Chapter 1
INTRODUCTION

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1.1 GENERAL INTRODUCTION AND LITERATURE REVIEW

River basin morphometry is a process of characterization which gives quantitative information about configuration of a basin. River basin morphometry study started probably in 1900, when Neumann gave the index of drainage density[1]. But the work of Horton gave river morphometry a modern meaning[2,3]. Horton used measuring and operating tools to quantify drainage basins and their nets. After the work of Horton, many authors have contributed to the development of basin morphometry as well as its understanding in hydrologic perspective[4-16]. One of the prime motivations of these works was to correlate hydrology and geomorphology with the science of basin morphometry.

Recent decades witnessed large extension of basin morphometric studies into the different environmental conditions throughout the world. This includes works on basins of North America[17,18], South America[19,20], Europe[21-22], Middle East[23,24], Africa[25,26] and India[27-29]. These efforts commonly attempt to appraise the measured morphometric parameters as fundamental descriptor of hydro-geomorphological investigations and allied disciplines.

The early works, in many instances, characterized linear, areal and shape aspects for quantitative description of basin morphometry. The parameters depicting these aspects are determined by a number of basic rules and numerical criteria defined by many authors[2,3,9,30-32]. These basic rules and numerical criteria provide a defined set of parameters that practically gives physical description and therefore helpful in interpreting the hydro-geomorphic behavior of a basin. For instance, drainage factors influence mean annual flood[13], flood potential[16], output of sediment[33] and gully erosion[34]; shape impact susceptibility towards erosion and sediment load[27] along with flow pattern[15,35,36] and the relief factor decides flow discharge[33] of a basin.

Evaluating these river morphometric parameters involve many basic inputs which can be termed as the basin indices. These basin indices include- basin area, perimeter, length and drainage structure and its (drainage) characterization. Drainage characterization involves ordering of streams following defined set of rules[3,14,32]. Although a large number of studies have been carried in all corners of the world, the uncertainties imposed by the fragmental nature, source limitation and subjectivities with the techniques of basic indices measurements have not been addressed adequately.

In the following sections, difficulties associated with the measurements of basic indices are discussed. The difficulties associated with river morphometric measurements are mainly associated with three aspects viz., drainage measurement, watershed delineation and basin length measurement. Depending on these aspects, the section is sub-divided into- (a) Drainage measurement, (b) Watershed delineation and (c) Basin length measurement.

1.1.1 Drainage measurement

Drainage structure, one of the primary indices in morphometric study, is still an area of apprehension as its identification and consideration possess subjectivities. The practical difficulties in drainage identification were recognized right from the early days of morphometric development[1,3,14,37]. As far as drainage identification is concerned topographical maps, imageries and digital elevation models (DEM) are the prime sources of information.

Though topographical maps have universal acceptability, they expose the scope of subjectivity in terms of selection of perennial and non-perennial channels, appropriate scale and availability in recent time scale[1,3,38-40]. Similarly for the other sources, number and length of identifiable drainage largely varies with the use of different type of imageries with unique scale and resolution[41]. Technically, lack of specific criteria for identification and interpretation of streams from images certainly leaves a great deal to be achieved. Thus the selection of correct scale for data acquisition, availability in recent time scale and lack of criteria for stream delineations give rise to problems by introducing errors in morphometric measurements.

Compared to other sources, use of DEM for drainage generation is a relatively new approach and an area of much innovation. In recent decades, DEM is widely recognized

source of drainage estimation throughout the world[42-47]. The foundation of stream estimation from DEM was laid by O'Callaghan and Mark when they proposed d8 method for determining flow direction[48]. It is unanimously used as the basic algorithm for stream estimation from DEM with determination of threshold. Later, with realization of subjectivities associated with the basic methods of stream estimation, many researchers modified and suggested new methods for streams estimation[49-56]. Inadequacy of the methods for stream estimation from DEM is an area of concern and demands exploration of effectual methods as it is an imminent source of stream estimation. Selection of DEM type is another issue which has been a point of discussion in amongst contemporary is researchers. Of the sources, majority of the works compare SRTM and ASTER DEMs in different landscapes[57-59]. While some favours SRTM over ASTER, others recommend ASTER over SRTM especially in hilly terrains[57,59,60,61]. It is, therefore, still an area of investigation and requires deeper assessments. It is important to note here that the major problem in stream estimation from DEM is in the method, especially the involvement of manual intervention, not the marginal difference in DEM types.

Yet another issue, not associated with technique of drainage identification, is the inaccessibility of data source due to administrative limitations. Topographical maps are one of the basic and inevitable sources of drainage information whose accessibility at times restricted due to administrative reasons. It is more so for the rivers spreading over two or more countries[62,63]. In such situations, one source of a stream is not sufficient for getting entire geometry of drainage basin. It necessitates using streams derived from two or more sources. Unfortunately presently there is no set of rules for consistent combination of streams derived from two different sources. There is a need to develop an approach that combines streams of two sources consistently. When faced with such condition, researchers commonly use more than one source[64] but lack consistency in the absence of any set of rule. Therefore, ambiguity inherently creeps in combining the streams.

Apart from identification and consideration, uncertainties in application of fundamental rules of stream classifications impose serious practical difficulties in its characterization. There are two popular schools of thought to classify streams, represented by Horton-Strahler and Scheidegger-Shreve method, which practically assigns a value providing a sense of the size and magnitude of any particular stream with respect to the mainstream of

the drainage net[3,6,14,65]. The practicability of these rules is thoroughly debated by scholars[38, 66-68]. These fundamental methods of stream characterization, illustrated using regular stream-network are deficient in complex situations. When one applies these fundamental rules in complex interconnecting stream geometry, the subjectivities arise in consideration as well as ordering of the streams. It rationally demands expansion of these basic rules in complex interconnected stream patterns. Although a few studies have been attempted, they were mainly concentrated in braided or circuited networks[69-73]. The work of Howard et al. and Smart & Moruzzi developed procedures for characterization of circuited and braided networks of anastomosing streams and delta formation[69-70]. Riddell attempted to expand Horton's stream order method in circuited transportation network. He used breaking circuit method for simplification of the circuit keeping relative importance of the nodes in mind[71].Lanfear proposed an algorithm that assigns Strahler stream order in braided streams and multiple drainage outlets[72]. Strahler's method is again tested in braided networks, where recursive stream ordering algorithm is proposed for computing Strahler's stream classification in braided river[73]. Beside these stream conditions, drainage system exhibits complex distributary conditions. And, unfortunately, application of these classification methods in such complex distributary conditions is rarely attempted.

1.1.2 Watershed delineation

As far as delineation of watershed is concerned, the traditional methods include the use of contour lines and streams, where streams provide a logical placement of terminus points necessary for sub-dividing basins[74]. In recent decades, the method of locating watershed boundary has become much easier with availability of DEM. The modern processing tools automatically discriminate watershed boundary with DEM. Over last decades, several automated techniques were introduced for mapping watershed divides[75-80]. These watershed delineation techniques are now routinely available in geographic information systems (GIS) for use in hydrological studies[81].However, despite of large improvement in processing tools and availability of higher resolution DEMs, its applicability in delineating watershed in flat terrain is still a concern. Improvements of techniques for watershed delineation in flat terrains have been attempted[82,83]. These improved techniques are based on increment of vertical elevation or burning DEM with other geo-informational data. Flat terrains have missing topographical details that cannot be removed with elevation increment as it may lead to amplification of localized errors. On the other hand,

DEM burning approach that combines other information sources can be a better alternative. Although various approaches are proposed with application of DEM, results are still unsatisfactory due to the nature of flat terrain where insufficiency in altitude variation in DEM data itself a limitation. This demands an alternative to this approach. Since DEM is indispensable in watershed delineation, the obvious alternative is to integrate other geo-spatial information to improve efficiency in watershed delineation. Thus, a multi- geo-informational protocol to compute an unambiguous watershed boundary is imperative.

1.1.3 Basin length measurement

Basin length measurement probably started with Horton (1932) when he defined basin length as the length of the line measured from a point on the watershed-line opposite to the head of the main stream[2]. After Horton, many authors proposed principles and methods for computation of basin length[9,15,84,85]. These post Hortonian methods and indices were comprehensively reviewed and discussed by Gregory and Walling (1973), Cannon (1976), Gardiner and Park (1978), and Zavoianu (1985)[1,15,38,86]. Gregory and Walling (1973) argued that the main stream can be taken into consideration for certain situations whereas for very tortuous and irregular rivers with their unusually shaped drainage basin a subjective decision is required. Conversely, they acknowledged the precision of Potter's method where a line dividing the basin into two equal halves crosses the mainstream and then joins the centre of gravity of the basin with the mouth thereby providing centroid direction. Cannon (1976) opined that Schumm's definition of basin length measurement as the longest dimension of the basin parallel to the principle drainage line, has led to confusion and has been variously interpreted by investigators. For the purpose of his investigation, Cannon used basin length measured with three different techniques viz., main channel length, basin chord length and cumulative total of mean stream lengths. It was concluded that the selection of basin length method should be left to the individual investigator. Gardiner and Park (1978) discussed Ongley's vectorial method of basin length measurement and the debates associated with it. Zavoianu (1985) discussed the entire gamut from Hortonian definition to Ongley's vectorial method of basin length measurement. He drew attention to Ogievsky's method of using a line drawn from the mouth to the most distant point of the drainage area passing through the mid points of the line drawn across the basin- which basically divides a basin laterally into two

equal halves. He also differentiated between Maxwell's method based on the concept of drainage-basin parameter and Appollov's method which advocates determination of median. All the methods investigated thus far lead us to identify three basic ideas of basin length measurement viz., length of the main stream, length of the vectorial axis and length of the line that divides the basin laterally into two equal halves. But subjectivity lies in the main stream method as it overestimates basin length in case of meandering rivers[15,86]. On the other hand, the method of measuring vectorial axis, as basin length, works perfectly well for a simple and regular basin; however, leads to a faulty result if the basin is curved or crescent shaped[86]. Against the critical shortfalls of the methods discussed, we support the third idea of measurement by a line drawn from the mouth to the most distant point on the condition that it passes through the midpoints of lines drawn across the basin as being more practical in establishing basin length. But subjectivity lies in its manual determination which is the common practice. Although systematic lateral line method can compute better basin length, but it still carries approximation as smaller bends and irregularities commonly get neglected.

1.2 OBJECTIVES OF THE PRESENT WORK

The aim of this work is to investigate and overcome methodological difficulties in river morphometric measurements. Scientific discourse pertaining to methodological issues points out three major areas of investigations viz., drainage measurement, watershed delineation and basin length measurement. Consequently, the objectives of the study are set to investigate and overcome methodological difficulties in -

> 1. Drainage measurement
>> a. Identification and consideration of streams
>> b. Correct estimation of streams
>> c. Combining two sources of streams
>> d. Characterization of complex interconnecting streams
> 2. Watershed delineation
> 3. Basin length measurement

1.3 METHODOLOGIES

The focus of this study is development of methodical approaches and methodologies for unambiguous morphometric measurements. In virtue of its thorough and explicit presentation, methodologies involved in particular objectives are discussed in their corresponding sections. However, for overall visualization of the methods involved in the study, it is briefly presented in tabular form. The table categorically contains objectives, adopted methodologies and datasets used in its execution. Depending on three major problem areas, tables are arranged where **Table 1.1** illustrates the methodologies involved in overcoming the problems associated with drainage measurements, **Table 1.2** displays the systematic resource utilization approach adopted for removal of ambiguities associated with watershed delineation and **Table 1.3** presents method used to remove approximation associated with basin length measurement.

Table 1.1 A synoptic representation of the methodologies adopted for drainage measurement

Drainage measurement		
Objectives	Adopted methodologies	Dataset used
1. Identification and consideration of streams	Systematic protocols are suggested for consistent stream identification	Topographical maps; LISS IV images
2. Correct estimation of streams	Novel methods are proposed for correct estimation of streams from DEM	Topographical maps; DEM
3. Combining two sources of streams	An approach of combining streams of two sources is developed	Topographical maps; DEM
4. Characterization of complex interconnecting streams	The fundamental rules of stream characterization are expanded in complex interconnecting stream conditions	Modeled river network representing complex conditions

Table 1.2 A synoptic representation of the methodologies adopted for watershed delineation

Watershed delineation		
Objective	Adopted methodologies	Dataset used
1. Identifying water divide in plains	Systematic multi-geo-informational resources utilization coupled with field surveys is proposed	Topographical maps; LISS IV images

Table 1.3 Presents the methodology adopted for basin length measurement

Basin length measurement		
Objective	Adopted methodology	Dataset used
1. Removing approximation in basin length measurement	A numerical approach for measurement of basin length is proposed	Outlined basin models, Landsat Images, DEM

1.4 DATASET USED

As necessitated by the nature of the work, multiple geo-informational data collected from different sources are utilized to perceive methodological challenges in morphometric studies. The geo-informational data include- Survey of India (SOI) topographical maps of scale 1:50000, High Resolution Linear Imaging Self-Scanner- LISS IV images acquired from National Remote Sensing Centre (NRSC), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) of 30 m spatial resolution, Landsat Operational Land Imager (OLI) images and other collateral data in the form of published map and reports (**Table 1.4**).

Table 1.4 Showing details of the dataset used

Dataset	Resolution/scale	Details of the dataset	Year
Topographical maps	1:50000	78J/1, 78J/2, 78J/3, 78J/4, 78J/5, 78J/6, 78J/7 and 78J/8	Surveyed between 1964-71
LISS IV images	5.8 m	109 (52c,53a)	2013
ASTER DEM	30 m	--	2011
Landsat images	30 m	138 (41,42)	2014
Collateral data	Published maps, photographs		

1.5 RIVER BASIN SELECTED FOR ILLUSTRATION OF DIFFICULTIES, DEVELOPED METHODOLOGIES AND PROTOCOLS

The aim of this study is to identify and overcome the methodological complexities in river morphometric studies. It inevitably demands a landscape exhibiting the factors that triggers the difficulties in morphometric measurements. The rivers of Eastern Himalaya exhibits large physiographic disparity with an array of human activities which are the precursors of problems associated with river morphometry measurement. With this realization, a medium size (~1000 km^2) Eastern Himalayan river viz., Gaurang is taken to explore the methodological complexities. The practical necessity of taking a medium size

river is that it facilitates proper exploration of methodological difficulties with extensive and deliberate interpretation as well as field study.
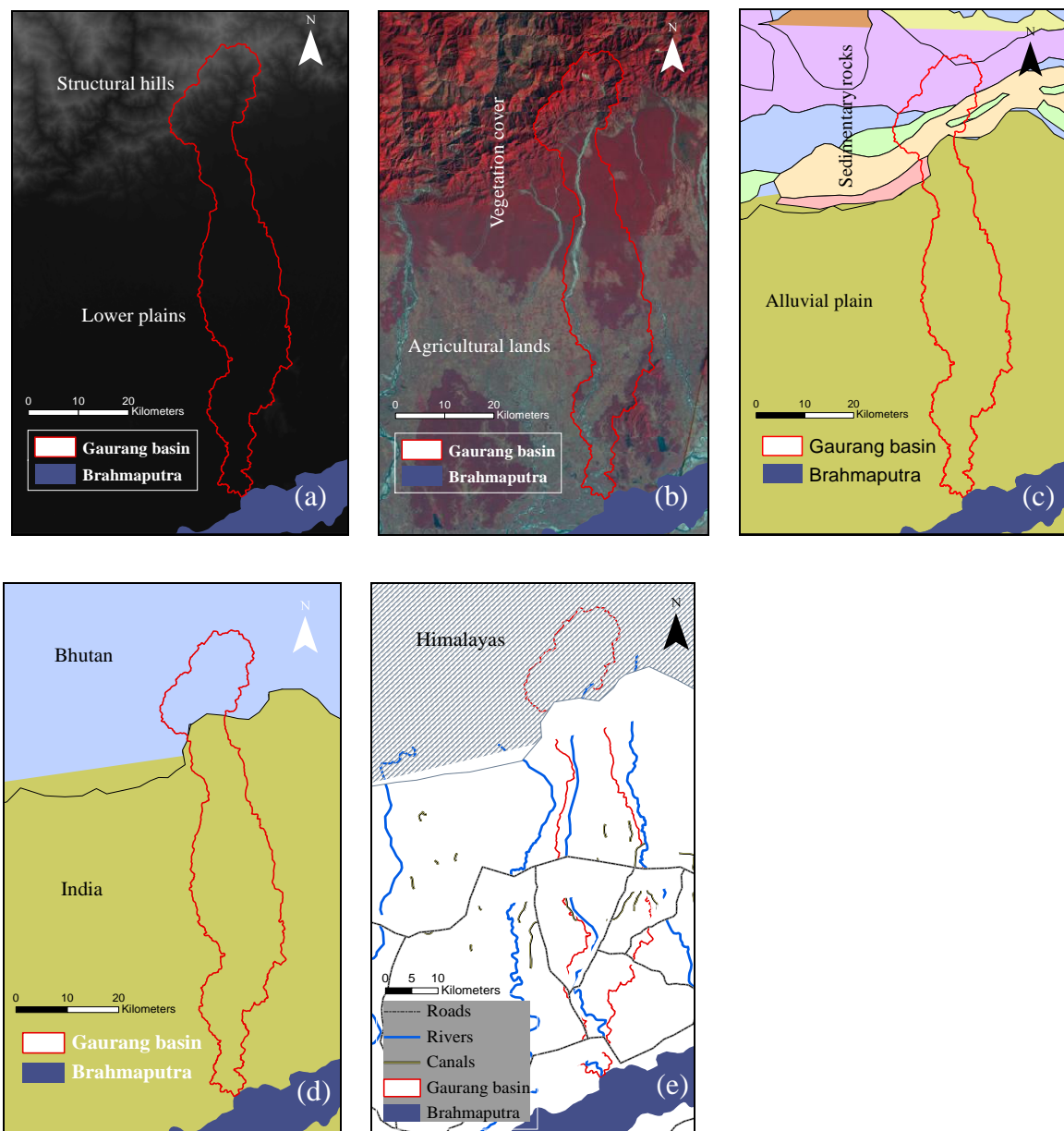

Figure 1.1 Maps showing- (a) topographical variation, (b) physiographic incongruity, (c) lithological disparity, (d) international boundary share and (e) large scale human interventions in the selected river basin (Gaurang) for illustration of methodological difficulties in river morphometric study

Topographically, the basin can be divided into two distinct regions- upper structural hills and lower plains. The slope largely varies, gentle to moderate in the plain and steep to extremely steep in the hills (**Fig. 1.1a**). Regarding vegetation cover, one of the most

important physiographic factors that furnish operational difficulties, the study area exhibits spatial incongruity. Upper hilly portion that lies in Bhutan is covered with moderately dense forest; immediate foothills are largely covered with highly dense forest exhibiting the features of Dooars followed by barren land predominantly used for agricultural purposes (**Fig. 1.1b**). Lithological variation is also prominent along the basin.

Upper hilly portion along the foothills of Bhutan consists of gray to brownish color moderately hard sand stone. The adjoining plains to the foothills are pediment zones formed by coalescence of several alluvial formations. The pediment is followed by older alluvial plain in lower middle of the Gaurang and lastly the southernmost newer alluvial plain (**Fig. 1.1c**). One of the cornerstones of considering an Eastern Himalayan river in exploring the operation difficulties is that most of the Eastern Himalayan rivers originate in the geographical areas of Bhutan or China which eventually joins mighty Brahmaputra in plains of India (**Fig. 1.1d**). These international rivers institute the problem of accessibility of data for the entire basin to the researchers. It is being the case for Gaurang, the demonstrated basin, where the uppermost part of the basin lies in Bhutan and the topographical map for it is not accessible. In addition, the plains of the Eastern Himalayan rivers have numerous roads, artificial streams and canals that create operational difficulties in morphometric measurements (**Fig. 1.1e**).