HYPSOMETRIC ANALYSIS OF OZAT RIVER BASIN (GUJARAT) USING REMOTE SENSING AND GIS TECHNIQUES

[*1]PAGHADAL, A. M.; [2]RANK, H. D. AND [3]PANDYA, P. A.

SOIL AND WATER CONSERVATION ENGINEERING DEPARTMENT
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH – 362 001, GUJARAT, INDIA

EMAIL: krishnapaghadal14@gmail.com

[1]Junior Officer (Technical), GGRCL, Fertilizer Nagar, Vadodara
[2] Professor and Head, Soil and Water Conservation Engineering Department, CAET, JAU, Junagadh – 362 001
[3]Assistant Professor, College of Agricultural Engineering and Technology, CAET, JAU, Junagadh – 362 001

ABSTRACT

This paper deals with the research work dealing with the geomorphometry and geomorphology of the Ozat River Basin (ORB) of Junagadh District of Gujarat State. In the present study, the watershed delineation process of Ozat river basin is made with the help of ArcSWAT tool, through process the entire Ozat river basin was divided into 17 sub-basins. Hypsometric analysis was carried out using ASTER DEM having 30 m resolution. GIS environment is used to calculate the hypsometric integral values through Elevation-relief ratio method. The values of Hypsometric integral (HI) was varies between 0.07 to 0.50, showed that the whole basin was falls under monadnock phase and was associated with a highly concave hypsometric curve, it indicates that the major portion of the basin of Ozat River lies at a comparatively low relief. These findings would help in the construction of appropriate soil and water conservation measures across the watershed and its sub-basins to control soil erosion, to conserve water and to reduce sediment discharge into the Ozat river basin.

KEYWORDS: ASTER DEM, ArcSWAT, Geomorphometry, Hypsometric, Hypsometry, Ozat River Basin

INTRODUCTION

Hypsometry refers to the relative proportion of an area at different elevations within a region, and the hypsometric curve is an area-elevation relationship curve which depicts distribution of the area with respect to elevation (Strahler, 1952a). The crucial indicators to define watershed conditions are hypsometric curve (HC) and hypsometric integral (Hi) (Ritter *et. al.*, 2002). Hypsometery is used to evaluate different measurements for different natural drainage basins; Differences in the shape of the curve and the hypsometric integral value are attributed to the degree of disequilibria in the balance of erosive and tectonic forces (Weissel *et al.*, 1994).

Hypsometric analysis of drainage basin is the study of the distribution of ground surface area, or horizontal cross-sectional area, of a landmass with respect to elevation (Langbein, 1947 and Strahler, 1952a) appears to have been introduced the hypsometric curve, which is an empirical cumulative distribution function of elevations in drainage basin. Hypsometric analysis was first time introduced in its modern dimensionless form by Langebein

(1947) to express the overall slope and the forms of drainage basin. The hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass (Hurtrez *et al.*., 1999a). It is a continuous function of non-dimensional distribution of relative basin elevations with the relative area of the drainage basin (Strahler, 1952a). This surface elevation has been extensively used for topographic comparisons because of its revelation of three dimensional information through two dimensional approach (Harrison *et. al.*, 1983; Rosenblatt and Pinet, 1994). Comparisons of the shape of the hypsometric curve for different drainage basins under similar hydrologic conditions provides a relative insight into the past soil movement of basins. Thus, the shape of the hypsometric curves explains the temporal changes in the slope of the original basin. However it was Strahler (1952a), who popularised the study of hypsometric curve through his excellent paper in which he has demonstrated the usefulness of hypsometric curve in geomorphometric research of drainage basins. At a later stage, (Miller, 1953; Schumm, 1956; Strahler, 1964) have extended the methodology to investigate small drainage basins of lower order. The hypsometric integral is employed as an estimator of the erosion status of a drainage basin, and subsequent prioritization for taking up soil and water conservation activities (Hurtrez *et al.*, 1999b; Bishop *et al.*, 2002; Singh *et al.*, 2008; Singh, 2009).

The hypsometric integral (Hsi) is also an indication of the cycle of erosion (Strahler, 1952a; Garg, 1983). Hypsometric integral, on the other hand measures the percentage volume of earth material remaining after the erosion of an original landmass having volume equal to the reference solid with base equal to basin area and the height equal to total height range in the basin. It was Strahler (1952a) who proposed the dimensionless hypsometric integral. This is used as a measure of landscape evolution. Strahler (1952a) suggested the percentage hypsometric curve in which he showed concretely how a detailed analysis of percentage hypsometric curve can provide valuable indications of the stage of evolution of a particular drainage basin associated with uplift and denudation. In very detailed studies, Strahler (1952a) and Schumm (1956) have demonstrated the multiple possibilities of interpretation of hypsometric curves regarding the stage of basinal evolution.

Hypsometric analysis, longitudinal and projected profiles description, and geomorphic investigation were conducted in the present research to extract valuable information on morphoevolution of the Ozat river basin in relation to erosion cycle. Inspection of hypsometric curve shape and hypsometric integral values, provide information for determining the stages of geomorphic development, which in turn afford an indicator of watershed susceptibility to erosion, hillslope and channel processes. Kusre (2013) also used the Hi values as an indicator for high surface runoff and thus, for prioritizing sub-watersheds for consideration. He argued that once the watersheds are identified, suitable measures can be planned on the basis of available finances. Sarangi and Bhattacharya (2000) employed the Hi values as a morphological index to predict surface runoff and sediment yields from different watersheds. Estimated sediment yield information (Ijam and Tarawneh, 2012) was employed to verify the indirect assessment of erosion status based on hypsometric value.

Hypsometric curve

The percentage hypsometric method, which has been used as early as 1947 by Langbein (1947), deals with the area enclosed between a given contour and the upper segment of the basin perimeter to the height of that contour above the basal plane. Two ratios are involved in this hypsometric method: (1) ratio of area between the contour and the upper perimeter to total drainage basin area, represented by the abscissa on the coordinate system, and (2) Ratio of height of contour above base (h) to total height of basin (H), represented by values of the ordinate.

Strahler (1952a) evaluated different shapers of hypsometric curves through the comparison of different drainage basins, and classified basins according to their stages of geomorphic evolution (Figure 1) as: youth stage (convex upward curves, where Hi ≥ 0.60), where the watershed is highly susceptible to erosion and land sliding; equilibrium or mature stage (S-shaped hypsometric curve which concave upward at high elevations and convex downward at low elevations, where 0.30 ≤ Hi ≤ 0.60); and pereplain (old) or monadnock stage (concave upward curve, where Hi ≤ 0.30). Variation in the shape of hypsometric curves exists during the early stages of geomorphic evolution, but followed by minimal variation after the drainage basins achieved equilibrium or mature stage. Both hypsometric parameters (HC and Hi) have a great bearing on the erosional characteristics of watershed, thus, it is an indicator of the "fluvial cycle of erosion" Strahler (1952a). Hypsometric curve is obtained by plotting on ordinate (y-axis) elevations in feet or meters) and, and on abscissa the area (in square miles or kilometers) lying above a contour of given elevation. The simplest form of it is that prepared in absolute units of measure. It is also known as hypsographic curve.

MATERIALS AND METHODS

Study area

Hypsometric analysis was carried out in Ozat watershed, Gujarat, India. It is the largest catchment among the other entire watersheds within the Gujarat state. It originates from one of the village of Visavadar taluka and discharges directly into the Arebian Sea near to the Porbandar district. The study area extends between North latitudes 21˚10' to 22˚40' and East longitudes 69˚40' to71˚00' (Figure 2).

The climate of the project area can be classified as tropical and sub-tropical. Temperatures exhibit large seasonal and diurnal variations, January is the coldest month with mean monthly temperature varying from 4ºC and 15ºC and the maximum monthly temperature varies between 40ºC and 46ºC in the month of May. Agriculture is the main occupation in the area. Groundwater is the main source of irrigation in study area.

The watershed consists of 10 tributaries: left side of the river basin connected through popatdi river, utavali river, ambajar river, gundajali and madhumati river, while left side of the river basin connected through uben river and madhumati river. Three tributaries merged near the vanthali taluka and travel towards Porbandar district where it discharges into the Arebian Sea. Eight major reservoirs were constructed across the Ozat river basin Namely Amipura, Dhrafad, Jhanjesri, Madhuvanti, Magharadi, Magharadi, Pasawala and Uben. The most important are: the OZAT II and Dhrafad dam. The basin has an aerial extent of 3788.44 sq. km. Terrain elevation varies from 1046 m as maximum to 1 m as minimum (above mean sea level) of India. The large difference in the contour value is due to the Holy Girinar Mountain at Junagadh existing in the basin. The close spacing of the contour in middle reach of the basin indicated hilly ranges, while wider spacing in lower reaches of basin indicates flat topography. The holy GIRNAR Mountain is located in upper reach of the basin. The middle reach is having the fine soils having slope of around 1 per cent and crops adopted are groundnut and cotton during monsoon; wheat, coriander and gram during winter and short duration crops like groundnut during summer season. The lower reach of the basin is having fine soils with fairly flat slope less than 1 per cent. There are problems of water flooding in lower reach of basin during monsoon season. Agriculture in the watershed is restricted to rainfed farming (ground nut, cotton, wheat and barley), irrigated vegetable farming, orchard farming, green house farming, and chicken farms. Ground water level is very deeper some where it is found > 300 m also, so that major part of the basin is depending upon the rain fed farming. Agricultural land use constitutes about 70.15 per cent of the total watershed.

The watershed is covered by a wide range of soil types, ranging from fine to rocky showed that 65.70, 12.45, 11.05, 7.32 and 3.48 per cent area is having soil type of fine loamy, fine loamy, clayey and rocky, respectively. Soil depth is varies between < 25 cm to > 150 cm throughout the entire river basin. The land use area spreads in to seven different categories which are 70.15, 4.31, 6.79, 10.3, 6.24 and 2.21 per cent were under agriculture, built up, forest, wasteland, others (prosophis) and water body, respectively.

Data collection

Topographic maps with a scale 1:50,000 (20 m contour interval) were acquired from the Bhashkrachrya Institute of Space Application and Geoprocessing (BISAG). All the topographic maps are geo-referenced with Universal Transverse Mercator projection (WGS 1984, Zone 43˚N) using Arc GIS tools. Stream order was assigned to each stream following the stream ordering system developed by Strahler (1952b and 1964). The entire Ozat river basin was found of seventh order. The main watershed and sub-watershed areas, perimeters and length of watersheds were measured using GIS software. GIS software and DEM were used to calculate the hypsometric curve and hypsometric integral, maximum elevation, minimum elevation, and mean elevation and slope of watershed. The attribute feature classes that accommodate these values were utilized to plot the hypsometric curves for the watersheds studied, from which the Hi values were estimated. To find out the hypsometric integral values (Hi), several methods were elaborated (Singh *et. al.*, 2008), but in the present investigation, it was calculated using the elevation-relief ratio method proposed by Pike and Wilson (1971). Within the GIS environment, it is very easy to calculate hypsometric integral values (Hi) accurately using the elevation-relief ratio method.

The relationship is expressed as:

$$E \approx \mathrm{Hi} = \frac{\mathrm{Elev_{mean}} - \mathrm{Elev_{min}}}{\mathrm{Elev_{max}} - \mathrm{Elev_{min}}}$$

Where, E is the elevation relief ratio equivalent to the hypsometric integral Hi; $Elev_{mean}$ is the weighted mean elevation of the watershed estimation from the identifiable contours of the delineated watersheds, $Elev_{min}$ and $Elev_{max}$ are the minimum and maximum elevations within the watershed. Soil and Water Assessment Tool (SWAT) applied for indirect assessment of erosion status across the Ozat river watershed based on hypsometric integral values. Hypsometric integral values were validated using the estimated sediment yield results achieved through the application of Soil and Water Assessment Tool (SWAT).

Tools and techniques

The entire basin of Ozat river has been captured from the latest available Survey of India topographic sheets of 1 : 25,000 scale and delineated with the of ArcGIS 10.1 software. In the subsequent phase of hypsometric study of the basin GIS has been used extensively in the present work. All the elevation data relevant to the drainage basin has been transferred to GIS platform (Figure 2). These data were then converted to vector format to enable further analysis. With the help of ArcGIS software, quantitative parameters were gathered and processed through Microsoft Excel. These were then computed and tabulated and various sets of hypsometric graphs were generated using ArcGIS 10.1.

RESULTS AND DISCUSSIONS

Results of the present investigation are discussed in terms of the following sub-headings: hypsometric curve shape and hypsometric integrals.

Hypsometric curve shape

Hypsometric curve of a drainage basin represents the relative proportion of watershed area below or above a given elevation. It is a measure of the erosional state or geomorphic age of a drainage basin, as it represents the mass of drainage basin remaining above a basal plane of reference. Convex hypsometric curves indicate youthful stage, S-shaped curves indicates mature stage and concave curves indicates peneplain stage (Bishop *et. al*., 2002)

Previous studies demonstrated that in small watersheds, the hypsometric curves are normally convex, indicating the dominance of hill slope processes. Whereas, large watersheds exhibit concave curves denoting the dominance of fluvial processes (Willgoose, 1994 and Hurtrez *et. al.*, 1999a). The hypsometric curves of the entire Ozat river basin and the 17 sub-basins exhibit remarkably concave upward and S shape curve (which upward at height elevations and convex downward at low elevations) curves (Figure 4). It expresses simply the manner in which the volume lying beneath the ground surface is distributed from base to top. The curve must always originate in the upper left-hand corner of the square (x = 0, y = 1) and reach the lower right hand corner (x = 1, y = 0). It may, however, take any one of a variety of paths between these points, depending upon the distribution of the landmass from base to top. The computation of the hypsometric integral (Hi) of Ozat watershed, based on the hypsometric curve has resulted in a value of 0.09 (Figure 4).

Graphical inspection of the HC and examining of Hi values revealed that 1) all the curves indicated that the watershed and sub-basins (SB 1, SB 2, SB 4, SB 5, SB 7, SB 8, SB 12, SB 16, and SB 17) are at the monadnock-age stage of geomorphic development and 2) sub-basins (SB 3, SB 6, SB 9, SB 10, SB 11, SB 13, SB 14 and SB 15) are at the mature-age stage of geomorphic development, and 3) marginal differences exist in mass removal from the watershed and the 17 sub-basins.

Although all present hypsometric curves are of concave upward shapes, it was possible to distinguish two groups of curves. The first group is characterized by a concave upward shapes, with an average Hi value of 0.17 (sub-basins SB 1, SB 2, SB 4, SB 5, SB 7, SB 8, SB 12, SB 16, and SB 17). This group represents the sub-basins of a monadnock stage of evolution, and relatively older than other sub-basins. They are located at upper and middle reach of the Ozat river basin. The second group of curves is characterized by a very sharp convex upward shape with an average of Hi value 0.87 (sub-basins SB 3, SB 6, SB 9, SB 10, SB 11, SB 13, SB 14 and SB 15). This group of sub-basins represents the mature stage of geomorphic development. Sub-basins occupy the lower reaches of the Ozat river basin which are moderately affected by soil erosion process.

Deforestation, land use/land cover changes, overgrazing, and poor conservation measures maximize soil erosion. Soil erosion from the entire watershed and its sub-basins were attributed essentially from the incision of channel beds, landslide movement of regolith and bedrock materials, washout of top soil, and undercut erosion of stream banks.

Hypsometric integrals

Markose and Jayappa (2011) postulated that hypsometric integral controls the shape of a hypsometric curve and thereby provides indicators for geomorphic evolution of drainage basins. In the present case study, hypsometric integrals vary from 0.07 to 0.50. Other morphometric characteristics are slightly or highly varied among the seventeen sub-basins also (Table 1). The sub-basins SB 3, SB 6, SB 9, SB 10, SB 11, SB 13, SB 14 and SB 15 are display a middle Hi value of 0.44, 0.35, 0.50, 0.37, 0.32, 0.30, 0.34 and 0.30, respectively. Although noticeable variation is present in Hi values among the 17 sub-basins, two important categories of Hi are dominant. The first category ranges from 0.07 to 0.28 and middle and lower parts of the Ozat river basin (Figure 4). The second category (Hi >= 0.30) characterizes the upper part of the watershed. Lower values of Hi indicated that the watershed and the sub-basins are attaining the monadnock-age stage of geomorphic evolution. Lower Hi values also indicated high total runoff without subsurface processes as the major geomorphic processes (Vivoni *et al.*, 2008). Without exception, 8 sub-basins are considered to be of moderately susceptible to erosion, incised channel erosion and mass movement. This conclusion is verified by the soil erosion loss estimated for Ozat river basin using the SWAT model (Ijam and Tarawneh, 2012).

CONCLUSION

The hypsometric integral (Hi) is a functional parameter that intends to assess tectonic activity and erosion processes. The entire river basin and the 17 sub-basins show concave upward hypsometric curves and S shape curve (which upward at height elevations and convex downward at low elevations) and low hypsometric integral values ranging between 0.07 to 0.28 denoting that whole river basin is at the monadnock age stage, while discussing among 17 sub basins, some of them are at mature stage of geomorphic evolution, whose hypsometric integral values ranging between 0.32 to 0.50. Thus, from all some sub basins are of medium susceptibility to surface runoff, soil erosion loss, landsliding and flooding. Such processes are encouraged by the presence of structural discontinuities and the exposure of soft rock units of low shearing resistance in the middle and lower reaches of the watershed. Five sub basins (SB 1, SB 2, SB 4, SB 12, SB 16, SB 17) close to the Arebian Sea area and 3 sub basins (SB 5, SB 8, SB 7) which occupied the middle reach of Ozat river watershed are characterized by lower hypsometric values. Such figures indicated that there is no any or very moderately erosive process is going on in middle reaches of the watershed. Other sub basins (SB 3, SB 6, SB 9, SB 10, SB 11, SB 13, SB 14 and SB 15) showed middle values of Hi (0.32 – 0.50), indicating hillslope processes of lesser magnitude (i.e., shallow landslides and moderate soil erosion). Generally, sub-basins with lower Hi values have less total runoff with major contribution from surface runoff, whereas for sub-basins with middle Hi values, the total runoff is higher with sub-surface runoff as major process. These results necessitate the construction of appropriate soil and water conservation measures across the watershed and its sub-basins to control soil erosion, to conserve water, and to reduce sediment discharge through Ozat river basin into Arebian Sea.

ACKNOWLEDGEMENT

The authors would like to express their heartily thanks to Bhaskaracharya Institute For Space Applications and Geo-Informatics (BISAG), Gandinagar, State

Water Data Center (SWDC) Gandhinagar, and Central Ground Water Board (CGWB) Ahmedabad for providing necessary data, facilities and support during the study period.

REFERENCES

Bishop, M.; Shroder, J.; Bonk, R. and Olsenholler, J. (2002). Geomorphic change in high mountains: a western himalayan perspective. *Global Planetary Change*, **32:** 311-329.

Garg, S. K. (1983). *Geology- the Science of the Earth*. Khanna Publishers, New Delhi.

Harrison, C. G. A.; Miskell, K. J.; Brass, G.W.; Saltzman; E. S. and Sloan, J. L. (1983). Continental hypsography. *Tectonics*, **2**: 357-377.

Hurtrez, J. E.; Sol, C. and Lucazeau, F. (1999a). Effect of drainage area on hypsometry from an analysis of small-scale drainage basins in the Siwalik hills (Central Nepal). *Earth Surface Processes and Landform*, **24**: 799-808.

Hurtrez, J. E.; Lucazean, F.; Lave, J. and Avouac, J. P. (1999b). Investigation of the relationship between basin morphology, tectonic uplift and denudation from the study of an active foldbelt in Siwalik hills (Central Nepal). *J. Geophysic. Res.*, **104**: 779-796.

Ijam, A. and Tarawneh, E. (2012). Assessing of sediment yield for wala dam catchment area in Jordan. *European Water*, **38**: 43-58.

Kusre, B. C. (2013). Hypsometric analysis and watershed management of diyung watershed in north eastern India. *J. Geologic. Soc. India*, **82**: 262-270.

Langbein, W. B. (1947). Topographic characteristics of drainage basins. U.S.G.S., *Water Supply Paper*, **968C**: 127-157.

Markose, V. J. and Jayappa, K. S. (2011). Hypsometric analysis of kali river basin, karnataka, india, using geographic information system. *Geocarto International*, **26**: 553-568.

Miller, V. C. (1953). A quantitative geomorphic study of drainage basin characteristics in the clinch mountain area, virginia and tennessee, project NR 389-042. *Tech. Rept. 3*, Columbia University, Department of Geology, ONR, Geography Branch, New York.

Pike, R.J. and Wilson, S.E. (1971). Elevation-relief ratio, hypsometric integral and geomorphic area-altitude analysis. *Geologic. Soc. America Bull.*, **82**: 1079-1084.

Ritter, D. F.; Kochel, R.C. and Miller, J. R. (2002). *Process Geomorphology*. McGraw Hill, Boston.

Rosenblatt, P. and Pinet, P. C. (1994). Comparative hypsometric analysis of earth and venus. *Geophysic. Res. Lett.*, **21**: 465-468.

Sarangi, A. and Bhattacharya, A. (2000). Use of geomorphological parameters for sediment yield prediction from watersheds. *J. Soil Water Conserv.*, **44**: 99-106.

Schumm, S. A. (1956). Evolution of drainage systems and slopes in Badland at Perth Amboy, New Jersey. *Geologic. Soc. America Bull.*, **67**: 597-646.

Singh, O.; Sarangi, A. and Sharma, M. (2008). Hypsometric integral estimation methods and its relevance to erosion status of northwestern lesser himalayan watersheds. *Water Resourc. Manag.* **22**: 1545-1560.

Singh, O. (2009). Hypsometry and erosion proneness: a case study in the lesser himalayan watersheds. *J. Soil Water Conserv.*, **8**: 53-59.

Strahler, A.N. (1952a). Hypsometric (Area-Altitude) analysis of erosional topography. *Geolog. Soc. America Bull.*, **63**: 1117-1141.

Strahler, A.N. (1952b). Dynamic basis of geomorphology. *Geolog. Soc. America Bull.*, **63**: 923-938.

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. *Transactions*, *American Geophysical Union*, **38**: 913-920.

Strahler, A. N. (1964) *Quantitative Geomorphology of Drainage Basins and Channel Networks. Section 4-II*. In: Chow V. T., Ed., *Handbook of Applied Hydrology*, McGraw Hill, New York, pp. 439-476.

Vivoni, E. R.; Di Benedetto, F.; Grimaldi, S. and Eltahir, E. B. (2008). Hypsometric control on surface and subsurface runoff. *Water Resourc. Res.*, **44**: Article ID: W12502.

Weissel, J.; Pratson, L. and Malinverno, A. (1994). The length-scaling properties of topography. *J. Geophysic. Res.*, **30**: 151-159.

Willgoose, G. R. (1994). A physical explanation for an observed area-slope-elevation relationship for declining catchments. *Water Resourc. Res.*, **30**: 151-159.

Table 1: Hypsometric integral values and sub-basin parameters of Ozat river basin

Sub-Basin No.	Area (km^2)	Perimeter (km)	Elev.$_{Max.}$ (m)	Elev.$_{Mini.}$ (m)	Elev.$_{Mean}$ (m)	Hi
SB 1	44.49	59.79	18.00	3.00	5.60	0.17
SB 2	110.18	94.64	23.00	0.00	5.96	0.26
SB 3	71.47	66.93	47.00	10.00	26.14	0.44
SB 4	200.91	143.16	311.00	10.00	94.08	0.28
SB 5	1049.48	290.32	1046.00	8.00	85.75	0.07
SB 6	4.67	16.87	23.00	9.00	13.97	0.35
SB 7	266.68	163.17	873.33	22.00	91.69	0.08
SB 8	204.54	106.03	1044.00	48.00	169.15	0.12
SB 9	180.84	109.05	205.00	63.00	134.34	0.50
SB 10	213.58	133.74	292.00	70.00	152.81	0.37
SB 11	1.31	8.19	20.00	7.00	11.15	0.32
SB 12	150.65	85.90	123.00	8.00	38.47	0.26
SB 13	1.98	11.51	118.00	64.00	80.01	0.30
SB 14	143.37	107.57	150.00	11.00	57.65	0.34
SB 15	261.26	130.60	325.00	42.00	127.27	0.30
SB 16	576.13	211.63	63.00	2.00	10.61	0.14
SB 17	306.89	137.19	476.00	57.00	204.32	0.35
Basin	3788.44	606.13	1046.00	0.00	90.81	0.09

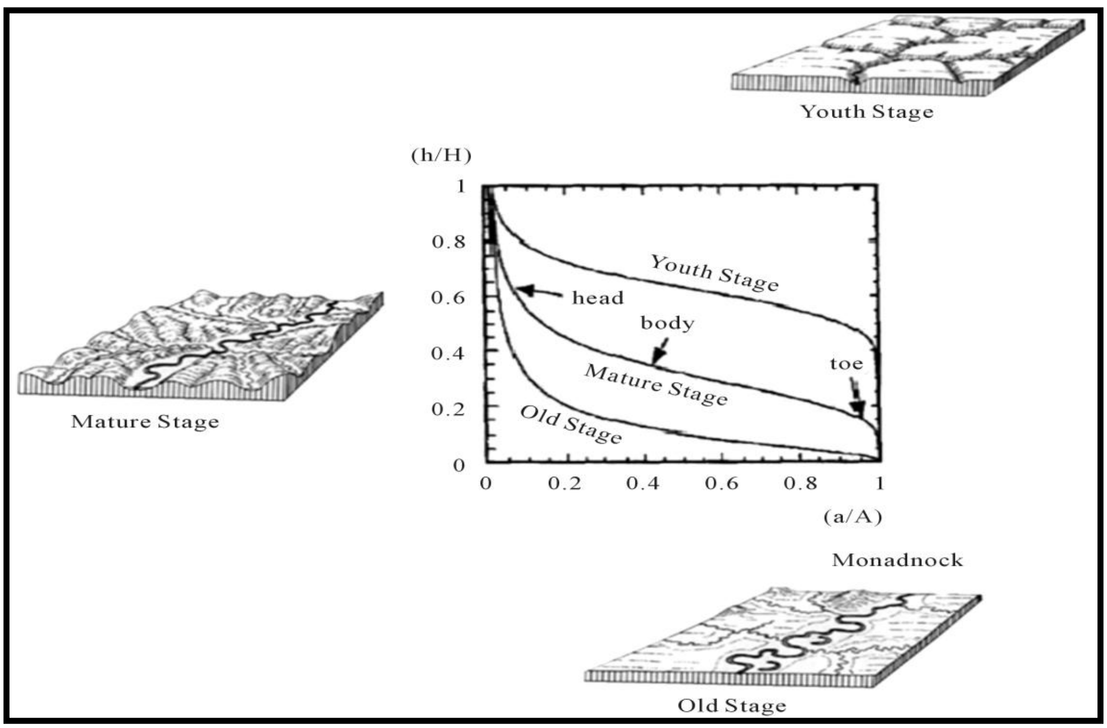


Figure 1: The types of hypsometric curves (youth, mature and old stages of geomorphic development) as elaborated by Strahler (1957 and 1964)

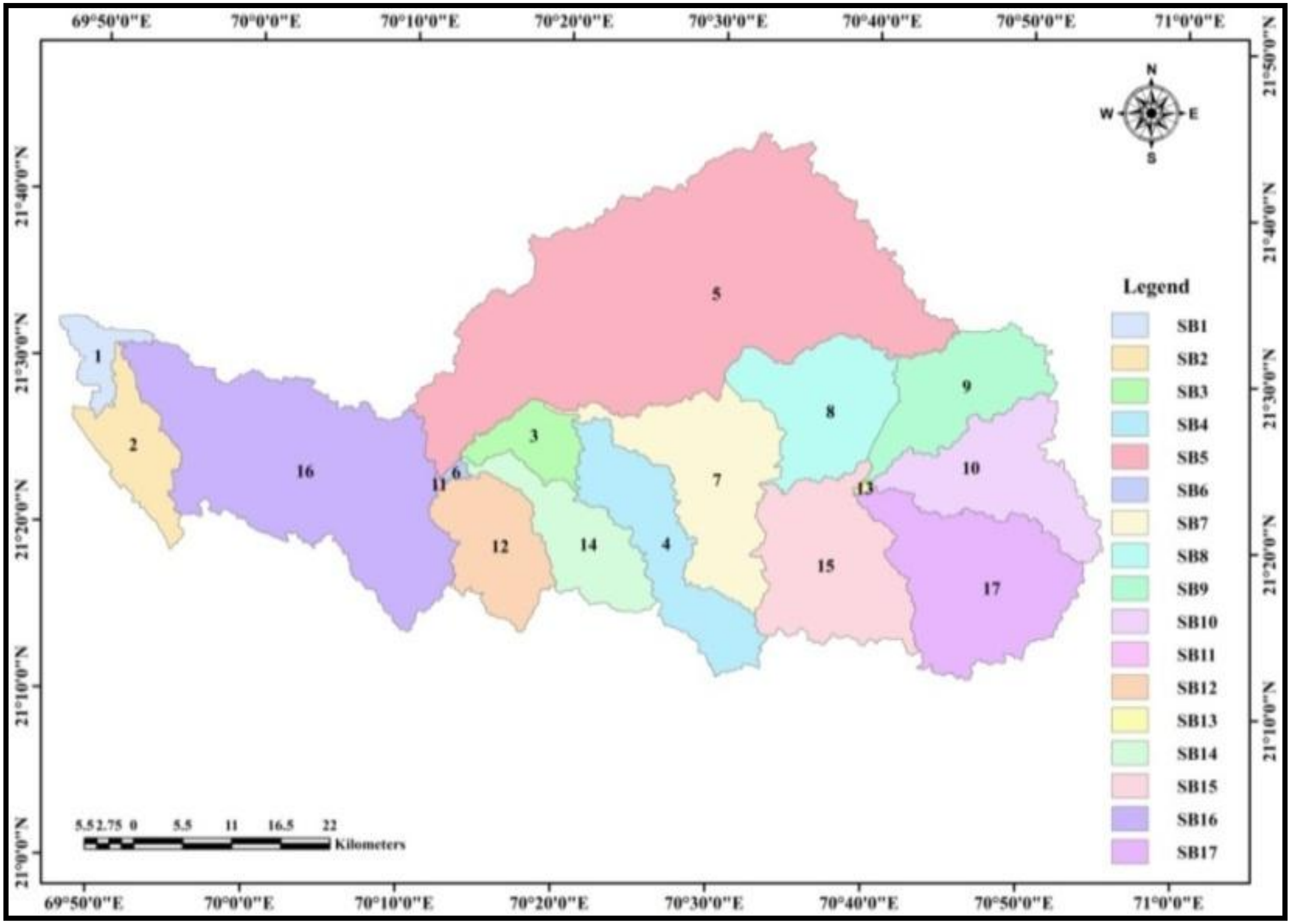


Figure 2: Sub basin map of Ozat river basin

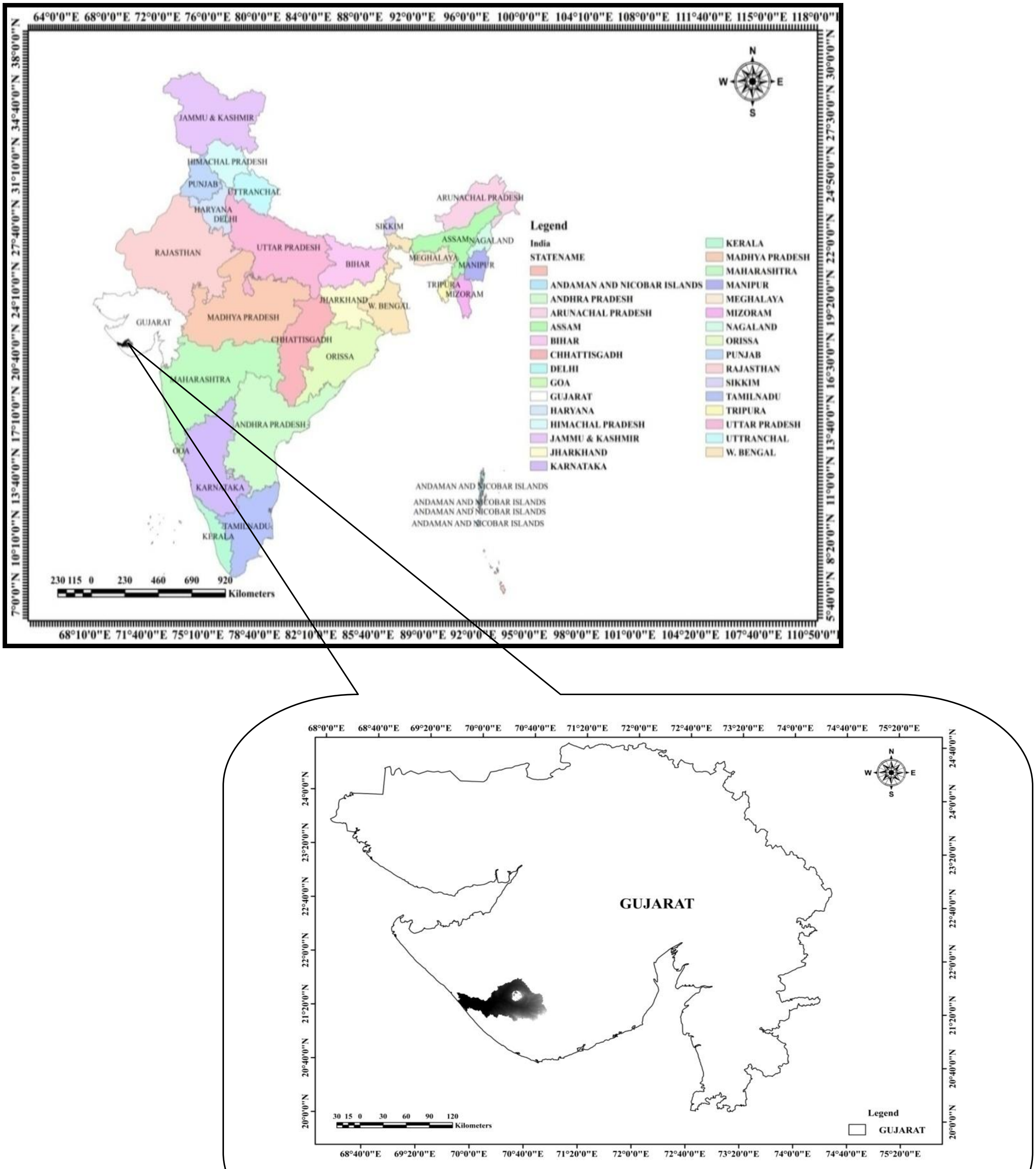
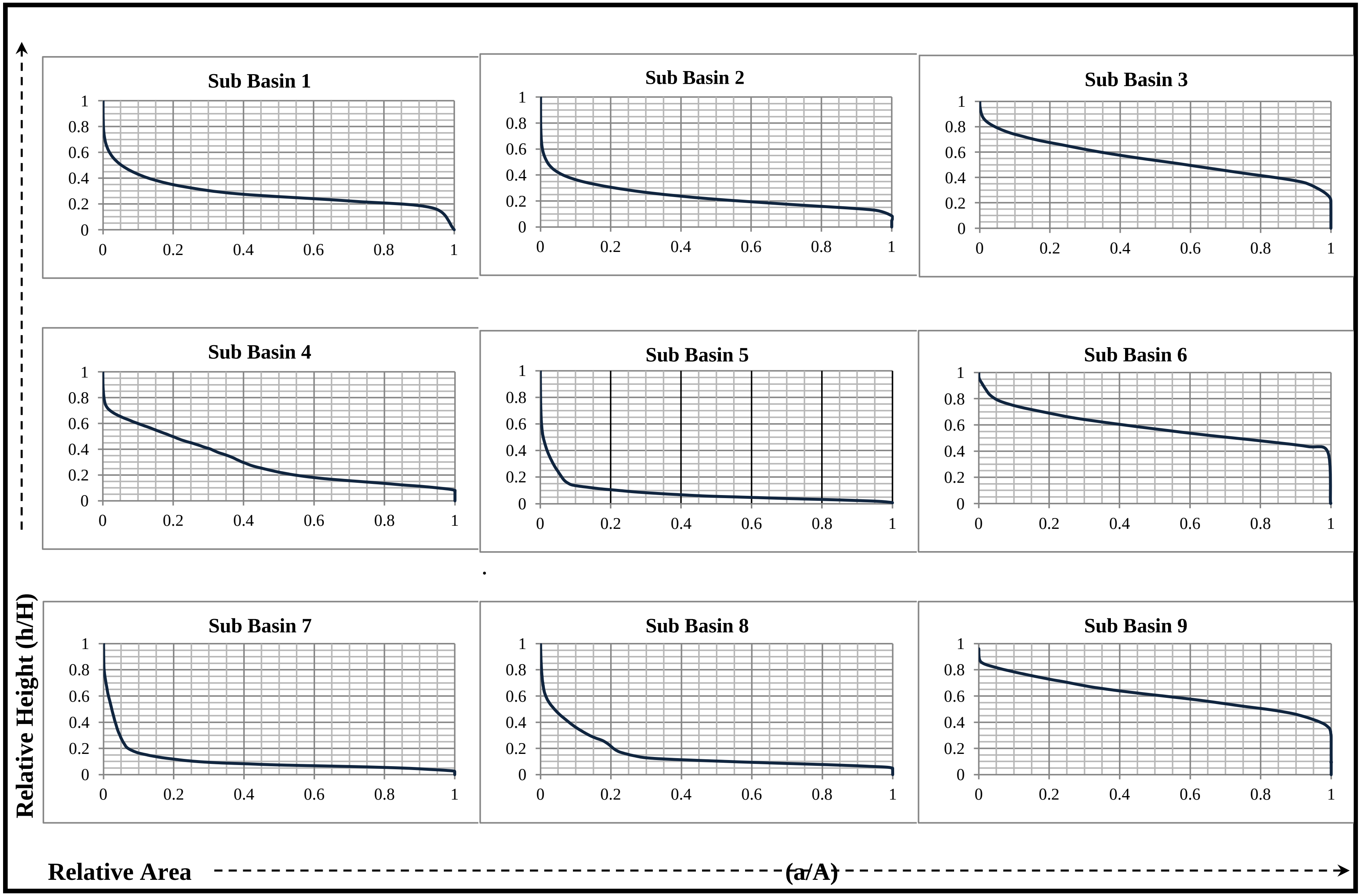


Figure 3: Location map of Ozat river basin in India as well as in **Gujarat**


Sub Basin 1
Sub Basin 2
Sub Basin 3
Sub Basin 4
Sub Basin 5
Sub Basin 6
Sub Basin 7
Sub Basin 8
Sub Basin 9
0
0.2
0.4
0.6
0.8
1
Relative Height (h/H)
Relative Area
(a/A)

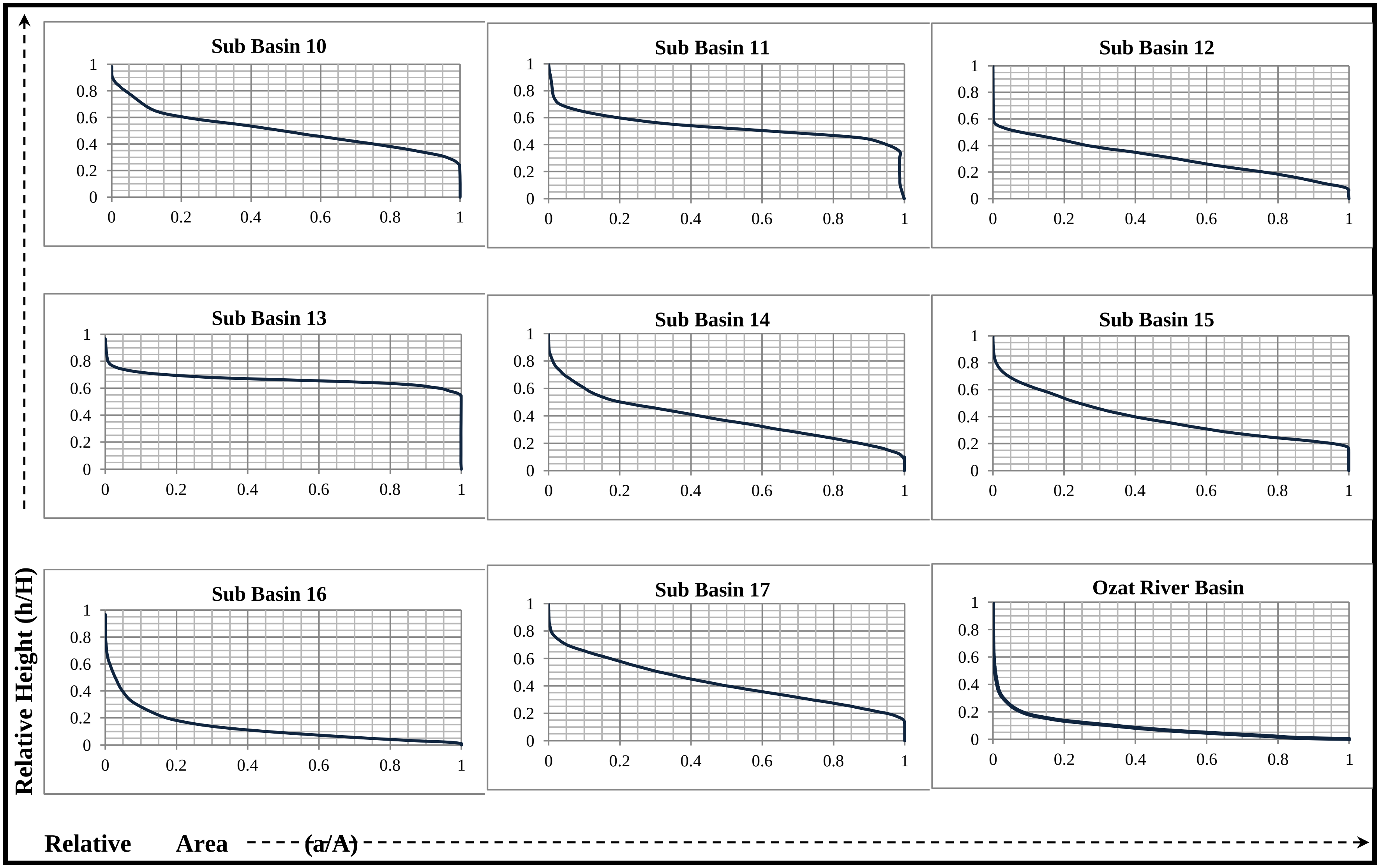


Figure 4: Hypsometric curves of seventeen sub-basins (sub-basin 1 to sub-basin 17) as well as entire Ozat river basin

[MS received : January 07, 2018] ***[MS accepted : January 21, 2018]***