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Geographic information system for generating spatial pattern of natural streams: A case study in Nainital, India

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ABSTRACT
The study of natural streams in a location helps us to understand and manage many environmental problems such as land degradation, soil erosion, occurrence of flood, draught etc. Heavy rainfall areas suffer from very severe soil erosion, land degradation and flooding condition. In this study, a raster image of digital elevation map has been used to propose a methodology for creating sub-watershed boundaries and natural streams for more than 100 ha area basis using QGIS image processing software. To validate the results of generated natural streams, ground truthing was performed by direct investigation in the study area from 2 December 2014 to 4 December 2014 at 10 different random locations to determine locations of streams and water bodies. Supervised classification was done with seven locations data to create an image over the study area using maximum likelihood classifier algorithm and three locational data have been used for qualitative accuracy assessment by visual evaluation. Quantitative accuracy assessment has also been performed by preparing a confusion matric between QGIS generated streams and image based on ground truth data in ENVI image processing software. Overall classification was performed for the image of 3 Dec 2014. According to producer's accuracy, consumer's accuracy, overall accuracy and Kappa coefficient, it was found that generated streams are accurate over Nainital district of Uttarakhand, India.
Keywords: Sub-watershed boundaries, Natural streams, Geographic information system, Accuracy assessment, Confusion matrix

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Introduction

Natural streams play major role to sustain the life in any watershed and their quality control is the big agenda. Quality of a stream degrades because of soil erosion, land degradation, flood, rapid urbanization, expansion of agriculture and deforestation. These environmental disturbances have changed the land use pattern and occur directly or indirectly, by human beings [14-16]. Many projects have been launched in last three decades by Indian government to improve and to maintain the quality of Ganga river and its tributaries such as Ganga action plan (1986), Ganga *gram yojana* projects (2016) etc. However, such projects can be improved after considering their implementation on sub-basin level instead of large scale basin.

Study of natural streams in watershed provides complete information about the flow of water and water storage structures within the watershed and helps to locate water quality control structures [17, 25]. The latest advances in remote sensing technology have provided very useful methods of surveying, identifying, classifying and monitoring several forms of earth resources. Remote sensing data provide accurate, timely and real time information on various aspects of the watershed such as land use/cover, physiographic, soil distribution, drainage characteristics etc. [26, 27]. Many studies states that RS and GIS techniques are of great use in characterization [1-12], surface temperature estimation [6, 19, 21], soil, plant and environmental parameters estimation [7, 24], watershed prioritization [11], study of coal fires [22], object detection [4, 26, 30, 31, 28, 23, 13], soft computing [30], water quality control [20, 1], soil erosion control [5], disaster management [9], spatial modelling [2] for maintaining and improving soil water productivity of watershed. The objectives of this study are (i) To present a methodology of generating sub-watershed boundaries and natural streams on sub-watershed level over Nainital district of Uttarakhand state, India and (ii) To validate results by quantitative accuracy assessment using confusion matrix.

MATERIAL AND METHODS

Study area and data collection

Nainital district (Fig. 1.) covers an area of 3422 square kilometers and located between Longitude 80°14'E to 78°80' E and Latitude 29° 05' N to 29°05'N. The temperature varies from -5.4 °C to 40.2 °C. The average rainfall in the district is 1407mm. This region is full of hills, vallies, plains, lakes, mountains, evergreen forests, barren rocky areas, scrub lands and built up lands. Snowfall, heavy precipitation, land slide and soil erosion are common environmental disturbances in this region. These are the reasons which force us to study flow pattern and location of water storage body in this region, so that one can concentrate on their remediation.

Ground truth data is that source or reference which is assumed to be 100 % correct in accuracy assessments. In this study, ground truth data is locational information of natural streams and have been collected carefully by conduction field survey in Nainital district from 2 December 2014 to 4 December 2014 at 10 random locations (Table 1), consistently with vigilant quality control. Seven locational data have been used for generating natural streams and water bodies map using maximum likelihood classifier algorithm in supervised classification and remaining three have been used for cross checking of classified image using quantitative accuracy assessment by visual evaluation. An image of 3 December 2014 of Nainital district obtained from LANDSAT-8 satellite (30 m spatial resolution) was used for this classification process and working in software was started after completing ground truthing of field survey.

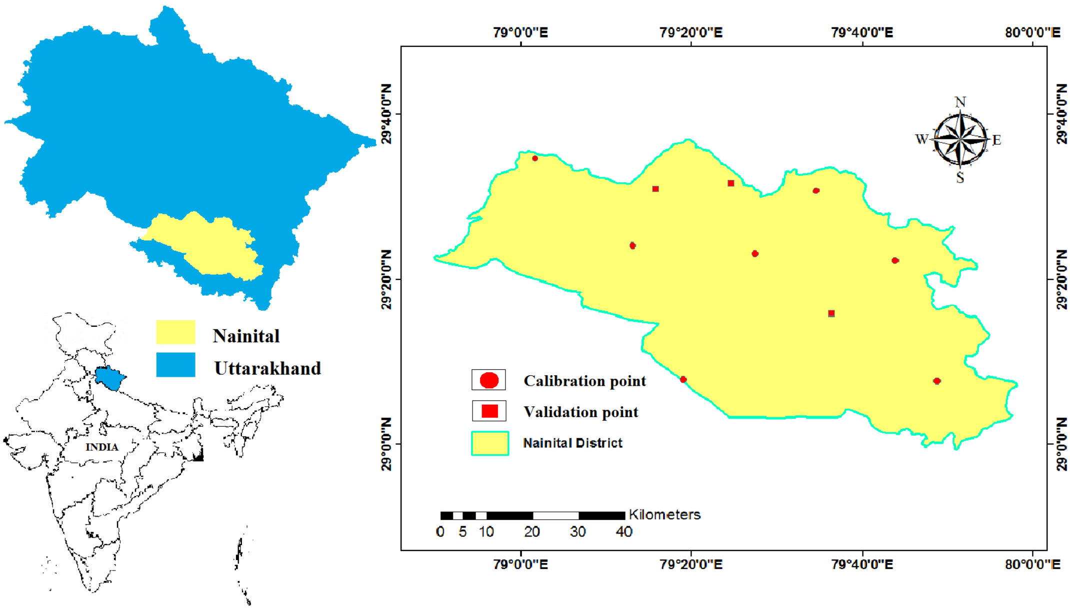

Fig. 1. Location map of Nainital

Table 1. Co-ordinate of ground truth points obtained by field survey

Co-ordinate		Point used
Longitude	Latitude	
79°03'03.6''	29°34'22.8''	Calibration
79° 13' 12.0''	29°24'14.4''	Calibration
79° 16' 26.4''	29°32' 06.0''	Validation
79°19'33.6''	29° 07'30.0''	Calibration
79°23'52.8''	29°31' 08.4''	Validation
79°27'25.2''	29°23'27.6''	Calibration
79°35' 06.0''	29°30' 43.2''	Calibration
79°36'18.0''	29°16' 01.2''	Validation
79°42'54.0''	29°22'30.0''	Calibration
79°48'36.0''	29°07'48.0''	Calibration

Digital elevation map (DEM)

It is often used as a generic term for digital surface maps (DSMs) and digital terrain map (DTMs)and only representing height information without any further definition about the surface [8]. DEM is a rectangular grid whereas DTM is a three-dimensional model; however DEM is a subset of DTM. It could be acquired through techniques such as photogrammetry, lidar, land surveying, remote sensing technique etc. [18]. Common uses of DEMs include are extracting terrain parameters for geomorphology, modeling water flow for hydrology or mass movement, modeling soils wetness, Creation of relief maps, rendering of three dimensional visualizations, rectification of aerial photography or satellite imagery, terrain analysis in geo-morphology and physical geography, geographic information systems, surface analysis etc. In this study, DEM of advanced space borne thermal emission and reflection radiometer (ASTER)with 30m spatial resolution, has been used in two image procession software viz. QGIS 2.18.4 and ENVI 4.7.QGIS has been used for sub-watershed and natural stream delineation whereas ENVI has been used for accuracy assessment.

Accuracy Assessment

Accuracy assessment determines the quality of the information derived from remotely sensed data [3]. It can be either qualitative or quantitative; in qualitative assessment, we determine if a map"looks right" by comparing what we see in the imagery with what we see on the ground; however quantitative assessment attempts to identify and measure remote sensing-based map error. In such assessments, we compare map data with reference data. In this study quantitative assessment has been performed using confusion matrix which assesses accuracy for each class as well as for the whole image; this includes errors of commission and errors of omission because we must accept some level of error as a trade-off for the cost savings of remotely sensed data. A confusion matrix contain following terms:

(a) **Producers accuracy (PA)**

It is the probability of a reference pixel being correctly classified

(b) Consumer's (user's) accuracy (CA)

It is the probability that a pixel classified on the image actually represent that category on the ground

(c) **Error of omission (EO)**

It is proportion of observed features on ground that are not classified and given by:

$$EO\ (\%) = 100 - PA\ (\%)$$

(d) **Error of commission (EC)**

It is proportion of observed features on ground that is wrongly included in classification and given by:

$$EC\ (\%) = 100 - CA\ (\%)$$

(e) Kappa coefficient

It reflects the difference between actual agreement and the agreement expected by chance. It is given by:

$$K = \frac{observed\ accuracy - chance\ agreement}{1 - chance\ agreement}$$

Observed accuracy is determined by diagonal in confusion matrix whereas chance agreement incorporates off-diagonal

(f) **Overall accuracy**

It is the ratio of correct pixels to the total pixels in the classified image and shows overall accuracy of the classification.

RESULTS AND DISCUSSION

Delineation of watershed boundaries and Natural streams

To delineate the boundaries of sub-watersheds and to locate natural streams of the Nainital district, QGIS 2.18.4 software has been used (Fig.2 through Fig. 5). A digital elevation map covering Nainital district boundary has been opened in *QGIS* window. A*New Mapset* has been created and saved as a folder in any drive of the window and default *GRASS* region was selected as current region of digital elevation map.*WGS 84* coordinate reference system has been used for whole delineation process. Delineation has been performed in "*Plugins/Grass/Open GRASS tools*" (Fig. 2).Modules have been performed in following manner *r.in.gdal.qgis/r.watershed* (Fig. 2 and Fig. 3). Area of each sub-watershed was selected asat least 100 hectare or near about 1111 cells for each basin (Fig. 3) i.e. micro watersheds were not delineated. When delineation process was successfully finished, sub-watershed and streams of Nainital district were extracted from whole map in *Raster/extraction/clipper*pop-up window (Fig. 4).

Although, Nainital district is not a watershed so boundary of this district can not been be considered as watershed boundary. Each and every sub-watershed is containing at least single stream and a single outlet (Fig. 5), which demonstrate that delineation of watershed and natural streams are accurate.

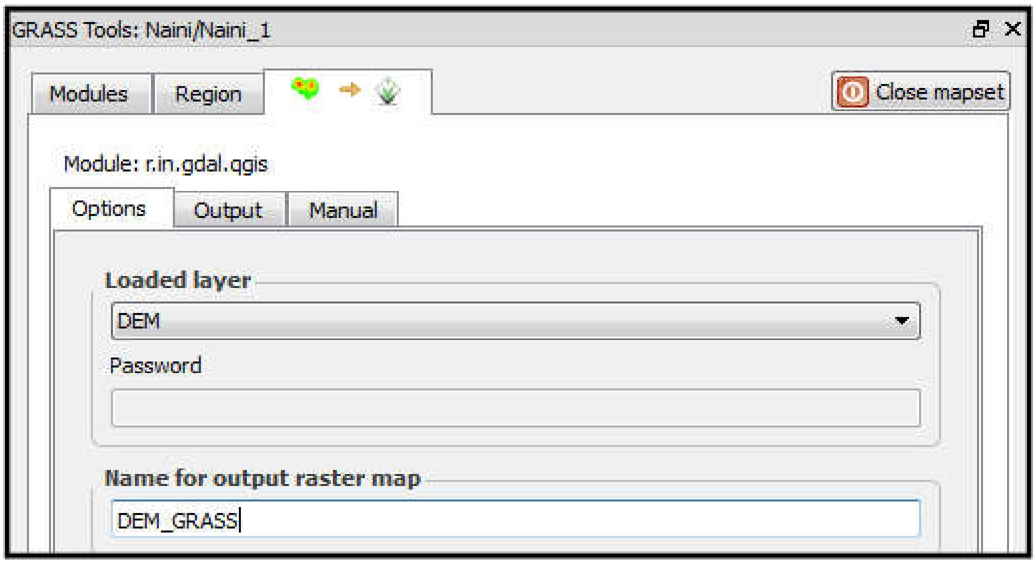

Fig. 2. Opening DEM image in GRASS window

Qualitative and quantitative accuracy assessment for natural streams and water bodies

Qualitative accuracy assessment was performed by visual evaluation of three validation points over classified image of natural streams and water bodies (Fig. 6) and it was visualized that all three points are very close to the natural water bodies which demonstrate that classification using maximum likelihood is accurate. In quantitative accuracy assessment, a confusion matrix (Table 2) was prepared between ground truth based classified image (Fig. 6) and natural stream map generated (Fig. 7) by QGIS software. From confusion matrix, it was found that correct. pixels of the study area is 3625257 out of total pixels of 3802223, which shows that overall accuracy of classification is 95.35 %.

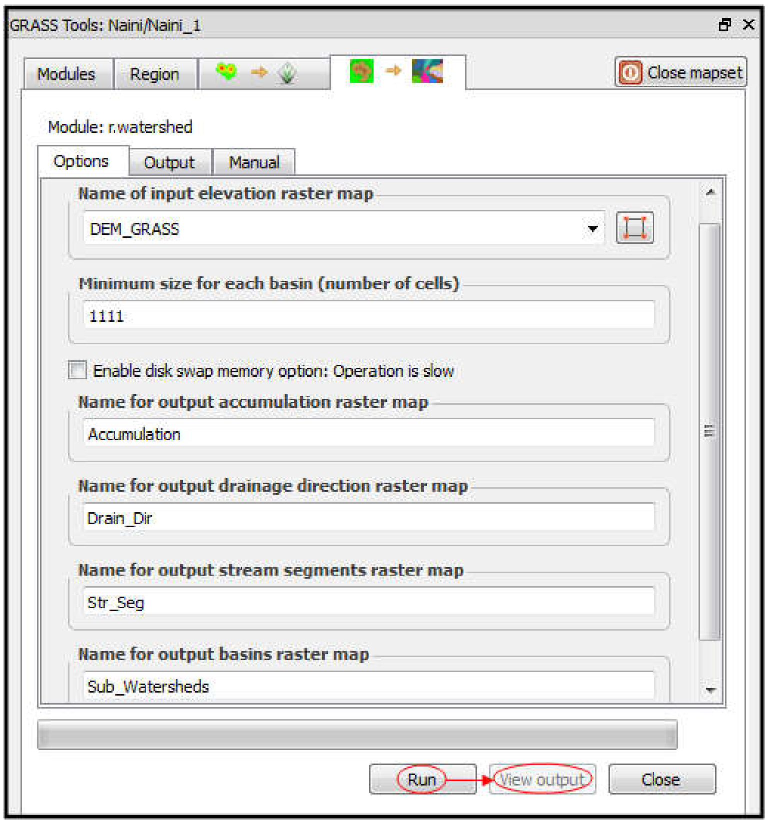

Fig. 3. Filling up required field before delineation of sub-watersheds and their streams

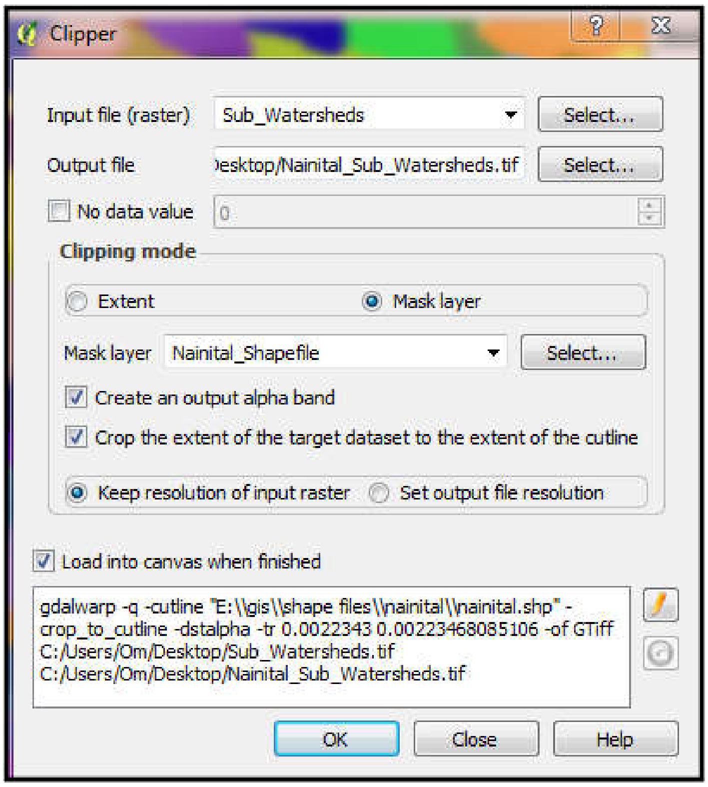

Fig. 4. Extracting sub-watershed of Nainital district from delineated image

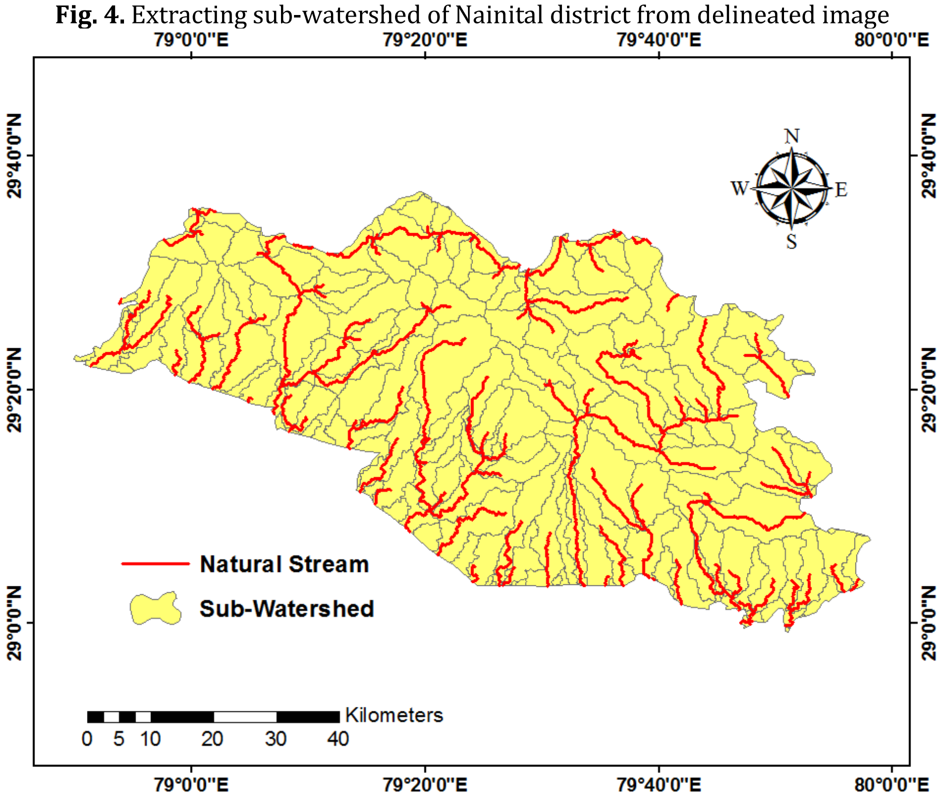

Fig. 5. Sub-watershed boundaries and natural streams of Nainital district

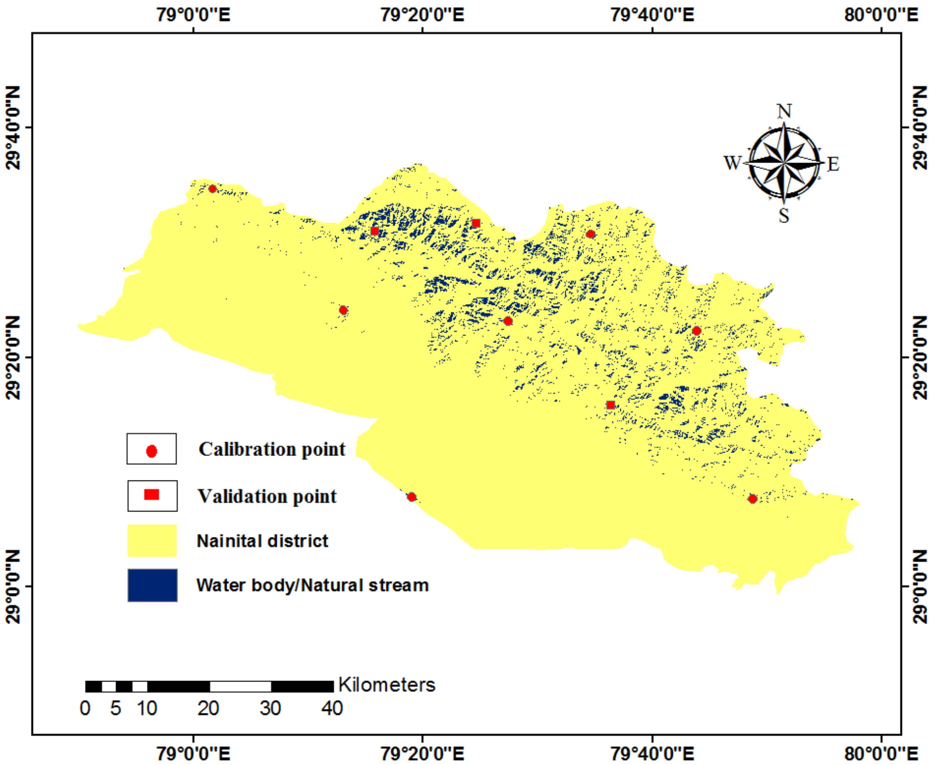

Fig.6. Ground truth based classified image using maximum likelihood classifier algorithm

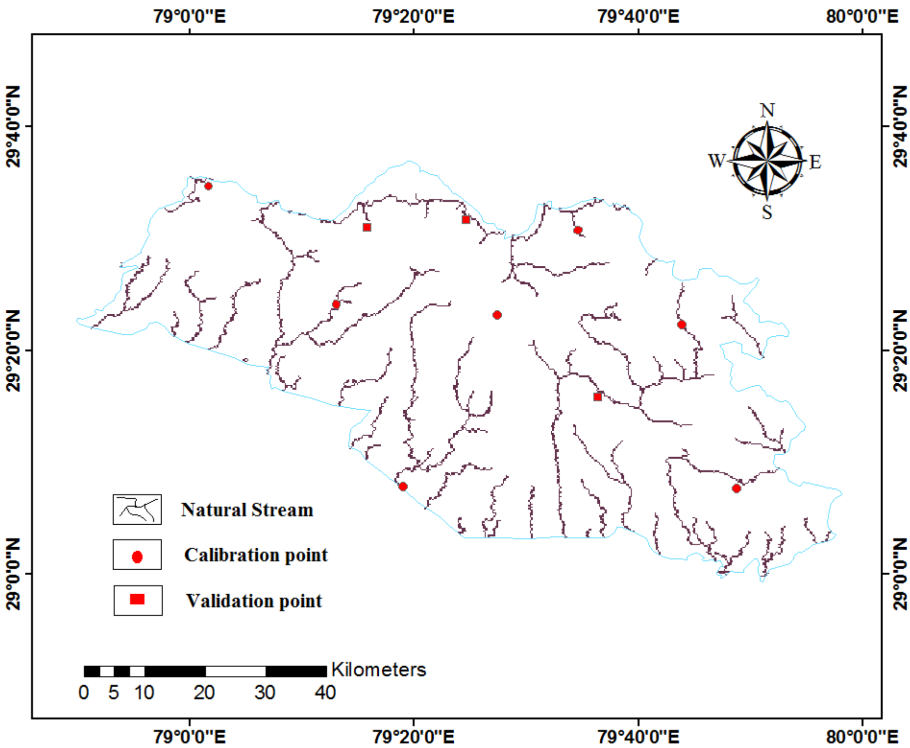

Fig.7. Natural stream raster map generated by QGIS software

Table 2. Confusion matrix between ground truth based classified image and generated natural stream map

Generated image (Pixels) / Ground truth (Pixels)	Natural stream/Water body	Sub-watershed	Total	PA	EO
Natural stream/Water body	105031	72857	177888	59.04 %	40.96 %
Sub-watershed	104109	3520226	3624335	97.13 %	2.87 %
Total	209140	3593083	3625257		
CA	50.22 %	97.97 %			
EC	49.78 %	2.03 %			

Note: PA, CA, EO, EC represent producer's accuracy, consumer's accuracy, error of omission and error of commission, respectively. Area of each pixel shows 900 sq. meter

Observed accuracy, chance agreement and kappa coefficient are 0.9535, 0.9034and 0.5191, respectively, which shows that there is 51.91 % better agreement than by chance alone. Producer's accuracy, consumer's accuracy, error of omission and error of commission was obtained as 59.04 %, 50.22 %, 40.96 % and 49.78 %, respectively, which demonstrate that 59.04 % of a reference pixel being correctly classified, a classified pixel on the imagerepresents50.22 % that category on the ground, 40.96 % observed features on ground are not classified and 49.78 % observed features on ground are wrongly included in classification.

CONCLUSIONS

In this study, delineation of natural streams and sub-watershed boundaries was performed using DEM map, LANDSAT 8 imagery of 3 Dec 2014 and ten location data of natural streams and water bodies within the study area. QGIS software has a very useful *GRASS* tool which was used for overall delineation. Ground truth based image was created by supervised classification for seven locational data of natural streams and remaining three data were used for visual evaluation of classification. Visually, it was found that maximum likelihood classifier algorithm classifies the ground truth based image accurately. Natural streams locations obtained by QGIS software were validated with ground truth based image using confusion matrix and it was found that the presented methodology is accurate to generate natural streams with 95.35 % overall accuracy. Observed accuracy, chance agreement, kappa coefficient, producer's accuracy, consumer's accuracy, error of omission and error of commission were found as 0.9535, 0.9034, 0.5191, 59.04 %, 50.22 %, 40.96 % and 49.78 %, respectively, from confusion matrix. Such methodology is useful for watershed planning and management, construction of water quality control projects and planning of water harvesting structures.

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