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6 Delineation and Characterisation of the Crater Watershed Using GIS

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Abstract

The Geographical Information System GIS have been utilized to delineate and characterize the watershed of the historical city of Crater (Aden). Satellite imagery, remote sensing digital elevation data, and available old maps of storm water system have been combined together to produce a physiographic definition of the watershed in a form ready for integration with the hydrological characterization to construct a numerical watershed model that can be used to estimate the storm runoff volume and hydrograph at any location in the watershed.. This paper also highlights the ancient advanced hydrological knowledge and sophisticated flood training, detention and storage engineering works present in the Aden historical drainage system.

Keywords: Watershed, Modelling, GIS, Storm Drainage, Hydrology

الملخص

تم استخدام نظام المعلومات الجغرافية GIS لتعيين حدود و معالم الحوض المائي لمدينة كريتر (عدن) التاريخية. حيث تم الجمع بين التصوير الفضائي والاستشعار عن بعد وما توفر من الخرائط القديمة لنظام تصريف مياه الأمطار, للحصول على تعريف فيزيوغرافي للحوض المائي في صورة جاهزة للتكامل مع التعريف الهيدرولوجي للحوض لإنشاء نموذج حوض مائي رقمي Digital Watershed Model يمكن استخدامه لتقدير حجم الجريان السطحي وتحديد منحنيات التدفق الزمنية Hydrographs لأي موقع في الحوض. كما أن هذه الورقة تبرز مدى تقدم المعرفة الهيدرولوجية عند قدماء العدنيين و قدرتهم على تنفيذ أعمال تصريف و حجز وخزن مياه المطر البالغة التعقيد.

1. INTRODUCTION

Over the last three decades, a number of computer based hydrologic simulation models have been developed to simulate the rainfall-runoff processes. Singh and Woolhiser [2002] provide a comprehensive list and discussion of the numerous models available. Physically-based hydrologic models are based on an understanding of the physics of the hydrologic processes that control watershed response by accounting for all runoff components and emphasizing an over-all moisture balance within the basin [Nicklow et al., 2004].

Earlier, such models were considered to be too computationally and data intensive to use for projects other than major research undertakings or large-fund projects. However with the present advancement in geographical information systems (GIS), remote

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sensing and satellite imagery and computational capabilities of personal computers, physically-based models have become the standard tool of watershed or basin management. Input data required by such models could be easily obtained from satellite imagery and remote sensing as will as traditional database and engineering drawings using standard GIS software like the Environmental Simulation and Research Institute (ESRI) ArcGIS® or ArcView. Most of the models nowadays are GIS enabled or can be integrated with GIS software which facilitates input data and output results management.

Some of the more commonly used hydrologic simulation models are the Hydrologic Modelling System (HEC-HMS) of the US Army Corps of Engineers Hydrologic Engineering Center (HEC, 2000), the Storm Water Management Model (SWMM) of the US Environmental Protection Agency [Hubert & Dickenson, 1988], The Kinematic Runoff and Erosion Model (KINEROS) [Woolhiser et al.,1990] and the National Resources Conservation Center (NRCS) (formerly Soil Conservation Service, SCS) of the US Department of Agriculture Urban Hydrology for Small Watershed TR-55 (SCS,1986) and TR-20 Computer Model for Project Formulation (SCS, 1965).
The major challenge in using such models the availability of the huge input data requirement for delineation and characterization of the water shed to be simulated. Conventional methods of watershed delineation and characterization are costly and time consuming. Use of the emerging trends of watershed delineation and characterization through the use of GIS, remote sensing and computer aided drafting systems proofed to be an optimal option for limited budget storm water management agencies, especially in remote areas and in areas where no hydrologic or physiographic data records are available. The present work introduces an example of applying such methods to delineate and characterize the watershed and the historical storm drainage system of the city Crater (Aden).

2. THE STUDY AREA

Crater is the colonial name of the old Yemeni city of Aden. 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. Figure (1) shows a general view of the crater district.

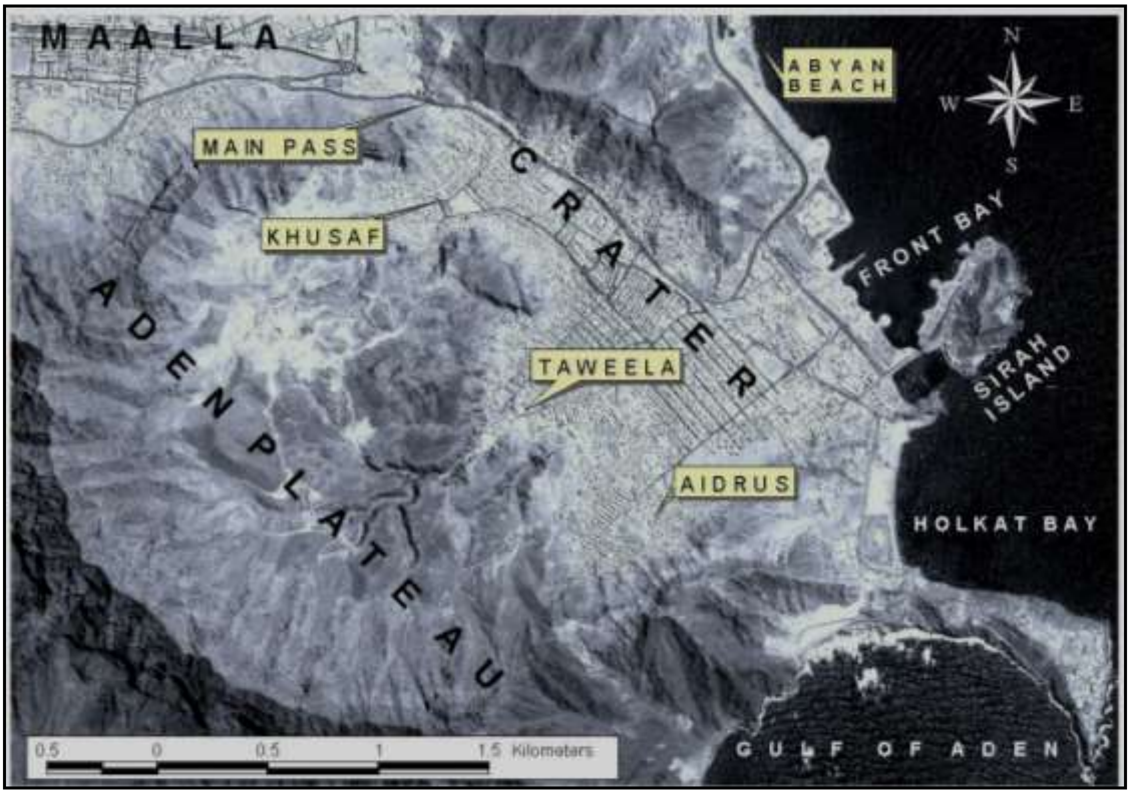

Fig. (1). General View of the Crater District

The rainfall and water resources are very scarce. Nevertheless the flood water resulting from some rare extreme rainfall events proofed to be catastrophic to the city. The extensive watershed of Crater comprises the entire Crater Plateau and the urban areas. Generated storm water drains to the sea through three wadis traversing the city and discharge at a single outlet location at the Front Bay. The uncontrolled urban expansion and the great value for lands in this commercial district led to the encroachment of building into the storm channel areas, creating many bottlenecks in the storm water routes. This bottle necks poses a great risk of flooding to the high value estates and commercial commodities in the adjoining areas. The first step towards a comprehensive storm water management in this commercial and historical district is the delineation and characterization of its watershed, as will as the identification of the existing and potential bottle necks in the storm water routes. This paper presents an attempt to delineate and characterize the crater watershed and to identify the existing problems and bottle necks related to the storm water drainage. Satellite imagery of the crater district has been acquired along with a remote sensing digital elevation data. The digital elevation data have been used to produce a 5-m contour map for the district. Some old maps of crater storm water drainage available at the Crater District Municipality have been digitized, geo-referenced and incorporated into the GIS database.

3. THE CRATER STORM DRAINAGE

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 system consists of multiple reservoir-channel system comprising both surface detention / infiltration basins and subsurface storage ponds [Norris and Penney, 1953]. The storm water system is the number one tourist attraction of the district. It is popularly referred to as 'the Aden Cisterns' or 'Taweela Cisterns'. Ancient Adenis construct this magnificent engineering works to protect their prosperous city from flooding caused by the runoff from the extensive, mostly barren rock, catchment in response to extreme rainfall events and to utilize the water stored in subsurface ponds as a drinking water source for the city inhabitants. 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, Taweela and Aidrus (Qati') wadis towards the sea to discharge at a single outlet location at the Front Bay [Ali, 1997]. Within the main business and commercial areas of the city the storm water from the wadis is conveyed to the out let through storm drainage channel system. The 5-m contour map of satellite interpreted level data of Crater watershed is shown in Fig. (2) below.

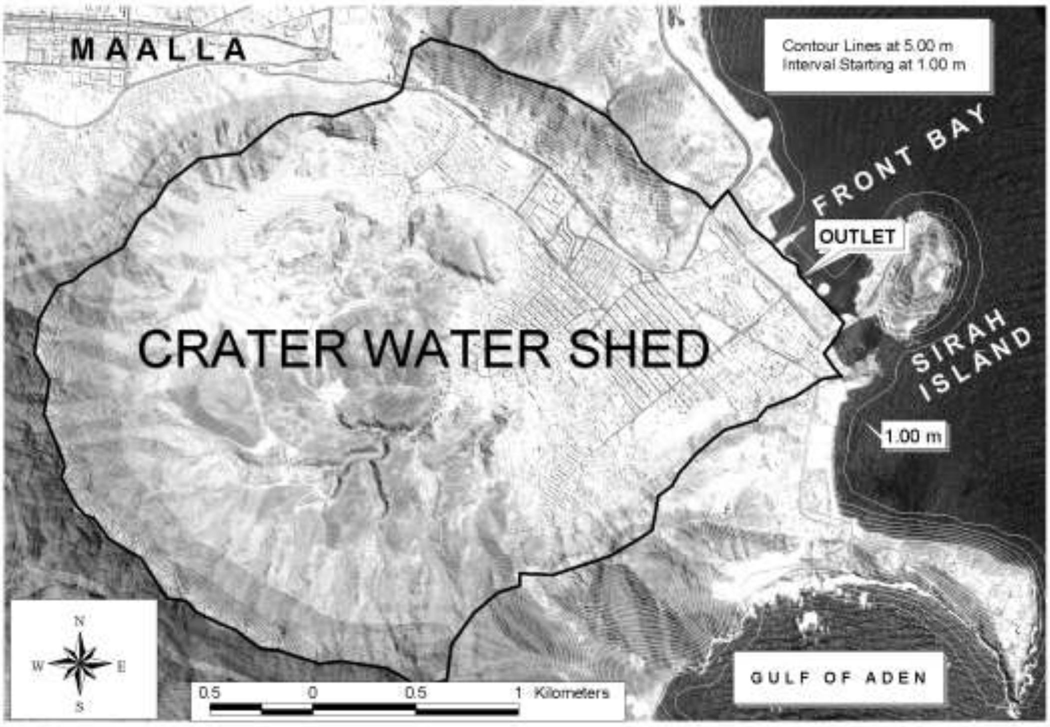

Fig.(2) Contour Map of The Crater watershed

The three wadis system of storm water is shown in Fig. (2)

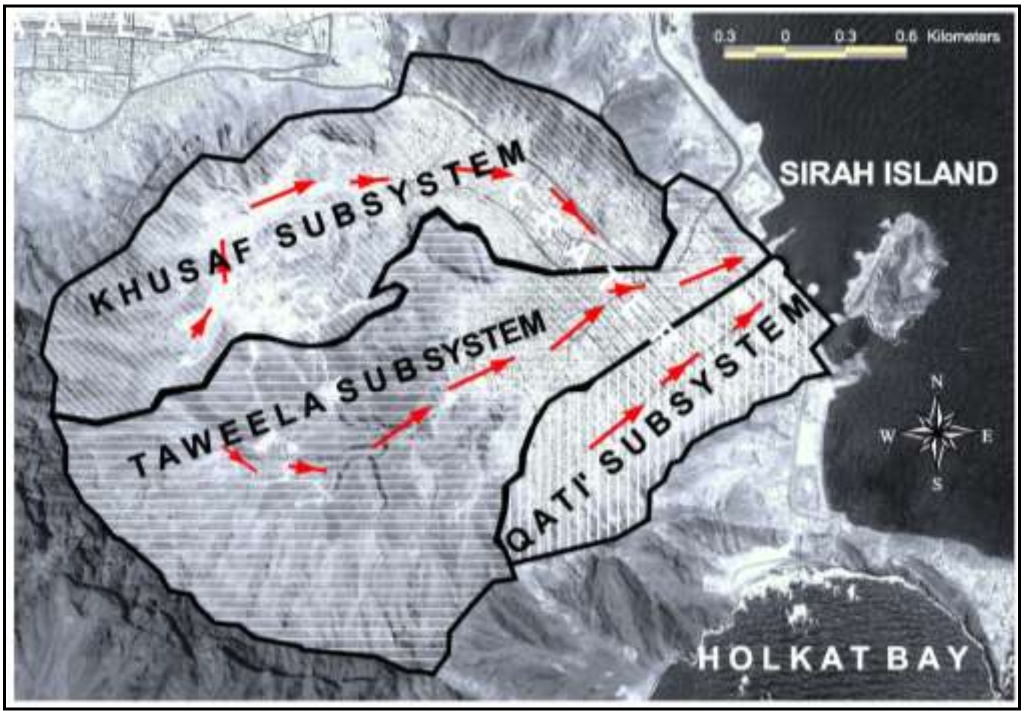

Fig.(3) Three Wadi System of the Crater Watershed

The stored storm water had been the source of water supply for the city until the early 1950s when the British colonialist hire a well field from the neighbouring Sultanate of Lahj at Sheikh Othman district which is around 15 km distant from the city.

4. WATERSHED DELINEATION AND CHARACTERIZATION USING GIS

Geographical Information System (GIS) provides a cost effective and practical approach to delineate and estimate the physiographical characteristics of watersheds. Digital satellite imagery at a very high resolution has become easily and affordably accessible via the World Wide Web (WWW).

For the purpose of the Crater watershed modelling a 60-cm resolution satellite image of the Crater watershed and a 5-m interval satellite interpreted contour map have been acquired. Some 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. ESRI ArcGIS software was used to process and compile the database, to obtain the various watershed parameters needed for watershed modelling or runoff estimation.

Watershed boundary has been identified from the satellite image with the 5-m contour layer overlaid. With the available high resolution, the delineation of the boundary became a straight forward assignment that could be accomplished at high accuracy greater than that required by the watershed modelling criterion. A shape file layer of the watershed boundary was created. The identified boundary of the Crater watershed is shown on Fig. (3).

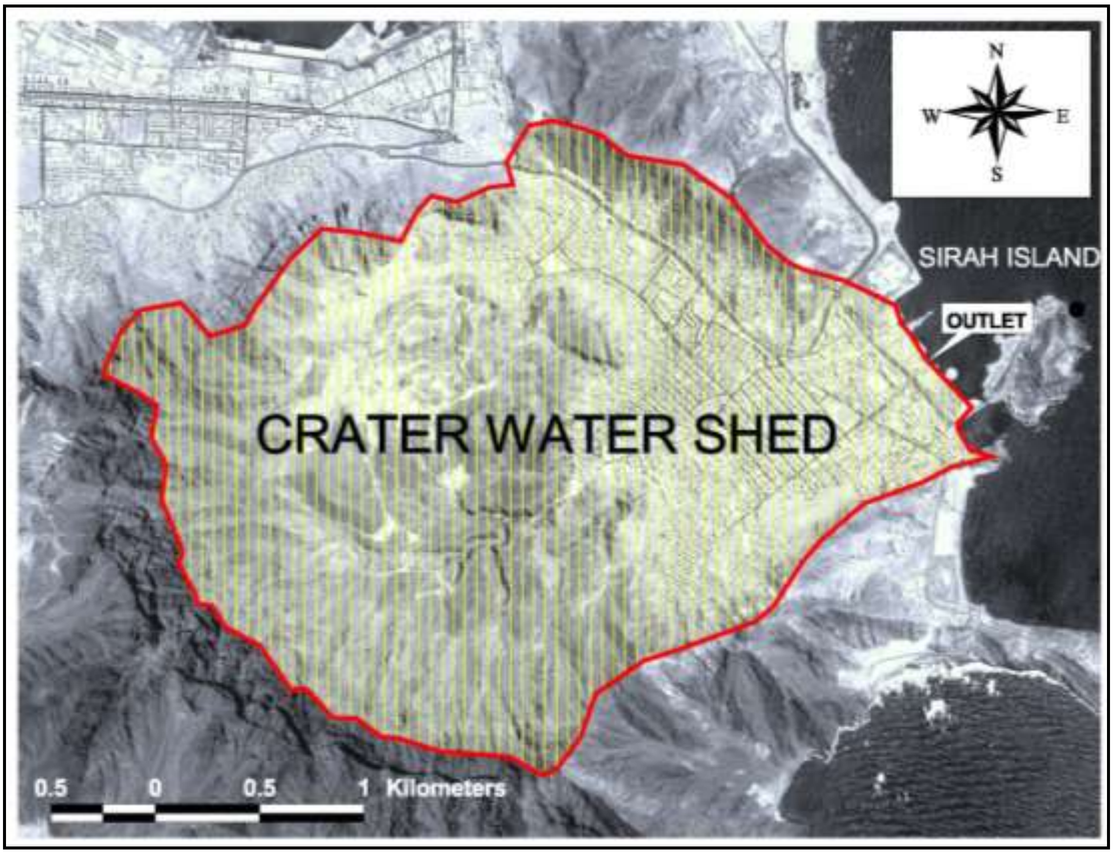

Fig. (4) Delineation of the Crater Watershed

As the crater watershed comprises three wadis, namely Khusaf, Taweela and Al Aidrus. The boundaries of basins of these three drainage wadis have been traced on the satellite image guided by the contour layer and the personal knowledge of the authors. Next, each wadi basin was divided into sub-basins based on the drainage pattern and the physiographic characteristics to represent the various detention/infiltration basins and subsurface ponds (Cisterns) existing within wadi basins. The sub-basins of the Khusaf basin have been labelled K1, K2, and K3. The Taweela sub-basins have been labelled T1, T2,T3, T4, T5, T6, T7, T8 and T9, while the Qati' basin comprises only two sub-basins Q1 and Q2.

Areas and perimeters of the various basins and sub-basins have been computed from the created shape files using X-tools add on utilities within the ESRI environment. Flow length for each su-basin has also been determined from the GIS environment. The average slope for the sub-basins has been found from the contour layer and the satellite image of watershed. Table (1) below gives the computed areas, perimeters, flow length, average slope of the various sub-basins of the crater wadis along with identified physiographic description of each basin.

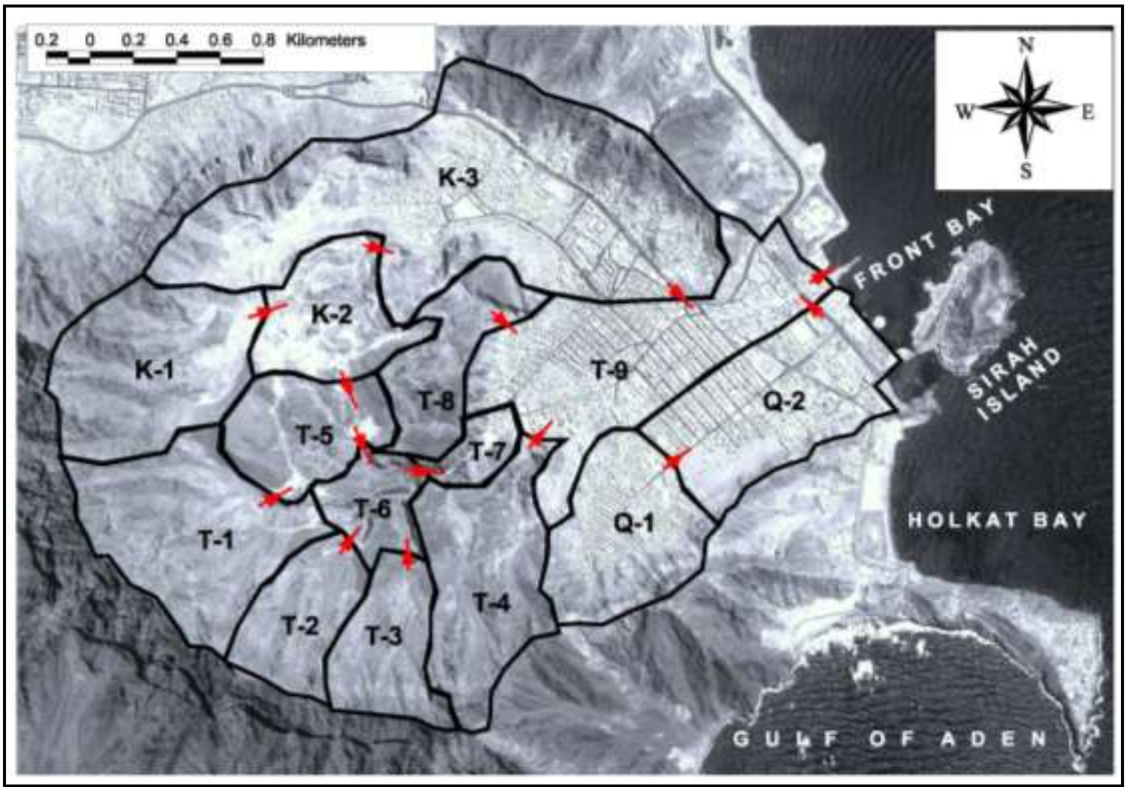

Fig.(5) Identified Sub-basins of the Three Wadis of the Crater Watershed

Table (1) Geometric and Physiographic Characteristics of the Watershed

Wadi Basin	Sub-Basin	Area (Ha)	Perimeter (m)	Av. Slope	Flow Length (m)	Type
KHUSAF	K1	174.507	7125.673	0.22	1200	Barren Rock
	K2	62.872	3147.663	0.07	900	Barren Rock
	K3	67.98	3917.533	0.11	2450	Urban area/stone quarry
	Total	**305.359**				
TAWEELA	T1	55.804	3806.718	0.41	775	Barren Rock
	T2	48.344	2733.378	0.40	765	Barren Rock
	T3	35.416	2747.9	0.37	800	Barren Rock
	T4	32.123	3217.946	0.24	1300	Barren Rock
	T5	87.146	5649.025	0.14	450	Barren Rock
	T6	34.532	2391.284	0.08	470	Barren Rock
	T7	28.749	3210.105	0.14	525	Barren Rock
	T8	62.284	3554.057	0.14	800	Barren Rock
	T9	10.375	1502.47	0.08	1500	Urban Area
	Total	**394.773**				
QATI'	Q1	29.781	2299.92	0.17	845	Urban Area
	Q2	30.931	2492.972	0.02	985	Urban Area
	Total	**60.712**				
Entire Watershed	**Total Area**	**760.844**				

Each of the Crater three wadis discharge to the see through a drainage system which safely guides and discharge the storm water to the sea at the Front Bay outlet. The drainage system components of each wadi have been identified fro the satellite imagery guided by the available Crater Municipality old maps as well as the personal familiarity of the authors with crater storm drainage system. The drainage areas mostly comprise of high storm water producing surfaces which are either barren rocks or paved urban areas. The upstream su-basins in the Crater Plateau have steep slopes. Only the Khusaf su-basins have land surfaces comprising gravels and crushed stone by products as the large parts of the Khusaf sub-basin have been used for quiet long time as a main stone quarry for the Aden governorate.

The Khusaf basin discharges through the khusaf drainage channel which joins the Taweela drainage channel just upstream the Bank intersection. Figure(6) below shows the layout view of the Khusaf drainage Channel.

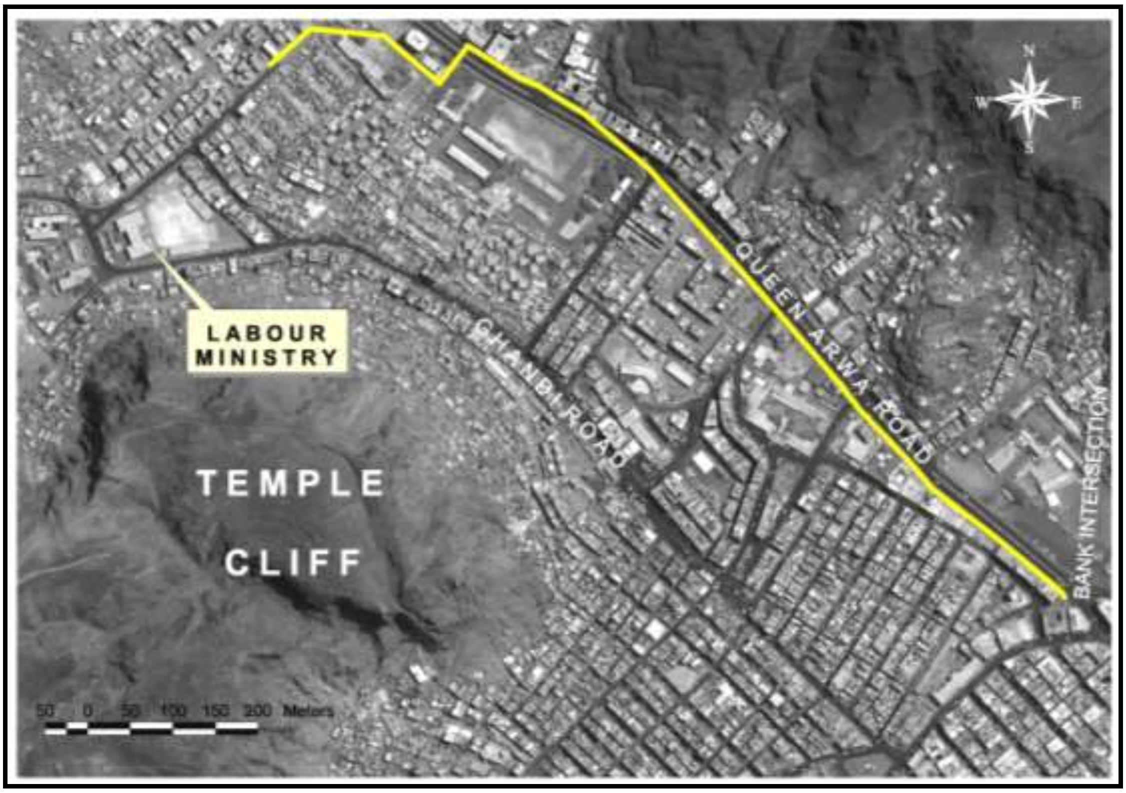

Fig. (6) The Khusaf Drainage Channel

The Taweela wadi is the largest wadi basin in the crater watershed discharge through the Taweela Channel which extends from the Playfair subsurface cistern to the discharge outlet at the front Bay. The layout of the Taweela channel as identified from the GIS database is shown in Fig. (7). Also in the same figure, the Qati' storm drainage network and the Khusaf storm drainage channel are visible. The down stream reach of the Taweela channel beyond the bank intersection is known as *Saila* It receives the combined storm flow from all the drainage channels and discharge at the Front Bay outlet to the sea.

Fig. (7) Taweela Channel, Crater Main Storm Drainage Channel

The Aidrus wadi storm water is discharged to the sea through the Qati’ Drainage system. The drainage system discharges at the Front Bay outlet where all the three wadis storm combine and discharge to the sea. The storm network extends from the Aidrus cemetery to the Front bay road where it flows along the road to join the *Saila.* The storm water net work traverse the Bakatheer school building to reach the front bay. The Qati’ storm drainage system has been traced using the GIS database. Figure (8) shows the Qati’ storm drainage network.

Fig. (8) The Qati' Storm Drainage Network.

5. 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.

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