Chapter 1

Quantitative Analysis of Geomorphometric Parameters of Wadi Kerak, Jordan, Using Remote Sensing and GIS

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Geomorphometric analysis was carried out to illustrate the drainage characteristics and morphology of Wadi Kerak watershed, southern Jordan. The basic and derived morphometric parameters (linear, areal and relief aspects of drainage network) for the basin were determined using ASTER DEM (30 m resolution) and Geographic Information System (GIS). These parameters describe the basin drainage network, geometry, texture, and relief characteristics. The hypsometric curve, hypsometric integral and clinographic curve were also prepared using topographic maps of 1:50,000 scale. Findings have revealed that W. Kerak is in the youth-age stage of geomorphic evolution. Fluvial erosion associated with successive phases of rejuvenation plays a significant role in drainage basin development, whereas structure and tectonics, lithology and relief dictate the drainage pattern and morphological setting of the catchment. The drainage area of the watershed is 190.9 km^2 and constitutes a 5th-order drainage basin. The commonly observed drainage patterns are the trellis type, with sub-dendritic pattern recognized in the upper catchment. The drainage pattern, and the semi-linear alignment of main and branching drainage indicate the prominent influence of the Kerak-Al-fiha fault system on the drainage network. High dissection, relative relief, relief ratio, steep slopes and breaks of

slopes are characteristic of W. Kerak. Morphometric analysis reveals that four rejuvenation phases caused severe erosion and down cutting activity in the past, and it is still susceptible to surface erosion at present.

1. Introduction

A drainage basin which is recognizable as being of fluvial erosive origin is considered a basic fundamental geomorphic, topographic and hydrologic areal unit for watershed management [1]. It is an ideal unit for management and sustainable development of natural resources. Adding to that, it implies the appropriate utilization of land and water resources of a watershed, for optimum production with minimum hazard to environmental resources, including people who live across the watershed [2]-[4]. A drainage basin represents a natural manageable hydrological entity which enables surface runoff to a defined channel, ravine, stream or river at a particular point [5]. More significantly, it provides the basis for geomorphometric analysis. A technique was introduced earlier by Horton [6] [7] and elaborated by Strahler [8]-[11], Smith [12], Miller [13] and Schumm [14], those who later established the quantitative fluvial geomorphic research [15].

Morphometry is defined as the measurement and mathematical evaluation of the configuration of the earth's surface, and of the shape and dimensions of its landforms. The main characteristics which are often analyzed are: Area, altitude, volume, slope, profile and texture of the land, and other different aspects of drainage basins [16].

Conventional geomorphometric studies were carried out to explore the relationship between morphometric properties of drainage networks and climate, relief, lithology, structure and tectonics in order to interpret the morphometric parameters [15] [17]-[19]. The role of tectonic control on geomorphological processes in shaping drainage networks was reported for selected river basins from Kerala, Southern India [20]. In the recent past, morphometric analysis of stream networks was employed for a wide range of applications. Assessment of natural resources and geo-environmental hazard, especially flash floods for arid watersheds, was addressed particularly in developing countries, such as Egypt [21]-[23] and Turkey [24]. Groundwater recharge potentials from flash floods in arid land alluvial basins, southern Red Sea coast in Egypt, were also investigated [25]. Morphometric analysis techniques were adopted to evaluate groundwater potential and hydrological behavior of watersheds [26] [27]. Watershed prioritization for soil and water conservation measures [28] was implemented in several parts of India. Such applications confirm the role of geographic information system (GIS), remote sensing (RS) and morphometric analysis as an efficient tool for locating water harvesting structures by prioritizing mini-watersheds in Gujarat and western Ghats regions, India [4] [24] [29], and Bago River, Myanmar [2]. Studies regarding the identification of artificial recharge sites in Manchi basin, eastern Rajasthan, India were carried out using morphometric analysis and GIS techniques [30]. Analysis of drainage basin morphometry based on multivariate statistical methods was achieved to delimit morphological regions in south-west Uganda [31] [32]. Evaluation of geomorphometric characteristics was carried out on a catchment level in India [33] and on a regional level in the western Arabian Peninsula [34]. Assessment of surface runoff in arid and data-scarce regions in the Madinah, western Saudi Arabia was conducted to predict flood hazard [35]-[37], and to estimate erosion rates and sediment yield [38]. Moreover, the relationship between morphometric characteristics and specific hydrological parameters for selected drainage basins (southeastern Brazil) was examined using multivariate statistical techniques [39]. The morphometric parameters (linear, area, shape and relief) of drainage basins and sub-basins, and their network properties, have been investigated using conventional manual methods, *i.e.* topographic maps (scales 1:25,000 and 1:50,000) and field observations in different environments [7] [8]-[13] [40] [41]. Since the mid-1980s, the development of geospatial analytical techniques (GIS and RS) and other software designed specifically to quantify and calculate linear, areal, shape and relief morphometric parameters [42] [43], along with increasing availability of digital elevation data, have enhanced the process of quantitative description of drainage networks, morphometric thematic mapping, and the applicability of geomorphometric analysis in different fields of research. Comparison and evaluation of morphometric data derived through conventional, manual methods, and automated geospatial techniques, indicate that modern technology provides powerful and cost-effective tools for managing and processing data and creating maps for different applications [24] [44] [45].

At present, digital elevation models (DEMs) provide the most standard technique to extract the required information which controls geomorphological processes. Furthermore, DEMs can be employed to delineate the drainage networks precisely with all first-order streams or the "fingertip" tributaries as described earlier by Horton [7]. Many researchers concluded that geographic information systems and remote sensing technology are efficient tools for measuring and calculating precise drainage basin morphometric parameters. Other advantages are the capabilities of managing and processing spatial information in large amounts accurately and in a time-saving manner [24] [44] [46]-[48].

The objectives of the present study are:

1) to analyze selected linear, areal, shape and relief parameters of the W. Kerak drainage basin using GIS;

2) characterization of drainage networks in relation to tectonic and structural disturbances, lithology, rejuvenation phases, landscape evolution and denudational chronology;

3) to identify major morphometric parameters which have a significant role on erosional landforms of the W. Kerak drainage basin; and,

4) to analyze distinct breaks of stream slope in relation to uplifting of the faulted/erosional scarp overlooking the rift floor and to relatively minor lithological variations. Findings provide valuable information that can be employed in assessing floods risk management through delimiting flood-prone terrain units, and selecting appropriate sites for water harvesting and in planning soil and conservation schemes. Morphometric analysis can also be applied to similar highland watersheds in southern and northern Jordan.

2. Study Area

Geomorphometric analysis was conducted in the W. Kerak watershed, southern Jordan. The study area lies to the south-east of the Dead Sea, east of the Lisan Peninsula. It is situated between E longitudes 35˚30' to 35˚44' and N latitudes 31˚14' to 31˚17'. The catchment is located in the middle part of the Kerak Governorate (**Figure 1**). W. Kerak watershed covers an area of 190.9 km^2. Terrain elevation varies from −410 meters below mean sea level close to the Dead Sea, and increases towards the east to 1000 meters at Kerak city, and then ascending to 1250 meters (a.s.l) in the upper catchment close to Mazar town. The watershed represents typical rift (Ghor)/ highland topography. In the Mazar and Kerak areas (the middle and upper catchment), the climate is classified as dry Mediterranean, whereas in the lower part, or Ghor Mazra close to the Dead Sea it is arid. Mean annual rainfall ranges from 325 mm at Kerak to 290 mm at Mazar east of Kerak, and 77.5 mm at Ghor Mazra west of Kerak. Rainfall is concentrated in winter during the cold season (October to March). The average maximum and minimum

Figure 1. The study area.

temperatures are 17˚C and 2˚C in Kerak and Mazar respectively, while the average maximum temperature in Ghor Mazra is 32˚C with summer months reaching 40˚C. In Mazar town, east of Kerak, part of the precipitation falls as snow. Several days of freezing temperatures (below 0.0˚C) are recorded between November and February. Progressive river incision and continuous rejuvenation of W. Kerak draining to the rift, associated with recurrent lowering of the base level (the Dead Sea), and uplifting of the scarp zone(during late Tertiary and Quaternary tectonics) produced irregular slope segments (15˚ - 35˚) separated by rocky benches. The wadi profile also displays prominent irregularities which probably represent some forms of rejuvenation points. When major breaks of slopes combined with major longitudinal profile irregularities [49], four or five rejuvenation phases can be recognized. Rejuvenation phases have resulted in deeply dissected topography, dense incised drainage and over-steepened slopes. Therefore, the catchment is part of the Jordan highlands region, which witnessed problems of slope instability, soil erosion, deforestation and changing land cover. Clay loam, silty clay, silty clay loam and silty loam soils dominate most of the catchment [50] and are characterized by low permeability. Thus, runoff erosion is expected to be high. The vegetation cover is poor in the southern highlands compared with the northern highlands, due to the dominance of more arid conditions. Here low rainfall and greater marginality are characteristic phenomena. Population densities are lower, and nomads from the eastern Jordanian desert occasionally visit the southern highlands with their herds of camels, sheep and goats [51]. Therefore, overgrazing and poor conservation measures maximize soil erosion.

Geologically, the study area is covered by a wide range of rock types, ranging from late Cambrian sandstone to Quaternary deposits, including lacustrine Lisan Marl, alluvial fan of Ghor Mazra and the fluvial terraces of W. Kerak. The Kurnub sandstone (Lower Cretaceous) is exposed along the deeply incised middle course of the wadi. The sandstones are overlain by the Turonian-Cenomanian Ajlune group, which consists of two lithological units: the Nodular limestone unit (marly clay unit), which is predominantly marls and clays interbedded with marly limestones, nodular limestones and dolomites. Deferential erosion acting on intensely jointed and weathered marls and clays has caused slope instability. The Echinoidal limestone unit, or the limestone marl unit consists of limestones, dolomitic limestones, marl, sandy limestones, marly limestones and chert nodules. The third lithological unit (Eocene-Senonian rocks) dominate the watershed to the east of

Kerak city. Various outcrops of limestones, marls, chalk, chert, phosphate, shales and clays are present [52]. The spatial distribution of these "soft rocks" represents a major factor influencing slope instability and soil erosion loss. W. Kerak is considered a part of the Kerak-Al-fiha fault system and the subsidiary dense branching faults to the north and south of W. Kerak main course. The major fault (early Miocene) is often obscured under the materials pertaining to old degraded landslide complexes [53]. Geomorphological units identified in the catchment include: structural plateau/ridges, remnants of planation surfaces, residual hills, denudational slopes, landslides zone, infilled valleys, glacis, fluvial terraces and badlands [54].

3. Materials and Methods

Geomorphometric analysis of W. Kerak catchment was carried out using topographic maps with scale 1:50,000 (20 m contour interval). The basin was divided into sub-watersheds 1 - 5 (**Figure 2**), and the drainage networks of the main watershed and sub-watershed were generated using ASTER DEM (30 m resolution), then digitized using Arc GIS 10.1 software package (**Figure 3**). The data extraction and data analysis were carried out using Arc GIS 10.1 and Terrain Analysis System (TAS). An assessment of the morphometric parameters for each drainage network was executed at a sub-basin level. The derived parameters were classified into five groups [42] such as basic, linear, areal, shape and relief aspects of the basin. The order was assigned to each stream following the stream ordering system developed by Strahler [8] [11]. The W. Kerak watershed was found to be of the fifth order. Basic parameters like basin area, basin length, number and lengths of streams of each different order, basin perimeter, total basin length and bifurcation ratio were measured using GIS software. Stream frequency, drainage density, drainage texture, lemniscate ratio, form factor, elongation ratio and circularity ratio were evaluated using the mathematical equations elaborated by Strahler [8] [9] [11].

Significant geomorphometric parameters such as relative relief, basin relief and dissection index have been quantified and calculated from the Digital Elevation Model (DEM). The hypsometric curve, hypsometric integral and the clinogrphic curve for W. Kerak were calculated and drawn manually using topographic