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LANDSLIDE SUSCEPTIBILITY MAPPING OF BHANDARDARA DAM CATCHMENT AREA, USING RS AND GIS TECHNIQUES

Bansode Chandrakant Mogalraw

Assistant Professor, Department of Geography, Arts, Science and Commerce College, Rahata, Dist. Ahmednagar, Maharashtra (India).

ABSTRACT

Landslide is a major natural hazard that cause billions of dollars damage and thousands of deaths and injuries each year. Developing countries suffer the most, where 0.5% of the gross national product per year has been lost due to landslides. Present study tries to analyze landslide occurrences in Bhandardara dam catchment area in Ahmednagar district of Maharashtra state. Various remote sensing and GIS techniques have been used to delineate landslide susceptibility for study area such as supervised classification, weighted overlay, ranking method etc. Various data have been used namely, SOI toposheets, satellite imagery, digital elevation model etc for better results. The layers are prepared using QGIS open source software. The study has revealed some important information regarding landslide susceptibility. 12% of the area has very high landslide susceptibility; this area contains 44.4% of the observed landslides. 18% of the study area has high landslide susceptibility and contains 16.9% of the observed landslides.38% of the study area has low landslide susceptibility, but still contains 25.3% of the observed landslides. The study reveals that the surrounding region of Bhandardara dam has very high susceptibility for landslides because of steep and unstable slopes. There is need of serious measures to minimize landslide occurrences.

KEYWORDS Landslide Susceptibility, Remote Sensing, GIS, DEM, Weighted Overlay.

INTRODUCTION

The study area is situated in the north-western part of Ahmednagar district. Landslides occur frequently in this area and seriously affect local living conditions. Therefore, spatial analysis of landslide susceptibility in the mountainous region of the study area is important. Hence, this study focuses on a particular mountainous region of about 262.7 km2 in Ahmednagar district. In the study area, recently some cases of landslides have been observed. In order to explain these landslides, various factors, i.e. slope, aspect, landuse, geomorphology, soil, elevation, distance from streams or rivers, were selected and prepared in GIS for landslide susceptibility mapping. The term natural hazard implies the occurrence of a natural condition or phenomenon, which threatens or acts hazardously in a defined space and time (Varnes, 1984; Alcantara-Ayala, 2002). In this sense, a natural hazard has been expressed as “an element in the physical environment harmful to man” (Burton and Kates, 1964), “a harmful interaction of people and nature” (White, 1973), “the probability of occurrence of a potentially damaging phenomenon” (UNDRO, 1982), or as “a physical event which has an harmful impact on human beings and their environment” (Alexander, 1993). In natural systems, landslides are recognised as one of the most significant “natural hazards” in many areas throughout the world (Crozier and Glade, 2005). Globally, landslides cause billions of dollars in damage and thousands of deaths and injuries each year. Developing countries suffer the most, where 0.5% of the gross national product per year has been lost due to landslides, and 95% of landslide disasters have been recorded in developing countries (Chung et al., 1995). The International Landslide Centre of the University of Durham recorded in 2007 that the most seriously affected country was China with 695 landslide-induced deaths, followed by Indonesia (465), India (352), Nepal (168), Bangladesh (150) and Vietnam (130). Worldwide 89.6% of the fatalities were caused by landslides triggered by intense and/or prolonged precipitation. Other triggering processes were construction (mostly undercutting of slopes) (3.4%), mining and quarrying (1.8%) and earthquakes (0.7%), while no cause would be identified for 3.4% of the landslides (Petley, 2008). Many different definitions of landslide are given by researchers all over the world. Some popular definitions of landslide are as follow: "...rapid displacement of a mass of rock, residual soil or sediments adjoining a slope in which the centre of gravity of the moving mass advances in a downward and outward direction" (Terzaghi, 1950).

"The usually rapid down slope movement of a mass of rock, earth or artificial fill on a slope" Webster's 3rd International Dictionary, 1966). “The outward and downward gravitational movement of earth material without the aid of running water as a transporting agent” (Crozier, 1986). “The product of local geomorphic, hydrologic and geologic conditions, the modification of these by geodynamic processes, vegetation, land use practices and human activities; and the frequency and intensity of precipitation and seismicity” (Soeters and VanWesten, 1996).

Among above definitions, the one of Cruden (1991) was initially the informal definition adopted by the Working Party on World Landslide Inventory in 1993, suggested for spreading use in the International Decade for Natural Disaster Reduction (1990–2000). Landslides are a type of “mass wasting” which denotes any downslope movement of soil and rock under the direct influence of gravity. These are complex phenomena, whosetime-space distribution results from an interaction of numerous factors: geological, geomorphological, physical, and human (e.g., Varnes, 1978; Crozier, 1986; Cruden and Varnes, 1996). The term “landslide” comprises varieties of mass movement on slopes asrock falls, topples, slides, spreads, and flows (Varnes, 1996). Landslides can be initiated by rainfall, earthquakes, volcanic activity, changes in groundwater, disturbance and change of a slope by man-made construction activities, or any combination of these factors. Landslide occurrences are attributable to the resisting strength of the soil or rockforming the slope against gravity, and a landslide results when the balance is tipped infavor of gravity. This balance can be changed by both natural and man-made circumstances. The elements that affect slope stability and landslides are numerous and varied, and interact in complex and often subtle ways (Varnes, 1984). Besides man made factors, Sidle and Ochiai (2006) summarized, reviewed and divided natural factors influencing landslide into five groups: i.e. seismicity; strength, chemistry, and mineralogy of soil; geology; geomorphology; and hydrology.

FACTORS INFLUENCING LANDSLIDES

1. GEOMORPHIC FACTORS

SLOPE GRADIENT

Slope gradient is important with regard to landslide initiation. In most studies oflandslides, the slope gradient is taken into account as a principal causative or triggerfactor (e.g., Lohnes and Handy, 1968; Swanston, 1973; Ballard and Willington, 1975).Slope gradients are sometimes considered as an index of slope stability, and because ofthe availability of a digital elevation model (DEM) can be numerically evaluated anddepicted spatially (e.g. O’Neill and Mark, 1987 ; Gao, 1993).

ASPECT AND ALTITUDE

Slope aspect strongly affects hydrologic processes via evapotranspiration and thus affects weathering processes and vegetation and root development, especially in drier environments (Sidle and Ochiai, 2006). Such aspect characteristics which increase landslide failure were defined in previous studies (Churchill, 1982; Gao, 1993; Hyllandand Lowe, 1997; Lan et al., 2004).The strong statistical relationships between elevation and landslide occurrence has been cited in many studies (e.g., Pachauri and Pant, 1992; LinebackGritzner et al., 2001;Dai and Lee, 2002). In general, altitude or elevation is usually associated with landslides by virtue of other factors such as slope gradient, lithology, weathering, precipitation, ground motion, soil thickness and landuse. For example, higher mountainous areas often experience larger volumes of precipitation, both rain and snow falls.

2. HYDROLOGIC FACTORS

Hydrology plays an important role in landslide initiation. Some of the most significant hydrologic processes in this respect are precipitation (spatial and temporal distribution of rainfall), water recharge into soil (and the potential for overland flow),lateral and vertical movement within the regolith, evapotranspiration and interception.

PRECIPITATION

Spatial patterns of rainfall are closely associated with landslide initiation(Campbell, 1966; So, 1971, Starkel, 1976) by means of their influence to the generation of pore water pressure in unstable hill slopes (Sidle and Swanston, 1982; Sidle, 1984;Iverson and Major, 1987; Tsukamoto and Ohta, 1988). Researchers usually refer to one of the four kinds of rainfall as factors of landslide initiation: (1) total rainfall, (2) shortterm intensity, (3) antecedent storm precipitation, or (4) storm duration. However, what type of rainfall attributes has the best correlation with landslide occurrence has not been determined. Some researchers concluded that short-term rainfall intensity is the most important determinant (e.g., Sidle and Swanston, 1982; Keefer et al., 1987). Others (e.g.,Endo, 1969; Glade, 1998) found a correlation of long-term precipitation with landslide occurrences. The hydraulic conductivity of a confining layer underlying unstable landforms regulates long-term drainage and thus controls the moisture content of the overlying soilmantle (Sidle et al., 1985). When a permeable layer is confined within a clayey matrix, pore pressures can accumulate leading to slope failure (Hardenbicker and Grunert, 2001).Additionally, high porosity moderately deep soils on very steep slopes may becomeunstable after extended periods of rainfall even if positive pore pressures do not develop(Sidle and Ochiai, 2006).

INFILTRATION

The term infiltration rate refers to the actual flux of water into the soil and depends upon the physical, biological, topographic and cultural factors as well as the water delivery rate (i.e. rainfall intensity or snowmelt rate). Infiltration capacity refers to the maximum or potential water flux into a soil at any given time (infiltration capacity is always greater than or equal to infiltration rate). The rate of water entry into the soil is highly influenced by soil physical properties (e.g., porosity, hydraulic conductivity, poresize distribution, preferential flow networks), vegetation cover, cultural practices, freezing phenomena, and macro- and micro-topography. It has been shown that there exists an indirect relationship between the rate of water infiltration and slope stability (Horton, 1993).

SUBSURFACE FLOW

Because subsurface flow processes control the movement of infiltrated water through hillslopes, they influence both the temporal and spatial characteristics of pore water pressure distribution. Preferential flow both within the soil (e.g., Tsukamoto et al.,1982 ; Sidle et al., 2000a, 2001 ; Uchida et al., 2001) and with underlying bedrock (e.g.,Montgomery et al., 1997; Uchida et al., 2003 ; Sidle and Chigira, 2004) may exert a major control on pore pressure development in steep hillslopes, and thus affect landslide initiation.

PORE WATER PRESSURE

Pore pressure, generally depicted by the transient development of a perched water table within the regolith, are largely responsible for the initiation or acceleration of landslides. Geomorphic hollows where landslide can be initiated are especially susceptible to the development of perched water tables due to convergent subsurface flow(e.g., Anderson and Burt, 1978; Pierson, 1980; Tsukamoto et al., 1982; Tsuboyama et al.,2000).

VEGETATION INFLUENCES

Vegetation augments slope stability in primarily two ways: (1) by removing soil moisture through evapotranspiration; and (2) by providing root cohesion to the soilmantle (Gray and Megahan, 1981; O'Loughlin and Ziemer, 1982, Riestenberg and Sovornick-Dunford, 1983; Greenway, 1987). Therefore, vegetation is a main factor influencing landslides. Roots, stems, and organic litter increase ground surface roughness and soil's infiltration capacity.

MAN-MADE FACTORS

Landslides may result directly or indirectly from the activities of people. But any attempt to address all activities by people that induce landslide occurrences will be incomplete. Therefore, only some examples will be given:

• Undercutting during construction of highways and railroads increases the average slope gradients, and increases the chance of slope failures.

• Overloading of hill slopes by housing construction is common. This extra weight may increase the chance of slope failure; altering the hydrology may have dramatic effects on hill slope stability.

• Clear cutting of trees promotes soil erosion and weakens the support of soils by treeroots. It also reduces evapotranspiration and raises the water tables.

• Vibrations occurring in earthquake consequence by hydroelectricity lakes, or other artificial causes (machine activities, underground explosions).

LANDSLIDE MAPPING

To determine existing landslide hazard and undertake an estimation of futurelandslide occurrence, an understanding of the conditions and processes controllinglandslides is required. A map of existing landslides serves as the basic data resource forunderstanding these conditions and processes. Existing landslides and their relationshipwith three other key factors – bedrock, slope steepness, and hydrology – form the basis ofa hazard assessment.

LANDSLIDE INVENTORY MAPPING

A landslide inventory map identifies the definite and probable areas of existing landslides, and is the most basic requirement for a landslide hazard assessment. The product of a landslide inventory map is a spatial distribution of landslides as points or to scale. Landslide inventory maps can and often are used as a basis for other landslide hazard zonation techniques or for an elementary form of a hazard map. A typicall and slide inventory map is based on aerial photograph interpretation, ground survey, and/or a database of historical movements within the area. These maps, however, only provide information for a short period of time, and they provide no insight into temporal changes in landslide distribution.In landslide hazard assessment, the historic information on landslide occurrencesis by far the most important, as this gives insight into the frequency of the phenomena, the types involved, the volumes and the damage that has been caused. Landslide inventory maps, derived from historic archives, field data collection, interviews and image interpretation are essential but unfortunately often lacking (Van Westen et al.,2006). Despite the fact that the quality of historical evidence is strongly dependent on recording procedures and available records, this approach provides an indication of atleast the minimum level of landslide activity in an area. The issue of using historical data in natural hazard assessments is discussed by Guzzetti et al. (1994), Glade (2001), and Petrucci and Polemio (2003) and is specifically addressed to landslides by Glade (2001), Bozzano et al. (1996) and Guzzetti (2000). Generally, widely used methods for making a landslide inventory map are field investigations and remote sensing techniques. By fieldwork surveys, evidence of current and former landsliding can be determined from slope morphology, sedimentary deposits, or impact features (e.g. deformed trees). As this type of evidence deteriorates or is obliterated progressively with time, care has to be taken in establishing long-term trends in occurrence. A wide range of both relative and absolute methods has been employed for dating of field evidence (Lang et al., 1999; Bull,1996). A number of papers dealing with the determination of frequency and magnitude of occurrence from field evidence can be found in Mathew et al. (1997). Remote sensing techniques greatly aid in the investigation of landslides, on both local and regional scale.

Although these cannot replace fieldwork, for interdisciplinary research strategies and testing of reliability of landslide prediction models, remote sensing techniques do offer an additional tool from which we can extract information about landslide causes and occurrences. The landslide information extracted from remotely sensed products is mainly related to morphology, vegetation and hydrologic conditions of a slope. Especially, stereo-remote sensing products reveal the true morpho-dynamical features of landslides.

LANDSLIDE SUSCEPTIBILITY ZONATION

Despite conflicting views among experts, all proposed methods for slope instability studies are based upon some widely accepted principles or assumptions(Varnes, 1984; Carrara et al., 1991; Hutchinson and Chandler, 1991; Hutchinson, 1995;Turner and Schuster, 1996; Guzzetti et al., 1999; Guzzetti, 2005), namely:

1. The main conditions that cause landsliding can be identified, and most can be mapped. In fact, slope failures leave discernible features that can be recognized, classified and mapped in the field or through remote sensing, chiefly stereoscopic aerial photographs(Rib and Liang, 1978; Varnes, 1978; Hansen, 1984; Hutchinson, 1988; Cruden andVarnes, 1996; Dikau et al., 1996; Guzzetti, 2005).
2. For landslides, "the past and present are keys to the future" (Varnes, 1984; Carrara etal., 1991; Hutchinson, 1995). Under this assumption, landslides in the future are likely to occur under the same geologic, geomorphic and hydrologic conditions as those that led to landslides in the past. Hence, the understanding of past failures is essential in the assessment of landslide hazard (Varnes, 1984; Carrara et al., 1991, 1995; Hutchinson,1995; Guzzetti et al., 1999; Guzzetti, 2005).
3. The conditions that lead to landsliding can be used to determine the likelihood of future landslide occurrence. The conditions can be varied and related in different ways. However, if the processes involved can be understood, then extrapolation from point/site information is possible to wider regions. Some authors (Crozier, 1986; Hutchinson, 1988;Dietrich et al., 1995; Guzzetti, 2005) confirmed that conditions which cause landslides(instability factors), or are directly or indirectly linked to slope failures, can be collected and used to build predictive models of landslide occurrence, because landslides are controlled by mechanical laws that can be determined empirically, statistically or indeterministic fashion.

PROBLEMS

In the study area, landslide is a major problem. Due to hilly terrain, steep slope, heavy rainfall and steep road cuts; landslide occurrence is very common in the study area. Major roads going to Shahapur (Thane), Ghoti (Nashik), Rajur (Ahmednagar) are there in study area. So any landslide on road can affect the transport system in study area. So this makes landslide a major concern in study area.

OBJECTIVE

The main objective of this study is to test different RS and GIS tools to assess the spatial landslide susceptibility distribution in Bhandardara Dam catchment area. To fulfil this major objective; following sub-objectives are chosen:

- Select landslide causative factors on the basis of previous landslide inventory analysis in the study area.
- Apply different methods for deriving landslide susceptibility maps of the study area.
- Recommend landslide hazard prevention measures to help the local community to be prepared and to respond adequately to disasters.

DATABASE

In this study, digitally enhanced products of LISS III and ASTER sensors were used. Toposheets of study area of scale (1:50, 0000) and other data obtained from Web,Books and case papers etc. have been used.

DESCRIPTION OF STUDY AREA

Bhandardara is a village on the western ghat region of Maharashtra. It is located at 19º 32' N latitude and 73º 45' E longitude. The village is located in the Ahmednagar district of the state of Maharashtra, about 185 kilometers (115 mi) from Mumbai.Bhandardara drained by the Pravara river, and is a blend of natural beauty, waterfalls, mountains, tranquility, greenery, invigorating air and pristine ambiance. The Bhandardara Dam built on Pravara and it is the major tourist attraction. Bhandardara is full of attractions – from Wilson Dam to Arthur Lake. As legend has it, Shri Agasti Rishi meditated here for a year, surviving only on water and air, pleased with this display of devotion, God came down to Earth and blessed Shri Agasti Rish i with a stream of theGanges river, which is now known as the Pravara

River.3.2 Physiography: Study characterized by mainly hilly, rugged terrain. Detailed physiography can be explained as follows.

MOUNTAINS AND HILLS

KALSUBAI RANGE

The Kalsubai range, branching off at Kulang, is the northernmost of the 3 spurs which for some 40 km. forms the boundary between the Ahmadnagar and Nasik districts. Viewed from the Nasik district it presents the appearance of a continuous and in many places a precipitous cliff of rocks. Almost every hill in this range had been a fort and many still have water cisterns and granaries. East of Kulang is the twin fort of Alang, both being spots of great natural strength. Then comes a series of rocky and precipitous speaks with a general pyramidal form averaging 1,500 m. in height followed by the Kalsubai 1,646 m., a conical summit of which is the highest point within the limits of Maharashtra State. East of Kalsubai is the natural depression in the range over which winds the Bari ghat road leading from Igatpuri and Ghoti on the Bombay-Agra highway to Bhandardara. The truncated hill of Pandara commands this road on the east. The next noteworthy peaks are Palan, Bitangad (1,427 m.) and Mahakali. The range here sweeps northward to the once-celebrated hill-forts of Patta and Avandhe which were scenes of many fierce contests between the Maralhas and the Moghals. The magnificent amphitheatre between these two forts is a striking feature of the range.

ADULA HILLS

The Adula hills branch off from the main Kalsubai range near the peak of Patta and run southwards at an average elevation of 900 m. carrying on their top extensive flattopped plateau levels and open jungles on the steep hill-slopes. This range abruptly endsabout 2 km. northwards of Sangamner. The other spur branching off from the Kalsubairange in Bitangad peak also running similarly with an easterly trend, parallel to the Adularange and south of it has a wider flat top forming a structural level at a height of 1,000 m. Between the two spurs, the Adulariver has carved its valley. This range also ends abruptly a few km. west of Sangamner.

BALESHWAR RANGE

The Baleshwar range, the second great spur of the Sahyadri, branches off at Ratangad, 11 km. south-east of Kulang and completely traverses the Akola and Sangamner talukas forming the water-shed between the Pravara in the north and the Mulain the south. On this range, east of Ratangad, are a series of lofty, craggy peaks such as Katradongar, Mura, Wakarai, Shirpunj, Ghanchakar (1,532 m.), Bahiroba and Sindola. The range culminates with Baleshwar as a centralmass whose summit has been crowned by a temple in Hemadpanthi style now in ruinsand surrounded by spurs radiating from the centre in all directions. On an isolated hill atthe end of one of these spurs extending to the north-west is the fort of Pemgad. Between Baleshwar and Hevargaon which is the last notable peak in the range is the Chandanapurivalley crossed by the Pune-Nasik road. East of Hevargaon, the hills decrease in height and finally subside in the open plains just west of Rahuri. This range is about 100 km. long.

HARISHCHANDRAGAD RANGE

The third range which leaves the Sahyadri at Harishchandragad is the longest in the district and forms the main water-shed between the Godavari and Bhima tributaries. Its direction for the first 25 km. is easterly; the Mula river flows between it and the Baleshwar range. This range forms the boundary between Ahmadnagar and Pune districts. East of Harish chandragad fort on this range lies the BalaKilla. Near Brahmanwada, the range gradually decreasing in height takes a turn to the south-east and enters Parnertaluka which it completely traverses. The summits of the hills here widen into the plateau of Kanhore, 850 m. above the mean sea-level and 200 m. above the bed of the Ghodriver; on the west the range presents a wall-like front towards the river. Near the village of Jamgaon in Parnertaluka, the flat-topped ridge shoots to the north-east to form a water-shed between the tributaries of the Godavari and the Bhima. The main ridge continues further south-east with widening summits and gradually widens into a flat-level country known as Balaghat that extends far into the districts of Marathwada. The length of the hills from the main line of Sahyadri to the Balaghat is about 200 km. The branch of this range leaving Kanhore plateau crosses the north-eastern corner of Shrigondataluka and enters Karjattaluka. A distinguishing feature of this branch is the succession of "Pathars" of flat-topped hills that are so uniformly horizontal as to present almost an artificial appearance.

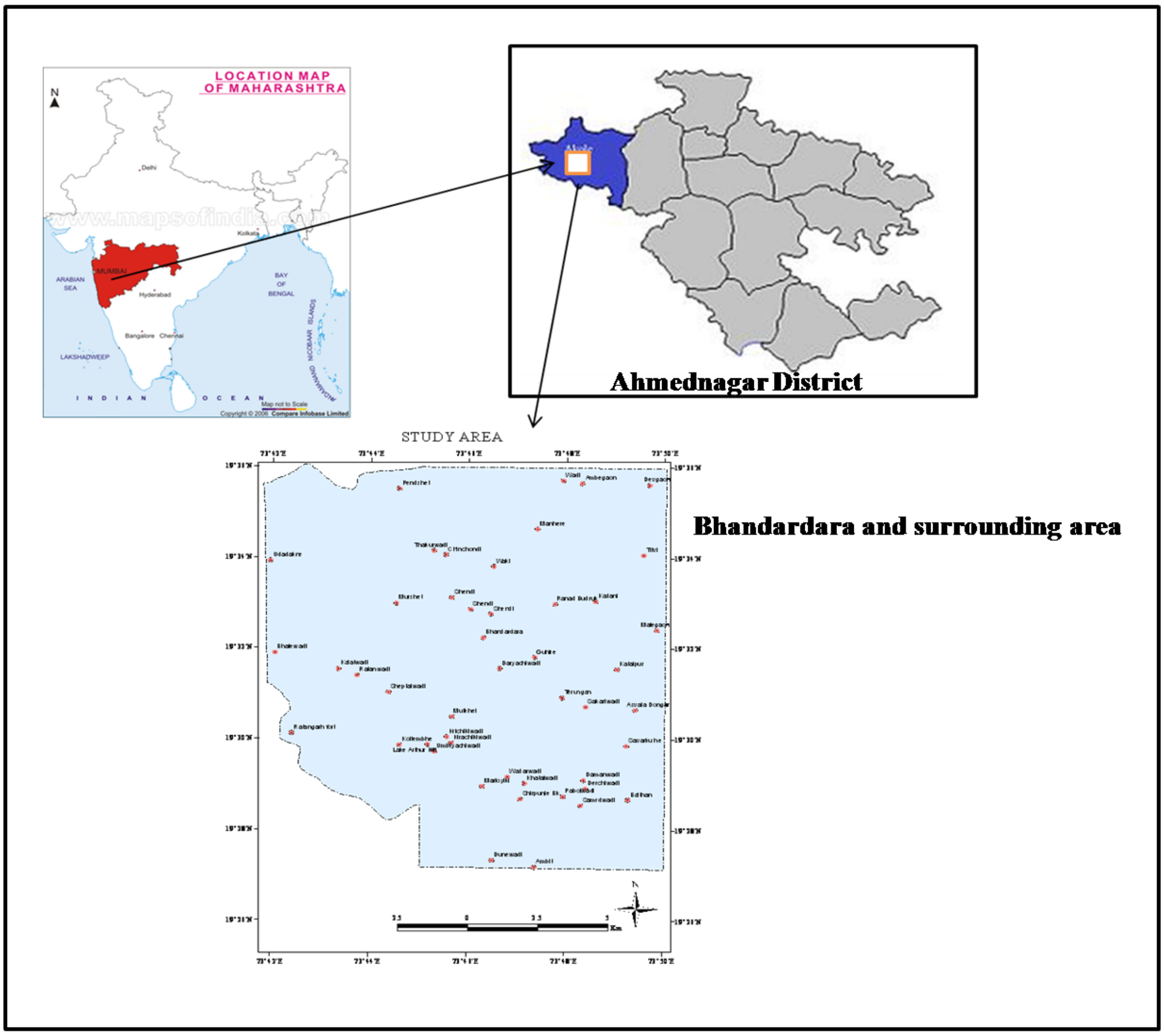

FIGURE 1
LOCATION MAP OF STUDY AREA

SOILS

GHAT ZONE

This zone covers hilly terrain including Sahyadri hill tops and the western slopinghilly land with variable altitude between 500 and 1,500 meters. The main soil types found in this region are high level, red to reddish brown lateritic soils and light brown to dark brown shallow gravelly loams. High rainfall zone with non-lateritic soils: This zone includes the narrow strip of land west to the ghat zone and receives rainfall of 2,000 to 3,000 mm. The major soil group, viz., non-lateritic red to reddish brown loams includes two types of soils— high level, red to reddish brown, shallow light textured soils and brown to dark brown, medium deep loams to clay loams locally known as manat.

TRANSITION ZONE I

Area on the western side of the high rainfall zone with non-lateritic soils comes under this zone. This zone receives rainfall of about 1,250 mm. to 2,500 mm. The soil group consists of soils of red to reddish brown colour with varied depth and texture.

TRANSITION ZONE II

Western part of Akola taluka and the limited area from south-east portion of Sangamner taluka is covered by this zone. This part of the district receives rainfall of about 700 mm. to 1,250 mm. The major soil group of this zone is brown to dark brown ofvarying depths and comprises three types of soils, viz., high level, low lime, shallow, reddish brown loams; intermediate, medium deep brown black clay loams; and low level,

FORESTS

The forests in the district represent the "Southern Tropical Dry Deciduous" type. They are scattered in sheltered pockets of spurs and valleys and are situated mainlyin Akola, Sangamner, Ahmadnagar, Shrigonda, Parner and Rahuritalukas. In the Rajur and Akola ranges some ever-green species also grow. The forests consist of the following species:-(1) Ano-geissuslatifolia (Dhawada), (2) Terminaliatomentosa (Ain), (3) Launeagrandis (Moyen), (4) Boswelliaserrata

(Salai), (5) Cassiafistula (Bahawa), (6) Bauhinia racemosa (Apta), (7) Phyllanthusemblica (Amla), (8)Tectonagrandis (Teak), (9) Terminaliachebula (Hirda), (10) Santalum Album(Chandan), (11) Acacia arabica (Babul), (12) Eugenia jambulana (Jambhul), (13)Pongamiaglabora (karanj), (14) Feroniaelephantum (Kavit), (15) Madhukalatifolia(Moho), (16) Meliaazadirachta (Nimb), (17) Acacia catechu (Khair), (18) Ailanthusexcelse (Maharuk), (19) Prosopisspicigera (Saundad), (20) Grewiatiliaefolia (Dhaman)Among the shrubs the following are found:-Rhusmysorensis (Amoni), Caesalpiniasepiaria (Chillar), Lantana camara (Tantani), Gymnosporiamontana (Henkal), Carrissacongesta (Karvand), Munduleasuberosa (Supli), Cassia auriculata (Tarwad), Mimeroahaomata (Arati), Buteasuperba (Palsvel) etc. The common grasses are Sheda, Gondal,Chirka, Marval, Paonya, Kusli, Kunda and Rosha.The forests in Akola and Sangamnertalukas produce small quantity of teak poles,charcoal, firewood, grass and myrobalans. The forest produce is transported in trucks toGhoti and Sangamner markets. The important market for the Ahmadnagar forest divisionis Ahmadnagar, though the production in that forest division is very meagre.

DRAINAGE

PRAVARA

The Pravara rises in the eastern slopes of the Sahyadri between the high peaks and hill-forts of Kulang and Ratangad; after a strenuous course of 20 km. in a pictures queamphitheatre enclosed between the Kalsubai and Baleshwar ranges in an easterlydirection, it falls near the village Renad into a rocky chasm, 60 km. deep and then windsfor about 13 km. through a narrow deep glen that opens into a wider valley east of and below the central plateau on which the town of Rajur stands. After flowing across thisvalley, the river enters the Desh, part of the Akola taluka. As it flows past the town ofAkola it receives on the left the discharges of the Adulariver and the Mahalungi both onthe left banks. Through Sangamner and Rahuri, the Pravara flows between low cultivated banks still keeping its easterly course. It receives, as it enters Newasataluka, the watersof the Mulariver and the combined flow turning to the north-east falls into the Godavariat the Pravara Sangam near the village of Toka. The total length of the Pravara is 200 km. The upper waters of the Pravara in the amphitheatre between the Kalsubai-Baleshwarranges have been developed into a huge reservoir lake, the lake Arthur, behind theWilson dam near Bhandardara. The dam impounds about 11 thousand million cubic feetof water behind the dam, i.e., the height of the dam above the deepest part of the riverbedis 90 m. The storage feeds two canals, the Pravara left bank and right bank canal, taking off from a pick-up weir at Ozar village 90 km. downstream of the dam. The system irrigates an area of 32,000 hectares of mixed crop mainly in the northern parts of the district. The dam-site near Bhandardara with its picturesque beautiful landscape around and the boating facilities in the reservoir is a source of attraction for the holidaycrowds of Bombay city.

ADULANADI

The Adulanadi rises in the northern parts of Akola taluka on the slopes of the Patta and Mahakali peaks. It flows for 25 km. in an easterly direction between two spurs which includes the narrow Samsharpur valley; then, after falling into a rocky chasm 45m. deep, it winds between rocky and precipitous hill sides for a couple of miles beforede bouching into the plains of Sangamner. It turns south and falls into the Pravara 5 km. west of town of Sangamner. Though only 40 km. in length, the Adula during rainy seasonis subjected to swirling rapid floods owing to the rocky country and heavy rainfall in the upper parts of its course. In the lower course the banks are sloping but fissured by minor tributaries to such an extent that the approach to the bed of the river is not always easy. It has a perennial flow and near the village of Samsharpur where the bed is rocky the water is much used for direct irrigation. The river has a number of bandharas or weirs both above and below Samsharpur to store water and make use of it for irrigation.

MAHALUNGI

The Mahalungi rises on the southern and eastern slopes of Patta and Avendapeaks. After a course of about 6 km., it passes east into Sinnartaluka of Nasik district flowing north of and nearly parallel to the Adula, the two rivers being separated by theAdula range; it re-enters Ahmadnagar after taking a beautiful bend to the south and stillpreserving a course parallel to the Adula. it joins the Pravara at the town of Sangamner in the lower part of its course which lies within this district. It has a wide shallow sandy bed. During heavy rains, the course of the water-current in the river is so tremendous thatit often blocks the water in the Pravara upstream and makes it over-flow its banks for a long distance above the town of Sangamner. This is due to the heavy discharge in an arrow catchment area. The Mahalungi, like the Adula, is about 40 km. long. Its water isnot used much for irrigation since its regime has a more marked seasonality and in itslower sections the river-banks are deeply gullied and eroded.

MULA RIVER

The Mula rises on the eastern slopes of the Sahyadri between Ratangad and Harishchandragad. For the first 25 km., it flows parallel to the Pravara draining the southernmost Kotul valley of Akola taluka. The river is incised in a deep valley almost from its source and its steep valley-sides are highly dissected by deep gullies formed bymountain torrents which rush into the main stream. Skirting the large market village ofKotul it takes a bend to the south, winding past the rocky precipitous slopes at the foot of Baleshwar hills. It then flows through the south-west parts of Sangamner taluka and follows an easterly course between Shevgaon and Parnertalukas flowing in a deep bedbetween rugged hills on the north and the tableland of Vasunda on the south. It then takesa sudden turn to the north-east and enters the plains in the same direction for another 30km. It joins the Pravara at the village of Sangam. The total length of the river from its source to its confluence with the Pravara is 145 km.; except in lower parts of its course on account of an entrenched course, the Mula is used for agriculture only in alluvial flats on the foot of the rugged ledges jutting into the river-bed.

CLIMATE

The climate of the study area is characterised by a hot summer and general dryness during major part of the year except during south-west monsoon season. The cold season in the district commences from December and ends in the month of February. The period from March to the first week of June is the hot season. It is followed by the southwest monsoon season which lasts till the end of September; October and Novemberconstitute the post-monsoon or the retreating south-west monsoon season.

RAINFALL

The average annual rainfall in the study area is 227 cm. The district mostly is in rain shadow to the east of western ghats. But from a line roughly north-south in the central parts of the district the rainfall gradually increases towards the north-west. About77 per cent of the annual rainfall in the district is received during the south-west monsoon season, September being the rainiest month.

TEMPERATURE

The cold weather starts by about the middle of November and continues till the end of February. December is the coldest month of the year with the mean dailymaximum temperature at 28.5° C (83.3° F) and the mean daily minimum at 11.7° C(53.1° F). From March to the break of south-west monsoon the day temperatures increase progressively, the nights remaining comparatively cool. In the hot season, the sweltering heat of the afternoons is sometimes relieved by thunder-storms. May is the hottest month of the year with the mean daily maximum temperature at 38.9° C (102.0° F) and the mean daily minimum at 22.4° C (72.3° F). With the onset of southwest monsoon in the tahsil there is an appreciable drop in temperature and weather becomes pleasant. With the withdrawal of the monsoon by about the first week of October day temperatures increases lightly and a secondary maximum in day temperatures is recorded in October. However the night temperatures decrease steadily after the withdrawal of the monsoon.

HUMIDITY

The air is generally dry during the months from February to May and particularly so in the afternoons when the humidity is about 20 per cent on the average. The relative humidities during south-west monsoon period are between 60 and 80 per cent. Thereafter they decrease rapidly.

POPULATION AND ECONOMIC PROFILE

The total population of Akoletahsil is 271719 according to 2001 census. Some ofthe tribal population resides at hilly region in the study area. Population density on an average is 180/km2. Due to its scenic beauty and huge Bhandardaralake (Dam), many tourist attracted towards this place. Mainly in rainy season tourist visit this place. There are many cliffs in this region; so it attracts the trekkers. So, the tourism industry is important and one of the source of income to people. Still majority of people depend on agriculture for income.

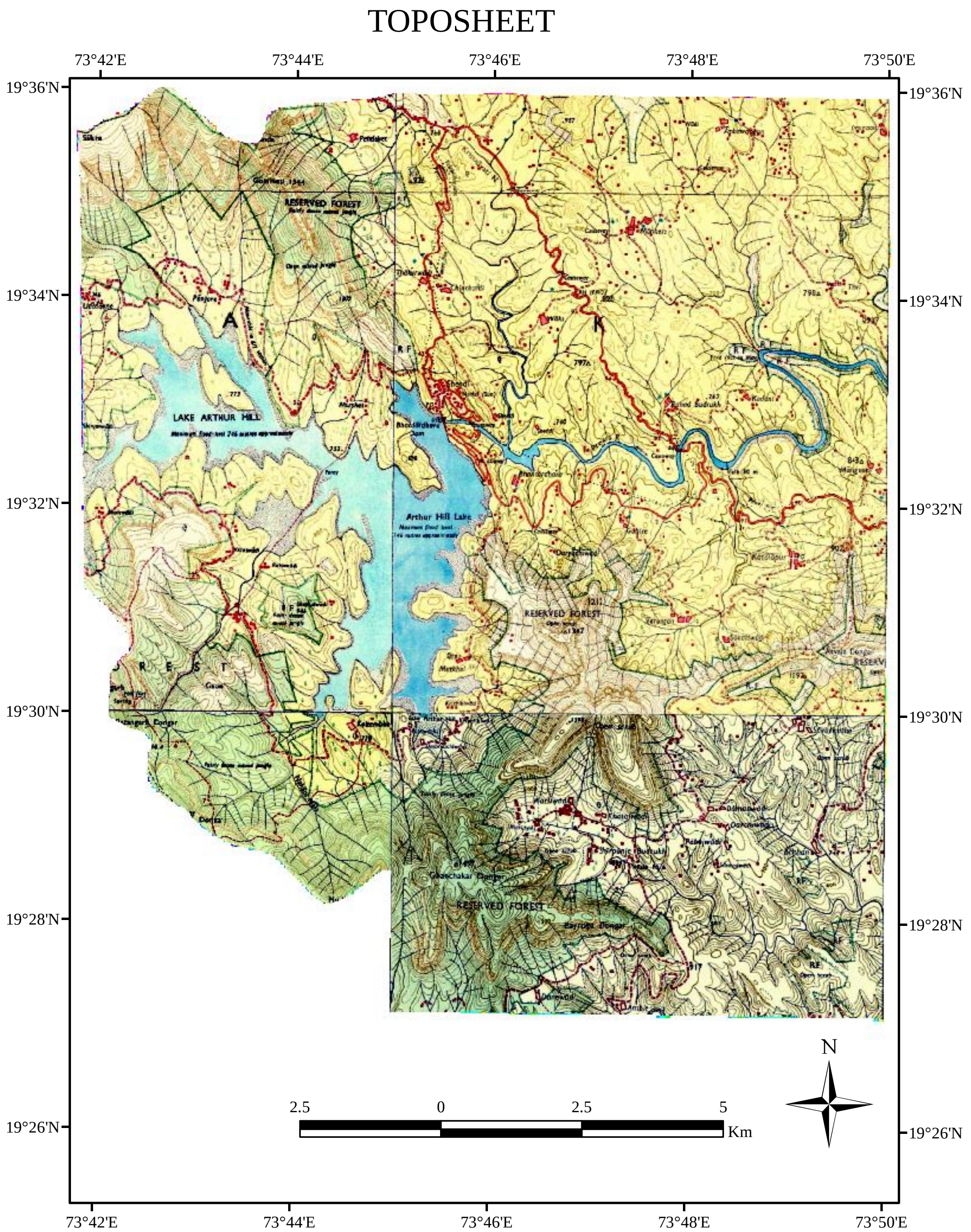

FIGURE 2
TOPOGRAPHICAL MAP OF STUDY AREA

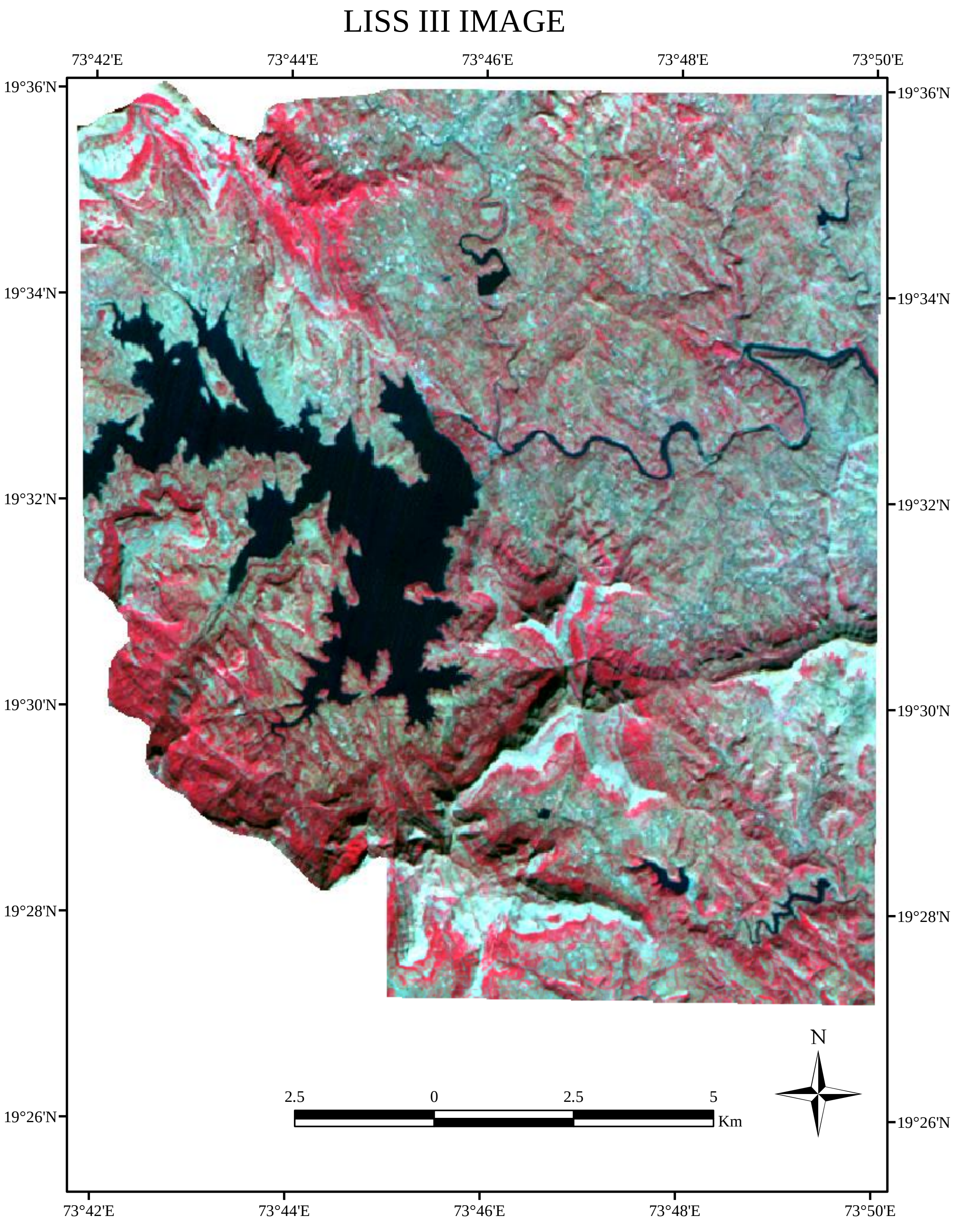

FIGURE 3
SATELLITE IMAGE OF STUDY AREA (LISS III)

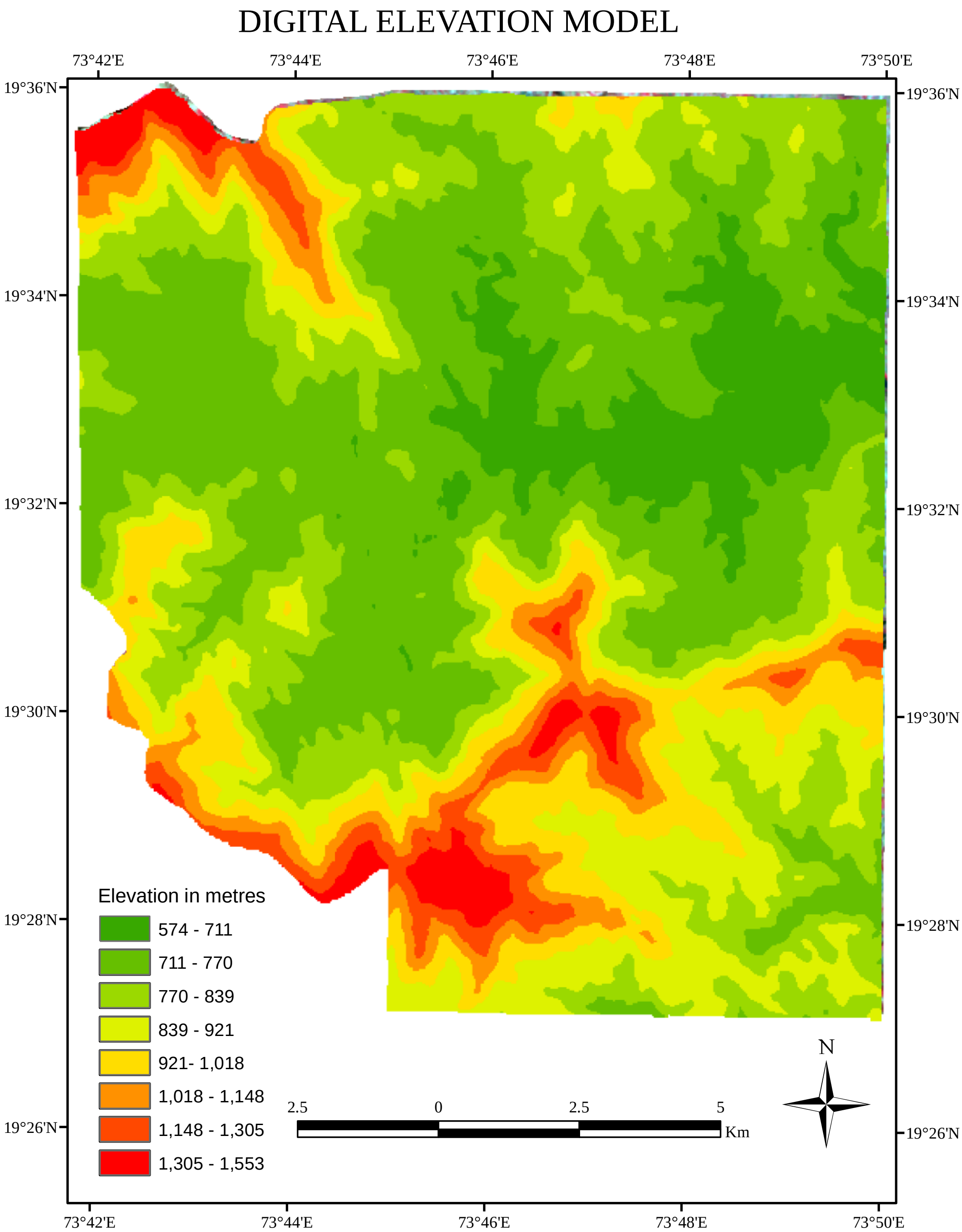

FIGURE 4
DIGITAL ELEVATION MODEL (ASTER)

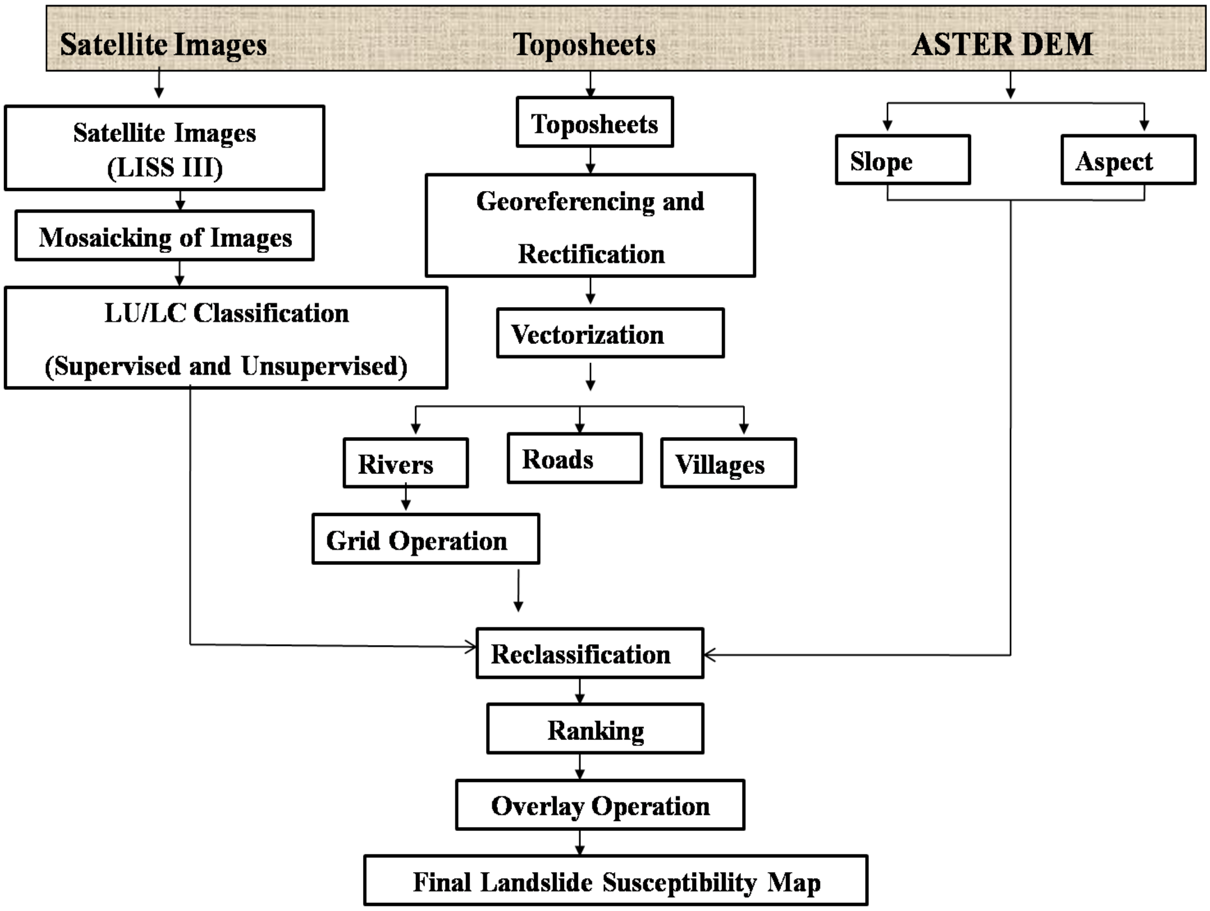

FIGURE 5
METHODOLOGY OF PRESENT STUDY

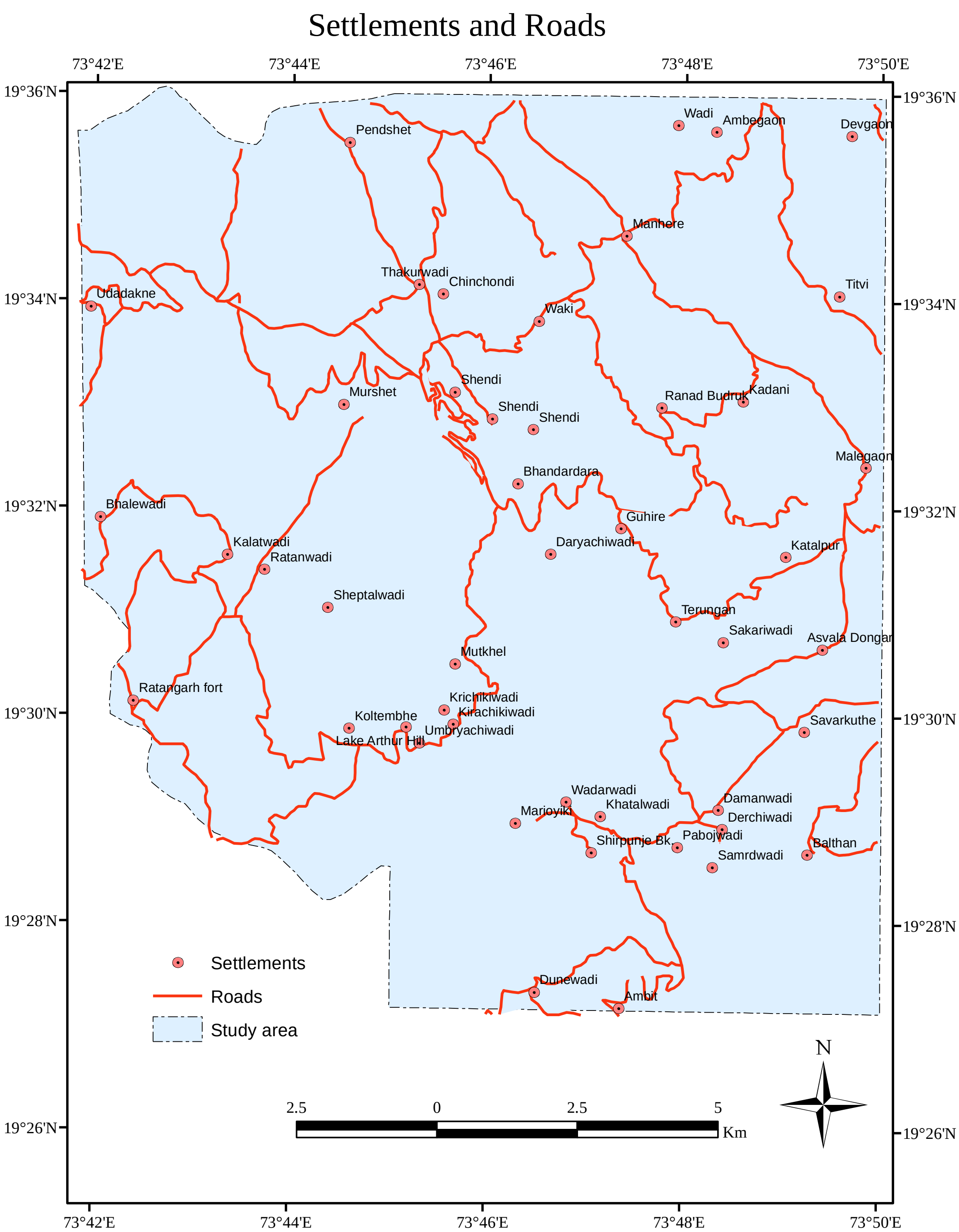

FIGURE 6
ROAD NETWORK AND VILLAGES

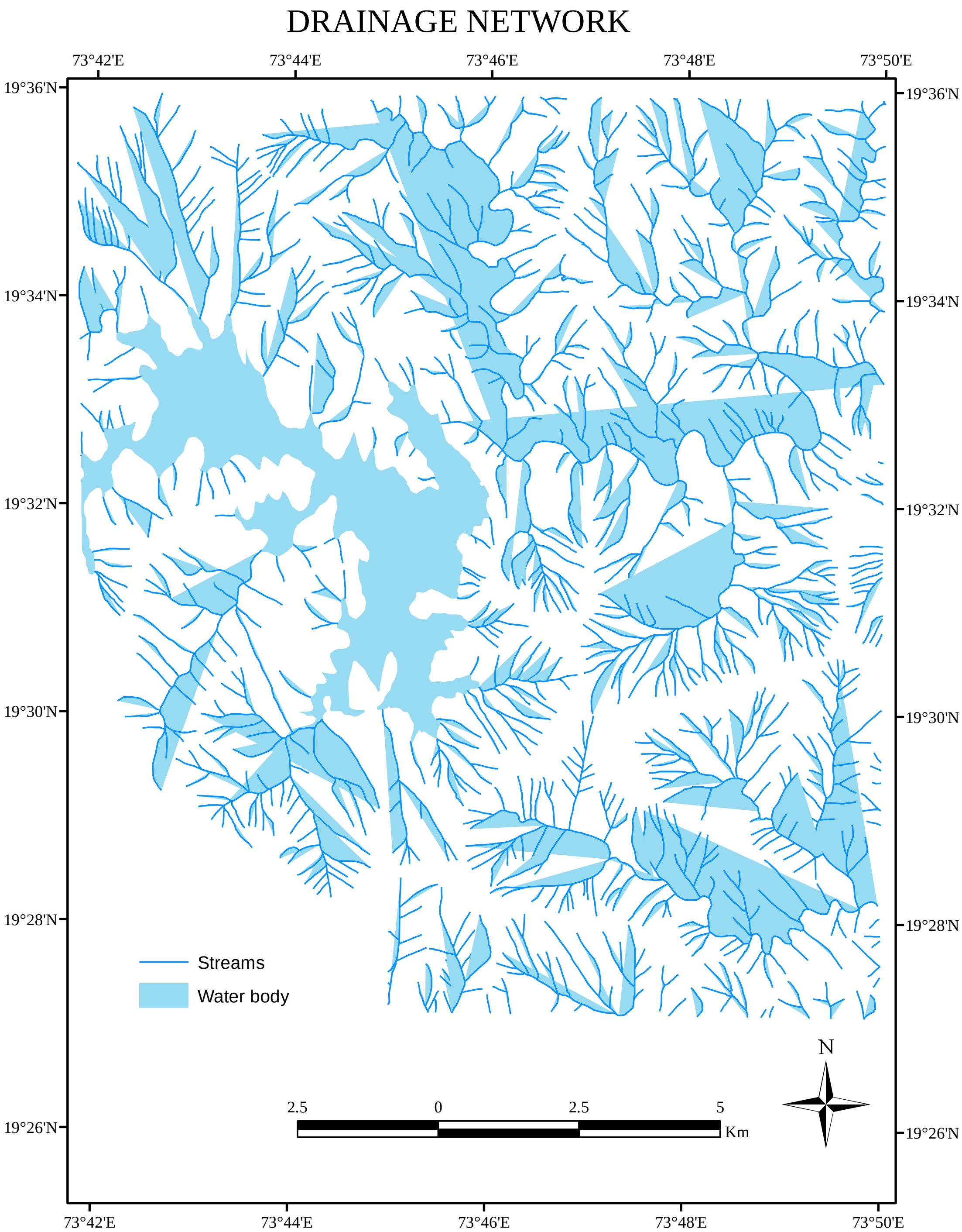

FIGURE 7
DRAINAGE NETWORK

DATABASE AND METHODOLOGY

In more than 10 years different methods and techniques for evaluating landslide occurrence have been developed and proposed worldwide (Hansen, 1984; Varnes, 1984; Hutchinson, 1995; Crozier, 1995). These methods include inventory mapping (direct approach) and a set of indirect, quantitative methods, namely the knowledge-based (index), statistical (data-driven) and deterministic approaches (Carrara et al., 1998).

Quantitative methods rely on observed relationships between controlling factors and landslides (Guzzetti et al. 1999). Statistical analysis in quantitative methods are used to obtain predictions of the mass-movement from a number of parameter maps (Yin and

Yan, 1988; Gupta and Joshi, 1990; Lee et al., 2002; Ayalew et al., 2004; Carrara et al., 1991; Chung and Fabbri, 1999). They can be categorized into two subgroups according to their data analysis methods: bivariate and multivariate (Soeters and van Westen, 1996). The bivariate models consider each individual thematic map in terms of landslide distribution and can be easily implemented in GIS (van Westen 1997). Mapping past and recent slope movements, together with the identification and mapping of the conditioning or preparatory factors of slope instability, are key components for predicting future landslides (Carrara et al., 1998). Generally, the purpose of landslide susceptibility mapping is to highlight the regional distribution of potentially unstable slopes based on a detailed study of the contributing factors (Ayalew et al., 2004).

DATABASE

Following database used in present study:

- SOI Toposheets at 1:50000 scale (47/E/10, 47/E/11, 47/E/14, 47/E/15)
- LISS III images of 23.5m resolution
- ASTER DEM of 30m resolution
- Other collateral data from Web, Books, Articles, Research papers etc.

METHODOLOGY

The index-based approach using simple ranking and rating methods for landslide hazard zonation was initially proposed by Anbalagan et al. (1992). Some case studies of landslide hazard zonation in the Himalaya were based on this technique (Anbalagan et al., 1992; Nagarajan, 2000; Saha et al., 2002). In the index-based approach, causative factors of slope instability of the study area are selected in the first step. Each causative factor is considered as a parameter map. The relative importance of each parameter map for slope instability is evaluated according to subjective experts' knowledge.

THEMATIC MAPS GENERATION

All the Toposheets were rectified and reprojected in UTM projection. Afterwards they mosaicked using ERDAS Imagine 9.1. Using Arc GIS 9.3 features were vectorized from toposheet. Mainly rivers, water bodies, roads and villages have been extracted. Attributation had done for all the features e.g. rivers, villages etc.

GRID OPERATION

Grid operation performed on vectorized river layer to obtain drainage frequency map. One grid of 1*1 meter put on river layer (vector). That helped to get the drainage frequency map of study area.

RECLASSIFICATION AND OVERLAY

After grid operation, output map was reclassified and used for overlay operation to get final map.

LANDUSE/ LANDCOVER CLASSIFICATION

LISS III images were reprojected and mosaicked. Then image was cropped to have study area crop of image. Afterwards image were classified with supervised scheme with 9 classes namely, Hillslope, Deep water, Shallow water (streams), Settlements, Farmland, Dense Vegetation, Sparse vegetation and Wasteland. Out of these classes, hillslope has the highest share of total study area followed by barren land and wasteland.

RECLASSIFICATION AND WEIGHTED OVERLAY

Classified satellite image was reclassified and overlaid for getting final output i.e. landslide susceptibility map.

3D ANALYSIS USING DEM

Digital elevation model of ASTER sensor used to prepare 3d maps for present study. Mainly Slope and Aspect maps were obtained.

SLOPE

Slope map is obtained in Arc GIS software. Slope values obtained in percentage. In the study area maximum area is under high or steep slope. Then that map was reclassified for further processing. Then reclassified map was overlaid to obtain final map.

ASPECT

Aspect map obtained from DEM was used for analysis. It is seen that the NW (northwest) facing slopes (aspect) has greater probability for occurrences of landslides. Then the map was reclassified and used further in overlay analysis.

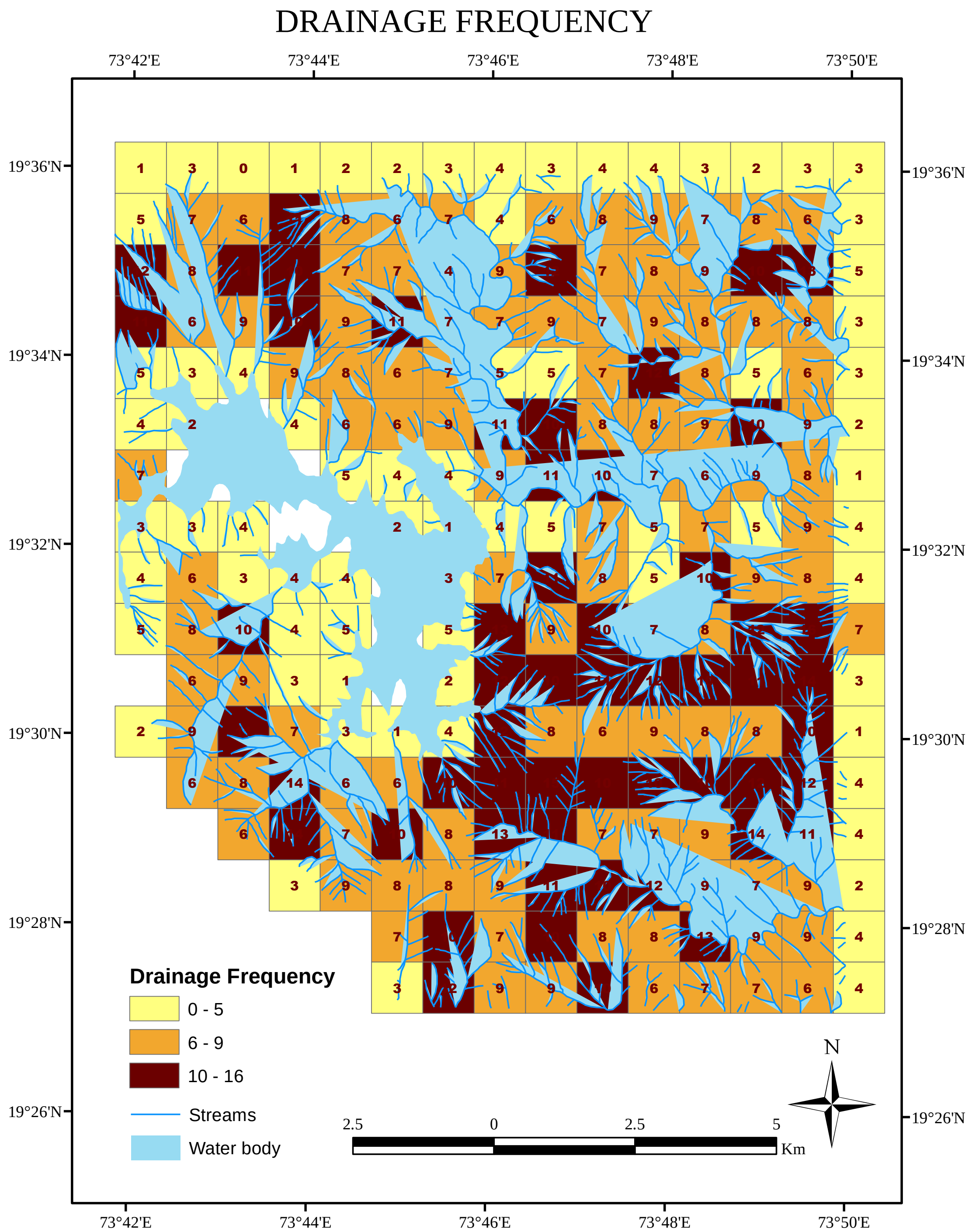

FIGURE 8
DRAINAGE FREQUENCY MAP

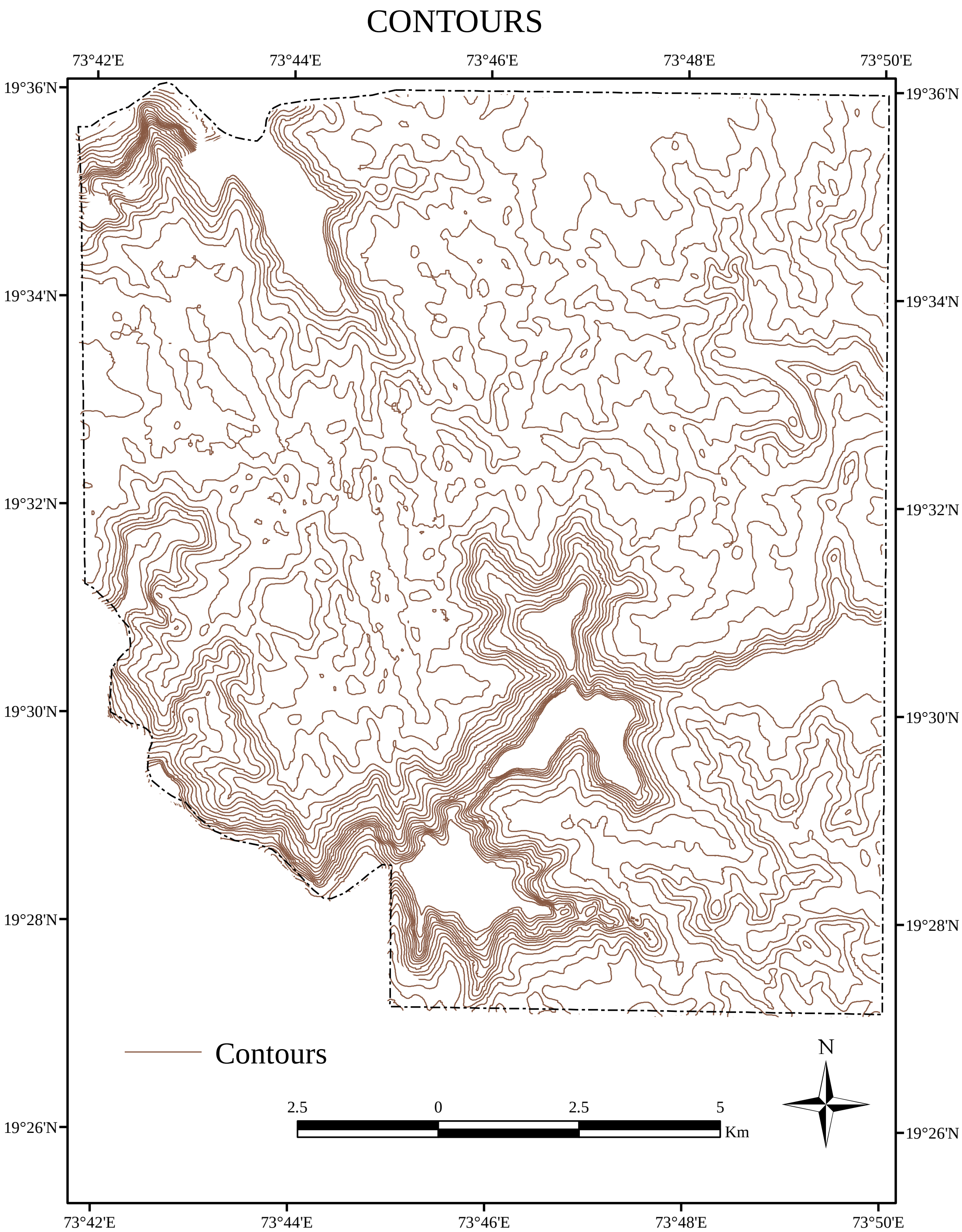

FIGURE 9
CONTOUR MAP

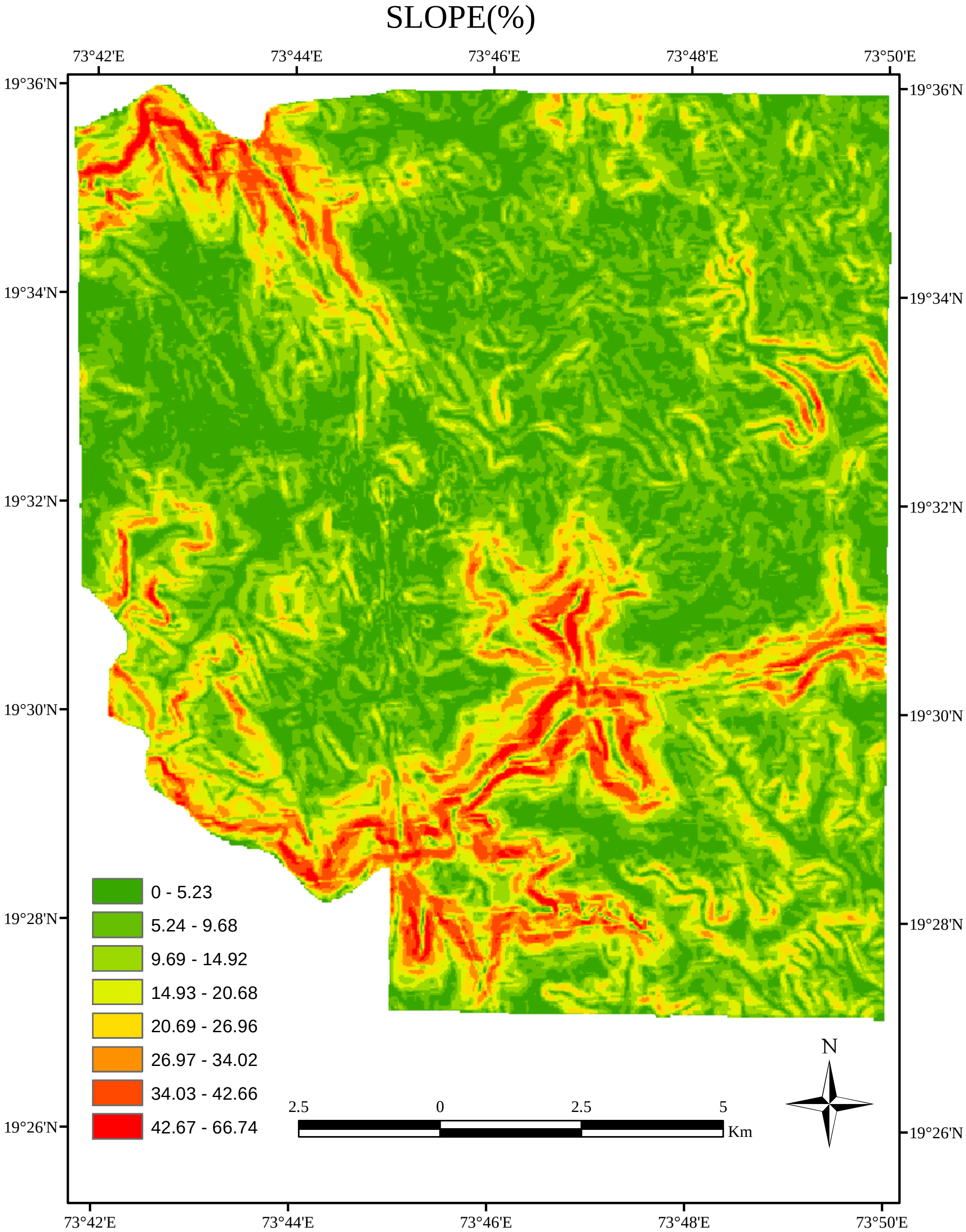

FIGURE 10
SLOPE MAP

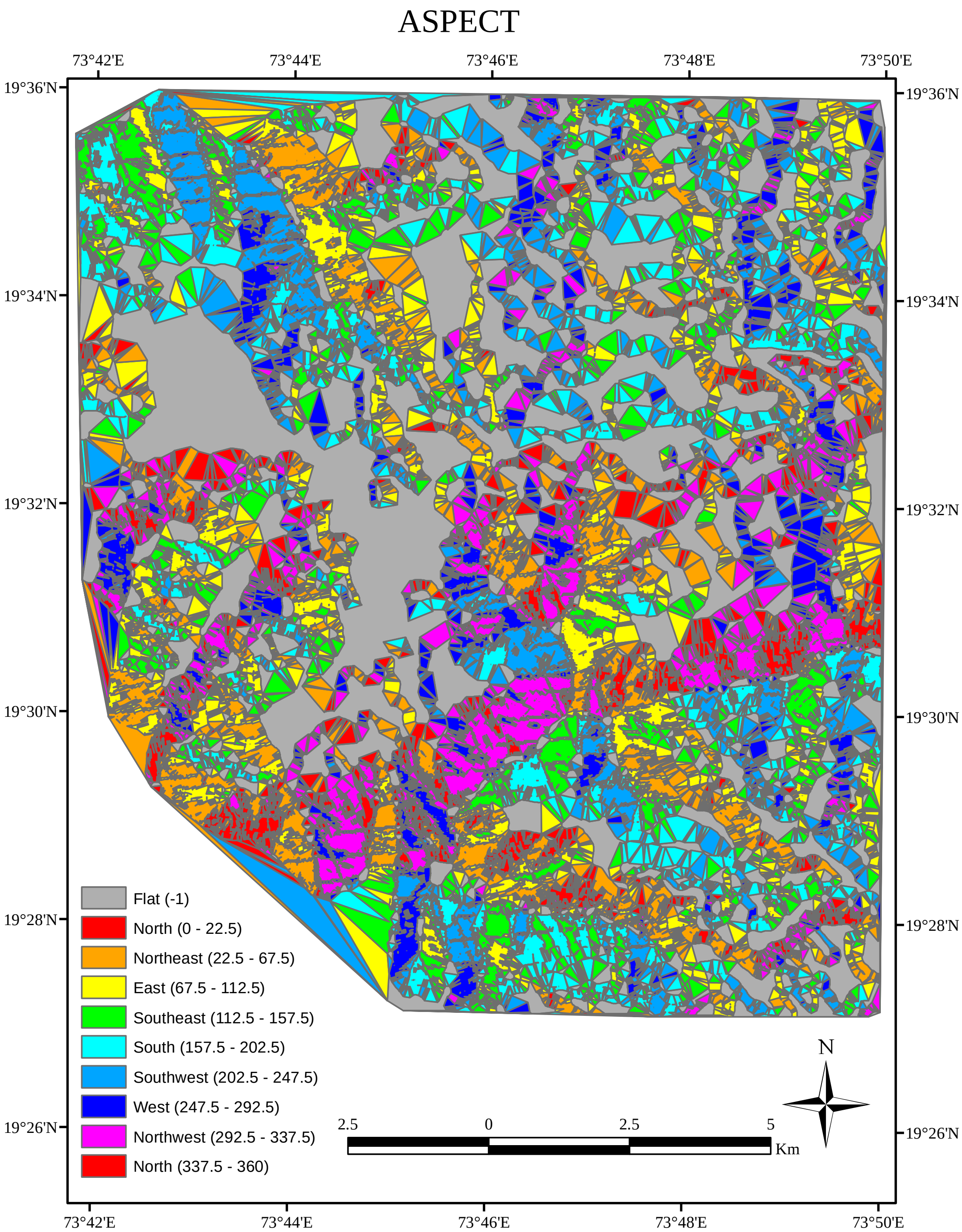

FIGURE 11
ASPECT MAP

RANKING

After creation of different reclassified maps, ranking was performed with the help of Delphi method. Delphi may be called as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.

To prepare the landslide susceptibility map, rank was assigned to each entity in a thematic map using Delphi approach. Higher the rank for an entity, more the susceptibility to landslides compared to others. Weightage of each theme was provided depending upon the severity of the theme. In the recent time 13 landslides were observed in study area. Following are the tables of ranking for each theme:

1) Landuse / Landcover Ranking

Sr. No.	Class Name	Rank
1	Waste Land	08
2	Sparse Vegetation	04
3	Shallow Water	02
4	Settlement	06
5	Hill slope	09
6	Farm Land	07
7	Dense Vegetation	06
8	Deep Water	01
9	Barren Land	03

TABLE 1
LANDUSE / LANDCOVER RANKS

2) Drainage Frequency Ranks

Sr.No.	Drainage Frequency	Rank
1	0-5	02
2	6-8	04
3	9-11	06
4	12-16	08

TABLE 2
DRAINAGE FREQUENCY RANKS

3) Slope Ranking

Sr.No.	Slope Ranking	Rank
1	Low	02
2	Medium	04
3	High	06
4	Very High	08

TABLE 3
SLOPE RANKS

4) Aspect Ranking

Sr.No.	Aspect Class	Rank
1	Flat	00
2	North	06
3	North-East	01
4	East	02
5	South-East	03
6	South	04
7	South-West	05
8	West	07
9	North-West	08

TABLE 4

ASPECT RANKS

WEIGHTED OVERLAY

Weighted overlay is a method in which effective results can be obtained by using multiple parameters. In this method each parameter is first reclassified and then weightage are assigned on the basis of its influence. In present study parameters chosen are slope, elevation, landuse/ landcover, aspect, drainage frequency etc. For all parameters; raster layers are prepared and and then reclassified using ranking method. And in final stage; weighted overlay tool is used using all reclassified layers and assigned influence to each layer depending on its effect on occurrences of landslides.

LANDSLIDE SUSCEPTIBILITY MAP

Finally output obtained through weighted overlay tool is the landslide susceptibility map for study area. The map clearly showed that most of the area (around 44 %) is under high susceptibility for landslide occurrences.

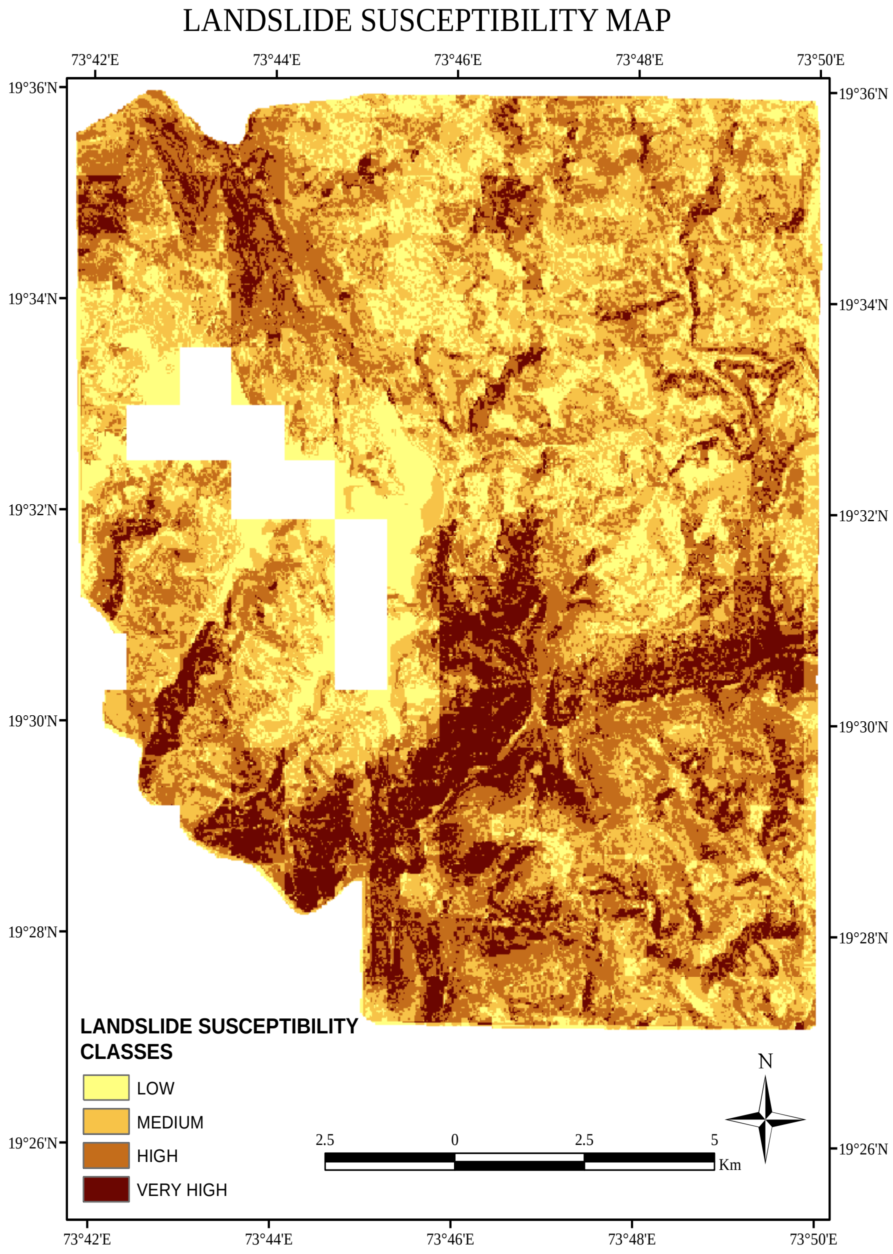

FIGURE 12
LANDSLIDE SUSCEPTIBILITY MAP

RESULTS AND CONCLUSIONS

1. 12% of the area has very high landslide susceptibility; this area contains 44.4% of the observed landslides.
2. 18% of the study area has high landslide susceptibility and contains 16.9% of the observed landslides.
3. 32% of the study area has moderate landslide susceptibility and contains 13.4% of the observed landslides.
4. 38% of the study area has low landslide susceptibility, but still contains 25.3% of the observed landslides.
5. The study reveals that the surrounding region of Bhandardara dam has very high susceptibility for landslides because of steep and unstable slopes.
6. Serious measures are necessary for minimizing the occurrences of landslides in the study area.

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