Spatial analysis of the geomorphic evolution of Tigris River basin using developed ArcGIS- Morphometric toolbox

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Abstract. Studied parts of Tigris river basin extended over an area of about 202702 square kilometres mostly extended within Turkish, Iranian and Iraqi territories with a narrow area in Syria and located between latitudes 32° 30’ to 38° 30’ N and longitudes 40° 00’ to 48° 00’ E. The basin is characterised by a complex topography, lithology, and structural features, which have impacts on the geomorphic development stages of the sub-basins. The study aims to evaluate the geomorphic stages of the river sub-basins based on hypsometric and volumetric analysis of each sub-basin using ArcGIS-morphometric toolbox developed by the author. The analysis was carried out using SRTM one arc-second DEM data. The basin is divided into 34 sub-basins and the hypsometric and volumetric parameters i.e., area, elevation, volume ratios, hypsometric and volumetric curves and integrals are calculated. The results show Tigris river basin has been passing in the Monadnock phase, while the sub-basins are classified into three geomorphic development stages i.e, middle - later maturity stage, early Monadnock phase and later Monadnock phase. According to the hypsometric curves, hypsometric integral, volumetric integrals; most of the sub-basins are passing in steady state of erosions and weathering processes with the prevailed fluvial system, terrain slopes and rock types.

1. Introduction

Estimation of the geomorphic development of a large basin represents a challenge for the researchers, due to the difficulty of measuring the required morphometric parameters. The inaccurate explanation of rivers or valley basins as “young, mature, old and poor drain or well drain” is probably due to the lack of suitable measuring and operating tools [1]. The hypsometric curve of area – altitude distribution is suitable for defining the slope of the basin [2]. Strahler [3] recognized three development stages of the basins according to the value of Hypsometric integral (HI) i.e., inequilibrium (youth stage) with HI greater than 60%, equilibrium (Mature stage) with HI between 60% and 35% and Monadnock when HI drop below 35%. Watershed conditions are well recognized using hypsometric curves and hypsometric integral, whereas the differences in their shapes and values indicate the imbalance of tectonic forces and erosive [4-8]. Basin conditions can be evaluated based on hypsometric integral and hypsometric curves [5, 8]. Convex hypsometric curves are typical of a youthful stage; s-shaped curves are related to a maturity stage, and concave curves are indicative of a peneplain stage [3, 7, 9]. In past, hypsometric analysis has been limited due to intensive computation requirements and lack of effective analysis equipment; Strahler was involved planimeter as a tool for area measurements increased the efficiency of assessment of contours, and dramatic advances in GIS technique after that was rigorously increased the quantitative measurement of basin characteristics [10]. Pérez-Peña, Azañón [11] have been developed CalHypso- ArcGIS extension to calculate statistical moments of hypsometric curves using Visual basic and ArcObjects with input layers i.e.,
basin boundary, integer DEM data. Beg [12] has developed ArcGIS-morphometric toolbox including script to calculate the area, height and volume ratios, plotting the hypsometric and volumetric curves and to calculate the HI and VI using trapezoidal method. Several factors are controlling the hypsometry of the basin i.e., shape, size, relief and dominant erosion process, as well as HI is sensitive to erosion resistance, basin outcrops and uplift rate [13]. The analysis and development of landscape can be initially assessed using HI [14, 15]. Hamza [16] referred to the importance of hypsometric parameters in distinguishing between the tectonically active area and the inactive area in a basin. The cycle of erosion in any basin can be indicated by hypsometric integral [3, 17].

Tigris river is one of the two major water resources of Iraqi lands beside Euphrates river. The river basin extends on a large area recognised by a different geological setting of lithology and structures with terrains varied in elevations and slopes. In fact, these characteristics are impacted in various manners on the development of the river sub-basins.

The current study aims to a). Assessment of the geomorphic development phases of Tigris river sub-basins based on hypsometric and volumetric analysis of SRTM-DEM data, b) Implementing the analysis using ArcGIS-morphometric toolbox, c). Evaluating the geological setting and slopes impact the geomorphic development of each sub-basin using the spatial analysis methods.

2. Location of study area
Tigris river basin extends over an area of about 202702 square kilometres mostly within Turkish, Iranian and Iraqi territories with a narrow area in Syria and bounded between latitudes 32° 30′ to 38° 30′ North and longitudes 40° 00′ to 48° 00′ East (figure 1) as measured from ArcGIS software. Tigris River is one of the important water resources for Iraqi lands. The river flows through a basin of various topographic regions starting from the mountainous lands in southeastern Turkey and northwest of Iran to the sedimentary plain in middle and south of Iraq, which merged with Euphrates river making Shatt al-Arab

3. Data and analysis method
In current, study the digital elevation model of SRTM-DEM data of one arc second resolution [18] are used to delineate the watersheds of sub-basins and calculation of elevation levels in hypsometric analyses (figure 2) and calculating the distribution of the slopes over the basin (figure 3). Geological map [19] was used to show the spatial distribution of rock outcrops and lithology at different sub-basins (figure 4). The hypsometric analyses have been illustrated in figure 5 and implemented according to the following steps:-

- Downloading the SRTM-DEM data and converting the projection into UTM-WGS84 or any suitable projected coordinates system.
- Using ArcGIS- Hydrology toolbox to calculate flow direction and flow accumulation.
- Execution of Con (“Flowaccum” >100, 1) from map algebra, and selecting pour point for each sub-basin to delineate the watersheds.
- Extraction of the drainage network based on Strahler stream order using spatial analyst-Hydrology - Stream order tool.
- Delineation of the boundaries of sub-basins watersheds using spatial analyst-Hydrology-Watershed tool.
- Extraction of the DEM data for each sub-basin using an extraction tool - extract by a polygon.
- Execution the developed ArcGIS-morphometric toolbox - hypsometric script [20] to calculate the hypsometric parameters, and the input data as illustrated in figure 6.

4. Results and discussion
Results given in table 1 and figure 7 show that the Tigris river basin passing in later Monadnock phase of geomorphic development with hypsometric integral of 26.9%. Whereas, the volumetric integral
indicate that 20.8% of the basin rocks and soil are still waiting for erosion. The concaved shape of the hypsometric curve (figure 7) shows the basin reached the old geomorphic stage and the knick point appeared on the curve indicating the upstream area of the basin as structurally controlled and dissected by complex ridges of geologic outcrops.

To identify the spatial variation of geomorphic developments through different parts of the basin; hypsometric and volumetric analyses of the sub-basins are carried out as shown in figures 8 to 10 and table 2. Based on the hypsometric integral values and according to Strahler [3] the sub-basins of Tigris River are identified in three groups of geomorphic development stages i.e., Middle- Later Maturity stage, Early Monadnock phase and Later Monadnock phase. In current study the SRTM DEM data of approximately 30 meters do not give clear difference in the values of planimetric and surface area at each specified elevation levels, therefore, surface hypsometric calculations are not considered in the current study.

Figure 1. Location map of study area.

Figure 2. SRTM-DEM data and Tigris river sub-basins.
Figure 3. Slope distribution map.

Figure 4. Lithological map of study area [19].

Figure 5. Procedure of hypsometric analysis design.

Figure 6. Execution window of hypsometric analysis script of developed morphometric toolbox.

Table 1. Planimetric area, surface area, volume and height ratios of Tigris river basin.

| (h/H) ratio | (a/A) ratio | (as/As) ratio | (v/V) ratio | (h/H) ratio | (a/A) ratio | (as/As) ratio | (v/V) ratio |
|-------------|-------------|---------------|-------------|-------------|-------------|---------------|-------------|
| 0.025       | 0.824       | 0.830         | 0.892       | 0.606       | 0.042       | 0.045         | 0.016       |
| 0.051       | 0.745       | 0.753         | 0.799       | 0.631       | 0.033       | 0.035         | 0.012       |
| 0.076       | 0.679       | 0.689         | 0.715       | 0.657       | 0.026       | 0.028         | 0.008       |
| 0.101       | 0.617       | 0.629         | 0.638       | 0.682       | 0.019       | 0.021         | 0.006       |
| 0.126       | 0.572       | 0.585         | 0.568       | 0.707       | 0.014       | 0.015         | 0.004       |
| 0.152       | 0.529       | 0.543         | 0.503       | 0.733       | 0.010       | 0.010         | 0.002       |
| 0.177       | 0.482       | 0.496         | 0.443       | 0.758       | 0.006       | 0.007         | 0.001       |
| 0.200       | 0.430       | 0.446         | 0.389       | 0.783       | 0.004       | 0.004         | 0.001       |
| 0.227       | 0.385       | 0.400         | 0.341       | 0.808       | 0.002       | 0.002         | 0.000       |
| 0.253       | 0.344       | 0.359         | 0.298       | 0.834       | 0.001       | 0.001         | 0.000       |
| 0.278       | 0.311       | 0.326         | 0.259       | 0.859       | 0.000       | 0.000         | 0.000       |
| 0.303       | 0.285       | 0.299         | 0.224       | 0.884       | 0.000       | 0.000         | 0.000       |
| 0.328       | 0.260       | 0.273         | 0.192       | 0.909       | 0.000       | 0.000         | 0.000       |
| 0.354       | 0.235       | 0.247         | 0.163       |             |             |               |             |
| 0.379       | 0.209       | 0.220         | 0.136       |             |             |               |             |
| 0.404       | 0.185       | 0.195         | 0.113       |             |             |               |             |
| 0.429       | 0.161       | 0.169         | 0.093       |             |             |               |             |
| 0.455       | 0.137       | 0.145         | 0.075       |             |             |               |             |
| 0.480       | 0.116       | 0.122         | 0.060       |             |             |               |             |
| 0.505       | 0.096       | 0.102         | 0.047       |             |             |               |             |
| 0.530       | 0.079       | 0.084         | 0.037       |             |             |               |             |
| 0.556       | 0.064       | 0.068         | 0.029       |             |             |               |             |
| 0.581       | 0.052       | 0.056         | 0.022       |             |             |               |             |

Hypsometric Integral = 21.1
Surface Hypsometric Integral = 21.8

Figure 7. Hypsometric, surface hypsometric and volumetric curves of Tigris river basin. Based on [18,
Volumetric Integral =19.02

4.1 Middle- Later Maturity stage
Many sub-basins i.e., 2, 30, 28 and 6 are identified in a group of middle- later maturity stage as shown in table 2 and figure 8 with hypsometric integrals ranging from 39.5% to 52.5%. However, according to the volumetric integrals, the remaining rock masses still waiting for erosion are ranging from 22.6% to 30.9%. The sub-basins 2 and 6 are characterized by gentle slope, but geologically the mixed sedimentary rocks are exposed with 94% and 71% of the sub basins area respectively which make the upstream area more resistant to weathering and erosion processes. While the average slope of sub-basin 28 is 17.43 degrees, and covered mainly by basic volcanic rocks with 57% and the remaining area are covered by metamorphic and carbonate sedimentary rocks, despite the relative slope of the basin, however, the dominance of hard rocks reduce the denudation processes. Whereas the sub basin 30 is recognised by dominace of carbonate sedimentary rocks with 42%, 21% basic volcanic rocks and 13% metamorphic rocks of the area, which lead to active chemical weathering in the basin. All the hypsometric curves in this group are of S-shape with convex curves and the volumetric curves indicating that most of the rock masses at upstream area are more resistant to the denudation processes.

4.2 Early Monadnock phase
The results of evolutionary status of 17 sub-basins shown in table 2 and figure 9 are passing in early Monadnock phase. The hypsometric integral values are ranging from 20.3 at sub basin 8 to 34.9 at sub basin 27. Based on volumetric integrals, basin 8 is recognized as the area most subjected to erosion, whereas the sub basin 27 shows value of volumetric integral about 24.4 compared to 26.5 at sub basin 22; in fact, this means volumetric integral gives more accurate idea about the remaining rock mass. Geologically, mixed sedimentary rocks, quaternary deposits, and carbonate sedimentary rocks are the major outcrops dominant in the sub-basins of this group. Terrains of most of the sub-basins having low average slopes except the sub-basin 27 and 26 come with average slope about 15.03 and 13.62 degrees, respectively. Most of the hypsometric curves are from concave shape except sub-basins 1 and 39, which are near to S-shape because they are at the beginning of the transit from later maturity to early Monadnock phase.

4.3 Later Monadnock phase
Most of the sub-basins passing in later Monadnock phase are located at the downstream area of the Tigris River basin as shown in table 2 and figure 10. The values of hypsometric integrals range from 3.7% at sub-basin 37 to 19.8% at sub-basin 21, while VI range from 10.3% at sub-basin 11 to 20.5% at sub-basin 20 with hypsometric curves of concave shape. Mixed sedimentary rocks and Quaternary deposits exposed at this group of sub-basins with average terrain slopes ranging from 0.35 to 5.26 degrees.
Figure 9. Hypsometric and volumetric curves of Early Monadnock phase. Based on [18, 20].
Figure 10. Hypsometric and volumetric curves of Later Monadnock phase. Based on [18, 20].
Table 2. Hypsometric, volumetric integrals, slopes, lithology and geomorphic stages of Tigris river sub-basins

| Basin No. | HI   | VI   | Area (km²) | Average slope | Dominant Lithology % * | Geomorphic development stage |
|-----------|------|------|------------|---------------|------------------------|------------------------------|
| 2         | 41.0 | 23.5 | 326.6      | 1.02          | 94% Sm & 6% Ad         | Middle-Maturity              |
| 6         | 52.9 | 30.9 | 164.5      | 0.70          | 71% Sm & 29% Ad        |                              |
| 28        | 50.6 | 28.7 | 8914.3     | 17.43         | 57% Vb,20% Mt, 13%Sc   |                              |
| 30        | 35.7 | 24.0 | 2519.4     | 14.68         | 42% Sc,21% Vb,13%Mt    |                              |
| 27        | 34.9 | 24.4 | 6021.8     | 15.58         | 50% Sc, 44% Sm         |                              |
| 1         | 34.3 | 19.7 | 1312.6     | 0.99          | 68% Sm & 32% Ad        |                              |
| 8         | 20.3 | 15.1 | 12582.1    | 2.69          | 65% Sm & 35% Ad        |                              |
| 3         | 25.3 | 18.9 | 19826.1    | 10.09         | 58% Sc, 27% Sm & 14% Ad|                              |
| 9         | 29.9 | 18.8 | 805.0      | 0.27          | 100% Ad                |                              |
| 10        | 23.9 | 21.8 | 6200.6     | 0.41          | 68% Ad & 32% Sm        |                              |
| 14        | 21.6 | 21.8 | 3820.0     | 6.15          | 36% Sm, 34% Sc, 30% Ad |                              |
| 15        | 30.1 | 20.5 | 1459.8     | 9.89          | 56% Sc, 33% Sm, 11% Ad |                              |
| 16        | 30.0 | 22.5 | 114.8      | 0.46          | 100% Ad                |                              |
| 17        | 27.3 | 19.7 | 177.6      | 0.44          | 100% Ad                |                              |
| 18        | 30.8 | 20.2 | 141.9      | 0.42          | 100% Ad                |                              |
| 22        | 29.0 | 26.5 | 307.8      | 1.60          | 80% Ad, 20% Sm         |                              |
| 26        | 32.3 | 24.0 | 26251.6    | 14.06         | 70% Sc, 21% Sm         |                              |
| 29        | 22.6 | 16.3 | 24442.9    | 8.29          | 50% Sm, 38% Vb         |                              |
| 32        | 31.9 | 23.0 | 29705.1    | 10.03         | 44% Sm, 38% Sc, 10% Cl |                              |
| 34        | 25.5 | 20.7 | 2694.1     | 7.73          | 47% Sc, 43% Sm, 10% Ad |                              |
| 35        | 31.8 | 21.8 | 503.8      | 0.36          | 85% Ad, 15%            |                              |
| 39        | 33.6 | 19.0 | 2813.9     | 0.31          | 100% Ad                |                              |
| 4         | 18.3 | 11.6 | 436.5      | 0.92          | 89% Sm & 11% Ad        |                              |
| 5         | 19.0 | 14.4 | 362.0      | 1.45          | 100% Sm                |                              |
| 7         | 14.6 | 12.8 | 4266.2     | 0.66          | 29% Sm &               |                              |
| 11        | 13.5 | 10.3 | 1377.0     | 0.42          | 100% Ad                |                              |
| 19        | 8.5  | 13.4 | 732.3      | 3.10          | 67% Ad, 21% Sm, 13% Sc |                              |
| 20        | 18.3 | 20.5 | 634.7      | 4.80          | 52% Ad, 37% Sm, 11% Sc |                              |
| 21        | 19.8 | 17.1 | 206.4      | 0.89          | 100% Ad                |                              |
| 23        | 12.2 | 13.8 | 838.9      | 2.58          | 70% Ad, 30% Sm         |                              |
| 24        | 14.7 | 16.4 | 641.0      | 1.02          | 94% Ad, 6% Sm          |                              |
| 33        | 18.6 | 20.0 | 3316.9     | 5.54          | 57% Sm, 25% Sc, 18% Ad |                              |
| 36        | 11.5 | 19.7 | 4808.4     | 1.84          | 54% Ad, 45% Sm         |                              |
| 37        | 3.7  | 15.3 | 1716.6     | 1.12          | 58% Ad, 41% Sm         |                              |

* Ad: Quaternary deposits, Cl: Clastic rocks, Ep: Evaporites, Mt: Metamorphic rocks, Pa: Acid plutonic rocks, Pb: Basic plutonic rocks, Sc: Carbonate sedimentary rocks, Sm: Mixed sedimentary rocks, Ss: Siliciclastic sedimentary rocks, Su: unconsolidated sediments, Vb: Basic volcanic rocks, Wb: water bodies.

5. Conclusions
The results show that Tigris river basin passing in the Monadnock phase, while the sub-basins are identified in three geomorphic development stages i.e, Middle- later maturity stage with HI values ranging from 39.5% to 52.5% and volumetric integral (VI) between 22.6% to 30.9%, early Monadnock phase with HI values range from 20.3% to 34.3% and VI values between 15.1% and 26.5%, and the later Monadnock phase include the sub-basins near and around the main Tigris channel and downstream area with HI values between 3.6% and 19.7% and VI values range from 10.3% to
20.5%. According to the hypsometric curves and hypsometric integral values, most of the sub-basins are passing in steady state in the processes of erosions and transformation with the prevailed fluvial system, terrain slopes and rock types. The volumetric integrals indicate the remaining volumes of rock masses in the basin. Regarding the geological setting, the main lithology controlling the hypsometric parameters and consequently the geomorphic development of the sub-basins are carbonate sedimentary rocks, mixed sedimentary rocks and Quaternary deposits. The impact of knick points on the shapes of hypsometric curves is recognized in the upstream area of the sub basins due to the presence of folds and faults structures. The results of hypsometric curves show that wherever the volumetric curve comes above the hypsometric curve it means that the terrains have highly rough and complex structures.

Acknowledgments
The author wishes to express his sincere thanks and gratitude to Mustansiriyah University for providing the financial support and entrusting to implement the research project.

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