A Case Study on Watershed Study for Flood Mitigation of Belgavi Region, Karnataka, India Using ArcGIS

Geena George [*1] *and Bhavyashree M.* [2]

Abstract

During the monsoon season, many regions in India are prone to floods among which Belagavi district, Karnataka (the study area) is one of the most affected. It has suffered huge lives and property losses. This study focuses on areas of rainfall analysis, watershed area mapping, flood vulnerable areas mapping and possible mitigation measures. DEM analysis is used to understand flood risk assessment. The rainfall data is collected for three taluks which are more prone to flood. These are Athani, Chikodi, and Raibagh in Belgavi regions. The study area was analyzed by generating maps for soil type, lithology, geomorphology, land use, and land cover using ArcGIS software. Maps were obtained for the percentage of land contributing to each attribute. Further flood vulnerability mapping has to be done by creating weightage map considering factors such as drainage density, soil type,, precipitation, land use land cover, slope, and watershed compressed together by weighted overlay analysis, and the flood hazard zone map is developed to classify the areas into zones according to the risk of flooding which helps to suggest various non-structural mitigation measures.

Keywords : DEM Analysis, flood mitigation, flood vulnerability, geomorphology, rainfall analysis

I. INTRODUCTION

In recent years, flooding has become a natural disaster that causes severe losses and damage across the world. The main factors that contribute to this risk of flooding include changes in climatic conditions, land use and land cover, and other anthropogenic activities. Human activities such as rapid urbanization and enhanced construction activities, deforestation, improper construction of roads and bridges, changing the alignment of water bodies, etc. further promote risk of flood [1]. The extent of flooding depends upon the intensity and duration of rainfall, drainage basin conditions, soil type, and the presence of dams and reservoirs in a particular region. Flash flooding in small basins is mainly due to short-duration, high-intensity rainfall [2]. The damage due to flooding is not only due to the high speed, uncontrollable flow of water, but also because of the suspended and dissolved loads in flood water, which consist of a wide range of pollutants causing serious health hazards [3]. It also affects agriculture by causing crop losses, root damage, and soil erosion. It also increases soil compaction. The increased occupancy of flood plains, as well as the reclamation ofwetlands and water bodies increases the extent of flood damage. It is very important to identify the flood-prone areas and flood-proof them for effective flood management [4].

Recently, Geographical Information Systems (GIS) and Digital Elevation Models (DEM) have been widely used in modelling of geospatial and hydrological data including flood prediction, drainage, and watershed delineation etc. GIS integrated with DEM can be used in

Manuscript Received : October 10, 2022 ; Revised : October 28, 2022 ; Accepted : November 6, 2022. Date of Publication : December 5, 2022.

G. George[*1], *Associate Professor,* Department of Civil Engineering, East Point College of Engineering & Technology, Bengaluru - 560 049. Email : geenasajith@gmail.com ; ORCID iD : https://orcid.org/s0000-0003-4230-710X
Bhavyashree M.[2], *Ex-student,* East Point College of Engineering & Technology, Bengaluru - 560 049.
Email : bhavyashreemoorthy1998@gmail.com ; ORCID iD : https://orcid.org/0000-0001-9856-9243

DOI: https://doi.org/10.17010/ijce/2022/v5i2/172605

flood disaster management which includes flood prediction, preparation, and prevention; mitigation measures, and also post-flood activities. Digital topographic data such as contours, natural and man-made features are used to generate DEM, and the resulting DEM is used in hydrological studies [5]. Bajabaa, Masoud, and Al-Amri [6] did flood hazard mapping using a digital elevation model (DEM) and GIS. Parameters such as watershed boundary, flow length, and direction etc. were considered. For the sustainable development of water resources and for flood management, flood hazard studies and mapping are important. Hydrological data such as rainfall and runoff data are essential for the flood mapping of affected areas [7]. Remote sensing and GIS have played a major role in watershed management such as assessing watershed conditions through modelling the impact of anthropogenic activities to visualize the impact of alternative scenarios [8]. Flood vulnerability mapping gives susceptibility to damage due to sudden floods. These flooding related factors and flood prone areas were taken into account. Delineation of the areas prone to flooding is obtained using an effective tool such as GIS. GIS is a widely used application in flood related studies, considering its application as an informative tool, an analytical tool, and a decision-supporting system. The multi-parameter evaluation is adopted by giving weights to prioritize the importance of various factors. The flood related studies have greatly improved with the use of geospatial techniques, mainly in three phases:

(i) flood preparedness phase

(ii) monitoring phase during floods.

(iii) flood damage assessment and mitigation phase.

The GIS database is developed during the preparedness phase and includes socio-economic, communication, agriculture, population, and infra-structural data. This data is considered along with the flooding data to adopt mitigation measures such as evacuation strategy and rehabilitation, and also damage assessment during a critical flood situation [9].

India is considered a country having the most natural disaster prone regions in South Asia, which results in losses of infrastructure and human life every year. Floods in India are mainly due to the rainfall caused by monsoon depressions and cyclonic storms from June to September. The delta areas of the Mahanadi, Godavari, and Krishna rivers on the east coast periodically experience flooding and drainage problems. These rivers have adequate capacity to carry floodwater within their natural banks, with a very flat bed slope [10]. In the recent past, a series of floods occurred that affected 13 states in late July and early August due to intense rains. In the year 2019, Kerala, Karnataka, and Maharashtra received the heaviest monsoon in the last 25 years. More than 1600 people died and millions of people lost their homes and livelihoods. Karnataka was one of the worst affected states by floods in 2019 among which the northern,coastal, and Malnad districts experienced the worst. During the monsoon season, many regions in Karnataka were prone to flooding, among which Belagavi district, our study area, is one of the most affected, having experienced a large losses of lives and property. The study focuses on areas of rainfall analysis, watershed area mapping, flood vulnerable areas mapping, and possible mitigation measures.

It is the need of the hour to study the vulnerabilities, considering previous flood data and using geospatial technologies to bridge the existing gaps. This study is an attempt to identify and accurately delineate flood hazard risk zones in the Belgavi region using remote sensing techniques and GIS to develop a flood risk zone map which can be used as a base map for developing future flood control strategy, reallocation of human resources and infrastructure, and emergency planning.

II. METHODOLOGY

This study aims to develop flood hazard risk zone maps of flood affected taluks of the Belgavi region, that is, Athani, Chikkodi, and Raibagh based on multi-criteria assessment using remote sensing and GIS tools. The study was conducted under multi-criteria evaluation methods in which factors such as rainfall distribution, drainage density, slope, soil type, Land Use Land Cover (LULC), and size of micro watershed were considered to prepare a flood hazard risk zone map using ArcGIS. Weightage maps were created by giving weights to these thematic maps. The Weighted Overlay Analysis method is adopted to prepare the flood hazard risk zone map. Thus, developed hazard maps will help to classify the areas subjected to the hazards into very low, low, moderate, high, and very high -risk zones. With the help of risk zone maps, mitigation measures can be taken to reduce the risk of flooding in Belgavi region. The data from Digital Elevation Mapping (DEM) is being used to delineate the watershed boundaries using ESRI's ArcGIS Software 10.3. Rainfall analysis is mainly done to determine the amount, intensity, and frequency of rainfall. Data were collected from Karnataka state Disaster Management Authority (KSDMA) and the quantity of storm water was calculated. The boundaries of the watershed are generated using the appropriate collected data. Maps were prepared for rainfall distribution, slope, drainage density, soil type, LULC, and size of micro watershed. With these weightage maps and the Weighted Overlay Analysis method, the flood hazard risk zone map is developed. A flood vulnerability map is generated using the ArcGIS software. The non-structural flood mitigation measures were suggested according to the outcome of the study.

A. Study Area

Belgaum is the biggest district of Karnataka situated near the foothills of the Sahyadri mountain range located at 15.87°N 74.5°E in Fig. 1.The city lies in the north-western part of Karnataka having Maharashtra and Goa along the western ghats. The Belgavi region is more prone to rain during the north-east monsoon, followed by the south-east and pre-monsoon respectively. The study was conducted in the three taluks which are more prone to flooding: Athani, Chikodi, and Raibagh, where the flow of river Krishna is profound. Since the regions close to the

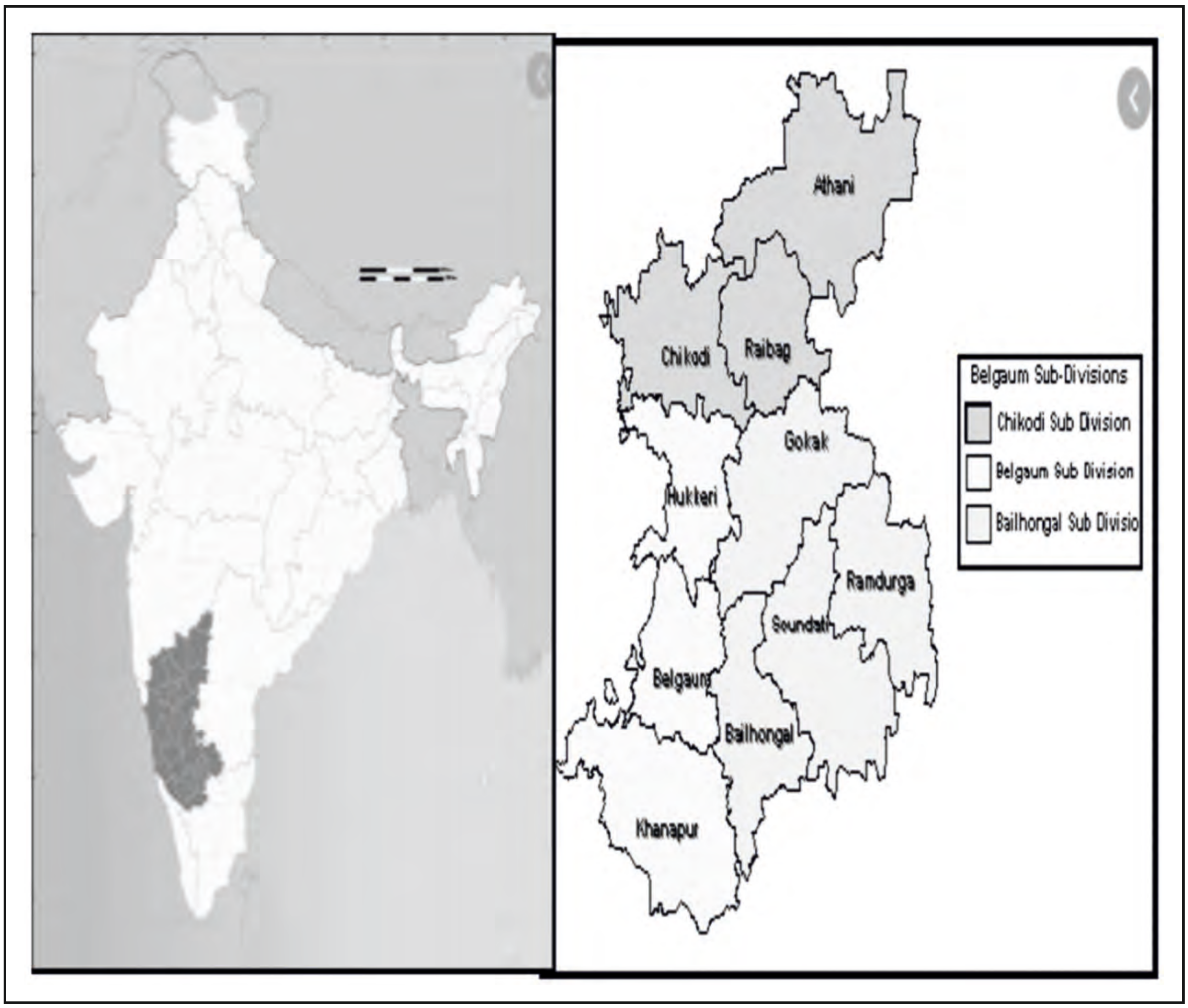


Fig . 1. Map showing the study area

river Krishna are flood vulnerable, rain gauge stations in and around are selected and rainfall analysis was done from the years 1989 to 2014.

Belgavi mostly consists of clayey soil, which is around 48.570% of the total land available. Next comes loamy soil, which is 34.875%, followed by clayey skeletal soil, which is 16.142%, and clayey mixed soil, which is 0.431%. As a result, the clayey type of soil covers the majority of Belgavi. As shown in Fig. 2. It consists mostly of 45.15% of Deccan Traps and Intertrappean types of rock group, with other types of rocks such as consolidated sediments (17.374%), metamorphic rocks (12.406%), plutonic rocks (12.632%), volcanics/meta volcanics (9.969%), residual capping (1.643%), unconsolidated sediments (0.706%), and semi-consolidated sediments (0.110%) of the total available land area given in Fig. 3. The land use land cover of the Belgavi region consists of 26.54% of land which is cropped in two seasons, followed by 24.46% of kharif land and 21.56% of land that is not cropped in two seasons as shown in Fig. 4. Geomorphology is the study of the physical features of the earth's surface and their relationship to its geological structures. From the geomorphological data of the study area as shown in Fig. 5, it mostly consists of 19.35% of the Pedi plain shallow type of land, followed by the rest of the land types according to their respective percentages of land.

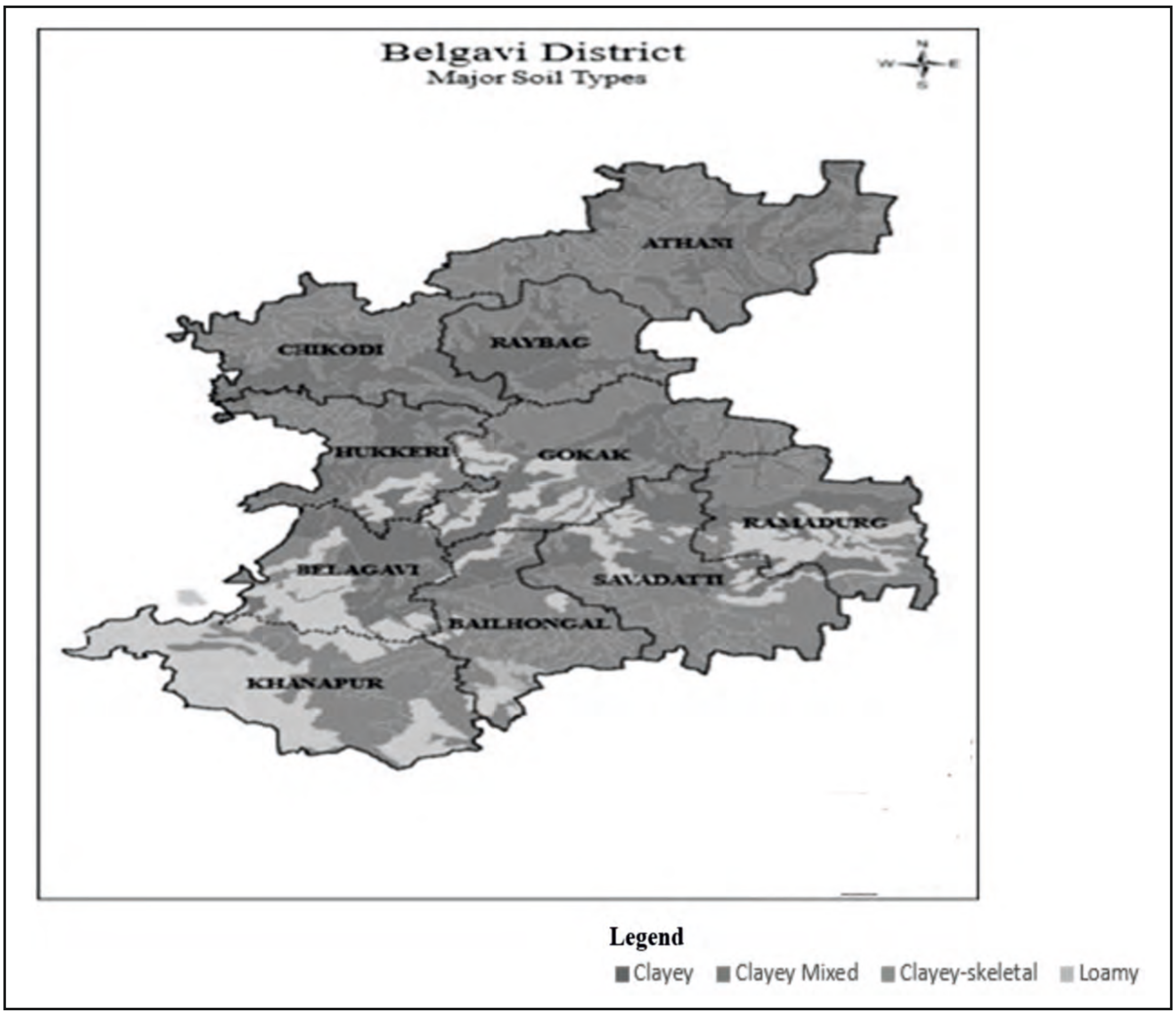


Fig. 2. Type of soil in Belgavi region

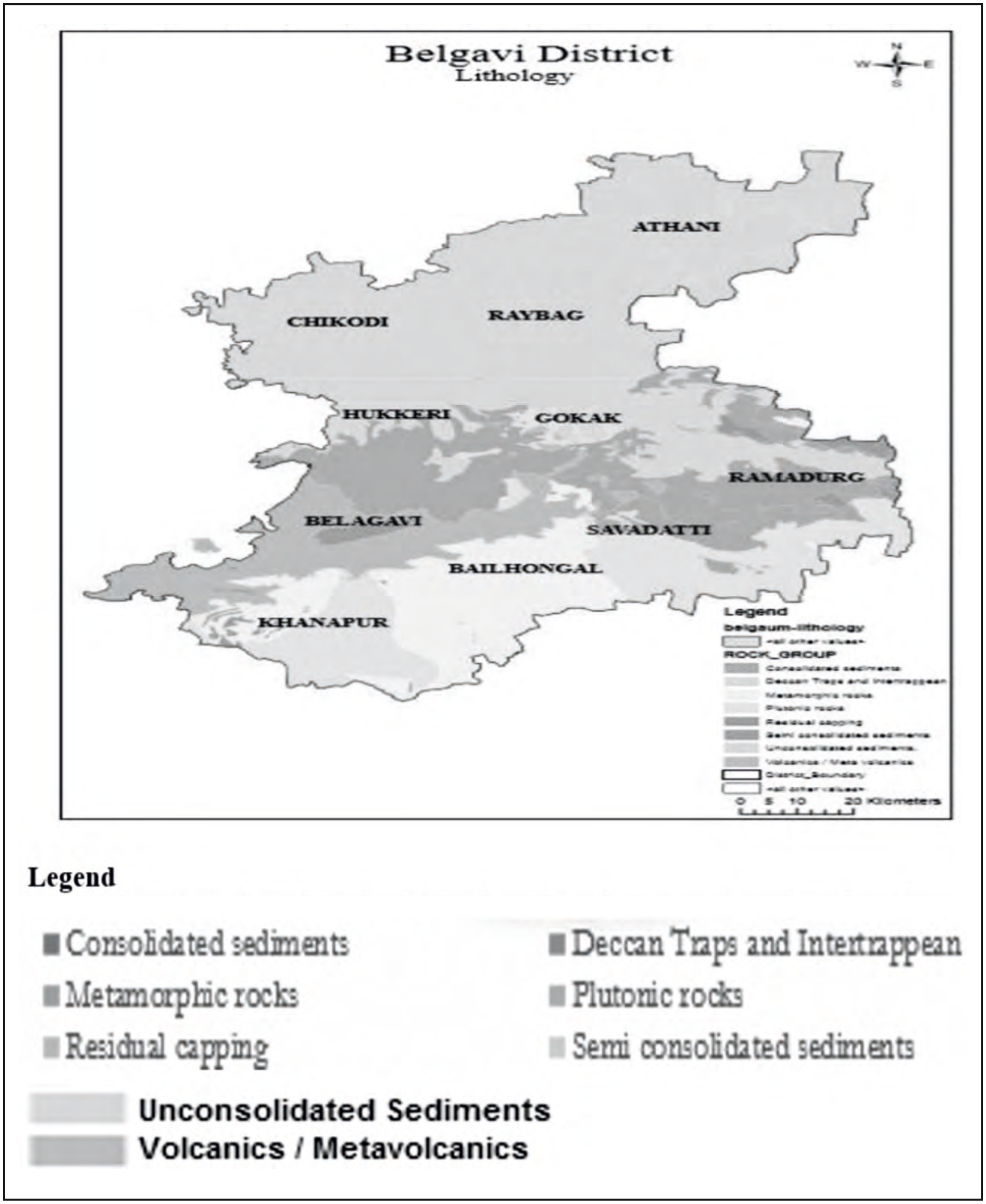


Fig. 3. Types of rocks in Belgavi region

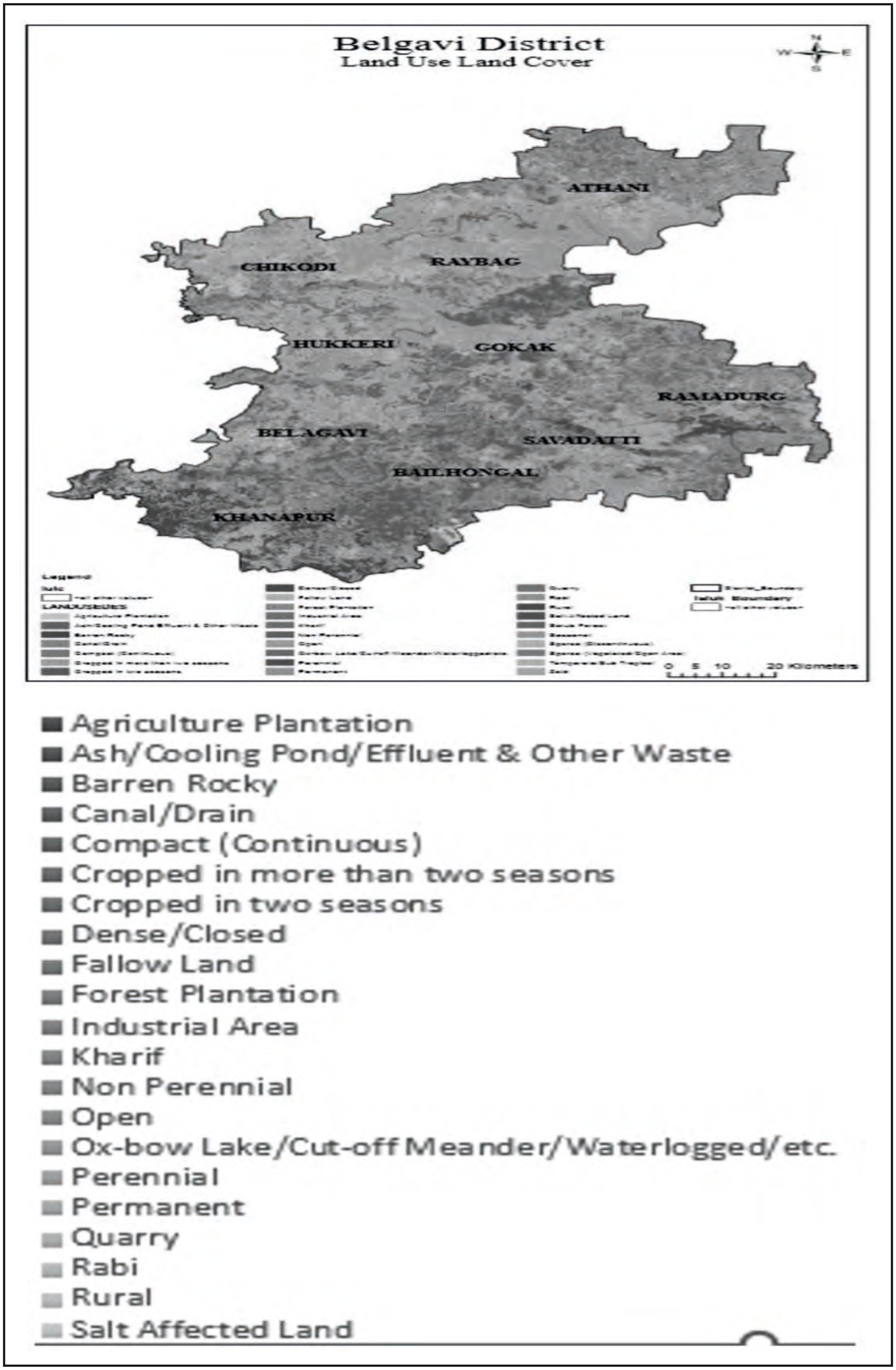
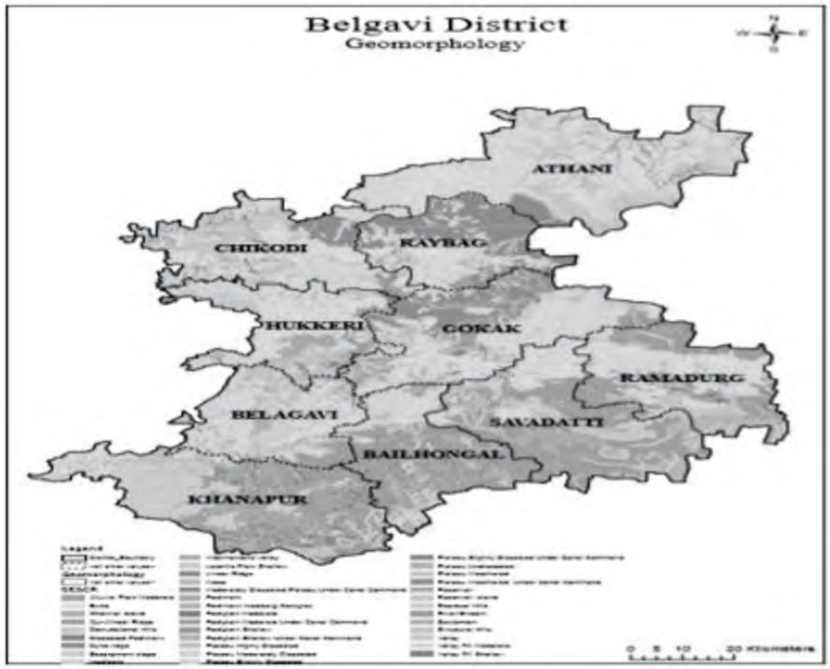


Fig. 4. Land use land cover of Belgavi region



Legend

- Alluvial Plain Moderate
- Butte
- Channel Island
- Curvilinear Ridge
- Denudational Hills
- Dissected Pediment
- Dyke ridge
- Escarpment slope
- Inselberg
- Intermontane Valley
- Lateritic Plain Shallow
- Linear Ridge
- Mesa
- Moderately Dissected Plateau Under Canal Command
- Pediment
- Pediment Inselberg Complex
- Pediplain Moderate
- Pediplain Moderate Under Canal Command

Fig. 5. Geomorphology of the Belgavi

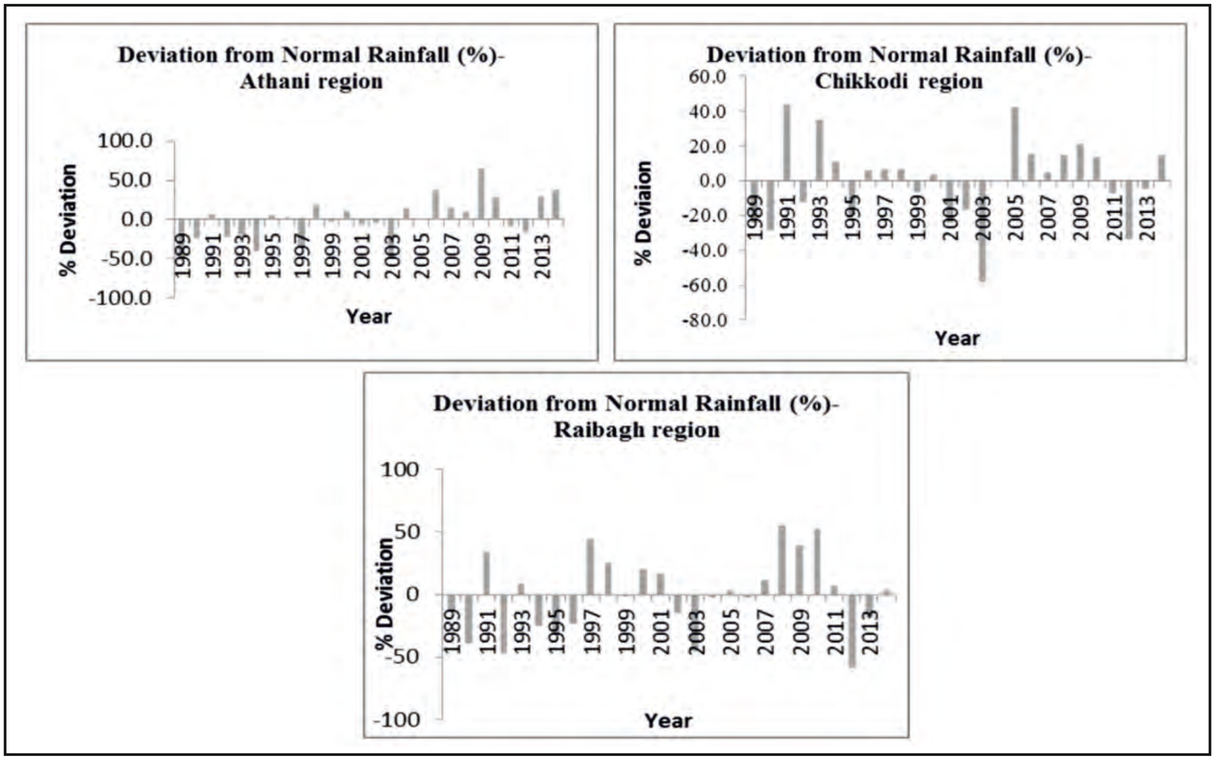


Fig. 6. Rainfall (%) deviation of study area

III. RESULTS AND DISCUSSION

Rainfall analysis is done to determine the amount of rainfall ultimately which is being done by calculating the following from the data collected from the year 1989 to 2014 for the taluks of Athani, Chikkodi, and Raibagh. The study was conducted on the mean and standard deviation, coefficient of variation, percentage contribution for each of the seasons (pre monsoon, SW monsoon, and NE monsoon), deviation from normal rainfall in percentage, and seasonal rainfall of this region. A graph for deviation from normal rainfall in percentage, annual rainfall, and seasonal rainfall is plotted in Fig. 6.

A. DEM Analysis

The Digital Elevation Model (DEM) is a digital three dimensional representation of the Earth's surface that consists of an ordered array of elevations and is referenced to a geographic coordinate system. DEMs are considered a critical source of information regarding land topography. In recent days, the advances in information technology and graphics visualization capabilities have led to the usage of DEM in many engineering fields such as mapping, landscaping, and GIS [11]. It also provides an elevation data which is useful for applications including hydrologic modeling and flood management planning [12].

A DEM is a digital three-dimensional representation of a topographic surface. It is considered an effective tool for terrain analysis considering attributes such as slope, flow direction, watershed etc. [13]. In hydrological modeling, DEM is an important input to generate flood hazard maps. The preciseness of watershed calculation depends mainly on the scale and precision of topographic maps. The difference in the scale of used maps causes simplified growth of stream orders and also changes the ration of lower order streams. [14]. The delineation of water shed is being done in the surface analysis. In this, a two-dimensional array of elevations is represented in squared cells (pixels) associated with each pixel. Water sheds are being delineated using ESRI's ArcGIS software 10.3 by computing the flow direction and using it in the watershed tool. DEM analysis is done for the study area as given in Fig.7. On August 1, 2010 this entry was published.

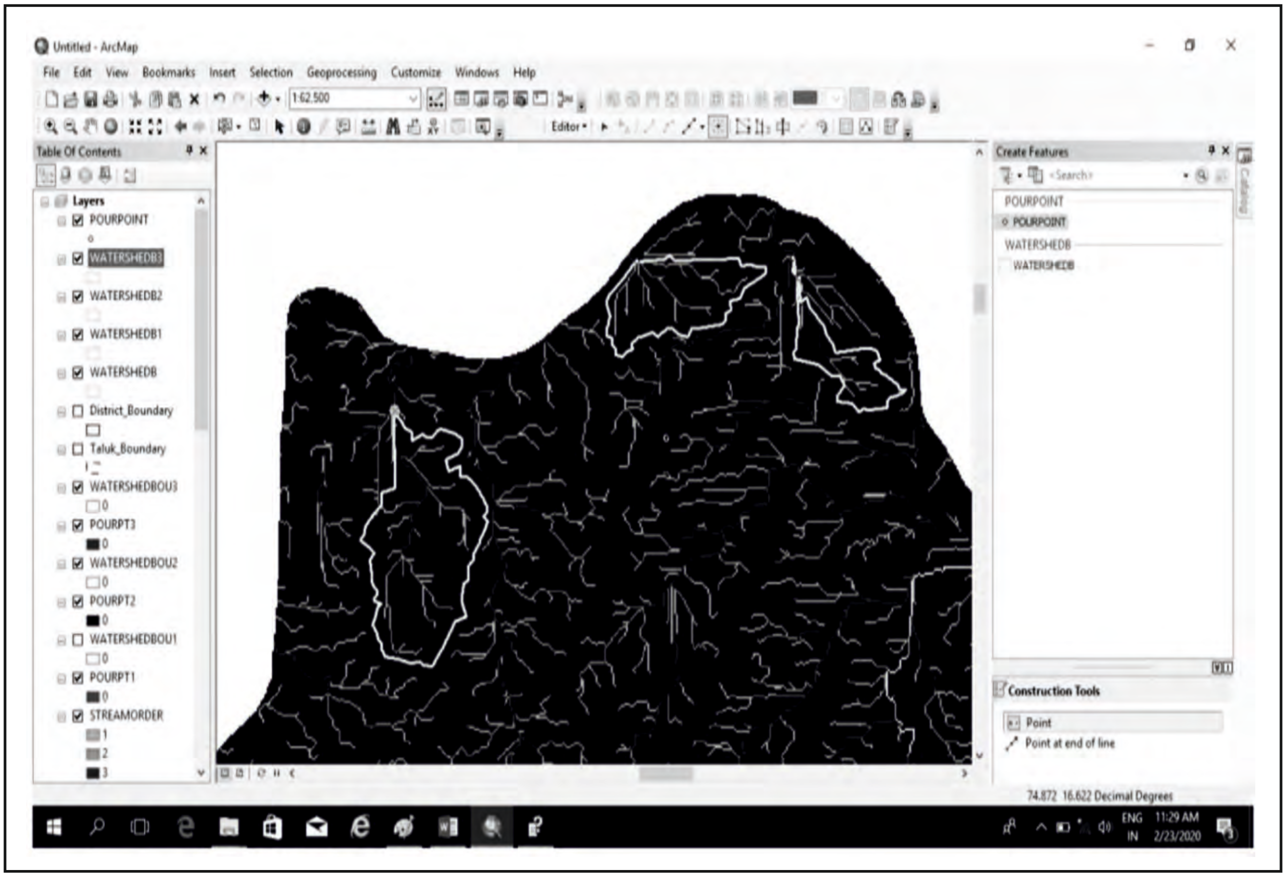


Fig. 7. DEM Analysis

B. Flood Vulnerability Mapping

Flood hazard risk zone mapping was done by obtaining the weighted map for each of the following parameters: drainage density, LULC, soil type, size of water shed, precipitation, and slope. Finally, after obtaining weighted maps for these parameters, all the maps were overlaid using weighted overlay analysis. Thus, we obtained a flood hazard risk zone map.

(i) Drainage density

A watershed with drainage density greater than or equal to 5 is considered as adequate drainage while with drainage density classes 1–5 and less than one as moderate and poor respectively. In this case, the drainage density obtained is moderate to poor. Higher weights are assigned for areas of poor drainage density and lower weights for areas with adequate drainage. By assigning these weights, drainage density map was created for each class using ArcGIS spatial analyst tools. The drainage density map prepared is shown in Fig. 8.

(ii) Land Use Land Cover (LULC)

The LULC data were collected from Karnataka State Natural Disaster Monitoring Centre (KSNDMC) and analyzed using ArcGIS spatial analyst tools. The area is classified as per land use classes as built up, mixed vegetation, plantations, forest, and water bodies. Land use types were grouped into different categories, weights were assigned to each class and the the map was prepared as shown in Fig. 9.

(iii) Soil Type

Soil maps were developed on the basis of infiltration capacity and types of soil found in the basin includes loamy and clayey. In this case two types of soils loamy soil with more infiltration capacity and clayey with less infiltration capacity. Weights are assigned to each soil classes and maps are prepared as shown in Fig.10.

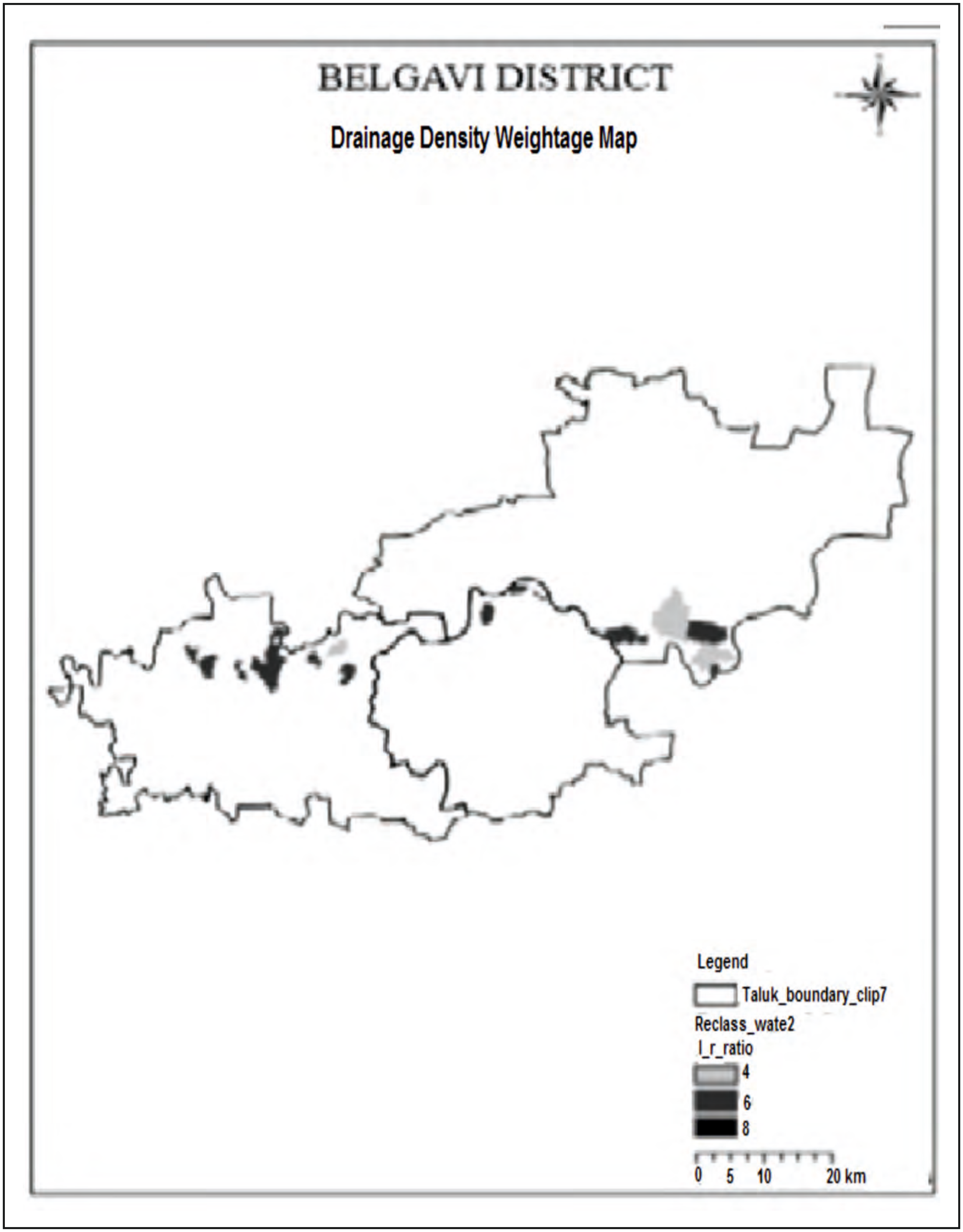


Fig. 8. Drainage density weightage map

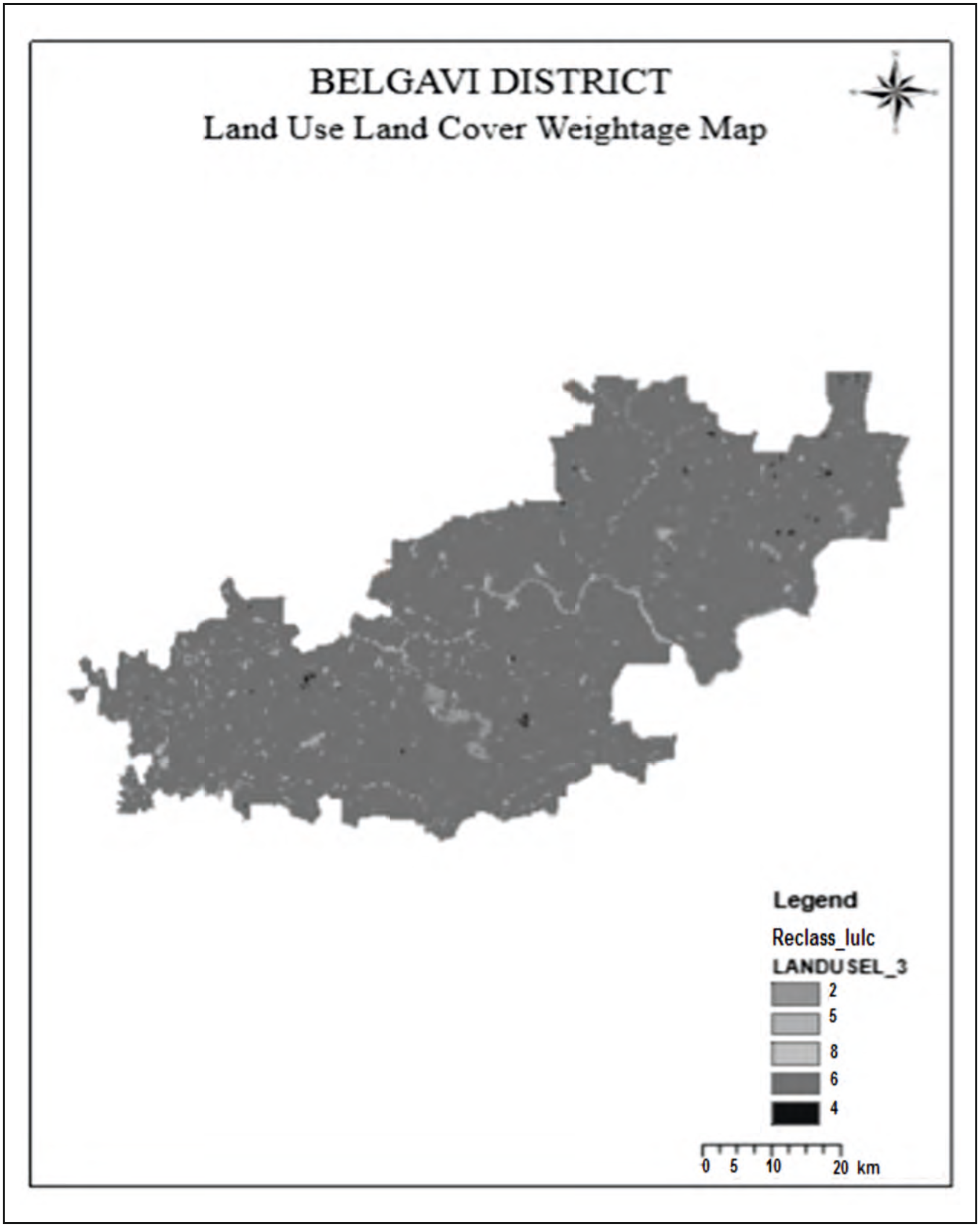


Fig. 9. Land Use Land Cover Weightage Map

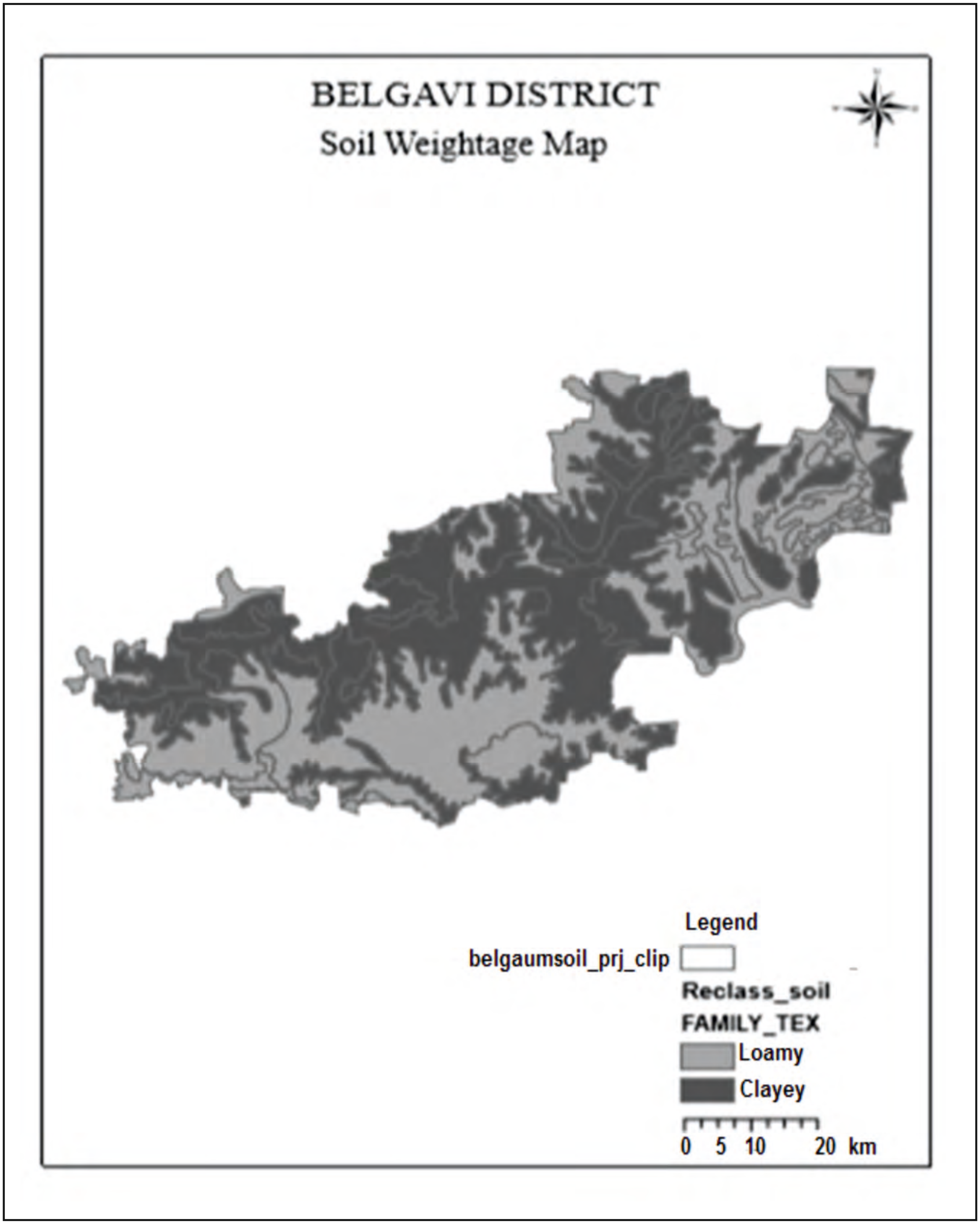


Fig. 10. Soil Weightage Map

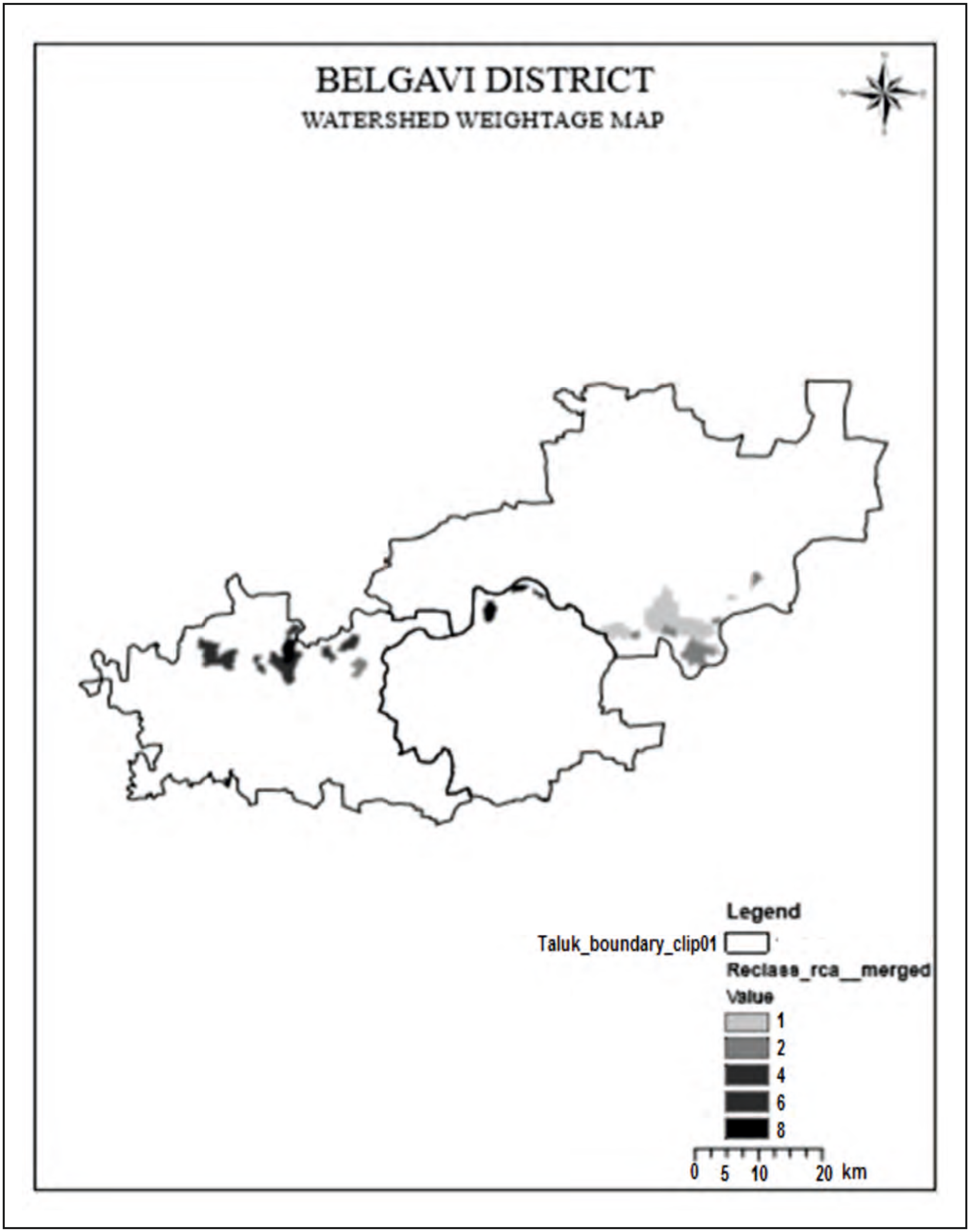


Fig. 11. Watershed Weightage Map

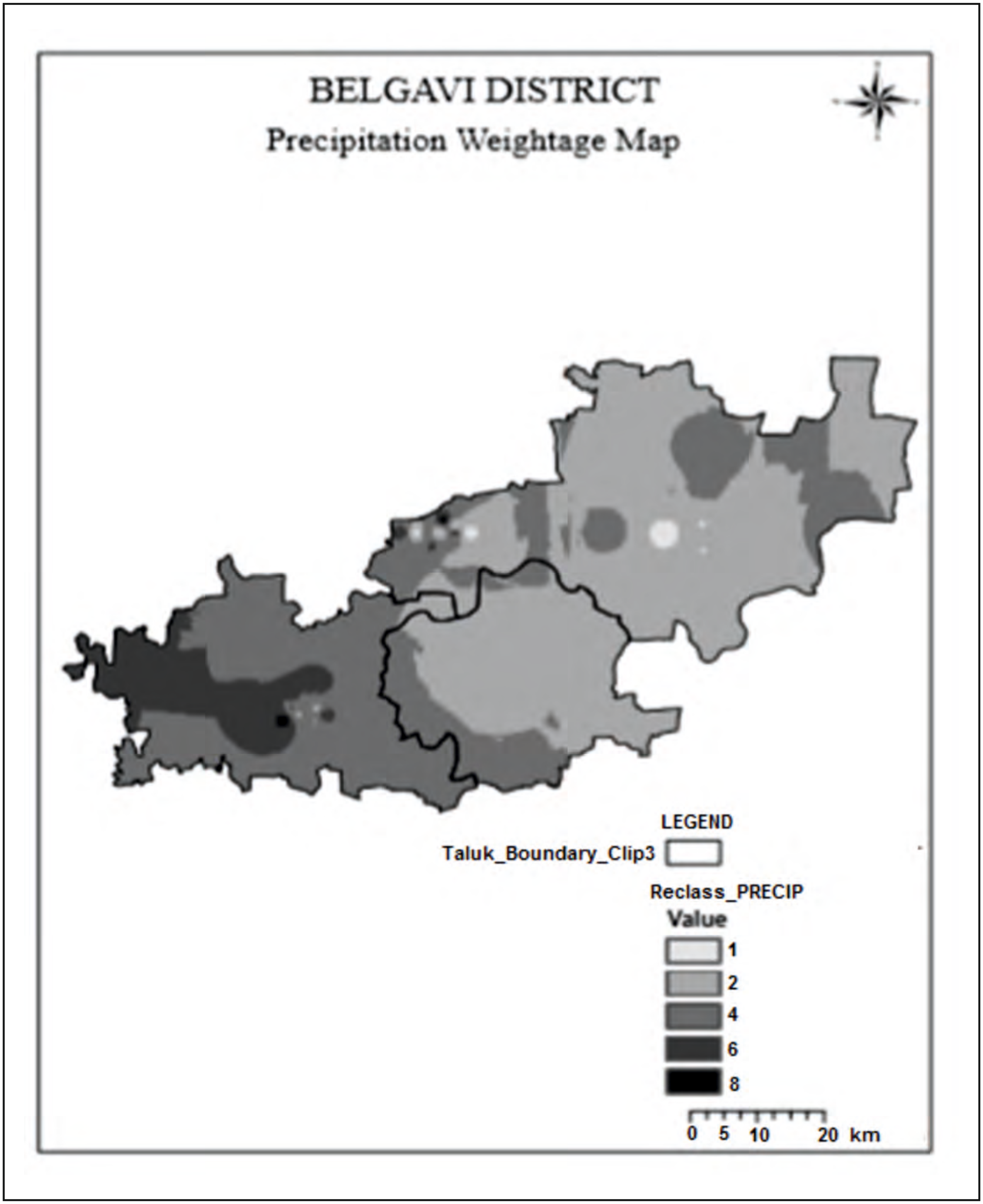


Fig. 12. Precipitation Weightage Map

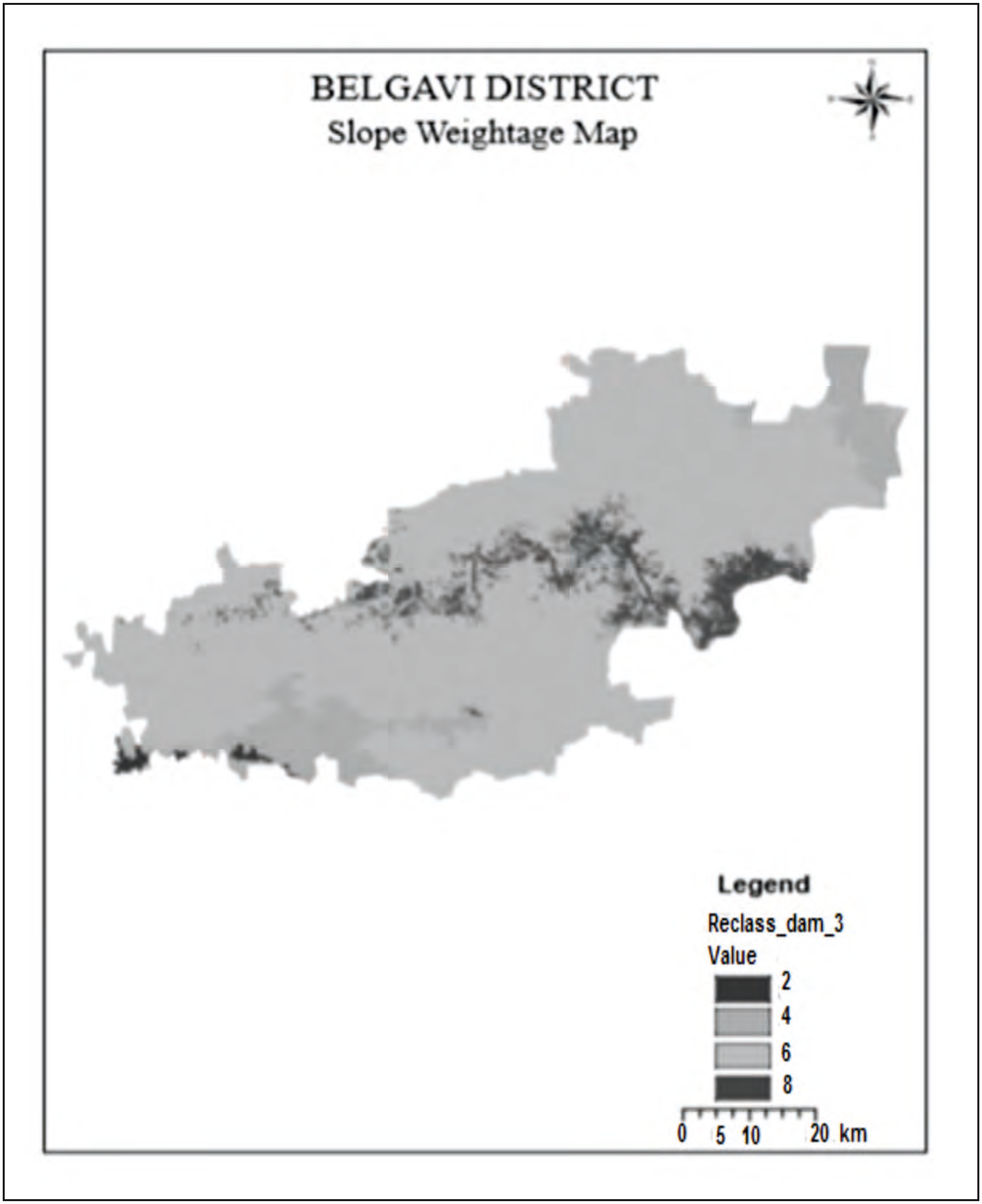


Fig. 13. Slope Weightage Map

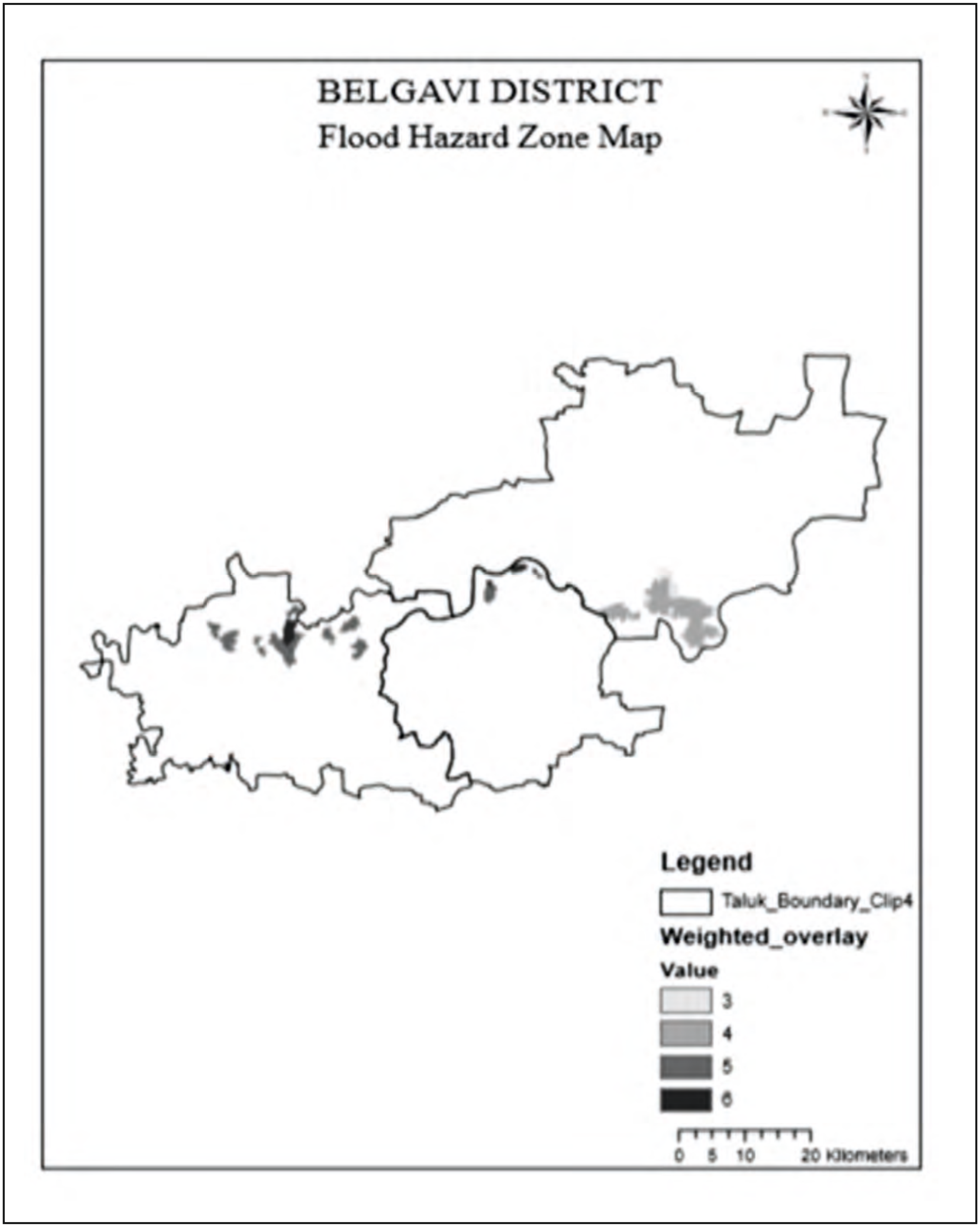


Fig. 14. Flood Hazard Zone Map

(iv) Watershed

Watersheds with higher drainage properties require longer duration runoff for a significant increase in water level to become a flood. Water sheds were delineated using ArcGIS 10.3 on the basis of third order stream separation. Each watershed area was computed, and maps were prepared by classifying watershed area on the basis of size. The size of the watershed in study area varies from 1 to 26 sq. km. Thus, watersheds having less area were assigned with more weightage and watersheds with higher area were assigned with less weightage. Weights assigned and the map prepared is given in Fig.11.

(v) Precipitation

The rainfall data of 25 years were collected for the study. The precipitation map was being prepared by Inverse Distance Weighted (IDW) method using spatial analyst tool in ArcGIS 10.3. The weightage given and the map for precipitation is given in Fig. 12.

(vi) Slope

The slope map was prepared using the DEM and slope generation tools in ArcGIS software. Slope angle of watershed ranges from 403–902, class having less value was assigned higher weightage due to flat terrain while lower weightage is given for maximum value due to relatively high run-off. The slope map prepared is shown in Fig.13.

C. Flood Hazard Risk Zone

The net probability of the occurrence of flooding in each flood hazard zone is estimated from the total sum of the weight of each contributing factor considered. All of these processes, the compilation of contributing factor maps, the overlaying of all maps, and the calculation of hazard areas were obtained by using the Raster Calculator in the ArcGIS Spatial Analyst tool. The factors which contribute to the floods are given in the table. The flood hazard map was prepared by giving suitable ranks (6 being highest; 1 being lowest) to these contributing factors, and the prepared map is shown in Fig. 14. Zones were numbered from 1 to 6 with a high risk of flooding and Zone 6 is considered as very high risk, zone 5 as high risk, zone 4 as moderate risk, and zone 3 as low risk, and below that as very low risk zones.

IV. CONCLUSION

Preparation of the Flood Hazard Zone Map of the Belgavi study area is done by using the application of geographic information systems. The flood vulnerability maps prepared in this study help the stakeholders identify areas that need to be given more attention to reduce flooding. From the study and analysis of the study area, the following mitigation measures are suggested. Early warning systems and relocating people in high-risk zones have to be taken when the rainfall increases beyond 100 mm. Considering the flood hazard risk zones mapping done in the study, high alert has to be declared in zones 6 and 5 if the rainfall intensity increases.

Construction activities within the river bed, i.e., 50 m from the river have to be restricted. Restoration of the river and water bodies by desilting not only reduces the risk of floods but can also control bank erosion. Diverting flood water into canals, pipes, reservoirs or other conduits helps mitigate flooding by allowing for a controlled release of water outside residential areas. All the buildings constructed in these regions shall be confined to the norms of the National Green Tribunal. Use planning and zoning is a non-structural flood mitigation activity and is an effective tool for reducing risk at the community level. Land-use planning implements public policy to direct the extent of land-use area.

AUTHORS' CONTRIBUTION

Under the guidance of Dr. Geena George, the Under Graduate student Bhavyashree M. conducted the studies on flood mapping and collected detail from KSDMA and developed the maps using Arc GIS software.

FUNDING ACKNOWLEDGMENT

The authors wish to thank Karnataka State Council for Science & Technology for funding and KSDMA for helping to collect the data required for the study.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

REFERENCES

[1] N. N. Kourgialas and G. P. Karatas, "Flood management and a GIS modelling method to assess flood-hazard areas—a case study," *Hydrological Sciences J.,* vol. 56, no. 2, 2011, doi: 10.1080/02626667.2011.555836.

[2] Z. W. Kundzewicz, "Flood risk and climate change: Global and regional perspectives," *Hydrological Sciences .J,*vol. 59, no. 1, 2014, doi: 10.1080/02626667.2013.857411.

[3] Z. W. Kundzewicz, "Changes in flood risk in Europe," 2012. Wallingford: IAHS Press.

[4] R. S. Ajin, R. R. Krishnamurthy, M. Jayaprakash, and Vinod, P. G., "Flood hazard assessment of Vamanapuram River Basin, Kerala, India: An approach using Remote Sensing and GIS techniques," *Advances Applied Sci. Res.*, vol. 4, no. 3, pp. 263–274, 2013. https://www.primescholars.com/articles/flood-hazard-assessment-of-vamanapuram-river-basin-kerala-indiaan-approach-using-remote-sensing--gis-techniques.pdf

[5] D. D. Konadu and C. Fosu, "Digital elevation models and GIS for watershed modelling and flood prediction – A case study of Accra Ghana," *Appropriate Technologies Environmental ProtectionDeveloping World*, pp. 325–332, 2009, doi: 10.1007/978-1-4020-9139-1_31.

[6] S. Bajabaa, M. Masoud, and N. Al-Amri, "Flash flood hazard mapping based on quantative hydrology. geomorphology and GIS techniques (case study of Wadi Al Lith, Saudi Arabia). *Arabian J. Geosciences,* 7, pp. 2469–2481, 2013, doi: 10.1007/s12517-013-0941-2.

[7] A. D. Pawar, J. Sarup, and S. K. Mittal, "Review of flood management techniques," paper presented at *Nat. Conf. Climate Change Sustain. Water Resour. Manage.* (CSWM-2015), 2015.

[8] D. G. Hadjimitsis, "Integrated remote sensing and GIS applications for sustainable watershed management. A case study from Cyprus," *Remote Sens. Environ. Integr. Approaches,* 2012.

[9] S. P. Aggarwal, P. K. Thakur, and V. K. Dadhwal, "Remote sensing and GIS applications in flood management," 2009. [Online]. Available: https://www.researchgate.net/publication/230660751_Remote_sensing_and_GIS_Applications_in_Flood_Management

[10] O. Singh, and M. Kumar, "Flood occurrences, damages, and management challenges in India: A geographical perspective,"*Arabian J. Geosciences*, Article no. 102, 2017, doi: 10.1007/s12517-017-2895-2.

[11] E. K. Forkuo, "Digital terrain modelling in a GIS environment," *Int. Arch. Photogrammetry, Remote Sens. Spatial Inf. Sciences*, 37(B2), pp. 1023–1029, 2008.

[12] K. McDougall, X. Liu, B. Badri, and A. Apan, "Evaluation of current DEM accuracy for condamine catchment," in *Proc. 8th Int. Symp. Spatial Accuracy Assessment Natural Resour. Environmental Sciences.* In: Accuracy in geomatics. World Academic Union, Liverpool, England.

[13] B. Huaxing, L. Xiaoyin, and G. Mengxia, "Digital terrain analysis based on DEM," *Frontiers Forestry China,* 1, 54–58, 2006, doi: 10.1007/s11461-005-0002-4.

[14] I. Elkhrachy, "Flash flood hazard mapping using satellite images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA)," *Egyptian J. Remote Sens. Space Sci.,* vol. 18, no. 2, pp. 261–278, 2015, doi: 10.1016/j.ejrs.2015.06.007.

About the Authors

Dr. Geena George has done M.Tech. (Environmental Engineering) and Ph.D. in Civil Engineering. She has 16 years of teaching as well as research experience and has published 20 journals papers and has presented 5 papers in international conferences. Her areas of interest include recycling of waste materials in concrete, water quality analysis, and watershed management.

Bhavyashree M. completed her degree in Civil Engineering and is now working with one of the reputed construction companies of Bengaluru.