**AN AUTOMATED APPROACH AND COMPARATIVE ANALYSIS FOR QUANTIFYING STREAM NETWORK USING DIGITAL ELEVATION MODEL: CASE STUDY OF MANIMUTHARU RIVER SUB-BASIN, TAMIL NADU**

Aarthi Deivanayagam (1), Jannath Firthouse Mohammed Yashin (1), Abdul Rahaman Sheik

Mohideen (1)

1Department of Geography, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India.

Email: [aarthideivanayagam.cdm@gmail.com](mailto:aarthideivanayagam.cdm@gmail.com); [jannathyas97@gmail.com](mailto:jannathyas97@gmail.com);

[abdulatgeo@gmail.com](mailto:abdulatgeo@gmail.com);

**Abstract:** Finding the efficient Digital Elevation Model (DEM) for quantifying stream network from Manimutharu river sub-basin, which is a tributary of Thamirabarani main basin, is the primary objective of this research work. The quantitative analysis of the drainage network is prominent to knowledgeably aware of the hydrological and environmental interaction and its process in an area. The automatic approach for watershed delineation is predominantly hinged on a river network extracted from the Digital Elevation Model (DEM). The conventional approach to quantify the drainage network is to use an eight-direction(D8) flow model which is derived from a raster DEM. In general, the DEM quality is relying on two crucial aspects. i.e. horizontal resolution and vertical accuracy. In this study, Digital Elevation Models (DEM) derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER-30 m resolution), Shuttle Radar Topography Mission (SRTM-30 m and 90 m resolution), Cartosat-1 (30 m resolution), The Advanced Land Observing Satellite - Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR-12.5 m resolution) and TerraSAR-X add-on for Digital Elevation Measurement (TANDEM-X-90 m resolution) are used individually assessed and compared with each other DEM. Through the hydrological analysis in ArcGIS, stream network properties such as flow direction, flow accumulation and stream order are delineated for the threshold values of 100, 250, 500, and 750 at various altitudes for comparison between various DEM. The drainage area, length, density and can be computed mathematically without relying on any software. The computable measurement of these characteristics is used to prospect the basin’s contribution to the hydrological cycle, the shape, size and the formation of local landscapes in the region. So, the results are invigorating in terms of the shape and geometry of stream network. A comparison between the outcomes obtained with the eight-direction (D8) flow model approach from multiple DEM exhibit the necessity over the conventionally modeled drainage structure. The result highlights some interesting relationships between DEM’s of varying resolution and their impact on various morphometric parameters mainly related to stream network.

**Keywords:** DEM, Basin morphometry, Stream network, Resolution, GIS

1. **INTRODUCTION**

The natural extent or an area of land where surface of water from precipitation accumulates to a single point specifically at a lower elevation and contributes runoff to a mutual point along a water path is referred as Watershed or Drainage basin. In the case of sustainable development approaches, a watershed is considered to be an ideal unit especially for the water & land resource management and for mitigation of natural disaster impacts (Rahaman et al. 2015). The morphometric analysis of watershed have inconceivable importance for suitable planning of basin, according to its potentiality to extract information about the characteristics of the basin in terms of topography, runoff characteristics, slope, surface water potential and soil conditions etc., In addition, it to provide a quantitative description of stream systems (Nadia et al. 2020). In a planimetric map, the delineated pattern of tributaries and cardinal streams in a drainage basin is referred to as drainage networks (Tarolli et al. 2009). Drainage network is one of the paramount inputs in the case of rainfall runoff assessment, predicting flood levels and water resource management. Accordingly, many natural resource management issues need unerring delineation of drainage networks in low time consumption. So, it is an efficient way to extract river network from DEM (Shanshan et al. 2008) than manual digitization. Automation of drainage networks delineation from Digital Elevation Model (DEM) has received substantial deliberation. Because, it undergoes facile delineation, computation of various drainage and terrain morphometric parameters from them. The quality of the DEM is crucial cogitation for the automatic extraction of drainage networks. GIS facilitates various geo-processing functionalities for estimating primary morphometric characteristics like stream length, basin width, area, etc (Asif et al. 2014).

In the recent decades, various algorithms for drainage characteristics extraction have evolved. The most commonly used approach to quantify drainage network is designated as D8 algorithm was introduced by O’Callaghan and Mark and has become widely used (O’Callaghan & Mark, 1984). This approach (based on a grid-based DEM) specifies flow directions by stipulate flow from each cell to one of its eight neighbors, in the direction with steepest downward slope. For all the downstream points through which the water flows, the contour is incremental because of the course of water is traced downhill from a point. The stream counts define characteristics of drainage network, throughout the upstream drainage area exceeds a specified threshold (Daisy et al. 2015). Hence in the delineation of drainage networks approach, DEM resolution as well as on the choice of the ideal flow accumulation threshold are considered to be critical factors. The morphometric parameters are strongly controlled by the resolution of the DEM and flow accumulation threshold (Daisy et al. 2015).

SRTM provides a satellite DEM, which is widely used for watersheds delineation and hydrological studies because of its global coverage of the earth surface with acceptable reliability. SRTM DEM 90 m provides viable alternatives to analyze the terrain attributes of the area (Sayantan et al. 2016)**.** The Cartosat-1 with 30 m resolution dataset does not provide reliable information comparatively in DEM based morphometric analysis. Inherent limitations of the Cartosat-1 dataset might have played a part in reducing the accuracy of the first generation of Cartosat-1 DEM. Even though Cartosat-1 (DEM) data prove to be a competent tool in morphometric analysis, it is unable to match the accuracy and consistency of the results produced by other (Sayantan et al. 2016 and Ahmed et al., 2012).

Through with ASTER DEM, the variation in drainage characteristics might be due to changes in slope and topography (Evangelin, 2015). ASTER GDEM, owing to its better reliability particularly in craggy hilly and complex terrain than SRTM DEM (Kuldeep et. al, 2011). Different landforms were identified in the watershed based on ASTER DEM data with 30 m spatial resolution and it is characterized by very high accuracy of mapping and measurement prove to be a competent in morphometric analysis (Clodis et al. 2012). Lineament attenuation in ALOS images enhances proportionally with widen land use. Other important interferences are that the natural characteristics of the L-band PALSAR sensor imposes significantly attenuate linear structures (Clodis et al. 2012). This data is very effective in extracting stream network and are suggested for morphometric studies (Nitheshnirmal et al. 2019). SRTM DEM is revealed to be an important tool to provide mapping of tectonically significant morpho-structural lineaments in tropical areas, where application of optical products might be difficult compared to ALOS PALSAR. PALSAR images might contain several interferences caused by distortions due to layover, not eliminated completely even after processing, which contributed to preclude or attenuate the detection of linear features in particular region (Manfred et al. 2016).

The TANDEM-X mission uses two identical X-band radar satellites and its DEM fits for morphological studies of terrestrial impact craters. As it encompasses the high absolute and relative vertical accuracy, it could promote mapping in great detail (Isabel et al. 2015). It was built to represent a new standard in global DEMs, with remarkable level of detail and consistency (Carlos 2018). Their elevation data are superlative to the ASTER and SRTM datasets (Kaliraj et al. 2014).

The predominant goal of this present study is to find the optimal DEM for computing the morphometric attributes of drainage basin including the stream orders, stream length, basin area and stream density from various DEM. The flow accumulation threshold and their efficiency and impacts on the drainage networks delineation are also discussed in this paper.

**2. STUDY AREA**

Thamirabarani river basin, which is one of the 20 major river basins of India and has its origination from the peak of Pothigai hills on the Eastern slope of Western Ghats at an altitude of 6132 ft and covers the districts of Tirunelveli and Thoothukudi. The basin is fortifies by both the South-West & North-East monsoons and is seen in full torrent twice a year if the monsoons do not fail. The entire basin receives average annual rainfall of about 985.77 mm and temperature is about 29⁰C approximately. The study area of the present research is the Manimutharu sub-basin which is originated from Manjolai hills and joins Thamirabarani river in Aladaiyoor village. It lies between 8°28'41.51" N to 8°54'9.83" N latitude and 77°10'33.02" E to 77°48'11.3"E longitude (as shown in Fig.1). The study area wraps the administrative boundaries of Ambasamudram, Southern part of Tenkasi, North-western part of Nanguneri, Western part of Palayamkottai and South-western part of Tirunelveli. The most notable picnic spots located are Papanasam Dam, Manimutharu falls, Agasthiyar falls, and Karayar Dam. The tranquil tea plantations covered in south-west part is the Manjollai hills station tucked away deep in Kalakaadu Mundhanthurai Tiger reserve. Courtallam adds striking beauty to the study area as its hold scenic spots like Peraruvi, Chithar river, Five falls. Many anicuts, dams and reservoirs in the study area serves as the primary source of irrigation and power generation for Tirunelveli district.



Fig.1 Study area

**3. DATA AND METHODOLOGY**

**3.1 Data Source**

In this present research, six DEMs with varied resolution datasets (Table.1) are downloaded to assess the stream properties through automated delineation of the stream extraction in Manimutharu sub-basin. The Cartosat-1 DEM with resolution of 30 m was downloaded from Bhuvan (<https://bhuvan.nrsc.gov.in/>); Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) with the resolution of 30 m from Earthdata (<https://earthdata.nasa.gov/>); Shuttle Radar Topography Mission (SRTM) with resolutions of 30 m and 90 m from the site maintained by CGIAR (<http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp>); The Advanced Land Observing Satellite - Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR) from Earthdata (<https://search.asf.alaska.edu/>); TerraSAR-X add-on for Digital Elevation Measurement (TANDEM-X) 90 m resolution from Earth Observation Center (EOC) Geoservice (<https://download.geoservice.dlr.de/TDM90/>). The collected data are integrated into the ArcGIS Environment and morphometric analysis is performed to quantify the stream network.

Table.1 Data characteristics



**3.2 Stream network and Basin extraction methodology**

The flow chart in Fig.2 schematically represents the way to extract stream network from Digital Elevation Model (DEM) through ArcGIS Environment and graphical relation were made to correlate the basin parameters. The following steps involves in the basin and drainage extraction:

1. **Fill/Sink:** The DEM downloaded from sources will have “pits” or “sinks” caused by rounding of elevations to the nearest integer value or spatial resampling. These sinks have no outflow which may affect the flow direction and stream network, and cause internal storage (Jenson & Domingue, 1988). To ensure effective delineation of streams and basins, these errors should be rectified by Fill/Sink process using Arc Hydro tools and preprocessed sink-free DEM tile is generated.
2. **Flow Direction:** The well known D8 algorithm is an eight direction pour point model. The filled DEM is processed in ArcHydro toolsto depict the flow direction of the raster**.**
3. **Flow accumulation:** The flow direction outcome is used to generate flow accumulation dataset, in which each cells has a value based on number of cells flow into it. The value will be higher if the cell belongs to stream network.
4. **Stream line extraction:** The stream network represents the cells at which runoff are more concentrated and it is derived by applying various threshold values using Raster calculator. It is subjective to apply any threshold values, as per the terrain analysis. For the present research work the values of 100, 250, 500 and 750 were chosen. The effect of chosen threshold on the flow accumulation dataset would affect the stream count, order and density. Higher the threshold value, lower is the stream network properties (Ibrahim, 2018)**.**
5. **Stream Order:** Strahler Stream order method (Strahler, 1954) is used to depict the order of Stream network. In which, the most upstream will have the order 1; when two streams of order i joins, a stream of order i+1 is generated; when the stream of order i joins a stream of order i+1,stream order is not altered. The flow accumulated raster with the threshold values of 100,250,500,750 and flow direction raster are taken as input and processed to find the stream order. The outcome raster is converted to polyline features.
6. **Pour points and Watershed delineation:** Pour points are determined from Strahler ordered stream network; indicated by the spot where flow is out of the cell and in high flow accumulation area. These points with flow direction delineate the watershed. It delineates the watershed boundary by joining the high elevation points. The extracted basin attribute is explored for area calculation.
7. **Stream Length (L):** The stream features are clipped to the DEM derived watershed extent and its attributes are explored to find the stream length. The total stream length of watershed has various stream orders.With the extracted stream features, line density map is generated using the population field as stream order.
8. **Drainage Density (D):** It measures the concentration of drainage stream network and is defined by Hortan as the ratio of total stream length (Li), which includes main stream and its tributaries, to the drainage area(A) (Hortan 1932), as represented in Table.2

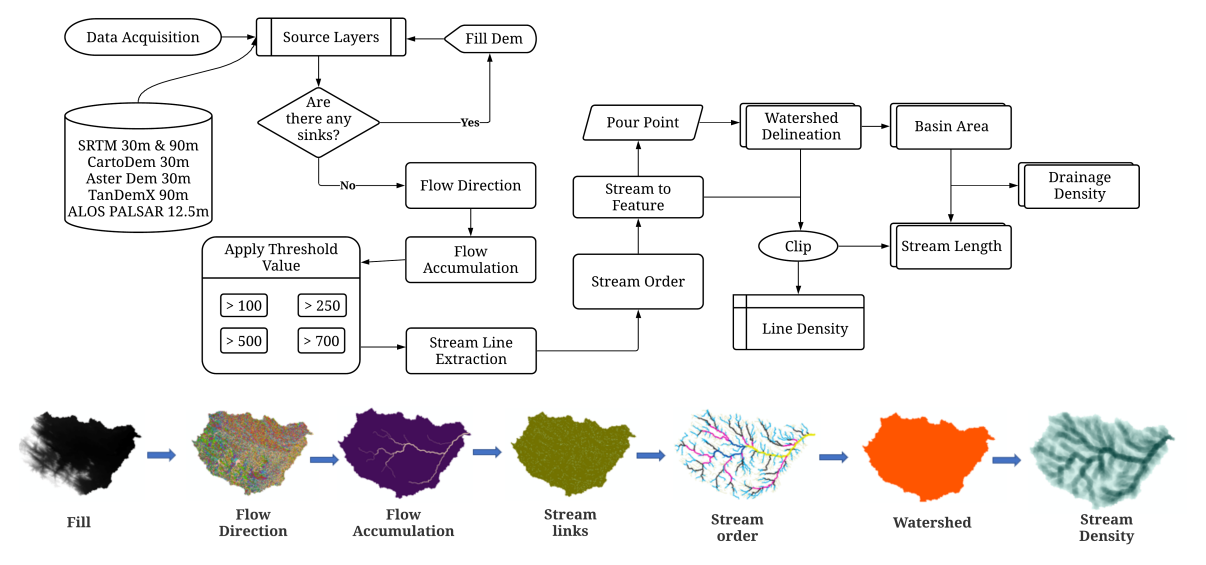
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Fig.2 Stream extraction methodology

Table.2 Parameters considered and its corresponding computed values

|  |  |  |  |
| --- | --- | --- | --- |
| S.No | Parameters | Values and Formulas | References |
| 1 | Threshold | 100, 250, 500, 750 | - |
| 2 | Stream Order | Hierarchical rank | Strahler (1954) |
| 3 | Stream Length (km) | Li= L1+L2+…..Ln | Horton (1945) |
| 4 | Drainage Density (km/km2) |  | Horton (1932) |
| 5 | Basin Area (A) | DEM derived | - |

*\*Source: Compiled by author*

**4. RESULTS AND DISCUSSION**

The stream networks are extracted and parameters in Table.2 are derived for Manimutharu sub-basin. In the following part, the implications of considered parameters on different DEM at various resolutions are discussed.

**4.1 Different DEM with same resolution**

The 30 m spatial resolution DEM of ASTER, Cartosat-1, SRTM is processed as per the methodology (as shown in Fig.2) and mathematical analysis were performed to study about its extracted stream order, density and area. In general, higher the resolution of DEM greater will be the quality of drainage network generation.

ASTER_30.tif

3a

3b



3c

Fig.3 Watershed delineation in 30 m (a) ASTER, (b) Carto DEM, (c) SRTM for various threshold values of 100, 250, 500 and 750

In order to understand each DEM properties and its flow accumulation, following threshold values of 100, 250, 500, and 750 were set to extract the stream networks. As shown in Fig.3, all DEMs with the flow accumulation threshold of 100 yields higher values of parameters considered as listed in Table.2. For example, 30 m ASTER DEM with threshold value of 100 generates 7th order stream with the stream length of 54.13 km and with 250 threshold, the order and length decreased to 6th and 42.48 km respectively (as shown in Fig.7a). By comparing ASTER DEM results to Carto DEM and SRTM, stream features of Carto DEM with all thresholds are low. It is noted that ASTER generates 6th order at 500 threshold with length of 64.7 km but the Carto DEM and SRTM generates 6th order at 250 threshold. From the observation it is found that, increase in threshold value alters the stream hierarchical order. The fine and tiny tributaries of Manimuthar river basin with order 1 and its basin area delineated by ASTER DEM moreover matches the real-world features when overlaid on Google Earth. Hence, the present study founds ASTER as an optimal DEM, for the spatial resolution of 30 m, to perform morphometric analysis in low lying regions followed by SRTM and Carto DEM. The 90 m DEM of SRTM and TANDEM-X is processed and the extracted stream features at all thresholds are compared and found that stream length, drainage area and density outcome looks moreover similar (as shown in Fig.4). But it is noted that stream order generates by 30 m DEM at all threshold values is higher and speculates effectual stream density at low threshold values than by 90 m.

srtm_90.tif 

4b

4a

Fig.4 Watershed delineation in 90 m (a)SRTM and (b)TANDEM-X for various threshold values of (a) 100, (b) 250, (c) 500 and (d) 750

**4.2 Comparative assessment of same DEM and different DEM with various resolutions**

By comparing low (90 m) and high (30 m) resolution SRTM DEM, as shown in Fig.3b & 4a, the stream features in 30 m are delineated well with high density and stream length for low thresholds. But, increasing the threshold values in 90 m DEM depromotes the stream hierarchical and density as graphed in Fig. 6. The analysis depicts that the elevation accuracy works well in high resolution and it is fit for speculating the elevated terrain and the down-sloped tributaries efficiently. And also for low resolution DEM, this study advises to use lower threshold values (say 100) to yield appropriate results.



|  |  |
| --- | --- |
| Fig.5 Stream extraction and Basin delineation in ALOS PALSAR | Fig.6 Relating DEM with Drainage density and Area |

To delineate meticulous stream features with different higher resolution DEM, ALOS PALSAR with 12.5 m resolution in examined. As shown in Fig.6, the threshold values at 100 and 250 forms denser stream with greater length and unique outcome with distinct values than other. It is noteworthy that 8th higher order stream is generated as graphed in Fig.7f.



7b

7c

7a



7e

7d

7f

Fig.7 Relationship between stream order and length at various thresholds for different DEM

|  |  |
| --- | --- |
|  | Table.3 Integrated cross-correlation of DEM properties with various threshold |
| *\*Source: Compiled by author* |
| Fig.8 Correlation analysis between DEM properties and Threshold |

To cross validate the extracted stream properties values from various DEM and multiple thresholds, correlation analysis was tested. It signifies that 100 and 750 are similar at certain point (Fig.8 and Table.3) shown that the stream length and density extracted from 30 m DEM are very nearer. The threshold of 100 generates more first order streams when compares to highest threshold of 750, which has an important role in altering the streams hierarchical order and its density. The major observation from this study is to extract the finest or tiny streams using the threshold of 100 from any DEM product. This kind of study is not only to categorize the DEM and threshold value but also to observe how those factors are influencing the other applications like terrain, hydrological aspects. For instance, groundwater potential and recharge analysis following major input parameters essential such as drainage and its density, relief, curvature, and slope; which can be extracted from using DEM alone. In this concern, selection of appropriate DEM with thresholds is more indispensable, which depends on terrain condition and specific application**.**

**5. CONCLUSION**

In last few decades, DEM grabs attention in watershed extraction, stream network delineation studies and morphometrical calculation of the basin parameters. There are variety of DEMs varied in resolution and accuracies. One cannot precisely know which DEM will give efficient results at certain geomorphological conditions. The present research work is an attempt to find the best possible one for low lying drainage area. By analyzing the parameters in Table.2, it is found that i) High resolution DEM (say 12.5 m) relents greater density of stream network ii) low threshold values gives greater yield of stream length and density. So, low range values can be used in high altitude study region. In contrast, high threshold when applied generates more bias on hilly regions in terms of stream density, and order. So high threshold value suits probably well for low lying area like coastal regions. The depicted facts and results can be considered while choosing DEM and threshold conditions for hydrological applications. iii) For the present study spot, ASTER with 30 m spatial resolution meant to be optimal DEM as it gives efficient stream extracted results in 100 threshold and delineated features matches probably well when cross compared in Google Earth. It will be the crucial use and cost-effective for basin analysis and land use planning of basin environ. The drainage network modelling in terms of DEM based analysis is a vivid technique that promotes earth surface evaluation and mapping. In addition, it assisted to observe the influencing factors of hydrological processes, rainfall runoff estimation and rainwater harvesting also.

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**REFERENCES**

1. Ahmed, S., Sreedevi, P.D., Sreekanth, P.D., and Khan, H.H., 2012. Drainage morphometry and its influence on hydrology in an Semi Arid region: using SRTM data and GIS. Environ Earth Sci.
2. Asif, K., Keith, S., Richards, G., Parker, T., McRobie, A., Biswajit, M., 2014. How large is the Upper Indus Basin? The pitfalls of auto-delineation using DEMs. Journal of Hydrology, 500, pp.442-453.
3. Carlos, H.G., 2018. Evaluation of TanDEM-X DEMs on selected Brazilian sites: Comparison with SRTM, ASTER GDEM and ALOS AW3D30. Remote Sensing of Environment, 212, pp. 121-133.
4. Clodis, D.O., Andrades, F., and Fatima Rossetti, D.D., 2012. Effectiveness of SRTM and ALOS-PALSAR data for identifying morphostructural lineaments in northeastern Brazil. International Journal of Remote Sensing, 33(4), pp-1058-1077.
5. Daisy Paul, V., Ravibabu, M., and Tejpal, S., 2015. Quantifying and modeling of stream network using digital elevation models. Ain Shams Engineering Journal, 8, pp. 311-321.
6. Evangelin, R.S., Selvakumar, R., Rajasimman, U.A.B., Rajamanickam, G.V. 2015. Morphometric analysis of subwatershed in parts of Western Ghats, South India using ASTER DEM. Geomatics, Natural Hazards and Risk., 6(4), pp. 326-341.
7. Horton, R.E., 1932. Drainage-Basin Characteristics, 13, pp.350-361.
8. Horton, R.E., 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America, 56, pp.275-370.
9. Ibrahim, M.O., and Turkay, G., 2018. Examining the Stream Threshold Approaches Used in Hydrologic Analysis. International Journal of Geo-Information, 7(6), pp.201.
10. Isabel, P., David, L., and Frank, L., 2015. Evaluation of TanDEM-X elevation data for geomorphological mapping and interpretation in high mountain environments — A case study from SE Tibet, China Geomorphology, pp. 232-254.
11. Jenson S.K., and Domingue, O., 1988. Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis. 54(11), pp-1593-1600.
12. John, F.O., and David, M. M., 1984. The Extraction of Drainage Networks from Digital Elevation Data. Computer Vision, Graphics, and Image Processing, 28, pp 323-344.
13. Kaliraj, S, Chandrasekar, N., and Magesh, N.S., 2014, Morphometric analysis of the River Thamirabarani sub-basin in Kanyakumari District, South west coast of Tamil Nadu, India, using remote sensing and GIS. Environ Earth Sci,
14. Kuldeep, P., and Upasana, P., 2011. Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India using ASTER (DEM) Data and GIS. International Journal of Geomatics and Geosciences, 2(1), pp. 248-269.
15. Manfred, G., Thoma,s F., and Helko, B., Birgit, S., and Alan, H., 2016. Remote sensing of terrestrial impact craters: The TanDEM-X digital elevation model. Meteoritics & Planetary Science, pp. 1-16.
16. Nadia, A.A., Zaidoon, T.A. and Marwa M., 2020. GIS-based watershed morphometric analysis using DEM data in Diyala river, Iraq. Iraqi Geological Journal, 53(1C), pp. 36-49.
17. Nitheshnirmal, S. Thilagaraj, P., Abdul Rahaman S. and Jegankumar R. (2019). Erosion risk assessment through morphometric indices for prioritisation of Arjuna watershed using ALOS-PALSAR DEM. Modeling Earth Systems and Environment, 5, 907–924. <https://doi.org/10.1007/s40808-019-00578-y>
18. Rahaman SA, Ajeez SA, Aruchamy S, Jegankumar R. 2015. Prioritization of Sub Watershed based on morphometric characteristics using fuzzy analytical hierarchy process and geographical information system—a study of Kallar watershed, Tamil Nadu. International conference on water resources, coastal and ocean. Aquatic Proc. 4:1322–1330. <https://doi.org/10.1016/j.aqpro.2015.02.172>
19. Sayantan, D., Priyank, P.P, and Somasis S., 2016. Evaluation of different digital elevation models for analyzing drainage morphometric parameters in a mountainous terrain: a case study of the Supin–Upper Tons Basin, Indian Himalayas. SpringerPlus, 5(1544), pp.1-38.
20. Shanshan, G.E., and Guoan, T., 2008. DEM-based investigation on stream network nodes and their features, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII (B2), pp. 293-298.
21. Strahler, N., 1954. Statistical Analysis in Geomorphic Research. The Journal of Geology.
22. Sumita, G., Gouri Sankar, B., and Pravat Kumar, S., 2013. Morphometric Analysis of Kangshabati-Darkeswar Interfluves Area in West Bengal, India using ASTER DEM and GIS Techniques. Geology & Geosciences, 2(4) pp. 1-10.
23. Tarolli, P., Dalla Fontana G., Moretti, G., and Orlandini, S., 2009. Cell Size Dependence of Threshold Conditions for the Delineation of Drainage Networks from Gridded Elevation Data. Proceedings of Geomorphometry, pp. 208-217.