

Tracing and Characterising a Historical Rain Water Drainage and Harvesting System Using GIS

Salem M. Ben Qadhi and Abdussalam K. Mohammed
Faculty of Engineering, University of Aden, Yemen

Abstract

The Taweela water tanks probably built by the Himyarites in the first millennium BC are one of the major historical and touristic landmarks of the old Yemeni city of Aden (Crater). This intricate water system is a series of cisterns and waterways carved out of volcanic rock of the Shamsan Mountain surrounding the city. Using GIS and utilizing satellite imagery, elevation grid and old municipal records and maps of the old city of Aden in addition of the personal familiarity of the authors with city and its history it was possible to delineate and characterize the entire basin of the Taweela *wadi* (valley) that drains the major part of the Aden plateau and the city within which these tanks lie. It was found that these tanks are only part of an integrated water system for storm drainage, flood protection, rain water harvesting, groundwater recharge and community entertainment in which advanced hydraulic and hydrologic engineering knowledge and practices were used. A highly sophisticated and well-engineered hydrologic and hydraulic system comprising of multiple drainage sub-basins, multiple surface and subsurface detention ponds, drainage channels and waterways was identified. The advanced hydrologic and hydraulic knowledge of the ancient Adenis could be noted from this marvelous hydraulic engineering works.

Introduction

The old city of Aden is the Crater district of the present day Aden- the economical and commercial capital of Yemen. Crater is the colonial name given to the old Yemeni city of Aden by the British who rules Aden for more than a century (1839-1967). Crater or Aden as referred to it by its natives is a commercial city on the Gulf of Aden. It derives its name from its location inside a great crater of an old inactive volcano, which is opened from one side to the sea. The tiny island of Sirah situated few hundred meters off the shoreline gives the city a great, well-defended natural harbour. This wonderful harbour, in addition to the geographical location of the city as a central station on the trade routes between India and the Middle East, gave the city its glory, prosperity and fame. Aden is considered to be the southern gate of the Red Sea. The Tawila Tanks are one of the major historical and touristic landmarks of the city of Aden and are considered one of the greatest historical engineering feats in South

Arabia. They are located at the head of Tawila Valley in the southwest sector of the Crater district. They were probably built by the Himyarites (ancient south Arabian civilisation) in the first millennium BC with the double purpose of collecting and distributing rain water to the population and protecting the town from the ravages of exceptional floods. Although the rainfall and water resources are very scarce in Aden, the flood water resulting from some rare extreme rainfall events proved to be catastrophic to the city because of the extensive barren rock watershed of city.

This paper presents an attempt to trace, identify and characterise the historical rain water drainage and harvesting system of the historical city of Aden (the present day Crater) using simple GIS approach and tools. It also presents a brief historical description of the historical development of the system

The historical city of Aden

The city of Aden has a history which dates back nearly 3000 years. It was founded by the merchants of Sheba and was the greatest trade centre between the East and the West on the sea trade route between Egypt and India and the land trade route between South Arabia and the Mediterranean.

The historical city of Aden (Crater) is located on a nearly elliptical peninsula of volcanic rock with an area of about 50 km², known as the Aden Peninsula. The city lies in an area formed by an extinct volcanic system capped by a circular mountainous ridge of the Shamsan Mountain. The Aden peninsula is located in the Gulf of Aden on the southern coast of Yemen. It is connected to the main land through a narrow sandy strip of low land resembling a neck known as Ismuth separating the Tawahi bay and the Sailan Bay. The land of Ismuth was used to become submerged at high tide. It was only less than 100 years ago, when the British forces in Aden built earthen dykes along the Khormaksar Creek and reclaimed the Ismuth land where an international airport, a military air base and a residential quarters and shopping areas for the British military personnel were built to form the present day Khormaksar district of present day Aden (See Figure 1)

The old town and its famous ancient harbour were located on the northern slopes of the volcano and opens on the sea for less than 1 km at Sira Bay (Now the Front Bay) (See Figure 2.). Three valleys (*wadis*), Tawila, Khusaf and Aidrus, emerging from the upper Aden Plateau divides the city into three distinct storm drainage basins. The storm water from these valley basins were draining to the sea the Front Bay through three natural drainage channels. Figure (2) below shows general view of the present day city of Aden (Crater) along with its three wadis system

The old city of Aden was limited only to the area between the Holkat Hill in the South and The Tawila drainage channel in the North (Shihab, 2006). The upper area of Aidrus valley also was not inhabited. The shore line of the old Sira Bay (present Front Bay) was not the same as the present day Front Bay shore line. The whole Front Bay Area of the present city was part of the sea and the old harbour coast. This area was reclaimed in the forties of the 19th century after the British occupation of the city in 1839 (Shihab, 2006).

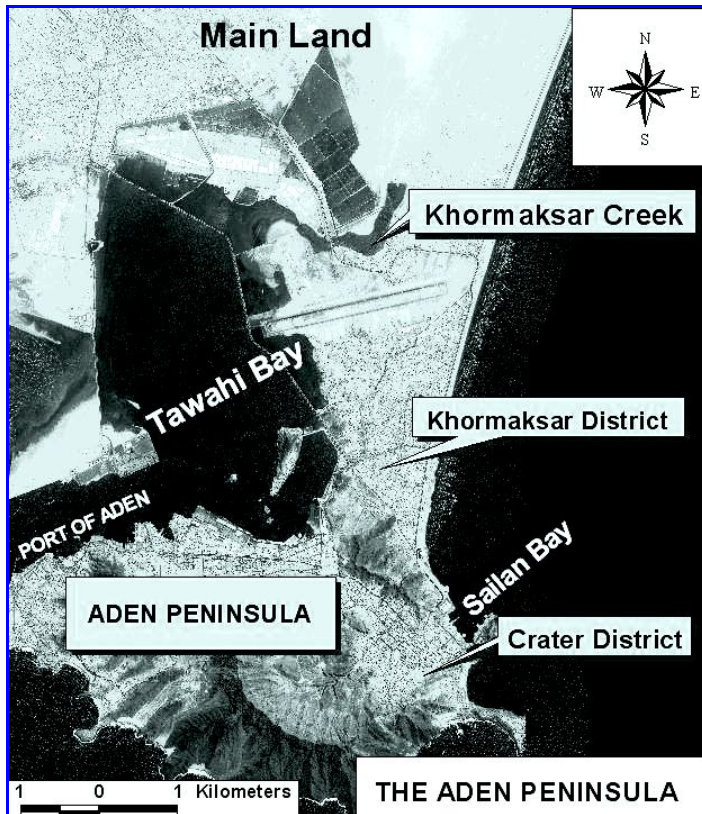


Figure (1) The Aden Peninsula



Figure (2) General view of present city of Aden and its wadis

The British developed the Front Bay area after they had constructed a new harbour at Tawahi Bay, which is the present day Port of Aden. Figure (3) shows the location and extent of the old city of Aden and the location its old

port and Figure (4) shows an old photograph of the city taken in the eighties of the 19th century. The lower reach of the Tawila drainage channel approaching the Front Bay can be seen in the front of photograph. The limits of the city between the Tawila drainage channel and the Holkat Hill can also be identified from this photograph.

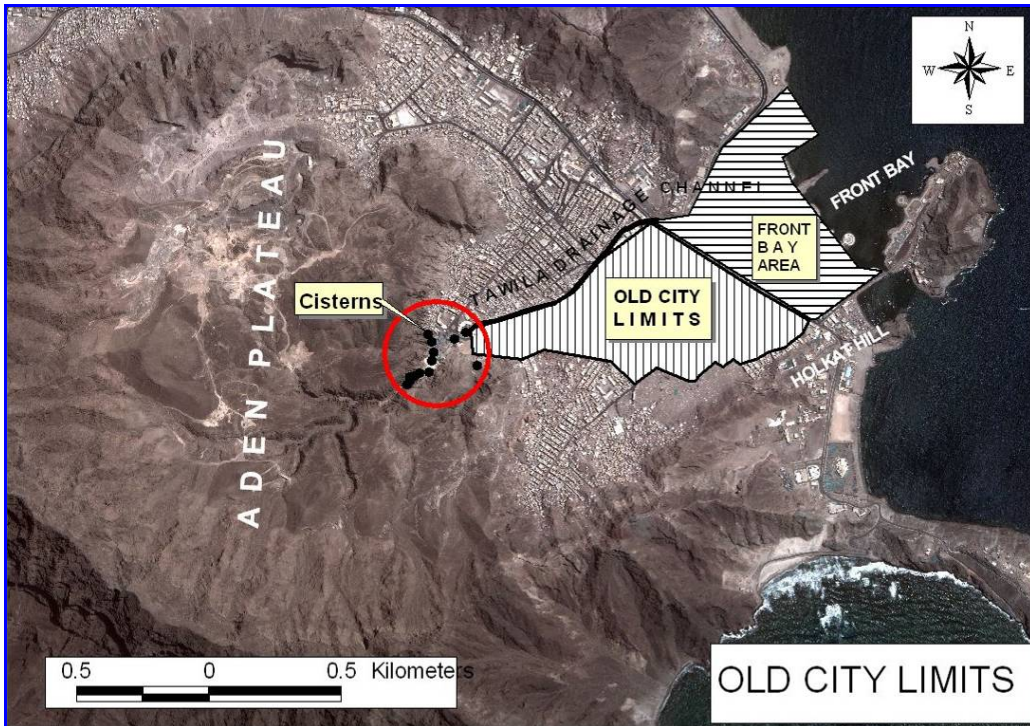


Figure (3) The old city limits

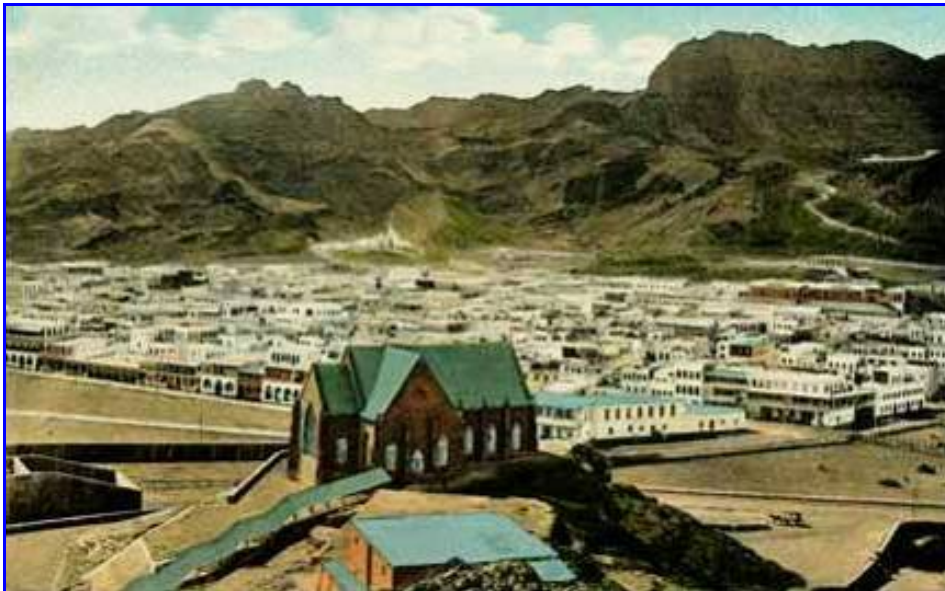


Figure (4) An old photograph of the city with the St. Mary's church in the front.

Storm drainage and harvesting system of the city of Aden

The historical storm water drainage and harvesting system has developed over a long period of time. The old system of the historical city is widely believed to be originated by the Himyarites who developed a great civilization in south Arabia between 115 BC and 500 A.D. At some unknown

point of time the system was completely buried, filled with stones and soil washed down from the mountain slopes by the rains. The System was discovered by the British who occupied Aden in 1939. The British in their attempt to restore the old system has changed it significantly. A brief description the old historical drainage and harvesting system and the British modified system is given in the following sections.

The historical Tawila Cisterns

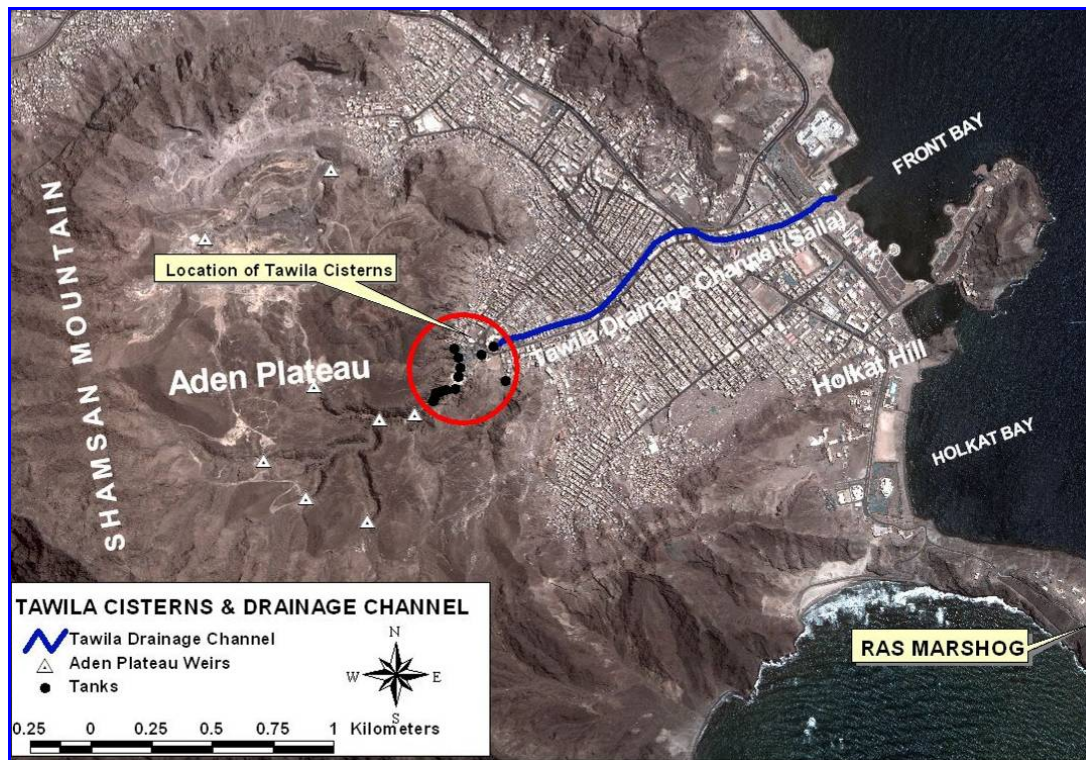
The Tawila Tanks, also known as 'Aden Tanks', the 'Cisterns', 'Queen of Sheba Tanks' or 'Solomon's Tanks', are located at the head of Tawila Valley (Wadi Tawila) in the southwest sector of Crater. They are considered one of the greatest historical engineering feats in South Arabia. The Cisterns of Tawila, or the Tawila Tanks, are the best-known historic site in the Yemeni city of Aden. This intricate water system is a series of cascading cisterns of varying shape and capacity and waterways carved out of volcanic rock. Originally there were about 53 tanks, (Norris & Penhey, 1953) but only 13 remain following a succession of renovations, including those done by the British in the 19th century. The existing tanks have a combined capacity of about nineteen million gallons. The system of tanks were built with the double purpose of collecting and distributing rain water to the population and protecting the city from the ravages of exceptional floods by ensuring a safe drainage of the storm water generated from the large barren rocks catchment of the Aden Plateau.

The tanks were excavated out of the volcanic rocks of Wadi Tawila and then lined with special stucco that included volcanic ash to create strong, natural cement that rendered the tanks' walls impermeable in order to retain water for extended periods of time.

It is not known when or by whom these tanks were built. Some attribute their construction to the Himyarites, and date them back to 1500 BC. Others believe that they were built by the Persians during their second invasion of Yemen in 600 AD (Kour, 1981). The Tanks were mentioned in some manuscripts after the coming of Islam to Yemen in the 7th century (Al-Akwa, 1983). There is indeed little hard evidence and there are few reliable sources of information about the Tanks. It is widely believed that the Tawila Cisterns are of Himyaritic origin but many successive innovations were introduced to the system at different times of the city history. However, at some unknown point in time the Tawila Cisterns became completely buried, filled with stones and soil washed down from the mountain slopes by the rains. Figure (5) shows the location of the Cisterns and recent photograph of the Cisterns

The British modification of the system

By the time of the British occupation of Aden (beginning in 1839), the Tanks had been almost completely buried by debris carried down the mountains by successive floods.



a)



b)

Figure (5) a) Location of the Cisterns b) A recent photograph of the Cisterns

They were discovered accidentally by Lieutenant R. L. Playfair, the British Assistant Resident in Aden in 1854. However, the British Commander Haines who occupied Aden in 1839 was aware of the Cisterns when he visited Aden in 1835 whilst surveying the South Arabian coast (Norris, and Penhey, 1953) Sir Robert L. Playfair rediscovered the tanks and recognized their potential value. Aden had no fresh water and was often cut off from mainland water supplies by hostile tribes. Playfair hoped that the Tanks, once repaired, could provide a reliable source of water for the British military and public consumption. At that time the British thinking was restricted to repairing the Cisterns for the purpose of storing storm water. It is not known whether they did not understand the original purpose of the system i.e., storm water drainage management, or they did know but their priority was ensuring a sufficient

storage of water to meet their military needs. The British did not restore the tanks to their original function. They modified the design and layout of the Tanks significantly from their original state. With the intention of storing the greatest quantity of water possible, British engineers replaced an intricate network of numerous, small, cascading cisterns along the valley walls with a few, larger tanks. The Tanks' ability to both control floods and store water was thus hampered.

The restoration of these magnificent public works commenced in 1856 and on 23rd October 1857 the tanks which had been cleared were filled with rainwater for the first time since restoration. The lower circular tank, named Playfair Tank after R. L. Playfair, the British Assistant Resident in Aden in the fifties of the 19th century, is the largest among the Tanks. Similarly the second largest Tank, the rectangular one at the centre of the site was also named Coghlan after the British Resident in Aden at that Time. Figure (6) below shows an old photograph for the Tawila Cisterns site with the Playfair Tank at the centre of the first photograph and the Coghlan Tank at the end of the of the main water course connecting the Tanks in the second.

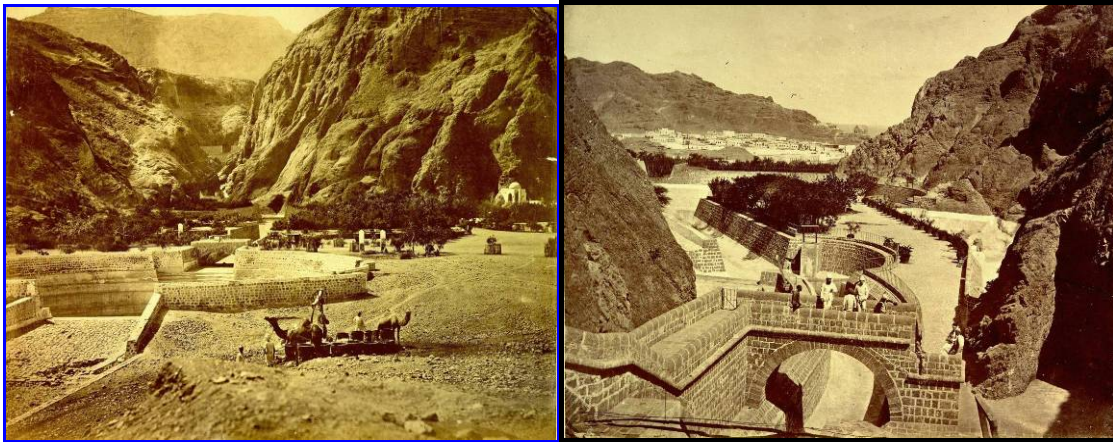


Figure (6) a) Tawila Valley circa 1880 with Playfair Tank in foreground.
b) The main water course connecting the tanks

After the clear failure of the restored system to control the floods, the British then realised the original function of the Cisterns as storm water drainage and harvesting system. To rectify the mistake, they had committed, they decided to create detention basins in the upper catchment area of the Tawila Valley by building weirs across the natural narrow rocky drainage channels of the various drainage basins of Aden Plateau upstream their junction points with the main Tawila Valley. In the seventies of the 19th century they built six such weirs in the Tawila valley catchment (T1, T2, T3, T4, T5 and T6) and two in the Khusaf Valley catchment (K1 and K2). Figure (7) below shows the location of the weirs of the Aden plateau

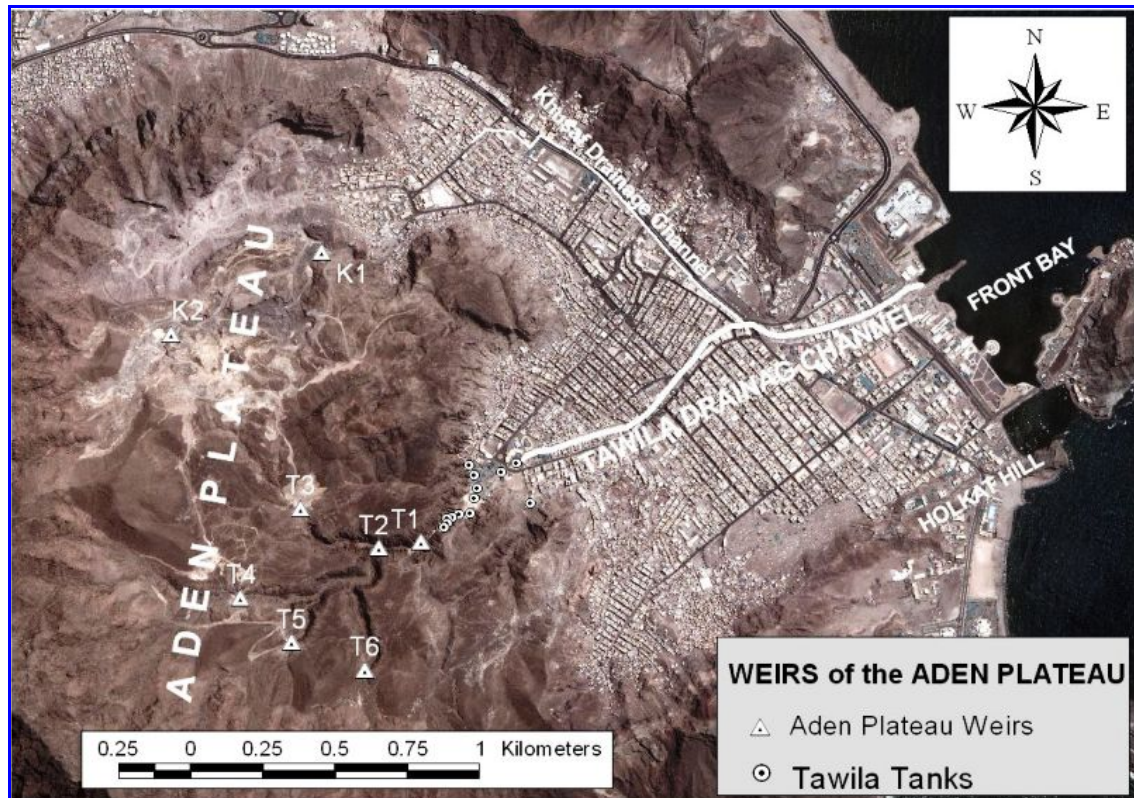


Figure (7) Aden Plateau Weirs

Tracing and characterizing the crater drainage system

The historical city of Aden-the present day Crater-has developed since olden times a very efficient, sophisticated and perfectly engineered storm water detention and drainage system. The crater watershed comprises the whole area of the Aden Plateau (Crater Plateau) and the entire urban areas of the city. The resulting storm water flows through three distinct natural drainage channels, namely, the Khusaf, Tawila and Aidrus (Qati') wadis towards the sea to discharge at a single outlet location at the Front Bay (Othman, 1996).

Geographical Information System (GIS) provides a cost effective and practical approach to delineate and estimate the physiographical characteristics of watersheds. For the purpose of the Crater watershed delineation and characterisation a 60-cm resolution satellite image of the Crater watershed and a 5-m interval satellite interpreted digital contour map available at the Local Water and Sanitation Corporation of the city of Aden (LWSCA) have acquired. Old maps of the storm water drains available at the Crater Municipality have also been collected, digitized and geo-referenced in standard UTM coordination to produce various ESRI shape files of the storm drainage elements. Some old photographs of the city and the Cisterns were also collected to asses identifying old status of the city. ESRI ArcView3.3 software was used to process and compile the database, to obtain the various watershed parameters needed for watershed modelling or runoff estimation.

A TIN surface of the watershed was generated. Using this TIN surface and the high resolution satellite imagery in addition to the field verification, the Crater watershed could be delineated at accuracy sufficient for hydrological modelling of the watershed.

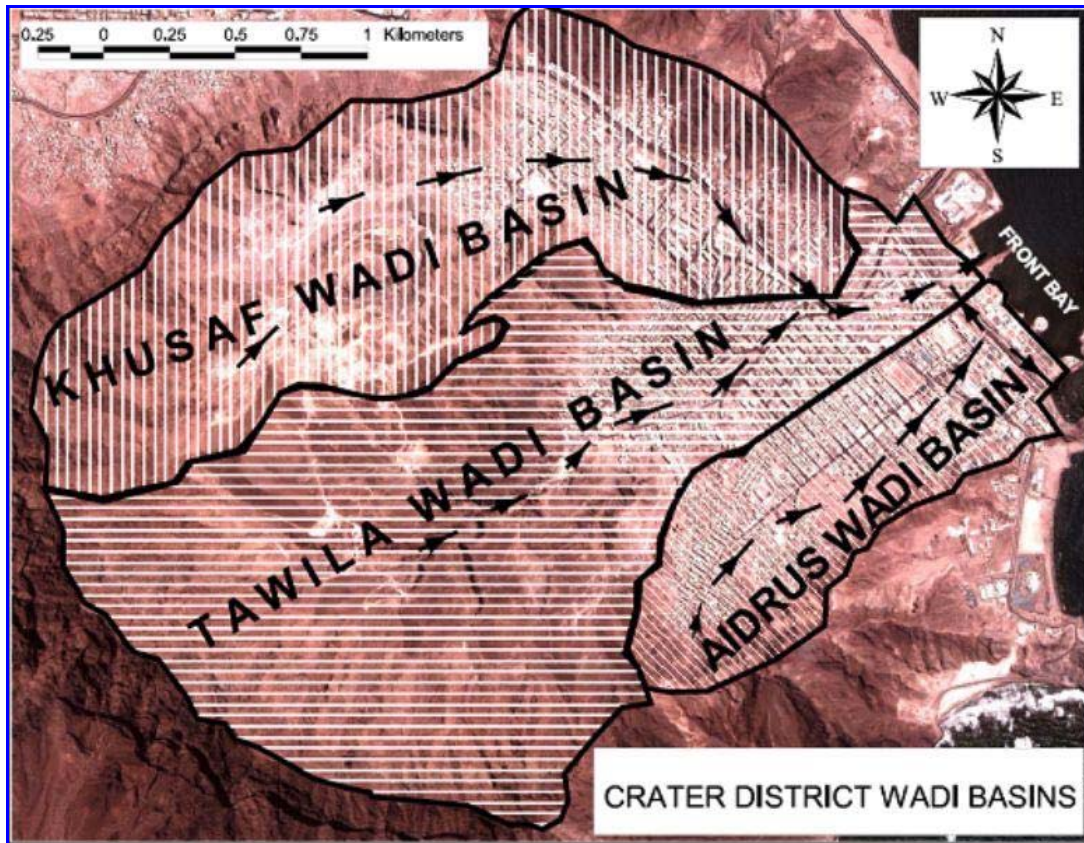


Figure (8) Three Wadi System of the Crater Watershed

The sub-basins of each drainage valley system were delineated and physiographically characterised. Figure (9) below shows the delineation of the Crater watershed. The sub-basins of the Khusaf wadi basin have been labelled K1, K2, and K3. The Tawila sub-basins have been labelled T1, T2, T3, T4, T5, T6, T7, T8 and T9, and those of the Aidrus basin have been labelled A1 and A2.

Areas and perimeters of the various basins and sub-basins have been computed. Average slope and Flow length for each sub-basin has also been determined. Table (1) below gives the physiographic characters of the watershed.

Tawila Drainage Subsystem

The Tawila wadi is the largest wadi basin in the crater watershed. The storm water generated in the upper Tawila sub-basins (T1, T2, T3, T4, T5, T6 and T7) discharged into the ancient Tawila Cisterns system located in Sub-basin T8. The Cistern system serves as flood detention and rain water harvesting facility. It helps ensuring safe disposal of the combined storm flow from the large barren rock upper Tawila catchment and the storm water flow from the urban area in the lower drainage sub-basin T8 through the Tawila drainage Channel. It also provides reserve storage of drinking water used for irrigation and entertainment requirements of the Tawila Garden Park located in the Cisterns site and in emergency cases.

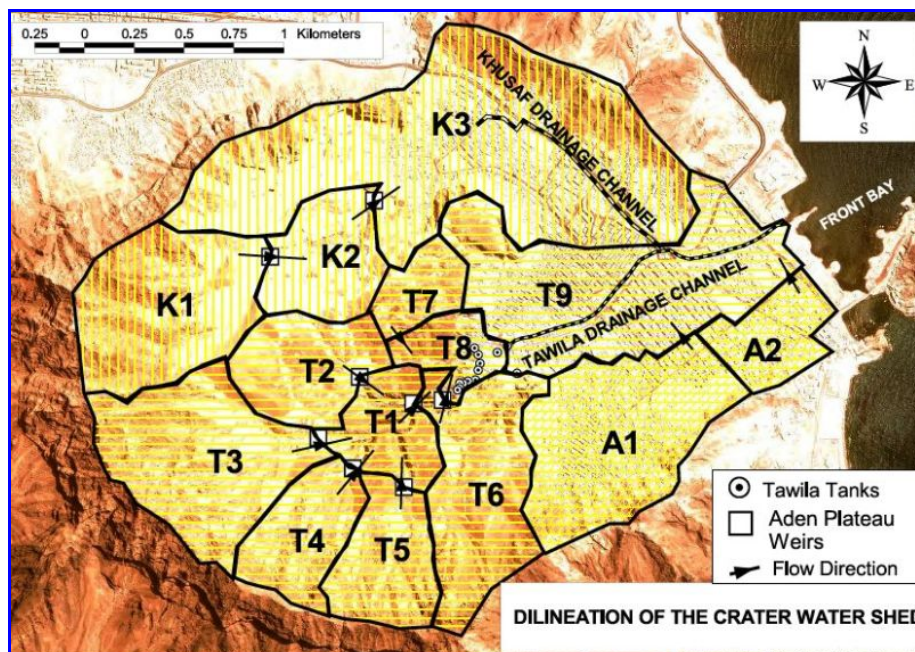


Figure (9) Identified Sub-basins of the Three Wadis Drainage System of the Crater City

The Tawila Cisterns system was inspected. The existing 13 tanks of the system were identified and located using global positioning systems and high resolution satellite imagery of the area. Their capacities were measured. Figure (11) below shows location map of the system of the Tawila Cisterns ,and Table (2) gives the present capacities of the existing tanks of the system.

Table (1) Geometric and Physiographic Characteristics of the Watershed

Wadi Basin	Sub-Basin	Area (Ha)	Perimeter (m)	Flow Length (m)	Av. Slope	Surface Type
TAWILA	T1	24.1	2163.4	460	0.31	Barren Rock
	T2	34.2	2374.2	650	0.02	Barren Rock
	T3	69.2	3776.3	970	0.32	Barren Rock
	T4	29.7	2330.1	730	0.40	Barren Rock
	T5	32.0	2383.9	700	0.33	Barren Rock
	T6	55.5	4172.3	980	0.23	Barren Rock
	T7	48.4	1660.6	370	0.67	Barren Rock
	T8	15.8	1917.0	590	0.24	Barren Rock
	T9	97.6	5583.4	1500	0.02	Urban area
Basin Total		406.5				
KHUSAF	K1	64.1	3178.6	1200	0.23	Barren Rock
	K2	48.4	2368.0	900	0.06	Barren rock & crushed stones
	K3	176.3	7335.9	2450	0.04	Urban Area
Basin Total		288.8				
AIDRUS	A1	73.5	3722.3	1300	0.12	Urban Area
	A2	22.9	2154.4	410	0.01	Urban Area
Basin Total		96.4				
Entire Watershed		791.8				

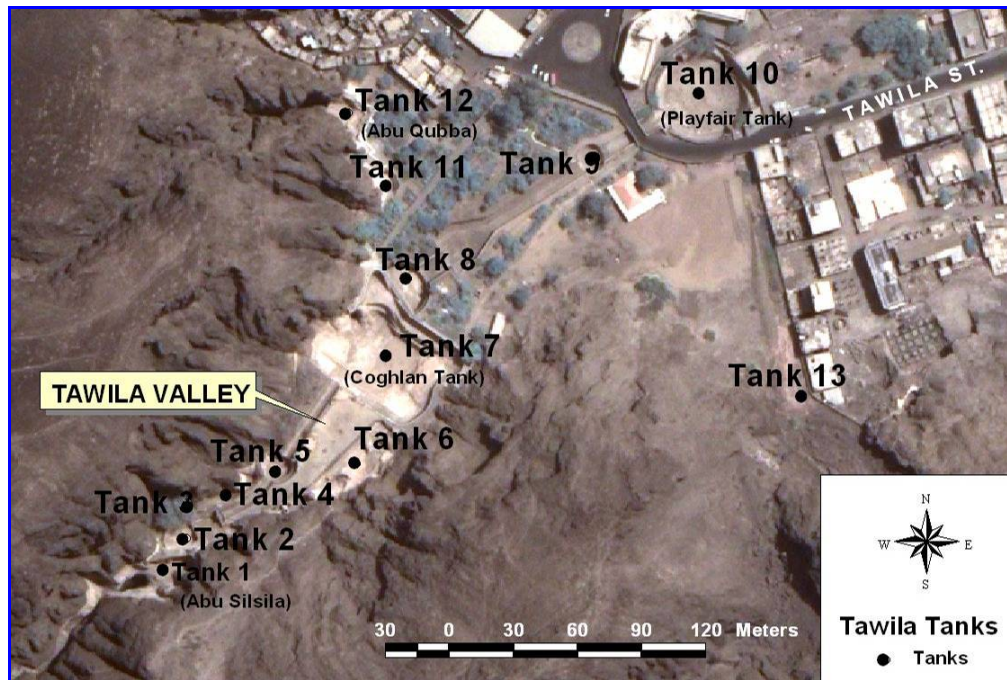


Figure (10) Location Map of Tawila Tanks

TABLE (2) existing Tawila Tanks and Their Capacities

Sl. No.	Tank Designation (Name)	(Capacity m ³)
1	Tank1 (<i>Abu Silsila Tank</i>)	3700
2	Tank2	700
3	Tank3	200
4	Tank4	800
5	Tank5	400
6	Tank6	1000
7	Tank7 (<i>Coghlan Tank</i>)	18000
8	Tank8	800
9	Tank9	400
10	Tank10 (<i>Playfair Tank</i>)	14500
11	Tank11	500
12	Tank12 (<i>Abu Qubba</i>)	800
13	Tank13	200
	Total	42000

The Tawila drainage channel were also traced and located in the GIS environment. It extends from Tank 10 (Playfair Tank) of the Tawila Cisterns system (See Figure 11 above) to the discharge outlet to the sea at the front Bay. The lower reach of the Tawila channel beyond the bank intersection is known as *Saila* It receives the combined storm flow from all the drainage channels and discharges at the Front Bay outlet. The layout of the Tawila drainage channel can be seen in Figure (11).

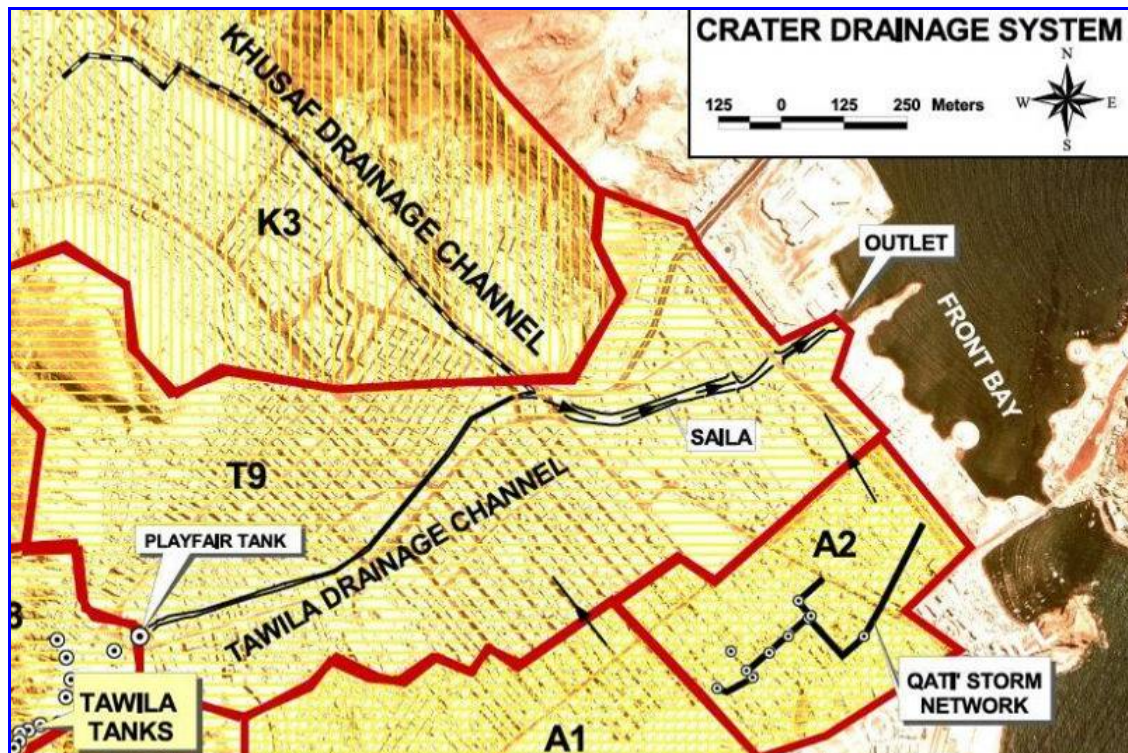


Figure (11) Tawila Channel, Crater Main Storm Drainage Channel

Khusaf Drainage Sub-System

The Khusaf basin comprises three drainage sub-basins K1, K2 and K3. The upper Sub-basin K1 discharges into the next sub-basin K2 which in turn discharges into the lower sub-basin K3. Sub-basin K3 discharges into the Khusaf Drainage channel running within its lower part to join the Tawila drainage channel. The combined flow continue flowing through Saila (Lower reach of Tawila Channel) to reach the discharge outlet at the Front Bay. The layout of the Khusaf drainage Channel can be seen in Figure (11) above.

Aidrus Drainage Sub-System

Historically the Aidrus valley was a natural drainage area with its lower natural drainage course extends to the sea. The urban development in the Lower Aidrus wadi (Qati' Neighbourhood) started after the British occupation of Aden. It occupied the natural drainage course of the valley to the sea. Hence a storm water drainage pipe network was built to collect the storm water from the Qati' neighbourhood and convey it to the sea at the Front Bay. Presently the lower segment of the network within the Front Bay area are out of service due to unplanned urban development and negligence of the municipal authorities. The Aidrus main road was built also inside the drainage course of the upper Aidrus wadi. Development of the Aidrus residential area started around the end of the 18th century. This area is a public residential area and a considerable unplanned urban expansion has been going for decades. Presently the storm water from the upper Aidrus Area flows along the Aidrus Road to join the Tawila Drainage Channel. The Lower Aidrus (Qati') Area storm water flows partly through the Qati' storm drainage network and partly through the streets and eventually joins the lower reach of Tawila channel. Small portion flows

directly to the sea. The Aidrus basin consists of two drainage sub-basins A1 and A2. All of them discharge through the lower part of the Tawila T9 sub-basin to the Tawila Channel lower reach or Saila. The layout of the Qati' storm drainage network can be seen in Figure (11)

Conclusions

GIS and remote sensing provide an attractive and affordable option for watershed delineation and characterization. It offers an accurate, convenient, less costly and efficient solution to governmental, municipal and environmental monitoring agencies dealing with urban storm water management. Efficient integration of various data sources available enable small-budget agencies to construct sophisticated watershed models replicating accurately the existing or the future conditions in watersheds under their management or supervision. The historical Tawila system is an efficient drainage and harvesting system which should be studied thoroughly by the city municipal agencies. They are a marvellous engineering achievement in the history of storm drainage management.

References

- Norris, H.T. and F.W. Benney, 1953, *An Archeological Historical Survey of the Aden Tanks*, Hodgson & Sons, London, England.
- Zaki, M. O., Rehabilitation of Tawila Water Tanks, Aden, System Hydraulics and Storm water Drainage. Project document, UNECSCO/UNDP & GOPHCY, 1996.
- Al Akwa', h., A., Al Hasan Bin Ahmed Al Hamadani-Sifat Jazirat Al Arab (in Arabic), Beirut, 1983
- Shihab, S. H., Aden The Port of Yemen.(in Arabic), Shara'abi Printing & Publishing House, Sana'a, Yemen, 2006.
- Khor, Z. H. , The History of Aden, 1839-72, Taylor & Francis publishers, London, 1981