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A Semi-Automated Approach for Mapping Geomorphology in Mountainous Terrain, Ferozpora Watershed (Kashmir Himalaya)

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Abstract: Mapping geomorphology in a mountainous terrain is very critical for understanding various land surface processes for their accurate quantification and prediction on different spatial and temporal scales. In the present study, geomorphological mapping was carried out in Ferozpora watershed of Jhelum using remotely sensed data supported by extensive field observations. Three approaches were adopted for mapping geomorphology of Ferozpora watershed. A geomorphological mapping model, Topographic Position Index (TPI), on Screen Image Interpretation (OSII) of satellite data and a hybrid approach utilizing information from TPI and OSII of satellite data were employed. Geomorphology of the area, mapped using the three approaches, was cross checked and verified with the ground data collected by extensively surveying the area and recording the geo-location of the geomorphological features using GPS. Overall, 12 different landforms were mapped which include Alluvial plains, Deeply incised streams, Glacial terrain, Highly dissected hills, Karewa, Fluvial landforms, Moderately dissected hills, Mountain ridges, River channel and U-shaped valleys. The study revealed that Hybrid approach, using inputs from TPI, OSII and field observations, is appropriate in mapping different geomorphological features in this topographically complex terrain with an overall accuracy of 91.53% as compared to TPI (45.56%) and OSII (77.82%) approaches. The study could be extrapolated to other parts of topographically complex Himalayan terrain so as to bring about a very high resolution geomorphological map of Himalayas which could aid policy makers, planners and earth scientists in better modelling the earth surface processes like soil erosion, landslides, hydrology, etc. in the region.

Keywords: Geomorphology, Himalaya, Geoinformatics, Topographic position index, Hybrid approach, On-screen image interpretation, Kashmir.

INTRODUCTION

Geomorphology is concerned with the study of surface features of earth's surface involving interpretative description of landforms, their origin and nature and mechanism of geomorphological processes(Strahler 1957; Blaszczynski 1997; Singh 1998). The recent advances in remote sensing technology have added new dimensions to the mapping of the geomorphological features from space (Bishop et al. 2012; Walsh et al 1998). Information extracted from remote sensing data provide a synoptic view of terrain features and enable mapping of inaccessible terrain in a timely and cost efficient manner (Baker 1986; Hengl and Reuter 2009; Pike 2000; Shroder and Bishop 2003). Remote sensing data, analysed in a GIS environment, is very useful in mapping geomorphology (Liang 2007; Smith and Pain 2009; Tarolli et al. 2009). An up-to-date geomorphological information of an area can serve as an important input for better understanding earth surface process like landslides, floods, erosion, glaciations (Sharma and Owen 1996; Naithani et al. 2001; Reddy and Maji 2003; Bolch et al. 2005; Kaushal and Singh 2006; Nainwal et al. 2008). Topographic information from satellites, called Digital Elevation Models (DEM), in recent years have been extensively used for various earth system science studies like morphological characterization (Fielding et al. 1994; Philip and Sah 1999), tectono-geomorphic studies (Dar et al. 2013; Dar et al. 2014), crustal deformation (Bilham et al. 1998; Lave and Avouac 2000) and seismic hazard mapping (Raj and Nijagunappa 2004; Sitharam and Anbazhagan 2007). Recently, geospatial models, with inputs from remotely sensed data mainly DEMs, have been developed for characterizing geomorphology of an area (Guisan et al. 1999; Jones et al. 2000). However, accuracy and validation of geomorphology derived from satellite platforms remains a major concern for geomorphologists.

As of now, there is not a single high resolution geomorphological map for Himalayas, although very coarse resolution geomorphological maps do exist for certain regions (Nakata 1972; Owen and Sharma 1998; Zeitler et al. 2001). In this context the present study aims to suggest a robust approach for accurate geomorphological mapping using cutting edge technology of geoinformatics. The main objective of the study was to develop an accurate, high resolution geomorphological map of the study area based on satellite data, geospatial model-TPI and extensive field observations.

STUDY AREA

Ferozpora is one of the major, left bank watersheds of Jhelum river covering an area of 454.62 km^2 located between 33°55'-34°18' N lat and 74°17'-74°43' E long. (Fig.1). Topographically, the watershed is dominated by plains in the lower portion and steep slopes and mountain ridges in the upper reaches. The elevation ranges from 1455-4538 m asl. A major stream, Ferozpora nallah, rises in the Pir-Panjal between the Jamianwali Gali (4084m) and the Apharwat (4143m) and after a course of about 51 km drains into the Wular lake. Ferozpura has a number of streams forming a well developed dendritic drainage pattern in the upper portion of catchment and more or less parallel drainage pattern in the lower portion. Geology of the area is dominated by the Quaternary group of Karewa deposits, alluvium, Triassic Limestone Formation, basic volcanic rocks of Panjal traps (Middlemiss 1910; Wadia 1975; Bhatt 1989). The Panjal Trap and agglomeratic slate rock formations together with a few bands of Gondwana shales and quartz slabs form the hard rock.

MATERIALS AND METHODS

Datasets

Multispectral satellite data of LandSat 8 (Path/Row: 148/36; Acquisition date: 25 October 2013) was used to map the geomorphology of the area. Additionally, CartoDEM with a spatial resolution of 30m was used as an input into TPI to generate the geomorphology of Ferozpora watershed. Besides, field observations, supported by GPS (Trimble Juno SB) with an error factor of ±4m, are used for accuracy assessment of geomorphological maps derived from different methods.

Methodology

Geomorphological mapping using TPI: TPI is a measure of where a location is in the overall landscape

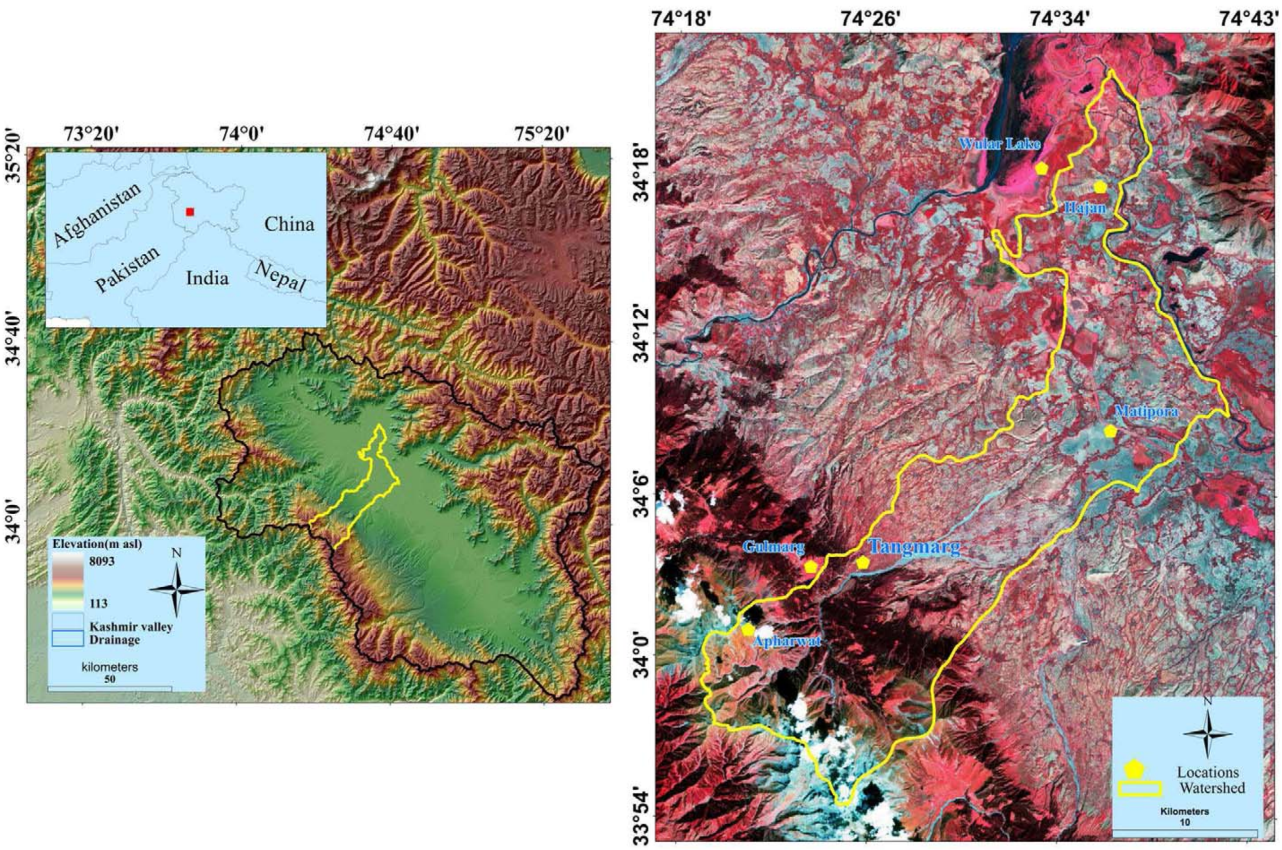

Fig.1. Location of study area (Ferozpora watershed)

(Jennesss 2006; Weiss 2001). TPI indicates the topographic position of a place and it may be a hilltop, or a valley bottom, or a slope, or an exposed ridge, or a flat plain, or other feature. TPI can be calculated for each cell in a grid by comparing the elevation of the cell to the mean elevation of the surrounding cells. TPI compares the elevation of each cell in a DEM to the mean elevation of a specified neighbourhood around that cell (Weiss 2001; Dar et al. 2012). Since the only input required is DEM, TPI can be readily generated almost anywhere. Positive TPI values represent locations that are higher than the average of their surroundings, as defined by the neighbourhood (ridges). Negative TPI values represent locations that are lower than their surroundings (valleys). TPI values near zero are either flat areas (where the slope is near zero) or areas of constant slope (where the slope of the point is significantly greater than zero). From the CartoDEM, slope was generated in a GIS environment, which acts as input to TPI. TPI classifies a landscape (Jenness 2006) into both slope position (i.e. ridge top, valley bottom, mid-slope, etc.) and landform category (i.e. steep narrow canyons, gentle valleys, plains, open slopes, mesas, etc.).

Geomorphological mapping using OSII: Using OSII of multispectral LandSat 8 satellite data on 1:30000 scale, different geomorphological features were delineated in a GIS environment. OSII method, supporting cognitive inputs from image analyst, was employed keeping in view its potential in delineating geomorphology and other surface characteristics in a topographically rugged terrain (Rashid et al. 2013). In order to delineate different geomorphological features of the area, standard false colour composite band combination was used (Xiuwan 2002).

Hybrid approach: The geomorphological maps generated from TPI and OSII were superimposed upon each other in GIS environment to generate a hybrid geomorphological map. Certain modifications were made in the hybrid geomorphological map, using OSII, so that a specific landscape feature is represented by single geomorphology.

Comparison and Accuracy Assessment: An important aspect of the present study was to compare the geomorphological maps derived from the three approaches. Comparison of the three geomorphological maps was done by extensive field observations. The field data served as a basis for accuracy assessment of the three approaches. Extensive field verification, involving a set of 248 sample points, well distributed over all the prevalent geomorphological units in the study area, was carried out in order to compare and assess the accuracy of geomorphological maps derived from the three methods. Stratified random sampling approach, involving sampling of different geomorphological features (Cottam and Curtis 1956) based on their spatial extents, was adopted to carry out the validation. Although, it would have been ideal to sample different geomorphological features based on their spatial extents, complex topography of the region did not allow it in certain areas of the watershed. The overall accuracy (Foody 2002) of the geomorphological maps was calculated using the following formula:

$$\rho = (n/N) * 100$$

where ρ is classification accuracy; ‘n’ is number of points correctly classified on image, and ‘N’ is number of points checked in the field.

RESULTS AND DISCUSSION

Geomorphological Mapping Using TPI

TPI modelling in GIS provided 8 different classes of the geomorphological features (Fig.2, Table 1). The dominant geomorphology is the alluvial plains while the least dominant class is midslope ridges, small hills in plains. Furthermore, the geomorphological features which are highlighted by TPI include deeply incised streams; midslope drainage, shallow valleys; mountain tops, high ridges; steep slopes; U-shaped valleys and upper slopes, plateaus.

Table 1. Distribution of different landforms based on TPI map

Geomorphology	Area (km^2)	% Area
Deeply incised streams	48.74	10.93
Midslope drainage, shallow valleys	2.28	0.51
U-shaped valleys	2.27	0.50
Plains	218.5	49.01
Steep slopes	123.5	27.69
Upper slopes, plateaus	2.05	0.46
Midslope ridges, small hills in plains	1.64	0.36
Mountain tops, high ridges	47.0	10.54

Table 2. Spatial extents of different geomorphologies as mapped from OSII approach

Geomorphology	Area (km^2)	% Area
Glacial terrain	73.05	16.37
Highly dissected Hills	42.08	9.43
Karewa	13.59	3.04
Fluvial terrain	111.40	24.97
Moderately dissected Hills	23.74	5.32
Alluvial plains	119.48	26.78
Piedmont slopes	44.96	10.08
River	16.48	3.69
Wetland	1.07	0.23

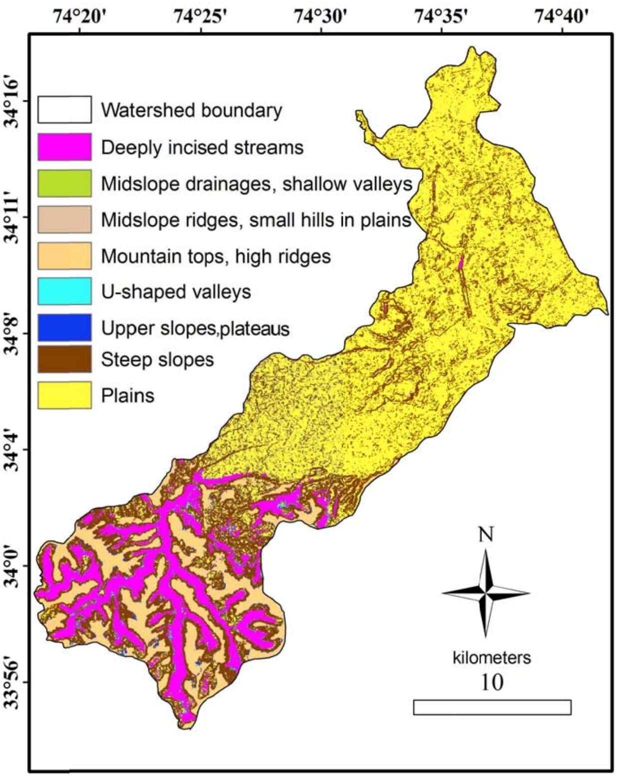

Fig.2. TPI-based geomorphological map of Ferzopora watershed

Table 3. Spatial extents of different geomorphologies as mapped from Hybrid approach

Geomorphology	Area (km^2)	% Area
Alluvial plains	120.77	27.07
Deeply incised streams	28.75	6.44
Glacial terrain	34.08	7.64
Highly dissected hills	19.68	4.41
Karewa	18.08	4.05
Fluvial terrain	101.44	22.74
Moderately dissected hills	14.92	3.34
Mountain ridges	51.01	11.43
River channel	22.81	5.11
Steep slopes	48.80	10.94
Wetlands	8.65	1.94

Geomorphological Mapping Using OSII

Using OSII of 1:30000 scale on LandSat 8 data, 9 different geomorphologies were mapped for Ferozpora watershed (Fig.3, Table 2). These include alluvial plain, glacial terrain, highly dissected hills, Karewa, fluvial landforms, moderately dissected hills, piedmont slopes, river channel and wetlands. As can be seen from the Fig. 3, OSII enables a user to delineate different geomorphologies as compared to TPI based approach. This could be because of the fact that OSII allows to use prior landscape knowledge and cognition on contrary to automatic approaches (Romshoo et al. 2011; Romshoo and Rashid

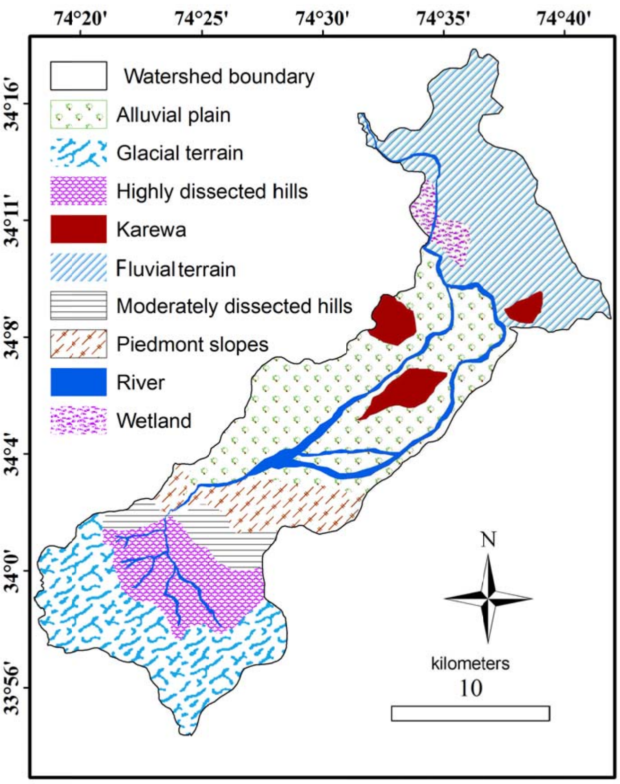

Fig.3. Geomorphological map of Ferzopora watershed based on OSII approach

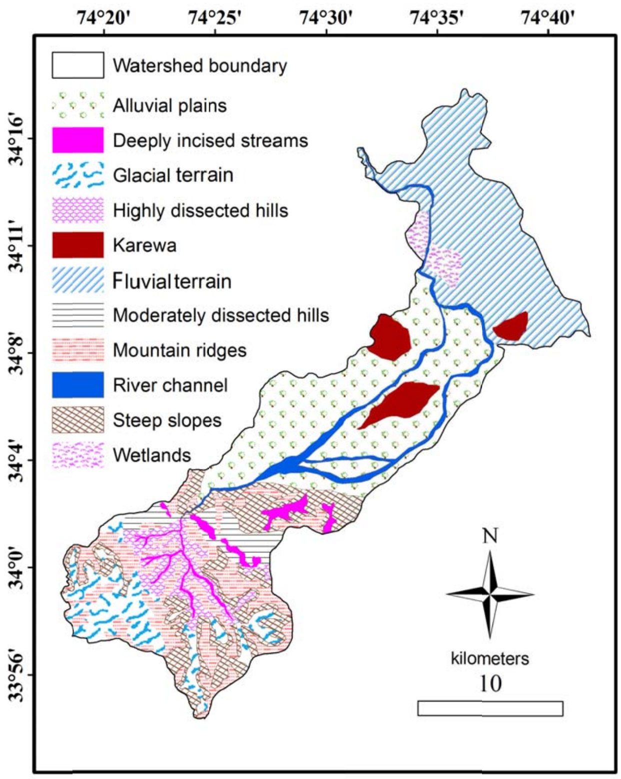

Fig.4. Geomorphological map of Ferzopora watershed derived from hybrid approach

Table 4. Accuracy assessment TPI, OSII and Hybrid approaches for geomorphological mapping

Geomorphology	Field Data	Mapping approach			Classification Accuracy		
		TPI	OSII	Hybrid	TPI	OSII	Hybrid
Deeply incised stream	40	23	25	36	57.50	62.50	90.00
Glacial terrain	3	0	3	3	0.00	100.00	100.00
Hills	18	9	13	17	50.00	72.22	94.44
Karewa	31	0	28	28	0.00	90.32	90.32
Midslope drainage, shallow valleys	4	3	0	3	75.00	0.00	75.00
Midslope ridges/Mountain tops	16	12	9	14	75.00	56.25	87.50
Fluvial terrain	25	0	22	22	0.00	88.00	88.00
Piedmont slopes	11	7	9	10	63.63	81.81	90.91
Plains / Alluvial Plains	40	35	36	39	87.50	90.00	97.50
River	20	0	18	18	0.00	90.00	90.00
Steep slopes	28	24	19	26	85.71	67.86	92.86
Wetlands	12	0	11	11	0.00	91.66	91.66
Overall Statistics	248	113	193	227	45.56	77.82	91.53

2010; Rashid et al. 2010). As can be seen from Fig.3, alluvial plains are still the dominant class, although some of the plains have been classified as fluvial landforms owing to their fluvial characteristics and proximity to the river courses.

Hybrid Approach

Hybrid Approach was adopted to produce a geomorphological map based on inputs from TPI and OSII techniques (Fang and Liang 2005). The information generated from TPI and OSII was intersected in a GIS environment to produce a hybrid map (Breunig 1999). Some of the features, like deeply incised streams, highly and moderately dissected hills, and steep slopes, were not identified from the OSII but were captured very well by TPI. Similarly using the OSII approach, certain features like fluvial landforms, Karewa, river channel, wetland, were better identified. From all this information, a hybrid map (Figure 4, Table 3) was produced which was very much representative of the ground conditions (Debevec et al. 1996; Lo and Choi 2004). Some of the geomorphological features as observed in the field are shown in Fig.5.

Accuracy Assessment

In order to validate the geomorphological maps derived

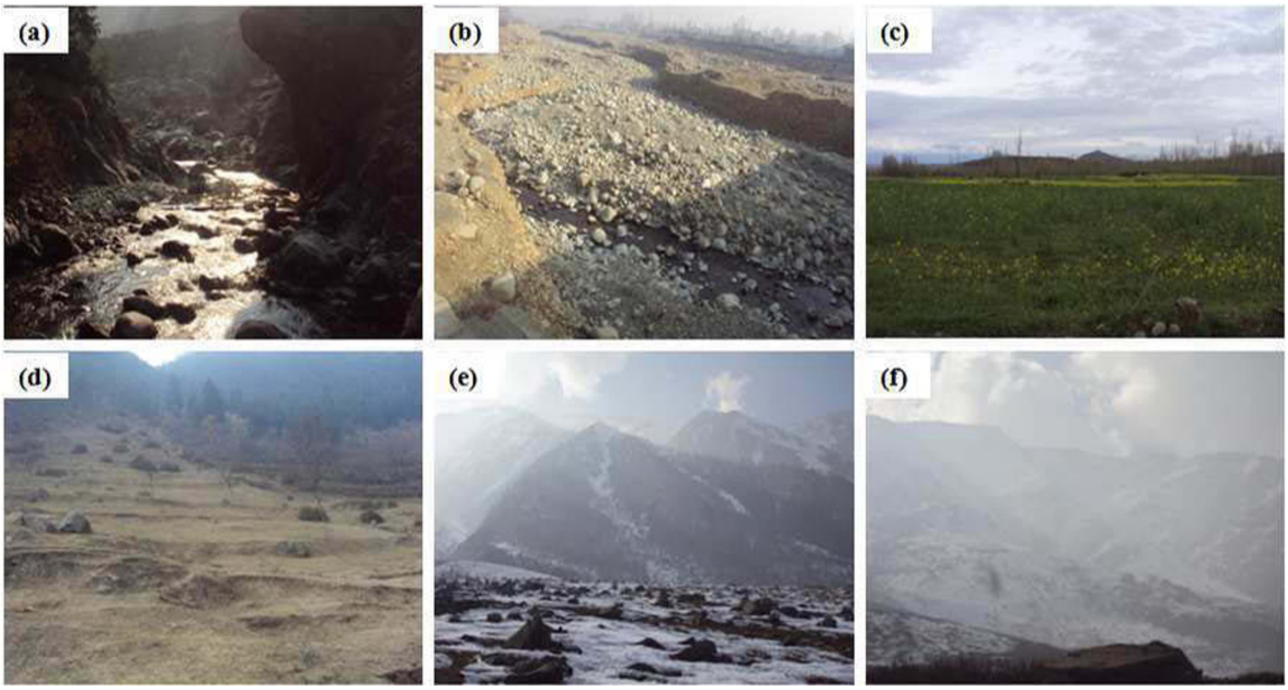

Fig.5. Various geomorphological features of Ferzopora watershed (a) Deeply incised stream; (b) River channel; (c) Alluvial plains; (d) Piedmont slopes; (e) Hills and (f) Glaciated terrain

from the three approaches, accuracy assessment was carried out to determine the best geomorphological map for Ferozpora watershed (Congalton and Green 2008). Maps from TPI, OSII and hybrid approaches were validated with field data and the accuracy of each map was estimated (Table 4). The field data was collected very extensively and comprised of 248 locations. The class-wise accuracies of geomorphological features were determined. It is clear from Table 4 that hybrid approach is the best method for mapping geomorphology in this mountainous Himalayan terrain.

It was observed that only a few classes of the landforms were mapped from both TPI and OSII approaches. However, the study demonstrated the suitability and robustness of the hybrid approach for geomorphological mapping as it reasonablly mapped the major and dominant landforms in the area with acceptable accuracies making best use of the strengths of both TPI and OSII approach (Friedl and Brodley 1997; Ozesmi and Bauer 2002).

CONCLUSION

In this study, the landforms of Ferozpora watershed were mapped to understand the extent and distribution of various geomorphological features. The study demonstrates the application of geoinformatics for geomorphological mapping in a complex mountainous terrain. For this study, an integrated approach, utilizing data from remotely sensed platforms along with extensive field observations in a GIS environment, was adopted to map the geomorphology of Ferozpora watershed. The landforms were mapped using TPI, OSII and hybrid approaches. Out of the 3 approaches employed, the Hybrid classification approach gave the best results yielding an accuracy of 90%. It is pertinent to mention here that medium spatial resolution remotely sensed data (~30m) was used in this study as high resolution data was not available. It is hoped that the work shall serve as a prototype for doing similar work in Himalayas elsewhere and in fact, can be taken forward by using high resolution remotely sensed data that will improve the details and accuracy of the geomorphological mapping in the mountainous region. The deliverables of this study can aid better understanding of the land surface processes where the information about geomorphology is a pre-requeiste for predicting and quantifying these processes. The availability of information on land surface processes like erosion, hydrologic, landslides etc can help the planners, earth scientists and policy makers to plan for optimal utilization of the land and water resources in the mountainous Himalayas.

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References

Baker, V.R. (1986) Introduction: regional landforms analysis. Short and Blair, pp.1-26.

Bhat, D.K. (1989) Geology of Karewas basin, Kashmir. Rec. Geol. Surv. India, no.122.

Bilham, R., Blume, F., Bendick, R., Gaur, V.K. (1998). Geodetic constraints on the translation and deformation of India: Implications for future great Himalayan earthquakes. Curr. Sci., v.74(3), pp.213-229.

Bishop, M.P., James, L.A., Shroder Jr, J.F., Walsh, S.J. (2012). Geospatial technologies and digital geomorphological mapping: Concepts, issues and research. Geomorphology, v.137(1), pp.5-26.

Blaszczynski, J.S. (1997) Landform characterization with geographic information systems. Photogrammetric Engineering and Remote Sensing, v.63(2), pp.183-191.

Bolch, T., Kamp, U., Olsenholler, J. (2005) Using ASTER and SRTM DEMs for studying geomorphology and glaciation in high mountain areas. New Strategies for European Remote Sensing, pp.119-127.

Breunig, M. (1999) An approach to the integration of spatial data and systems for a 3D geo-information system. Computers & Geosciences, v.25(1), pp.39-48.

Congalton, R.G., Green, K. (2008) Assessing the accuracy of remotely sensed data: Principles and Practices. CRC Press.

Cottam, G., Curtis, J. T. (1956). The use of distance measures in phytosociological sampling. Ecology, pp.451-460.

Dar, R.A., Chandra, R., Romshoo, S.A. (2013). Morphotectonic and lithostratigraphic analysis of intermontane Karewa Basin of Kashmir Himalayas, India. Jour. Mountain Sci., v.10(1), pp.1-15.

Dar, R.A., Romshoo, S.A., Chandra, R., Ahmad, I. (2014) Tectono-geomorphic study of the Karewa Basin of Kashmir Valley. Jour. Asian Earth Sci., v.92, pp.143-156.

Debevec, P.E., Taylor, C.J., Malik, J. (1996) Modeling and rendering architecture from photographs: A hybrid geometry- and image-based approach. *In* Proc. 23rd Annual Conf. on Computer graphics and interactive techniques (pp. 11-20). ACM.

Fang, H., Liang, S. (2005) A hybrid inversion method for mapping leaf area index from MODIS data: experiments and application to broadleaf and needleleaf canopies. Remote Sensing of Environment, v.94(3), pp.405-424.

Fielding, E., Isacks, B., Barazangi, M., Duncan, C. (1994) How flat is Tibet? Geology, v.22(2), pp.163-167.

Foody, G.M. (2002) Status of land cover classification accuracy assessment. Remote Sensing of Environment, v.80(1), pp.185-201.

Friedl, M.A., Brodley, C.E. (1997) Decision tree classification of land cover from remotely sensed data. Remote Sensing of Environment, v.61(3), pp.399-409.

Guisan, A., Weiss, S.B., Weiss, A.D. (1999) GLM versus CCA spatial modeling of plant species distribution. Plant Ecology, v.143(1), pp.107-122.

Hengl, T., Reuter, H.I. (Eds.), (2009) Geomorphometry: Concepts, Software, and Applications: Developments in Soil Science

Jenness, J. (2006). Topographic Position Index (tpi_jen. avx) extension for ArcView 3. x, v. 1.3 a. Jenness Enterprises.

Jones, K. B., Heggem, D. T., Wade, T. G. et al (2000). Assessing landscape condition relative to water resources in the western United States: a strategic approach. In Monitoring Ecological Condition in the Western United States (pp. 227-245). Springer Netherlands.

Kaushal, A., Singh, Y. (2006). Extraction of geomorphological features using radarsat data. Journal of the Indian Society of Remote Sensing, 34(3), 299-307

Lavé, J., Avouac, J.P. (2000) Active folding of fluvial terraces across the Siwaliks Hills, Himalayas of central Nepal. Jour. Geophys. Res., Solid Earth (1978-2012), 105(B3), pp.5735-5770.

Liang, S. (2007) Recent developments in estimating land surface biophysical variables from optical remote sensing. Progress in Physical Geography, v.31(5), pp.501-516.

Lo, C.P., Choi, J. (2004) A hybrid approach to urban land use/ cover mapping using Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images. Internat.Jour. Remote Sensing, v.25(14), pp.2687-2700.

Middlemiss, C.S. (1910) Revision of Silurian-Trias sequence in Kashmir. Rec. Geol. Surv. India, v.40(3), pp.206-260.

Nainwal, H.C., Negi, B.D.S., Chaudhary, M., Sajwan, K.S., Gaurav, A. (2008) Temporal changes in rate of recession: Evidences from Satopanth and Bhagirath Kharak glaciers, Uttarakhand, using Total Station Survey. Curr. Sci., v.94(5), pp.653-660.

Naithani, A.K., Nainwal, H.C., Sati, K.K., Prasad, C. (2001) Geomorphological evidences of retreat of the Gangotri glacier and its characteristics. Curr. Sci., v.80(1), pp.87-94.

Nakata, T. (1972) Geomorphic history and crustal movements of the foot-hills of the Himalayas.

Owen, L.A., Sharma, M.C. (1998) Rates and magnitudes of paraglacial fan formation in the Garhwal Himalaya: implications for landscape evolution. Geomorphology, v.26(1), pp.171-184.

Ozesmi, S.L., Bauer, M.E. (2002) Satellite remote sensing of wetlands. Wetlands Ecology and Management, v.10(5), pp.381-402.

Philip, G., Sah, M.P. (1999). Geomorphic signatures of active tectonics in the Trans-Yamuna segment of the western Doon valley, northwest Himalaya, India. International Jour. Appld. Earth Observ. Geoinfor., v.1(1), pp.54-63.

Pike, R.J. (2000) Geomorphometry—diversity in quantitative surface analysis. Progress in Physical Geography, v.24(1), pp.1-20.

Raj, K. G., Nijagunappa, R. (2004). Major Lineaments of Karnataka State and their Relation to Seismicity: A Remote Sensing Based Analysis. Jour. Geol. Soc. India, v.63(4), pp.430-439.

Rashid, I., Romshoo, S. A., Vijayalakshmi, T. (2013). Geospatial modelling approach for identifying disturbance regimes and biodiversity rich areas in North Western Himalayas, India. Biodiversity and Conservation, v.22(11), pp.2537-2566.

Rashid, I., Romshoo, S.A., Muslim, M., Malik, A.H. (2010) Landscape level vegetation characterization of Lidder valley using geoinformatics. Journal of Himalayan Ecology and Sustainable Development, 6, 11-24

Reddy, G. O., Maji, A. K. (2003) Delineation and characterization of geomorphological features in a part of lower Maharahstra metamorphic plateau using IRS-ID LISS-III Data. Jour. Indian Soc. Remote Sensing, v.31(4), pp.241-250.

Romshoo, S.A., Ali, N., Rashid, I. (2011) Geoinformatics for characterizing and understanding the spatio-temporal dynamics (1969 to 2008) of Hokersar wetland in Kashmir Himalayas. Internat. Jour. Physical Sci., v.6(5), pp.1026-1038.

Romshoo, S.A., Rashid, I. (2010) Potential and constraints of geospatial data for precise assessment of the impacts of climate change at landscape level. Internat. Jour. Geomatics and Geosciences, v.1(3), pp.386-405.

Savinder, S. (1998) Physical Geography. Prayag Publication, India.

Sharma, M.C., Owen, L.A. (1996) Quaternary glacial history of NW Garhwal, central Himalayas. Quaternary Sci. Rev., v.15(4), pp.335-365.

Shroder Jr., J.F., Bishop, M.P. (2003) A perspective on computer modeling and fieldwork. Geomorphology, v.53, pp.1-9.

Sitharam, T.G., Anbazhagan, P. (2007) Seismic hazard analysis for the Bangalore region. Natural Hazards, v.40(2), pp.261-278.

Smith, M.J., Pain, C.F. (2009) Applications of remote sensing in geomorphology. Progress in Physical Geography, v.33(4), pp.568-582.

Strahler, A.N. (1957) Quantitative analysis of watershed geomorphology. Eos, Trans. AGU, v.38(6), pp.913-920.

Tarolli, P., Arrowsmith, J.R., Vivoni, E.R. (2009) Understanding Earth surface processes from remotely sensed digital terrain models. Geomorphology, v.113, pp.1-3.

Wadia, D.N. (1976) Geology of India (p. 536). India: The English Language Book Society

Walsh, S. J., Butler, D. R., Malanson, G. P. (1998) An overview of scale, pattern, process relationships in geomorphology: a remote sensing and GIS perspective. Geomorphology, v.21(3), pp.183-205.

Weiss, A.D. (2001) Topographic positions and landforms analysis (Conference Poster). ESRI International User Conference., San Diego, CA July 9–13.

Xiuwan, C. (2002) Using remote sensing and GIS to analyse land cover change and its impacts on regional sustainable development. Internat. Jour. Remote Sensing, v.23(1), pp.107-124.

Zeitler, P.K., Meltzer, A.S., Koons, P.O. et al (2001) Erosion, Himalayan geodynamics, and the geomorphology of metamorphism. GSA Today, v.11(1), pp.4-9.

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