Flood Plain Characterization of a River in Lower Assam Using Digital Elevation Model Data

Diganta Barman and Arup K. Sarma

Abstract This paper conveys the strength of geospatial technology for characterization of flood plain in order to establish relation between river flood level and flood plain inundation. We have adopted geospatial approach to analyze and characterize flood plains coupled with profiles of river channels using CARTODEM. A case study on the downstream flood plain of Pagladia River in Lower Assam has been presented. The study shows that apart from conventional flooding reasons such as congestion due to high upstream contribution, embankment breach, etc., the flood plains of the aforesaid river is having a peculiar flooding genesis of backflow from receptor to feeder channel causing congestion in the confluence region. Here the reliability of CARTODEM for characterizing the flat terrain of the flood plain is exhibited.

Keywords CARTODEM · Congestion zone · Backflow · Hypsometry

1 Introduction

The Assam region of Brahmaputra basin mainly comprises of alluvial flood plains characterized by dominant land uses such as agriculture, rural and urban settlements, forest, etc. More than 30 tributaries in both North and South bank populate the 640 km stretch of the Brahmaputra river flowing through the relatively narrow Assam valley. Various parts of Assam valley get flooding almost every year due to high flood waves both in Brahmaputra main channel as well as the tributaries on North as well as South bank causing small, medium, and large scale inundation in the adjoining flood plains. The phenomenon of flooding in the flood plains of

D. Barman (✉) · A.K. Sarma
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, India
e-mail: diganta_isro1@yahoo.co.in

A.K. Sarma
e-mail: aks@iitg.ernet.in

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Assam is also characterized by frequent changes in river course, rapid bank line erosion, breaching of embankments, etc. As the flood plains of Assam is dominantly a flat alluvial terrain, a minor difference of elevation also plays important role in the extent and spread of flood inundation. Hence, a common but very difficult question often asked by decision-makers is the inundation spread for a particular magnitude of flood in terms of discharge and gauge or level. A precise characterization of the flood plain becomes necessary in order to address the aforesaid issue with a satisfactory level of confidence. With the advent of geospatial technology, it has become possible to characterize flood plains synoptically by studying its drainage, elevation, land use, etc. The horizontal and vertical resolution of satellite-based digital elevation model (DEM) plays important role in near realistic characterization of flood plains from inundation point of view. Hence, the appropriate selection of the digital elevation model data is of utmost importance for flood plain studies.

1.1 Study Area

The **Pagladia** watershed is one of the major watersheds of the north bank of Brahmaputra River. The Pagladia as the name implies, has been a chronic source of trouble due to annual flood and severe bank erosion leading to frequent changes in its flow course. The main river course originates at the foothills of Bhutan and finally terminates into the Brahmaputra near a village named Lowpara. In its entire course, the river consists of important tributaries like Mutunga, Nona, Baralia, and Chaulkhoa. This river system drains an area of 1674 km^2 and the drainage area lies between longitudes 91°20′E and 91°42′2E and between latitudes 26°14′N and 26°59′N. Out of the total catchment area of 1674 km^2, area within Indian territory is 1251 km^2 and the rest 423 km^2 lies in Bhutan. The hilly portion of the catchment area is about 465 km^2 of which 423 km^2 are in Bhutan and the rest 42 km^2 lies in Indian territory (Master Plan report of Brahmaputra Board, Ministry of Water Resources, Govt. of India 1996). The River flows for a length of 19 km in hilly tracts of the Bhutan territory and for the rest 178 km, it flows through the Nalbari district of Assam, India. In the hilly portion, slope of the river bed is very steep, being 1 in 75, in the middle reach it is 1 in 200 and in the lower reach, i.e., from Hajo-Nalbari road to outfall it is 1 in 2600. Figure 1 shows index map of the Pagladia Basin. Based on basin topography, river gradient and joining points of tributaries, the Pagladia river has been divided into three distinct reaches based on the hypsometry as shown in Fig. 2 such as (a) Bhutan hill range to Chowki in Baksa district of Assam, (b) from Chowki to NT road crossing in Nalbari district of Assam and (c) NT road crossing to the confluence of Brahmaputra. The second and third reaches mainly comprise the flood plain of Pagladia river whose characterization has been studied with the help of DEM data.

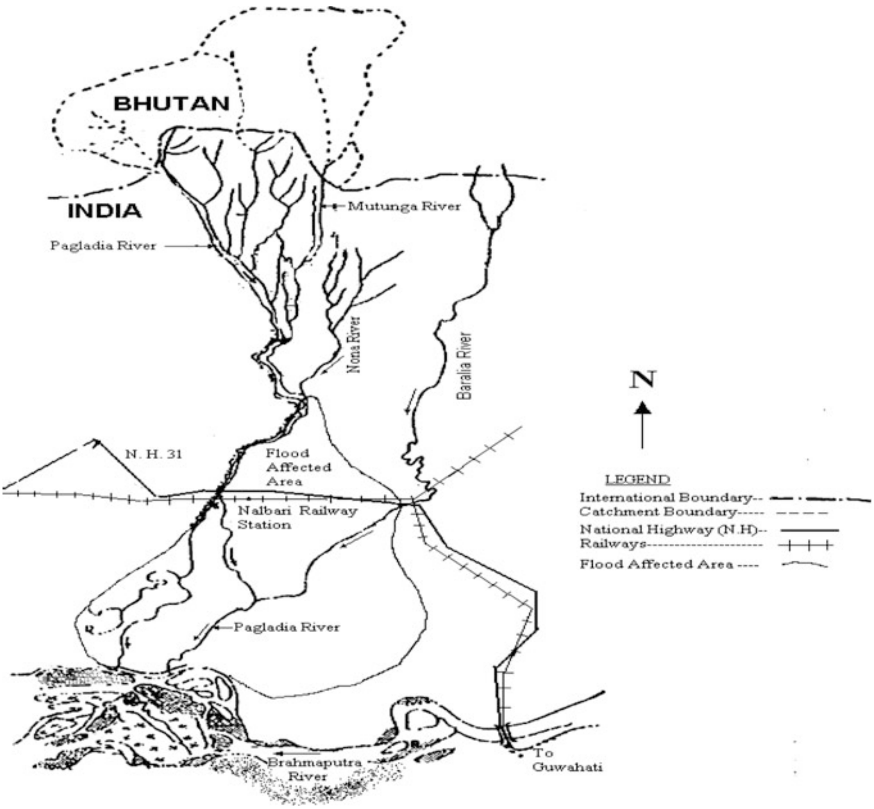

Fig. 1 Index plan of the river

2 DEM for Flood Plain Studies

Digital elevation models (DEM) are raster datasets that can be derived either from a pair of stereo photos or satellite images. DEM can also be created from a set of scattered points with elevation information, contour lines, and triangulated irregular networks (TIN). The main limitation of a regular gridded DEM appears to be the fixed grid cell size. Such DEM cannot accurately describe the flood plain topography especially on landscapes with varying complexity. Error are also introduced during interpolation through whatever method and most of the times these errors are spatially autocorrelated. Again for saving memory, pixel elevations are often rounded to nearest whole figure that creates flat areas with abrupt changes in altitude in regions of gentle slopes. While the slope gradient has the same degree of error as the original elevation data, slope aspect error is usually amplified during calculation (Dismet 1997). For most hydrological applications in flood plains the vertical resolution of a DEM is considered to be satisfactory if the ratio between the

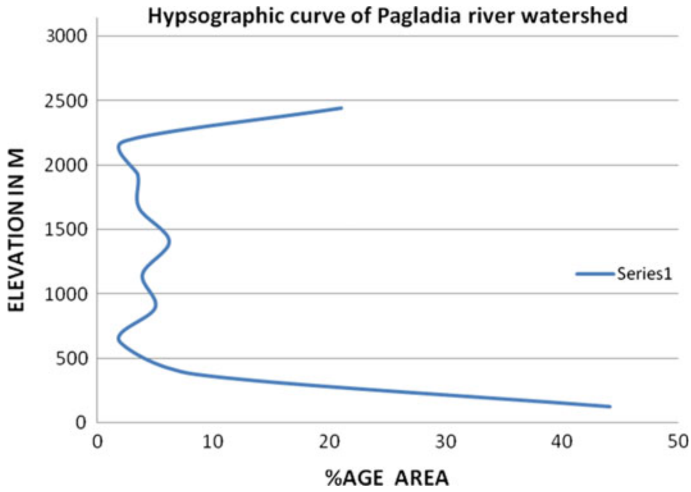

Fig. 2 CARTODEM derived basin hypsometry

average drop per pixel and the vertical resolution is greater than unity (Catchment delineation and characterization—A review, 2000).

$$\frac{d}{h} > 1 \tag{1}$$

where d is the average pixel drop and h is the vertical resolution of the DEM. The average drop per pixel is defined the difference between the elevation of a pixel and its next steepest descent (Walker and Willgoose 1999).

2.1 Problems of Flat Areas

The well known difficulty in a DEM is to discriminate between flat areas drained by incised channels and truly flat areas that carry water as sheet flow. This is a general problem that follows from both horizontal and vertical resolution of the DEM. It is clear that when the size of a drainage feature and the relative average undulation of elevation both are smaller than the pixel or grid size and elevation value, respectively, the channel and the undulations cannot be captured satisfactorily by the DEM. That is why a low to medium resolution DEM such as SRTM (90 m cell size), ASTER (30 m cell size), etc. though performs satisfactorily in hilly part of a watershed, fails measurably when it comes to capturing of drainages and local terrain undulations in flat alluvial flood plains (Fig. 3).

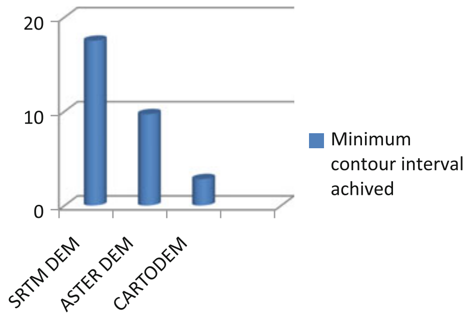

Fig. 3 Average vertical resolution achieved (m)

2.2 Parameterization of Alluvial Flood Plains

A typical analysis of alluvial flood plains requires important characteristics such as drainage (pattern and cross-section), surface topography, land use (for ascertaining roughness) apart from other parameters such as soil characteristics, vegetation, etc. where the DEM has no role to play. Comparison of applicability of different DEMs such as SRTM (Gorkovich and Voustonioke 2006), ASTER & CARTODEM for characterizing the above-mentioned vital parameters and their limitations in case of alluvial flood plains has been the focus of this paper where the **Pagladia** river flood plain has been considered as a case study as this particular flood plain has got good degree of similitude with the flood plains of number of other important parallel flowing north bank tributaries of the Brahmaputra river so that the findings can be representative for a number of flood plains of similar nature.

2.3 Applicability and Limitations of CARTODEM

CARTOSAT-I DEM is generated by combination of two stereo images of 2.5 m cell size in 26° and 5° inclination with the true vertical. Its horizontal and vertical accuracy determines its capability to effectively capture the land features for correctly characterizing flood plain parameters as mentioned under heading 2.2. Alluvial floods plains of Assam especially on the north bank of river Brahmaputra comprises of vast area within a very narrow elevation range. In the present study area 460 km^2 has been estimated as the total flood plain of Pagladia river system. Total river stretch along the flood plain is about 64 km (source: Departmental field maps). From a survey done with total station in few points just at the bottom of the embankment all along the 64 km stretch of the flood plain a total drop of 26.9 m (from 71.2 to 44.3 m) has been found, i.e., an average drop of 0.42 m/km. If we further upscale up to the cell size (2.5 m) of a CARTODEM pixel, the drop per 2.5 m becomes $\frac{0.42}{1000} * 2.5 = 0.00105$ m. Had this been actual rate of drop of elevation in the ground, the normal conclusion would have been that a precision of less than or equal to 0.00105 m (1.05 mm) is needed for a CARTODEM in order to accurately generate the surface profile of the flood plain from the highest point to the lowest point. Since 1.05 mm vertical precision is an unrealistic precision to expect from any high resolution DEM especially from space-based and arial platform, it is simply an issue not worth discussing. But as 1.05 mm is only a computed average and does not represent the actual undulation of the surface, the usefulness and limitations of CARTODEM for the purpose may well be discussed and worth attempting.

3 Data and Methodology

3.1 Data Sources

Keeping in view the research focus, three data sets as mentioned above, namely, SRTM, ASTER, and CARTOSAT-I generated DEM have been used to characterize the alluvial flood plain surface of the river concerned. Apart from that, spot elevations have been surveyed through total station in critical locations wherever history of occurrences of flood inundation is authentically documented (Reports of Water Resources Department, Assam). Moreover, field maps of the drainage system from various sources have also been referred to for ground validation of land features derived from the three DEM datasets. Survey of India (SOI) reference maps of 1:25,000 scale has also been used for identification of various subchannels of the main river and correlating them with the rivers names mentioned in other references such as field maps, departmental reports, etc.

3.2 Methodology and Workflow

The present study involves assimilation of multisource information and datasets to characterize the flood plain of the river concerned. The entire workflow comprises of the following prime steps:

Step 1: Delineation of the floodplain boundary by integrating satellite data with SOI ref maps, departmental reports and other field maps, etc.

Step 2: DGPS survey in critical point of the flood plain for collection Ground Control Points (GCP) for generation of CARTODEM.

Step 3: Processing of CARTOSAT—I stereo pair in LPS plate form incorporating the GCPs collected through DGPS survey for generation of CARTODEM of the floodplain area.

Step 4: Comparison of two online DEMs of SRTM and ASTER with CARTOSAT-I in terms extraction of various land features relevant to characterization of the flood plain.

Step 5: Morphometric analysis of the entire watershed with special focus on the drainage of the floodplain area.

Step 6: Comparison of ground elevations at critical locations such as embankment base with CARTODEM derived elevation values.

4 Results and Discussion

4.1 Morphometry of the Watershed

The analysis of the hypsometry reveals that around 50 % of the total watershed belongs to the flat alluvial flood plains (Fig. 2). While 20 % is in the upper elevation ranges, rest 30 % belongs to the mid elevation ranges. This steep drop in elevation covering the mid elevation ranges results in bed scour in the interface region between hills and plains producing good amount of silt load further downstream which affects the channel configuration across the flood plain. Following table reveals the other important morphometric parameters of the watershed. The values of both circularity ratio and elongation ratio suggest a fern shaped watershed which also has been found to be the shape when the basin is delineated automatically from CARTODEM by defining only the outlet. This clearly exhibits the suitability of the above DEM to delineate the basin boundary not only of the hilly upstream areas (where other coarse resolution DEM such as SRTM, ASTER, etc., also performs satisfactorily) but also of the flat alluvial flood plain areas. The dendritic drainage pattern as revealed in Fig. 4 suggests stable tectonic behavior of the watershed. This indicates that all frequent geomorphologic changes are purely fluvial in nature (Table 1).

4.2 Analysis of the Digital Surface Model

The flood plain of Pagladia river starts at a place known as Thalkuchi where the main channel of the river is joined by two more rivers namely Mutanga and Nona. The average elevation of the flood plain at embankment base drops from 71.2 to about 44.3 m at the outfall at Brahmaputra. The main channel traverses a distance of around 64 km for this drop. Elevation values of CARTODEM were compared with various spot heights from departmental field maps and the result is presented in Fig. 5. A correlation of 0.9759 has been observed between CARTODEM elevation values and the corresponding spot heights on the field. Moreover, further analysis of the DSM also reveals values of threshold elevations below which are low lying drainage congestion zones. Thus, few major flooding and congestions zones have been identified.

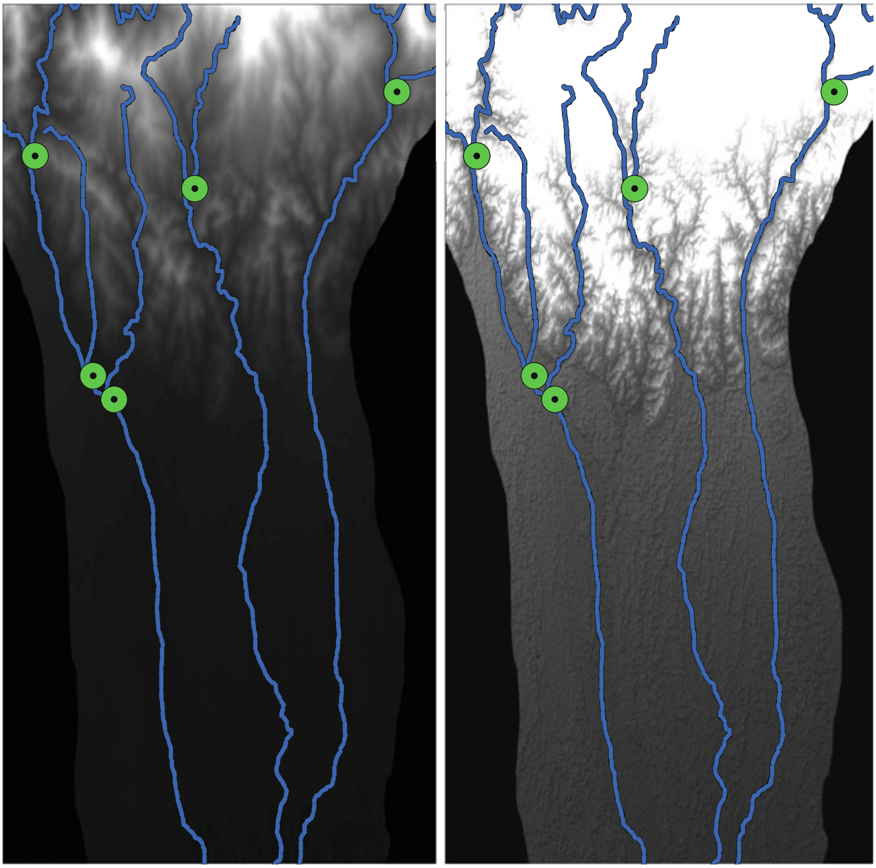

Fig. 4 Surface visualization of the flood plain in ASTER and CARTOSAT DEM

Table 1 Morphometric parameters

Sl No.	Morphometric parameter	Values
1	Form factor	7.26
2	Circularity ratio	0.26
3	Elongation ratio	0.42
4	Drainage pattern	Dendritic

Among them the upstream portion of the flood plain, i.e., the upper middle reach and the lower middle reach of the river the genesis of flood has been found to mainly due to excess run-off and inadequate channel capacity downstream of the confluences. But the lower most part of the flood plain toward the river's outfall with river Brahmaputra, Figs. 5 and 6 reveals that some portion of the downstream areas are at higher elevation that its preceding upstream areas which results in congestion due to backflow from the receptor to the feeder channel. Such a peculiar

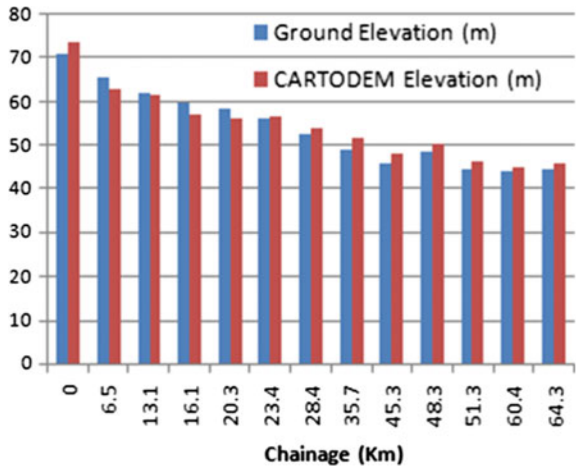

Fig. 5 Comparison of CartoDEM elevation values with field heights

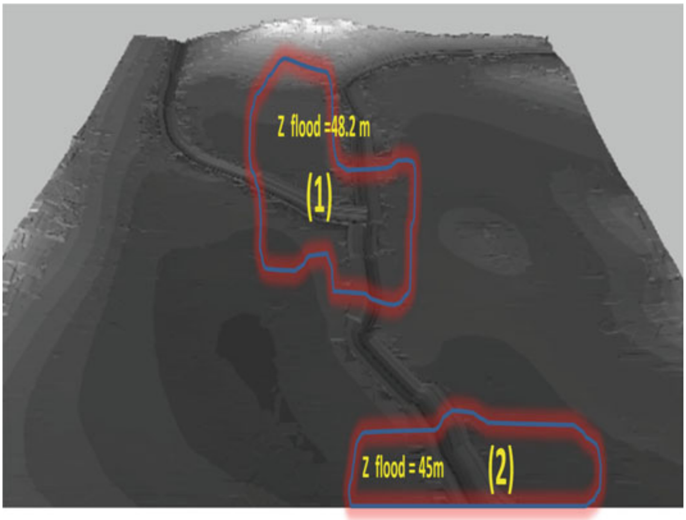

Fig. 6 CARTODEM derived lower flood plain showing congestion zones

low lying area has been found in the lower most portion of the Pagladia river flood plain locally known as Barbhag. This area comes under frequent flooding zone not only due to heavy rainfall and subsequent flood discharge in its own upstream catchment but also due to back flow from river Brahmaputra whenever its water level remains higher than that of river Pagladia. This genesis of flood is not very common in other north bank tributaries of river Brahmaputra especially in upper Assam.

5 Conclusion

This study has revealed the suitability and limitations of DEM generated from CARTOSAT I stereo data for geomorphologic and surface characterization of fluvial floodplains. An average vertical precision of 2.5 m as achieved has been found to be adequate to capture major elevation drops and lifts along the 64 km long downstream flood plain, whereas the computed hypothetical local relief of 1.05 mm as discussed in Sect. 2.3 above has been found to be far beyond its capability. Hence whenever an application demands capturing of very minor local undulations within a very small area, alternatives such as field leveling with total station, Airborne or terrestrial laser scanning (Stratmaa and Baptist 2009), etc. should be the obvious choice for terrain mapping.

Moreover processing of CARTOSAT stereo data is another research area where there is enough scope for exploring new methods and techniques in order to improve its accuracy as required for different hydrological applications.

Apart from the present river under study, there are other similar rivers on the lower Assam part of the Brahmaputra valley, which also have their origin in the kingdom of Bhutan. Similar approach for flood plain characterization of those rivers will also result in interesting revelations about their flooding characteristics.

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