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Application of accuracy improvement algorithms for extraction of topographic information and drainage network from DEM using GIS

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Abstract. The extraction of drainage network and watershed information is prerequisite for the study of watershed characteristics like morphometric analysis, which provides a basis for hydrological planning and modeling. The advanced tools of algorithms, Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data and Geographical Information System (GIS) software are used to extract drainage networks and their watershed boundaries. These tools are complicated to use or produce more errors in the extraction of elevation and drainage networks when applied to flat areas. For removal of errors and to improve the accuracy in preparation of DEM and extraction of drainage network, Burada Kalava River Basin, Andhra Pradesh, India has been taken for application of accuracy improvement algorithms. An automatic generation of drainage network and watershed using digital elevation model results in positional errors due to variations in slope and topography. This study aimed to generate a catchment area and stream network that closely represent the natural stream network and the streams' real positions. The step-by-step methodology using GRASS-interfaced Quantum GIS algorithms are given for pre-processing of DEM data to improve the positional accuracy before automatic extraction of the stream network and catchment area to resemble the real situation of the watershed. Secondly, efforts are made to analyze the DEM during automatic generation of the stream network and catchment area by assigning various area threshold values, including the application of pour point coordinates in improving the stream network and watershed characteristics. The results are verified and validated with the field information in order to improve the accuracy levels of DEM quality in generation of drainage network and catchment area.

Key words:
SRTM,
DEM,
QGIS,
drainage network,
catchment area

Introduction

Watershed delineation and the extraction of drainage networks are the foremost activity in any hydrological analysis. Hence, there is a need for the accurate extraction of drainage networks and delineation of catchment areas in order to study the flow direction, flow capacity, flow length, drainage density and terrain properties of a drainage basin. In earlier days, watersheds were studied using topographic maps (Sathyamoorthy 2008). Due to significant advanced techniques in remote sensing and GIS applications, digital elevation models (DEM) are widely used to extract drainage networks and to study watershed characteristics in watershed management and hydrologic models (Turcotte et al. 2001; Jones 2002; Zhang et al. 2014). A digital elevation model is a two-dimensional array of elevation measurements at regularly spaced ground points that represents a continuous terrain surface (Wang and Liu 2006). DEMs play an important role in the study of surface topography and hydrological characteristics of watersheds. The Shuttle Radar Topography Mission (SRTM) is providing a homogeneous, consistent, high-resolution digital elevation dataset with nearly global coverage and giving fruitful results in the fields of geology, water resources and hydrology and other fields like geomorphology, natural hazards, etc. (Liping et al. 2011). Several researchers (Falorni et al. 2005; Kaab 2005; Kiamehr and Sjoberg 2005; Li and Yao 2005; Ludwig and Schneider 2006; Gorokhovich and Voustianiouk 2006; Liping et al. 2011) have studied and verified the accuracy of SRTM data with Shuttle Laser Altimeter data, GTOPO30, GLOBE, Compute Maps DEM, ETOPO5 and ETOPO2, Sandwell-Smith DEM and Differential Global Positioning System (DGPS) survey studies and found that the overall quality of SRTM is sufficient for hydrologic modelling in mesoscale areas. Their results still show that the accuracy of the SRTM DEM is about 10 m (standard deviation of errors), which is also better than the SRTM specification.

Geographic Information System (GIS)-based technologies are increasingly being used in automatic delineation of stream channels for use in hydrologic models (Reddy et al. 2018). Though the DEM is widely used, it contains some depression and positional errors in its execution. Depressions that occur naturally or artificially in a plain landscape are widely included in DEMs (Li et al. 2019). However, care is to be taken in the automatic extraction of drainage network in order to replicate the hydrologic reality of a watershed, especially in plain areas. As DEMs contain local pits or sinks, pre-processing is essential to delineate the watershed areas. Local pits and sinks form in DEMs due to various errors in the spatial sampling and interpolation process associated with remote-sensing data (Ray 2018). As a result, hydrological modelling analysis and geo-morphological analysis are greatly influenced (Moore et al. 1991; Cho and Lee 2001). Thus, external processing methods are to be adopted in order to recondition DEMs to improve the accuracy, such as removing pits, sinks and positional errors and adopting external stream vector data from known sources for stream burning or carving (Saunders 2000; Soille et al. 2003; Getirana et al. 2009).

The wide variation in the topography of Burada Kalava River basin, Andhra Pradesh, India, hampers the extraction of drainage network and catchment boundaries directly from DEM using general algorithms in a GIS platform. Many algorithms for depression processing and improving accuracy of DEMs have been used to determine the flow direction in depressions (Martz and Garbrecht 1998; Wilson 2018). Although fill-sink is applied to remove the pits and flats, the positional errors in the DEM remain unchanged. This causes the main stream to join with the other tributaries and finally drains into the main channel at another point that does not exist in reality. Hence, a digitized stream network from topographical map is used as an external input for improving the accuracy of the DEM and to extract the updated stream network and catchment area.

Apart from the creation of an accurate DEM, analysis of the DEM during automatic generation of stream network and catchment area in a flat region is also an important task. The total area of the threshold value determines the flow accumulation. The pour point coordinates determine the catchment area. Therefore, defining a threshold value and pour point coordinates for an accurate stream network and its catchment area is very important in this study. So, a detailed study using SRTM DEM data and Quantum GIS (QGIS, an open source spatial modeling software with GRASS) is used in this study.

The objective of the present study is to eliminate all the depressions, flats and positional errors using pre-processing algorithms and to analyze the DEM during automatic delineation of stream network and catchment area in order to replicate the real situation of the watershed and stream network, especially in a flat region. The complete methodology to use the pre-processing algorithms and their influence on watershed characteristics were analyzed. Verification of results with the field information is carried out for the validation of DEM quality in order to closely represent the real situation of the drainage network and catchment area.

Study area

The Burada Kalava river basin lies between 17°02' and 17°28' N and 81°40' and 82°0' E and has a draining area of 1,018.67 km^2 (Fig. 1). The river flows from north-east to south-west and finally joins the river Godavari as a tributary near to Torredu village in Rajamahendravaram mandal, East Godavari district, Andhra Pradesh. The prominent drainage pattern in the basin is dendritic to sub-dendritic. This river is the main source for meeting the domestic and irrigation needs of this region.

Materials and methods

Source of data

The primary source of data for the present study is Survey of India (SOI) topographic maps and remote-sensing elevation data. The topographic maps (65G/11, 65G/12, 65G/15, 65G/16, 65K/03) at 1:50,000 scale are used to obtain the primary boundary line of the watershed and its drainage network. The SRTM DEM data of 1 arc second 30-m resolution with high vertical accuracy of GCS-WGS-84 is downloaded from https://earthexplorer.usgs.gov/ for this study. The entire study area is covered by four DEM scenarios.

Topographic maps geo-referencing, digitization of stream network and catchment boundary

The hard copies of topographic maps were scanned and converted into digital format. However, the size and shape of the topographic map changes during the scanning process. So, to overcome this, the topographic maps were initially geo-referenced and are overlaid on the Google Earth image as a "fly over". The stream nodes and the road connections were verified with the coordinates of these points collected from the Google map to

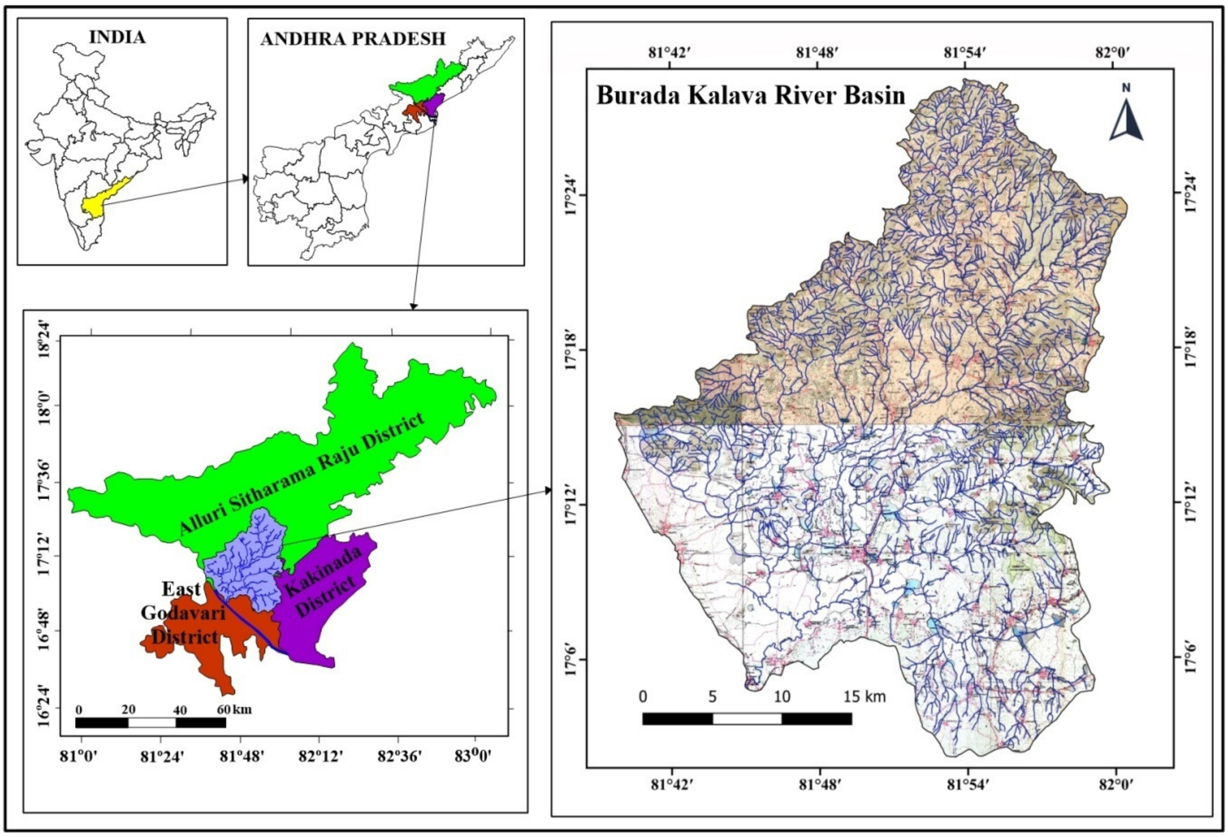

Fig. 1. Location of study area of Burada Kalava river basin, Andhra Pradesh, India

correct the topographic maps. So, the topographic maps are updated in order to more accurately geo-reference the topographic maps. The geo-referenced topographic maps were re-projected to WGS 1984 UTM zone 44N datum, and a mosaic map of all five topographic maps was prepared. Then, the stream network and the catchment area are digitized using vector digitization tools in QGIS as shown in Figure 1.

SRTM DEM data analysis

For accurate catchment area delineation and stream network extraction, especially in flat or plain areas, the analysis and processing of a DEM is a crucial task. The pre-processing methods applied in this study were stream burning, filling sinks, determining the flow direction and flow accumulation using an accurate area threshold value, and identifying pour points or outlets of the catchment in order to remove sinks and to improve the positional accuracy of the DEM. These detailed applications are made using spatial hydrological modules of GRASS-interfaced QGIS.

Extraction of stream network from DEM

The watershed analysis program, i.e., “r.watershed”, a GRASS GIS module in QGIS developed by the GRASS development team, is used to generate maps of, for example, flow direction and flow accumulation for the extraction of stream networks. Flow direction is an important factor in hydrologic modelling studies. To identify the landform draining location, the determination of each cell flow direction in the landscape is an important factor (Bhatt and Ahmed 2014). Assigning either a single flow direction or multiple directions and a threshold value is a part of using “r.watershed” to generate a quantitative drainage network.

Various algorithms are available to determine flow direction and accumulation either in single flow direction (SFD) or multiple flow directions (MFD). The choice of algorithm influences the simulated spatial distribution of hydrologic characteristic such as soil moisture content. Venkatesh (1999) made a comparison study of single- and multiple-flow-direction algorithms and concluded that the choice of algorithm does not make any difference, if applied for simulation of stream flow. O’Callaghan and Mark (1984) developed the D8 algorithm in which water flows from a cell to the one with the lowest elevation among the eight nearest neighbor cells. The flow direction is determined from the eight neighboring cells to the single neighboring cell in the direction from the highest to the lowest slope. If, in any case, the elevations of two or more downstream cells are equal, then the flow is directed to only one adequate cell in the D8 algorithm (Greenlee 1987), so that the flow can be realistic, and the positional errors can be nullified. Dávila-Hernández et al. (2022) proved that the D8 algorithm gives more accurate results in concave hillsides and flatter regions, but that the MFD algorithm shows overestimation of flows in concave hillsides. MFD is mostly used in convex shaped hillsides and in terrain regions. Many researchers like Orlandini et al. (2014) and Dávila-Hernández et al. (2022) used the D8 (SFD) algorithm to determine the flow direction in areas of moderate slopes or concave hills and in plains. Huang and Lee (2016) applied the D8 algorithm and concluded with robust results that it differentiates canals and streams.

Flow accumulation is the next step in the process of extracting a drainage network and its watershed to give the eventual flow path for each cell of a raster. The drainage network was developed using the flow accumulation from the flow direction of each cell (Saha and Singh 2017). In the application of “r.watershed”, a specific threshold value is assigned to generate the stream network precisely that represents the real composition of stream network that quantifies the hydrological characteristics of the catchment area. So, the SFD algorithm, i.e. D8, is applied in this study to generate a more realistic flow path and accumulation and to get a realistic drainage network. The generated stream network is a raster. So, it is converted into a vector layer using the GRASS tool “r.to.vect”.

Delineation of catchment area from DEM

A GRASS GIS module named “r.water.outlet” is used for the automatic extraction of the catchment area and its boundary (Fig. 2). The generated flow direction is used as input. The coordinates of pour

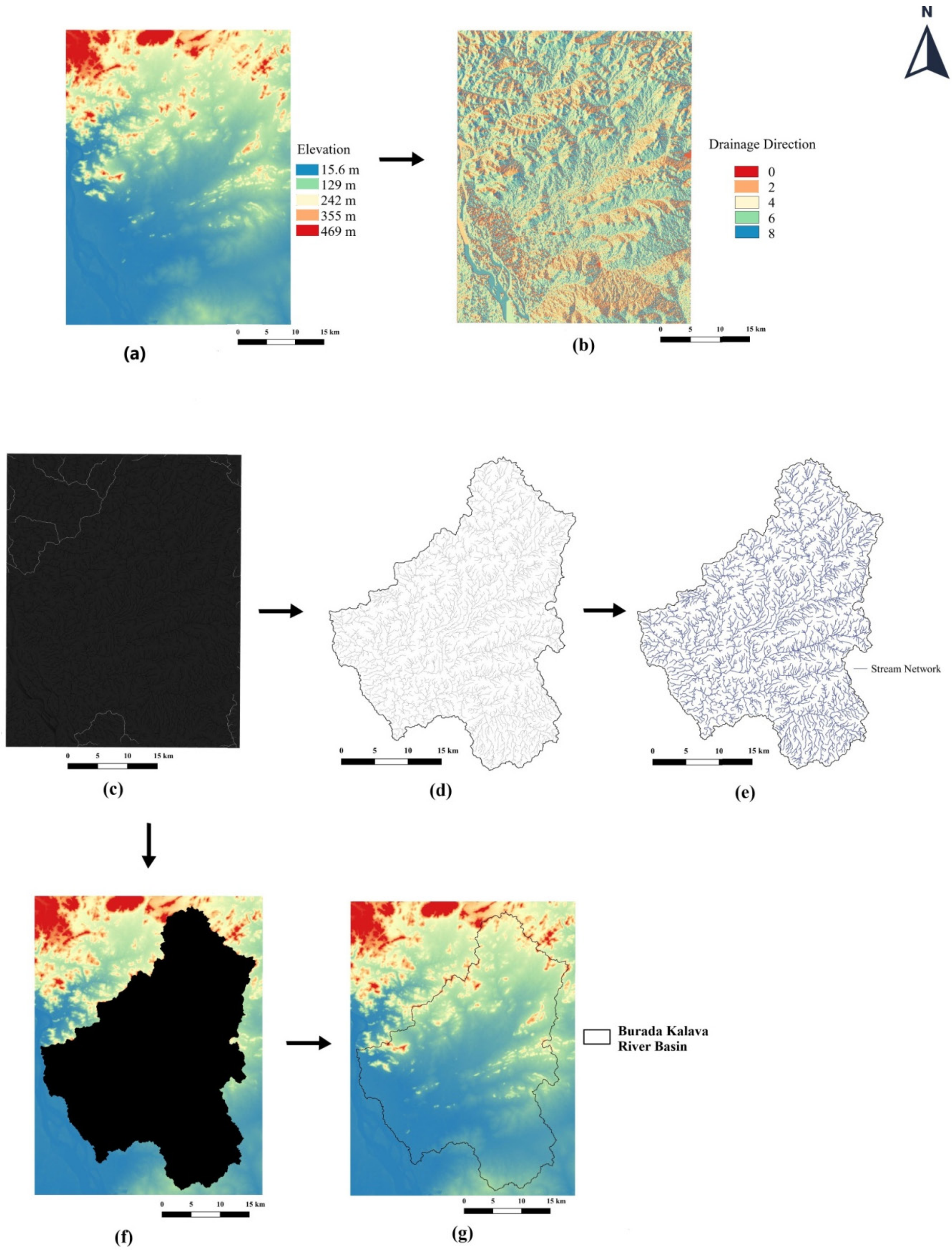

Fig. 2. Extraction of drainage networks from SRTM DEM. (a) Pre-processed and DEM, (b) Flow direction, (c) Flow accumulation, (d) Streams raster, (e) Streams vector, (f) Basin raster, (g) Basin vector

point (i.e., outlet/confluence) is used as input to create a catchment boundary. Field survey with GPS is conducted to get the coordinates of the pour point (i.e., 5th-order streams) to correlate and validate the generated catchment area and boundary. Since the output of this algorithm is a raster, it is converted into a vector layer using the GRASS tool "r.to.vect".

Results and discussion

To attain an accurate catchment area and stream network, a quality DEM is a pre-requisite. The quality of a DEM depends on factors like spatial resolution of elevation data, source of the data obtained and topographic conditions of the landscape (Ariza-Villaverde et al. 2015). The presence of natural shallow depressions and artificial elevation errors in flat landscapes, especially in downstream areas, create difficulties in assigning flow direction and flow accumulation, though high-resolution DEM data is used in the study (Saunders and Maidment 1995). Many authors (Jenson and Domingue 1988; Saunders and Maidment 1995; Martz and Garbrecht 1998) have proposed various algorithms to minimize the errors for the delineation of a stream network and its catchment area. In the present study area, where flat landscape exists, a systematic methodology with suitable algorithms is used to verify the stream network, catchment area and its boundary generated from DEM.

Fill-DEM

Surface depressions (i.e., pits and sinks) are common in the flat regions of a DEM. A surface depression forms where one or more cells of the same elevation are spatially connected and surrounded by higher-elevation cells. These points act as a sink for the surrounding overland flow, directing water to the depression point within the interior basin rather than the basin border (Wang and Liu 2006).

The Fill-DEM algorithm is proposed by Jenson and Domingue (1988) to fill the sinks caused by depressions by raising the elevation of a depression cell to an elevation that equals the surrounding cells. It is highly implemented in many spatial analysis programs like Arc Info (ESRI 1999) and GRASS. In this method, the depressions in the DEM will be filled with the same elevation values of their neighboring cells, which results in flat areas with the same elevation values. In some places where topography variation exists, direct application of this algorithm gives some unrealistic parallel flow directions in flat areas near the outlets of tributaries joining the main stream, as shown in Figure 3. This is because the flow direction at a filled cell allows the stream to flow equally to all the nearest neighboring cells, resulting in unrealistic parallel flow patterns. So, direct application of this algorithm for higher-resolution DEMs (30 m) without considering the cell elevations at the flatter regions creates problems in defining the flow direction and drainage routing (Tribe 1992; Martz and Garbrecht 1995). To overcome this situation, an algorithm named "stream burning" is applied to pre-process the DEM before applying the Fill-DEM algorithm.

Stream burning

A DEM's information may not be sufficient to replicate the real stream path due to inaccuracy in the DEM's topographic representation, especially in areas with flat terrain (Martz and Garbrecht 1998). In a flat region, it becomes difficult to produce a hydrologically corrected DEM using the above-mentioned depression-filling algorithm (Holmes et al. 2000; Getirana et al. 2009). The extracted drainage networks are highly sensitive to elevation errors in the DEM, meaning that the modelled drainage network will be unrealistic if the Fill-DEM algorithm alone is applied. To correct these errors, a number of algorithms were proposed, such as depression breeching (Soille et al. 2003) and incorporation of other qualified data (Maidment 1996; Sanders 2007; Getirana et al. 2009; Zhang 2014). The stream burning algorithm uses known stream network data and lowers the elevation of depressions along the entire river channel to obtain exact positions and lengths in flat regions. The results obtained from the application of Fill-DEM algorithm for the pre-processed (burned) DEM gives a realistic drainage network.

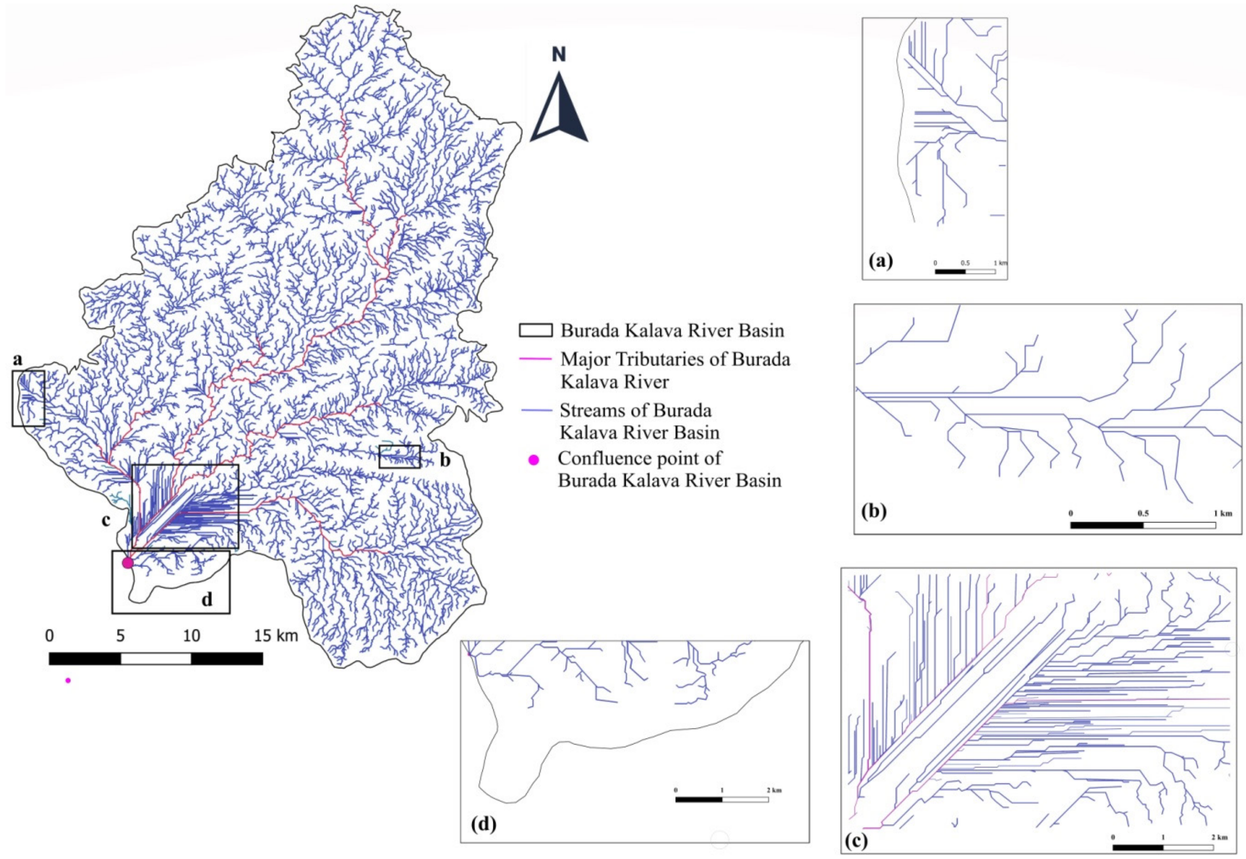

Fig. 3. Stream network extracted from SRTM DEM by applying only Fill-DEM. 3(a), (b), (c) showing the regions of stream network with parallel unwanted streams in a flat lowland area due to depression errors. 3(d) position and pattern stream network error

Application of stream burning and Fill-DEM

The digitized stream network from the verified and geo-referenced topographic maps is used as an input for the stream burning. First, the vector stream network is converted to raster format using a conversion tool of the GRASS module in QGIS, i.e. "v.to.rast". The stream burning algorithm is applied using the "r.carve" GRASS module in QGIS to lower the elevation values of depression cells, which carves the terrain by dissolving the known elevations of the digitized stream network.

A GRASS module named "r.fill.dir" in QGIS is applied to DEM after stream burning. This procedure takes an elevation layer as an input and generates slope direction from its neighbor cells using the D8 (SFD) algorithm. The D8 algorithm creates a code for each cell to generate slope (i.e., from highest to lowest elevation) using a nine-cell grid (i.e., each cell surrounded by its 8 neighbor cells). If the slope is flat in more than one direction, then the code selects an alternate cell and assigns the flow direction. This algorithm gives more accurate results if applied to a pre-processed or burned DEM. The streams that are extracted before and after applying Fill-DEM algorithm to the pre-processed or burned DEM are shown in Figure 4.

Effects of stream burning and Fill-DEM

Before application of stream burning to the study area, though the DEM depressions have been filled using Fill-DEM, it is observed that the position of the stream flow has shifted from the real position due to the variation in the positional elevations of the DEM. This changes the flow direction and stream paths, resulting in the formation of parallel first-order streams, as shown in Figure 3. The result of applying Fill-DEM generated parallel streams that created ambiguity in the identification of mainstream paths and stream ordering. So, to rectify this problem, pre-processing of DEM is done using "stream burning" for elevation strategy.

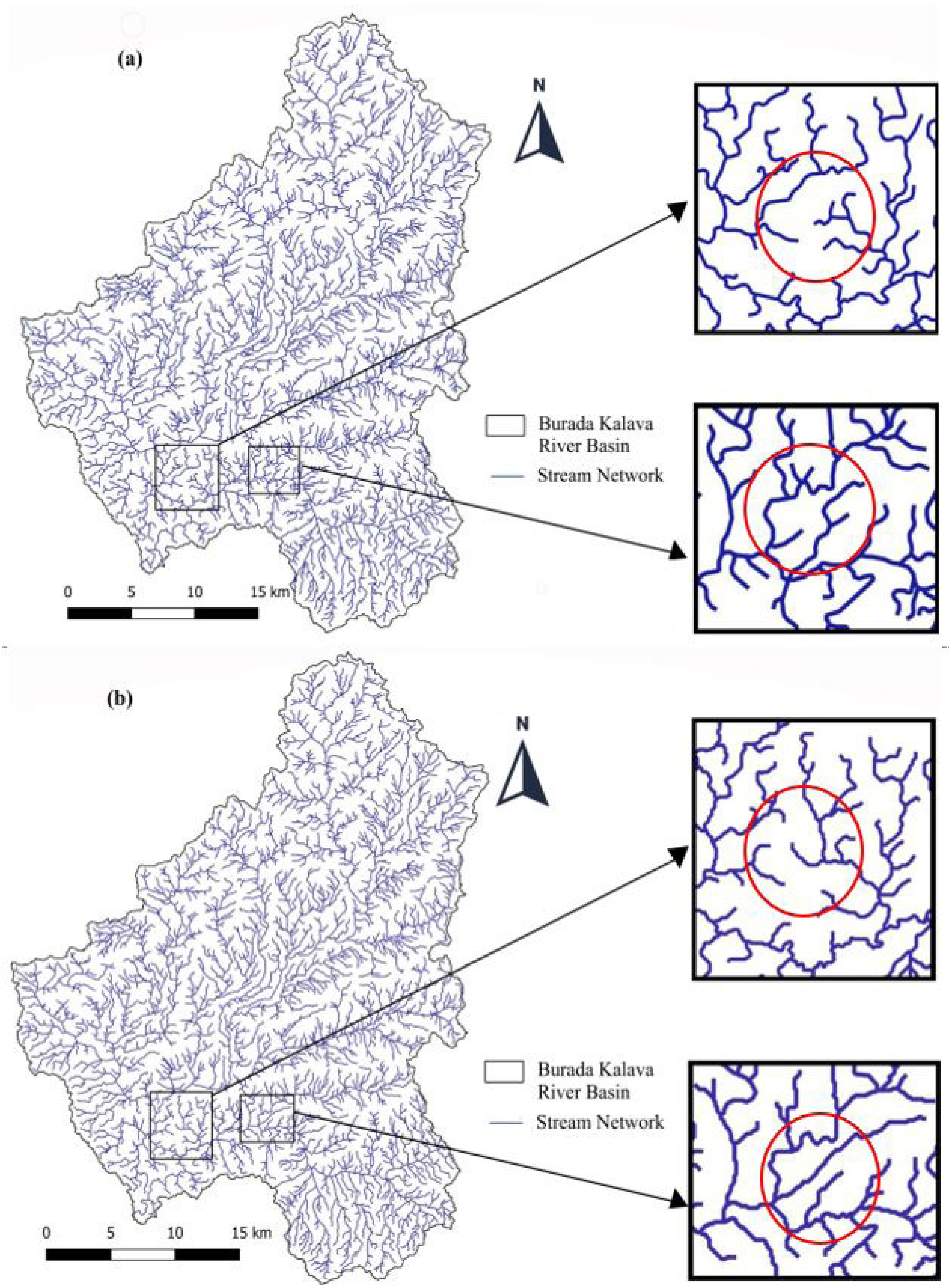

Fig. 4. Showing the stream network variation extracted from SRTM DEM before and after Fill-DEM for a pre-processed (burned) DEM. (a) Regions of stream network extracted before applying Fill-DEM. (b) After applying Fill-DEM (depression-less)

Making use of the stream burning technique, the parallel first-order streams and the positional errors are removed, as shown in Figure 5. Then, Fill-DEM is applied to obtain appropriate results that provide more accurate stream paths, as shown in Figure 4b.

Verification and validation of stream network and watershed boundary

The generated stream network is verified by overlaying it on the reference drainage network in a Google Earth image for validation. The results of the drainage network (Fig. 6) generated automatically by the pre-processing technique are shown in blue on the image. The stream network obtained through stream burning and Fill-DEM application showed accurate results, as represented in yellow in Figure 6.

Extraction of quantitative drainage network

Quantitative analysis of drainage network is essential, since the drainage pattern and network characterize the watershed (Strahler 1964). Using either SFD or MFD is part of using the "r.watershed" for generation of flow path and accumulation. The qualitative drainage network generated from the data of flow direction and accumulation by the use of D8 algorithm (SFD) affects stream network count, i.e. the stream number for the hydrological analysis (Dobos and Daroussin 2005; Reddy et al. 2018; Munoth and Goyal 2019). Stream number, stream length and density are the primary aspects to quantify the drainage development, erosional status and runoff potential in a given area (Horton 1945). Hence, care needs to be taken during direct delineation of the stream network. The area threshold value specifies a minimum drainage area to initiate a channel (Tarboton et al. 1988). However, in the present study, for selection of an optimum area threshold value in extraction of a stream network, basic stream morphometric parameters were taken to compare against reference digitized data from topographic maps.

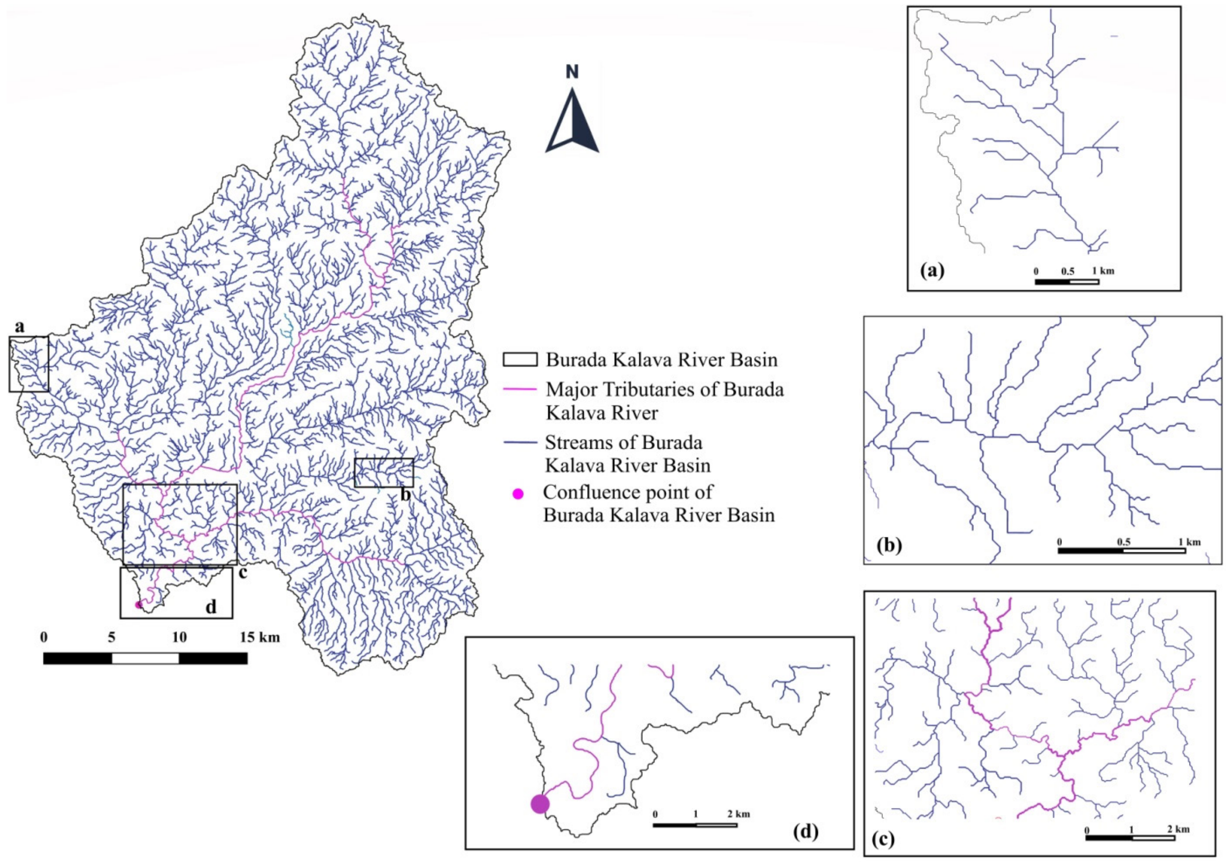

Fig. 5. Stream network extracted from SRTM DEM after applying the stream burning. Regions showing the removal of parallel streams and correlated with the referenced major tributaries

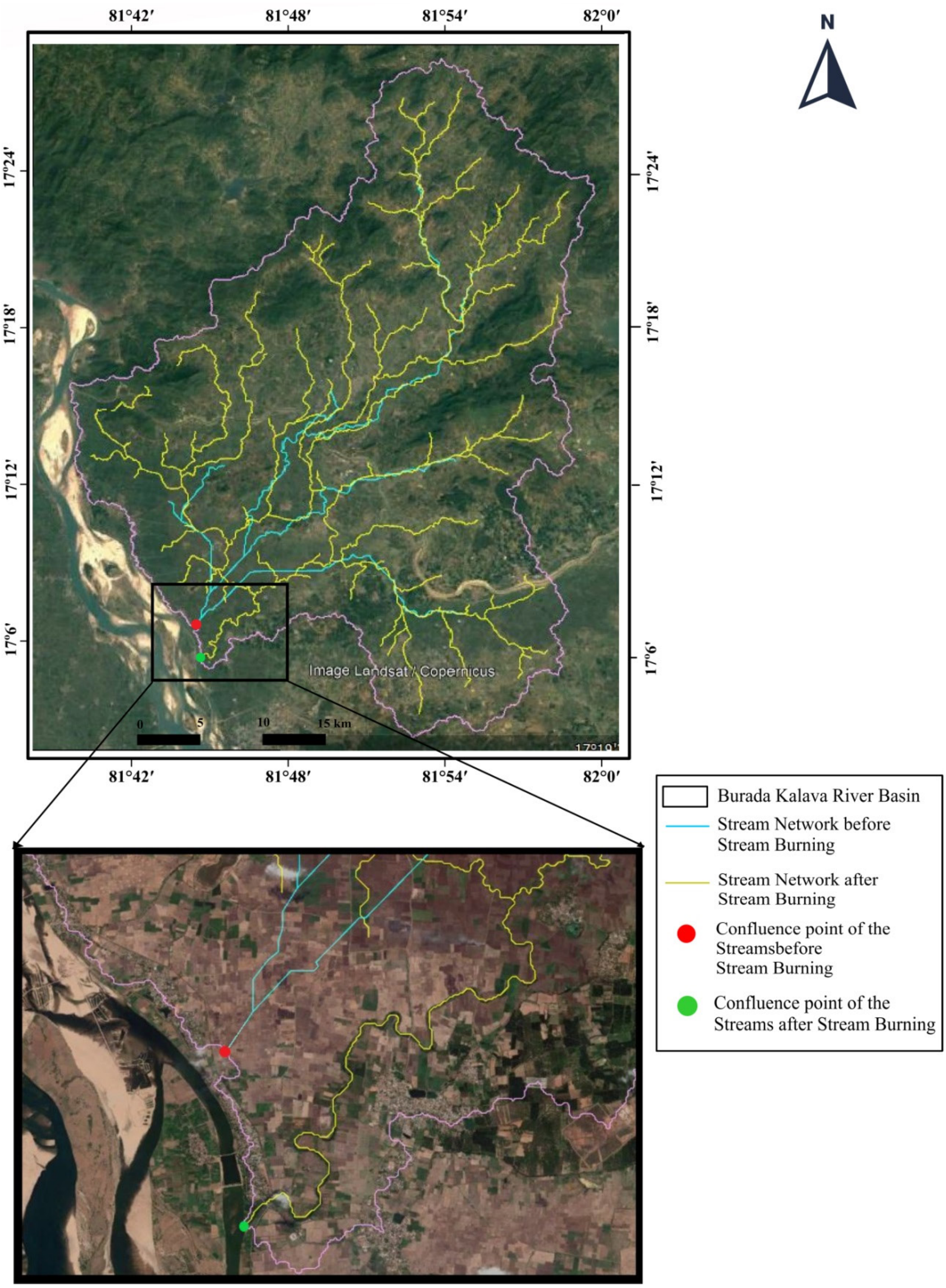

Fig. 6. Verification and validation of stream network extracted with Fill-DEM before stream burning and after Stream Burning using Google Earth imagery

Importance of assigning a threshold value

Assigning a threshold value to DEM is a method to decrease or increase the number of pour points for each cell. The number of streams within each stream order is inversely proportional to the area threshold values (i.e., the smaller the threshold value, the higher the details of lower-order streams especially first-order streams; and the larger the threshold value, the lower the details of streams). Tribe (1991), Wharton (1994) and Liu and Zhang (2010) have indicated that the accurate extraction of first-order streams is a principal work in the mapping of a drainage network for the analysis of hydrologic processes. So, care should be taken in giving the threshold value for generating the drainage network, especially at the head waters for the accurate extraction of drainage networks.

Assigning a threshold value is part of using the "r.watershed" for generation of a quantitative drainage network. The parameter of threshold value is to be defined for fixing the minimum and maximum size of basin areas in "r.watershed" for extraction of streams and watershed area. Threshold values starting from 500 m^2 to 100 m^2 with an interval of 100 m^2 (i.e., 500 m^2, 400 m^2, 300 m^2, 200 m^2 and 100 m^2) were assigned and then the interval was reduced to 5 m^2 for the values from 150 m^2 to 130 m^2 (i.e., 150 m^2, 145 m^2, 140 m^2, 135 m^2 and 130 m^2) to reach an accurate realistic stream network. The generated respective stream networks to the assigned threshold values are shown in Figure 7. The basic stream characteristics like stream ordering and order-wise stream numbers with the respective assigned threshold value were calculated and compared with the data calculated from the reference topographic map (Table 1).

Among the threshold values assigned, the 100-m^2 threshold generated the maximum number of first-order streams, which are more than the reference streams from topographic maps. The 135 m^2 threshold is the optimal value that provided the nearest result to the referenced topographic maps streams and its orders. It is observed that there is no change in the number of streams in higher orders (i.e., 4, 5 and 6), but there is higher increase from first- to third-order streams as the area threshold value decreases (Table 1). This in turn affects the bifurcation ratio, stream frequency and drainage density value as well, which quantifies the drainage development.

Importance of pour-point coordinates

The size and shape of a watershed determine the hydro-geomorphic characteristics like amount and distribution of runoff. The size and shape of a watershed depend on the accuracy of mapping of the basin divide. Mapping the drainage divide is more difficult in flat regions than in hilly terrain (Oksanen and Sarjakoski 2005). The confluence point is referred to here as an outlet pour-point of the river network. The variation in confluence point, i.e., either positioned upstream or downstream of a river network from the real location, influences the size and shape of the catchment. Sometimes, the impact of a positioning error leads to null image due to an outlet pour point falling outside the catchment

Table 1. Comparison of number of streams against each stream order derived from the topographic map and extracted from DEM at various threshold values

Stream order	Topographic map	Threshold value									
		100 m^2 Interval					5 m^2 Interval				
		500	**400**	**300**	**200**	**100**	**150**	**145**	**140**	**135**	**130**
1	1426	588	729	807	1181	1991	1362	**1462**	**1497**	**1551**	**1611**
2	365	140	163	186	234	475	280	**296**	**339**	**372**	**382**
3	87	25	28	35	52	97	64	**68**	**71**	**76**	**78**
4	19	8	10	13	13	19	15	**16**	**16**	**16**	**16**
5	4	3	3	4	4	4	4	**4**	**4**	**4**	**4**
6	1	1	1	1	1	1	1	**1**	**1**	**1**	**1**

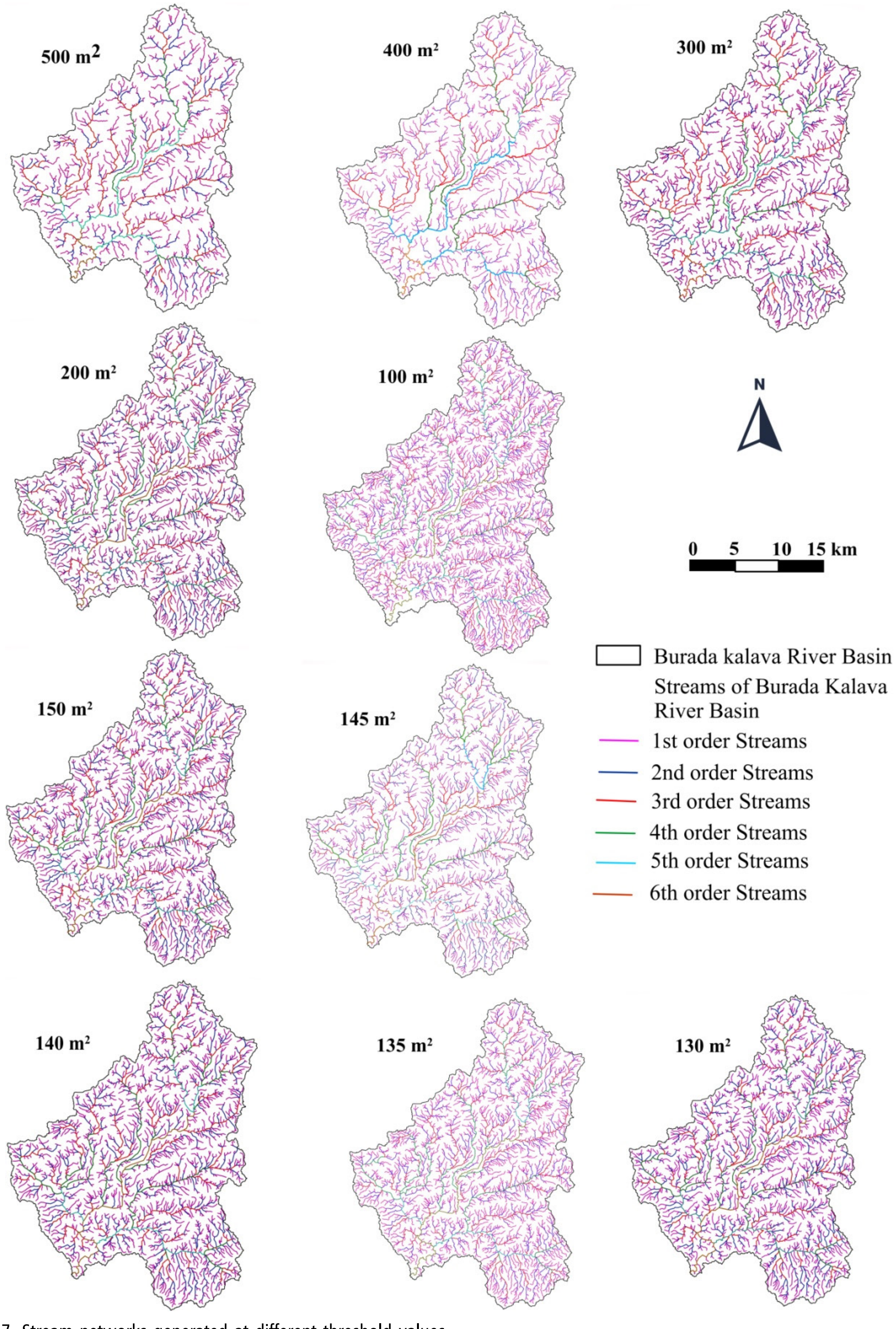

Fig. 7. Stream networks generated at different threshold values

area. This happens due to the algorithm being unable to detect a divide from the grid cell elevations – especially in flat regions, where the grid cells of the stream network are sparser than in other areas. So, in the present study, mapping the accurate drainage divide in the flat region of downstream area became difficult due to uncertainty in confluence point identification. This issue was rectified after assigning the D8 and appropriate pour-point threshold values. The confluence point of Burada Kalava river into the river Godavari (Fig. 8) is taken as the verification point and verified against coordinates collected in the field using GPS. Figure 9 shows the details of the confluence point and catchment boundary of the river before rectification and after rectification. So, the accurate positioning of the outlet pour-point coordinates and its location are very important for mapping the accurate catchment area.

Verification and validation of pour-point coordinates

Making use of a digitized drainage network from topographic maps, the pour-points are correlated and verified with field GPS data on the confluence point coordinates of the main stream (i.e., Burada Kalava River) in the Godavari river, as well as confluence points of tributaries (5^{th}-order streams) into the main stream of Burada Kalava River for generation of an accurate catchment area map. The final rectified map is shown in Figure 9. It is found that they are in the buffer radius of 5 m. The coordinates of outlet positions are snapped to the drainage network by using "r.stream.snap", since they are within the buffer radius of 5 m from the delineated stream network.

Fig. 8. Location of confluence point (17°04′59″N: 81°45′E) of Burada Kalava River into the Godavari River

Conclusions

For accurate stream network extraction and catchment area delineation from DEM, the preprocessing and its validation increases its accuracy level. This study provides a detailed methodology to apply the pre-processing algorithms in preparation of DEM to generate an accurate stream network and catchment area through this case study using GRASS-interfaced QGIS and SRTM DEM data. The verification and validation of results with the ground-truth GPS data improved the accuracy of the results.

Applying Fill-DEM to fill the spurious sinks in the original DEM results in the formation of parallel streams and positional errors, especially in the flat regions. This happens as the flow direction of a filled cell allows the stream to flow to all neighboring cells. Hence, application of stream burning to the original DEM removes all the parallel streams and nullifies the positional errors. The application of Fill-DEM to the burned DEM fills the spurious sinks more accurately when compared to the directly filled original DEM, and the resultant drainage network matched with the referenced drainage network. Although the DEM is pre-processed for more accurate stream paths, it is still important to analyze the output details of streams and catchment area. Comparative examination and visual inspection of extracted drainage network at different area threshold values with the reference topographic datasets and Google Earth image gives the most precise and accurate results.

The analysis of number of streams and the changes in stream paths at various assigned threshold values helps to understand the influence that the threshold area value has on the extracted stream network and stream paths. From this study, it is observed that major changes occur in the lower-order streams as the threshold value changes. From all the alternatives, 135 m2 is the optimum threshold value, for which the generated number of streams and stream orders are nearer

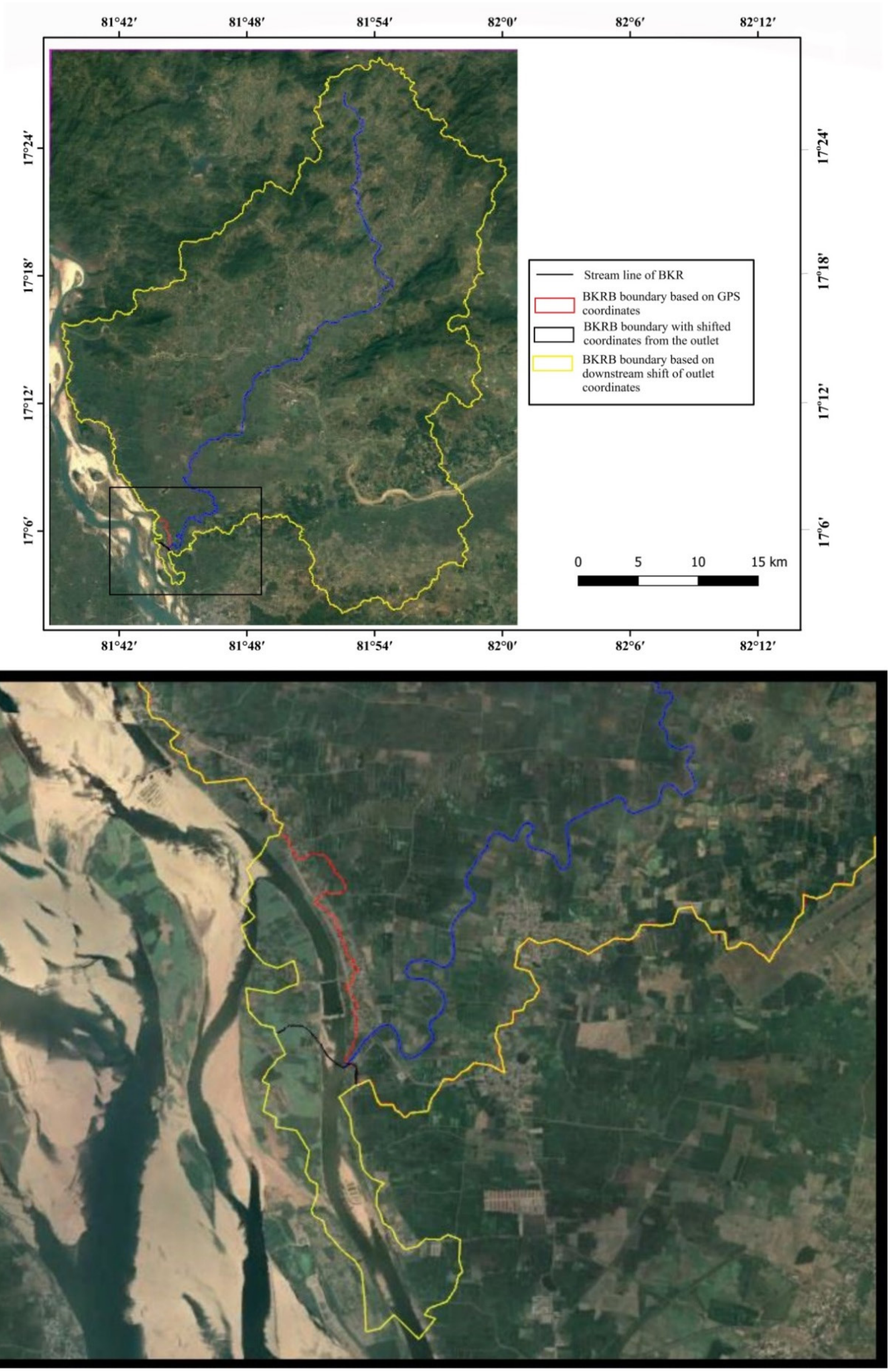

Fig. 9. Rectification of confluence point and basin boundary

to the digitized streams of the topographic maps of 1:50,000 scale in this type of terrain. This study demonstrates the best way to eliminate errors and get a precise stream network and catchment area to compare the automatically generated stream network and boundary of catchment area to the manually digitized stream network and catchment boundary from topographic maps and with Google Earth image.

In generation of the catchment boundary, the outlet pour-point location and its coordinates play an important role. From the results of this study, it is observed that the positional changes of the outlet point from its appropriate location affect the generated catchment area. To avoid this disruption and to get more accurate results, obtaining the real coordinates of the outlet pour points using GPS field survey and validating the same has improved the accuracy of results. It is important to note that the distance of the stream outlet and the outlet coordinates should be within the buffer radius of 5 m in order to generate an accurate outlet pour-point position for the automatic delineation of the catchment boundary.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: SY; data collection: SN, SY ; statistical analysis: SY; result interpretation: SN, ; manuscript preparation: SN; literature review: SN, SY.

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