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FLASH FLOOD HAZARDS OF DRAINAGE BASINS OF SINAI PENINSULA, EGYPT

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ABSTRACT

The drainage network of Sinai Peninsula drains terrains of different lithology, structure and physiography. 108 drainage basins were defined and sorted out, area-wise, into 13 large basins, 11 medium basins and 84 small basins. Furthermore, they were differentiated into internal and external systems. The former comprises 28 basins located in NNW Sinai, and the latter includes 80 basins, classified into 4 groups pertaining to : (a) Gulf of Suez (37 basins), (b) Gulf of Aqaba (41 basins), (c) Mediterranean Sea (W. El Arish basin), and (d) Dead Sea (W. Garrafy basin). The quantitative morphometric parameters of each basin were defined. On the basis of morphometric parameters, physiography and geologic setting (including lithology and structure), the basins were relatively assorted in respect to possible surface runoff potentiality into four classes. Besides, flash flood-vulnerable sites along the main highways, as well as, urban sites and farmlands were appraised and differentiated, risk-wise, into three categories.

INTRODUCTION

The Sinai Peninsula is triangular in form with apex at Ras Mohammed to the south. It is located in the northeastern corner of Egypt and is separated geographically from the Eastern Desert by the Suez Canal and Gulf of Suez (Fig. 1). It covers an area of approximately 61,000 km^2 representing about 6% of the entire area of Egypt.

The direct goal of the present study is to evaluate the flash flood hazards of the drainage basins of Sinai Peninsula. To achieve this goal, it was necessary to: (a) build the drainage network and delineate its drainage basins, (b) determine the morphometric parameters of the hydrographic basins and their hydrogeologic significance (flash flood potentiality), (c) delineate the geomorphological, lithological and structural features of the defined basins and their possible relation to the surface drainage system in order to address the factors influencing the flooding, and finally (d) assess the flash flood hazard sites.

Studies dealing with fluvial morphometry and flash floods in Sinai are numerous and include those by Saad et al. (1980), Abdel Mogheeth et al. (1985), Hammad and Misak (1985), Saleh (1985,1989), Moustafa (1987), El-Ghawaby et al. (1989), El Rakaiby (1989), El-Etr et al.(1990,1993), El-Shamy (1992), El-Shamy and El-Rayes (1992), Hammad et al. (1994) and Shendi et al. (1997).

GEOMORPHOLOGY

More than half of Sinai Peninsula is situated between the Gulf of Aqaba and Gulf of Suez. The Peninsula is bounded from north by the Mediterranean Sea. The southern part of Sinai forms its core (Fig. 2), which rises considerably to elevations up to 2641m (G. Katherina). To the north, the core is flanked by a great limestone plateau of an 800 m average altitude (Fig. 2). This plateau has a gentle gradient toward the Mediterranean Sea. The central portion of the plateau surface forms a fairly open country draining to the Mediterranean Sea by numerous tributaries of Wadi El Arish, which has a catchment area of about 21,500 km^2. The northern part of Sinai consists of a wide plain, littered by a number of inselbergs and sand dune chains.

Geomorphologically, Sinai can be divided broadly into the following main units (Fig. 3), namely: (a) Mountainous basement terrain, (b) Upland plateaus, (c) Folded hilly terrain, (d) Mediterranean coastal plain belt, and (e) Pediplains.

(a) Mountainous Basement Terrain: This sector occupies the southern part of Sinai, covering an area of approximately 7500 km^2, and forms a triangular horst block. This terrain is built up of a series of mountain groups, more or less coherently disposed in a linear fashion, with some detached masses and peaks. It represents a part of the Arabian-Nubian Shield, and is composed of igneous and metamorphic rocks. It is intensely dissected by a large number of wadis, issuing from topmost parts of the mountainous terrain and trending either easterly toward the Gulf of Aqaba or westerly toward the Gulf of Suez.

(b) Upland Plateau: To the north, the horst block of the mountainous basement terrain is immediately flanked by an extensive stretch of flat-topped plateau, covering most of the central Sinai. The general surface of the plateau slopes gently northward, where it merges into Central Sinai pediplain near Thamada- Nakhl stretch. The plateau is bounded on its east, south and west by vertical scarps. The northern boundary is marked by large east-west faults, that cross almost the entirety of Sinai. The plateau land is intensely drained by numerous dry natural water courses descending northerly toward the Mediterranean Sea (through W. El Arish), westerly toward the Gulf of Suez, easterly toward the Gulf of Aqaba, and northeasterly toward Palestine (through W. Garrafy).

(c) Folded Hilly Terrain: This terrain is developed in the northern section of Sinai Peninsula, occupying an area of about 1600 km^2 and sloping gently towards the northeast. It is characterized by a number of isolated domal hills of considerable size. These hilly masses are elliptical in shape and aligned in ENE-WSW trending parallel lines, separated by relatively low topographic areas. The most prominent hills are Gabal Maghara (735 m), which represents the biggest uplift, Gabal Halal (890 m) and Gabal Yelleg (1090 m). Besides, there are several others of smaller magnitude.

(d) Mediterranean Coastal Plain Belt: This belt covers a broad tract (800 km^2) of roughly triangular shape, extending between the Mediterranean coast and the line between the Bitter Lakes in the west and Rafah in the east. This area is relatively of low relief and consists of a wide plain with a maximum width of nearly 80 km in the N-S direction. It slopes gradually northward and comprises coastal areas with a complex of parallel coastal dunes, attaining altitude of 100 m a.s.l., and offshore bars in the center enclosing the vast Sabkhet (Lake) El-Bardawil. The interdunal lowlands are covered by sabkha deposits, particularly in El-Tina plain and the southern part of Suez Canal. The inland desert plain is partly covered by outwash material derived from the surrounding high country and transported by the running water through drainage courses.

(e) Pediplains: Several parts of Sinai Peninsula consist of extended areas of pediplains particularly along the foot slopes of highlands. The most prominent pediplains are found in Central Sinai and along the Gulf of Suez. The Central Sinai pediplain covers an extensive plain extending between the plateau lands in the south and folded hills in the north for a distance of about 55 km in N-S direction and 125 km in east-west direction. Through this pediplain, the wadis coming down the elevated plateau fan on the pediplain surface and progress northerly forming the drainage net of W. El Arish.

Along the Gulf of Suez, many segments of pediplains are formed at the foot slope of the western edges of El-Tih plateau and the southern basement terrain. El-Qaa plain is the most prominent feature in this stretch. It is an extensive gravelly plain running in a northwest direction for a distance of about 150 km. It is crossed by numerous drainage lines issuing from the adjacent highlands and flowing westerly toward the Gulf of Suez.

GEOLOGIC BACKGROUND AND STRUCTURAL SETTING

The rocks exposed in Sinai are varied and range in age from Precambrian to Recent (Fig. 4). The Precambrian rocks occupy the southern part of the Peninsula. They represent a part of the Arabo-Nubian Shield and consist of intricate complex of igneous and metamorphic rocks. The northern flank of the basement exposure is overlain unconformabley by younger sedimentary formations ranging in age from Paleozoic to Tertiary and Quaternary. Further elaborations on the lithologic units forming the outcrops of Sinai, can be found in Said (1962, 1990) and the geologic maps of Sinai (scale 1:250,000), published by the Egyptian Geological Survey and Mining Authority (1992, 1993, 1994).

The main linear structural features (fractures) of Sinai (Fig. 5) were assessed and traced using Landsat TM images (scale 1:500,000). The density and length of the detected fractures (including faults) show appreciable spatial and orientational variations. Thus, the southern part is characterized by the maximum density of fractures. Fractures govern substantial parts of the main wadis and their large tributaries and have a great practical value in controlling groundwater distribution in fractured bedrock aquifers, which represent favourable sites for groundwater harvesting (Kusky and El-Baz 1998).

The spatial distribution of the mapped fractures (Fig. 5) reveals the following characteristics:

(a) In South Sinai, fractures with northwesterly and north northeasterly trends are pronounced and show spatial clustering in the vicinity of the Gulf of Suez and Gulf of Aqaba respectively.

(b) The fracture pattern of the central plateaux of Sinai is simpler and less dense than that of the southern basement highlands. Central Sinai is bounded on its eastern and western sides by fractures (mostly normal faults). To the west, the eastern boundary scarp is marked by fractures assuming N-S and NW-SE directions. To the east, Central Sinai is strongly broken by fractures principally trending NNE, N and NE. These fractures control parts of main stream courses (such as W. Watir and W. Garrafy). In the interior part of Central Sinai, the fractures are oriented predominantly

NW, NNE and N. The northernmost part of Central Sinai is crossed by east-west trending fractures.

(c) The northern part of Sinai is structurally and tectonically linked with the Syrian arc tectonism. It is deformed by several east-northeast and northeast oriented doubly plunging anticlines aligned in six elongate parallel belts (Moustafa and Khalil 1990). This folded province is dissected mainly by east-northeast to northeast oriented fractures, running more or less parallel to the axes of folding structures, and subordinate NW trending fractures.

CLIMATE

Sinai is located within the arid belt dominating the northern part of Africa and extends to southwest Asia. It is characterized by arid climatic condition dominated by long hot, rainless Summer and mild Winter. The monthly mean temperature varies between 23–33ºC during Summer, and 9–14 ºC during Winter. The relative humidity varies between 32% in Summer and 62% in Winter. The average evapotranspiration varies between 2.6 mm/day in Winter and 9.3 mm/day in Summer. The average annual precipitation ranges between less than 20 mm/y on the southwestern part near of Abu Rudies and El Tor, and 304 mm/y on the northeastern part near of Rafah. The amount of rainfall decreases sharply in the northern part of Sinai, which ranges between 300 and 40 mm/y and extends along an area of less than 20% of the entire Sinai, and very gently in the resting area (more than 80% of the entire Sinai), which ranges between 30 to less than 20 mm/y (Saad et al. 1980). The central part of southern Sinai receives higher annual precipitation than the surrounding areas of southern Sinai, ranging between 50 to 40 mm/y. This concentration is ascribed to fairly high mountains (such as St. Katherina). Most of the precipitation occurs during Winter and the transitional times of Autumn and Spring. Runoff (flash flooding) is expected to develop, when a storm with rainfall intensity is more than 10 mm in sedimentary areas and 5 mm in igneous regions (Allam et al.1992). The frequency of runoff exceeding 10 mm/day ranges between 4 times per year in North Sinai to one time per year in Central Sinai. In South Sinai, the runoff frequency is less than one time per year, indicating that runoff possibility may not take place for many years (Saad et al. op.cit.).

DRAINAGE NETWORK AND BASIN MORPHOMETRY

The properly enhanced Landsat TM composites (bands 7, 4 and 1) at scale 1:250,000 were used as database with much confidence in visual interpretation, to delineate and trace the drainage network of Sinai. Topographic maps at scale 1:250,000 (Egyptian Military Survey 1971, 1974, 1975, 1986, 1987, 1993, 1996, 1997, 1998) were consulted frequently during the progress of this work. The entire land of Sinai is located in 11 maps at scale 1:250,000. Each one is bounded by one degree latitude, and one and one half degrees longitude.

The drainage network of Sinai (Fig. 6) is well developed, integrated and fairly dense but is not consistent all over the area. The degree of uniformity of the drainage lines and their angles of junction differ from one place to another. The main (consequent) streams and their (subsequent) tributaries are mostly oriented and show high degree of control. Qualitatively, the common types of drainage patterns along the highland are coarse dendritic to subdendritic and parallel to sub-parallel, and less common types are trellis,

rectangular and radial. On the other hand, the dominant types in the relatively low plains (pediplains and coastal plains) are sub-parallel, braided and dichotomic.

Drainage network of Sinai is demarcated into drainage basins (Fig. 6). Basins of less than four streams are not counted in the present study. Accordingly, 108 drainage basins are identified in Sinai, occupying a total of 47500 km^2 with 9945 drainage lines of about 42223 km total length. They have average density of 0.9 and average frequency of 0.2. The waterdivides of the defined basins are crooked and run over the high peaks of the highlands. They are commonly defined by the name of the trunk wadi and also are numerically designated. Master wadis of main basins take mostly asymmetric courses within their catchment area. The defined basins are sorted out, area-wise, into three main categories, namely: large (more than 500 km^2), medium (500-150 km^2), and small (less than 150 km^2). Thirteen basins ranked as large, 11 basins as medium, and 84 basins as small. The large basins occupy a total area of about 39450 km^2 (representing 83% of the entire area); medium basins occupy a total area of about 2894 km^2 (representing 6.1 % of the entire area); and small basins cover an area of about 5157 km^2 (representing 10.9 % of the entire area). Streams draining the highlands differ largely from those draining the lowlands. The highland terrains, represented by mountainous basement country and upland plateau, are dissected by narrow, persistent, deep, steep sided, partly oriented, and highly integrated and ramified drainageways, whereas the drainageways, crossing the low-lying (peneplained) terrains, are shallow, wide, gently sloping, and mostly gravity controlled. Local fans are common at the foot slopes of the highland. The drainage basins exhibit different shapes, such as leaf-like, fan-like, plume-shape, rectangular, and triangular (Fig. 6).

Quantitatively, the morphometric parameters of the 108 basins delineated are defined in terms of order, bifurcation ratio, frequency, density, basin shape (circularity and elongation ratios), relief ratio, ruggedness number, and slope ratio. The statistical values of these parameters are listed in Tables 1 through 5, according to definitions given by Horton (1932, 1945), Strahler (1952, 1958), Miller (1953) and Schumm (1956). This analysis was performed as an attempt to elucidate the possible surface water potentialities of these basins and their bearing on runoff (flash flooding) behaviour.

According to stream order, the large basins reach the seventh (one basin), sixth (2 basins), fifth (6 basins) and fourth (4 basins) orders. The medium basins reach the fifth (one basin), fourth (8 basins), third (one basin), and second (one basin) orders. The small basins reach fourth (7 basins), third (55 basins), and second (22 basins) orders.

The drainage basins of Sinai are differentiated into basins of internal and external systems. The internal system is represented by 28 internally draining basins located in NNW Sinai. The external system (80 basins) is classifed into four groups pertaining to: (a) Gulf of Suez (37 basins), (b) Gulf of Aqaba (41 basins), (c) Mediterranean Sea (W. El Arish basin), and (d) Dead Sea (W. Garrafy basin).

(a) Gulf of Suez Basins

Thirty-seven drainage basins with outlets to the eastern side of the Gulf of Suez were defined. They occupy an area of about 11597 km^2 (representing about 19% of the total area of Sinai) with 2397 drainage lines of about 8650 km total length (Table 1). Seven basins are large, which occupy a total area of about 8597 km^2, four basins are medium,

occupying a total area of about 1141 km^2 and twenty-six basins are small, occupying a total area of about 1859 km^2. The large basins reach the fifth (3 basins) and fourth (4 basins) orders. The medium basins reach fourth (3 basins) and third (one basin) orders. The small basins reach fourth (3basins), third (16 basins) and second (7 basins) orders.

The slope gradient of these basins is mostly steep in the upper reaches (issuing part) and tends to be gentle to the west towards the lower reaches (debouching part). Delta is sometimes formed at the debouching part of the main wadis, such as W. Feiran, W. Wardan and W. Sudr.

The upper reaches of main basins drain either basement rocks of mountainous terrain (such as W. Feiran, W. El Aawag, W. El Mahashi and W. Amlaq), or sedimentary rocks of upland plateau (such as W. Sudr, W. Wardan, W. Gharandal, W. Tayiba, W. Khaboba, W. Baba, W. El Sodra, and W. El Araba). Few basins such as W. Feiran, dissect largely the mountainous terrain of basement rocks, while their outlets seem to drain sedimentary rocks of low plains. Whereas numerous basins drain either entirely in sedimentary rocks (such as W. Rieina, W. Lahata, W. Sudr, W. Wardan, W. Khor Seda, W. Gharandal, W. Waseiyit, W. Thal, W. Khaboba and W. El Araba), or partly in basement and partly in sedimentary rocks (such as W. El Sodra, W. Araba, W. El Aawag, W. Selli, W. Abu Garf, W. Sed, W. Mahashi, W. Latthi, W. Umm Markha, and W. Elat El Gharbi).

With respect to the above mentioned descriptive-analytic study, the Gulf of Suez basins are assessed in relation to surface runoff (flash flooding) potentiality and are relatively differentiated into the following classes:

1- Basins of low runoff: include W. Abu Mheiherrat (8), W.Khaboba (12), W. El Taiyba (13) and 30.

2- Basins of moderate runoff: include W. Rieina (1), W. Wardan (5), Khor Seda (6), W. Gharanadal (7), W. Waseiyit (9), W. Thal (10), W. Tayiba (11), W. El Sodra (15), 17, W. El Araba (18), W. Araba (19), Khor El Sherief (24), El Rabod (29), Amlaq (35), and Elat El Gharbi (36).

3- Basins of moderate to high runoff: include W. Mirba (2), W. Lahata (3), W. Sudr (4), W. Baba (14), W. El Aawag (20), W. Imlahah (21), W. Selli (22), W. Abu Garf (23), W. Merrikh (25), W. Thamman (26), W. Sed (27), W. Latthi (31), 33, W. Umm Markha (34), and 37.

4- Basins of high runoff: include W. Feiran (16), W. El Mahashi (28), and W. Aghsha (32).

In view of the present assessment, the basins of classes (2), (3) and (4) would yield sharp peaked discharge and their contribution to replenishment of near-surface groundwater aquifers is expected to be limited. Therefore, construction of simple flood-retardation structures (such as earthy dams and gabions) at suitable sites across the main wadis and tributaries, is recommended to enhance the infiltration rate of runoff.

(b) Gulf of Aqaba Basins

This group of basins covers an area of about 8500 km^2 (representing 14% of the entire Sinai) with 2246 drainage lines of about 6967 km total length (Table 2). They are 41 basins with outlets to the western side of Gulf of Aqaba. Three basins are large (of total 6591 km^2), one basin is medium (362.5 km^2) and thirty-seven basins are small (of total 1547 km^2). The large basins attain sixth (W. Dahab) and fifth (W. El Kid and W. Watir)

orders. W. Um Adawi (medium basin) assumes the fourth order. The small basins reach fourth (W. Taba), third (23 basins) and second (13 basins) orders.

Most of these basins, if not all, are characterized by steep slope gradient towards the Gulf. Highlands (mountainous terrain or upland plateau) occupy almost the entire basins with a negligible part of low land. The upper and lower reaches of the main basins drain largely basement and/or Cretaceous rocks. The low plain, extending along the western bank of the Gulf of Aqaba is very narrow and becomes wider in the southern part. Some basins form conspicuous dry deltas at their lower parts, such as W. Watir , W. Dahab and W. El Kid.

Through the analysis of quantitative data (Table 2) and descriptive details (physiography and geology) of the Gulf of Aqaba basins, these basins are appraised in respect to surface runoff potentiality and are relatively sorted out into 4 classes, namely:

1- Basin of low runoff: includes basin designated number 46.

2- Basins of moderate runoff: include Nos. 38 and 39, W. Ardeimayia (40), W. El Khareita (42), W. Awaga (43), 44, W. El Mobalag (47), W. Zewaira (48), W. Mekaimen (58), W. Hebaiq (61), W. Mezariq (62), W. El Sada El Samra (63), W. Watir (56), and W. Taba (78).

3- Basins of moderate to high runoff: include W. Elat El Shariq (41), 45, W. Umm Adawi (49), W. Umm Raka (50), W. El Kid (51), W. El Samra (52), W. El Qabeila (53),W. El Ghorabi (54), W. Qanni El Atshan (55), W. Dahab (56), 57, W. Umm Afae (59), W. Sokhn (60), W. El Beida (64), 66, W. El Malhah (67), 68, W. El Mahashi El Astal (69), W. Meqabela (73), W. El Marakh (75), W. Mzeirah (76) and 77.

4- Basins of high runoff: include W. Qaseib (70), W. Umm Moghra (71), W. El Mahashi El Aala (72), and 74.

Basins of classes (2), (3) and (4) have low seepage/runoff ratio, and augmentation of the recharge of the near-surface groundwater aquifers in these basins can be accomplished by construction of light indigenous engineering works in selected sites.

(c) W. El Arish Basin

W. El Arish basin is the largest basin in Sinai and covers a vast area of about 21500 km^2 (representing about 35% of the total area of Sinai) with 3250 drainage lines of about 18922 km total length (Table 3). The basin as a whole has about 0.9 average density and 0.2 average frequency. The basin is fan-shaped and its main wadi (W. El Arish) assumes a seventh order. It emanates from the upland plateaux of El Egma, El Tih and Hazim with steep slopes and with elevations up to 1250 m. The basin is asymmetric with a large catchment area and discharge at the eastern side of the main channel. The trunk wadi is oriented northerly to north-northeasterly at its upper and middle parts, and northwesterly to northerly at its lower part, where it debouches to the east of El Arish town on the Mediterranean coast. W. El Arish is coalescened along its course with many large tributaries. The most conspicuous of these are W. El Bruk, W. Abu Tareifiya, W. El Ruwaq, W. Aqaba, W. Abu Qiraiya, W. El Gaifi and W. El Azariq. Substantial segments of W. El Arish and its main tributaries are governed by fractures (Fig. 5).

W. El Arish basin drains entirely sedimentary outcrops of Triassic and younger ages, and crosses terrains of upland plateau, pediplain, folded hills and coastal plain. Through the path of W. El Arish (340 km long), its width varies from place to place. It is generally wide and highly ramifying in the upland plateau and pediplain, and low ramifying and very narrow in the folded hilly terrain, where it assumes a gorge-like path particularly at Deiga El Kherim, Deiga Talat El Badan and Deiga El Halal. In the Mediterranean coastal plain, W. El Arish course is relatively shallow, narrow, low ramifying, sluggish and markedly sinuous. In view of surface runoff potentiality, W. El Arish basin, as a whole, is considered on the basis of topography, and geological and morphometric characters, as a moderate runoff basin.

(d) W. Garrafy Basin

It is a part of the large basin of W. El Araba, that leads ultimately to the Dead Sea. The upper reaches of W. Garrafy are situated to east of Central Sinai. W. Garrafy in the Egyptian territory runs northerly to northeasterly from elevations up to 969 m, and is combined through its main course with many tributaries. The most conspicuous tributaries at its western side are W. Umm Haluf, W. Khadakhid, W. El Tamarani, W. Shaart Mudhan, and W. Shairet Umm Arqub; and at its eastern side are W. El Bayda, W. El Ghadra, and W. El Khamila. W. Garrafy basin crosses the terrains of upland plateau and pediplain, and drains largely sedimentary rocks of Cretaceous and younger ages, and subordinately acidic metavolcanics of Precambrian age.

W. Garrafy basin assumes sixth order and occupies a fan-shaped catchment area of about 2168 km^2 (about 3.6% of the total area of Sinai) with 830 drainage lines of about 2740 km total length (Table 4). The basin as a whole has about 1.3 average density and 0.4 average frequency. The slope gradient of W. Garrafy in the Egyptian land is steep to moderate. With respect to surface runoff potentiality, W. Garrafy basin is depicted as a basin of moderate to high runoff, in relation to quantitative morphometric parameters, geology (including lithology and structure) and physiographic features.

(e) Internal Basins

This group of basins is presented in NNW Sinai and covers an area about 3735 km^2 (about 6% of the total area of Sinai) with 1222 drainage lines of about 4945km total length (Table 5). It has 1.3 average density and 0.3 average frequency and is represented by 28 basins with outlets towards subdued inland. Only one basin (W. El Meleiz) is large (595 km^2) and assumes fifth order. Six basins are medium (ranging between 472 - 150 km^2) and attain fifth (W. El Hasana), fourth (four basins) and second (W. El Letheili) orders. Twenty-one basins are small and reach the fourth (3 basins), third (16 basins) and second (2 basins) orders. Their upper reaches drain mostly the slopes of folded hills in North Sinai and run with low gradient towards the subdued lowlands, that are mostly covered by Quaternary alluvial and eolian deposits.

In relation to surface runoff potentiality, these basins are of low runoff, in which the infiltration rate is high and consequently the groundwater recharge is expected to be high.

FLASH FLOOD HAZARDS

Sinai is occasionally subjected to heavy showers followed by sporadic torrential floods, commonly characterized by sharp peak discharge of short duration. Such floods cause serious problems and excessive loss of life and property. Human manifestations in Sinai comprise urban areas, farms and highways. They are constructed either along the floor of drainage courses or crossed by drainageways. Substantial parts of the exploited areas are subjected to swift water during rainstorms and flooding, and consequently exposed to flash flood hazards (Fig. 7).

Risk assessment maps at scale 1:250,000 were prepared for roads, urban sites, and cultivated areas, threatened by flooding. Flash flood-prone sites are identified and differentiated into three categories: slightly, moderately and highly dangerous. Judging is relative and depends on combination of the following parameters: slope gradient, catchment area, shape, relative drainage density, confluent angle, flow direction, width and depth of the affecting drainage channel, rock types, geological structures, and presence of settlements, farms and/or transport network.

Desert roads traversing Sinai, are mostly built without account of flash flooding hazard. Therefore, many parts of these roads are vulnerable to flooding (Fig. 8). Flood hazard does not only affect the trafficability of these roads, but extends also to existing urban areas, farms and touristic villages along and close to them. The details of flood vulnerable sites are summarized as follows:

(a) Gulf of Suez District

The catchment area of the Gulf of Suez basins includes essentially the coastal highway of the eastern side of Gulf of Suez and a sector of transverse highway connecting between coastal roads of Gulf of Aqaba to the east and Gulf of Suez to the west. The coastal highway extending along the Gulf of Suez, is constructed close and rather parallel to the Gulf of Suez shoreline. This highway at areas between Ahmed Hamdy Tunnel - Belayim, and El Tor - Sharm El Sheikh, is crossed from east to west by lower reaches of most of Gulf of Suez drainage basins, whereas the coastal road between the mouth of Wadi Feiran and El Tor, is constructed along the floor of Wadi El Aawag. The transverse (inland) highway of Gulf of Suez province runs roughly E-W and links between St. Katherine and coastal road. It is constructed mainly on the floor of main wadi of W. Feiran basin.

The coastal highway between El Tor and Sharm El Sheikh is less susceptible to flood hazard than the other parts. This is ascribed principally to wideness and gentle slope of the pediplain stretch in this sector (El Qaa plain), which is covered by thick pervious unconsolidated sediments. These factors lead to decreasing the runoff potentiality of drainageways coming from the mountainous terrain of basement rocks. The highways coinciding with the floor of W. Feiran and W. El Aawag are subject to hazard particularly at bend areas of main wadis, and connection sites between tributaries and main wadis.

The sites, vulnerable to flash flood along the highways included in the Gulf of Suez drainage basins, are as follows:

(i) Highly dangerous sites include:

- El Tor city and touristic sites, built over the alluvial fan of Wadi El Aawag.

- Ras Sudr- El Tor road crossings with wadis Lahata and Sudr..
- Hammam Faraun–Ras Sudr road, where it is crossed by W. Gharandal.
- El Tor-Ras Mohamed road, where it is crossed by with W. Wardan.
- Abu Rudies-El Tor road, where it is crossed by wadis Sidri and Baba.
- Abu Rudies-Belaiyim road, where it is crossed by the alluvial fan of W. Feiran.
- Abu Rudies-El Tor road, where it is crossed by wadis Feiran and El Aawag.
- Katherina-Feiran road, where it is crossed by wadis Solaf, El Akhdar and Rahaba.

(ii) Moderately dangerous sites include:

- Tunnel-Ras Sudr road at its crossings with wadis Wardan and Rabeina.
- Ras Sudr-El Tor road at the crossing with W. Gharandal.
- Hammam Faraun-Ras Sudr road, where it is crossed by W. Abu Magaraat.
- El-Shatt-Abu Zeneima road, where it is crossed by wadis Waseiyit, Thal and Tayiba.
- El-Shatt-El Tor road, where it is crossed by W. Nukhul.
- Abu Zeneima-Abu Rudies road, where it is crossed by wadis Kahiel and Sieh.
- El Tor-Sharm El Sheikh road, where it is crossed by wadis Imlaha, Selli, Merrikh and Thamman.
- El Tor-Ras Mohamed road, where it is crossed by W. Mahashi.

(iii) Slightly dangerous sites include :

- Tunnel-Ayun Musa road, where it is crossed by W. Mabuq.
- Ayun Musa-El Tor road, where it is crossed by wadis Ayun Musa and Wardan.
- El Shatt-El Tor road, where it is crossed by wadis Abu Mheiherrat and Umm Isla.
- Abu Rudies-El Tor road, where it is crossed by wadis Hadahid, Umm Gurdi and Hebran.
- Katherina-Feiran road, where it is crossed by wadis El Sheikh Nisriyin, Harqous , Bayad, Sahab, Nazba El Beda and Haziza.
- El Tor-Ras Mohamed road, where it is crossed by wadis Khor El Sherief, El Maen, Sed, Mahashi, Latheya, Aghsha, Umm Markha, Amlaq, Elat El Gharbi and Khashabe.

(b) Gulf of Aqaba District

The main highways constructed within the catchment area of Gulf of Aqaba basins, link between Sharm El Sheikh and Taba, passing through Dahab and Nuweiba, and between St. Katherina (in central South Sinai) and Nuweiba (on the Gulf of Aqaba). These roads are partly crossed by streams and partly extend along the floor of stream courses. Besides, Nuweiba and Dahab towns are built over the alluvial fans of Wadi Watir and Wadi Dahab respectively. Roads crossing main wadis are endangered only from one side, but in case of roads running along wadi floors, they are assailable to damage on both sides, and this damage may extends for considerable distances along the road stretch.

It is worthy to mention that, the mountainous terrain in this district has steep slopes and is separated from the Gulf of Aqaba shoreline by a very narrow coastal plain. Such conditions increase the damage of wadi-road crossings. The flash flood hazard sites, along the main highways in the Gulf of Aqaba district are as follows:

(i) Highly dangerous sites include:

- Touristic villages at Nuweiba, which are built over the alluvial fan of W. Watir.
- Dahab city, which is constructed over the alluvial fan of W. Dahab.

- Sharm El Sheikh-Dahab road at its crossing with wadis Madsus, Mogeirat and El Bada.
- Dahab-Nuweiba road, where it crosses the alluvial fans of W. Watir. and outlet of W. Zoughra.
- Nuweiba-Taba road, wher it is crossed by wadis Mzeirah, El Abied, El Hemiera El Bahari, El Hemira El Qabli, El Mahash, Qaseib, El Malha and Maqbala.

(ii) Moderately dangerous sites include:

- Ras El Naqab Airport – Pharoan Island road at its crossings with wadis Mzeirah and El Khaleifia.
- Nuweiba-Taba road, where it crosses wadis Suweir and Himeira.
- Dahab-Nuweiba road at the crossing of W. Abu Samra.
- Sharm El Sheikh- Dahab road at the crossings of wadis Abu Khisheib, El Thaalbi, and Umm Saala.
- Ras Mohamed-Taba road, crossings with wadis Aawag, Nageiat, Madsus and Ardeimayia.

(iii) Slightly dangerous sites include :

- Nuweiba-Taba road, crossings with wadis Tueiba, Qreiya and Umm Moghra.
- Dahab-Nuweiba road, crossings with W. Qanatir and Upstreams of W. Dahab.
- Sharm El Sheikh- Dahab road, crossings with wadis Umm Shuki, Qanni El Atshan, Qanni El Rayan, Melhig, Qabielet El Bahar, El Samaa and Batah.
- Ras Mohamed-Taba road, crossings with wadis Umm Marakh, Gidla, Elat El Sharqi and Abu Muneisel.

(c) W. El Arish

W. El Arish basin is traversed by several highways and subsidiary roads linking between eastern and western sides of Sinai. The Wadi also includes many farms and urban sites, built on the floor of the main stream and its large tributaries. Numerous sites of them are vulnerable to flash flood. These sites are:

(i) Highly dangerous sites include:

- Reclaimed agricultural lands in W. El Arish fan.
- Eastern extension of W. El Arish city.
- Farmlands on the bottom of the main course of W El Arish (at El Daiqa, El Munbatih plain, Talet El Badan, Khashm El Had, Deiqat Kherim and Qalat El Nakhl) and several localities within W. Qiraiya and W. El Qureid.
- W. El Arish at its crossings with Lehfan crossings, Ismailiya – El- Quseima road (at Al Rawafah dam), Hasana – El Quseima road (at Talet El Badan), and Ras El Naqab – Tunnel road (at Qalat El Nakhl).
- Nuweiba–Tunnel road where it is crossed by W. El Arish and its tributaries (W. El Feihi, W. El-Ruwaq, El Khaseis, W. El Ghabiya, W. Abu Tareifiya and W. El Natila).

(ii) Moderately dangerous sites include:

- Hasana–El Quseima road, crossing with W. Safra El Moatem.
- Nakhl–Tunnel road, crossing with W. El Saheimi.
- Nakhl–Nuweiba road, crossing with W. Aqaba.
- Farmlands on the floor of W. El Arish (at El Munbatih plain), W. Gurur and W. Khoraiza, and at mouth of wadis Abu Kheima, El Mahmasha, El Ahmer, Abu Aaqar, El Malih and El Mizeira**.**

(iii) Slightly dangerous sites include:

- El Arish–El Quseima road, crossings with wadis Hareidin and Sabha.
- Hasana-El Quseima road, crossing with W. Abu Seila.
- Nakhl-Hasana road, crossings with wadis El Bruk and El Faliq.
- Ras Sudr–Hasana road, crossings with wadis El Qudeie, Abu Aleidie, El Minerish, El Mithan and Ruweisa.
- Nakhl-Tunnel road, crossings with wadis Tamira, Abu Kanadu and Abu Gidil.
- Nakhl-Nuweiba road, crossings with wadis Abu Darag and Umm Feiran.
- El Temed-El Kuntella road, crossing with W. Aqaba.
- Farmlands at mouth of wadis El Hazira and El Tariq (at Deiqat El Hazira), and on the floor of wadis El Gaifi, Qiraiya and El Faliq.

(d) Wadi Garrafy

The catchment area of Wadi Garrafy encompasses parts of Nuweiba-Ras El Naqab road, Ras El Naqab - El Temed road, Ras El Naqab-El Quseima road, and Ras El Naqab-El Kuntella road. Significant sites of these roads are threatened by flash floods. These sites are sorted into:

(i) Highly dangerous site: located at the crossing of Ras Naqb-El Quseima road with W. Garrafy at El Kuntella area.

(ii) Moderately dangerous sites include :

- Ras El Naqab-El Quseima road, crossings with wadis El Ghadra and Musaweb Nejm.
- Ras El Naqab–Tunnel road at its crossing with W. El Juweidleia.
- Ras El Naqab–Wasit road , where it is crossed by W. Shairet Umm Arqub.

(iii) Slightly dangerous sites include :

- Ras El Naqab–El Quseima road, crossings with wadis Haragis and Mijrah.
- Ras El Naqab–Tunnel road, crossing with W. Garrafy.
- Ras El Naqab–Wasit road at its crossings with wadis Garrafy, Abu Rahaiya and Umm Hassa.

(e) Internal Drainage Basins

Several sites of roads included in the internal basins province, are crossed by wadis and are prone to flash flood damages. These sites are differentiated as follows:

(i) Highly dangerous site: represented by the crossing of Ismailya–El Arish road with the mouth of W. El Meleiz.

(ii) Moderately dangerous sites include:-

- El Gifgafa–El Thamada road, crossings with wadis Muzeira, El Karam, and El Hazira.
- Farmlands at the mouth of W. El Sirr and on the floor of W. El Meleiz.

(iii) Slightly dangerous sites include:-

- El Gifgafa–El Thamada road, crossings with wadis Umm Zarub, El Murr, Abu Rima, El Baha and El Hazira.

- Nuweiba–Tunnel road at its crossings with wadis El Hagg, Mitla, El Giddi and Umm Khisheib.
- Farmlands on the floor of W. El Meliez.

SUMMARY AND CONCLUSIONS

The present work deals with the hydrographic characteristics of drainage basins of Sinai Peninsula. Eleven Landsat TM composites at scale 1:250,000 were used as data base for delineation and tracing of the drainage network of Sinai Peninsula. This network is well developed, fairly dense but is inconsistent all over the area, and drains terrains of different lithology, structure and physiography (landforms). Qualitatively, the types of drainage pattern along the highlands are coarse dendritic to subdendritic and parallel to sub-parallel, and less common types are trellis, rectangular and radial. On the other hand, the dominant types in the relative low plains are sub-parallel, braided and dichotomic. Generally, the drainage system of Sinai Peninsula is essentially a result of gravitative control modified by lithologic and structural variables.

The drainage net of Sinai was demarcated into 108 drainage basins, occupying a total of 47500 $km^2$with 9945 drainage lines of about 4223 km total length. These basins were sorted out, area-wise, into large (> 500 km^2), medium (500-150 km^2) and small (<150 km^2) basins. The large basins (13 basins) occupy a total area of about 39450 km^2, medium basins (11 basins) cover a total area of about 2894 km^2, and small basins (84 basins) occupy totally an area of about 5157 km^2. Furthermore, the drainage basins were differentiated into basins of internal and external systems. The former is represented by 28 internally drained basins located in NNW Sinai, and the latter (80 basins) was classified into four groups pertaining to: (a) Gulf of Suez (37 basins), (b) Gulf of Aqaba (41 basins), (c) Mediterranean Sea (W. El Arish basin), and (d) Dead Sea (W. Garrafy basin). The quantitative morphometric parameters of the delineated basins were defined in terms of order, bifurcation ratio, frequency, density, slope index, basin shape (circularity and elongation ratios), relief ratio and ruggedness number, in order to elucidate their bearing on runoff (flash flooding) behaviour.

According to the morphometric parameters, physiography and geologic (lithology and structure) setting, the basins were relatively assorted in respect to possible surface runoff potentiality into four classes; namely: (1) low runoff basins, (2) moderate runoff basins, (3) moderate to high runoff basins, and (4) high runoff basins. Basins of classes 2, 3 and 4 would be expected to yield sharp peaked discharge, and their contribution to recharge the near-surface groundwater aquifers is limited. Therefore, construction of simple flood-retardation structures (earthy dams and gabions) at suitable sites was recommended to enhance the infitration rate of surface runoff water.

Because of unawarness of flood hazard in landuse planning, many segments of main roads, settlements and farmlands in Sinai are threatend by flash floods. In view of slope gradient, catchment area, shape, drainage density, confluent angle, flow direction, width and depth of the affecting drainage channels, rock types, geological structures, and presence of settlement, farms and/or roads, risk assessment map for main highways, settlements, and farmlands was prepared showing sites vulnerable to flash flooding. Vulnerability was appraised and differentiated into three categories; namely: slight, moderate and high.

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