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LANDSLIDE SUSCEPTIBILITY ZONE IDENTIFICATION OF MARKHAM WATERSHED, PNG A STUDY BASED ON REMOTE SENSING AND GIS TECHNOLOGY

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Abstract

Landslides are natural hazards that often cause serious damages of properties and even life losses. Because of the rugged terrain in the mountain region, deforestation, mining activity and short rapid rivers, the landslides usually happen after heavy rains and the resulting erosion and flash floods in Papua New Guinea. In this study landslide susceptibility zone are pinpointed based on spatial decision support system based on remote sensing and GIS technology. The study area is Markham Watershed in the eastern part of Papua New Guinea, extended from 145.97 to 147.08 East and 5.86 to 7.53 South. Eleven parameters are selected for this GIS based multi-criteria decession support system, namely absolute relief, slope, aspect, Lithology, landforms, soil erodibility, rainfall, distance from road, land use, forest cover and drainage density. The result shows that some small pocket of high susceptible landslide area in the south and southwest corner of the watershed. The low landslide susceptible zone has been delineated in the central part of the watershed because of the flat terrain.

Keywords: Landslide, soil, drainage, slope, landforms and lithology, land use, vegetation cover, decision support system

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1. Introduction

Landslides have become one of the major natural disasters in worldwide. Over the last decade, it is possible to find many studies on landslide susceptibility assessment. The basic concept was first introduced by Akgun and Bulut (2007), Akguan et al., (2008), and Oh and Lee (2009) as the spatial distribution of factors related to the instability processes in order to determine zones of landslide prone areas without any temporal implication. It is widely recognized that geology, landform characteristics, soil type, land use, vegetation, slope and elevation etc play a significant role in landslide occurrence. With remote sensing techniques one can attain information for a large area from time to time and by amalgamating with GIS, all information can be combined, manipulated and data analysed to establish probable landslide areas (Akgun and Turk 2010; Nefeslioglu et al. 2010; Yeon et al. 2010; Sezer et al. 2011; Akgun 2011).

Papua New Guinea is prone to earthquakes, volcanic eruptions, tsunamis, cyclones, river and coastal flooding, landslides and drought. It is ranked 54th among countries most exposed to multiple hazards based on land area, according to the World Bank's Natural Disaster Hotspot study. The mountainous regions of Papua New Guinea are the areas most susceptible to landslides causing damage (Wikipedia 2012).

Due to its topography, high seismicity and high annual rainfall, the country ranked highest in terms of landslide hazard profiles according to the World Bank Hotspot study. According to Geoscience Australia (2008), three of the world's largest landslides recorded in the last 120 year have occurred in PNG. In the Highlands area, intensified land use due to increasing population and increasing climate variability are adding to the problem.

2. Study area

Markham river is the 4th largest river in eastern part of Papua New Guinea, that rises on the Finisterre Range at an elevation of 475m at 6° 06' 30" S 146°11' 30" E and receives the Erap river, which courses south from the Saruwaged Range, and the Watut River, which flows north from the Bulolo valley for 180 km to empty into the Huon Gulf at 6°44' 20"S 146°58' 05". The study area covers an area of about 12766 sq km. This area is dominantly covered by primary forest and vegetation. Deforestation in the study area has been extensive in recent decades and is continuing at an estimated rate of 1.4% of tropical forest being lost annually. Most parts of the Highlands were not accessed by outsiders until the 1930s and many settlements are still inaccessible except by very difficult overland routes. The mean annual rainfall is around 4200 mm in the Lae area, but less over most of the Markham River catchment. Eastern part of Eastern Highland province (3%), southern part of Madang province (3%) and a major part of Morobe province (94%) are occupied by Markham catchment (Figure 1).

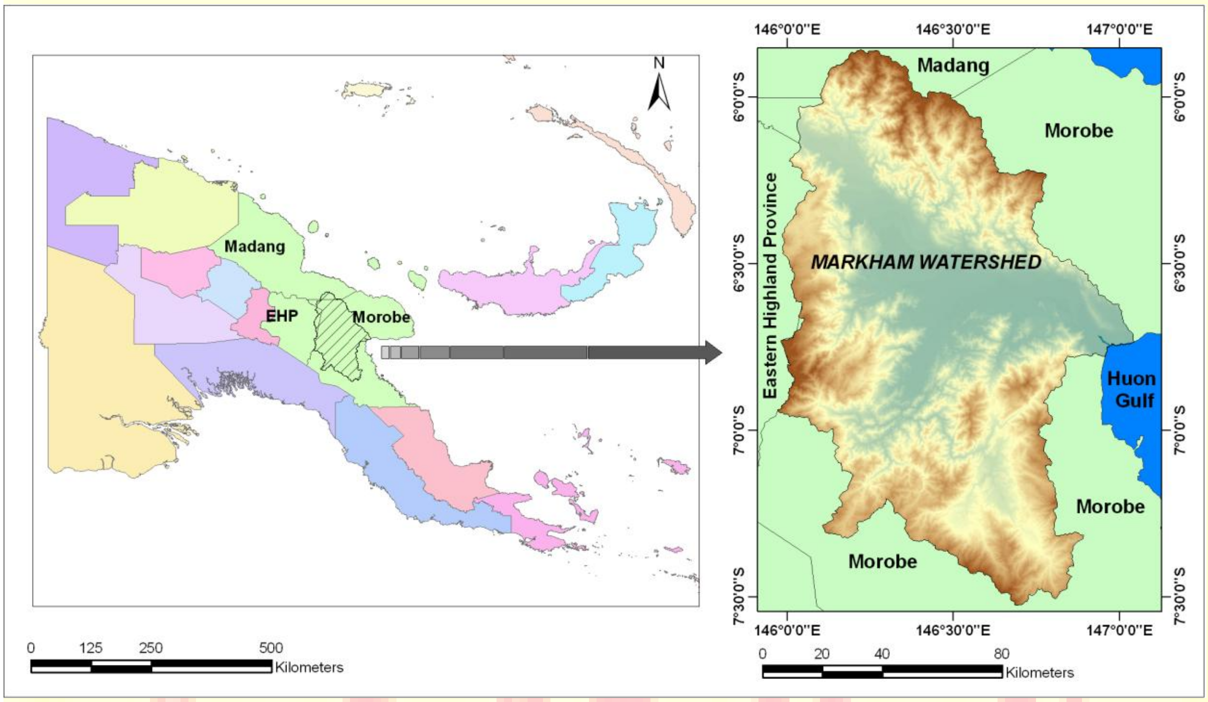


Figure 1. Location map of the Markham catchment area

3. Methodology

For the study area, variables relevant to landslide incidence were built in raster and vector-type spatial datasets using ERDAS Imagine v9.0 and ArcInfo v9.2 software package. To measure maximum and minimum heights within Markham watershed, Digital Elevation Model (DEM) has been created from the Shuttle Radar Topographic Mission (SRTM) data at 90 meters resolution. The slope and aspect map were prepared using the SRTM DEM data. Rainfall of the study area was estimated by interpolating between the point data from the rainfall station network of Climate of Papua New Guinea (McAlpine et al. 1983). The interpolation takes into account the strong orthographic influences that are a major feature of PNG rainfall variability. A lithology map of the study area is digitized from the existing Loffler (1974), and is based on simple criteria, such as origin, composition and grain size of parent material. These criteria are relevant to the interpolation of resource information, particularly soil properties, to unsurveyed parts of the country. The three main rock type categories recognised are sedimentary rocks, metamorphic rocks and igneous rocks. Loffler's (1974) 1:1000000 Geomorphology of PNG map and the 1:100 000 Topographic Survey maps were also used to delineate some landform types, in particular fluvial and littoral depositional landforms. The land use/land cover map was used from the NOAA (AVHRR) satellite image, derived from the Global Land Cover Facility (GLCF) is a NASA-funded member of the Earth Science Information Partnership at the University of Maryland (www.landcover.org). Vegetation canopy cover data set was generated from satellite images using a hybrid maximum-Normalized Differential Vegetation Index (NDVI) and minimum-red compositing technique (Hansen et al., 2000). Drainage map was prepared from the topographic maps with additional inputs from the satellite images. Road map was generated from the topographical sheet of the study area.

A zonation map was generated using lithological, geomorphological, altitudinal distribution, slope, land use, aspect, vegetation, drainage domains, rainfall, soil and distance to road maps. In this study, we used the weighted index overlay method. The values were extracted based on the level of influences. Expert opinion which depends on observed physical characteristic of landslide sites determined the levels of the influencing factors. Depending on the risk posed by each class the landslide susceptibility index e.g., weightings were allocated. The data layers have been incorporated in GIS environment by overlay analysis.

4. Results and Discussion

Assortment of factors and preparation of consequent thematic data layer are vital component of any model for landslide susceptibility mapping. The features leading instability in a terrain are mainly altitude, slope, aspect, lithology, landform characteristics, drainage, land use, soil, rainfall, vegetation cover and distance from the road. However, the importance of an exacting parameter depends on site-specific conditions. The following eleven types of parameters are considered as persuading strictures in landslides in this study.

4.1 Altitude

Altitude is a noteworthy landslide conditioning factor, as it is embarrassed by numerous geologic and geomorphological processes (Gritzner et al. 2001; Dai and Lee 2002; Ayalew and Yamagishi 2005). The elevation of the study area is ranged from 0 - 3939m (Figure 2A). Based on the altitudinal variation of the study area, has been categorized into five classes, e.g., (i) less than 500m, (ii) 501 – 1000 (iii) 1001 – 2000m, (iv) 2001 – 3000m and (v) more than 3000m. Landslide density decreases both upward and downward from the elevation.

4.2 Slope

Slope gradient is the most substantial cause of landslide. Slope angle is the most imperative constraint in the slope stability analysis, as it is directly related to the landslides and it is recurrently used in generating landslide susceptibility maps (Saha et al. 2005; Ercanoglu and Gokceoglu 2004; Lee 2005). A slope map of the study area was generated from DEM that represents the spatial distribution of slope values in the study area. The slope in this area is ranges from 0º to 89º (Figure 2B). The slope map of the study area is prepared from the DEM, and divided into five slope categories, viz. Less than 10º, 10 - 20º, 20 - 30º, 30 - 40º and more than 40º. It is a piece of evidence that less landslides crop up on mild and steep slope angle.

4.3 Aspect

Several other studies have been considered that aspect is also a landslide conditioning factor (Saha et al. 2005; Ercanoglu and Gokceoglu 2004, Yalcin 2005). Consequently, in this study, the aspect map of the Markham watershed is generated to demonstrate the aspect susceptibility area (Figure 2C). Aspect demarcates the steepest downslope direction from each cell to its neighbours. Exposure to sunlight, drying winds, rainfall (degree of saturation), and discontinuities influence by the aspect may control the occurrence of landslides. The northwest and southeast part of the Markham watershed showed to be higher risk for the landslide occurrence, observed in the north-eastern and south-western part.

4.4 Rainfall

A characterization of landslide triggering storms by rainfall duration and intensity has been used to establish a relation between storms and landslide in temperate and humid tropical areas of the world (Wieczorek, 1987; Wilson and Wieczorek, 1995; Dahal and Hasegawa, 2008). Rainfall characteristics of the study area is illustrated in Figure 2H. The mean annual rainfall of the study area is ranged from 2500 – 3000mm. Based on the rainfall intensity; the study area has been categorized into six different zones and there percent of area covered by each rainfall zone is also calculated, like (i) less than 1500mm (9.82%), (ii) 1500 – 2000mm (2.89%), (iii) 2000 – 2500mm (65.24%), (iv) 2500 – 3000mm (20.32%), (v) 3000 – 4000mm (1.27%) and (vi) more than 4000mm (0.46%).

4.5 Soil erodibility index

Soil with sparse vegetation is more susceptible to erosion. Soil erodibility of the study area is determined by the texture of the surface horizon and organic matter content (Table 1). The higher the soil erodibility is, the larger the breach size is, the shorter the breach time is, and the higher the peak outflow rate is. In the study site, it was found that the erodibility of soil is very high for the vertisols, while low soil erodibility characterized by high to very high organic matter content and moderate to rapid permeabilities. The soil erodibility zonation map of the study area is shown in Figure 2K.

Table 1: Soil erodability index of Markham watershed, PNG

Risk values	Soil erodibility
1	Very low - soils with high to very high organic matter content and moderate to rapid permeabilities. Granular to fine crumbly surface horizons. Some lowland Adepts may have moderate very fine sand and silt contents.
2	Low - except for sandy Entisols, these soils have moderate organic matter content and moderate permeabilities. The sandy Entisols have generally low organic matter content and are rapidly permeable and structureless.
3	Moderate - Generally slowly permeable soils with moderate organic matter content; the alluvial Entisols have low to moderate organic matter content, are massive and may have moderate very fine sandy and silt content.
4	High - Vertisols: very slowly permeable, often subject to surface scaling and have prismatic or coarse blocky structures, but moderate organic matter content. Ultisols and Alfisols: generally relatively low organic matter content and relatively high very fine sandy and silt content. Poorly structured topsoils.

4.6 Lithology

Landslides are significantly embarrassed by the lithological characteristics of the land surfaces. Since diverse lithologic units have different landslide susceptibility influence, they are very imperative in providing data for vulnerability mapping. In view of the fact, it is necessary to assemblage the lithological characteristics appropriately (Pachauri et al. 1998; Luzi and Pergalani 1999; Dai et al. 2001; Duman et al. 2006). The lithological characteristic of the study area is shown in Figure 2D. Mixed and undifferentiated sedimentary rocks were found in the northern and western part of the study area, covered by 22.49%. However, some small pockets of limestone and mixed sedimentary with limestone were observed in the north-east and central part of the district, covered only 2.11% of the study area, considered to be higher risk for landslide occurrence. Furthermore, the volcanic and igneous rocks (e.g., 22.01%) were found in the southwest, southeast and north-eastern part of the study area, marked to be lower risk for landslide occurrences. The low grade metamorphic rocks were observed in the southern part of the district, wrapped by 17.70% of the study area. Remaining part of the study area enveloped by the sedimentary and alluvial deposits, allocated in the central and some small pockets in the northern part.

4.7 Landform characteristics

It is extensively accepted that geomorphology significantly influences the occurrences of landslides, because landform characteristics and structural variations often escort to a disparity in the strength and permeability of rocks and soils (Pair and Kappel, 2002). The landform characteristic of the study area is shown in Figure 2E. 74.69% of the study area enclosed by mountains and hills terrains with weak or no structural control, which is highly risk for land slide occurrences. Little dissected recent alluvial fans are extended in the central part of the study area, covered by 6.90%. Remaining 18.40% of the study area is covered with the others alluvial, colluvial, structural plateaux, back swamps and plains etc.

4.8 Land use/land cover characteristics

Inappropriate and disorganized cultivation increase slope instability. The infiltration rate in cultivated land is maximum, while bare soil erodes hastily. If water is stirring on apex of the soil, it has a superior capability to shift loose soils and rocks. Land use/land cover alters like substitution of forest and agricultural land to road and other infrastructure is an vital factor in eliciting landslides. The land use map of the study area is shown in Figure 2F. The study area was classified into 14 land cover classes (Table), and the area covered by each land cover class was calculated. However, most of the study area is covered by evergreen broadleaf forest (e.g., more than 61% of the total area) and woodland forest (13.27%). In the central part, woodland grassland was found, enveloped with 16.88%. The closed and open shurblands were found, covered approximately 0.25%, and extended in the northern and south-western part of Markham. Cropland area is covered by 1.33%, while urban and built up region is wrapped only 0.07% and followed by waterbody (0.003%) of the study area.

4.9 Vegetation characteristics

Some researchers (Jakob 2000; Ocakoglu et al. 2002) accentuated on the significance of vegetation cover or land use characteristics on the stability of slopes, and they considered vegetation cover to assess the conditioning factors of landslides. Dense vegetation interrupts undeviating rainfall before raindrops shock the soil surface, so plummeting or eradicating rainsplash erosion. With dense vegetative cover and broad forest litter, the overland flow is also abridged in power and velocity, diminution surface erosion. Vegetation types have been described as evergreen and dense forest (Figure 2G). The area of vegetation characteristics was divided into five category based on the geometric interval, like (i) less than 10% coverage, (ii) 10-20% coverage, (iii) 20 – 30% coverage, (iv) 30 – 40% coverage and (v) 40% coverage. In the central and south-eastern part the density of vegetation is very less in the study site, considered as high potential for landslide occurrence.

4.10 Drainage density

In hilly regions, drainage density provides an indirect appraise of groundwater circumstances, which have a significant function to play in landslide activity. Generally, the higher the drainage density, the lower the infiltration and the faster the movement of the surface flow (Cevic and Topal, 2003; Yalcin, 2008). This phenomenon reduces the amount of infiltration, and ultimately sustains the soil strength as its initial condition. Conversely, streams may negatively affect stability by eroding the slopes or by saturating the lower part of material until resulting in water level increases (Gokceoglu and Aksoy 1996). Drainage density map of Markham watershed was generated by 2km^2 grid area (Figure I) and classified with five equal intervals into low to high drainage density, such as (i) less than 0.005, (ii) 0.006 – 0.100, (iii) 0.101 – 0.500, (iv) 0.501 – 1.00, (v) more than 1.01.

4.11 Proximity to roads

Road-cuts are typically sites of anthropologically provoked unsteadiness. Road construction may act as a barrier, a net source, a net sink or a corridor for water flow, and depending on its location in the mountains, it generally provides as a source of landslides (Shaban et al., 2001). Landslides may occur on roads and on slopes affected by roads (Ayalew and Yamagishi, 2005; Yalcin, 2008).For this reason, five different buffer areas are created on the path of the road to determine the effect of the road on the stability of slope as well as the landslide occurrences (Table 2and Figure 2J).

Table 2: Criterion table for identifying groundwater recharge potential zones

Criteria	**Classes**	**Rank**	**Weightage**
Altitude (meters)	<500	1	1.0
	501 – 1000	4	
	1001 – 2000	5	
	2001 – 3000	3	
	>3000	2	
Slope (°)	<5	1	2.0
	6 – 10	2	
	11 – 20	3	
	21 – 35	4	
	>35	5	
Aspect	Flat	0	0.5
	North	5	
	Northeast	3	
	East	4	

Criteria	**Classes**	**Rank**	**Weightage**
Land use/land cover characteristics	Urban and built up	1	1.0
	Evergreen broadleaf forest	1	
	Deciduous broadleaf forest	1	
	Woodland grassland	1	
	Closed shrubland	2	
	Open shurbland	4	
	Grassland	2	
	Crop land	2	
	Woodland	1	
	Bare ground	4	
	Water	0	
Vegetation density (% of coverag	Very high (more than 40%)	1	1.5
	High (30- 40%)	2	
	Moderate (20 – 30%)	3	

	Southeast	1		e)	Low (10 – 20%)	4	
	South	2			Very low (less than 10%)	5	
	Southwest	1		Rainfall intensity (mm)	Less than 1500	1	1.0
	West	2			1501 – 2000	2	
	Northwest	3			2001 – 2500	3	
Lithology	Fine grained sedimentary	1	0.5		2501 – 3000	4	
	Coarse grained sedimentary	2			3001 – 3500	5	
	Mixed or undifferentiated sedimentary	2			More than 4000	2	
	Mixed sedimentary and limestone	4		Drainage density (km^2)	Less than 0.005	1	0.5
	Limestone	5			0.006 – 0.100	2	
	High grade metamorphic	1			0.101 – 0.500	3	
	Mixed sedimentary and volcanics	3			0.501 – 1.00	4	
	Basic to intermediate volcanic	1			More than 1.01	5	
	Intermediate to acid volcanic	1		Distance from roads (in meters)	<100	1	0.5
	Mixed or undifferentiated volcanic	1			101 – 200	1	
	Acid to intermediate igneous	2			201 – 300	2	
	Mixed or undifferentiated igneous	3			301 – 400	2	
	Pleistocene sediments	2			401 – 500	3	
	Alluvial deposits	1			501 – 600	3	
Landform characteristics	Dissected relict alluvial, colluvial mudflow and fans	4	0.75		601 – 700	4	
	Structural plateaux	1			701 – 800	4	

	Hilly terrain with weak or no structural control	5			801 – 900	5	
	Mountains and hills with weak or no structural control	3			>900	5	
	Mountains and hills associated with relict surfaces with weak or no structural control	3		Soil erodability	Very low	1	0.75
	Homoclinal ridges and cuestas: inclined asymmetrical structurally controlled ridges	2			Low	2	
	Polygonal karst: plateaux or broad ridges on limestone covered with numerous rugged hills	4			Moderate	3	
	Little dissected or undissected relict alluvial, colluvial mudflow or fans	2			High	4	
	Back plains	1					
	Back swamps	1					
	Undifferentiated swamps	1					
	Braided floodplains or bar plains	1					
	Composite alluvial plains	1					

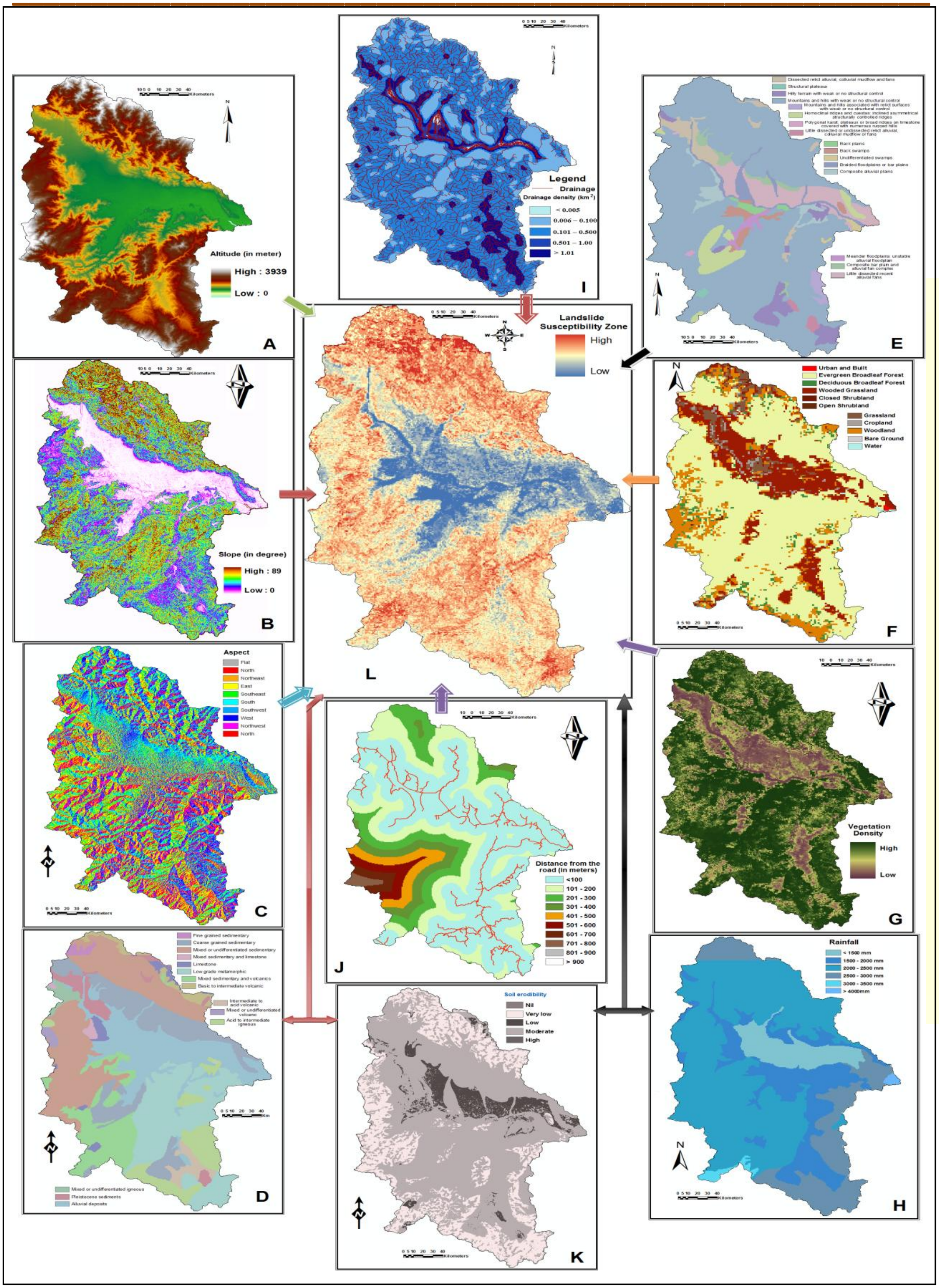
4.12 Landslide susceptibility mapping

In this method, all factors were classified into a few groups. The level of influence for groups and parameters were determined by the range of weighting and were determined by the range of weighting values between spectrums from minimum to maximum. The range value is between the minimum and maximum weight value. The final weight value for each class parameter is produced by multiplying the group weight value, parameter weight value and normalized priority value of class parameter (Table 2). Based on total weight value, the susceptibility map for Markham watershed was generated (Figure 2L). The result of our analysis showed that the northern zone of the watershed is highly susceptible for landslide occurrence; while, some small pocket of high susceptible landslide area were also portrayed in the south and southwest corner of the watershed. The low landslide susceptible zone has been delineated in the central part of the watershed because of the flat terrain. However, in the southern and western part of the watershed were marked as a medium vulnerable for landslide event.

5. Conclusion

The landslide susceptibility map prepared in the present study is the result of a combination of various factors responsible for landslide susceptibility, in which each factor has relative importance to probable landslide activity. A reliable and accurate susceptibility map depends on the inclusion and proper determination of the role of these parameters. In this study, twelve landslide-controlling parameters namely slope, aspect, altitude, land use, lithology, landform characteristics, rainfall, vegetation coverage, soil, drainage density, distance from rivers, distance from roads were considered. The outcome of the present study is shown very promising result that can be used for planning programme to control the landslide occurrence area in Markham watershed. As the methodology implemented in this research is based on logical conditions and reasoning; however, it can be applied in other regions for delineating the susceptible zone for landslide occurrence.

Figure 2: Integration of geo-environmental characteristics of Markham watershed for delineation of the probable area for landslide occurrence. (A) Altitude, (B) Slope, (C) Aspect, (D) Lithological characteristics, (E) landform characteristics, (F) Land use/land cover characteristics, (G) Vegetation characteristics, (H) Rainfall, (I) Drainage density, (J) Distance from the road, (K) Soil erodability, and (L) Landslide susceptibility map of Markham Watershed (Next Page).



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