

Quantitative Geomorphological and Hydromorphometric Analysis of Drainage Basins of As Sabriyah (Kuwait) Using GIS Techniques

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Abstract

A well-developed drainage network was carved in the study area in a hard calcareous and gypcretized gravelly sand of the Dibdibba Formation (Al-Rukham slope) in pluvial episodes in the post-pleistocene age, and is referred to be paleo-drainage due to the current witnessed aridity. This study aims to investigate the geomorphologic, morphometric, and stratigraphic characteristics of the paleo-drainage system and its role in recharging shallow aquifers. Morphometric analysis was accomplished using GIS and remote sensing techniques. Six vertical pit holes were dug across the area to investigate the stratigraphy and recharging capacity. The drainage system is composed of 10 closely spaced, subparallel, dendritic, elongated, and variant-sloped drainage basins with highest stream order of 5. Water flows NE from Al-Rukham ridge's crest (60 m a.m.s.l.) downstream in Khor Al-Subiyah coastal flat. The bed rock's hard resistant nature lowered its infiltration and recharging capacity to the shallow aquifer, whereas the coarse-grained wadi fills deposits increased infiltration capacity of the surface sediments, but the water percolation chance is limited as it eventually directed seaward by the same-directed general topography resulting in limiting potential recharge to the shallow aquifers. This is suggested to oppose the salt water intrusion and thus enhance fresh water quality.

Keywords

Drainage System, Morphometric Characteristics, Wadi Fill Deposits, Dendritic Pattern, Calcretic, Gypcretic

1. Introduction

The study area (As Sabriyah) is located on the north and the northeastern part of Kuwait adjacent to As Sabbiya area towards the northeast and along the coastal line of Khor As Sabbiya, which separates the area from Bubyah island (**Figure 1(a)**, **Figure 1(b)**). According to topographic base map of the area (scale 1:250,000, 1995) (**Figure 2**), the elevation of the study area is ranging from about 2.7 m at

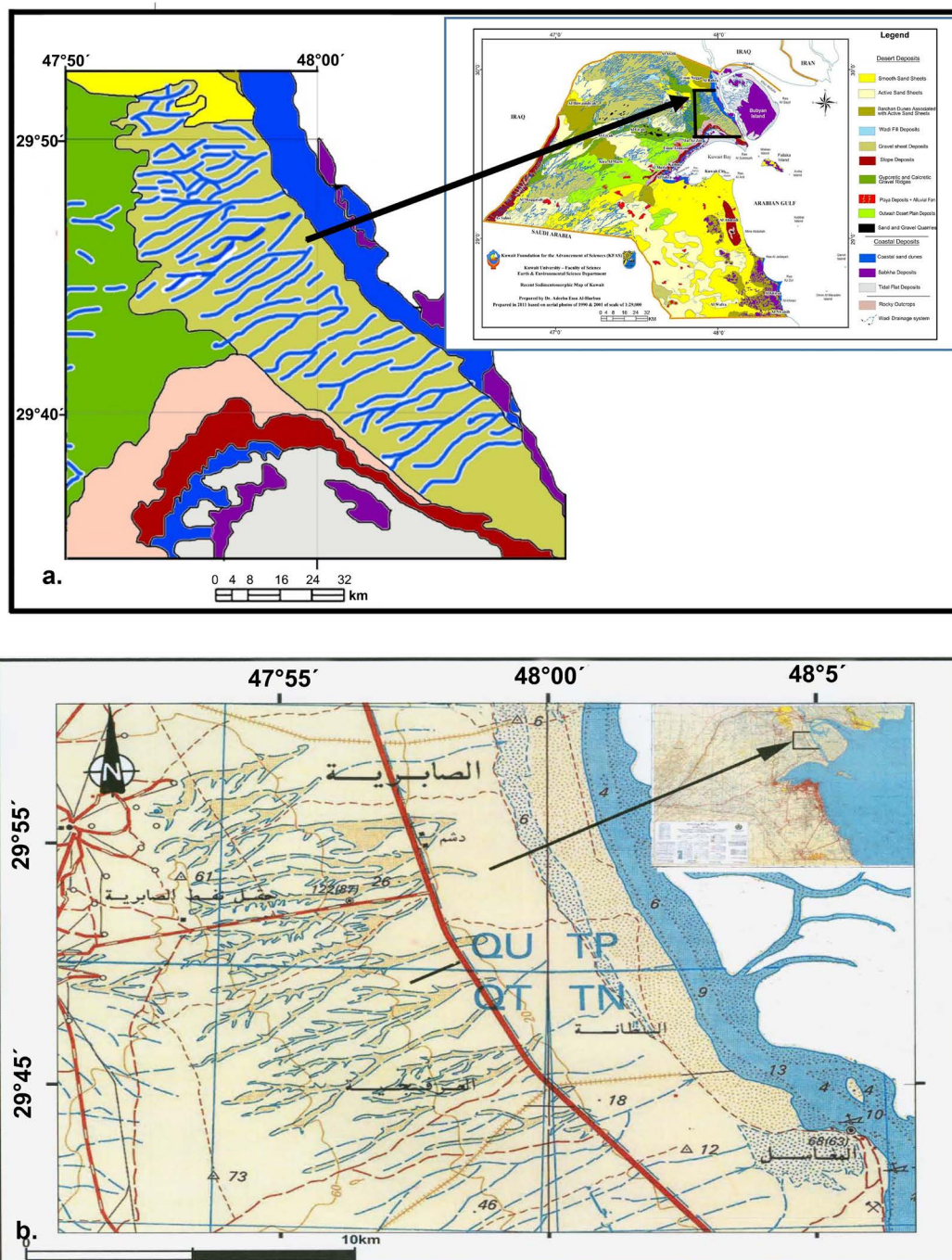


Figure 1. (a, b) Maps showing location, topography, sediment morphology, and the existing base lines and drainage pattern of the study area (after [1] (a) and [2] (b)).



Figure 2. Satellite images showing the location of the study area in the northeastern part of Kuwait. Source: Google Earth (image 2019 CNES/Airbus, 2019 Maxar Technologies).

the coastal parts to about <60 - 65 m heading to the middle inland westward and about 34 - 36 m to the west, with geographic coordinates (E47°47' - 48°00' - 48°04', N29°42' - 29°53') and it occupies an area of $\approx 301.056 \text{ km}^2$. In As Sabriyah area, a well-developed drainage network was carved in a hard calcretized and gypcretized gravelly sand of the Dibdibba Formation. This drainage network is thought to be developed in pluvial episodes in the post-pleistocene age due to the current aridity that the area witnesses, and therefore they are referred to be paleo-drainage network. This study aims to investigate the geomorphologic, morphometric, and stratigraphic characteristics of the Paleo-drainage system in As Sabriyah area in the north and the northeastern part of Kuwait, in order to assess the role of drainage network in recharging of shallow aquifers. The drainage basins were classified and mapped using GIS and remote sensing applications. The study is also aiming to discuss the environmental implications of the

studied drainage systems in the study area.

2. Previous Studies

The pattern, density and geometry of a drainage system of any geographic area are controlled by several factors. Such factors include the area's morphology, topography, surface geology, and climatic conditions, particularly the rate and frequency of precipitation which plays a significant role in triggering the drainage pattern and retaining it through the action of the surface runoff on the exposed rocks and sediments [3] [4]. The fluctuation in precipitation and the drought periods will directly affect maintaining the drainage system and indirectly the hydrological system and recharge off the shallow aquifers in an area, especially in arid deserts. Therefore, it is essential to study the geomorphological characteristics of the area in order to reveal their influence on the hydrological and environmental conditions of the present-day arid deserts; and in assessing the catchment of the present-day runoff and recharging of shallow aquifers, as well as, the development of soil material.

Though, the literature on drainage morphology in Kuwait is limited, but the drainage system of Jal Az-Zor escarpment was studied [5], as well as its sedimentomorphology [6]. A detailed morphometric analysis of the drainage basins in Kuwait was conducted, in addition to their genesis, their impact on the present-day arid environmental conditions, and the localities of natural recharge and the potential occurrence of limited shallow phreatic aquifers were estimated [3]. Several investigations on the paleodrainage system in Ar-Raudhatain and Umm Alish areas north of Kuwait were conducted [7] [8].

Generally, Kuwait is characterized by a long, dry, hot and windy summer climate that witnesses remarkable diurnal and monthly variations. Annual mean precipitation range is (23 - 45 mm). Monthly mean evapotranspiration range is 67 mm in January to 324 mm in July. Dust and sandstorms characterize Kuwait's weather, where sandstorms frequently occur in summer, the wind prevailing direction is from northwest and wind speed may exceed 5.5 m/s.

Kuwait Group is a terrigenous clastic depositional sequence of Miocene to Pleistocene age, and consists of three formations in the northern part of Kuwait, but barely differentiated in the southern areas (**Figure 3(a)**, **Figure 3(b)**). These are from bottom to top Ghar, lower Fars and Dibdibba Formations, where Dibdibba is a fluvial sequence of sands and sandy gravels and covers most of the northern area of Kuwait [1]. This shows that the study area geologically belongs to the upper member of Dibdibba Formations and physiographically, it is located in Al-Dibdibba gravel physiographic province.

2.1. Geomorphology and Morphostructural Features

Kuwait is situated on the fringe of two main physiographic regions: the sedimentary sequence of the Arabian monocline to the south and southwest, and the Mesopotamian plain with the Shatt Al-Arab delta to the north and northwest.

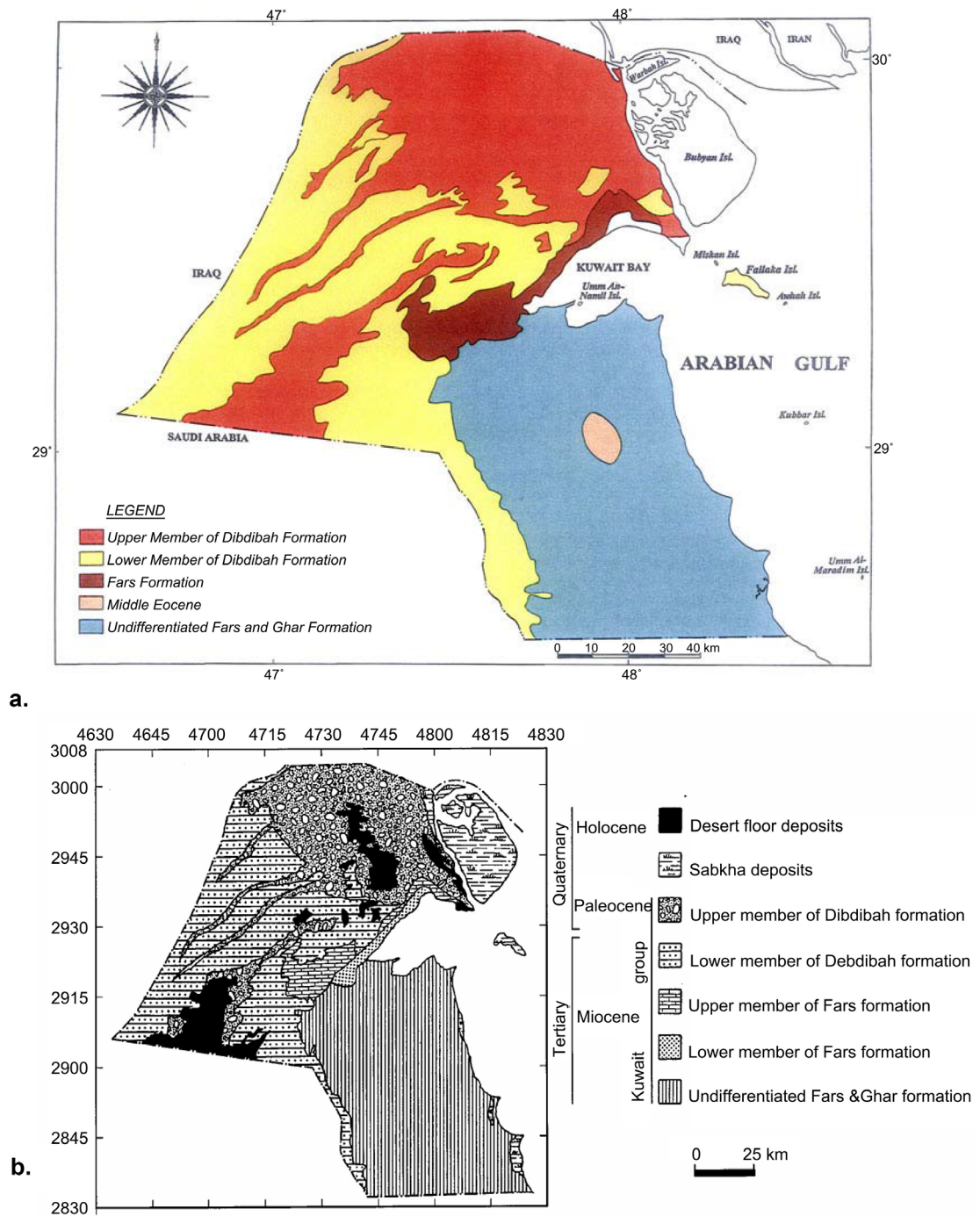


Figure 3. (a, b) Simplified geologic maps of Kuwait: a. geological maps using color (after [9]); and b. a geological map using the distribution of the sediments (after [3]).

Generally, the topographic surface is monotonously flat to gently rolling desert plain broken by occasional low hills, scraps, and shallow inland depressions [3]. The area is gently sloping from about 300 m a.m.s.l in the extreme southwestern corner towards the Mesopotamian lowland in the northeast. The existing geological structures and lithology of the exposed formations control the morphology of most of the country. **Figure 4(a), Figure 4(b)** shows the 15 classified

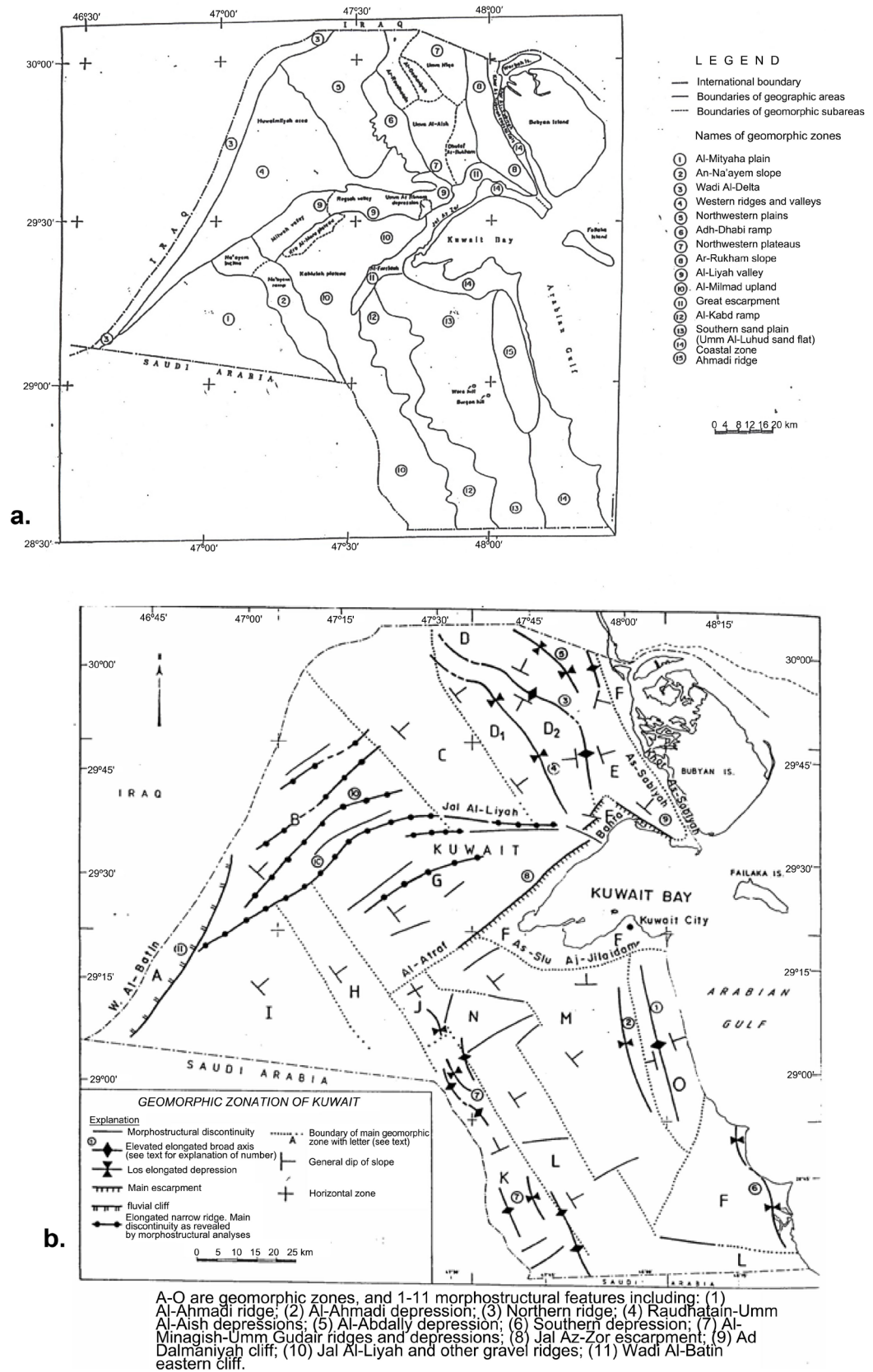


Figure 4. (a, b) Maps showing: (a) the 15 classified geomorphic zones of Kuwait [10] and (b) the classified morphostructural features of Kuwait [4].

geomorphic zones of Kuwait [10] showing that the study area is located in morphological zone (8) named Al-Ruham slope. The same figure also shows the classified morphostructural features of Kuwait surface [4], where the study area is surrounded by morphostructural features (3) the northern ridge, (4) Al-Rawdhatain and Um Al-Aish depression and (5) Al Abdali depression.

2.2. Hydrogeology

In general, Kuwait has extremely low surface runoff due to the low precipitation and the dry sandy soils. However, due to severe storms, substantial short duration flows may develop in the areas of integrated surface drainage and accumulated as playa lakes. The accumulated water infiltrates through the Dibdibba Formation to form fresh groundwater lenses in the Kuwait Group in the northern part of the country at Ar-Raudhatain and Umm Al-Aish areas [11]. The lithology of the Kuwait Group controls its content of groundwater, as the existence of local isolated aquicludes (calcrete and/or mud horizons) divides the Dibdibba Formation into two separate water-bearing horizons (Figure 5(a), Figure 5(b)) (Mukhopadhyay *et al.*, 1996; Al-Sulaimi and Al-Ruwaih, 2004). The water level of the Kuwait Group varies from about 80 - 90 m above sea level in the southwest to near ground level along the coast [3]. Groundwater generally

a.

Generalized Stratigraphy				Hydrogeological units	
KUWAIT GROUP (Quaternary)	Quaternary Sediments (<30m)		Unconsolidated sand and gravel, gypsiferous and calcareous silt and clays		Localized Aquifer
	Mio-Pliocene sediments of Hardruk, Dm and Hofuf Formation in Saudi Arabia; Ghar, Fars and Dibdibba Formations of Kuwait and southern Iraq (200-300m)		Gravelly sand, sandy, gravel, calcareous and gypsiferous sand, calcareous silty sandstone, sandy limestone, marl and shale; locally cherty		Aquifer
	Unconformity		Localized shale, clay and calcareous silty sandstone		Aquitard
HASA GROUP (Eocene)	Dammam Formation (60-200m)		Chalky, marly, dolomitic and calcarenitic limestone		Aquifer
			Nummulitic limestone and lignites and shale		Aquitard
	Rus Foramtion (20-200m)		Anhydrite and limestone		
	Umm Er Radhuma (UER) Formation (300-600m)		Limestone and dolomite (calcarenitic in the middle) with localized anhydrite layers		Aquifer
	Disconformity		Shales and marls		Aquitard
	Arum Group (400-600m)		Limestone and shaly limestone		Aquifer

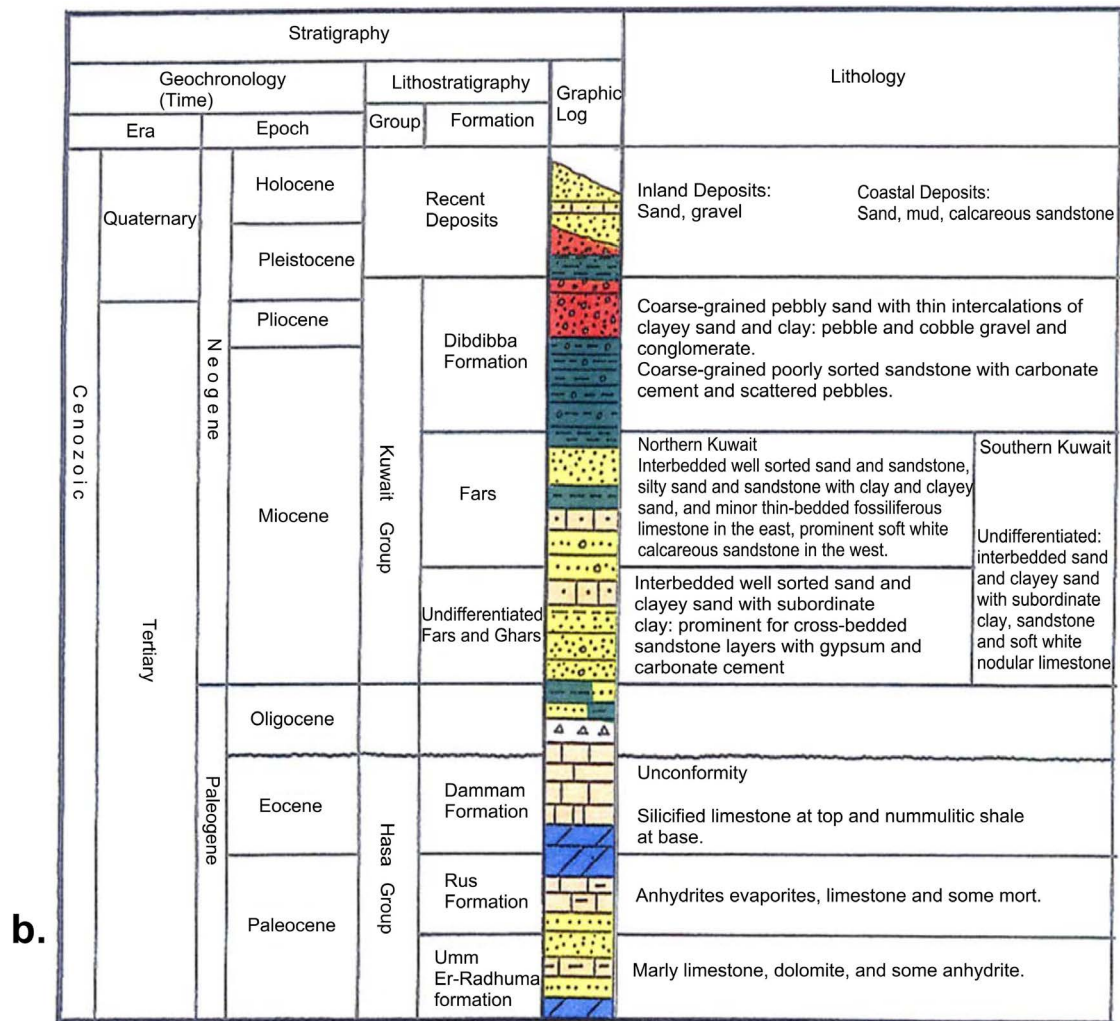


Figure 5. (a) Generalized stratigraphy [15] and hydrogeological units of Kuwait region [16]; and (b) Lithostratigraphic succession for the Kuwait region [17].

flows towards the northeast [12] [13], notifying that upward leakage of ground-water from the Dammam aquifer to the overlying Kuwait Group was confirmed by isotope data [14].

2.3. Drainage Distribution Pattern

2.3.1. The Late Pliocene/Early Pleistocene Phase

The last intense long humid period took place in late Pliocene/Early Pleistocene between 1.2 - 3.5 million years BP. It is characterized by its intense chemical weathering and enormous fluvial erosion and sedimentation processes from the mainly aeolian processes of the Quaternary. This is evident in the filled-up erosion channels of the ancient drainage system, and directly connected with them are the gravel fans, which declared long ago to the remnants of an intense humid period [18].

Kuwait desert is dissected by drainage systems that vary in patterns and dimensions (Figure 6). Despite the climatic aridity, the drainage patterns show a

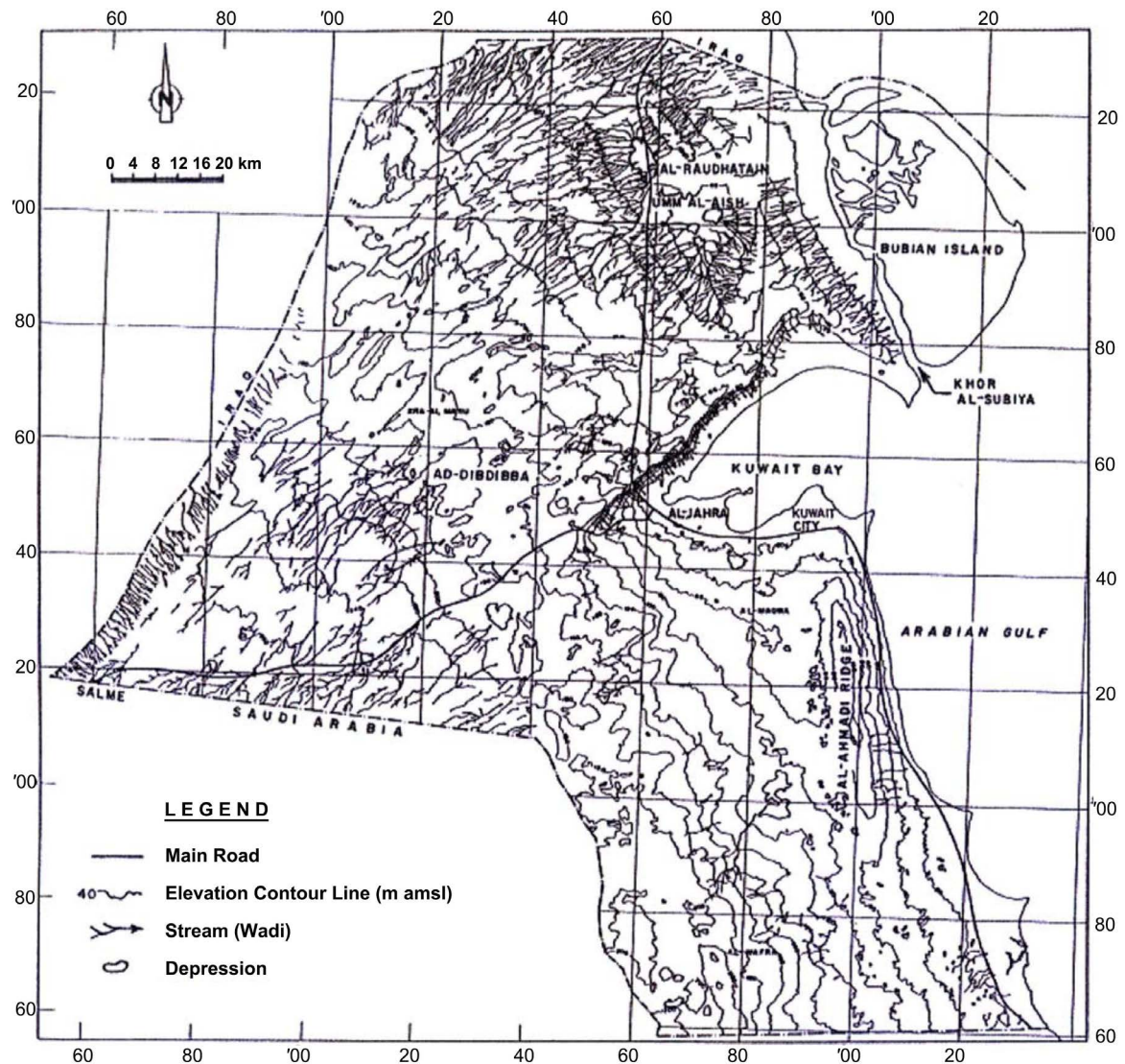


Figure 6. A topographic and drainage systems map of Kuwait (After [20]).

well-developed network in the Dibdibba gravelly plain, whereas it is very scarce in the southern sandy flat [3] [19]. Depending on the density and pattern of drainage network, seven drainage zones have been recognized all over Kuwait (Figure 7). Drainage Zone (I) is of prime importance to this research, because the present study area is part of it.

2.3.2. Zone (I): Al-Rukham Slope Drainage System

The drainage Zone (I) is developed on Al-Rukham slope (an Arabic term used to describe the debris in their final destiny) covering an area of about 560 km² and constituted of more than 30 closely spaced sub-parallel to dendritic drainage patterns, grooved into the Upper Member of the gravelly Dibdibba Formation. The drainage channels flow from the water divide along the crest of the Al-Rukham crest (about 60 m a.m.s.l.) towards northeast ending downstream lies in the Khor Al-Subbiyah coastal flat (Figure 7) (Al-Sulaimi *et al.*, 1997).

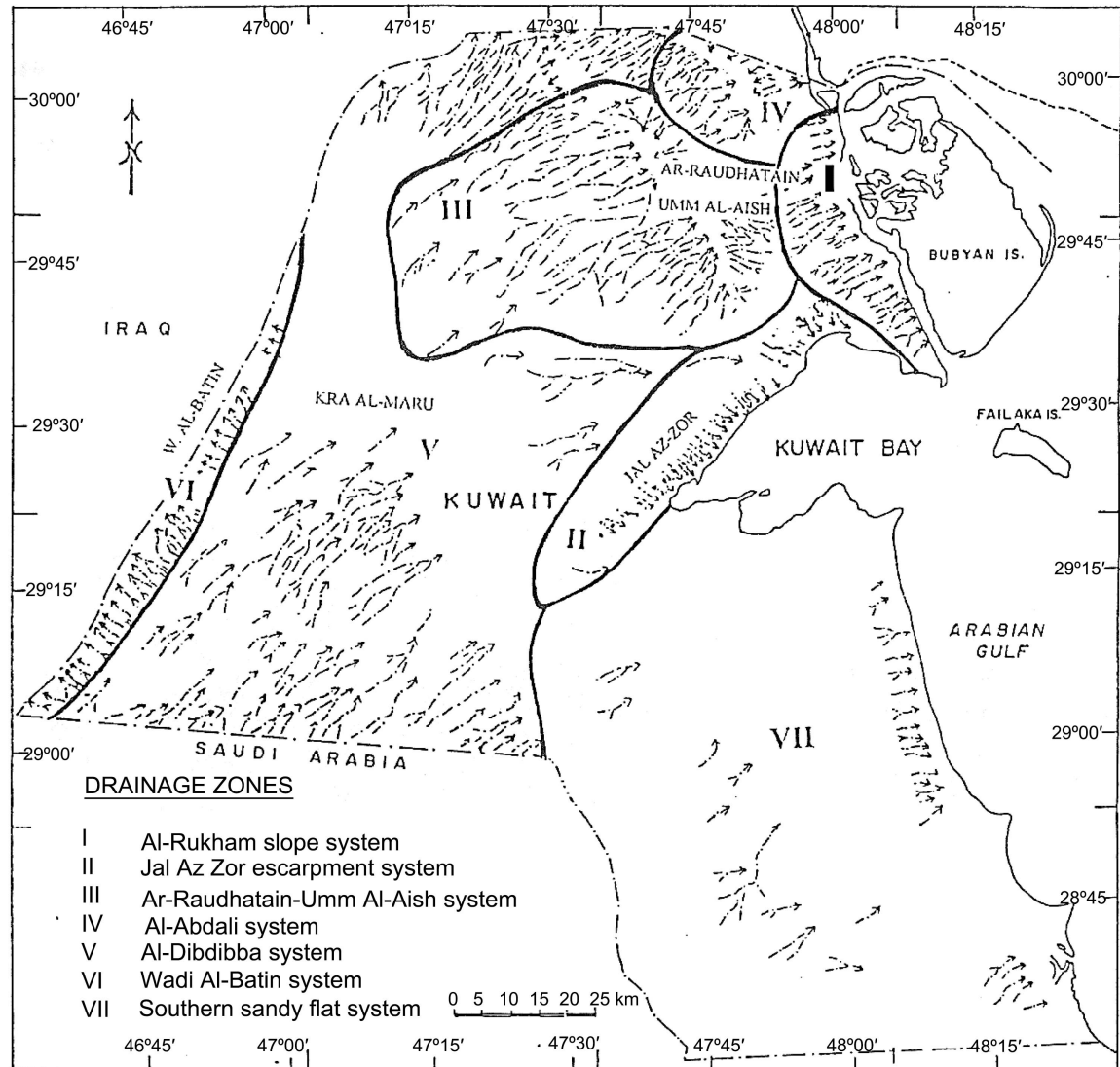


Figure 7. Zonation of drainage systems in Kuwait [3].

3. Methodology

3.1. Field Investigation and Sampling

Using GIS and remote sensing data, topographic, aspect and slope directions maps were constructed for the drainage network in the study area showing the water divide and the catchment area along with the morphology, pattern, wadis, streams, ephemeral rivers, dry creeks, erosion gullies undulations, tributaries to the main streams, and basins of the well-developed paleo-drainage network carved in the study area.

3.2. Field Work

Six sites were located for digging vertical pit holes (Figure 8) encompassing the different identified drainage basins taking into consideration changing between the catchment area and the surrounding arms of the basins, in order to allow

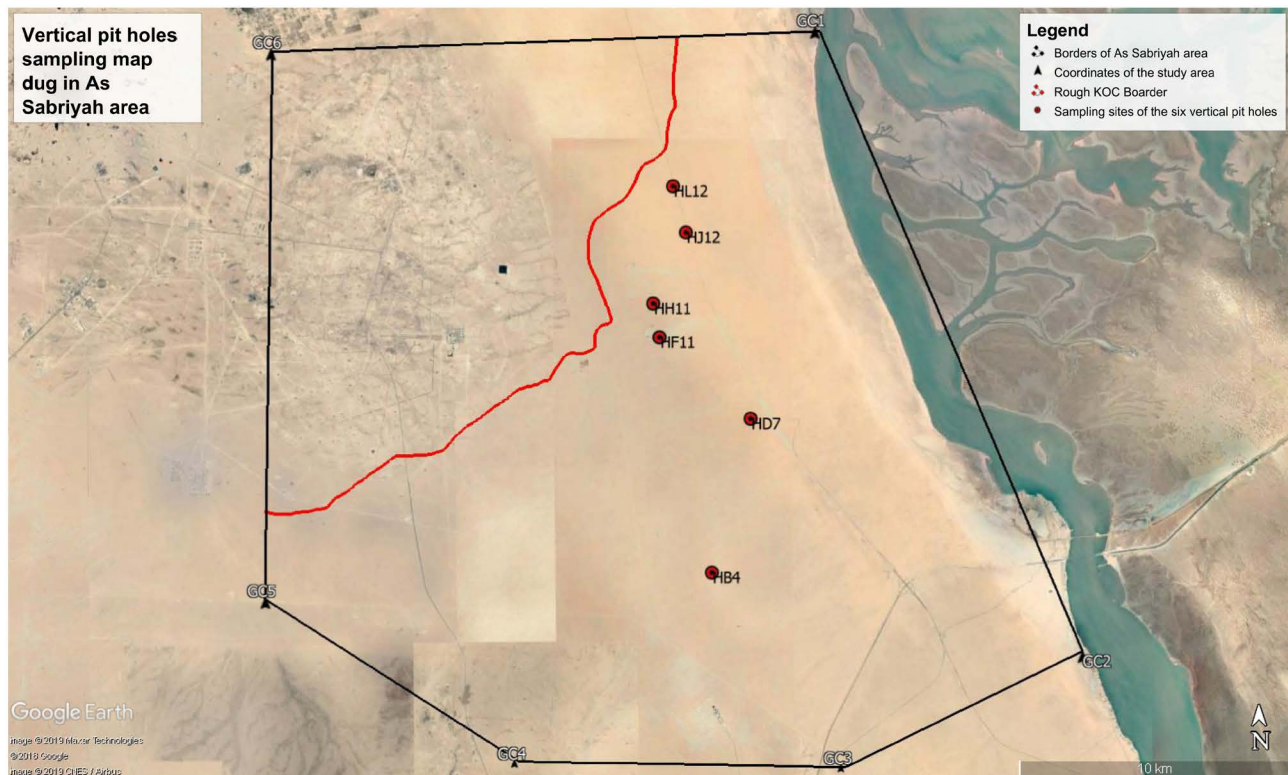


Figure 8. Satellite image showing the sites of the dug vertical pits dug in the study area (As Sabriyah) from which samples were collected at variant depths (source: Google Earth (image 2018 CNES/Airbus, 2018 Digital Globe)).

constructing basic stratigraphic information over this large landscape area, due to the absence of previous detailed studies regarding the sedimentary succession and stratigraphy, using an auger sampler. The obtained vertical pit samples were then packed in plastic bags, labeled, described, photographed and transported to labs for sediment and lithological analyses and correlation.

3.3. Laboratory Investigations

Different analyses of samples were conducted included: 1) mechanical analysis (grain size analysis); 2) mineralogical analysis (x-ray diffraction (XRD), x-ray fluorescence (XRF), inductively coupled plasma optical emission spectrometer (ICP-OES) and thin sections).

3.4. Surface Hydrology (Basin Analysis)

3.4.1. Basin Geology and Geomorphology

The portion of the precipitation which infiltrate may add to the moisture content of the soil or may become groundwater. The most influential factor in determining the steadiness or variability of flow is the source of supply. If the drainage basin is very permeable, as one having coarse sandy soil, there may be almost no surface runoff. The ability of a drainage basin to absorb and detain the water provides a key to the character of the resulting hydrograph and becomes important to the hydrologist. The main geologic factors affecting surface runoff

are lithology and structure. Lithologic effects are due to the composition, texture and sequence of rocks. To study the basin geomorphology, basin is described by introducing the concept of stream orders [21]. The drainage basin features of hydrologic importance are: elevation, stream length, basin perimeter, drainage area.

3.4.2. Morphometric Analysis Using ArcHydro GIS Technology and STRM Analysis System

To obtain information on the spatial variability in processes throughout a watershed requires delineation of the drainage system, which includes the stream channel network and smaller catchments within the basin.

In addition, every watershed can be characterized by geometric properties related to its linear, areal and relief properties. These properties are related to the position of a stream within the watershed, and can be used to compare watersheds. The raster GIS procedures were utilized and ArcHydro, state-of-the-art GIS technology for watershed sciences, was used to delineate the drainage basins and drainage network of the study area. In addition, several indices of drainage basin morphometry, including stream order (N_μ), stream length (L_μ), water divide length, basin's area (A), basin's perimeter (P), basin's length (L_b), basin's width (W_b), total basin relief (H), relief ratio (R_{hl}) and relative relief ratio (R_{hp}) of the drainage basins, elongation ratio (R_e), circularity ratio (R_c), combination coefficient (C_c), form factor ratio (R_f), ruggedness number (R_n), bifurcation ratio (R_b), drainage density (D_d), and drainage frequency (F_s) were calculated to quantify the morphometry of the watersheds in the study area, using the underneath indicated equations:

$$\text{Total basin relief: } H = Z - z \quad [22]$$

$$\text{Relief ratio: } R_{hl} = H / L_b \quad [23]$$

$$\text{Relative relief ratio: } R_{hp} = (H \times 100) / P \quad [24]$$

$$\text{Ruggedness number: } R_n = (D_d \times H) / P \quad [23]$$

$$\text{Circularity ratio: } R_c = 4\pi A / P^2 \quad [25]$$

$$\text{Elongation ratio: } R_e = \left(\sqrt[2]{\frac{A}{\pi}} \right) / L_b \quad [23]$$

$$\text{Form factor ratio: } R_f = A / L_b^2 \quad [21]$$

$$\text{Bifurcation ratio: } R_b = N_\mu / (N_\mu + 1) \quad [23]$$

$$\text{Drainage density: } D_d = L_\mu / A \quad [21]$$

$$\text{Drainage frequency: } F_s = N_s / A \quad [21]$$

where:

Z = Highest elevation inside the basin

z = Lowest elevation inside the basin

L_b = Basin's length (maximum parallel to the main stream (m))

P = Basin's perimeter (m)

A = Basin's area (km²)

D_d = Drainage density (km/km²)

P = Basin's perimeter (m)

L_b = Basin's length

N_μ = Streams number in a stream order

$N_\mu + 1$ = Streams number in higher consecutive ranking stream order adding 1

L_μ = Sum of all streams lengths in all orders (km)

N_s = Sum of streams numbers in all orders.

4. Results & Discussion

4.1. Mechanical Analysis

Grain Size Analysis

To investigate the grain size distribution of sediments, characterize size parameters, and their possible geological significance the collected sub-lag samples of sand nature were analyzed in the laboratory using standard sieving (The U. S. standard Set of Sieves) and sedimentation techniques [26] [27]. The obtained data were graphically represented by histograms and cumulative frequency curves, which were used in the identification of the various textural parameters for these samples. These parameters are mode, median, mean, sorting, skewness, and kurtosis. Interrelationships of these size parameters were constructed. **Table 1** shows the mechanical analysis results along with the statistical textural parameters.

Table 1. The mechanical analysis results along with the statistical textural parameters.

Sample		Grain Size							Cumulative Weight %							Mode	Median	Mean	Sorting	Skewness	Kurtosis	
		Gravel	V.C.	C.	M.	F.	V.F.	Mud	Sum.	Gravel	V.C.	C.	M.	F.	V.F.							Mud
			Sand	Sand	Sand	Sand	Sand				Sand	Sand	Sand	Sand	Sand							
1	HB4-1	17.43	13.36	15.13	18.98	20.41	13.09	1.6	100	17.43	30.79	45.92	64.9	85.31	98.4	100	-3.0/-1.25/ 1.25/1.75	0.99	0.79	1.95	-0.21	0.87
2	HB4-2	29.79	17.01	15.91	16.9	12.77	6.34	1.28	100	29.79	46.8	62.71	79.61	92.38	98.72	100	-3.0/-1.25/ 1.25	-0.01	-0.02	2.17	-0.08	1.01
3	HB4-3	54.05	17.43	12.71	10.12	4.02	1.38	0.29	100	54.05	71.48	84.19	94.31	98.33	99.71	100	-3.0	-1.42	-1.74	2.66	-0.21	1.04
4	HB4-4	65.85	12.29	9.62	8.59	2.43	1	0.22	100	65.85	78.14	87.76	96.35	98.78	99.78	100	-2.4	-2.46	-3.00	3.58	-0.26	0.93
Average		41.78	15.02	13.34	13.6	9.908	5.45	0.8	100	41.8	56.8	70.15	83.79	93.7	99.15	100		-0.7	-1	2.6	-0.2	0.96
5	HD7-1	22.68	15.55	14.6	19.31	19.1	7.9	0.86	100	22.68	38.23	52.83	72.14	91.24	99.14	100	-3.0/-1.25/ 1.25/2.75	0.60	0.50	1.98	-0.16	0.91
6	HD7-2	61.34	11.96	10	8.56	5.08	2.38	0.68	100	61.34	73.3	83.3	91.86	96.94	99.32	100	-3.0/-1.25	-2.45	-4.09	5.68	-0.45	0.94
7	HD7-3	44.3	19.89	15.12	11.95	5.93	2.51	0.3	100	44.3	64.19	79.31	91.26	97.19	99.7	100	-3.0/-1.25/ 0.75	-0.99	-1.03	2.25	-0.08	1.15
8	HD7-4	58.36	15.58	10.66	9.47	3.75	1.63	0.55	100	58.36	73.94	84.6	94.07	97.82	99.45	100	-3.0/-1.25/ 0.75	-1.67	-2.44	3.51	-0.35	0.99
Average		46.67	15.75	12.60	12.32	8.47	3.61	0.60	100	46.67	62.42	75.01	87.33	95.80	99.40	100		-1.13	-1.77	3.36	-0.26	1.00
9	HF11-1	47.55	20.34	13.95	8.87	5.67	3.22	0.4	100	47.55	67.89	81.84	90.71	96.38	99.6	100	-3.0/-1.25/ 2.75	-1.12	-1.18	2.31	-0.06	1.22

Continued

10 HF11-2	48.49	17.64	15.1	11.32	4.97	2.14	0.34	100	48.49	66.13	81.23	92.55	97.52	99.66	100	-3.0/0.75	-1.17	-1.23	2.25	-0.07	1.02
11 HF11-3	32.13	22.87	19.85	18.12	4.91	1.85	0.27	100	32.13	55	74.85	92.97	97.88	99.73	100	-1.25/1.25	-0.49	-0.46	1.72	-0.04	1.05
12 HF11-4	44.12	19.89	15.61	14.45	4.2	1.5	0.23	100	44.12	64.01	79.62	94.07	98.27	99.77	100	-3.0/-1.25/ 1.25	-0.96	-1.25	2.44	-0.24	1.06
13 HF11-5	37.74	14.89	15.99	16.19	8.83	4.85	1.51	100	37.74	52.63	68.62	84.81	93.64	98.49	100	-3.0/-1.25/ 1.25	-0.43	-0.86	2.92	-0.28	1.17
Average	42.01	19.13	16.1	13.8	5.716	2.71	0.6	100	42	61.13	77.23	91.02	96.74	99.45	100		-0.8	-1	2.3	-0.1	1.1
14 HH11-1	51.06	11.27	9.98	11.79	9.12	5.41	1.37	100	51.06	62.33	72.31	84.1	93.22	98.63	100	-1.75/-0.75/ 1.25/2.75	-1.36	-0.73	2.03	0.42	0.77
15 HH11-2	56.38	15.84	13.39	11.38	2.35	0.57	0.09	100	56.38	72.22	85.61	96.99	99.34	99.91	100	-3.0/-1.25/ 0.75	-1.56	-2.5	3.58	0.43	0.97
16 HH11-3	59.49	14.8	10.17	12.2	2.81	0.49	0.04	100	59.49	74.29	84.46	96.66	99.47	99.96	100	-3.0/1.25	-1.64	-1.85	2.61	-0.17	0.96
17 HH11-4	44.12	19.26	16.53	16.2	3.46	0.38	0.05	100	44.12	63.38	79.91	96.11	99.57	99.95	100	-3.0/-0.75/ 0.75	-0.96	-1.37	2.59	-0.31	1.04
18 HH11-5	50.95	16.2	14.66	12.97	4.28	0.8	0.14	100	50.95	67.15	81.81	94.78	99.06	99.86	100	-3.0/0.75	-1.25	-1.62	2.7	-0.25	0.98
19 HH11-6	59.81	16.82	12.55	8.11	2.19	0.46	0.06	100	59.81	76.63	89.18	97.29	99.48	99.94	100	-3.0/1.25	-1.71	-2.75	3.58	-0.45	0.97
20 HH11-7	47.22	18.66	15.16	14.6	3.5	0.8	0.06	100	47.22	65.88	81.04	95.64	99.14	99.94	100	-3.0/1.25	-1.11	-1.56	2.72	-0.31	1.04
Average	52.72	16.12	13.21	12.5	3.959	1.27	0.3	100	52.7	68.84	82.05	94.51	98.47	99.74	100		-1.4	-1.8	2.8	-0.1	0.96
21 HJ12-1	8.03	19.34	15.12	22.47	23.55	10.18	1.31	100	8.03	27.37	42.49	64.96	88.51	98.69	100	-3.0/-0.75/ 1.75/2.75	1.1	0.94	1.6	-0.14	0.76
22 HJ12-2	26.57	16.38	14.45	17.7	17.32	6.65	0.93	100	26.57	42.95	57.4	75.1	92.42	99.07	100	-3.0/-1.25/ 1.75/2.75	0.3	0.35	1.99	-0.08	0.91
23 HJ12-3	28.8	17.59	14.18	16.97	15.88	5.64	0.94	100	28.8	46.39	60.57	77.54	93.42	99.06	100	-3.0/-1.25/ 1.25/2.75	0.01	0.16	2.12	-0.05	1.04
24 HJ12-4	50.6	18.55	13.48	10.35	5.35	1.61	0.06	100	50.6	69.15	82.63	92.98	98.33	99.94	100	-3.0/-1.25/ 0.75	-1.25	-1.59	2.69	-0.22	1.09
25 HJ12-5	55.11	19.01	13.9	7.7	2.96	1.12	0.2	100	55.11	74.12	88.02	95.72	98.68	99.8	100	-3.0	-1.44	-1.71	2.34	-0.19	1.06
Average	33.82	18.17	14.23	15	13.01	5.04	0.7	100	33.8	52	66.22	81.26	94.27	99.31	100		-0.3	-0.4	2.1	-0.1	0.97
26 HL12-1	9.02	8.04	9.92	19.31	27.72	23.13	2.86	100	9.02	17.06	26.98	46.29	74.01	97.14	100	-3.0/-1.25/ 2.75	1.92	1.55	1.63	-0.33	0.96
27 HL12-2	33.09	14.79	10.84	15.61	13.94	9.96	1.77	100	33.09	47.88	58.72	74.33	88.27	98.23	100	-3.0/-1.25/ 1.75/2.75	0	0	2.47	-0.09	0.97
28 HL12-3	23.13	17.97	17.81	21.1	14.31	5.01	0.67	100	23.13	41.1	58.91	80.01	94.32	99.33	100	-1.25/1.25	0.33	0.3	1.7	-0.05	0.85
29 HL12-4	19.51	16.96	17.08	27.34	13.51	5	0.6	100	19.51	36.47	53.55	80.89	94.4	99.4	100	-1.25/1.25	0.59	0.4	1.68	-0.18	0.92
30 HL12-5	16.43	16.56	18.18	30.14	12.69	5.03	0.97	100	16.43	32.99	51.17	81.31	94	99.03	100	-1.25/1.25	0.69	0.47	1.55	-0.16	0.89
Average	20.24	14.86	14.77	22.7	16.43	9.63	1.4	100	20.2	35.1	49.87	72.57	89	98.63	100		0.71	0.54	1.8	-0.2	0.92

The highest frequency mode was the bi-modal (10×), but the tri-modal and the polymodal recorded slightly lesser frequency (8×) and come last the uni-modal, which was a frequency only for 3 times. This means that the size distribution is deviated from normal due to the presence of differently size sediments in the same sample. This indicates the presence of unstable and different

depositional environments of the grains, such as, playa or low depressions, wadi fill deposits and stream channel deposits, and the sediments were deposited in relatively high energetic fluvial medium as gravel, sand and mud sized deposits co-exist, and the sediments are frequently reworked and fed up with new load of sediments.

On average basis, the median recorded negative values ($-1.38 - (-0.26)\phi$) in all the pit holes except the last one to the north of the study area it recorded a positive value (0.71ϕ), the mean grain size changed from coarse sand size ($(0.00\phi-1.00\phi)$) to pebbly size ($-2.00\phi-6.0\phi$), the prevailing sorting class was very poorly sorted class ($2.00\phi-4.00\phi$), the prevailing skewness class was coarsely skewed ($-0.10\phi-0.30\phi$) and all the pit holes were of mesokurtic in kurtosis ($0.90\phi-1.11\phi$). It is worth mentioning that as heading to the north of the study area the mean size has a general trend to change from coarser to finer size. This means that the sediments are of coarse size general trend and the sediments are of fluvial transportation and frequent reworking and winnowing and reflecting the asymmetrical grains distribution and the multi-sized sediments.

4.2. Mineralogical Analysis

4.2.1. X-Ray Diffraction

On average basis, the XRD results pit holes' samples showed that Quartz mineral was the predominating constituent in pit holes with a range of (32.68% - 49.60%); followed by gypsum mineral with lesser range (16.79% - 30.38%). Calcite also recorded lesser amounts than quartz and gypsum (12.56% - 19.13%), Microcline (9.93% - 10.50%), then comes dolomite and Montmorillonite with very few percentage (0.00% - 0.60%) and (0.00% - 0.31%), respectively.

4.2.2. X-Ray Fluorescence (XRF)

The XRF results obtained for the samples collected from the six vertical pit hole dug in the catchment area of the well-developed drainage network in the study area showed, on average basis, that the predominating oxide is SiO_2 , *i.e.*, quartz, within the range (50.69% - 37.03%). This range was remarkably quantitatively higher (big difference) than the range of the quantitatively following oxides CaO (20.81% - 13.97%), SO_3 (8.26% - 10.66%), Al_2O_3 (6.35% - 3.46%), MgO (2.36% - 2.04%), Na_2O (2.28% - 1.81%), K_2O (1.92% - 1.28%), and Fe_2O_3 (1.45% - 1.07%). The other oxides (MnO , TiO_2 , P_2O_5 , and SrO , are in ranges less than 1%. This supports the suggestion that the existing rocks in the stratigraphy of the area are mostly calcareous gypsiferous sandy rocks.

4.2.3. Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES)

The data obtained from this analysis showed that, on average basis, calcium (Ca) metal is the predominating in all the holes (43,198.62 - 5953.99 mg/kg) followed by iron (Fe), but with considerable difference in recorded values (5079.85 - 3298.02 mg/kg), and lesser amounts of magnesium (Mg) (4106.93 - 1308.79 mg/kg). This suggests that the rocks calcareous or gypsiferous with iron-magnesium

bearing minerals or rock fragments.

4.2.4. Thin Sections

According to the analysis of the thin sections prepared from for selected bulk rocky samples extracted from the vertical pit holes, it was shown that these rocks are either calcretic lithic arenite, lithic arenite (greywacke), or wacke mud-supported sandstone. In general, all these rocks are very porous, where the pores are filled with mounting medium with carbonate mud as matrix and silica as cement in the form of quartz over growth. These rocks are formed as the result of rapid up-lift and intense erosion and high rate of deposition as a flush. In almost all the samples the matrix clay is affected by varying degrees by carbonate replacement. In some places there is also some kind of diagenetic replacement in carbonates.

4.3. Surface Hydrology (Basin Analysis)

4.3.1. Basin Geology and Geomorphology

The streams in the well-developed drainage system in the study area are of the ephemeral streams or dry washes that only occasionally have water flowing. They are above the water table and occur in dry climates with low amounts of rainfall and high evaporation rates. They flow mostly during rare flash floods. Using GIS and remote sensing techniques several maps were made for the drainage system in the study area (**Figures 9-14**), as well as a table showing the characteristics of the basins found in the drainage system of the study area (**Table 2**).

4.3.2. Morphometric Analysis and Characteristics Using ArcHydro GIS Technology and STRM Analysis System

As for the elongation rate, 3 groups were noticed (**Table 3**): 1) low rate (4 basins),

Table 2. Characteristics of the 10 basins in the drainage system of the study area.

Basins	Characteristics										Water divide length (Km)	Basin's area (Km²)
	Order 1		Order 2		Order 3		Order 4		Order 5			
	Length (m)	Number	Length (m)	Number	Length (m)	Number	Length (m)	Number	Length (m)	Number		
Basin 1	25,911	54	15,788	25	7387	16	4320	1	0	0	32	28
Basin 2	45,388	133	20,279	22	31,050	7	4321	2	4951	1	66	88
Basin 3	61,572	123	23,459	37	29,891	8	1207	3	8342	1	59.7	85.7
Basin 4	9346	23	8830	3	3728	1	0	0	0	0	23	15
Basin 5	10,543	24	2061	3	6811	1	5746	1	0	0	33	13.5
Basin 6	36,556	83	11,617	3	3300	2	15,470	1	2959	1	57	50
Basin 7	7544	21	5603	3	2088	1	6196	1	0	0	33	13
Basin 8	12,208	12	20,501	25	14,462	5	19,168	1	0	0	N/A	81
Basin 9	12,425	39	4966	9	10,096	1	0	0	0	0	30	17
Basin 10	24,491	43	23,792	7	1789	1	0	0	0	0	31	33

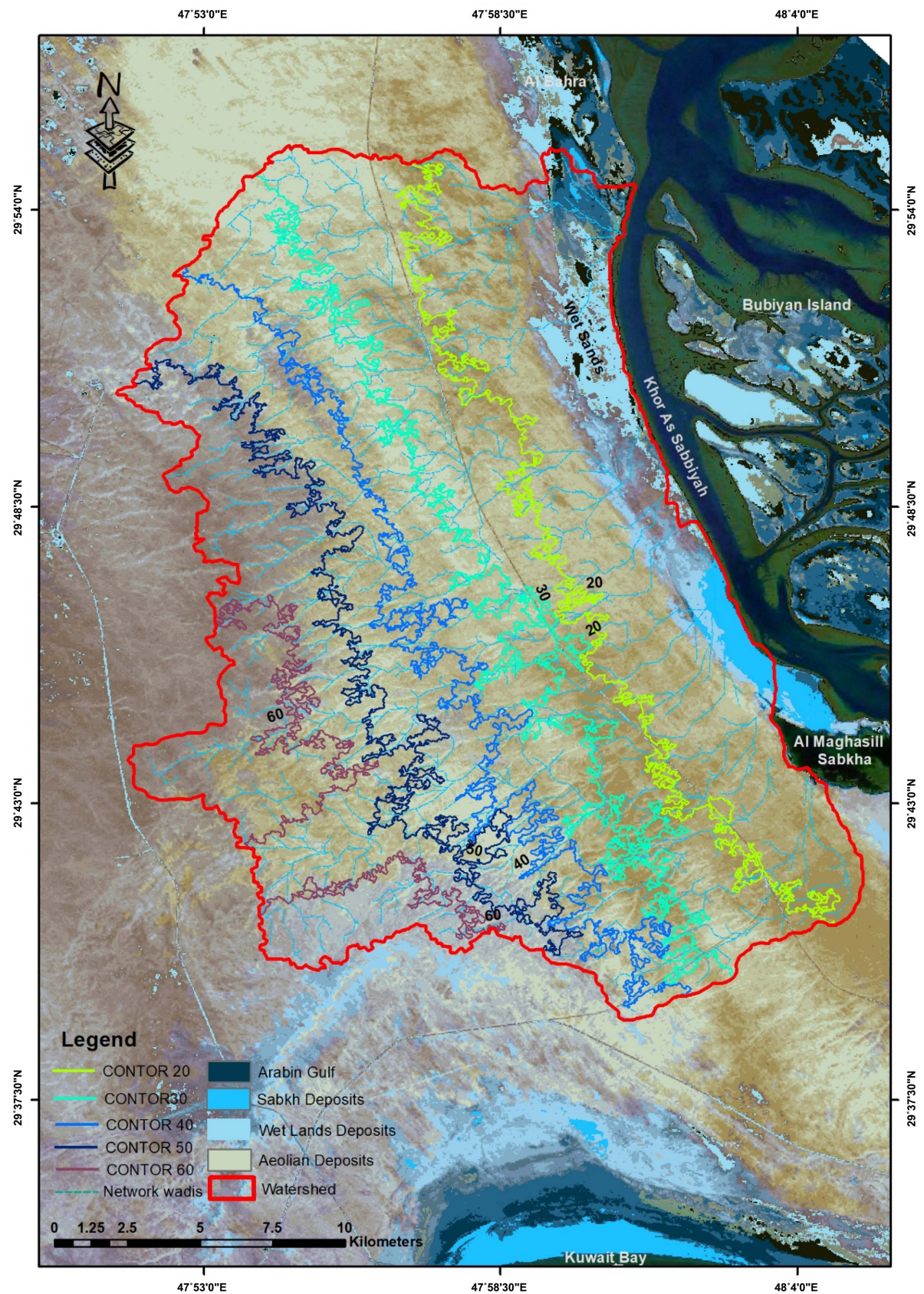


Figure 9. Contour map of the catchment area in As Sabriyah area.

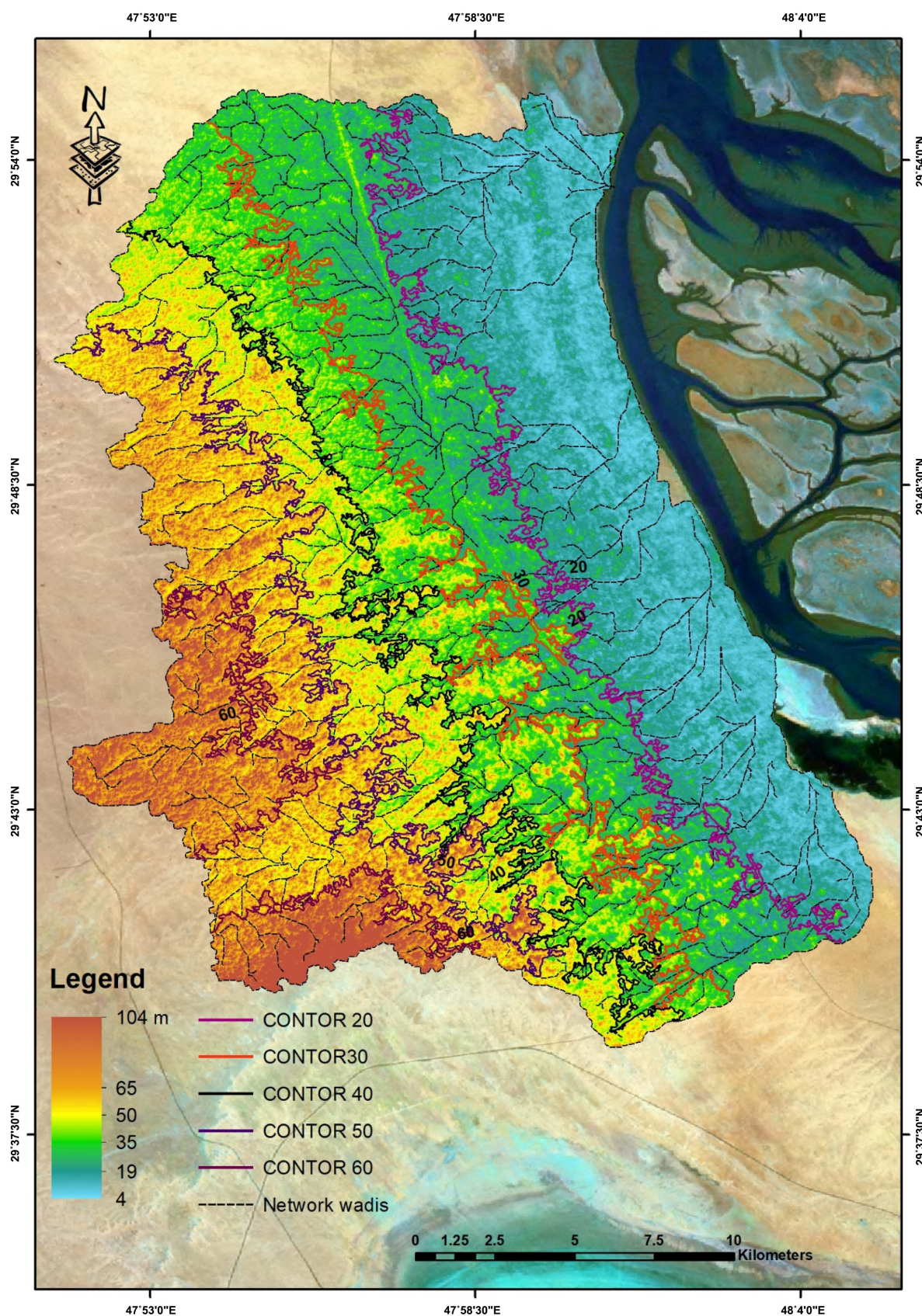


Figure 10. Contour map of the study area with the network wadis.

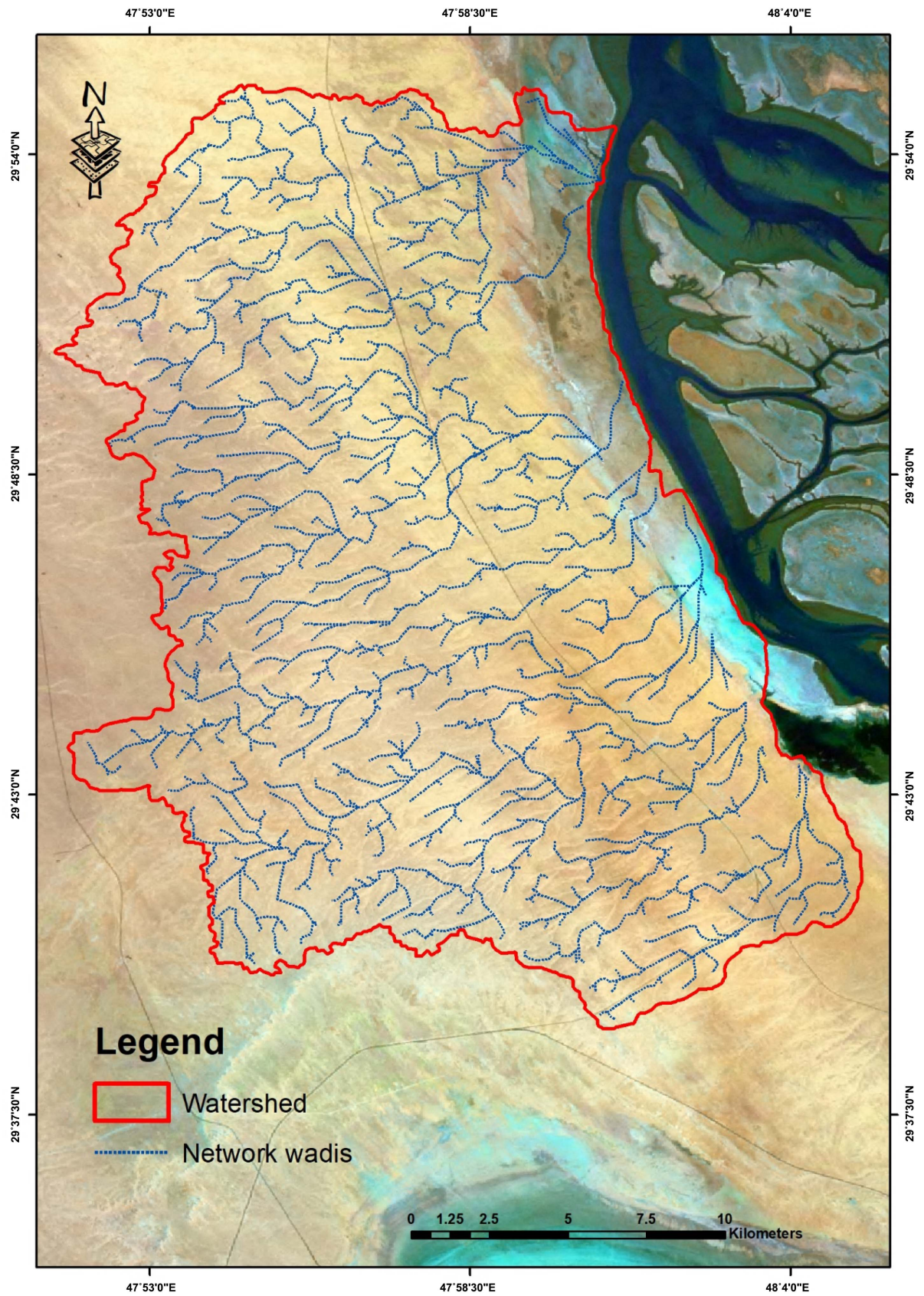


Figure 11. The pattern of the network wadis in the study area.

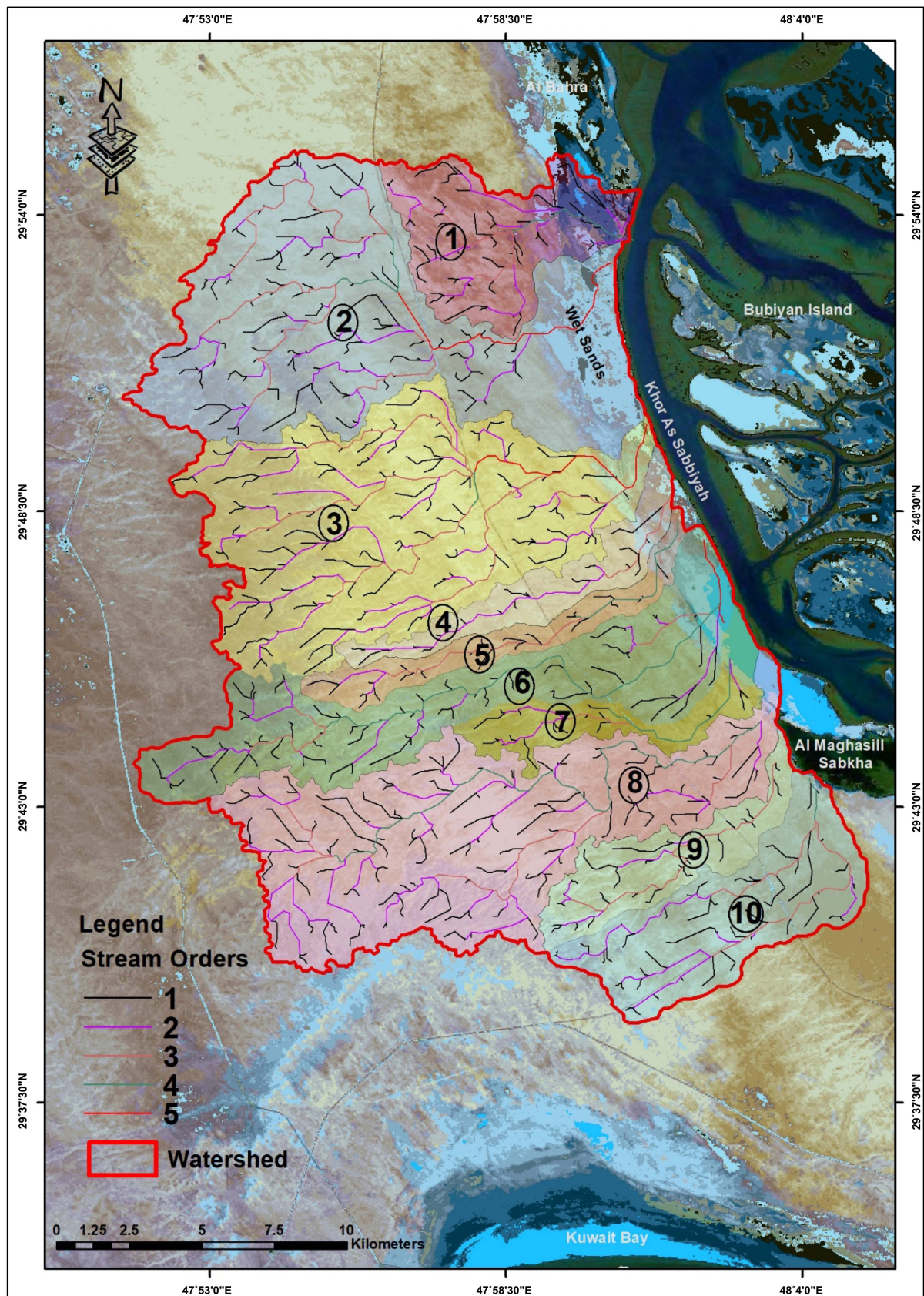


Figure 12. The basins of network wadis in the study area with their orders.

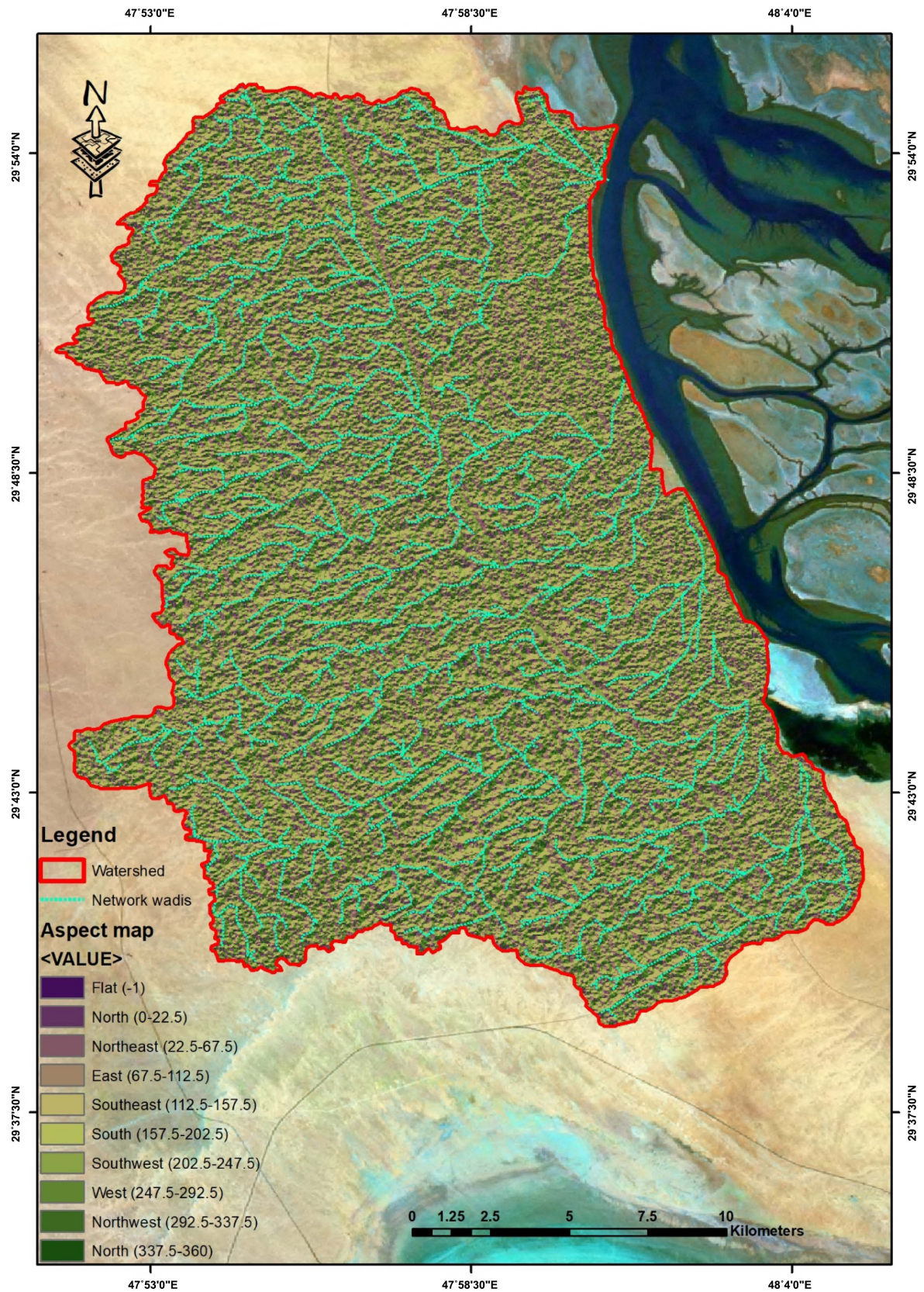


Figure 13. An aspect map of the drainage basin indicating the slope directions in the network wadis of the drainage system in the study area.

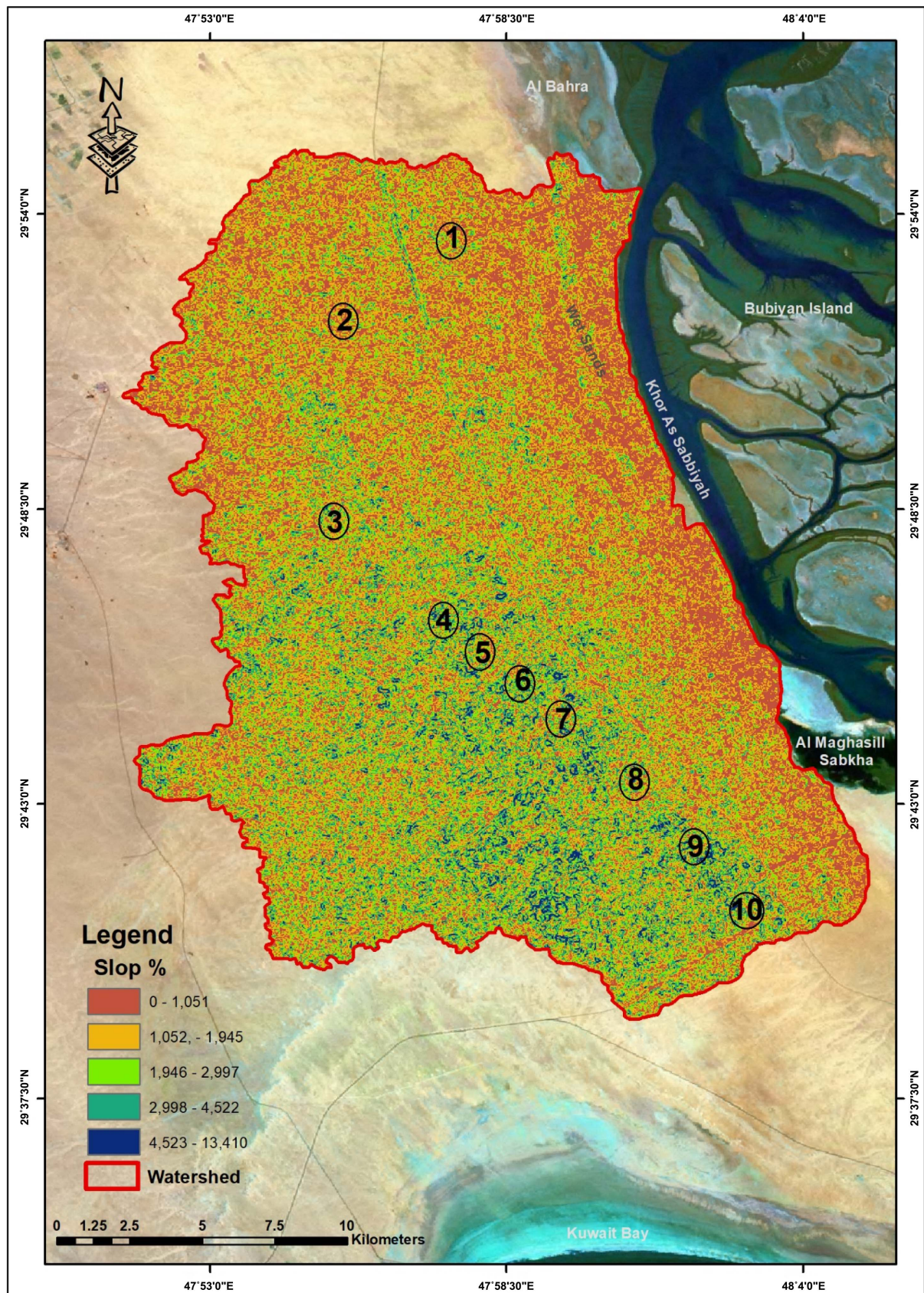


Figure 14. A map indicating the slope gradient ranges in basins of the drainage system of the study area.

Table 3. Morphometric parameters of the network wadis in the drainage basin in As Sabriyah area.

Basin	Area (km ²)	Perimeter (<i>P</i>) (m)	Length (<i>L</i>) (m)	Width (<i>W</i>) (m)	Form factor (<i>F_f</i>)	Circularity ratio (<i>R_c</i>)	Elongation ratio (<i>R_e</i>)	Combination coefficient (<i>C_c</i>)
1	28	66	7	4	0.5714	0.0808	0.8532	3.5435
2	88	66	14	7	0.449	0.2539	0.7363	1.9988
3	85.7	60	13	7	0.5059	0.2985	0.8028	1.8435
4	15	23	14	1.5	0.0765	0.3564	0.3122	1.6871
5	13.5	33	12	1.8	0.833	0.1385	0.3258	2.7064
6	50	57	13	1.2	0.2959	0.1934	0.6139	2.2901
7	13	33	13	1.8	0.0799	0.1558	0.319	2.5516
8	81	71	18	4.5	0.25	0.202	0.5643	2.2412
9	17	30	9.5	1.8	0.1884	0.2374	0.4899	2.0671
10	33	31	9.7	3	0.3507	0.4316	0.6684	1.5331

2) high rate (3 basins of high elongation rate), 3) 3 basins relatively rectangular and dented in their middle sector with shorter lengths than of the other 2 groups. Most of the basins are of very low circularity rate (0.13 - 0.43), not support the symmetry in the concentration of on basins' slopes and slowing the flow in the streams during precipitation. Most of the form factors values are among the values of elongated basins. Middle sector of basins (4 - 8) and southern and western sectors of basins (9 & 10) are of high slope gradient, whereas their lower sectors are of low slope gradients as getting closer to Khor Al-Sabbiyah, which might be due to the Arabian Gulf sea paleo-transgression movement and erosional leveling of the stream sectors. Basins (1 & 2) are of relatively high slope gradients compared to the previous basins. All of the basins are of high combination coefficient, which strongly supporting the elongation of most of the drainage basins and away from the circular form.

4.4. Interpretation of Stratigraphic Settings

Figure 15 shows the Correlation of the 6 stratigraphic columns constructed from the analysis of the samples taken from the 6 vertical pits from the study areas showing the 5 main dominant components: gravels (mainly quartz), sands, mud, calcite, and gypsum found in the 6 interpreted facies. The lateral and vertical distribution of these sediments is highly controlled by four major factors: general slope, local relief, drainage pattern and frequent storms. According to the lithofacies and stratigraphic correlation, it was found that the area is dominated by coarse-grained sediments with considerable fractions of gypsum, silts, and calcite. These types of loose sediment are characterized by high porosity and permeability, so the rate of infiltration is relatively high. Therefore, during frequent rain storms significant amounts of water may infiltrate through the sediments. This infiltrated water would have lower or limited chance to percolate due to the rigid underlying bed rocks and hence eventually directed to the sea

driven by the general slope and dip of strata trending seaward. As a result, there is a very limited chance of recharging from the well-developed drainage network in the area to the shallow aquifers.

Kuwait Group possesses a groundwater level that varies from about 80 to 90 m above sea level in the southwest to near ground level along the coast (2 - 20 m in the study area) [3]. The calculated total gradient in the study area is about 0.214% seaward. The Ghyben-Herzberg relation (which states, for every 1 m of fresh water in an unconfined aquifer above sea level (as the case in the study area) (Figure 16), there will be 40 m meters of fresh water in the aquifer below

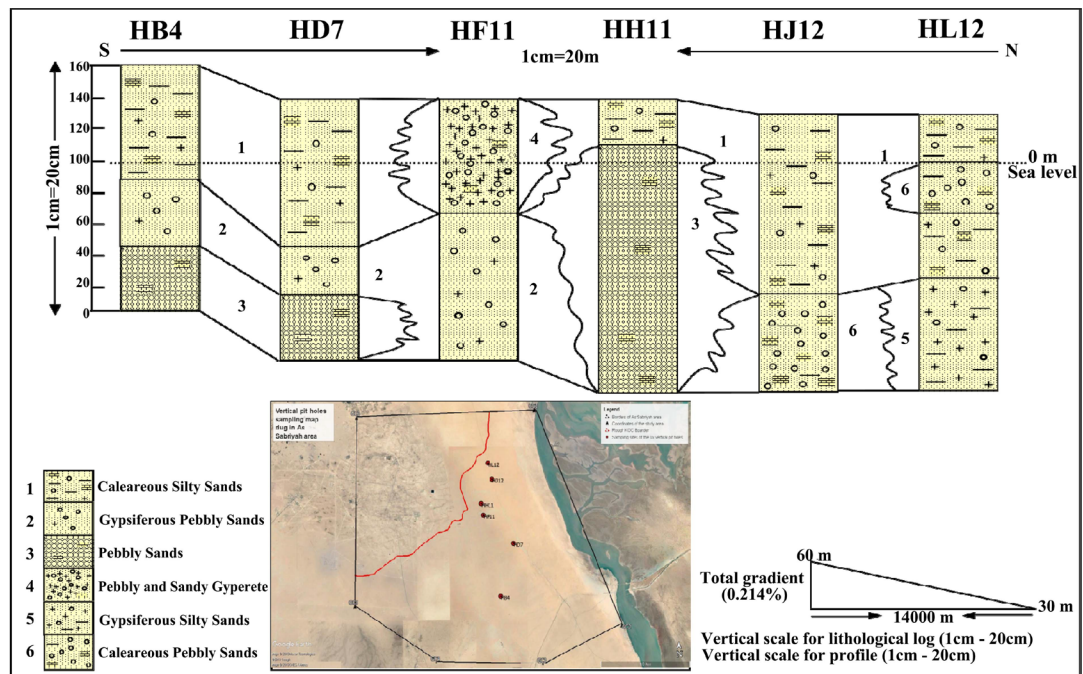


Figure 15. Correlation of the 6 stratigraphic columns constructed from the analysis of the samples taken from the 6 vertical pits from the study areas showing the 5 main dominant components: gravels (mainly quartz), sands, mud, calcite, and gypsum found in the 6 interpreted facies.

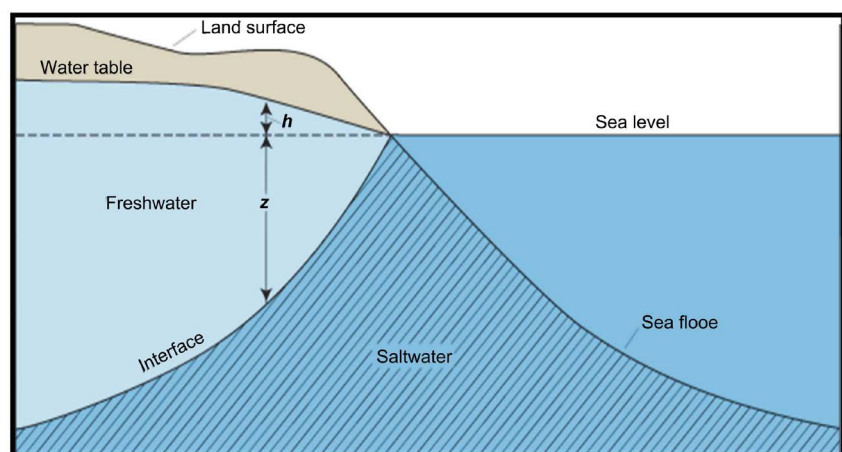


Figure 16. The Ghyben-Herzberg relation. Where the thickness of the freshwater zone above sea level is represented as h and that below sea level is represented as z (after [28]).

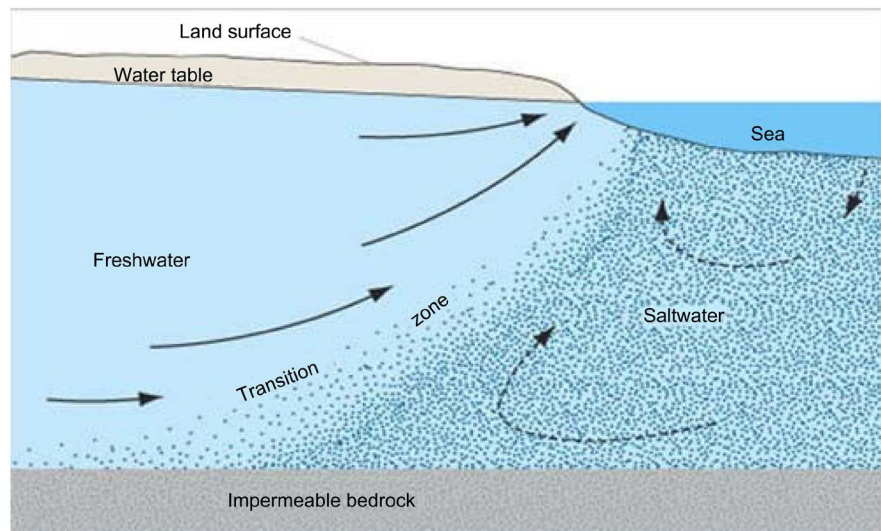


Figure 17. Groundwater flow patterns and the freshwater-saltwater transition zone. A circulation of saltwater from the sea to the transition zone and then back to the sea is induced by mixing of freshwater and saltwater in the transition zone (after [28]).

sea level). Accordingly, the movement of surface runoff and infiltrated water towards the sea is suggested to contribute in the stabilization of fresh water-saline water interface, and hence oppose the salt water intrusion, which consequently might play a significant role in enhance the water quality in the shallow aquifers (Figure 17).

5. Conclusions

The well-developed paleo-drainage system in As Sabriyah area is composed of 10 closely spaced drainage basins, which are subparallel dendritic elongated variant-sloped and of high compactness coefficient, of an area of (13 - 88 km²), a length of (7 - 18 Km), a width of (1.2 - 7 Km), with highest stream order of 5, where water flows NE from Al-Rukham ridge's crest (60 m a.m.s.l.) downstream in Khor Al-Subiyah coastal flat.

The hard resistant calcretic and gypretic gravelly sand deposits in the upper Dibdibba Formation lowered its infiltration and recharging capacity to the shallow aquifer, but retained the well-developed drainage network. Whereas the coarse-grained sediments with considerable fractions of gypsum, silts, and calcite of the friable gravelly sand or aeolian sand nature of the wadi fill deposits increased the infiltration capacity of the surface sediment. Thus, infiltrated water would have limited chance to percolate and eventually directed to the sea by the general topography of the area seaward, which would be of limiting potential recharge from the well-developed drainage network to the shallow aquifers.

According to Ghyben-Herzberg ratio for the fresh-salt water interface, the movement of surface runoff and infiltrated water towards the sea in the study area is suggested to contribute in the stabilization of fresh water-saline water interface, and hence oppose the salt water intrusion, which consequently might

play a significant role in enhancing the water quality in the shallow aquifers.

6. Recommendations

Any development management plan to be implemented in the study area should take into consideration the pattern and distribution of the well-developed paleodrainage network in the area for the following important issues:

1) Since surface runoff is of high potential to infiltrate through the surface wadi fills sediments of the drainage system in the area rather than the surrounding and underlying rigid calcretic gypcretic bedrock, the outcomes of this study should be considered for the morphometric characteristics of the existing drainage system as it is highly potential to play a significant role in water harvesting feasibility in the desert of Kuwait.

2) Knowing that such areas might be very susceptible to salt water intrusion due to pumping from the lower shallow aquifers, as if pumping lowers the water table by 1 m, the thickness of the freshwater body within the aquifer will decrease by approximately 40 m, according to Ghyben-Herzberg relation, thus allowing the denser saltwater at depth to “intrude” into the aquifer. Therefore, careful management of groundwater pumping in such areas is required to avoid the intrusion of saltwater into the freshwater aquifer.

3) The significant role of the well-developed drainage network in As Sabriyah area and its beneficiary contribution to hydrogeological matter of concern should be taken into consideration in any future developmental plans in the area.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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