JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.90, August 2017, pp.183-186

Overcoming Source Limitations in Drainage Delineation by Combining the Streams of Toposheet and DEM in River Morphometric Studies

Rajesh Kumar Sah[1] and Apurba Kumar Das[1]*

[1] School of Sciences, Department of Environmental Science, Tezpur University, Tezpur - 784 028, India

E-mail: *apurba@tezu.ernet.in*

ABSTRACT

This paper suggests an approach that combines the drainages of DEM and toposheets, by matching streams (number and length) and spatial coincidence, the critical aspects of such operations, for overcoming source limitation in river morphometric studies. We illustrate the approach taking Gaurang, a Himalayan river basin, as an example where the toposheets for the uppermost part is inaccessible. Stream matching in terms of number and length is controlled by a method of automatic stream generation from downscaled DEM and flow accumulated rasters. Stream estimated by this method are tested, verified and finally applied to the portion of the basin where the data is unavailable. The other critical aspect- spatial coincidence is controlled by commonly used method of GCPs. In the present case, use of the nodal points of the major tributaries generated from DEM as GCPs for georeferencing of toposheets have restricted the positional mismatch to much less than a pixel. With the consent of both the aspects i.e. stream matching and spatial coincidence, the DEM generated stream is considered to combine with the stream of toposheets to get the drainage of entire basin.

INTRODUCTION

Drainage pattern, which serves as fundamental input and largely decides the morphometric parameters, is a key descriptor of river morphometry. As a source map for stream identification, toposheets are the most common and have been in use right from the early days of development of morphometric studies (Horton, 1945; Gregory and Walling, 1968; Nag, 1998; Mesa, 2006; Bali et al., 2012). The other sources of stream include aerial photographs, imageries and Digital Elevation Model (DEM) data. Of these, DEM has emerged as very popular source.

As a source of drainage information, there are limitations commonly faced by the researcher in use of toposheets including inaccessibility due to administrative and security reasons and scarcity in terms of time scale. These limitations become all the more pronounced for the rivers with their basins lying in more than one country. For example, many rivers of Himalayas are spread over India, China, Bhutan, Nepal, Pakistan and Bangladesh. Toposheets for the entire basin for these rivers are not readily accessible. In India, this limitation is very common for rivers in the north and east as they originate in neighboring countries. These rivers include Ganga, Brahmaputra and Indus with their large number of tributaries.

Besides toposheet, DEM is being increasingly used for generating streamlines. However, for basins constituted by areas of high altitude and plain, DEM alone is not sufficient. While one can generate well defined streamlines by using DEM for hills, it is not so for the plains. Therefore, toposheets, other authentic maps, aerial photographs or imageries are indispensable sources of stream information for plains. Considering streams of toposheet for plains and DEM generated streams for hills can be very effective for consistent and accurate drainage identification, provided that two critical aspects- stream matching and spatial coincidence- are sufficiently addressed. Stream matching is indispensable as stream marked on toposheets and those generated from DEM varies with their scale and resolution. Spatial coincidence is hampered by error in georeferencing of imageries as well as during coordinate transformation and, therefore, requires methodical steps to restrict the positional mismatch.

In this work, streams generated from DEM is combined with the streams of toposheets to get the drainage pattern of entire basin addressing the critical aspects associated with the process. The approach can be effectively employed to overcome the source limitations mentioned earlier.

STUDY AREA

The proposed method is demonstrated taking Gaurang river basin as an example. Gaurang shares boundary between India and Bhutan. The toposheet of uppermost portion of the basin is not accessible to us due to administrative reasons (Fig. 1).

DATASET AND METHODOLOGY

The datasets used for the study include Survey of India toposheets of 1:50000 scale, Aster DEM of 30m resolution and LISS IV images of 5.8m resolution. The Aster DEM is downloaded from Global Land Cover Facility (GLCF) and the LISS IV Images are acquired from National Remote Sensing Centre (NRSC).

The methodology followed is organized in the sequence of (a) stream matching, (b) positional match in streams of the sources and (c) drainage and positional error calculation.

The upper portion of the basin for which the drainage information is available from both the sources is chosen for carrying out these steps. With a purpose of verification of the results, this upper portion of the basin is divided into two parts. For convenience, the lower part is termed as test area and upper as the verification area. The part adjoining to the portion where toposheets are inaccessible is termed as application area. Stream matching for both the sources are tested for the test area, the best result is verified with the verification area, and finally, applied to the application area.

Stream Matching

Flow accumulation raster generated by using d8 method of O'Callaghan & Mark (1984) is most commonly used for the purpose of stream estimation from DEM. As flow accumulation raster contains all channeled and unchanneled regions, to discriminate the drainage one need to provide threshold (Tarboton et al., 1989). But uncertainty remains with the use of threshold as it either compromises with stream number or length in case of high resolution DEMs whereas in case of

0016-7622/2017-90-2-183/$ 1.00 © GEOL. SOC. INDIA | DOI: 10.1007/s12594-017-0697-5

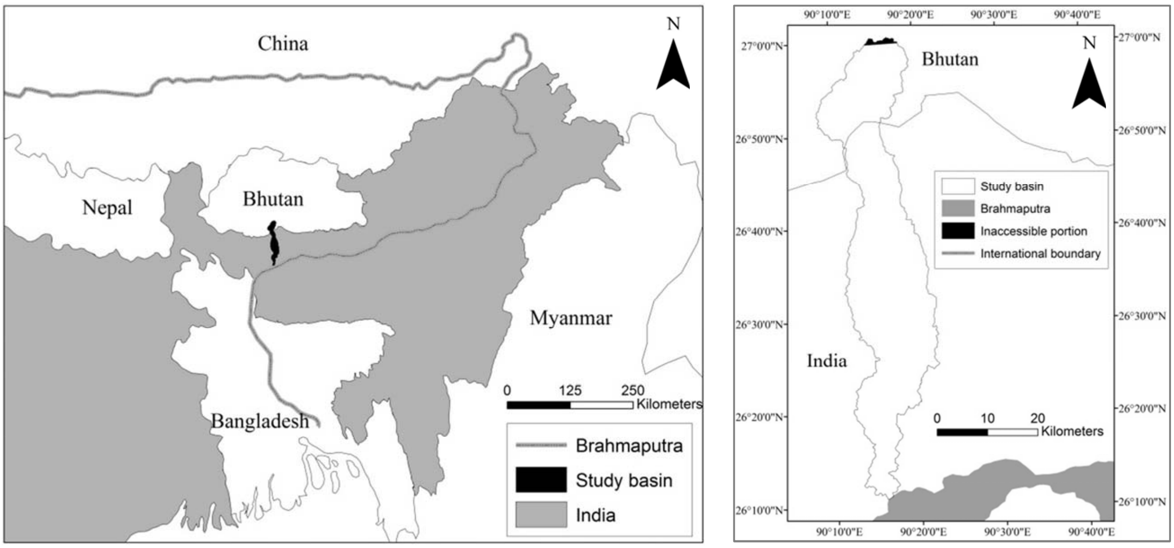

Fig.1. Location map of Gaurang – the basin used for illustration of the study.

low resolution DEM, it gives rise to the problem of pixel clumping (Sah and Das, 2015). To remove this uncertainty, Sah and Das (2015) developed a method for automatic stream generation based on DEM downscaling approach. The major advantage of the method is that it generates streams at greater head extent and thus facilitates application of downscaling approach to find out optimum resolution (flow accumulation) that has appropriate details requires for stream estimation at a reference scale. The method incorporates flow accumulation and flow direction raster, where flow accumulation raster serves as stream input, in stream order tool to generate drainages. Application of stream order tool automatically carves out stream geometry from a raster containing stream information. In this regard, application of raw DEM as stream input can be interesting as it exhibits more topographical information than flow accumulation raster.

With the above appreciation, stream estimated using flow accumulation raster and raw DEM as stream input in stream order tool of ArcGIS 10 are compared with stream of toposheet and subsequently better results are considered for stream matching. The entire process involve the following steps-

Data pre-processing: Pre-processing includes resampling of DEM, removal of discontinuity of data and generation of flow accumulation raster. Nearest neighbouring method is one of the most commonly used DEM resampling methods in GIS. It works on nearest assignment to club the neighbour pixels. The 30m Aster DEM is resampled using neighbour method for linear aggregation into blocks of 2x2, 3x3, 4x4 and 5x5. It provided a series of DEMs with spatial resolution of 60m, 90m, 120m and 150m. Then filling is performed to ensure removal of discontinuity present or induced (due to re-sampling) in DEM surface. After filling, flow direction maps are derived for all five resolution DEMs using hydrology tool of ArcGIS 10. Finally flow accumulation raster is generated from flow direction map.

Stream raster generation: After the preprocessing, DEMs of different resolution are incorporated with corresponding flow direction in stream order tool to generate stream raster. Similarly, flow accumulation rasters are incorporated with corresponding flow direction to generate stream raster. Further, streams are discriminated by removing the background with providing a zero value for class 1 (Sah and Das, 2015). Finally the drainages are vectorised from both (DEM-based-drainage and accumulation-based-drainage) the estimated drainage geometries. The delineated drainages are further verified with LISS IV images to filter the redundant streams.

Comparison and consideration: Basic stream parameters i.e. stream number (Nu) and stream length (Lu) are taken for comparison of the results. First, Nu and Lu estimated from DEM estimated drainage and accumulation estimated drainage are compared with those of the toposheets for the test area to determine the closest matching. The results are further verified for the verification area. After verification, stream derived from the resampled DEM having maximum matching for both test and verification area is considered for the application area.

Stream Positional Matching

Spatial mismatch of the streams of toposheet and DEM is a major concern in combining these two sources. The mismatch can occur due to inaccuracy in georeferencing of the used DEM. Before proceeding to core operations, it is ensured that the DEM used carried a fair level of accuracy in georeferencing. The accuracy is checked by overlay operation of GCPs from DEM against that of LISS IV images. Spatial mismatch can also arise as a result of the subjectivity in stream generation from DEM, particularly in headward ends (Melville and Martz, 2004; Li and Wong, 2010), and during transformation of co-ordinate system.

The Everest ellipsoid has been used for topographical mapping activities in India and adjacent countries, whereas DEM possesses geographic coordinate system of WGS 84. To combine the streams of both the sources, one needs to bring them into uniform coordinate system. For this, toposheets are registered with co-ordinate system of DEM. This transformation introduces geometric error in terms of planimetric shift (Singh, 2002; Srivastava and Ramalingam, 2003). An alternative source of transformed WGS co-ordinate system (with UTM projection) is Open Source Maps (OSM). However, mathematically transformed sources produce lot of mismatching (Ghosh and Dubey, 2009).

Thus it is important to follow an approach that can minimize spatial mismatch during coordinate transformation. The approach followed here starts with selection of regularly distributed GCPs representing the nodal points of major tributaries from DEM. After selection of GCPs, several attempts are undertaken to find out the GCP distribution combination that imports DEM's coordinate system to the toposheet with maximum spatial coincidence of the streams.

Calculation of Drainage and Positional Errors

Streams delineated from all five DEMs are compared with those of toposheet. The accuracy of matching in Nu and Lu is estimated to choose the best representing stream derived from DEMs. Similarly, accuracy matching for the verification area is done to ensure that resultant stream can be considered for the application area. To calculate the positional mismatch, the major tributaries of toposheet as well as DEM are used as the references. Systematic sampling points at a distance of 2 km from the end point of major tributaries are taken to measure areal displacements of the streams. RMS error is calculated using the areal displacements.

RESULT AND DISCUSSION

The drainages of the test-area derived from different resolution DEMs show large fluctuations in streams. It varies with resolution and shows a pattern of rapid decrease with coarser resolution which is in agreement with the general observations. Use of DEM as stream input facilitated generation of higher streams compared to the use of flow accumulation raster (Table 1). Coarser resolution DEM of 90m as stream input shows highest similarity with the reference drainage of toposheet. Whereas, flow accumulation raster of one scale finer in resolution i.e. 60m as stream input estimates streams that shows highest proximity with the reference streams of toposheets. As far as the accuracy is concerned, DEM-based-drainage shows superiority in stream estimation as compared to accumulation based drainage. The accuracy is found to be 86% and 99% for Nu and Lu respectively (Table 2) for DEM-based-drainage as against 71% and 94% for accumulation-based-drainage. Verification area also showed a similar result; 90m DEM-based-drainage has highest similarity with the streams of toposheets with accuracy as high as 95% and 96% (Table 3) in Nu and Lu respectively (Table 3).

The superiority of DEM-based-drainage approach in stream estimation is due to its ability of stream generation at greater head extent. The method used here is based on the motivation that it identifies stream at greater head extent and therefore provides opportunity to restrict the number by downscaling of DEM. DEM based approach generates streams at even greater head extent with higher number thereby highlighting a practical advantage over accumulation based approach. This enhances the chances of DEM downscaling to restrict Nu and certainly facilitates closer estimation of streams.

To minimize the spatial mismatch, the second critical aspect in such operation, toposheets are georeferenced using the GCP's of DEM generated streams. Sampling points for assessment of displacement and the shifting pattern of the streams of toposheet is shown in Fig. 2. The calculated RMS error from 40 reference stream points is found to be about 0.6 pixels. Visual assessment reveals that streams of DEM provide relatively accurate depiction of main streams in terms of its

Table 1. Shows the stream attributes estimated from raw DEMs, flow accumulation rasters and topographical maps for the test area

			DEM resolutions					Topographical map
			30m	60m	90m	120m	150m	1:50000
Stream input	Raw DEM	Stream number	2721	911	450	266	157	397
		Stream length	693.3	350	230.8	180.4	159.2	228.9
	Flow accumulation	Stream number	2494	512	251	155	103	397
		Stream length	593.4	241.96	163.3	122.6	98.4	228.9

Table 2. Shows the accuracy of stream matching in terms of number and length estimated from 90m raw DEM and 60m flow accumulation rasters for the test area taking streams of topographical maps as reference

			Sources		Accuracy	
			DEM	Topographical map	% Error	% Accuracy
Stream input	90m raw DEM	Stream number	450	397	13.36	86.64
		Stream length	230.84	228.95	0.83	99.17
	60m flow accumulation	Stream number	512	397	24.94	71.03
		Stream length	241.96	228.95	5.68	94.32

Table 3. Shows the accuracy of stream matching in terms of number and length estimated from 90m raw DEM and 60m flow accumulation rasters for the verification area taking streams of topographical maps as reference

			Sources		Accuracy	
			DEM	Topographical map	% Error	% Accuracy
Stream input	90m raw DEM	Stream number	454	436	4.13	95.87
		Stream length	255.45	246.21	3.75	96.25
	60m flow accumulation	Stream number	521	436	19.5	80.5
		Stream length	266.42	246.21	8.2	91.8

spatial coincidence with the streams of topographical maps. However, spatial mismatch is relatively high for the streams along the ridge of the basin (Fig.2). The subjectivity inherent in the stream identification from DEM in headward ends (lower order streams) (Melville and

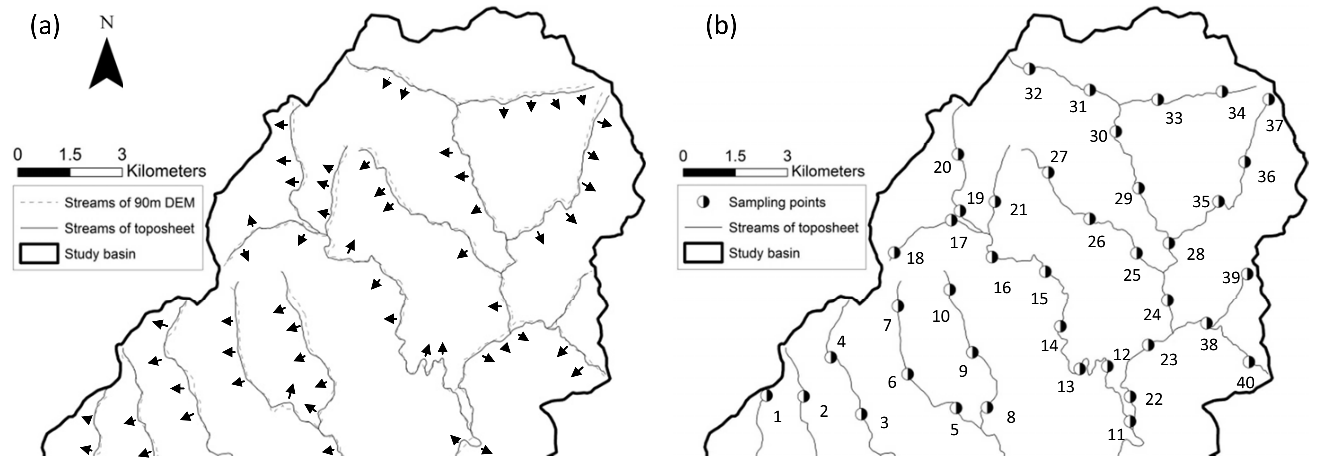

Fig.2. Shows **(a)** the planimetric shift of the streams and **(b)** systematic sampling points for RMS error calculation.

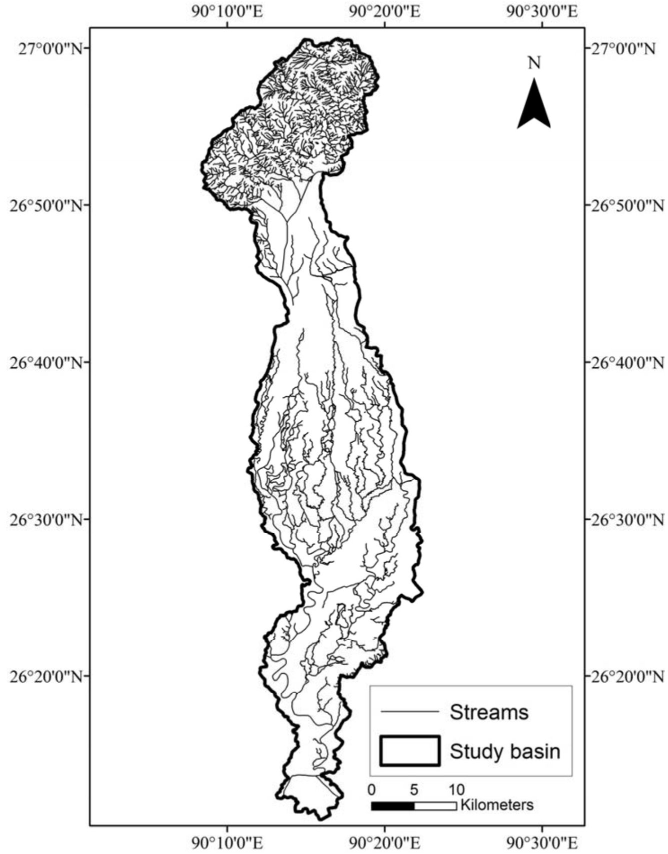

Fig.3. The entire drainage geometry of Gaurang basin.

Martz, 2004; Li and Wong, 2010) is largely responsible for this mismatch. In spite of this subjectivity, GCP operation has restricted the spatial mismatch to well less than a pixel size.

In this study the two most critical aspects of combining two sources of streams are addressed. In the present case, 90m DEM streams show closest similarity in terms of basin drainage parameters with the streams of toposheet. GCP operation limited the spatial mismatch of the streams to much smaller than a pixel size. Therefore, the streams derived from 90m DEM is considered to combine with the stream of toposheets to get the drainage map of entire basin (Fig. 3).

CONCLUSION

The proposed approach of combining drainages from toposheets and DEM can be effectively used for complete drainage delineation where unavailability and inaccessibility of sources are limiting factors. The work highlights the two major constrains, stream matching and spatial matching, associated with source combining. In this work stream matching in terms of Nu and Lu is controlled by a method of automatic stream generation from downscaled DEM and flow accumulated raster. Stream generated from downscaled DEM shows superior results in terms of both the basic stream parameters. The superiority is basically due to its ability of stream generation at greater head extent thus promotes further DEM downscaling for correct estimation of Nu and Lu. In our illustration, stream geometry of 90m resolution DEM has the maximum matching with that of toposheet. It must be noted that 90m DEM resolution is not by rule as headward identification of streams depends upon the slope of the terrain in DEM based methods. Therefore, selection of appropriate DEM resolution is required that provides maximum stream matching with the streams of reference maps in different terrain conditions. GCPs are used for spatial accuracy; the GCPs of the nodal points of major tributaries of DEM have restricted the positional mismatching to less than a pixel size. With the consent of both the aspects i.e. stream matching and positional matching, the streams derived from 90m DEM is considered to combine with the stream of toposheets to get the drainage map of entire basin.

Acknowledgements: The first author gratefully acknowledges the University Grant Commission for fellowship. This work uses high resolution data (LISS IV images) for verification of result procured under the DST-SERB sponsored project (SB/EMEQ-108/2013). We acknowledge DST-SERB for the same.

References

Bali, R., Agarwal, K.K., Ali, S.N., Rastogi, S.K. and Krishna, K. (2012) Drainage morphometry of Himalayan Glacio-fluvial basin, India: hydrologic and neotectonic implications. Environ. Earth Sci., v.66, pp.1163-1174.

Ghosh, J.K. and Dubey, A. (2009) Impact of India's new map policy on accuracy of GIS theme. Jour. Indian Soc. Remote Sens., v.37, pp.215-221.

Gregory, K.J. and Walling, D.E. (1968) The variation of drainage density within a catchment. International Association of Scientific Hydrology, Bulletin, v.13(2), pp.61-68.

Horton, R.E. (1945) Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geol. Soc. Amer. Bull., v.56, pp.275-370.

Li, J. and Wong, D.W.S. (2010) Effects of DEM sources on hydrologic applications. Comput Environ. Urban Syst., v.34, pp.251-261.

Melville, J.K. and Martz, L.W. (2004) A Comparison of Data Sources for Manual and Automated Hydrographical Network Delineation. Can. Water Resour. Jour., v.29(4), pp.267-282.

Mesa, L.M. (2006) Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). Environ Geol., v.50, pp.1235-1242.

Nag, S.K. (1998) Morphometric analysis using Remote Sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. Jour Indian Soc. Remote Sens., v.26(l,2), pp.69-76.

O'callaghan, J.F. and Mark, D.M. (1984) The extraction of drainage networks from digital elevation data. Computer Vision, Graphics, and Image Processing, v.28, pp.323-344.

Sah, R.K. and Das, A.K. (2015) Drainage skeletonization from flow-accumulated area without the use of threshold. Geocarto Int., v.30, pp.894-904.

Singh, S.K. (2002) Coordinate transformation between Everest and WGS-84 datums – A parametric approach: Geodetic & Research Branch, Survey of India, Dehradun, India.

Srivastava, B.K. and Ramalingam, K. (2003) Error estimates for WGS-84 and Everest (India- 1956) transformation, Map Asia conference, GIS development.

Tarboton, D.G. Bras, R.L. and Rodriguez-Iturbe, I. (1989) Scaling and elevation in river networks. Water Resources Research, v.25, pp.2037–2051.

(Received: 23 October 2016; Revised form accepted: 17 January 2017)