on the punishment for those who violate the agricultural systems in place, and his decisions are effective as he has the right to deprive land from water, especially if it has been neglected or is not ready. He decides on the types of crops that are to be grown each season. He distributes water to each farmer according to his share of the ma'yaan. He decides and supervises maintenance on the ma'yaan.

Ma'yaan water distribution system

There are two types of ma'yaan:

- Large ma'aayeen where irrigation is non-stop day and night;
- Small ma'aayeen where water is collected in jawaabi (pools) at night and land is irrigated during the day.

Water distribution in the ma'aayeen is usually done according to the 'farda' system. In a large ma'yaan, one farda is equivalent to the water from the ma'yaan for one day (from sunrise to sunset) or one night (sunset to sunrise). In a small ma'yaan, one farda is equivalent water from the ma'yaan for one day and one night (as water is collected in pools at night and land is irrigated during the day). One farda is 32 feet, and one foot is 12 banana, a local measurement using the width of a finger.

Each ma'yaan has a determined area that is irrigated in a fixed cycle of 10 to 15 days. It is divided up into an uneven number of firad (Arabic plural for farda), for example 13, 15 or 17, so that the same land is not irrigated at the same time during night or daytime twice in a row.

In the larger ma'aayeen, water would be distributed non-stop throughout the day and night. During daytime one farda of water equalled 32 feet of water, and was divided up into four fourths or eight eighths. Thus, a fourth of a daytime was 8 feet of water and an eighth was 4 feet of

water.
One daytime was then divided from sunrise to midday (when the sun is mid-sky) into two morning fourths and four morning eighths, and into two afternoon fourths or four afternoon eighths from then until sunset (Figure 9).

For the daytime, tables show the link between a foot of shade (showing the time) and a foot of water, because the length of the shade differs during the day and from one season to another.

As for nighttime, it was divided up into 24 degrees according to the appearance of the stars.

1. The night's first quarter was from sunset, and was made up of four degrees or four stars appearing one after the other in the sky at a fixed time. Each degree signified 2 feet of water, and the first quarter thus signified 8 feet of water.
2. The night's second quarter was made up of three degrees or three stars that appeared one after the other. Two of the degrees signified 2 and 2/3 feet of water, and the second quarter thus signified 8 feet of water.
3. The night's third quarter was made up of three degrees or three stars that appeared one after the other. Two of the degrees signified 2 and 2/3 feet of water, and the third quarter thus signified 8 feet of water.
4. The night's fourth and last quarter before sunrise, was made up of four degrees or four stars, each signifying two feet of water. The fourth quarter thus signified 8 feet of water.

In this way, night was divided into four quarters each signifying 8 feet of irrigation water. Together, these quarters signify 32 feet of irrigation water, or one farda of water.

In the smaller ma'aayeen, one farda is also made up of 32 feet. Irrigation water distribution follows the same system as in the larger ma'aayeen, except that it is in the morning only, as water is collected in the jawaabi (or pools) in the evening.

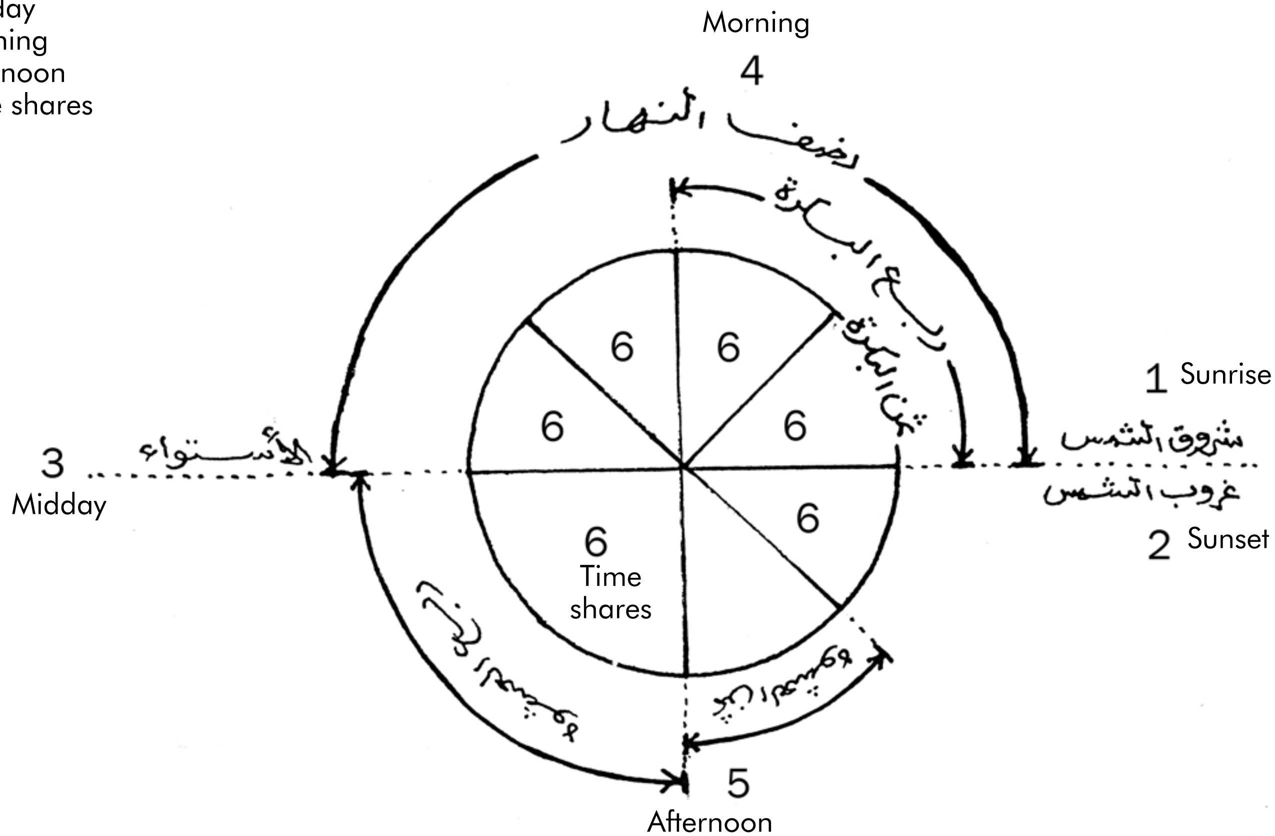
On this basis, the ma'yaan supervisor and his workers, who have a good knowledge of the stars, allocate irrigation water to the farmers. (See Appendix 1 for a summary on reading the stars at the end of the study.)

This system is applied to most of the ma'aayeen in Ghail Bawazeer, except for three ma'aayeen with a strong flow: Ma'yaan Al-Harth and Ma'yaan Lashol (Ghaleb) and Ma'yaan Wadi Sarur, all of which are stated-owned. There, the irrigation system is that of land rented from the state, which means that the ma'yaan supervisor decides on the quantity of water necessary for each plot of land and on irrigation times so that they are not the same in two consecutive cycles.

In some other ma'aayeen, like in the ma'aayeen of Southern Dais, there is a system similar to the farda and feet system, but in which a farda equals 24 qeeraat (Arabic plural of qirat) with one qirat being more or less equivalent to half and hour. One qirat equals 1 and 1/3 foot, so that 3 qirat equals 4 feet, or an eighth of a farda.

Figure 9: Division of daytime from sunrise to sunset according to the ma'aayeen norms of water distribution

1. Sunrise
2. Sunset
3. Midday
4. Morning
5. Afternoon
6. Time shares



2-1-2-6 Land tenure system and ownership of the ma'aayeen

The different land tenure systems for the ma'aayeen are:

- Land tenure system before 1967
- Land tenure system after 1967

Tenure system before 1967

There used to be several tenure systems for the ma'aayeen and its agricultural land.

Private property

Land, water or both had been owned by the same individual or group for a long time. The management and maintenance expenses of the ma'aayeen were covered by the owners relative to how big a share they owned.

The ajeez system

The land was rented from the state or those responsible for the awqaf (Arabic for endowments) on specific conditions. An agreement was made to pay a specific amount each year to the state for the land and water, and management and maintenance expenses including the fees of the supervisor and his workers were covered by the state or by the endowments. The farmer only had to cultivate the land and pay his rent to the state under the agreement. Perennial plants like palms and coconut trees might come under special arrangements: they might have been rented for a specific amount, or according to the ajeez contract.

The fakhd system

In this agreement between a single person or group of persons and the state, the state would provide the agricultural land and the land through which the water conduit of the ma'yaan would pass. The water users would manage the ma'yaan at their own expense or with a state contribution. The share of the state would be a fifth or a third, according to the agreement, of the ma'yaan's harvest of its main crops like dates, grains and tobacco. The other crops would be the users' share.

These shares are defined after deduction of a number of firad (Arabic plural of farda) for maintenance. Of the ma'yaan's many firad, three to four were called the 'sirkaal' and were sold or rented out. Their return covered the ma'yaan's maintenance costs and the rest is divided between the state and water users according to the conditions of the agreement.

In a fakhd agreement, the area was often not defined in meters but with vague boundaries, far away from the agricultural land. Here is an example:

West: mountain
East: valley
South: road
North: name of a village or other ma'yaan

The actual area of the ma'yaan was limited to the area of the land being cultivated only. If a farmer cultivated a large area, then this would be defined as the area of the ma'yaan, and the opposite was true too.

One of the conditions of the fakhd system was that, if land stopped being cultivated or was neglected, the state repossessed it without any compensation. When a person was not able to manage it, the state repossessed it and had the right to offer it up in fakhd to someone else.

In this system, the state encouraged persons to manage ma'aayeen. Many did and agriculture flourished as a result, with the state successfully providing food staples like grains and dates as well as tobacco which was exported to neighbouring countries like Saudi Arabia, Egypt, and Djibouti.

The state followed a special policy when leasing agricultural lands, i.e. leasing out land in several different locations to the same person. For example, if a farmer has rented a farda of water and its equivalent in land, then he would be given a plot of land near the village and another relatively far away. He might also be given one near to the source and the other far from it. This method of distributing land prevailed for the following reasons:

- It allowed the farmer and his family members to work daily on land near the city growing vegetables, berseem (a clover grown for forage) and other fast-growing crops that the can easily be transported and sold every day, while growing main main crops like tobacco and grains on the land further away.
- In case of drought, the water source dries up and land far away from the source receives less water as irrigation is concentrated around the source. When a farmer was given a plot of land near the source and another far from it, he only made losses on the plot of land far away from the source.
- When a specific crop disease spreads in a specific area, not all of one farmer's plots suffer because they are in different locations.
- This distribution system ensured equality between farmers, who received both plots of land close to home for vegetables, fruits, and animal fodder and plots of land further away for field crops. This encouraged good relations and fruitful cooperation between them.

Land tenure system after 1967

After 1967, the same system continued in Ghail Bawazeer despite the first agricultural reform in 25 March 1968 which focused on the following:

- The confiscation of all property previously belonging to sultans, emirs, sheikhs and their families, previous ministers or agents of colonisation convicted by the courts.
- The limitation of the amount of land allowed to be owned by one person to 25 feddan for irrigated land and 50 feddan for unirrigated land, and a new compensation system for those who exceeded the limit.
- The distribution of confiscated lands to following categories:
- Families of martyrs, the needy, and those severely wounded in the liberation war (armed struggle against the British);
- Needy agricultural workers;
- Farmers whose land ownership did not reach the allowed minimum;
- Persons who had emigrated from the cities and deserts.

According to the law, beneficiaries should receive 3 to 5 feddan of irrigated lands and 6-10 feddan of unirrigated land, provided that they pay its price within 25 years with a yearly interest of 1.5% starting from five years after receiving the ownership documents.

As this law contained some negative points, it was reviewed and amended in November 1970 after the Peasant Revolt on 7 October 1970 in the area of Hisn in the Abyan governorate that aimed to grab land from the big landowners for the farmers.

Despite these two laws being issued, they were not applied in Ghail Bawazeer for the following reasons:

- Small agricultural areas;
- Lack of large properties of agricultural land;
- Most of the agricultural land was owned by the state and in the possession of persons under fakhd and ajeez agreements;
- Scarcity of agricultural land depending on rain for irrigation.

Local authorities therefore took precautions deemed to be appropriate to the conditions of the area. In 1973, the principle of 'land for the person who cultivates it' transferred the ownership of leased lands from their original landlords and the state to farmers. All previous kinds of tenure were cancelled without consideration to private ownership. There was a new production tax payable to the state of around 10% on cash crops like tobacco, henna and different grains. In addition 5% of the value of total production went to the agricultural cooperatives, of which 3% was for ma'yaan maintenance and natural disasters and 2% was social security for the farmers. After a period, production tax on tobacco was raised from 10% to 15% in an attempt to encourage farmers to grow food crops.

In 1974, compulsory production teams of 3 to 4 farmers were formed and allotted a plot of land of 4 feddan. The elderly were excluded and given areas not exceeding half a feddan to work on individually.

This situation continued until the imbalances were redressed with the Agricultural Reform Law of 1989 on the principle of land for the person cultivating it and the principle of team work. The agricultural cooperatives addressed the balance with the following measures:

- Reconciliation of previous landowners and farmers;
- Handing land back over to previous landowners and compensating those who cultivated it before the law was issued with another plot of land from those owned by the state;
- Allocating state-owned land to the farmers cultivating it when the law was issued through a usufruct contract issued by the Ministry of Agriculture for an agreed annual rent;
- Allocating awqaf (endowment) land to the farmers cultivating it when the law was issued through a usufruct contract issued by the Ministry of Endowments for an agreed annual rent.

With these steps, more than 90% of the imbalances were corrected. A few problems occurred when former landlords were unable to produce legitimate land deeds and farmers did not recognise them as the legitimate owners. Some of these cases were transferred to the courts.

Consequences of the land tenure system on the ma'aayeen

Our forefathers set up a complete agriculture and irrigation system through building ma'aayeen, digging wells, and reclaiming wide areas of agricultural land. They defined regulations for the good management of these ma'aayeen. This led to sustainable development in the modern sense of the expression, with food available year round for these and surrounding areas, especially different type of grain and dates, although spate irrigation continued in some small plots of land.

The ma'aayeen system was efficient and led to food security and abundant production. In the days of famine that struck the area before and during World War II in the 1940s, due to drought as well as the breakout of the war, date production in the area reached 7,000 bahar (1 bahar = 300 lbs) in Ghail Bawazeer only, according to landowners at the time. These dates, along with large quantities of grains and other crops, helped to keep away the famine at a time when large segments of population in the Hadramout Valley were migrating to the coast in search of food.

After this famine and the end of World War II, people realised the importance of the ma'aayeen and their role in providing food in times of peace, war and drought. Ma'aayeen of different sizes were constructed by both the state and persons along the coast line from the east of Mukalla to eastern Raida to the east, as well as in other places where conditions were suitable for their construction. Thus, the knowledge of the sons of Ghail Bawazeer about surveying an area for water, planning, digging and managing ma'aayeen was transferred to these areas.

Our forefathers understood the importance of the ma'aayeen and their role in agricultural development. They conserved them by regularly maintaining their water conduits and clearing the cracks in the earth leading to their water sources. They also rationalised water use by building the barriers, small dams and pools to control water flow and wisely manage water distribution, and by depriving neglected lands of water.

With this system, large areas of agricultural land were reclaimed and cultivated. Farmers grew grain (maize, millet and 'musibili') and tobacco considered to be amongst the best types and famous with traders in and outside Yemen, including in Saudi Arabia, Egypt and Djibouti. Vegetables were grown according to the local climate and growing animal fodder led to the provision of meat.

The land tenure systems before 1967 played a big role in determining relations between the state, farmers and landowners, and in defining the good management of the ma'aayeen in conserving water, distributing it, and protecting its source. They were the result of the accumulated experience of generations of farmers from the area. The new system after 1967 did not take into consideration the traditional systems of private ownership, ajeez or fakhd, which led to many imperfections in the system especially in ma'yaan maintenance. At the same time, repeated waves of drought mean that water reserves had declined and water flow inside the ma'aayeen was low. To address this situation rainwater or floodwater were diverted directly to the source of the ma'aayeen. As a result however, some of the khuwa' became clogged up. This all led to many ma'aayeen drying up and to the sons of many farmers emigrating or taking up government jobs. All this led to:

- Desertification in many agricultural areas, reducing the area of cultivated land by half;
- Many ma'aayeen drying up, causing the death of most palms;
- Reducing production from four to two crops per year.

Despite efforts to pump water out of the source of the ma'aayeen and to line the main water conduit with cement to prevent water loss, the water levels of the past were not restored. All the measures taken were not enough to solve the problem.

Mid-April 1996, heavy rain improved raised the water level in all water sources in the area which led to water to flow in the main ma'aayeen, especially those with pumps at the water source where water conduits were clear of any debris because they had been used with the new pumps. Water flow there has resumed as in the past, according to some farmers also because the paths to the passages to the main water sources have been cleared by animals such as hedgehogs who use these cracks in the rock or khuwa' as shelter.

2-2 Spate irrigation

Floodwater is considered to be one of the most important sources of irrigation in the area, and accounts for the irrigation of 70% of total agricultural lands in Yemen's southern and eastern governorates.

Floodwater is the water that runs through valleys and water courses after rain or rain storms over a relatively wide area. The area has limited permeability which leads to floods after the valleys and water courses surrounding them have filled with water. These spate water flows continue for hours or days depending on the quantity of rainfall.

In the area of study, the nature of the rocks, the topography, and degree of slope in the valleys contribute to increasing the speed of the spate flood and high water discharge develop in a relatively short time. This is a common feature of the floods that run in most of the area's valleys. Because of this, large quantities of floodwater flow to the sea or to deserts without being utilized. The floods also wash away agricultural land every year.

Floodwater is not only a main source of irrigation and replenishment of groundwater reserves, but also a great fertiliser for the land as it it carries organic materials and fine sedment. It revives the soil and improves its structure.

Spate irrigation involves inundating agricultural plots, surrounded by field bunds, called 'soum'. These field bunds are typically 50-60 cm high. The farm land is served by diversion canals of up to several kilometers long.

We will here discuss two models developed in the Baihan Valley in the Shabwa governorate and in the Do'an Valley in the Hadramout governorate. The methods and names used in both cases are very similar, but there are some differences linked to the nature of each valley, rate of the water flow, and degree of slope.

The following table shows the volume of floods into some valleys in Hadramout and Shabwa:

Valley name	Estimated annual floodwater (in millions of cubic meters)
Hadramout Valley	280
Hajar Valley	200
Maseela Valley	27
Mayfa'a valley	110.5
Kher Valley	3
Wadi Valley	12
Baihan Valley	15

Source: Ref. No. (8)

2-2-1 The Baihan Valley model

Situated to the northwest of Shabwa, the Baihan Valley is considered to be one of the governorate's most important agricultural valleys and is well-known for its fertile soil and the variety of its crops (Figure 10).

This valley has a dry to semi-dry climate and is 1,000 meters above sea level. Its water basin extends for 3,600 square kilometers. Floodwater runs into the valley from areas as far as the Al-Baida governorate which is 2,000 meters above sea level and where rainfall is about 250 mm/year compared to 50 mm/year in lower parts of the valley. (Figure 1)

Over history, irrigation has been developed in the area by various civilisations. The Qutban state (which coexisted with the Sabean, Hadrami and Awsan states), for example, built diversion conduits, dams, and water channels. To the north of the valley, the Qutban established their capital, now known as Hajar Bin Humaid.

Here we will review the sawaqi (Arabic plural of saqiyya), flood water canals that span along the whole valley and play a vital role in diverting floodwater to agricultural land.

A saqiyya or water canal usually consists of two main parts: the entry of the saqiyya (a) and its main body (b).

a) The entry of the saqiyya or flood water channel

The diversion of flood water to the saqiyya is done with the help of the 'qaid' or 'dhameer' and the 'ras'.

The qaid or dhameer

A qaid or dhameer is a spur-like diversion structure made up of stones and rock. The structures have a deep base that extends at an obtuse angle from the 'ras' or beginning of the water channel up to middle of the valley, usually against the direction of the floodwater and the valley. The height of the spur gradually increases from ground level in the middle of the valley to 1-1.5 meters at the beginning of the water channel. This gradual difference in height is to avoid obstructing the water's passage, to avoid destroying the qaid or dhameer, and to control incoming water flow. This sort of qaid or dhameer exists in the Nahr Valley above the town of Naqub. The qaid or dhameer is found higher up in the narrower sections of the valley; they divert part but not all of the flood water.

At the foot of the valley where it widens out into the agricultural land and the flow spreads out, the valley needs to be closed off completely for the water to be diverted to the flood channels. A barrier usually made of thorny bushes, reinforced by trees and earth, replaces the qaid. However, these brushwoord barriers are usually washed away by floods after some time.

Today, a barrier or bunds can be built using modern mechanized tools to span across all or part of the valley's width. This diverts the water flow to the flood canals but the risk is that these stronger diversion structures could damage agricultural land on either side of the valley in the case of a heavy flood, as too much flood water may rush to the farmland, creating havoc. Therefore, when enough water flows into the channel system, an opening is made in the middle of the diversion barrier. This will quickly develop into a larger breach and flood water is allowed to continue flowing down the middle of valley, this sparing the farm land from high floods.

The ras

This is where the qaid joins up with the saqiyya or water channel. It is a conical abutment made of rocks with a deep base into the riverbed called 'ajlama' (Figure 11).

These conicial abutments are found at the beginning of water canals, on the edge of fields in the direction of the floodwater, and as partitions to support the wall of the main body of the water conduit. The ajlama has a circular base of 3 to 4 meters diameter and its height measures between 2 and 4 meters according to its size, location, and the purpose for which it has been created.

An ajlama is usually fixed on a solid rock base after removing all rubble from the valley floor. They are constructed with intersecting rock segments directed inwards to reach a cone shape the diameter of which is 1.5 meters at the top. The inner part of the ajlama is next filled up with sand and gravel instead of clay as sand and gravel better resist pressures and does not absorb water. If clay had been used, the structure might have swelled and shrunk leading to the collapse of construction, or the clay might have been washed away.

These constructions are usually undertaken by local experts.

b) The main body of the saqiyya or flood water channel

This is made up of two parallel walls, one of them along the agricultural land and the other along the course of the valley, in between which runs the water. The structure is solid and strong to withstand the great pressure of floodwater in the valley. As for its height, it differs according to the depth of the conduit. Its base is 2 meters deep and it is about 1.5 meters wide, and built from large and medium-sized rocks. Cavities are filled with small rocks. The conduit should always be as straight as possible. As for its depth and width, it is defined by the area of the land on which rain is to fall, the location of the conduit in the valley, and the volume of water flow. In the wall, a number of ajalim (plural of ajlama) are there to strengthen it and prevent it from it breaking down completely if any part collapsed.

The mansam (plural: manaasim)

In the first 100 meters of the saqiyya's wall along the valley is what is known as the 'mansam' (or sometimes 'budd'). This is a strong, solid low structure built 50 cm or more lower than the highest part of the saqiyya wall. Its width is a few meters and it is usually built between two ajlama. It is usually built high up the saqiyya's wall using trees and grass and fixed with stones. The mansam serves as flood escape. It is built to get rid of excessive floodwater beyond the saqiyya's capacity and return it to to the valley, thereby reducing pressure on the network of canals of the saqiyya.

The ma'dhar (plural: ma'aadhir)

This is a part of one of the saqiyya's walls. It is constructed from loose rocks and its base extends to the bottom of the saqiyya. The ma'dhar works as an escape too to get rid of all water in the saqiyya and return it to the valley in case there is no need for this water. It is also sometimes used a safety valve, if there is too much water in the canal and there is a danger for agricultural lands. (This water flow that can destroy land and structures is called 'jahla'.) Any person can withdraw some stones which might cause the ma'dhar to collapse under the pressure of the water as it is loosely built. Unlike the mansam usually the ma'dhar is positioned half way down the saqiyya or in its last third.

The masqat (plural: masaaqit)

This is built from stones on a solid base for the following purposes:

- To split the main canal into the smaller ones;
- To transfer water from a higher canal to a lower one;
- To divert water from one field to another;
- To help disperse the water flow's energy and reduce risk on the structure.

The madkhal (plural: madaakhil)

This is a waterfall-like drop structure in which water flows from a higher field to a lower field.

The maasih

This is a protection wall built on the side of the riverbed to protecting agricultural soil from being washed away. It is as high as the agricultural land and it inclines slightly towards the agricultural land. However, these walls often collapse despite their importance in protecting the land.

Irrigation customs in Baihan

Each area develops its own customs that become laws that cannot be ignored. Spate irrigation has its own regulations, developed from the knowledge and experience of those who have encountered challenges in their work with it.

Floodwater is considered to be a public property as long as it runs down the main course of the valley. Every man has the right to benefit from it on the condition that he does not harm the interest of others. The ownership of this water can however become private when it or part of it is diverted to the land by a saqiyya or any other means.

Water is therefore divided among landowners according to their needs. Any excess water can be benefitted from by others or returned through special openings (ma'aadhir and manaasim) to the valley. Custom is that priority is given to the irrigation of land at the top of the valley, followed by the land immediately below it, and so on. It is not allowed to irrigate the same plot of land for a second time during the same season (khareef or saif) when there are still plots of land in the lower part of the valley which have not yet been irrigated.

When the saqiyya is built, a group people usually participate in bearing the costs according to the location and size of their land, its distance from the saqiyya, and its level in relation to that of the saqiyya. Land higher than the level of the saqiyya is called 'mintaah', and the owner of this land pays more that the owner of land lower down below the saqiyya. The owner of a small plot of land pays less than the owner of a large plot of land. The same considerations are applied for covering the cost of reparation and maintenance.

Before building the saqiyya, its capacity, depth, and the location of its beginning are determined according to the volume of seasonal and annual floodwater flows in the valley. The saqiyya should be as straight as possible in order to allow its passage through some plots of agricultural land. Either the owners of this land are appeased or compensated with another plot of land to replace what they have lost, or they agree by themselves or to evacuating it for the saqiyya to run through it. Appeasement and compensation rarely happen, as in most cases the saqiyya is allowed without any problems. In this case, the landowner who has given right-of-way for the flood channel is allowed to cultivate the bed of the canal, once the flood water has passed. He usually grows fodder. As the right is given to the saqiyya's owners to channel water into the saqiyya at any time the water will destroy anything that is grown there – but fodder can usually be harvested quickly.

Rules for water are applied to the natural course of the valley. The valley is considered a public property and nobody has the right to change or expand the main water course in a valley, except with permission from the concerned authority. There are clear agreements between the owners of land on the valley banks about the necessary distance between their land and the edges of the valley, and a certain protection is determined for their land. However, over the last years families and farmers violated these customs, widening the natural course of the valley and thereby compounding destruction for instance during the flood disaster of 1996.

If any participating land is deprived from irrigation due to negligence or sabotage, then the guilty party will be fined all costs of the plot. Its owner will be compensated based on a comparison between his and neighbouring lands or according to what cultivation experts see fit.

The partial collapse of a soum (the 50-60 high field bund, surrounding a plot of land) can lead to adjacent land being washed away in what is called a 'lakhf'. When the land is washed away after water floods uncontrollably over the soum, it is called 'kabr'. This must be fixed quickly as the rutting will deplete the soil mositure. Removing any plants can be done with the tools used for reparation, and soil can also be taken to close the ruts and gullies from nearby agricultural land according to the size and location of the damage. This also has its own set of customs.

Figure 10: Map showing the course of the Baihan Valley and its most important towns and villages

1. DawAan wadi
2. Bayhan wadi
3. Hajr wadi
4. Hadramouth wadi

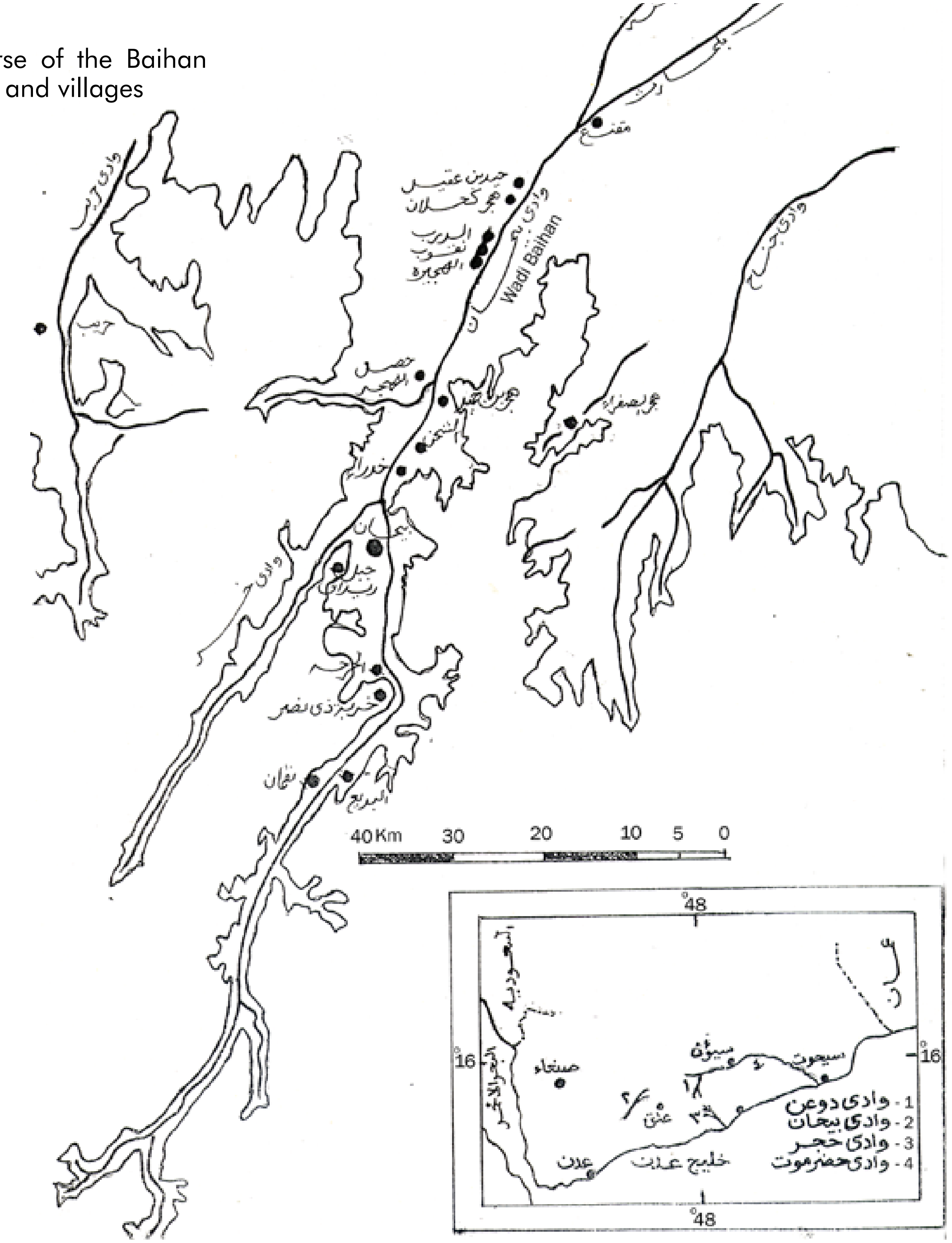
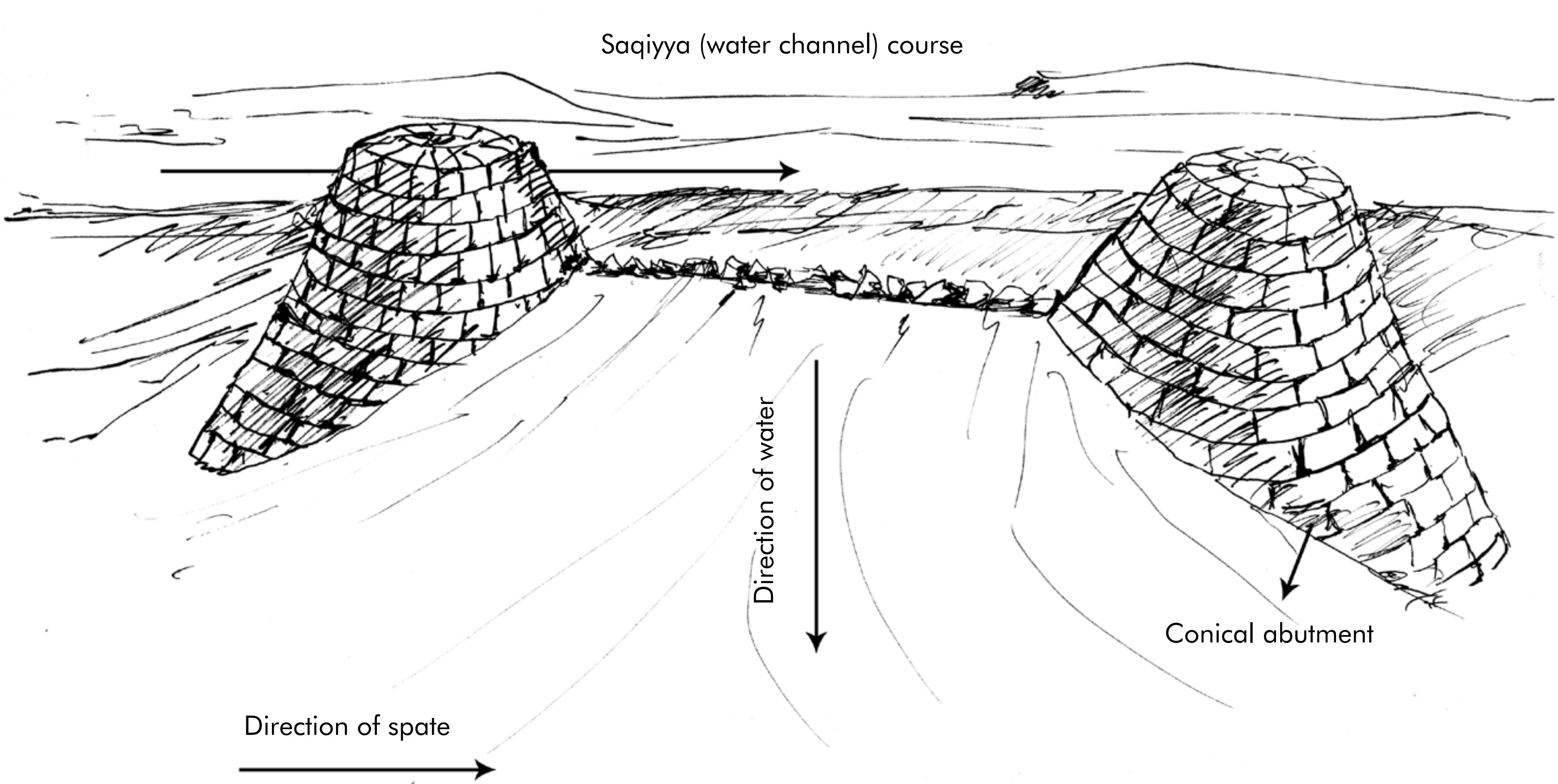


Figure 11: Design of the saqiyya's mansam (water escape)



2-2-2 Model of Doan valley

The Do'an valley has long been famous for being one of Hadramout's fertile valleys. It is distinguished not only for its agriculture, but for the architecture of its mud towns, a mark of the skill of those who built them (figure12).

Irrigation in the Do'an Valley is very similar to that in Baihan Valley in that the water flow is channelled from the valley to the land via a saqiyya, with a few differences imposed by the nature of valley.

Many of the valleys that feed into the Hadramout Valley are narrow and flanked by high walls in which are cracks, which leads to floodwater gushing through them at great speed. Specific structures have therefore been put in place to protect the land as well as the irrigation structures such as the sawaqi (Arabic plural of saqiyya) and dams.

Here we describe the structure of a saqiyya or water conduit in the Doan Valley, concentrating on differences in construction techniques and terminology with one in the Baihan valley.

The two parts of a saqiyya or water conduit are: the entry of the saqiyya and its main body.

a) The entry of the saqiyya

It is made up of the dhameer and the ras.

The dhameer

This is built on the valley floor to divert floodwater to the saqiyya, but is not also called qaid like in the Baihan Valley. Its construction is also different according to the nature of the valley.

In a right-hand valley where the natural water course is wide, the dhameer is built at a height of 10 cm at its beginning in the middle of the valley and gradually rises to reach 1-1.5 meters where it reaches the saqiyya (Figure 13).

It is to be based on solid ground. Digging will continue until this is reached. Two walls are then built close to each other using large and medium-sized rocks. The gap between them is then filled in with sand and gravel, and closed off on top with medium-sized rocks. Today, cement could be used instead.

In a narrower (50 to 60 meters) left-hand valley, the dhameer is built diagonally across valley, thus closing off the water course (Figure 14).

The structure needs to be solid to withstand high water pressure. At the base, it is 3 to 4 meters wide. After digging out its base and clearing out the rubble, large rocks are used to build a front and back wall. The front wall slopes slightly to the back, but the back wall is shaped like stairs to break the force of water rushing over it. The space between the back and front wall is filled with sand and gravel, and the top is closed off using large rocks. The structure is at least 30 cm higher than the flow in the valley. It redirects water to the saqiyya and any extra water flows over behind the barrier. To avoid scour at the toe of the dhameer, the ground is covered with a layer of medium-sized and small rocks called 'farsha' or 'salqa'. When it is damaged, it is repaired as soon as possible.

One of the main benefits of the dhumur (Arabic plural of dhameer) is to reduce the speed of water flow in the valley and stablilize the riverbed. These water barriers are built alternatively sloping to the right and the left down the valley.

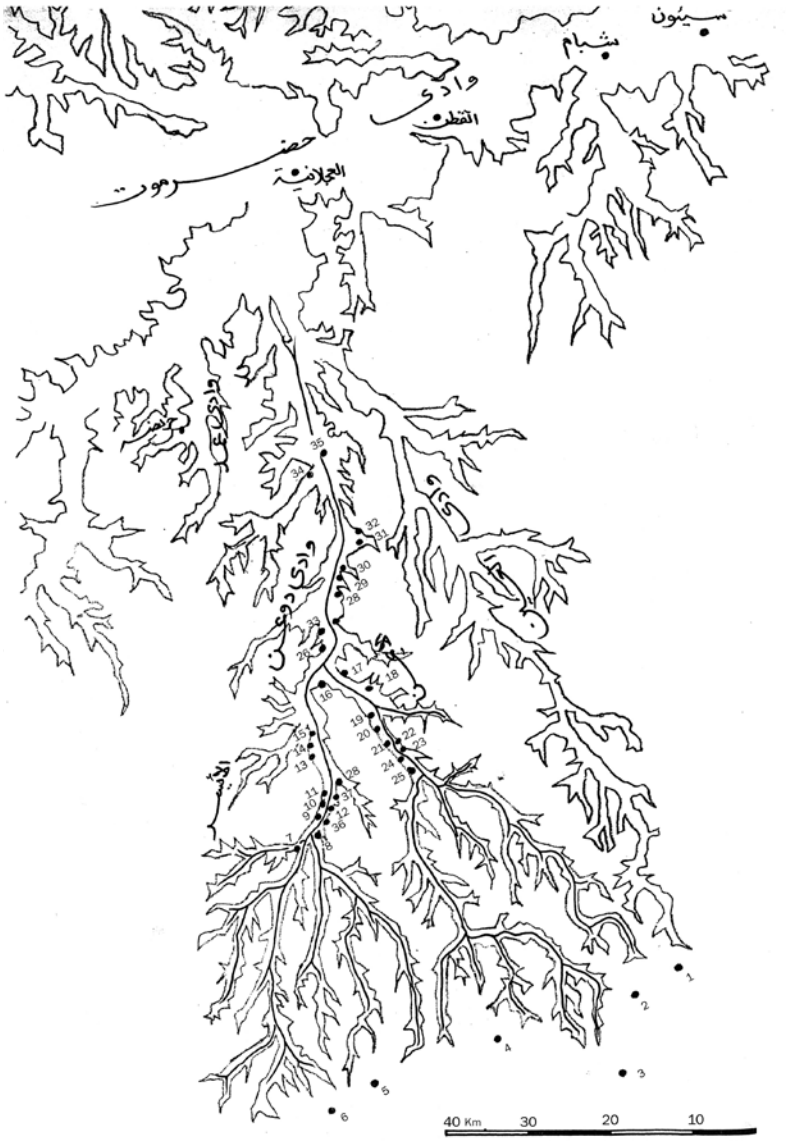
The qaid in Do'an is part of the saqiyya, and its function is different according to its location. It refers to the part that connects the two sides of the saqiyya at its entry. Part of it rises slightly above the bottom of the flood canal. This is to increase the water level to divert it to a secondary canal or to divide it between several secondary canals.

The ras

This is the name given to each of the two large structures on right and left hand sides of the beginning of the saqiyya. A qaid, of which only a few centimeters are visible above ground level, connects them. These ruus (Arabic plural of ras) are similar in shape and function to the ajaalem (Arabic plural of ajlama) in Baihan, except that they can be in various shapes (not only conical) including that of a cylinder or an irregular circle and can be coated in cement or lime to increase their strength.

This part is built by digging a ditch of suitable depth along the direction of the saqiyya. This ditch is then widened until the base of the ruus on either side, aligned with the direction of the saqiyya. Layers of large and medium-sized rocks are placed one on top of the other and gaps are filled with gravel and sand. When the ground level of the saqiyya is reached, building stops in the center and this is called the qaid. It then continues on the two sides until the ruus are finished. Each ras is 1.5 to 2 meters high, as the same height or higher than the the saqiyya wall.

Figure 12: Map showing the course of the Do'an valley



1. Ras Huwayrah
2. Almahal
3. Algamrah
4. ALdahma
5. Al Haysar
6. Labnah
7. GarHat baHaish
8. Arribat
9. AlKharibah
10. Arrashid
11. Alguwayrah
12. Almoshrigi
13. Hadun
14. Taher
15. Aljibil
16. Aljahi
17. AarDbagadir
18. adduFah
19. Sabak
20. Almashgahah
21. Tulbah
22. Sara
23. Khawfah
24. Muwayrah
25. Khalifjazil
26. Hadithayn
27. Hisnawajiiz
28. RiHab
29. Garahbin Sam
30. laghadir
31. NaSrah
32. MaSnaAah
33. Kuka
34. Algarah
35. Alhajrayn
36. GarnbaHakir
37. Algasin

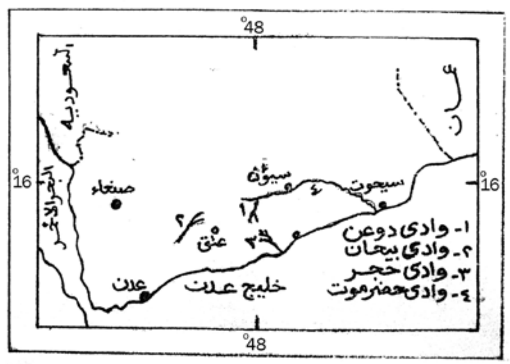


Figure 13: Location and length of a dhameer in a wide valley

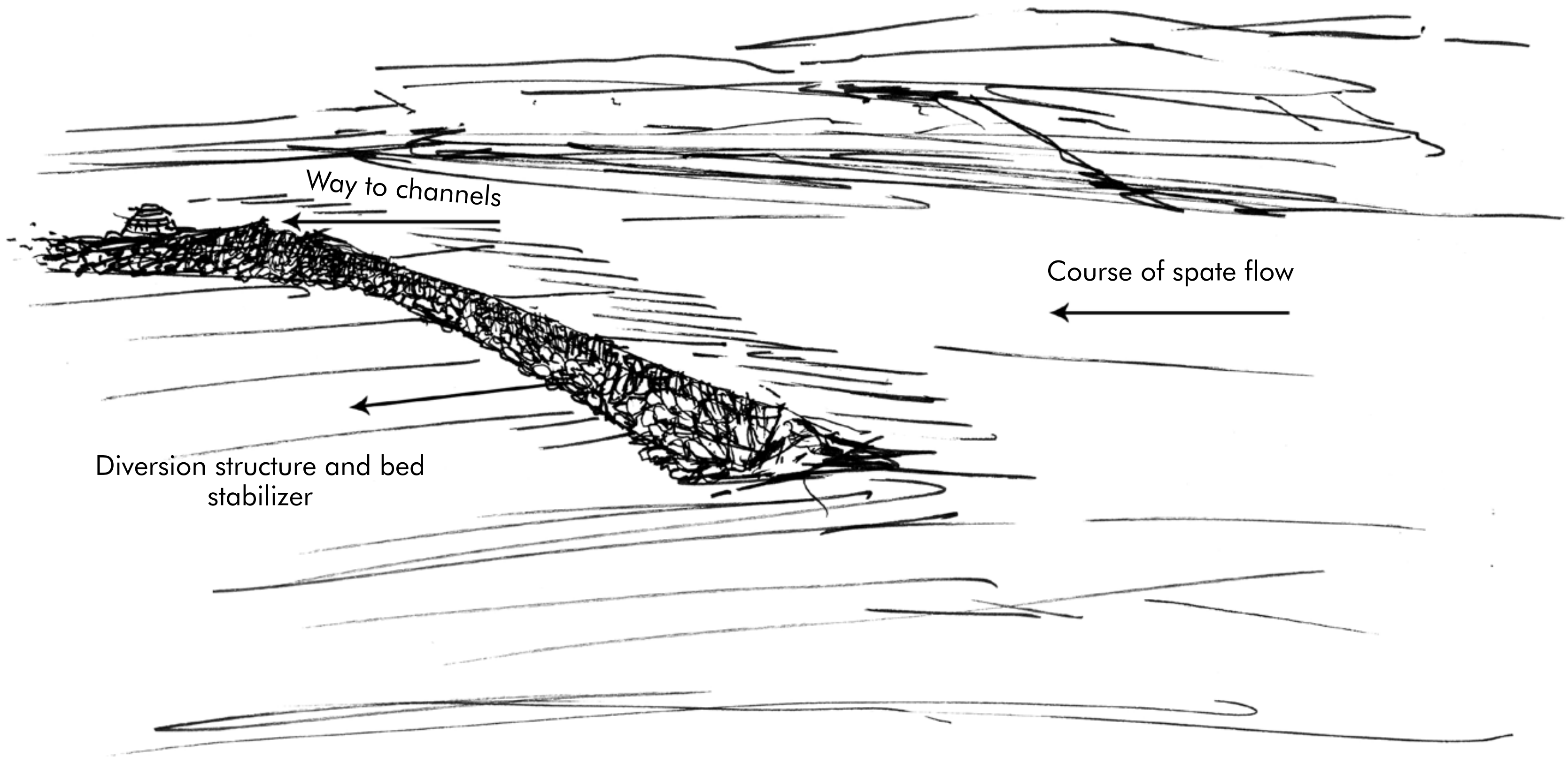
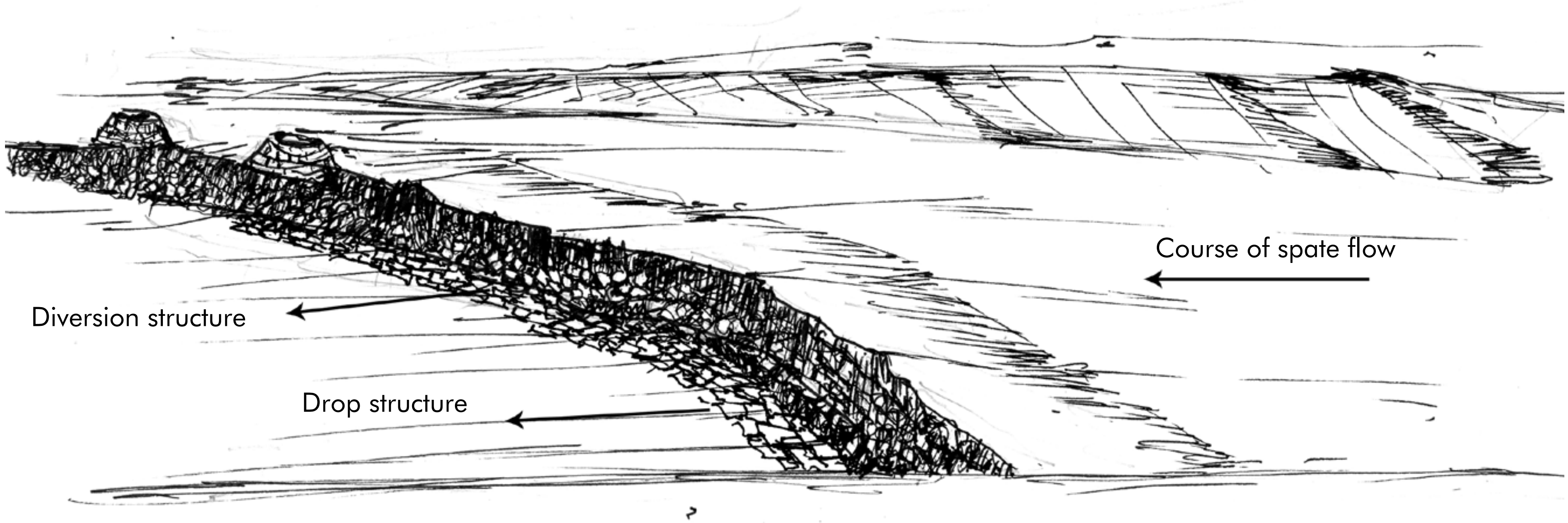


Figure 14: Location and length of a dhameer in a narrow valley



b) The saqiyya (channel network)

The main body of the saqiyya is made up of two walls, one outside wall facing the valley and an inside wall facing agricultural land, containing openings to divert water to agricultural land or back to the valley.

Its construction differs from that of a saqiyya in Baihan.

The foundation of the outside wall that faces the valley is dug 2 meters deep and up to 2 meters wide, often starting from the side of the land to be irrigated. The wall is built in two parts, i.e. two parallel walls in between which is an empty space that is filled up with gravel and sand. The side of the wall facing the valley is shaped like stairs, while the other leans slightly out towards the valley.

Along the wall, there are various structures in different locations that serve different purposes. The ruus (Arabic plural of ras) and quyud (Arabic plural of qaid) support and reinforce the wall. The manaasim (Arabic plural of mansam), and ma'aadhir (Arabic plural of ma'dhar) and manaaki (Arabic plural of manki) protect the structure and adjacent land against destruction from the pressure of massive floods. Here these structures are described.

The ruus (Arabic plural of ras) and quyud (Arabic plural of qaid)

These are similar to the ajaalem in Baihan and are usually spread along the saqiyya's wall that faces the valley and at its entry. Their purpose is to strengthen the structure and to prevent its destruction in the case of part of a wall collapsing. Each two ruus are connected by a qaid.

The mansam

Within the first 100 meters of the saqiyya, it is a 10 to 15 meter long depression in the height of the wall facing the valley. It is similar to the system existing in the saqiyya of Baihan, and helps excess water return to the valley if the water level in the flood channel is very high (Figure 11).

The ma'dhar

This is a part of the saqiyya wall that is built with loose stones half way down the saqiyya or in its last third. It can be easily opened to get rid of all the water in the the saqiyya by redirecting it to the valley when there is a danger of the agricultural lands being destroyed from excess water or when all land has been adequately irrigated.

The manki

These are openings at the end of the saqiyya, the fields, or the secondary water canals to get rid of excess water and redirect it to the valley.

The mudla'

It is similar to the maasih in Baihan. Its foundation is dug parallel to the edge of the agricultural land at the depth of 1 meter or more until it reaches solid ground. It is made of two walls 0.5 meter apart, and slopes slightly towards the land. The rocks of the back wall of the wall are fixed in the earth, and the space between the two walls with gravel and sand. Medium and small rocks are used. The wall rises above the level of the land.

Madaali' (Arabic plural of mudla') are widespread along the course of valley to protect land from being washed away.

As for saqiyya's inside wall facing the agricultural land, it consists of a number of openings with aim of conveying water into an agricultural land.

The harra

This is a square or rectangular opening in the saqiyya wall that faces the agricultural field in order to divert water to it.

The sada'

This is a vertical opening in the saqiyya wall supported either side by walls that prevent its collapse. The aim is to divert water in secondary canals to the fields.

The budd

The abdaad (Arabic plural of budd) are secondary water canals and field water canals. They divert water to the land, and their capacity varies according to the plot of land and its share in water.

Irrigation customs in Do'an

According to its natural conditions, each area develops its own set of rational norms or customs that are accepted by the community. In Do'an, as in Baihan and other agricultural valleys, local customs organize all agricultural works, including the construction and maintenance of the saqiyya, the distribution of water according to certain priorities, landowner and farmer relations, and the resolution of disputes. There are authorities to implement these customs.

When the saqiyya is built, landlords share the costs and the work. Usually, the saqiyya is established in an area of at least 25 feddans, and costs are allocated according to size and location of the land they own.

As there is very little agricultural land in Do'an due to the valley being narrow, plots of land tend to be small so that usually at least forty people share the saqiyya. To manage water distribution and ensure necessary regular maintenance, a committee of 5-7 people is formed, headed by an expert in agriculture and irrigation locally called the 'khayyal'. He has an assistant, a treasurer and a collector. Land, palms, or both from the users' land are set aside to fund saqiyya's running and maintenance. The return of investment in these is specifically written down in the name of the saqiyya.

But the saqiyya committee's duties do not stop there. There is a person called the 'raa'id Al-saqiyya' and another called 'raa'id Al-nakheel' (nakheel means palms).

The task of the first person, raa'id Al-saqiyya, is to monitor the state of the saqiyya when floodwater flows through it, to immediately repair any damaged part of the saqiyya, and to remove obstacles (trees and floatsam) swept into the saqiyya by the flood. If he cannot do all this himself, he can ask for the assistance of the khayyal (head of the committee) who generally supervises irrigation or of people nearby.

The destruction that is caused to the soum (the field bunds surrounding the land to be irrigated) of the saqiyya due to floodwater is called 'tawl', while the same destruction caused by water leaking out of a hole in the saqiyya made by a rabbit or hedgehog is called 'ghawl'.

The task of the second person, raa'id Al-nakheel, is to monitor secondary water channels in the fields, monitor irrigation, and determine the needs of each plot of land. During irrigation, he throws a stick, the length of an arm called 'mar'ada', into the beginning of a field's water canal. If the stick floats to the middle of the canal, then this means that the water is still reaching the land. If the stick hits either side of the conduit, then this means that the water has started to recede and the field canal should be closed off. No one can go against the orders of the raa'id. If someone protests one of his orders, the khayyal becomes the arbitrator. One of the raa'id's tasks is to remove any obstructions from the water canals, and to open or close off the field canal intakes to distribute the water.

Due to the importance of the palms in the area, there are two kinds of irrigation, especially if water is scarce. These are 'riat Al-nakheel' (palm tree irrigation) and 'riat Al-qasb' (literally, stalk irrigation). The openings from the irrigation channels to the palms were bigger than those to the other crops including grains, and thus the palms receive more water.

When there are disputes during irrigation, the khayyal arbitrates and solves the problem directly, and experts from the farmers who were there at the time of the dispute are called in. If a dispute is bigger, then a compromise is reached and the matter is passed on for arbitration. Those in charge of arbitration in Do'an and the Hadramout valley are known for being trustworthy.

It is an outstanding practice. The arbitrator is called the ''aada' (Arabic for custom), referring to what people usually do in similar cases. Arbitration is on two levels: at the level of the lower 'aada and that of the higher 'aada. After agreeing the name of the 'aada or arbitrator, statements are heard, the location is surveyed, and witnesses are called in. The issue is decided upon and very often the judgment is convincing. If people are not satisfied, the case is referred to the higher 'aada which is a committee of several recognised people from the area, and its decision is final and binding. Some of the families well-known for this are the Aal Jaber family in the valleys of Do'an, Al-Ain, and Amd, and Aal Badhamaan in the area of Al-Hajarain.

2-3 Spring irrigation

God said, "Hast thou not seen how God hath sent down water from the sky and hath caused it to penetrate the earth as watersprings, and afterward thereby produceth crops of divers hues; and afterward they wither and thou seest them turn yellow; then He maketh them chaff. Lo! herein verily is a reminder for men of understanding."
(The Troops, 39:21)

Springs exist in some mountainous areas and provide the surrounding area with necessary water for agriculture and other uses. The waterflow from these sources increases with heavy rain, although from some the flow is constant, even in years of drought. Due to the scarcity of these springs, the agricultural areas that depend of them are also limited. However, some are cultivated throughout the year and produce crops that have economic returns. One of the most important areas where these springs are found is along Habban valley in the villages of Gharir, Safaa, and Al-Maatir, in the higher parts of the Baihan Valley, in the area of Radhoum in the Mif'a Valley, and other places in the Shabwa governorate.

In the Hadramout Valley, the Hajar Valley is considered to be one the richest valleys in springs that run throughout year, as there are more than 90 springs used to irrigate palms as well as Ghail bin Yamin (the spring of bin Yamin), Ghail Amr (the spring of Amr), the springs of the Masila Valley and the Urf Valley, and others. Springs exist along the area from eastern Mukkalla to eastern Raida, in addition to a number of springs and hot springs used to treat many diseases, including Tibala, Suwaibar, Thuban and Al Saiq.

Yemenis have always made good use of the natural conditions where they live. They invented appropriate techniques to divert this water and benefit from it in the right time and place. Below is a description.

2-3-1 Water conduits on mountain edges

These channels are dug out on the edges of mountains along valleys, where spring water is diverted after being held back in a remote area. Because flows are modest, the water would not reach the valley, so channels are dug out in the rocks. Examples of such canals can be seen in the area of Gharir area and Safa in the Habban valley in the Shabwa governorate and in the Badsh Valley in a coastal area of the Hadramout governorate. These conduits are cleaned and maintained after the harvest for a period of one to three days, as in the case of the Gharir and Safaa.

Until about the mid-seventies, these canals were a source of drinking water as well as being used in the right time for agriculture and other uses. Thus many grains such as millet, sorghum, sesame, but also vegetables and palm trees were cultivated, mostly for local consumption. Shares in water distribution are determined according to the size of the land, and are transferred in case of sale and inheritance. As in the case of the saqiyya for spate irrigation, there are special customs and laws for the operation and maintenance of the spring water channel.

2-3-2 Diverting barriers and water conduits

These structures are built in the areas where the springs have a relatively high water flow as in the case of the Hajar Valley, where water is held back by a diverting barrier made of trees and soil about 1 meter high, more of less perpendicular to the water course. Water is then diverted to a saqiyya or water channel about 1-3 kilometers long before reaching the first plot of land and which can extend for 2 kilometers within agricultural land to irrigate it.

The biggest problem with this sort of barrier is that it is permanently at risk of being destroyed and washed away by floodwater. If this happens, it has to be built again and this can happen up to ten to fifteen times a year.

Usually, beneficiary farmers conduct maintenance works themselves or pay others to do it instead. Their contribution to the cost of maintenance depends on the size of their land. The larger the plot of land, the bigger the contribution. The customs for the construction and maintenance of the saqiyya, landowner-farmer relationships, and water distribution are similar to those that govern these issues in spate irrigation.

Chapter 3: Rainwater harvesting

In dry and semi-dry areas, rainwater harvesting is the collection of large quantities of rainwater and storing them for a long period for the benefit of agriculture, household purposes, and others. Man adopts techniques to help to reduce the waste of floodwater and rainwater and to protect its loss due to seepage, evaporation, or pollution. In these areas human activity is not restricted to diverting floodwater in the valleys and lower lands, but man also exerts efforts in water harvesting in the desert highlands and high hills where shepherd and Bedouins live.

Man's expertise has developed over time and his simple techniques have become the most appropriate and effective to provide water and to overcome natural conditions. Water is scarce in wide areas of Shabwa and Hadramout as annual rainfall does not exceed 50-100 mm, and any groundwater is relatively deep underground. This is the case, for example, for the areas of the Jardan Valley, the Dahr Valley, and the Aram Valley in the Shabwa governorate, as well as the areas of the Jawl called 'Sitan', which are plateaus in the Hadramout Valley.

An economic and social study about shepherds in the southern and eastern governorates indicates that 88% of shepherds in the Hadramout Valley receive water from karfaan (Arabic plural of kareef) or natural rainwater pools, 6% from springs and other water sources, and 6% from open wells (Ref. a). As for the Shabwa governorate, there are no similar statistics, but we can say that countryside residents collect and store water from traditional sources and open wells. The areas of Sitan are a unique and very special case in which traditional techniques have been developed to collect and store water over a long period despite scarce rain.

The topography and rock structure of the Hadramout plateau influences the development of the water harvesting techniques that have made life possible in some parts of this plateau.

Geomorphology of the areas of the Sitan and water harvesting

The Hadramout Plateau is formed of a rock base of limestone (calcium carbonate) up to 200 meters thick. In geology, this is called the formation of the Umm er-Raduma. The surface of this formation represents the base of the Jawl which is called locally Sitan. Above this formation, a rock layer made up of hard clay rocks and layers of limestone is called the Jeza' Formation and is 70-100 meters thick (Figure 2).

The plateau has been exposed to tectonic movements upwards over the course of time, leading to large-scale bending of the rock layers and relatively wide cracks (see geological profile). The area has been exposed to different types of erosion, most importantly water erosion during the rainy age which led to the formation of the water drainage network, as seen in the water course of the current valleys, and to large parts of clay and limestone materials being washed away to form the Jaza' Formation. The depositions left behind a formation of isolated hills and the extensive forms of the mesa (old crater pipes) spreading at different altitudes so that they look like terraces.

The population in this area has benefited from the natural structure of the ground and rocks, especially limestone and clay, in developing methods to collect and store rain water. We will briefly review the most important methods and structures in Sitan, which are the naqab, the karfaan or natural rainwater pools, barriers and dams, jawaabi and the shorooj.

3-1 The naqab (Arabic plural of naqaba)

These are cisterns dug out by man to collect rainwater for drinking water and for different daily needs. Naqaba is considered to be a model technique from the Hadramout Plateau from the Jardan Plateau and Arama in Shabwa in the west to most areas of Hadramout until Mahara in the East. They can store enough water to last several months, according to what is used for and how many people benefit from it (Figure 15-16).

The naqab are dug in specific areas, according to the topography and rock structure of the area.

Topography of the area

A naqaba needs to be located at the bottom of a large, slightly sloping area of solid, relatively non-permeable rock surface to feed it. Water flow is directed across and down this solid rock area and into the naqba by different sawaqi, rows of rocks in a line called 'habl' (plural: hibaal).

Rock structure of the area

The naqaba requires a solid layer of limestone for the feeding area followed by a clay layer (locally called 'qaraf' due to its tenacity) on a limestone layer. This geological structure exists in the Jaza'e Formation as we mentioned earlier. At the end of the feeding area, an opening is dug into the clay layer until the limestone layer is hit. The hole is then widened either side as much as possible until it had the shape of a jar. Then surface clay is used to hold back collected water in the hole and to prevent it from leaking out underneath or to the side.

For this documentation, we visited naqab in the areas between the village of Mahal and the town of Labna, via the villages of Qamra and Fardakha, and found that they were often next to natural karfaan or rainwater pools.

The location of the naqab was documented in the village of Qamra as a model, and measurements were taken. The diameter of the surface opening was about 0.70 m, and the solid limestone layer was 1.20 meter thick. At the bottom of the feeding area, the naqaba expanded in the shape of a jar. Its horizontal diameter was 3-6 meters maximum and 1 meter deep. These are the average measurements for six naqab positioned in semi-straight line with about 8 meter between them. Dug into the rock, an open kareef or natural rainwater pool exists beside this naqab from where the water was used for washing and to water cattle. Water from the naqab was only used as drinking water.

3-2 The karfaan (Arabic plural of kareef), and their barriers and dams

A kareef (plural: karfaan) is a natural basin or wide hole where rainwater gathers from surrounding slopes or water courses.

Man very often intervenes to hold back this water with a clay barrier to prevent water from seeping out. This water is mainly used to water cattle and to cover the domestic needs, as in the dry areas of Sitan in the Hadramout Plateau. Usually some sawaqi or water channels are set up from the feeding areas to the kareef to gather the largest possible quantity of water from different directions, like in the case of the karfaan in Qumra and Alisa.

As man's need for water increased, the quantities of water gathered naturally or held up behind clay barriers ceased to be sufficient and man had to use modern construction methods to collect the largest possible quantities of water to meet his many needs, as in the area of Haiser and Kareef Lubna. These structures could meet the need for water of more than 5,000 people for six months or more like in Kareef Haiser, also called Sad Haiser (the Haiser dam).

There is a distinctive pattern to the karfaan at the bottom of the mountainous slopes in the valleys where conditions encourage natural water collection. The water barriers and water conduits are built far above on the surfaces surrounding the valleys to direct water to these karfaan. For example, the kareef of Amjakheera in Jardan could meet the needs of 20,000 people and their cattle for two years.

Figure 15: The opening of a naqaba (cistern) on ground level

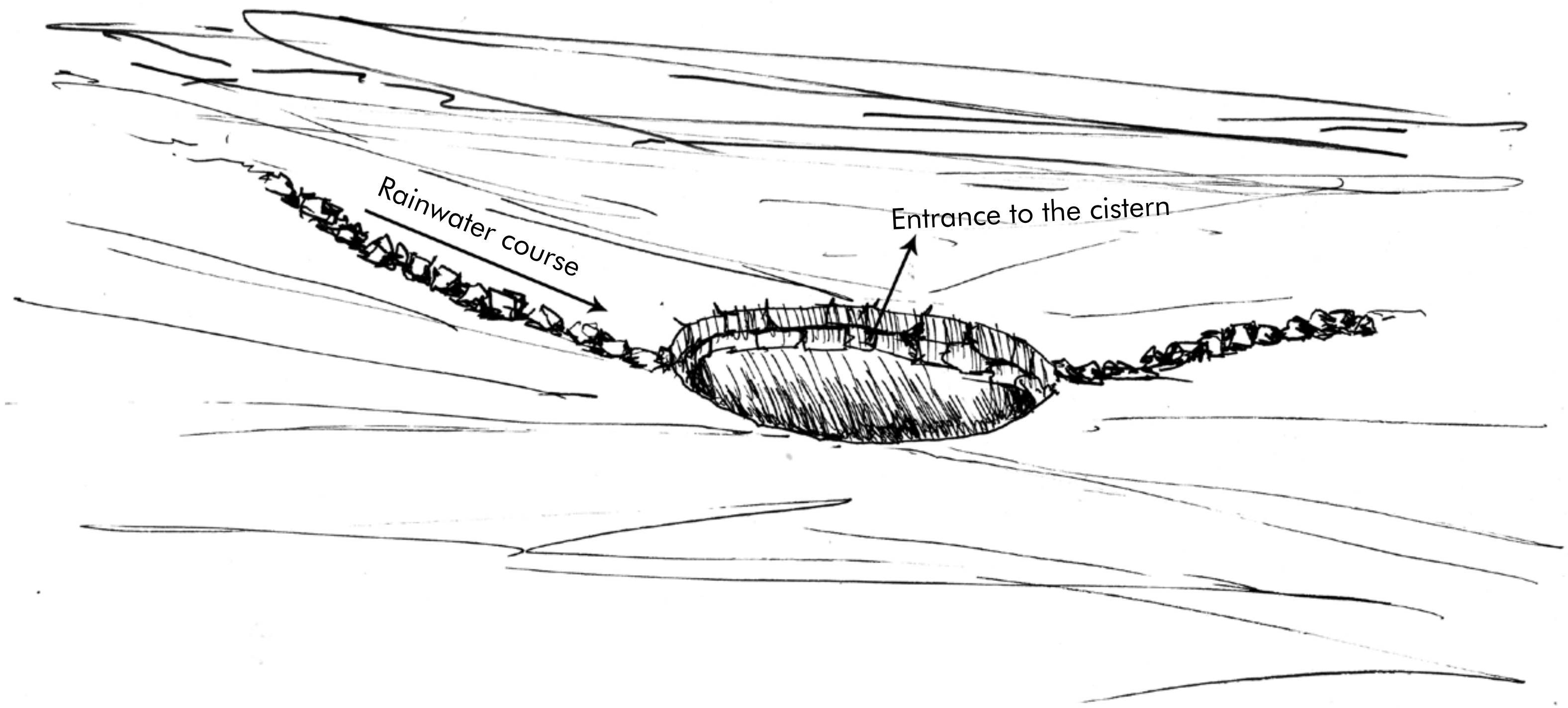
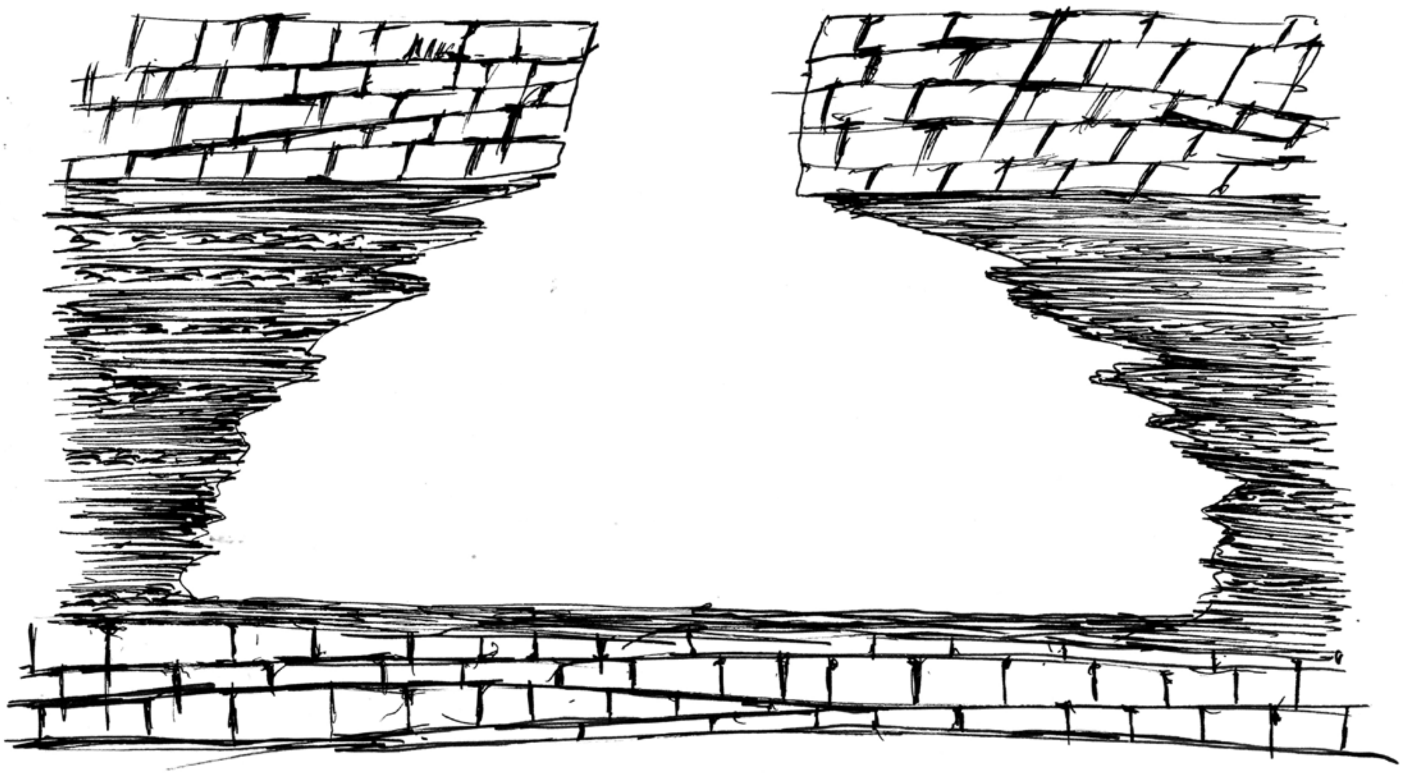


Figure 16: Drawing of a naqaba (cistern)



As man developed his skills, cement dams and barriers were built at the start of valley water courses, places considered to be natural collection points for large quantities of water. (It is worth pointing out that these areas were however not the location of the karfaan mentioned above, due to the intensity of the water flow and man's inability to control it with traditional methods like a clay barrier.) An example of a dam is the Labna Dam that provided water for 10,000 people in the town of Labna.

3-3 The jawaabi (Arabic plural of jaabiyya)

These are tanks or open reservoirs built to collect rainwater and floodwater for different purposes. The jawaabi we mention here differ in terms of form and purpose from those known in many other areas.

There are two types of jawaabi. The first is oval and open at the top and is widespread in the Jardan Valley in the Shabwa governorate. The second is cylindrical or barrel-shaped and becomes narrower at the base, and is covered at the top with a dome-like structure. It is widespread in the areas of Hajrain in Do'an in Hadramout. Usually, these Jawaabi are lined to prevent leakage (figure 17).

The jawaabi are built in different locations, like on the sides of valleys near agricultural land, on mountainous slopes, next to houses. Location varies according to the method used to direct water to the jawaabi.

In the area of Jardan for example, there are three ways of collecting water which are:

1. A jaabiyya (plural: jawaabi) is built near agricultural land. After a plot of agricultural land is immersed in floodwater to the level of field's soum, water is left in the field until all particles suspended in the water such as soil, dirt and sediment settle. Then a conduit is opened and connected to the jaabiyya and clean water flows into it. In this way, this water can be used for irrigation, as well as for human and animal uses.
2. A series of jawaabi are built one after the other on one of slopes. Conduits and simple diverting barriers direct the water towards them. When water in one of the higher jaabiyya overflows, it runs down to the next, and so on. In this way, water is harvested from the mountain slopes.
3. Water is directly carried from the floodwater's course. After the initial passage of the floodwater, when the flow is slower later on in the day or the day after, animals or humans carry the water directly to the jawaabi within their houses. In the area of Hajrain, a small quantity of floodwater is diverted from its natural course to a lower and safe location. After all sediment has settled, water is then transferred into the jawaabi to be used when needed. A household jaabiyya is usually relatively small compared to other types and contains enough water to last 1-3 months according to the number of family members. Today, pumps or water trucks are used to suck up water from the floodwater's natural course and to transfer it to the jawaabi or metal tanks within the houses.

The size of the jawaabi varies. A jaabiyya near agricultural land can be 3-4 meters wide, 8-10 meters long, and 4-6 meters deep. A jaabiyya this size provides for a good number of humans and their animals for about 10 months, depending on how much water is available in their homes. As for the cylindrical jawaabi in Hajrain, the diameter of their opening measures about 3 meters, their depth is 4-5 meters and the diameter of its base is 2-2.5 meters. This structure has been used in valleys, but is not noticed on the plateau.

3-4 The shurooj (Arabic plural of sharj)

These are delimited areas of land that formed in natural depressions. They are formed by the breaking up of local rocks as a result of natural erosion, notably by rain that falls on the area or in its immediate surroundings.

Locals call 'sharj' (plural: shurooj) land that is supplied directly by rainwater, not by floodwater. One study indicates that up to 5% of total agricultural land in southern and eastern governorates is rain-fed. Due to the scarcity of rain in the area, agricultural production is weak. Cultivation focuses on grains that have a short growth cycle, like local variety of sorghum called 'tahf' and millet whose growth cycle is three months for the three first crops. If the cycle is not completed, then the land is used for cattle grazing.

Shurooj are scattered over the area of the Hadramout Plateau due to the scarcity of rainfall, in water-poor valleys like those of Jardan, Arma, and Dahr, and in areas dispersed around the Shabwa governorate to make the best use of rainwater for agriculture.

The sharj is surrounded by a wall facing the surrounding slopes on three sides, and by barbed wire or a similar material on the fourth side to keep the animals out. The wall is made of three or four layers of rocks and is about one meter high. The other aim of the wall is to protect the crops from animals, especially in the more isolated shurooj.

In order to direct water to the shurooj, an opening is made in the wall of the highest plot of land. This opening is the beginning of a water channel. When rainwater runs down the slope that faces a wall, it is intercepted by the wall which directs it to the opening so that it irrigates the first plot of land. An opening is then made at the end of the first field. It is about 1 meter wide, is usually built with rocks bound together by earth, and it is locally called 'mafeedh'. It allows water to transfer to the next plot of lands, which are usually divided into terraces in the natural slope. Thus, water makes its way from the higher plots of land to the lower plots of land, and each plot receives an appropriate quantity of water. This process is repeated every time it rains. The first season of irrigation to the land is called 'khola', the second is called 'zaha', and the third is called 'zahi Al-zahi'. Rain usually falls during the summer and autumn.

For lands located lower down the slope that might not receive water in the case of low rainfall, running water is directed alongside walls and into channels at the end of these walls. If there is no need for this water, then it flows away from the land. In order to direct more water to this land, rows of rocks called 'hibaal' (Arabic plural of habl) are laid down over hundreds of meters on the slopes around the shurooj to direct water to them. As water repeatedly runs along the same path, a natural conduit forms itself and becomes a source of irrigation for these lands.

A number of local customs govern the priorities of irrigation, cultivation, and work on the shurooj. There are recognized rights for obtaining running surface water in the area surrounding the sharj, as well as the size of surfaces and slopes from which water can be collected.

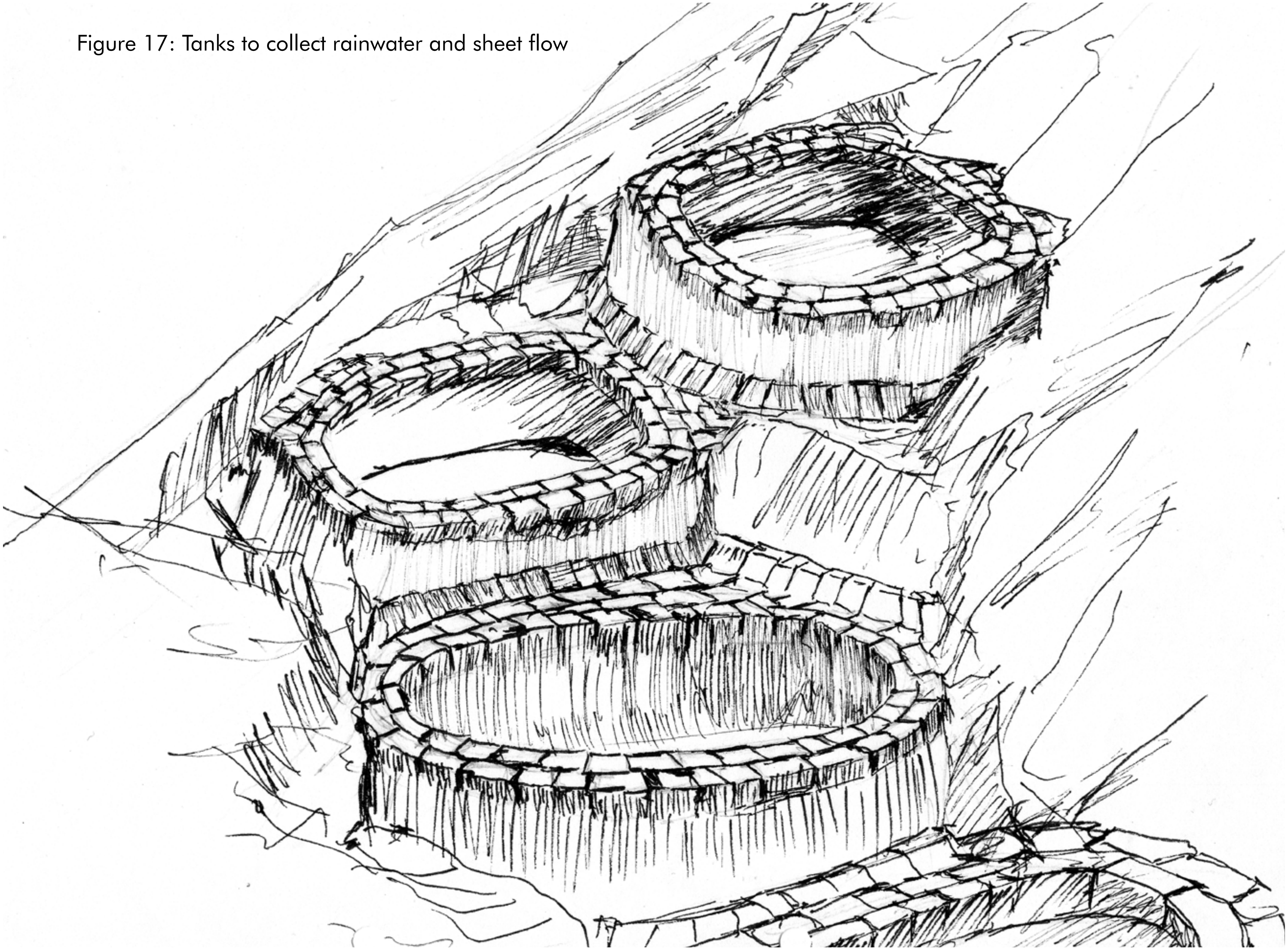


Figure 17: Tanks to collect rainwater and sheet flow

4-1 Environmental aspects of the traditional irrigation systems

Positive aspects of the traditional irrigation systems

Traditional irrigation systems are the product of man's accumulated expertise and effort. In this paper, we have reviewed various types of traditional irrigation including spate irrigation, spring irrigation, irrigation by ma'aayeen, methods of rainwater harvesting, as well as the set of customs that developed to regulate them. We have found that these systems are adapted to the local environment, efficient, and low on material costs, and that they have led to sustainable development in the modern sense of the term. We can summarise these aspects as follows:

Water resource and soil conservation

Certain practices are followed to dig the ma'aayeen irrigation conduits after a survey, planning and setting up structures to control water flow like the the maraadi', the haraath and mawaahid.

- Regular maintenance of the main water conduits is ensured to prevent any leakage or potential blockage, and regular cleaning out of the cracks and natural conduits that feed the water sources.
- Cultivation near the ma'aayeen's water sources is avoided, except for nurseries so as not to damage the water source.
- A fair method is followed to distribute water according to need of the land and firm commitment to prevailing conventions on its distribution.
- Irrigation water is not wasted on long-life plants under an irrigation system. Palms can be irrigated in periods between 45 and 52 days apart, while other crops are irrigated in periods between 10-15 days apart.
- A new ma'aayeen is only allowed to be dug after making sure that it will not cause any damage to the water source of a current ma'aayeen. It is also not allowed to establish new agricultural land at the expense of existing agricultural land.
- In spate irrigation, rules are followed that give priority to the irrigation of certain plants. We mentioned the rule of limiting irrigation to palm trees when floodwater is scarce in valleys.
- Additional irrigation is not allowed for a plot of land when neighbouring land has not yet been irrigated.
- In water harvesting, man has exerted efforts to maintain life by digging naqab water tanks and improve the natural karfaan to collect water in the arid area of the Sitan and especially on the Hadramout Plateau. Local customs help to allocate water from the naqab for drinking only and water from the karfaan for watering cattle and other purposes. The aim is to preserve water for as long as possible. Besides there are large dams that were built on the site of some of the old caravans, a system in which huge tanks provide inhabitants with the necessary water for all household purposes through a network of pipes.

- Around the water source, any activity that leads to its pollution or contamination, like defecating or bathing, is not allowed.
- The water source's good management is ensured by identifying someone to supervise all aspects of the irrigation system. This is the ma'aayeen supervisor in the ma'aayeen system and the khayyal in flood irrigation system.
- The ma'aayeen are benefited from to the maximum as the system is used for all purposes of urban and rural development. This is clear from the water conduits' passage through towns, hamlets, mosques, from its use for ablution, from the delimitation of private areas for women to bathe and wash in and other areas for watering cattle, in addition to the water's main uses in agriculture.
- Extreme care is exercised to benefit from the natural leakage of water through and over the sides of unlined main water conduits, and working to manage smaller water conduits to irrigate existing land and reclame new land. Making the best of the sides of earth channels that are saturated with water by planting some long-life trees like date and coconut palms there.
- Human and animal waste is used, when it is dried out and ground up, as fertiliser to increase the organic content of soil, as are dried sardines and fermented agricultural waste, especially in coastal towns. These natural fertilisers increase the soil's productivity, stimulate the development of micro-organisms (as in terra preta of the Inca culture), get rid of waste, and protect the environment.
- Agricultural soil from non-irrigated land is benefitted from, as it is transferred to areas without soil, thus leading to the reclamation of land that can then be irrigated by any of the methods previously mentioned.
- Due to the widespread use of mud for the construction of houses and other buildings near agricultural land, new customs were established to ensure its use did not harm agricultural land or the irrigation system.
- Protective walls, called madaali' or maasih, were built to protect the soil and irrigation structures along valley banks, and terraces were built on valley slopes to better benefit from available water and to reduce soil being washed away.

The protection of biodiversity

Traditional irrigation systems have had a remarkable effect on cultivation, and have improved man's living standards and stability. This led to the development of a set of customs to manage these systems that where handed down through generations from thousands of years ago until the present.

This human activity on land notable for its dry climate and harsh nature had a positive impact on man's environment as different types of fauna and flora thrived. In fact, man's behaviour within nature of an innate awareness of the importance of maintaining a natural balance and protecting biodiversity.

We can feel the protection of biodiversity through well-known systems like the hamaa system that protects plant coverage. Through this system, shepherds organize grazing according to specific times and close off certain areas so that grasses can grow back again. It was also not allowed to cut down or uproot trees, especially the sidr or Christ's thorn (zizyphus Spinachristi) and misht.

As for wild animals, it is well known that traditions and conventions organised hunting. Specific seasons were determined as was the number of animals allowed to be hunted. Female and baby animals were not allowed to be hunted.

Negative effects of breaking with the customs of traditional irrigation

Ignoring the customs of traditional irrigation during drought and the bad implementation of agricultural reform has had negative impacts on the environment and agriculture. We can summarise these as follows:

In the ma'aayeen system:

1. The maintenance of the cracks in the rock that feed the water source, of the natural courses, and of the main water conduits was ignored, causing the water level at the source to decline and agricultural land to dry up in many areas.
2. Many sons of farmers emigrated which led to many negative impacts including:
3. A decline in production and the size of the plots of land
4. Desertification in many areas
5. Poor land production and an increasing dependence on foreign imports to provide food, which is a continuing economic burden on the country
6. Disappearance of traditional crafts dependent on local raw materials, like weaving and making rope, which has led to wider use of plastic materials with bad impacts on the environment
7. Wastewater from homes and mosques was disposed of into the ground, usually under the limestone layer on which houses had been built. This threatened them with land collapse as the wastewater would eat away at the rock base they were built on, as well as with the possibility of the ground water being polluted, as is the case in Ghail Bawazeer.
8. Less vegetation led wild animals to migrate and to some species to disappear. These are rarely spotted today.

In spate irrigation:

1. The customs for spate irrigation regulate the entire valley system. When structures to protect agricultural land from floods were not maintained because of the migration of landowners and the negligence of those sharing the system, large areas of agricultural land were washed away. The best example is the floods of June 1996 that washed away large areas of land in both Shabwa and Hadramout.
2. Many 'modern' structures were damaged causing land to be washed away because they were not designed according to the traditional way, as in the case of the dhameer of the saqiyya in Qurhat Bahameesh in the Do'an Valley, the dhameer in Muza' next to the town of Shibam in the Hadramout Valley, and some barriers in the Baihan Valley in Shabwa.
3. Horizontal expansion of agricultural lands toward the main course of the valleys which resulted in this water course become narrower and in fertile agricultural soil being washed away.

4-2 Proposals and recommendations

From the above review, we suggest and recommend the following:

1. To hold a workshop with local experts and irrigation specialists to discuss the study's results and to agree on the most important techniques of traditional irrigation as well as how to develop them.
2. To declare that the area of underground water pools in Ghail Bawazeer and the surrounding areas as a protected area, as they containing huge water reserves that supply both the towns of Mukalla and Ghail Bawazeer and their suburbs. Since this area of karst caves is prone to collapses from time to time, any building in the area could cause human disasters and pollute the groundwater.
3. To clear the natural cracks in the land that feed the water sources cracks and natural cleaves in the areas of feeding and protecting them from being clogged up or destroyed by some of the farmers to whom agricultural lands have been distributed in or near these areas.
4. To take the necessary procedures to direct rainwater to these cracks and other natural feeding channels instead of directing them to the sea.
5. To provide the necessary assistance to the owners of ma'aayeen that have been filled with earth but cannot maintain them to benefit from them again.
6. To raise awareness among farmers about the importance of coating exposed irrigation channels with cement to limit water loss and to reduce waste.
7. To conduct studies on groundwater in the area and to identify the links between these water reserves and the neighboring valleys.
8. To encourage and support palm cultivation to quickly save the remaining agricultural land in Ghail Bawazeer from drought and negligence, and to establishing a model farm to protect the more than sixty different types of palms in the area.
9. To take all necessary procedures to protect agricultural land in valleys from being washed away, especially by floodwater, and to deal with valleys as integral systems.
10. To make the balance between traditional and modern methods when building irrigation structures, so as to obtain maximum benefit from local expertise that have proved its efficiency.
11. To benefit from abundant local materials when building irrigation structures.
12. To encouraging the introduction of modern irrigation systems like drip irrigation which has started to attract the attention of farmers in order to limit groundwater depletion.
13. To prevent the expansion of agricultural lands at the expense of the valleys' natural water course, and local authorities should take strict measures in this direction.
14. To document the customs that outline traditional water and land rights, and not to accelerate the implementation of modern water and land laws until careful studies have been conducted and

the benefits of traditions and modern legislation are reviewed.

15. To benefit from excess water that drains into the sea either from floodwater or from valleys rich is water sources, as in the Hajar Valley and in Maseela, and to redirect this water towards improving vegetation in neighbouring areas.

16. To conduct broad field studies on traditional water harvesting techniques and look into expanding and spreading its different applications.

17. To encourage and spread the construction of small and medium dams and barriers to collect water for arid areas.

18. To pay special attention to studying botanical species planted by locals in arid areas, especially grains to identify how well these types are acclimatised to surrounding environmental conditions.

List of appendices

Appendix 1

Irrigation water distribution system based on the changing location of stars and planets

Appendix 2

Table 1: Large ma'aayeen in Ghail Bawazeer (flow rate of 30-110 liter/second)

Table 2: Small ma'aayeen in Ghail Bawazeer (flow rate of less than 30 liter/second)

Table 3: Some of the small ma'aayeen in Ghail Bawazeer

Table 4: Some of the small ma'aayeen in Shaheer

Table 5: Some of the mineral water ma'aayeen in the Eastern Dais, Hami, and Tabaala

Appendix 3

Names of the persons interviewed

Appendix 4

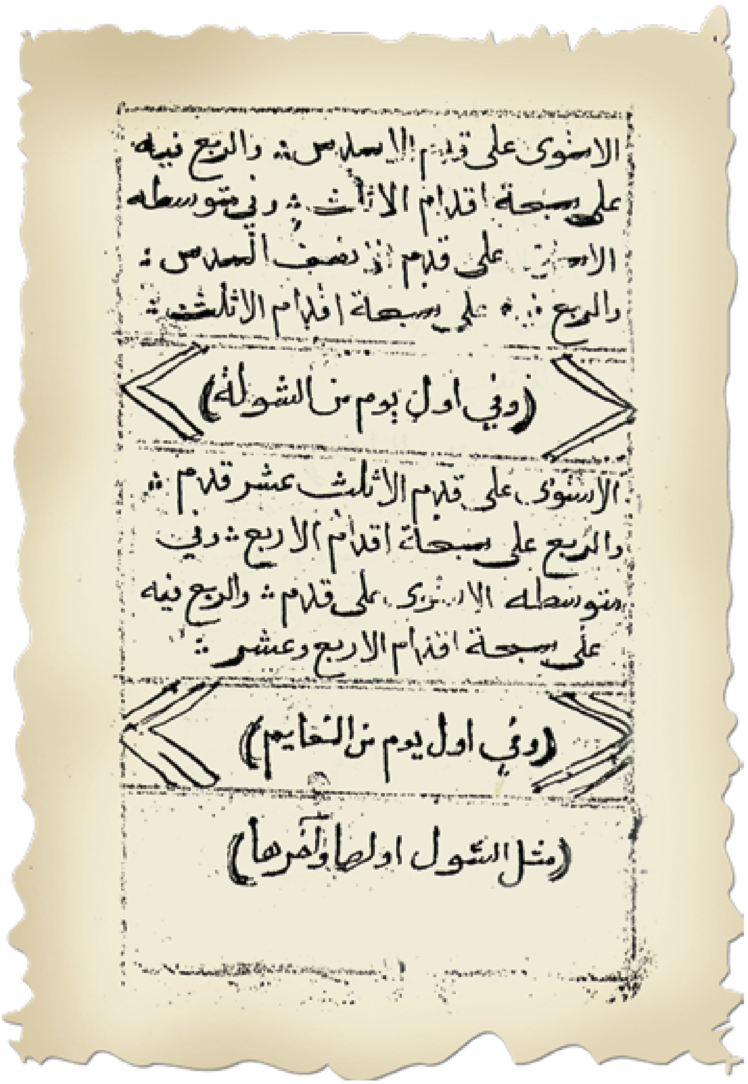
Photographs of the area

Appendix 5

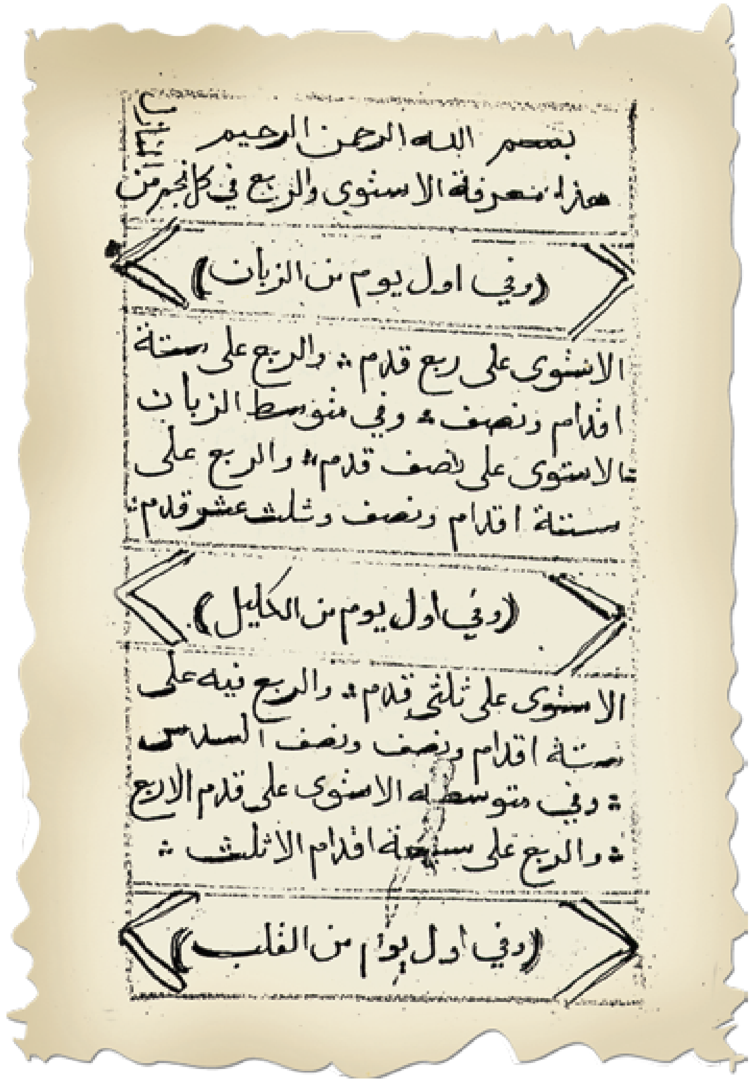
List of the illustrations

Appendix 1

Irrigation water distribution system based on the changing location of stars and planets examples of old documents



الاسنوى على قدام السدس ؛ والربع فيه
على سبعة اقدام الاثلث ؛ وفي متوسطه
الاسنوى على قدام ونصف السدس ؛
والربع فيه على سبعة اقدام الاثلث ؛
(وفي اول يوم من الشولة)
الاسنوى على قدام الاثلث عشر قدام ؛
والربع على سبعة اقدام الاربع ؛ وفي
متوسطه الاسنوى على قدام ؛ والربع فيه
على سبعة اقدام الاربع وعشر ؛
(وفي اول يوم من النعايم)
(مثل الشول اولها وآخرها)



بسم الله الرحمن الرحيم
هذا معرفة الاسنوى والربع في كل نجم من
(وفي اول يوم من الزبان)
الاسنوى على ربع قدام ؛ والربع على ستة
اقدام ونصف ؛ وفي متوسط الزبان
الاسنوى على نصف قدام ؛ والربع على
ستة اقدام ونصف وثلث عشر قدام ؛
(وفي اول يوم من الكليل)
الاسنوى على ثلثي قدام ؛ والربع فيه على
ستة اقدام ونصف ونصف السدس
؛ وفي متوسطه الاسنوى على قدام الاربع
؛ والربع على سبعة اقدام الاثلث ؛
(وفي اول يوم من القلب)

Appendix 2

Table 1

Name of the ma'yaan	Area	
	Qadam	Feddan
Al-Harth (Al-Kaafir)	900	225
Al-Furat	266	66.5
Wadi Surur	198	49.5
Lashol (Ghaleb)	180	45
Al-Sidaa'	192	48
Al-Naqab	110	27.5
Habit Al-Amal	138	34.5
Al-Sheen	104	26
Shaqeeb	138	34.5
Al-Naqa'a	140	35
Al-Zaahir	168	48
Habaayir	180	45
Al-Diwaan	-	-
Al-Makhbiyya*	232	58

Table 1: Large ma'aayeen in Ghail Bawazeer (Flow rate of 30-110 liter/second)

Table 2: Small ma'aayeen in Ghail Bawazeer (Flow rate of less than 30 liter/second)

Source: Statistics of the Ghail Bawazeer Agricultural Cooperative

Table 2

Name of the ma'yaan	Area	
	Qadam	Feddan
Al-Sawali	42	10.5
Ba'oum	32	8
Bakeer	32	8
Kameed	20	5
Bin Qaasim	30	7.5
Bin Sankar	50	12.5
Bin Qahtan	20	5
Bashatah	20	5
Bafateem	20	5
Dhuhaim	20	5
Al-'Akfal	30	7.5
Dhahban	44	11
Sahwat	-	-
Mashour	-	-

Notes:

A qadam or 'qadam turba' is a measurement unit for agricultural land and equals a quarter of feddan.

The area of the ma'yaan refers to cultivated land in the area of the ma'yaan, which varies from one year to the next and does not include the large palm plantations.

* Water from this ma'yaan was diverted for drinking water for towns of Mukalla and Al-Ghail and their outskirts.

Table 3: Some of the small ma'aayeen widespread in Ghail Bawazeer

Name of the ma'yaan	Area	Name of the ma'yaan	Area
Ba'ashen	qadam, or 4-8 1-2 feddan	Bin Shehna	qadam, 4-8 or 1-2 feddan
Bashher		Khalef	
Rabhaan		Haaj Bazaar	
Mohammad Bazaar		Balsa'ar	
Al-Shaib and Mara'aa		'Al-Bida	
Bakeer ((Shaheer		Haadi Mohammed	
Kazeem		Hadira	
Bin Muhrika		Sabakh	
Ahmed Al-Abd Bazaar		Al-Jaawi	
Awd Bazaar		Al-Heeqa	
Salmoun		Al-Tabana	
Al-Hasan		Bahareesh	

Source: Statistics of Ghail Bawazeer Cooperatives

Note:
The stated areas above represent the grown areas only from the Mayean lands. They are changing from one year to another and do not include the large areas related to palm agriculture.

Table 4: Some of the small ma'aayeen in Shaheer

Name of the ma'yaan	Area		Name of the ma'yaan	Area	
	Qadam	Feddan		Qadam	Feddan
Ghaith	12	3	Al-Rawda	15	3.75
Mashhour	17	4.25	Al-Shuaib	14	3.5
Bazaar 1	14	3.5	Ghail Al-Sheikh	16	4
Bazaar 2	16	4	Abdullah Saeed	14	3.5
Baraadim	13	3.25	Al-Saafi	14	3.5
Yahya	10	2.5	Ahmed Mubarak	13	3.25
Khanbiri	14	3.5	Al-Huri	13	3.25
Al-Khalaaqi 1	14	3.5	Al-Dawla	14	3.5
Al-Khalaaqi 2	12	3	Al-Askar	14	3.5
Al-Fardi	12	3	Al-Kharq	13	3.25
Dahdah 1	15	3.75	Al-Matula	12.5	3.12
Dahdah 2	14	3.5	Al-Dhana	14.5	3.5

Source: Statistics of the Ghail Bawazeer Cooperative

Notes:
As there are so many ma'aayeen around the area of Shaheer, most of them have been recorded separately from the others in Ghail Bawazeer.
A qadam or 'qadam turba' is a measurement unit for agricultural land and equals a quarter of feddan.
The area of the ma'yaan refers to cultivated land in the area of the ma'yaan, which varies from one year to the next and does not include the large palm plantations.

Table 5: Some of the therapeutic waters from ma'aayeen in the eastern Dais, Tabaala and Hami

Name of the ma'yaan	Notes
In the eastern Dais	
Al-Saiq	About 500 years old, this is one of the oldest, largest, and most famous of the ma'aayeen. Its water is used in agriculture and for drinking, as well as to cure mild rheumatism and hypertension. Women use its water after delivery. Its main water conduit went from being tunnels to open channels after its two walls collapsed.
Sana'a	One of largest and oldest ma'aayeen, this ma'yaan was destroyed when its walls collapsed and its owners were unable to repair them. Its water is used for agriculture, drinking, and medical purposes.
Swaiber	This is one of small ma'aayeen and famous as providing treatment for skin diseases and intestine worms. It attracts people seeing treatment both from inside Yemen and abroad.
Thawban	This is one of a smaller ma'aayeen and is famous for being good for rheumatism and diabetes.
In Tabaala	
Al-Dula	This is a small ma'yaan. Its water is used for medical purposes as well as drinking after it is collected in settling and cooling pools. This water then used to flow down to the town of Shihr via a traditional conduit. Today, metal pipes have replaced the traditional conduit.
Al-Ramada, Al-Salfi, Al-Dunia Bashaheer, Al-Tajar, Al-Bajar, Bafaleeh	Water from these ma'aayeen is used for its therapeutical properties as well as for drinking and agriculture after it is cooled down in jawaabi. Some of it passes through mosques and near homes for ablution and washing.
In Hami	
Al-Rawda, Bahaami, Bashahri, Baqu'aad, Bubak, Bin Qamri, Sabti, Abeed Salamain, Al-Taahira Bama'aybad, Al-sharqi, Abdallah Saeed, Shandour, Fatah, Abdalhabeeb Hisn, Mukharish	Water from these ma'aayeen is used for its tharapeutic properties, as well as for drinking and agriculture after being cooled off in jawaabi (Arabic plural of jaabiyya) or dug out water tanks.

Appendix 3

Names of persons interviewed:

Shabwa governorate

Name	Occupation
Saleh Habtoor	General director of the Shabwa governorate
Mohammed Aidaroos	Director of the eastern district development project- Mayfah district
Mohammed Faisal	Deputy manager of the Baihan Valley development project
Abdullah Al-Jaish	Head of the department for water resources in the conservation project for land and water (Shabwa unit).
Mohammed Abdullah Al-Fatimi	Agriculture supervisor for the Baihan district
Abdulqader Ahmed Ali Hadi	Head of the irrigation committee in Higher Baihan
Ali Mansour	Agriculture office for Shabwa, accompanied the team in Shabwa
Mohammed Al-Shabli	Deputy manager of the development project for eastern areas
Mohammed Saleh Al-Sulaimai	Teacher of Wadi Jardhan in Amjakheera
Haroun Mohammed Habtour	Overseer for agriculture in Rawda in Wadi Habaan

Name	Occupation
Abdullah Mohammed Habtour	Citizen of Wadi Ghareer
Mustafa Al-Shaibani	General director of the Hadramout governorate
Mohammed Abdusalam Al-Jilani	General director of statistics and planning, Hadramout
Abdulaziz bin Aqeel	General director of antiquities and museums, Hadramout
Saeed Salem Qaheez	Acting general manager, Agriculture Office, Hadramout
Ahmed Saeed Al-Amoodi	Irrigation department, Agriculture Office, Hadramout
Dr. Mohammed Saeed Mur'ee	Irrigation department, Irrigation Office, Hadramout
Muawad [second name missing]	Farmer and supervisor of the Shaqaq saqiyya (irrigation conduit), Hajar Valley
Mansour Salem	Deputy Manager, the Sadara Center
Ali Salem Bamakrama	General manager, General Authority for Water and Sanitation
Saeed Faraj Khanbash	Planning director, General Authority for Water and Sanitation
Yahya Mohammed Ali Yusr	Acting general manager, Yemen Mineral Wealth and Geological Survey Board
Salem Abdullah Al-Khalaqi	Economic department in the executive office, Hadramout, accompanied the research team

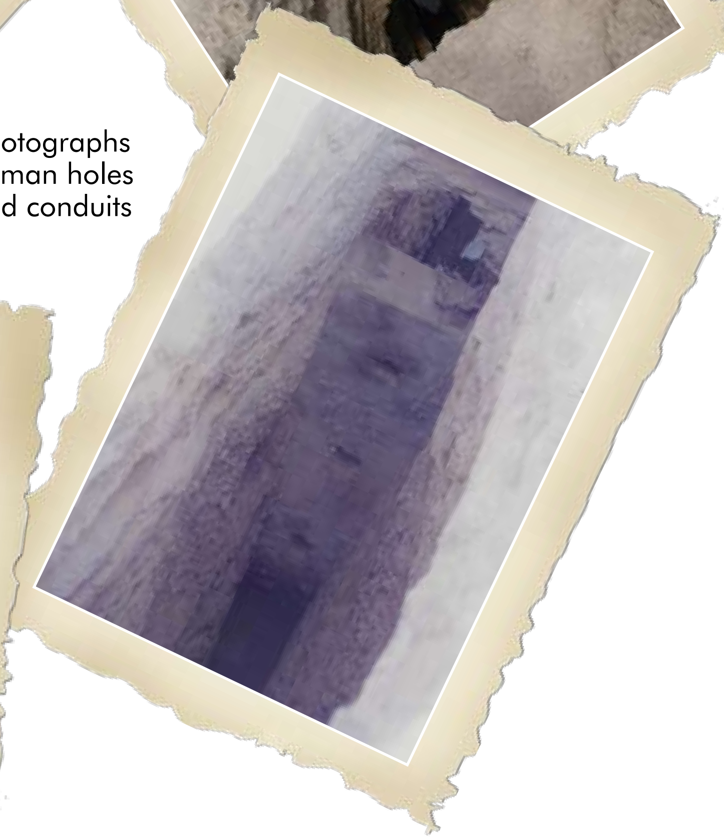
Name	Occupation
Ali Faraj bin Naser	Director of agricultural extension, Ghail Bawazeer
Awad Salem Bahameesh	Local expert in digging ma'aayeen, Ghail Ba Wazeer
Ali Awad Bahameesh	Head of the Ghail Ba Wazeer Cooperative
Saeed Omar Sa'ad Bar'iyya	Teacher and actor on behalf of the supervisor of the Firat ma'yaan
Haj Omar Mohammed Bamakhram	Supervisor of the Sheer ma'yaan in Ghail Bawazeer
Abdulqader Bakhder	Agriculture Office Director, Shehr District
Abdulqader Bin Hayool	Head of the Shihr Farmers' Cooperative
Hassan Bakhawar	Protection department, Agriculture Office, Shihr district
Abdulhameed Bakhder	Agricultural surveyor, Shihr
Junaid Bawazeer	Teacher, eastern Dais, Shihr
Mohammed Awadh Bajub	Farmer from Tabala, Shihr
Awadh Mubarak in Juman	Farmer from Al-Hami, Shihr
Aqeel Ba Abad	Farmer from Haqab, Araf Valley, Shihr
Mohammed Saleh Bahsan	Supervisor of the 'Irsha saqiyya in Wardi Araf, Shihr
Ali Mahdi Mohammed	Citizen, Hajar Valley
Mansour Saleh Barsheed	Farmer, Hajar Valley

Name	Occupation
Saeed Mansoor Barasheed	Farmer, Hajar Valley
Ahmed Krisaan	Director of the Hadramout Valley Development Project
Dr. Mohammed Abdalghani Ismail	Top advisor to the Hadramout Valley Development Project
Hussain Bamakhrama	Director of the Agricultural Research Center, Seyoun
Dr. Saleh Shakhdaara	Irrigation Manager, Hadramout Valley Director.
Isa Alqaf	Irrigation Official, Agriculture Research Center, Seyoun
Salem Al-Khanbashi	Teacher at the Education College in Mukalla, from Wadi Do'an, accompanied the research team to the valley
Mohammed Al-Khanbashi	Expert in building sawaaqi (irrigation channels) in Do'an, village of Al-Jahi
Salem Abood Badhaman	Supervisor of the saqiyya at Al-Hajrain
Haj Abdullah Ba'ashan	Expert in Irrigation affairs, Ba'ashan
Ali Hassan Al Atas	Teacher, Hareeda
Abdullah Salem Bin Sheikh Abu Bakr	Teacher, Sah, Seyoun

Appendix 4

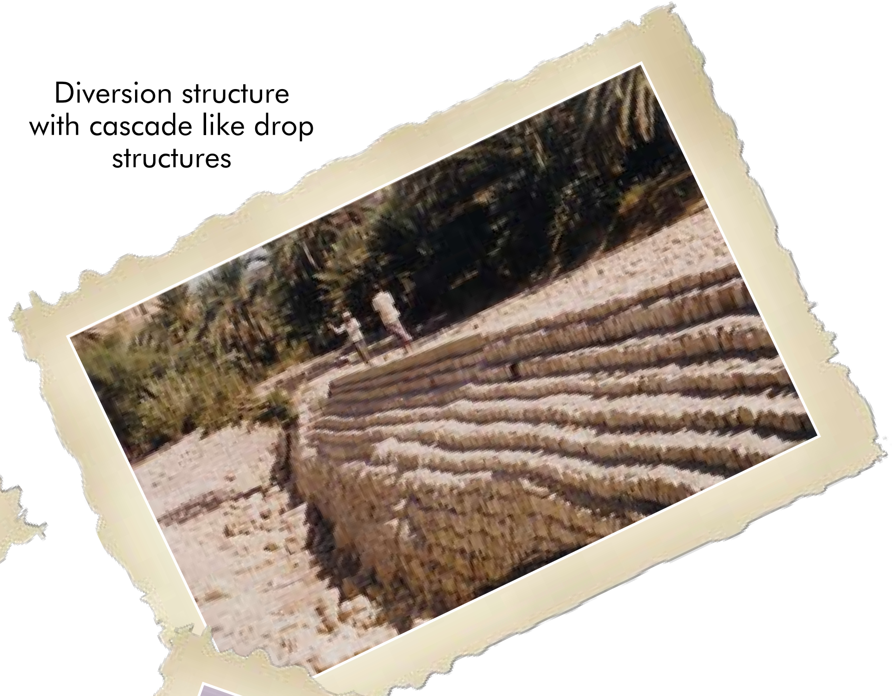
Photographs of the area

Photographs of man holes and conduits

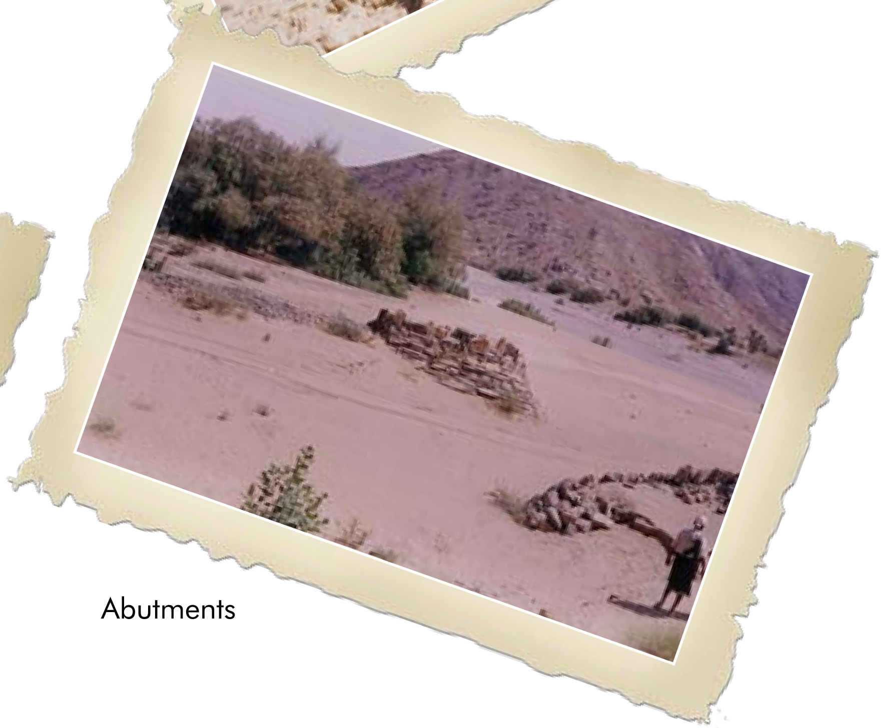


Conical abutment

Diversion structure with cascade like drop structures



Diversion structure



Abutments

Daylight point of the tunnel

Aqueduct

Canals

Appendix 5

List of illustrations

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