Contrasting an Effective Human Causes to Landslides Using GIS Technology

By

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Declaration

The work described in this thesis was carried out by me at the Landslide Studies and services division (LSSD), National Building Research Organization (NBRO), 99/1, Jawatta Road, Colombo 05, under the supervision of Mrs. Kumari M. Weerasingha and Dr. S. K. Gunatilake. The report on this has not been submitted to any other university for another degree.

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Affectionately Dedicated

To

My Parents & Teachers !

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ABSTRACT

During the last few decades, landslides occurred with increasing frequency in the slopes of the hill country by causing severe damages to life and property. Badulla district is taken as one of the most landslide affected area in Sri Lanka. Human activities add a new and very significant dimension to Initiation, Growth and Devastating potential of landslides in the rapidly developing hill country.

The study area consist Landslide prone 4 square Km's area in Viharagala G.S. Division within Badulla district. The study was initiated with a desk-study of State-of-Nature maps which represent the situation in the year 1994 and the field investigation was conducted to examine the state of the location in year 2006. Those two distinct state maps were analyzed by using spatial data interpreting methods. The modern GIS software was used to carryout these tasks, that provides an excellent tools to correlate the data spatially and generate and analyze maps & other forms of thematic information.

The spatial analysis results were showed that, from the year 1994 to 2004, people moreover moved and settled in landslide potential areas and the observations were revealed that, the people encroaching the land towards the steeper slopes by applying unprotected deep cuts, land fillings and land degradation practices. Analysis results revealed that the poorly managed Estate Plantations are highly contributed to occurring Landslides as because of poor soil conservation practices. Due to these, the acceleration of Landslides hazards and related other environmental degradation is prominent. Even during this period from 1994 to 2006, adverse land-use practices have been rapidly increased. Land Stability Analysis results were indicated that the moderate stabilized areas in 1994 were transformed to low & medium stabilize lands. The conclusion stated that the incidence of Landslides and potential slope failures has a direct link with human involvement. Although to reduce or mitigate the hazard of landslides, educating the villagers, on the issues such as the human influence in creating landslides and the good practice of land use, is a must.

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CHAPTER I

1. Introduction.

1.1 General background

Landslides are a common natural phenomenon in many part of the world, especially in hilly or mountainous terrains. Those events can be either natural or man-made. Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In low-relief areas, landslides occur as cut-and-fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, collapse of mine-waste piles (especially coal), and a wide variety of slope failures associated with quarries and open-pit mines. Landslides events are complex geological/ geomorphological processes and therefore difficult to classify (Daluwatta, 1994). The most commonly used landslide classification system is based upon material type and type of movement describes by Cruden and Varnes (Varnes, 1998).

Disasters due to landslide hazards have brought significant economic and social impact causing severe damages to life and property, environment and socio-economic life of the society. They cause property damage, injury and death and adversely affect a variety of resources. Water availability, quantity and quality can be affected by landslides. Therefore study, identify and mitigate landslides is one of the most important area in the current century (Amaratunga, 1994).

1.2 Landslides in Sri Lanka

In Sri Lanka during the last few decades, landslides occurred with increasing frequency in the slopes of the hill country. It consists of many districts of Badulla, Nuwara Eliya, Ratnapura, Kegalle, Kandy, Matale and Kalutara and due to devastation cause by heavy rains in May 2003, Matara and Hambantota districts have also been found to be landslide prone. These areas underlain by highly folded, fractured and weathered metamorphic rocks have a high probability for landslides. Intense precipitation is a major factor contributing to the occurrence of landslides. The all area covers an approximate extent of 10,000 km^2. It is about 20% of the total area of the island and occupied by about 30% of the total population of Sri Lanka. In the recent memory, peaks of landslide disasters had occurred in January 1986, May/ June 1989, October 1993, September 1997, April/ May 2002 and June 2003 (NBRO, 2005).

Major landslides occurred during the past two decades have caused loss of thousands of lives and about 175,000 people became homeless. Damages to life and properties due to frequent occurrences of landslide increase with run-out velocity and hence people who are living within the vulnerable area and along the run-out track of the slide have no time to escape (Amaratunga, 1994).

Those incidents awaken us to pay utmost attention to the dire effects of those catastrophes. It is even more important when looking from a viewpoint of sustainable development - a key word in vogue.

1.3 Nature of the problem

The past history of Sri Lanka has been experiencing a spate of landslides over extensive areas of its central hill country and south western region which have caused many problems to everyone. Thus studying area consists of landslide prone locations those stay within closer to each other. Therefore discrimination of former landslides will be important in landslide management process (Wilson, 1994).

Landslide risk management, like many other forms of risk management of natural and/or civil engineering hazards, is a relatively new discipline with evolving analysis techniques. Procedures for landslide risk management including risk assessment have not been standardized in the past, although use of "risk" or "hazard" zoning maps is widespread internationally. In Sri Lanka, there are little number of approaches done towards introducing scientific practices of landslide risk assessment delineating the degrees of hazard, identifying elements at risk and risk treatment. Therefore it is desired to identify a human intervention effect to evaluate and mitigate the landslide risk in central hilly areas. As a product of the risk assessment at specific site or elements at risk (property and person) describing in qualitative terms (high risk, medium risk, low risk etc.) was not sufficient to indicate the severity of damages (Jayamanna, 1994).

1.3.1 Scope of the study

Identification of landslide hazard area is important for the site selection and development planning of housing and infrastructure facilities within the landslide prone area. Landslide prone area and former landslides could be identified using landslide hazard zonation maps. (eg. Sri Lankan landslide hazard zonation maps of 1:10,000 scale). A significant feature of Sri

Lankan landslides of the Central Highlands is that most of theses are resulting from reactivation of dormant ancient slides that were in equilibrium. The reactivation may be due to natural reasons or man's interference (Dahanayake, 1995).

Lot of studies have been done mainly on underground Geology, hazard Zonation of landslide, and mitigation Practices. Although these studies have given less attention to changing land-use practices and human activities Dahanayake, 1994 pointed out that these reactivations may be due to natural reasons or man's interference. Therefore finding the effects of landuse practices on landslides in Beragala area is the main objective of this current study. To achieve these objectives, identifying landslide locations and landslide risk areas to mitigate landslide disasters in the study area is the major part of the research.

Geographical Information System (GIS) is used to predict suitable areas for human settlements and other land use practices in the study area. As this powerful software has more advantages to overlaying development new landslide hazards map will be developed using this tool.

CHAPTER 2

2. Literature Review

2.1 Landslide as a Natural Disaster

Landslides are attracting increasing attention in many countries in the world as a Natural Disaster. They cause substantial damage to the constructions and infrastructure etc., and therefore the development of many countries are threatened by them.

A landslide event is defined as "the movement of a mass of rock, debris, or earth (soil) down a slope (under the influence of gravity) (Cruden, 1991). The word "landslide" also refers to the geomorphic feature that results from the event. The materials may move by falling, toppling, sliding, spreading, or flowing. Figure 2.1 shows a graphic illustration of a landslide, with the commonly accepted terminology describing its features.

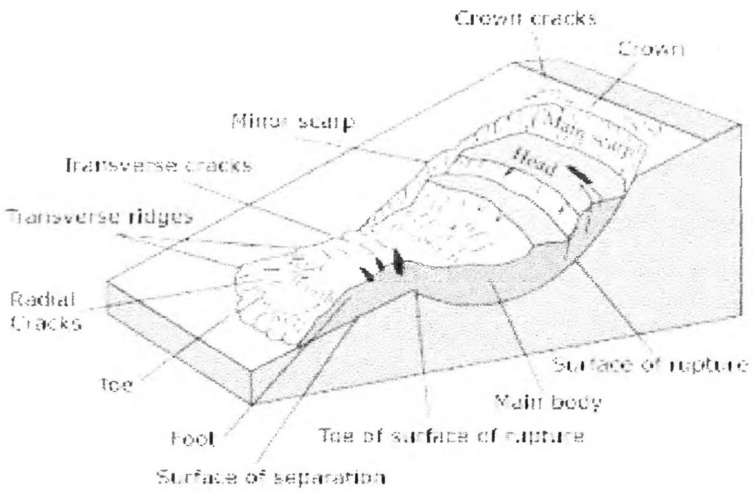

Figure 2.1 : An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a Landslide.

(Source :- http://nationalatlas.gov/articles/geology/a_landslide.html#one)

Once a landslide is triggered, material is transported by various mechanisms including sliding, flowing and falling. Landslides often occur along planes of weakness that may parallel the hill slope. In bedrock, planes of weakness are usually beds, joints or fractures. Soils such as silt and clay are weaker than rock and commonly have complex or multiple planes of weakness (Cooray, 1994).

In Sri Lanka, most of the landslides, rock and cutting failures occur in the central highland of the country. The central region of Sri Lanka is hilly and mountainous with highly fractured

and folded basement rock overlain by residual soil and colluvium soil layers. The elevation of the hilly region of the country ranges from 185 m to 2717m above mean sea level. It is about more than 20% of the total land area and is occupied by 30% of the total population of the country. Frequent occurrence of landslides, slope failures and rock falls and reactivation of them is a frequent phenomenon in these areas causing severe damages to life and property. Therefore occurrence of frequent landslides & slope failures could be considered as the most significant natural disaster in Sri Lanka. They are likely to have a greater economic impact in the urban and semi urban environment when there is a possibility of damage and losses to investments on various development projects, infrastructure facilities and more importantly to lives. Whereas, the total extents of loss of forest cover, wild life, and damage to the ecosystem cannot be estimated and will probably be remained still unknown.
(Dissanayake, 1994)

2.2 Classification of Landslides

The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. A classification system based on these parameters is shown in Figure 2.2. Other classification systems incorporate additional variables, such as the rate of movement and the water, air, or ice content of the landslide material.

Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In low-relief areas, landslides occur as cut-and-fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, collapse of mine-waste piles (especially coal), and a wide variety of slope failures associated with quarries and open-pit mines (Cruden, 1991).

Table 2.1 - Types of landslides. Abbreviated version of Varnes' classification of slope movements.

<table>
<tr><th colspan="2" rowspan="3">Type of Movement</th><th colspan="3">Type of Material</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Engineering Soils</th></tr>
<tr><th>Predominantly Coarse</th><th>Predominantly Fine</th></tr>
<tr><td colspan="2">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">TOPPLES</td><td>Rock topple</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">Rock slide</td><td rowspan="2">Debris slide</td><td rowspan="2">Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td></tr>
<tr><td colspan="2">LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="2" rowspan="2">FLOWS</td><td rowspan="2">Rock flow
(deep creep)</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td colspan="2">(soil creep)</td></tr>
<tr><td colspan="2">COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

(Source :- http://nationalatlas.gov/articles/geology/a_landslide.html#one)

The most common types of landslides are described as follows,

2.2.1 Slides : Although many types of mass movements are included in the general term "landslide", where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides.

2.2.1.1 Rotational slide : This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (Figure 2.2.1-A).

2.2.1.2 Translational slide : In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting (Figure 2.2.1-B). A block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move down slope as a relatively coherent mass (Figure 2.2.1-C).

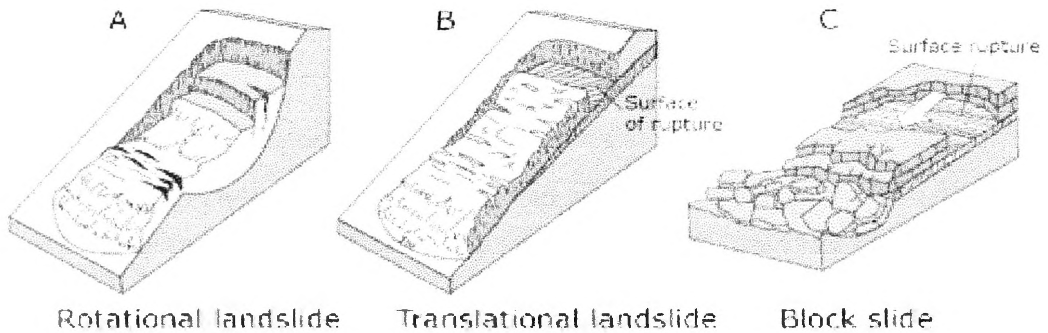

Figure 2.2.1 Schematic Illustration of major types of landslide movements. - 1.

2.2.2 Falls : Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs (Figure 2.2.2-D). Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.

2.2.3 Topples : Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks (Figure 2.2.2-E).

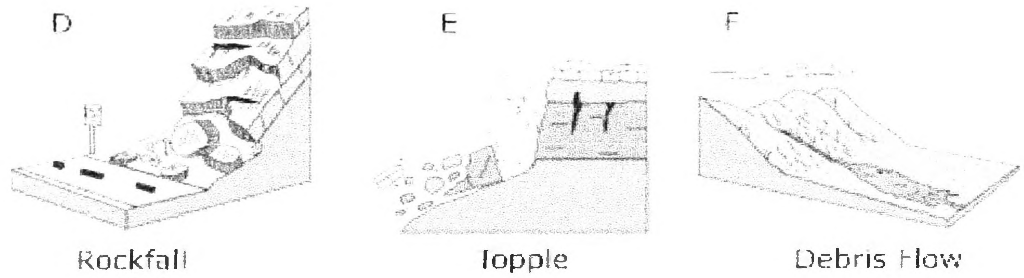

Figure 2.2.2 Illustration of major type of landslide movements. - 2.

2.2.4 Flows : There are five basic categories of flows that differ from one another in fundamental ways.

2.2.4.1 Debris flow : A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows down slope (Figure 2.2.3-F). Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows.

2.2.4.2 Debris avalanche : This is a variety of very rapid to extremely rapid debris flow (Figure 2.2.3-G).

2.2.4.3 Earthflow : That has a characteristic "hourglass" shape (Figure 2.2.3-H). The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

2.2.4.4 Mudflow : A mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."

2.2.4.5 Creep : Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges (Figure 2.2.3-I).

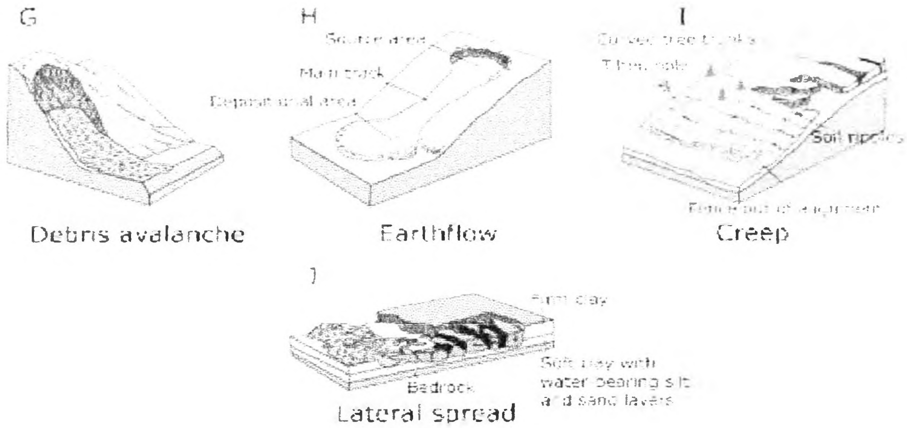

Figure 2.2.3 Illustration of major type of landslide movements. - 3.

2.2.5 Lateral spreads : Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain (Figure 2.2.3-J). The dominant mode of movement is lateral extension accompanied by shear or tensile fractures Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason. Combination of two or more of the above types is known as a complex landslide.

(Source :- http://nationalatlas.gov/articles/geology/a_landslide.html#one)

2.3 Causes of Landslides

Integral to the natural process of the earth's surface geology, landslides serve to redistribute soil and sediments in a process that can be in abrupt collapses or in slow gradual slides. Such is the nature of the earth's surface dynamics. Also known as mud flows, debris flows, earth failures, slope failures, etc., they can be triggered by rains, floods, earthquakes, and other natural causes as well as human-made causes, such as grading, terrain cutting and filling, excessive development, etc. Because the factors affecting landslides can be geophysical or human-made, they can occur in developed areas, undeveloped areas, or any area where the terrain was altered for roads, houses, utilities, buildings, and even for lawns in one's backyard.

As development pressures around the country increase, so does the likelihood of building in areas susceptible to landslides. Such areas are neither isolated nor far in-between. As our cities, towns, roads and highways steadily encroach onto steeper slopes and mountainsides, landslide hazards become an increasingly serious threat to life and property.

Some slopes are susceptible to landslides whereas others are more stable. Many factors contribute to the instability of slopes, but the main controlling factors are the nature of the underlying bedrock and soil, the configuration of the slope, the geometry of the slope, and ground-water conditions.

Three distinct physical events occur during a landslide: the initial slope failure, the subsequent transport, and the final deposition of the slide materials. Landslides can be triggered by gradual processes such as weathering or by external mechanisms including:

- **Undercutting** of a slope (by stream erosion, wave action, human activity.
- **Weathering** of weaker strata at the toe of the slope.
- Washing out of granular material by **seepage erosion.**
- Intense or **prolonged rainfall**, sharp fluctuations in ground-water levels.
- Natural **accumulation of water.**
- **Loading on upper slopes** or man made pressure.
- **Shocks or vibrations** caused by earthquakes or construction activity.

Once a landslide is triggered, material is transported by various mechanisms including sliding, flowing and falling. Landslides often occur along planes of weakness that may parallel the hill slope. In bedrock, planes of weakness are usually beds, joints or fractures. Soils such as silt and clay are weaker than rock and commonly have complex or multiple planes of weakness.
(Source :- http://www.em.gov.bc.ca/Mining/Geolsurv/Surficial/landslid/default.htm)

2.3.1 Effective human factor

Landslides may result directly or indirectly from the activities of people. Slope failures can be triggered by construction activity that undercuts or overloads dangerous slopes, or that redirects the flow of surface or ground-water.

Poorly planned forest clearing may increase rates of surface water run-off or ground-water infiltration. Inefficient irrigation or sewage effluent disposal practices may result in increased ground-water pressures, which in turn can reduce the stability of rock and sediment.

People increase the risk of landslides by modifying the landscape, for example, by building on unstable slopes or in the path of potential landslides. Unfortunately, many people are unaware of their exposure to landslide risks (Katupotha, 1994).

2.4 Landslides occurrences in Sri Lanka

In the case of occurrences of landslides in Sri Lanka, seven major districts have been identified as landslide prone areas that are Badulla, Nuwara-eliya, Rathnapura, Kegalle, Kandy, Matale and Kalutara. Nearly 12,500 Km^2 of highly prone area to landslides spread over these seven districts. However, during the last rainy season on 17^{th} May 2003, hilly areas belong to Matara and Hambantota districts were severely affected by large-scale landslides and slope failures.

Major landslides occurred during the past two decades have caused loss of thousands of lives and about 175,000 people became homeless.

Following are some of the most significant landslide events in the recent recorded history of Sri Lanka

1. Landslide at *Abayapura,* which occurred in May 2003 killing 68 people soon after a heavy rain. A large part of a village has gone under landslide debris and as a result of this transportation, communication, electricity, etc., were totally paralyzed.

2. Slope failures at *Badulla,* which occurred in year 2002 killing 9 people. As a result of these incidences, some 16 families became homeless.

3. Debris flow at *Balangoda,* which occurred in year 2002 killing 09 people and destroyed about 300 m long portion of *Colombo- Badulla* highway. Axial length of the slide is about 6 Km.

4. The landslide at *Naketiya,* which occurred in year 1997 destroying about 200 m long portion of *Beragala - Wellawaya* road 67 people homeless. The axial length of the slide is about 3 Km's and 5 - 10 hectares of land has been displaced as a result.

5. The landslide at *Rathnapaura,* which occurred in 1993, killed 38 people and destroyed 11 houses right after a heavy rainfall.

In addition, several other small-scaled landslides, slope failures and rock falls took place killing hundreds of people. Damages to life and properties due to frequent occurrences of landslide increase with run-out velocity and hence people who are living within the vulnerable area and along the run-out track of the slide have no time to escape.
(Bandara, 2004)

2.5 Some well-studied Sri Lankan Landslides

Large numbers of Sri Lankan landslides have been studied by the Scientists of NBRO and few of these are discussed below,

2.5.1 Watawala Landslide

The different aspects of Watawala Earthslide have been presented by Abeykoon, Rajaratnam and Bhandari. It is a well documented case record of an earthslide which is known to repeat itself more or less annually, on discrete boundary shears. The reactivation occurs chiefly during the period of the South-West monsoon, from May to October. The slope which historically stood safe at intensities of 400 mm per day now yields to rainfall intensity of as low as 80 mm per day. The slope surface movements acquire a speed close to 2 m per day. The measurements of surface movement, sub-surface movement, piezometric pressures and rainfall data, carried out particularly during 1992 and 1993 have yielded correlations which adequately explain the slide activity. The factor of safety of this earth slide hangs on a knife edge, as it tends to acquire pseudo - stability during the dry period, every time plunging into the domain of instability, during the wet period.

The following topics of research emerge from the study of the Watawala case resend.

(1) The shear strengths mobilized on discrete boundary shears are well below peak indeed very close to or at the residual. The magnitude of shear strength parameters of the sliding mass corresponding to peak and residual needs to be determined more reliably. The insitu shear tests and limited laboratory tests done so far indicate that the peak angle of shearing resistance of 40° may reduce to a figure as low as 14° at the residual state.

(2) The slip surfaces observed and mapped at Watawala carry clear signatures of large. It perhaps affords the best Sri Lankan example of slicken-sided slip surfaces, which deserve to be studied through polarizing optical microscope. The water content and the clay content on the slip surface may be higher than those in the soil masses above and below it.

(3) Vacillation of factors of safety in the neighbourhood of 1.0 (at limit equilibrium) is a direct result of rising piezometric profile in the slide area. How this build up of pore water pressure takes place in relation to rainfall and slide movements is a matter of profound practical importance. More investments are clearly necessary for piezometric monitoring, deploying a blend of quick responding vibrating wire as well as some rugged and more durable hydraulic piezometers.

(4) Because of the high coefficient of permeability of the sliding mass, rain water infiltration into the less weathered rock strata underneath, is very slow and recharge of ground water table may be expected when rainfall intensities exceed 100 mm per day. Therefore, study of the spatial variations of ground water permeability in the soil profile is of great importance.

(5) Sub soil exploration conducted so far has provided direct evidence of cavities perhaps in the marble strata. The distribution, extent and the nature of these cavities remains to be found. Naturally nothing much could be said about the role under ground cavities play in inducing slope instability. Nothing much is known or could be conjectured about their long range, eventual effect.

(6) The rather curvilinear geometry in plan of the Watawala earthslide is not amenable to simple stability analysis calculations. The different magnitudes of rates of slope movements at different locations within the slide further compound the problem. (Dahanayake, 1994)

2.5.2 Helauda Earthflow

Helauda earthflow of 8 October 1993 which killed about 31 people is a classical example of threat to the lives and property located at the mouth of a gully or at the toe of a problematic slope or a potential landslide (Bhandari, 1994).

The aspects which deserve to be studied are as follows,

(1) The effective methodology of mapping of the vulnerable sites where potential landslides threaten human settlements and infrastructure at the slope base. Once that is done it should be possible to closely monitor the site for timely preventive and/or corrective action.

(2) The zone of influence of the earthflow deserves to be mapped, because the threat is not limited only to those living at the mouth of the slope but also those living in the close vicinity of the slide. The side slope may often give way jeopardizing the stability of a slope, when a landslide tends to widen. What is important is therefore to understand the stability of the adjacent slopes by implementing an appropriate instrumentation and monitoring programme.

(3) The mechanism of initiation of such earthflows must be studied in order to facilitate the design of a cost effective remediation package.

2.6 Landslide Forecasting in Sri Lanka

2.6.1 Landslide Hazard Zonation Maps

Landslide Hazard Zonation Maps are the major tool for forecasting hazardous zones of the hilly area in Sri Lanka.

Mapping essentially represents a scientific attempt to unfolding the causative factors which directly or indirectly influence slope instability and concentrate them to develop a criterion on the basis of which slopes could be graded in terms of their estimated degree of instability danger and hazard. Therefore, it was important to identify the most important causative factors influence the instability and select the most relevant ones in order to collect the related information for compilation in map form. The data collection was carried out through extensive field survey and air-photo interpretations. The scale has been selected as 1:10,000 which is convenient and enough to register variations or changes of observations that could be elaborated in sufficient details in a map. The State-of-Nature maps covering the following aspects have been prepared ;

(a) Former landslides and colluvium
(b) Bedrock geology
(c) Hydrology and drainage
(d) Slope range
(e) Landuse and management
(f) Landform
(g) Human Settlement and infrastructure

An inferred landslide hazard map was prepared integrating the derived potential of each and every factor eg. Bedrock formations, colluvium thickness, hydrology, slope ranges, landuse management categories and morphological elements by allocating a relative ranking, a numerical value for each element or map unit. Then the inferred hazard was verified against the actual landslide occurrences given in old landside map to qualify the relative rankings or to find a appropriate convergence as the given score is an assessment by judgment. This graded landslide hazard map gives a zonal significance in respect of the landslide hazard potential (Bhandari, 1994).

2.6.2 Rainfall Forecasting

Almost all the Sri Lankan landslides investigated to date are known to be rain triggered. It has therefore been customary in Sri Lanka to interpret landslide events in terms of the rainfall history, immediately preceding the slide event. Statistical thresholds of rainfall obtained as a result of such studies are being deployed as regional early warning indicators. In late 80's when information was scanty, the landslide triggering threshold was placed at 200 mm of rainfall in a 72 hour period, provided rain in the area continued. The criterion did work only partially, in case of reactivation of recent, seasonally active landslides. Most first time landslide events fell on either side of the threshold, transgressing the criterion at several locations.

Analyses of rainfall records of a very large number of Sri Lanka landslides, conveys that the 24 hour rainfall associated with a landslide event was generally 2 - 23 times higher than the average daily rainfall of that location.

Despite the above finding which link occurrences of landslides with rainfall, the fact remains that rainfall alone is not a good enough early warning indicator, especially for the first time slides. Even in so far as the known repetitive landslides are concerned, it was inappropriate to rely wholly on rainfall. In fact, by ignoring other causative factors in landslide forecasting, the chances of raising a false alarm were higher than the chances of a reliable forecast. Early warnings against landslides are therefore usually not meaningful unless given in relation to the exact location of the anticipated event.

At the Watawala Earth-slide, the slopes which stood safe with rainfall intensities on the order of 400 mm in a 24 hour period in the historic past, are now known to yield and move at rainfall intensities as low as 70 mm in a 24 hour period, because of the chequered history, presence of discrete boundary shears and large movements on them.

Not all landslide events trigger landslides or lead to slope movements. Only with progressive weakening of slopes however, there comes a stage when first time landslides occur following precursory movements which often go unnoticed. Once a slope is weakened, subsequent showers of rain invariably triggers slope movements. In such cases, mere consideration of rainfall may prove to be a deceptive indicator, and recourse is invariably necessary to measurement of slope movements and piezometric pressures within the potentially unstable zone. (Wickremasekara, 1994)

2.6.3 Present being developing landslide forecasting system

Combine hydrological slope stability model for forecasting slope stability with the use of deterministic approach.

Slope instability hazard zonation is defined as the mapping of areas with an equal probability of occurrences of landslides within a specified period of time. (Varnes, 1998)

A landslide hazard zonation consists of two different aspects.

1. The assessment of susceptibility of the terrain for a slope failure.
2. The determination of the probability that a triggering event occurs.

An area is a declared to be susceptibility for landslides, when the terrain conditions at that site are comparable to those in an area a slide has occurred. The instability of a slope is governed by a complex of normals interrelated terrain parameters, such as : lithology, and the structural conditions of the rocks, the weathering and the contact with over lying soils, the properties of these soils. Slope gradient and form hydrological conditions, vegetation, landuse and landuse practice and finally human activities acting on the slope conditions.

The joint analysis of all these terrain variable in relation to the spatial distribution of landslides, has gained enormously by the introduction of Geographic Information Systems (GIS), the ideal tool for the analysis of parameters with high degree of spatial variability.

CHAPTER 3

3. Materials & Methodology

3.1 Physical conditions of the studying area

3.1.1 Geographical Location

The study area administratively located in Badulla district, Uva province within the DS (Divisional Secretariat) division of Haldummulla. The Studying area and its environs extend from 6 ° 44' 45'' to 6 ° 45' 52''N Latitudes and from 80 ° 55' 32'' to 80 ° 56' 42''E longitudes covering an area about 4 square.Km's.

This area can be accessible from the two main roads. One is Beragala-Wellawaya road by the distance of 1 Km from the Beragala junction (which meets Beragala-Wellawaya road to Badulla-Colombo Main road) towards wellawaya, and other can be reached within Badulla main road from 1 Km towards Badulla from the Beragala junction. The Figure 3.1 showing the Studying location.

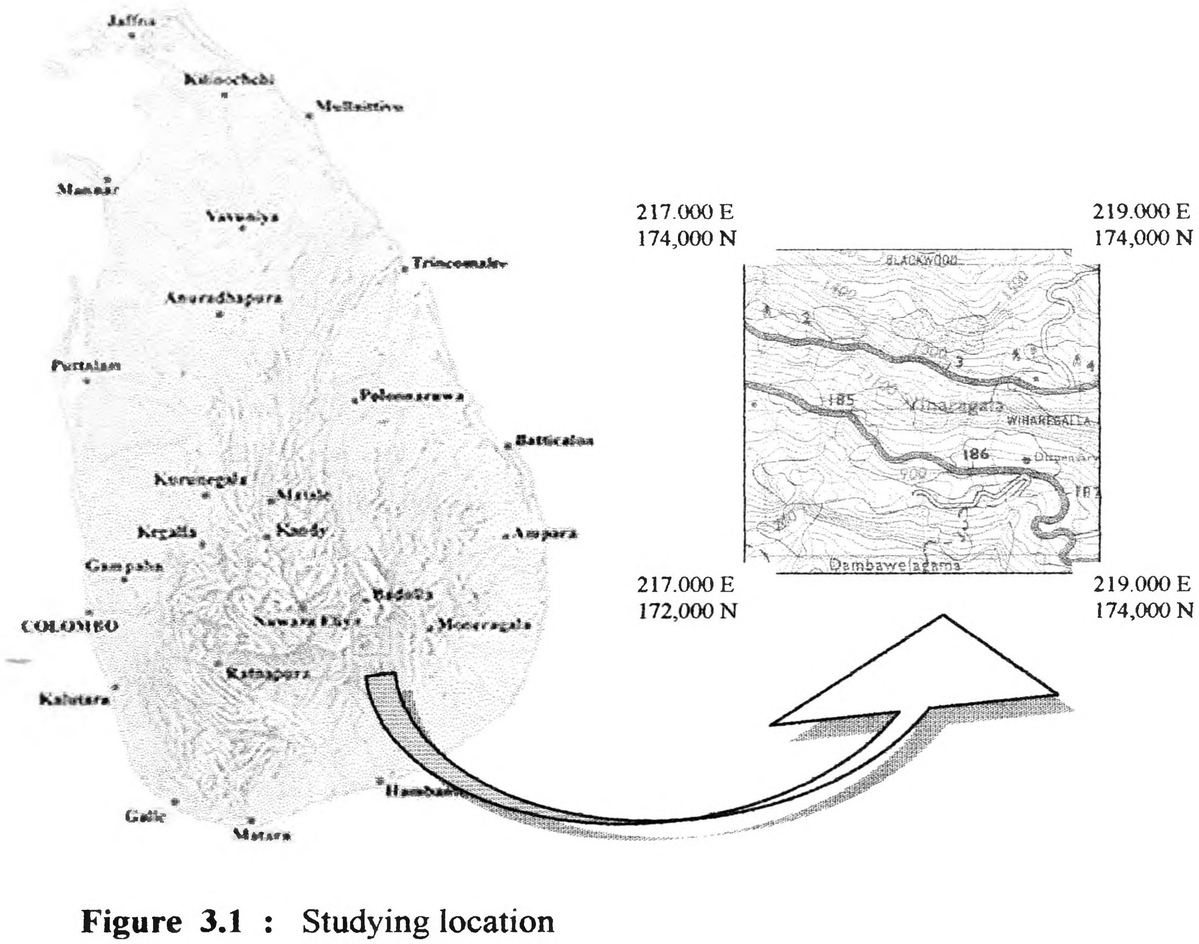

Figure 3.1 : Studying location

3.1.2. Geology

Landslides are commonest in the central hilly area of Sri Lanka which is generally considered to be land over 300 m above the mean sea level. However, few landslides occurred in the relatively low hills (100-300 m) of the South-West of Sri Lanka (Figure 3.2).

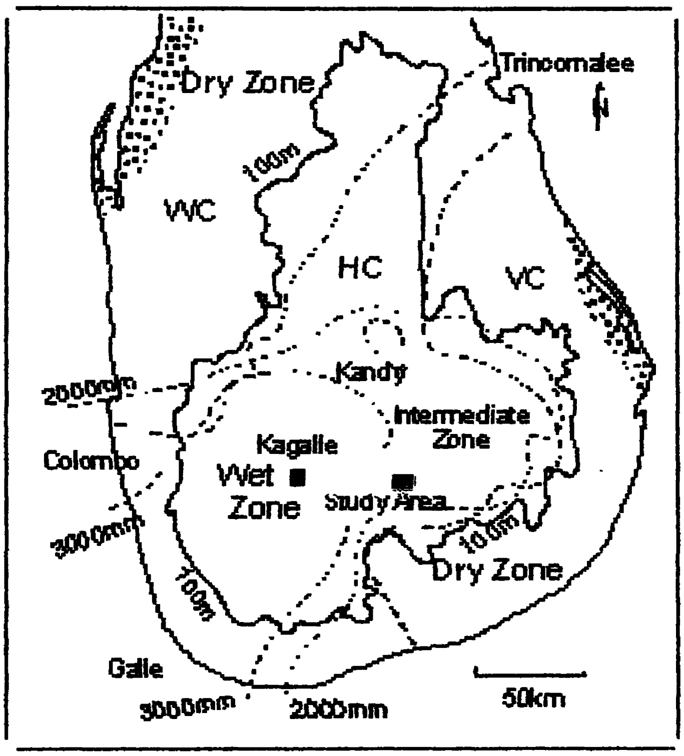

Figure 3.2 Sketch map of Sri Lanka showing; (a) land over 100m in elevation (shaded), (b) wet zone (over 3000mm annual rainfall), intermediate zone (2000 to 3000mm), and dry zone (less than 2000mm), (c) main geological units, HC- Highland Complex, WC- Wanni Complex, VC- Vijayan Complex, and sedimentary rocks (dotted)

The area is underlain by Precambrian metamorphic rock sequences belonging to the Highland Complex (Cooray, 1978). This series consist of quartzite, garnet-sillimanite gneiss, marble, and charnockitic gneiss. All these rocks have been deformed under granulite facies conditions into open, tight, up-right and overturned antiforms and synforms.
(Berger and Jayasinghe, 1976)

3.1.3 Geomorphology

The central hilly area of Sri Lanka has been categorized as uplands and highlands by Vitanage (1985). The uplands, with elevation from 270 m to 1060 m, are characterized by ridge and valley topography their average slope varies from 10° to 30°, depending on lithology and structure. Highlands, with elevations ranging from 900 m to 2420 m appear as a series of plateaus rimmed by mountain peaks and strike ridges they characterize the central part of Sri Lanka. In the well developed strike ridges of the area studied, three dominant structural trends are recognized namely, (a) NW-SE to NNW-SSE, (b) N-S to NE-SW and (c) E-W (Dahanayake, 1989). As a general factor, most of the hill slopes are covered with thick overburden deposits, mostly colluviums and lateritic residual soils.

3.1.4 Climate and Rainfall

The climate of Sri Lanka varies from semi-arid to mild temperature. This variation is due to central highlands which is surrounded by an extensive low land area as also because of the fact that the country is influenced by two monsoonal and inter monsoonal periods. Sri Lanka can be divided to three main climatic zones on the basis of annual rainfall. There are wet zone (over 3000 mm annual rainfall), intermediate zone (2000 to 3000 mm), and dry zone (less than 2000 mm). Landslides are very often triggered by continuous rainfall characterized by showers of high intensity that occur for short periods of time. Central hilly area of Sri Lanka experiences rain from two monsoons, North-East and South-West. Annual average rainfall in the area varies from 5500 mm in the South -West and mid country to 1750 mm in the North-East. (Katupotha, 1994)

3.2 Methodology.

3.2.1 Initial Data Collection

The study was conducted from 14th April 2006 to 26th June 2006 to initial data collection and studying the maps regarding this research. As the first step, National Building Research Organization (NBRO) prepared maps were studied. Those maps represents the state of the year 1994 and are prepared under 3 categories of,

1. Land-use and Management
2. Human Settlements and Infrastructure.
3. Ladslide and Colluvium.

All these maps are 1:10,000 scaled and referring sheet 76/03. Two of those maps were prepared with interpreting aerial photos but landslide map was constructed using field observations. NBRO used predefined Classification system for mapping the field observations. Landslide occurrences are demarcated on map using reference number. Human Settlements are categorized with regarding ownership and density of households. Land-use and Management map categorization was done with referring the Human involvement, state type and current Management state. This desk-studying gave prime information on year 1994 state.

3.2.2 Field Investigation

Field investigation was initiated with the examining of 1994 state maps as the next step. A field GPS handset (Global Positioning System) and 1:10,000 Topographical maps were used as a prime guidance apparatus. The present day year 2006 field observations were acquired and plot on a referring map. To this map sketching process separate 3 maps were created regarding its category. Field measurements and directions were taken using Branton Compass. Human intervention and their mal functions on land could be visually seen and moreover information can collected with the discussion of villagers. At the end of field investigation updated maps towards 2006 were constructed under 3 main categories of land-use & Management, Human Settlements & Infrastructure and Landslide category. In a field examining hindering of old landslides as well as out coming of some landslide signs were also observed.

3.2.3 Preparation of Maps

In this step, collected data in the field were prepared in-house to form suitable for analysis phase. All the referring maps were drafted on tracing sheets before they input to a digital format. At first, three maps regarding 1994 were converted to digital form by the use of manual digitizing process. To this purpose, a 'CAL-COM' Branded Digitizer board and digitizing pen were used to input hard-copied data.

A Digitizer (Figure 3.3) is an electronic device consisting of a table upon which the map or drawing is placed. The user traces the spatial features with a hand held magnetic pen often called a mouse or digitizing pen. All those recorded points were registered against positional control points, usually the map corners that were keyed in at the beginning of the digitizing session. The coordinates were recorded in a user defied coordinate system or map projection.

To input hard-copy data in point mode and stream mode were used to capture the data in an Arc and Node topological data structure. The present 2006 final three maps have also been entered in to the computer through Tablet Digitization. Each polygon in every map was digitized with appropriate code. Line type contour map was constructed for further analysis of collected data. Another line type map was created to show tensional cracks. This tensional crack line map was laid over the landslide map to make the landslide map up-to-date. PC based Arc/Info Software (Version 3.5.2) was used to generate the maps. This was a registered version of the software used at NBRO.

Data editing and verification in response to the errors occurred during data capturing are also performed using the same software. The built in subroutines of Arcedit and Arcplot were used to edit the data and fulfill the quality assurance phase.

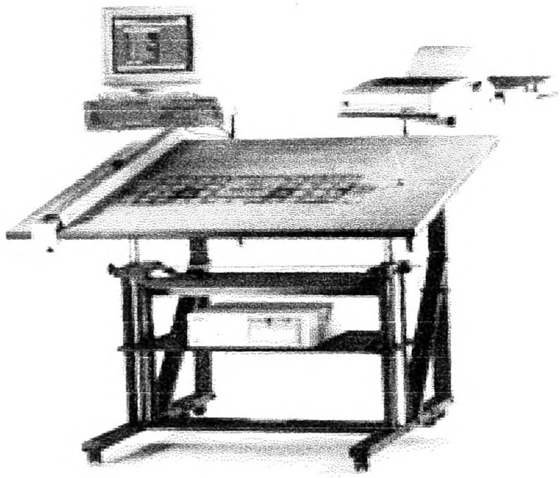

Figure 3.3 :- Tablet Digitizer

Further enhancement and clarifications were made to those maps by using PC based ArcView GIS Software (Version 3.2).

Prepared maps are included as Figure 4.1 – Figure 4.14 under Chapter 4.

3.2.4 Data Analysis.

Data analysis was conducted to reach the prime objectives of the study described in first chapter. The analysis phase mainly concerns on spatial data analysis and its variations. The following base maps have been used for analysis :

1. The 3 base maps which represent the state of year 1994, under three different categories of,

   Land-use and Management (Figure 4.1)
   Human Settlements and Infrastructure (Figure 4.2)
   Landslide (Figure 4.3)

2. The 3 base maps which, represent the situation in the year 2006 under the same three categories. (Figure 4.4 , Figure 4.5 & Figure 4.6)

3. Contour map of the study area was prepared to show the slope gradient (Figure 4.7).

Identification of varying factors and their extent is moreover prioritized in this study. Overlay technique was used to detect these variations. This overlay function helps to superimpose maps of any independent theme of the same area. The software, PC based Arc-View GIS Software (Version 3.2), was used to do this prime process.

The following sequence of steps were conduced in this regard,

1. To find out the variations in distribution of each categorized attributes from the year 1994 to the year 2006, a map of one category (eg. Land Use) prepared for the year 2006 was laid over the map of same category prepared for the year 1994.

2. To study the Land-use & Management and human settlement & infra structure in the areas where landslides had been occurred in 1994, the map of landslide distribution prepared for the year 1994 was laid individually on the map of Land-use and Management and also on the map of Human Settlements and Infrastructure prepared for the same year.

3. The same study described in step 2 above was performed by using same category maps prepared for the year 2006 to analyze the variations in categories with respect to landslides during the period from the year 1994 to the year 2006.

4. Contour map overlaid by the landslide map and the human settlement map was used to study the impact on landsliding due to the human settlements located on steep slopes.

The Classification system under every category is vital to the study of Land-use & Human-Settlements. Standard definitions of Land-use & Human-Settlements classes are the essential prerequisites for improving the data reliability and comparability. For this study and analysis, the same classification system used by NBRO was incorporated. (Appendix 1) and (Appendix 2)

The Materials & Methodology Illustration can be concisely defined using the following chart of flow events. (Figure 3.4)

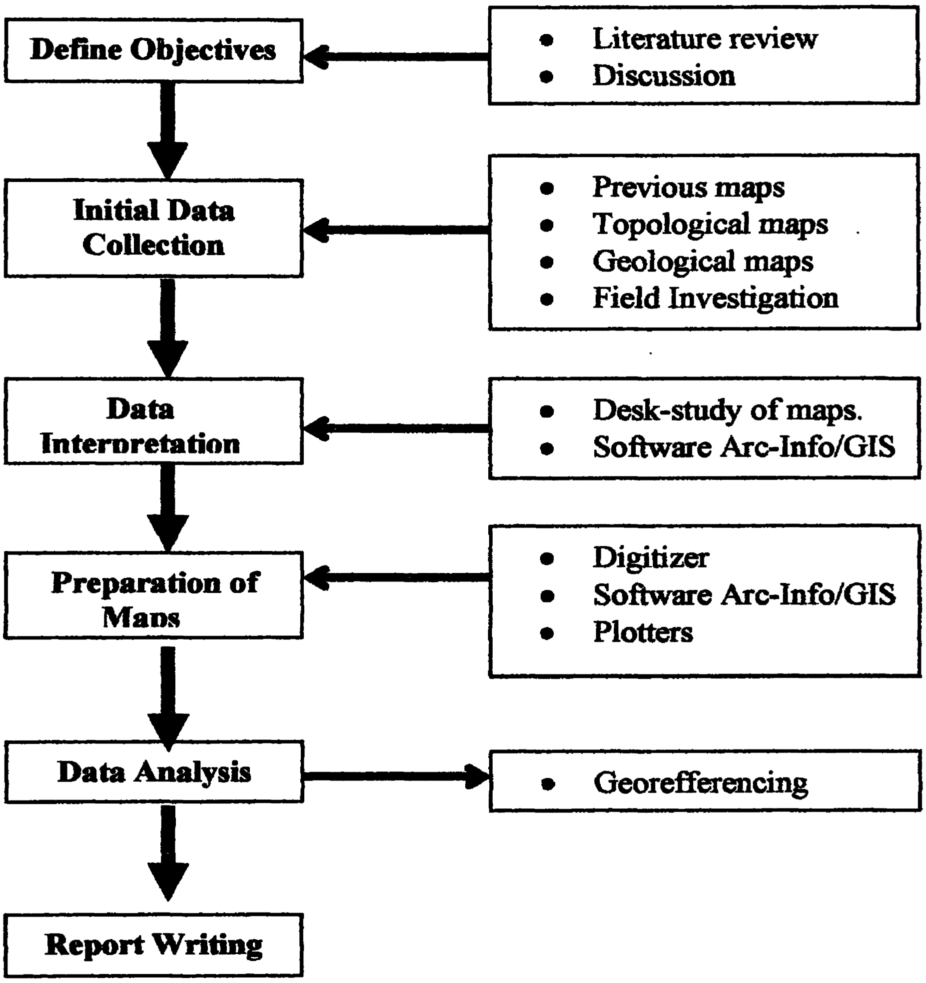

Figure 3.4 : Flow of Events in Methodology.

CHAPTER 4

4. Results and Discussion

4.1 Study of Human Settlements & Land-use patterns

The above described materials & Methodology were applied to collect and analyze data for the actual study area. The study area consists of 4 square Km's within Viharagala DS division, in Badulla District.

Almost all the population of the area practice agriculture and land is the basis for all their activities. Nearly all human activities disturb the environment to some degree. Some of the disturbances can be absorbed by the environment, but there are others which are beyond the limits of the tolerance of an environmental system. There are numerous indecent human activities that take place in this area. Those are both multifaceted and unpredictable in most situations.

Uncontrolled encroachment of state lands by the landless rural poor is a very prevalent phenomenon. The state lands that are on hill slopes are covered with jungles. Clearing the steep slopes and fill the slope without proper retaining system is practiced by these impoverished villagers and has become a major contributory factor for this disaster.
(Plate 4.1) & (Plate 4.2)

Plate 4.1 :- A land fill site where the filled earth is not properly compacted

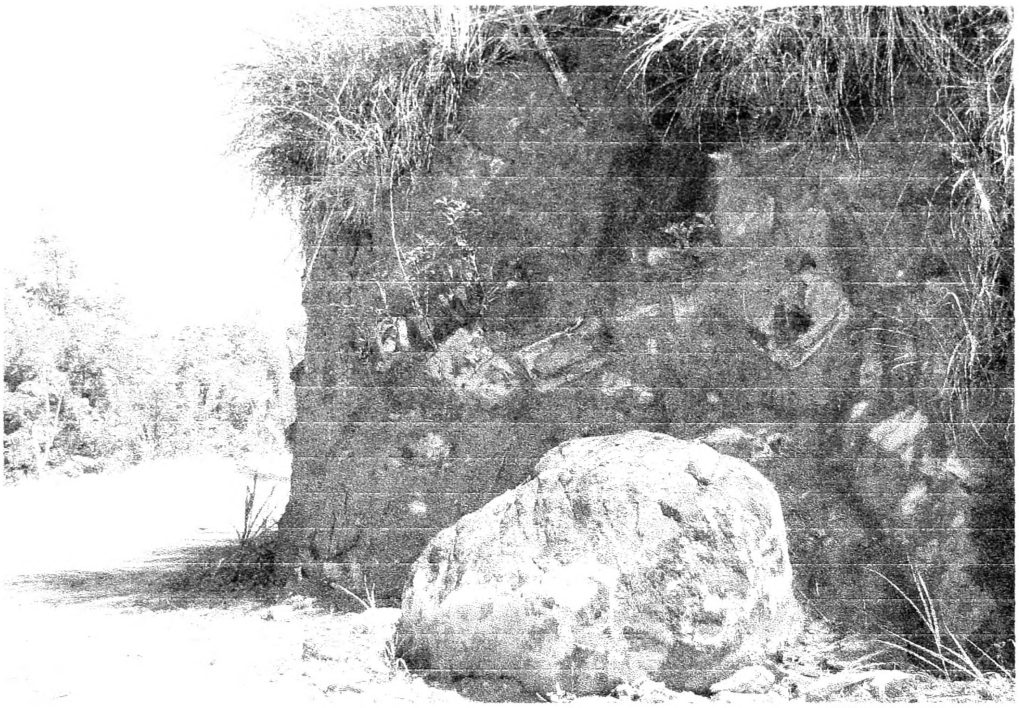

Plate 4.2 :- A deep road cut where the cut slope is not properly supported with a retaining structure

The population in the region has increased rapidly and the availability of land for agriculture has dwindled to the extent that the population is unable to live solely by the land. Consequently, the emergence of other means of supplement whatever is obtained from the small extents of available land. The field investigation encountered future threat on land. Most of the line houses/line of cottages are built in the middle part of the slope. Vertical cuts without earth retaining structures have been observed on the rear side of most houses. Those houses have no proper drainage facilities to direct rainwater away from the slopes. Minor slope failures have been observed behind the observed line of cottages. These failures spread further and form wall-cracks on the walls and the floor of the cottages. (Plate 4.3)

With the increment of new constructions and land involvements, there are numerous bad land use practices prevailing in the area. Tea plantations that were well managed earlier, are poorly manage now. Poor soil conserving practices, over-exploitation of land and no proper treatment exists in association with these cultivated lands. As a result of these mal-practices those lands may become future landslide prone areas. (Plate 4.4)

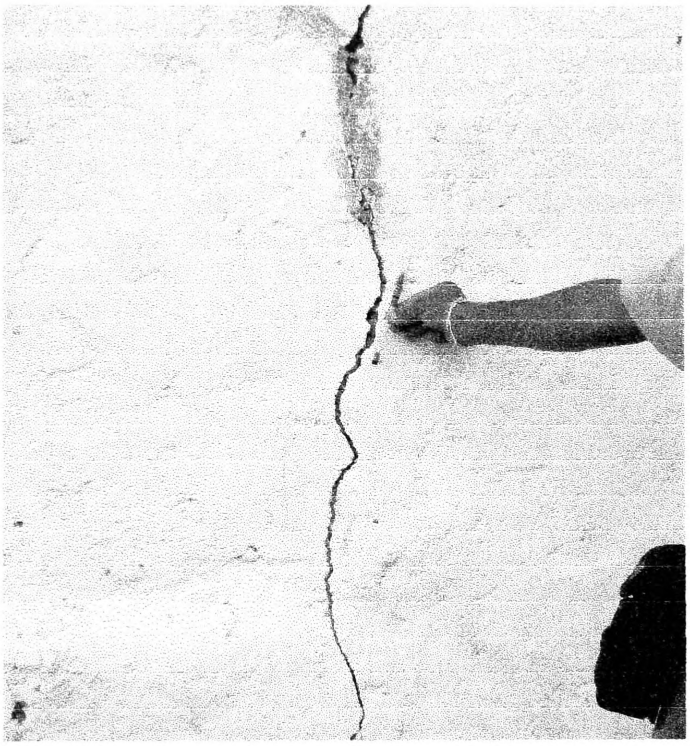

Plate 4.3 :- A fracture observed on the wall of a line cottage

Plate 4.4 :- Minor land slide occurred in a poorly managed tea plantation.

The high rate of soil erosion takes place on exposed surface boulders and rocks, and with the heavy rainfall, those boulders and rocks can roll down over the slope forming rock-falls (Plate 4.5). Rock-falls are frequent in this area.

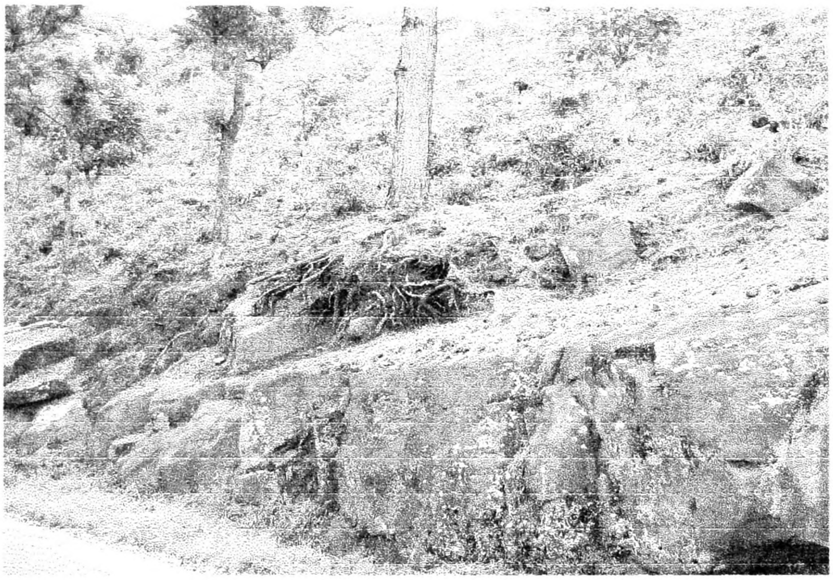

Plate 4.5 :- Soil erosion observed in a poorly managed tea plantation

Several villagers have encroached state owned land, where landslides have occurred in the past, for their agricultural purposes, especially for chena farming. They have prepared terraces to reduce slope and have cleaned the whole surface area without considering the natural drainage systems of the slope (Plate 4.6). Those practices can result in reactivation of stable landslide.

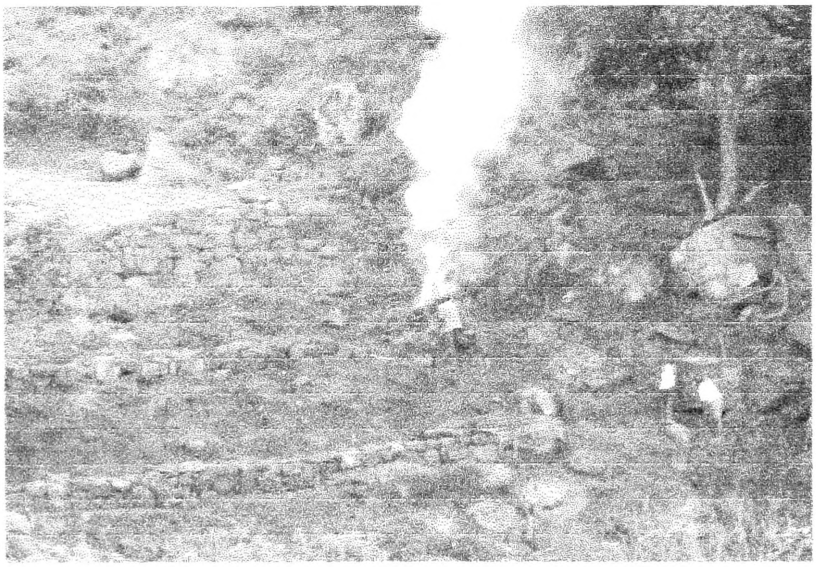

Plate 4.6 :- Clearance of slope in an area, where a landslide has occurred in the past.

4.2 Results of map interpretation.

The contrasting of two states in the year 1994 to the year 2006 has been started by preparing the number of base maps. To this preparation process Tablet Digitizer was used and Arc/Info Software package has been co-ordinate the input data to form the well preserved maps. There are 7 Base maps were constructed to obtain the expected results.

Following are the list of those,

1. The three base maps which represent the state of year 1994, under three different categories of Land-use and Management (Figure 4.1), Human Settlements and Infrastructure (Figure. 4.2) and Landslide map. (Figure 4.3)

2. The three base maps which represent the situation in the year 2006 under the same three categories in Land-use and Management (Figure 4.4), Human Settlements and Infrastructure (Figure. 4.5) and Landslide map. (Figure. 4.6)

3. Contour map of the study area was prepared to forecast the results and show the category of slope gradient (Figure.4.7).

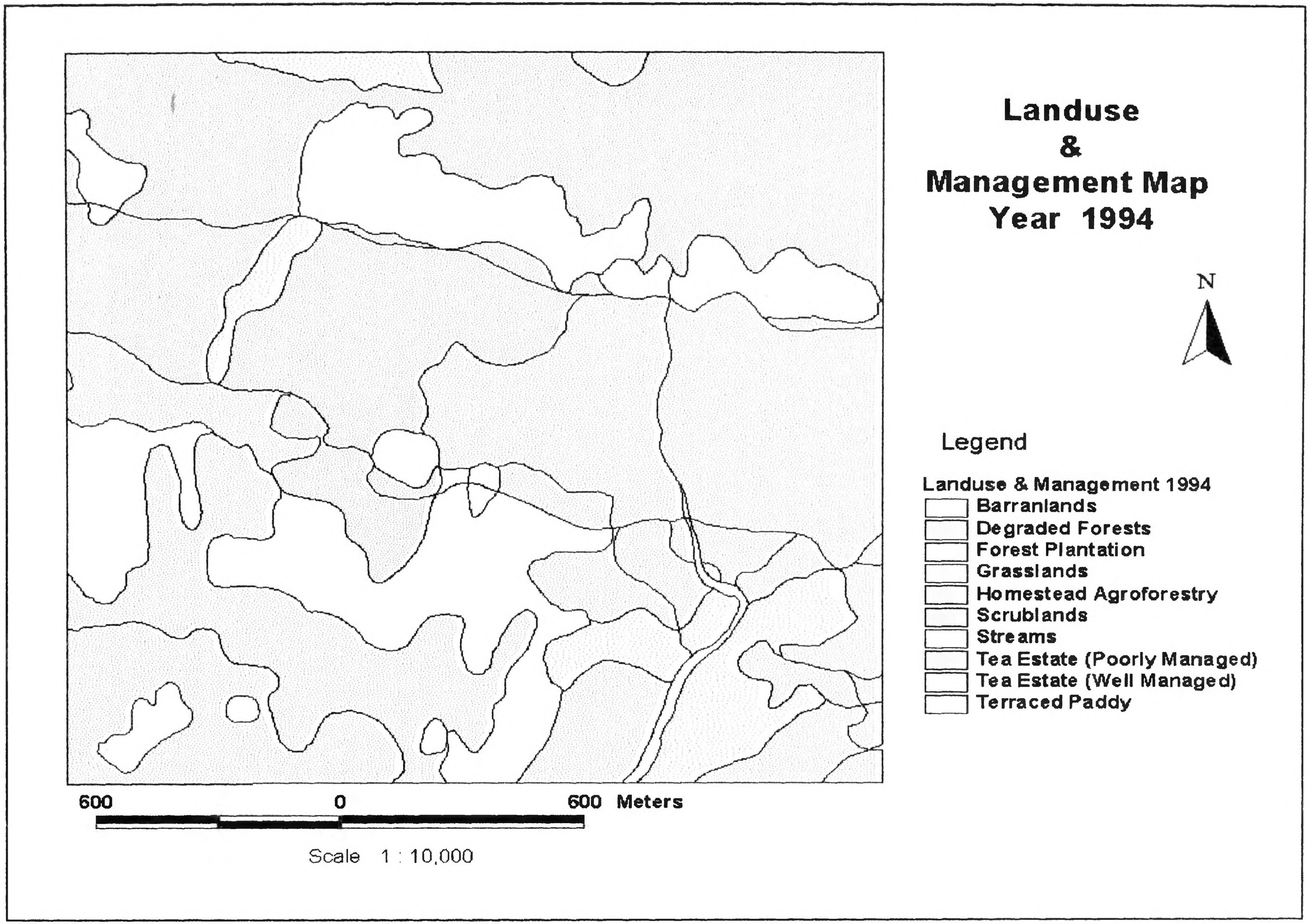

Figure 4.1 : - Land-use and Management map in the year 1994

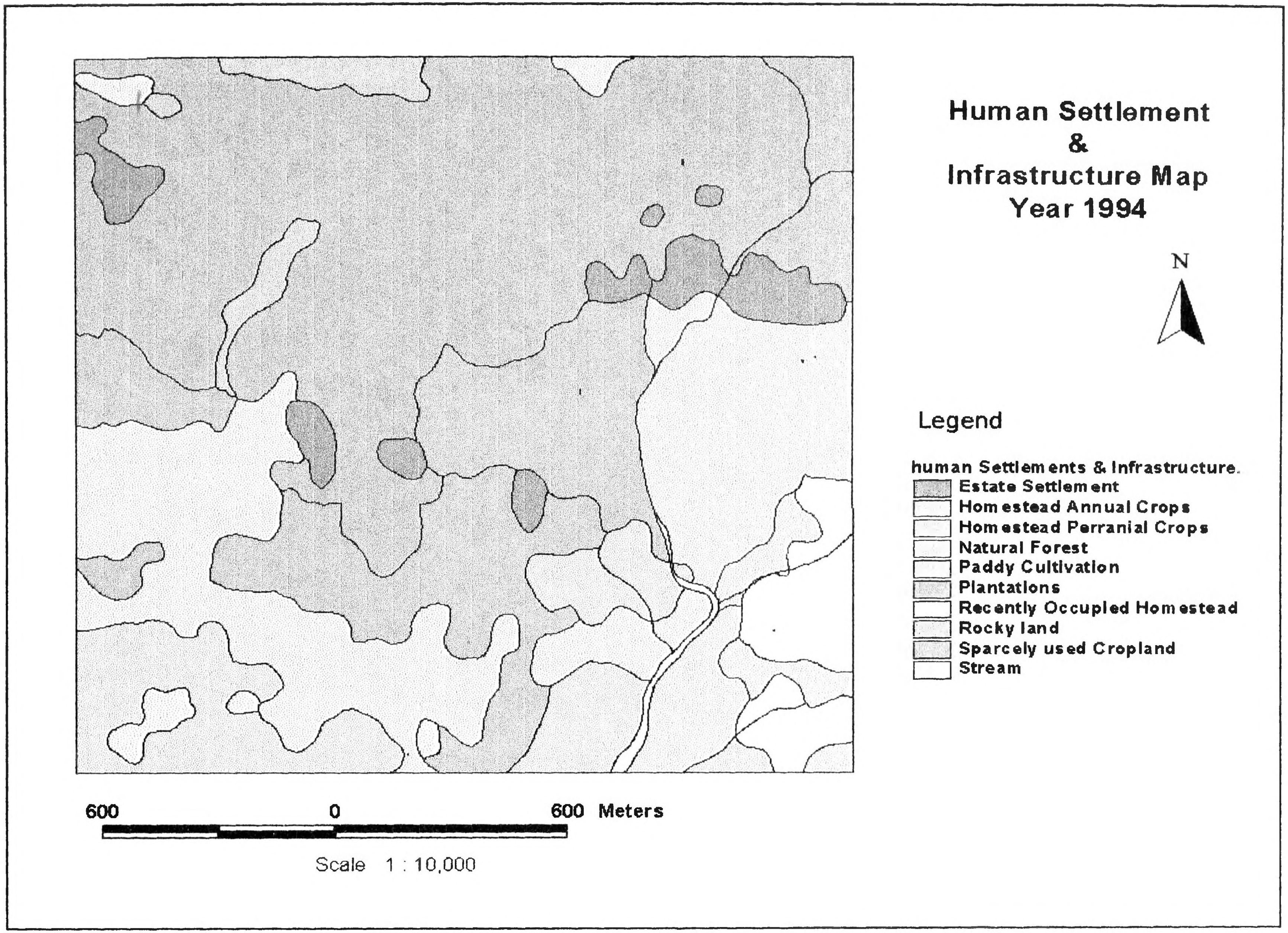

Figure 4.2 : - Human Settlements and Infrastructure map in the year 1994

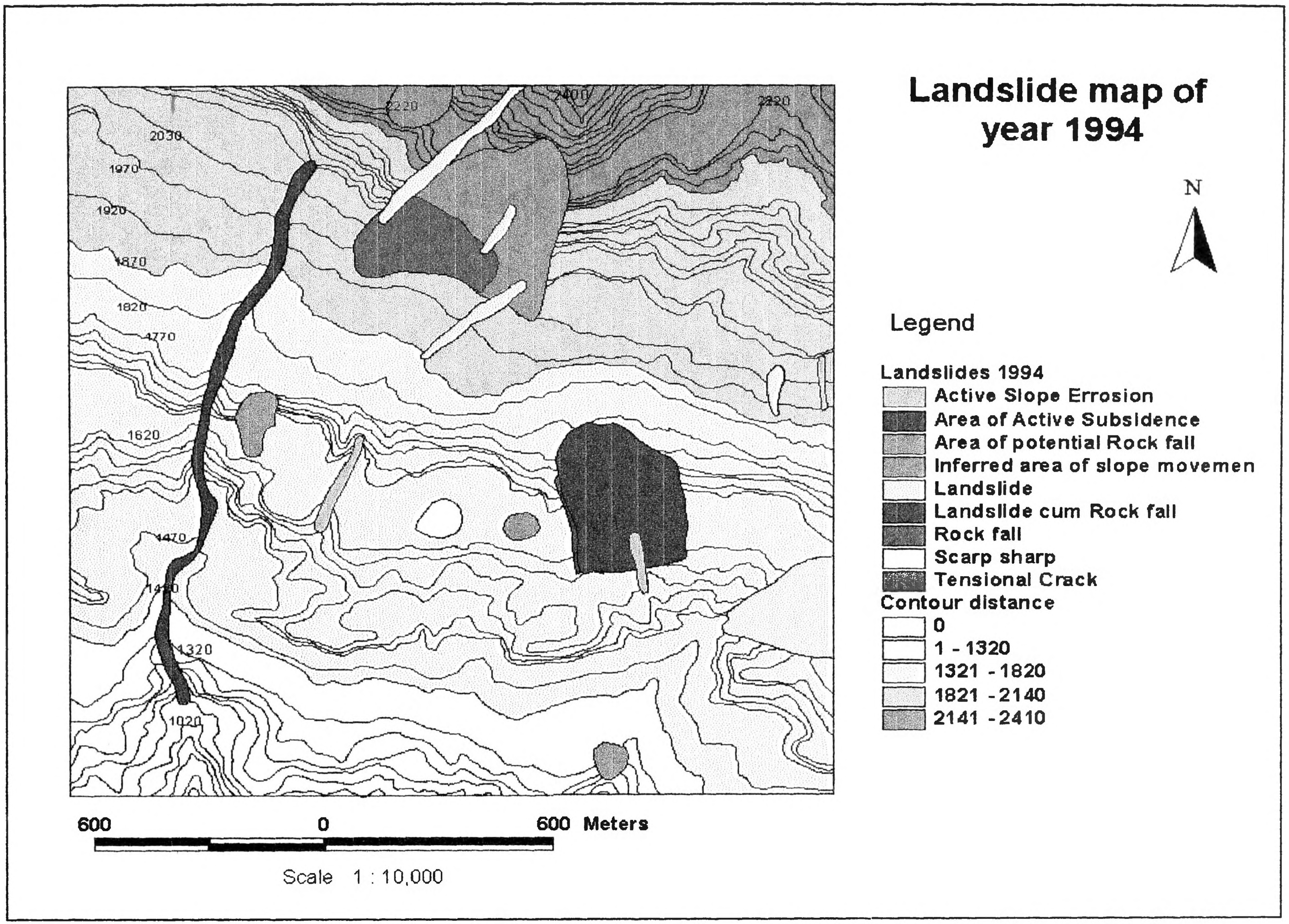

Figure 4.3 : - Landslides map in the year 1994

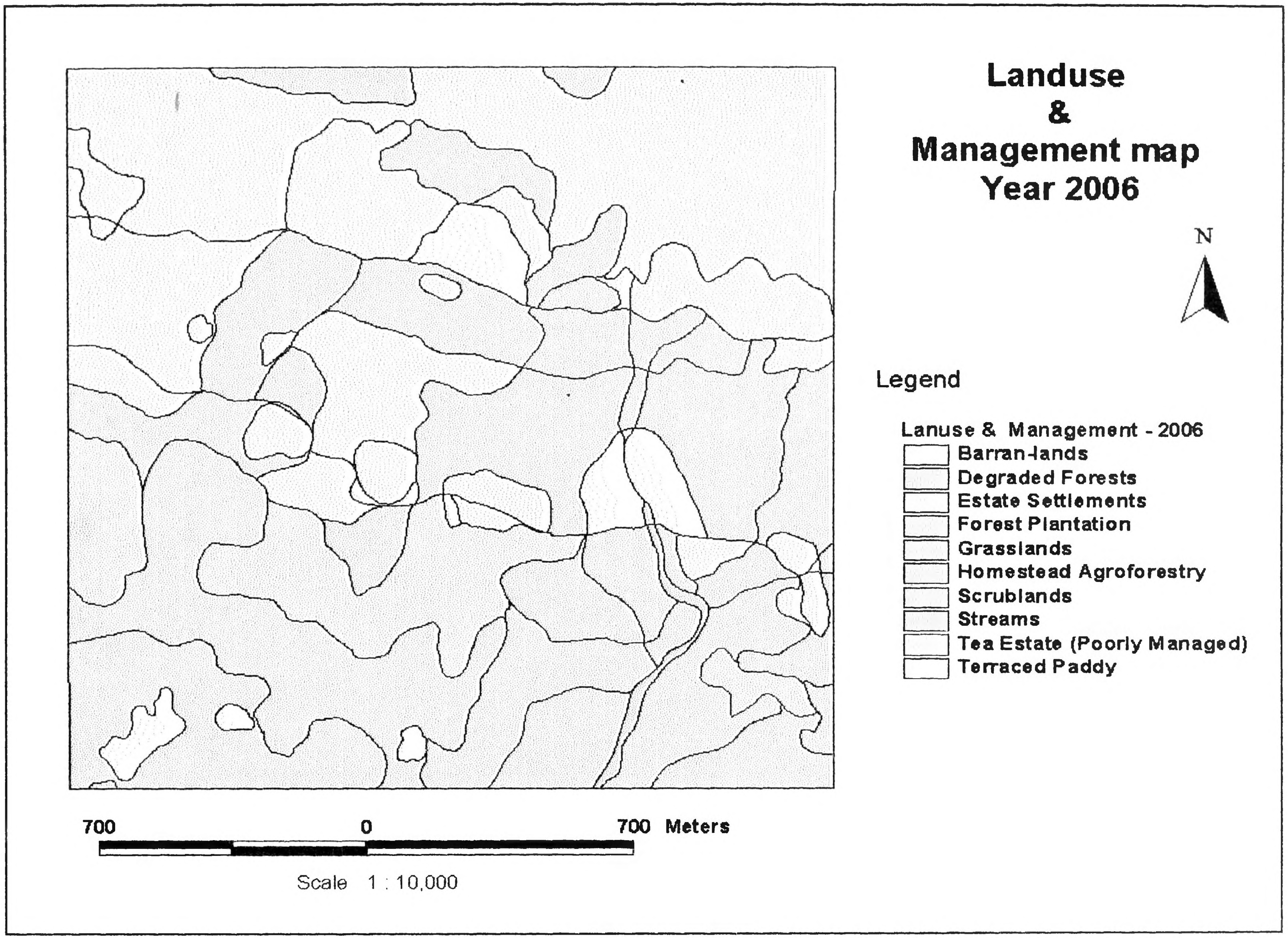

Figure 4.4 : - Land-use and Management map in the year 2006

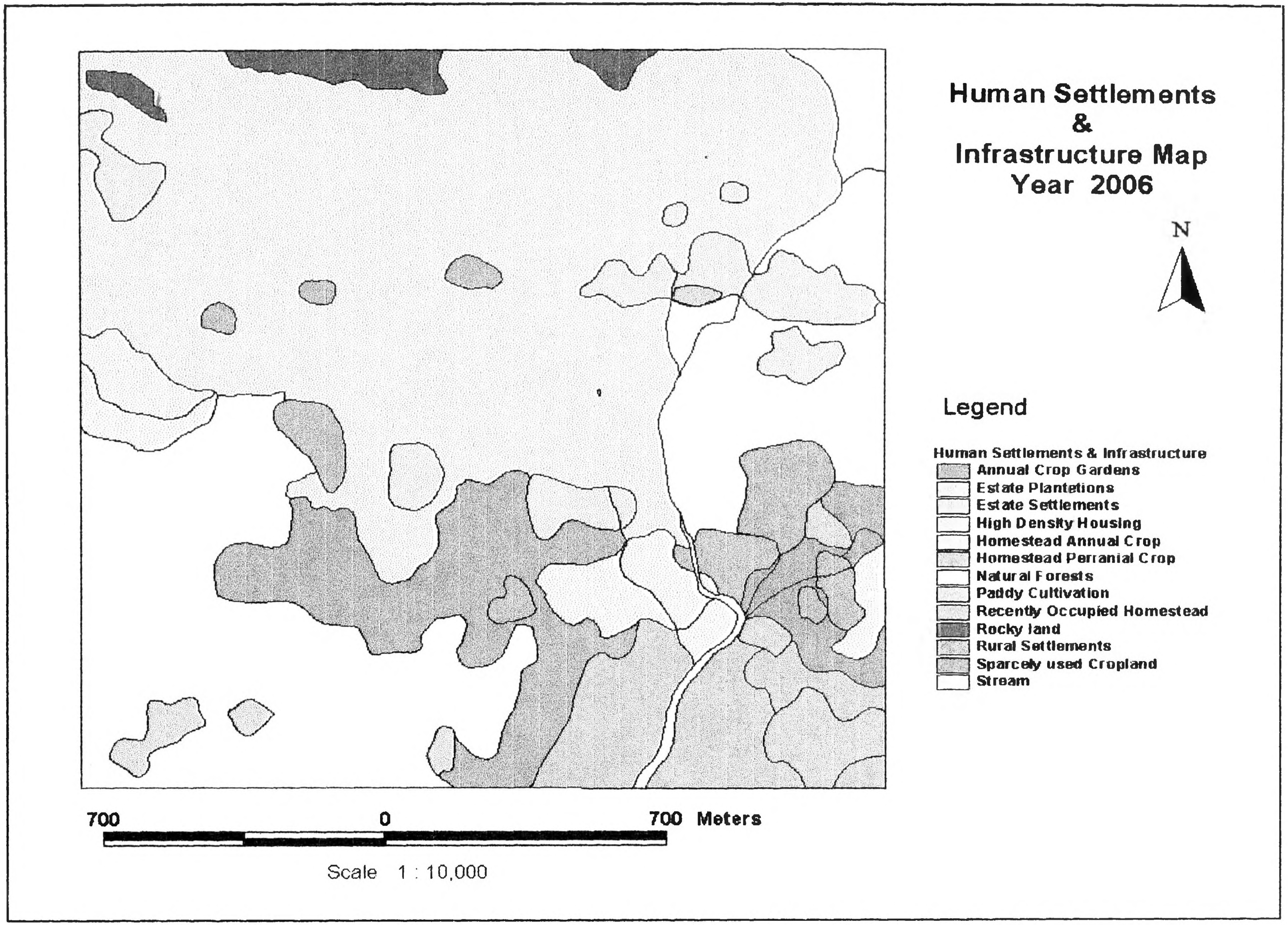

Figure 4.5 : - Human Settlements and Infrastructure map in the year 2006

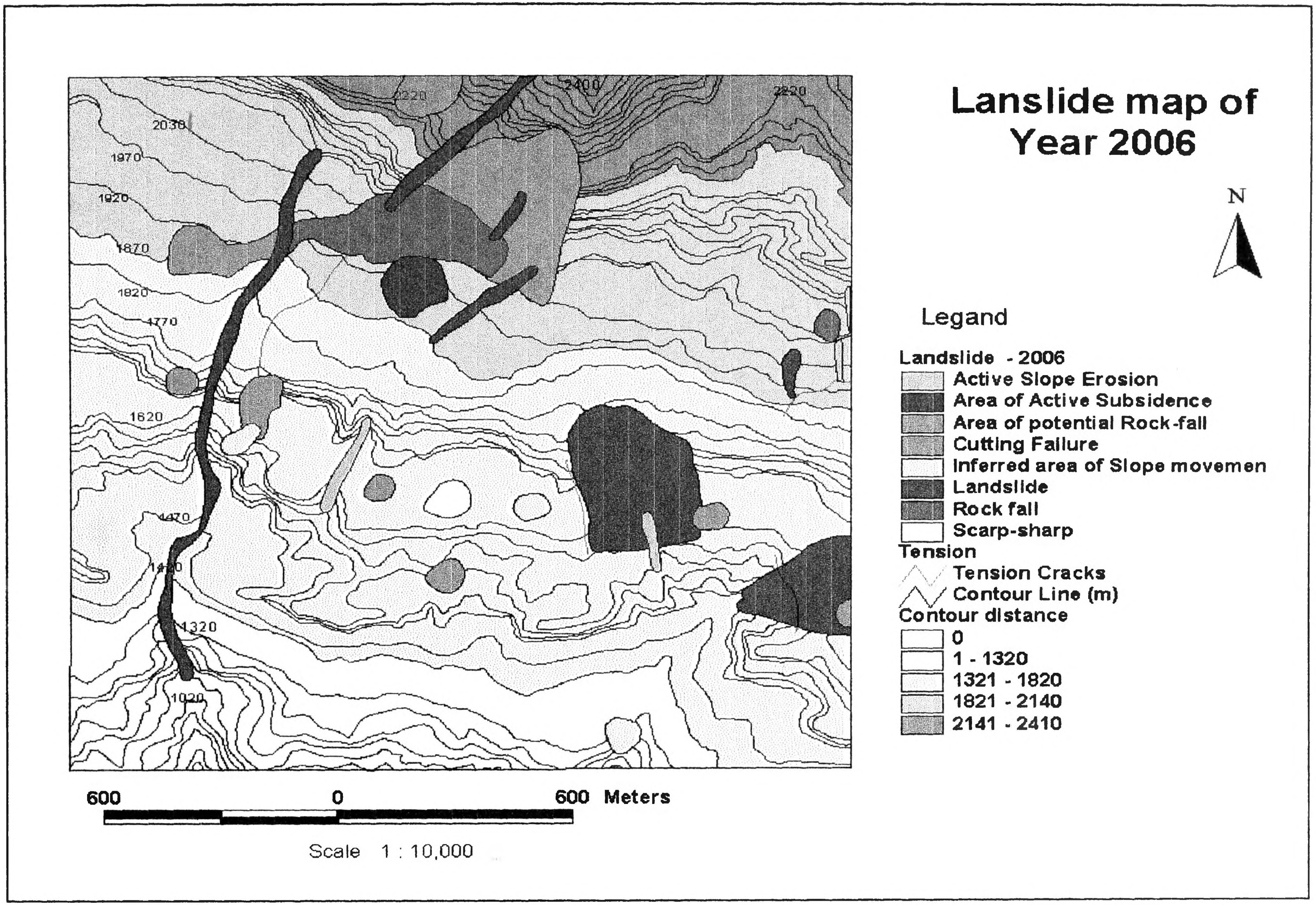

Figure 4.6 : - Landslides map in the year 2006

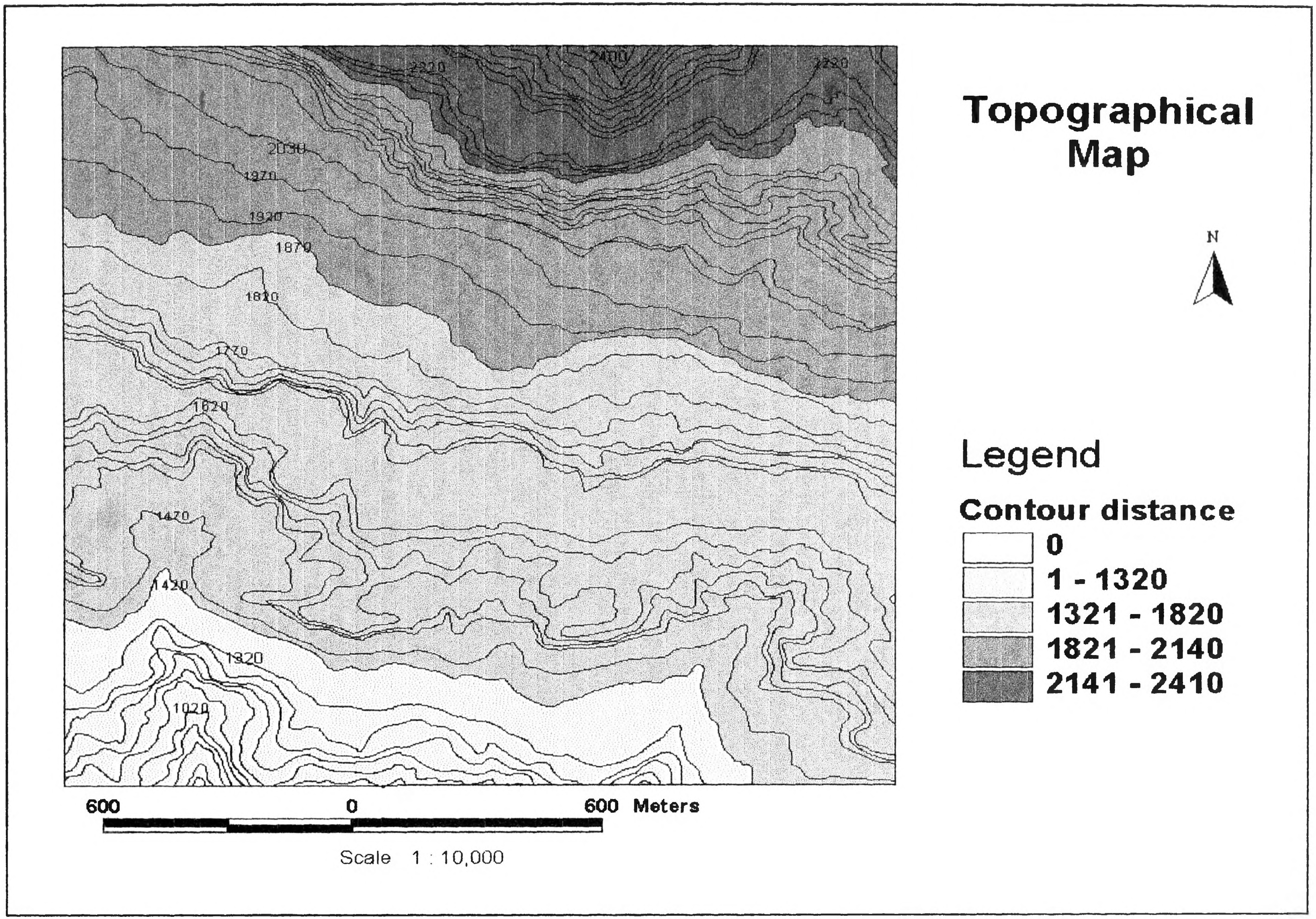

Figure 4.7 : - Contour map of the studying area.

By analyzing the above maps, it is visible,

1. The number of Landslides observed within the study area in 1994 is (Table 4.1) mainly composed of Landslides and Rock-falls.

Table 4.1 :- Recorded Landslides in 1994

Landslide type	Number of recorded incidences
Area of potential Rock-fall	3
Landslide	5
Rock fall	2
Area of Active Subsidence	1
Active Slope Erosion	3
Cutting Failure	0
Inferred area of Slope movement	2
Scarp-sharp	1

2. In year 1994, most Landslides that had been occurred are spreaded in the areas of high concentrated Human Settlement areas especially Estate settlement area & Homestead Annual crop cultivated areas (Tobacco and shifting cultivation). (Figure 4.8) and Land-use practiced areas of poorly managed tea estates and Natural grasslands areas. (Figure 4.9)

3. When the situation in year 2006 is analyzed, (Table 4.2) it is visible that, the number of Landslides and the sites of potential failures as indicated by tensional cracks have been increased. (Figure 4.10)

Table 4.2 :- Recorded Landslides in 2006

Landslide type	Number of Recorded incidences
Area of potential Rock-fall	4
Landslide	8
Rock fall	2
Area of Active Subsidence	1
Active Slope Erosion	4
Cutting Failure	5
Inferred area of Slope movement	3
Scarp-sharp	1

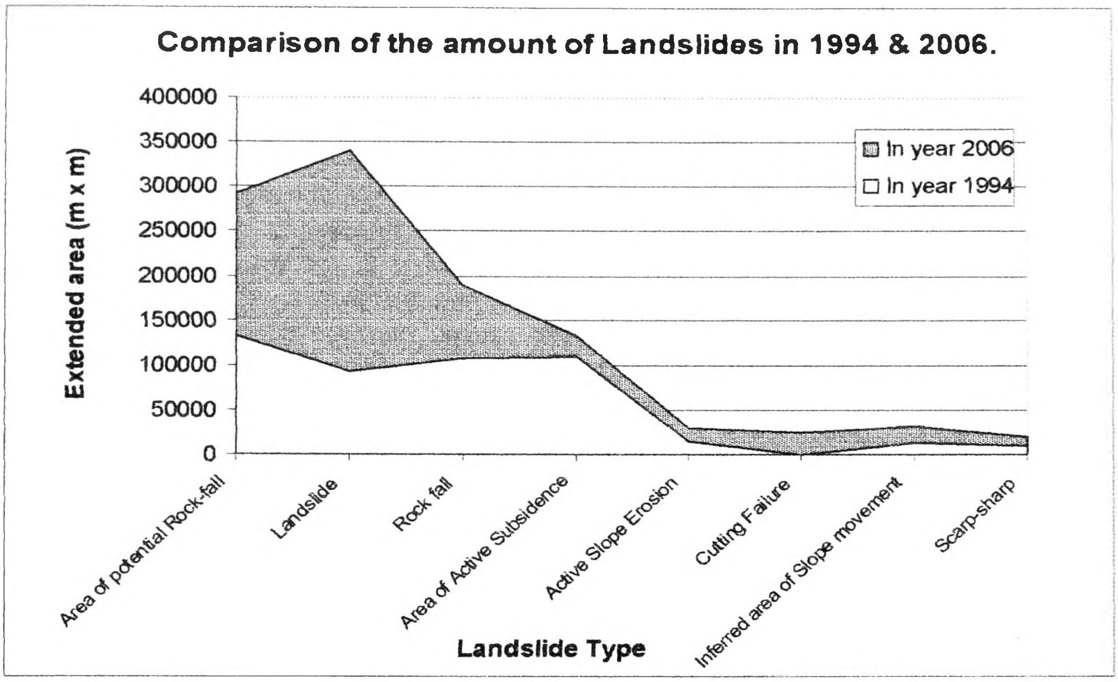

Figure 4.10 :- Comparison the Effective area of landslides in the year 1994 & 2006.

4. The Land-use pattern in state plantation has been changed specially from well managed tea plantation to poorly managed tea estates, within the year 1994 to 2006. (Figure 4.11)

5. Human settlements have been increased and as a result, improper land-use practices can be observed within the study area. Deep unprotected slope cuts and earth fillings without achieving proper compaction have been done in order to build houses and infrastructure. (Figure 4.12)

6. The proposed expansions to Balangoda-Bandarawela road which is located adjacent to the study area is also involved with deep slope cuts and earth fillings may have influenced the instability of the area.(Refer Figure 4.12)

7. Figure 4.12 also indicates that the areas used for Chena cultivation have also been increased and this also has an influence on the increase of Landslides and potential slope failures.

8. Most of the incidences of Landslides have been observed in steep slope areas. When considering the observations in year 2006, establishment of improper settlements and poor management practices of cultivation, especially associated with tea plantations have been spread in moderate to steeper areas.(Figure 4.13) & (Figure 4.14)

9. Field investigation also reveals that, the overgrazing of steep slopes has resulted in high rate of soil erosion. The same fact changes the topography of the region and also leads to active landslides. With the erosion of soil overburden, underground rock boulders have been exposed. With the high intensities of rain, these rock boulders continue to weather and eventually fall down over the slope gradient causing rock-falls.

10. The stability parameter analysis was implemented for the Land-use & Management categorized data of the year 1994 and 2006 (Figure 4.15) & (Figure 4.16).

11. The Results outcomes of the stability parameter analysis were revealed that, most of the stabilized land-use patterns in year 1994 has been transformed to low and moderate stability state in year 2006, with regarding the National Building Research Organization (NBRO) proposed stability parameter categorization for Land-use & Management list. (Appendix 03)

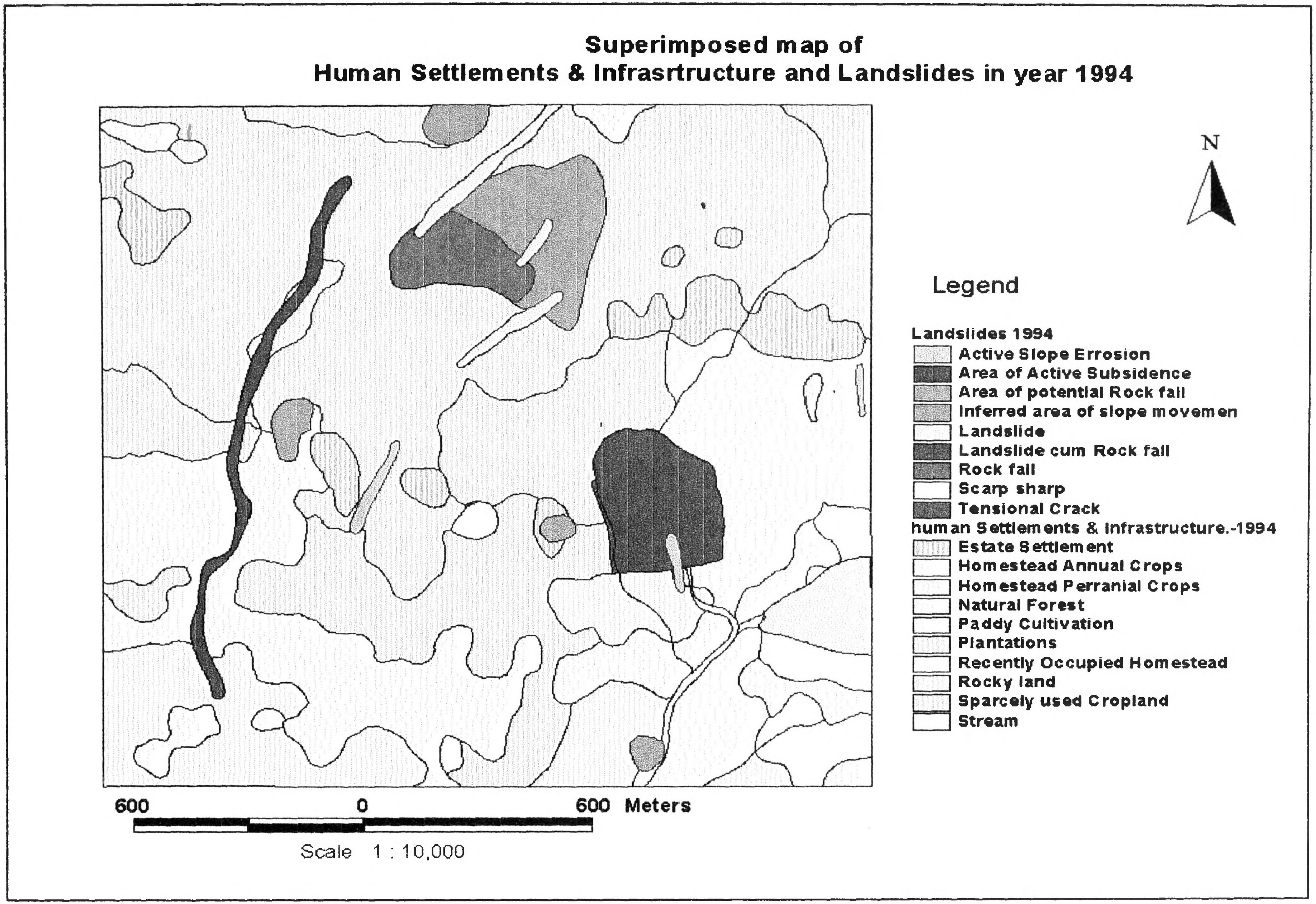

Figure 4.8 : - Human Settlement & Infrastructure and Landslides map in the year 1994.

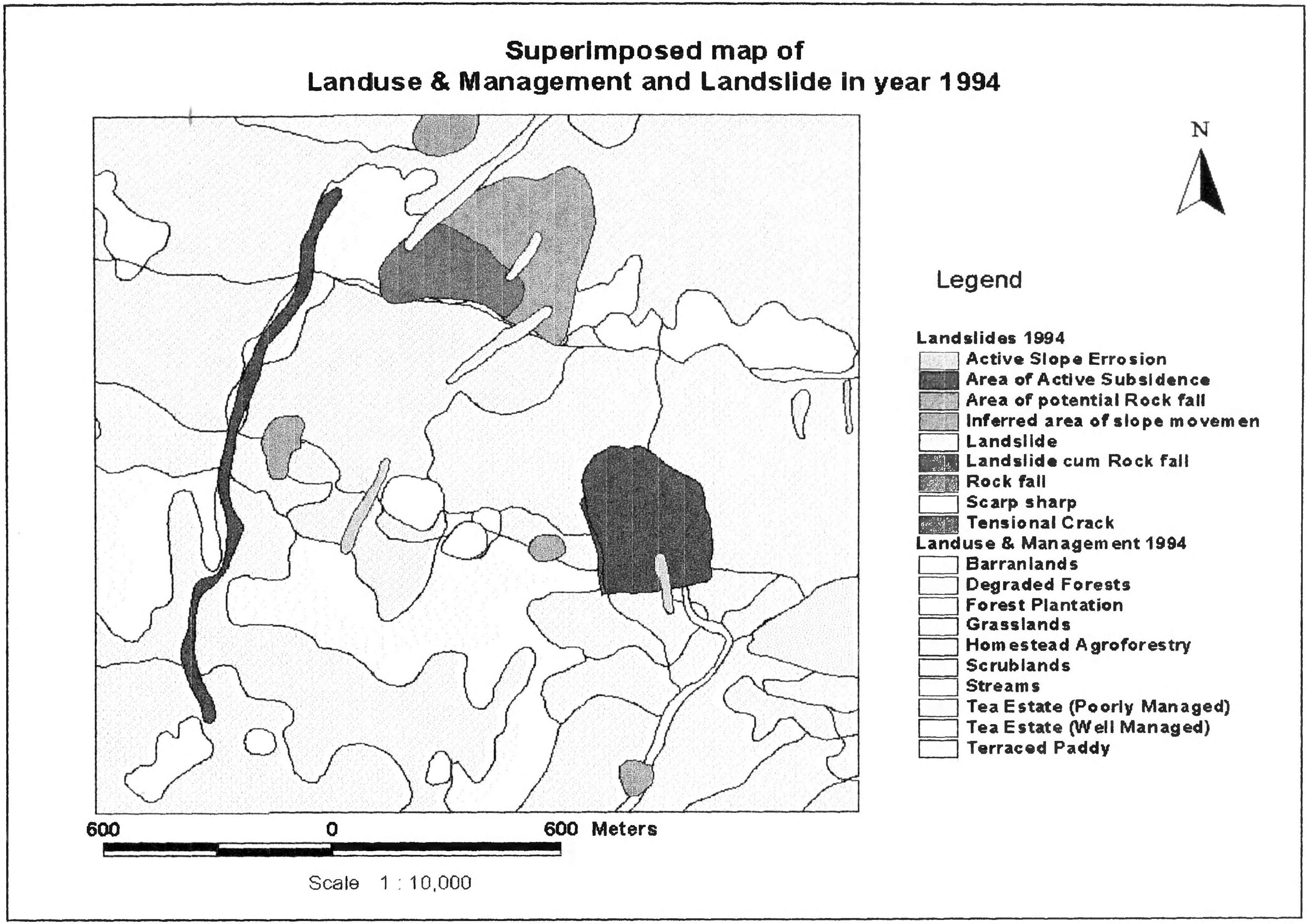

Figure 4.9 : - Land-use & Management and Landslides map in the year 1994

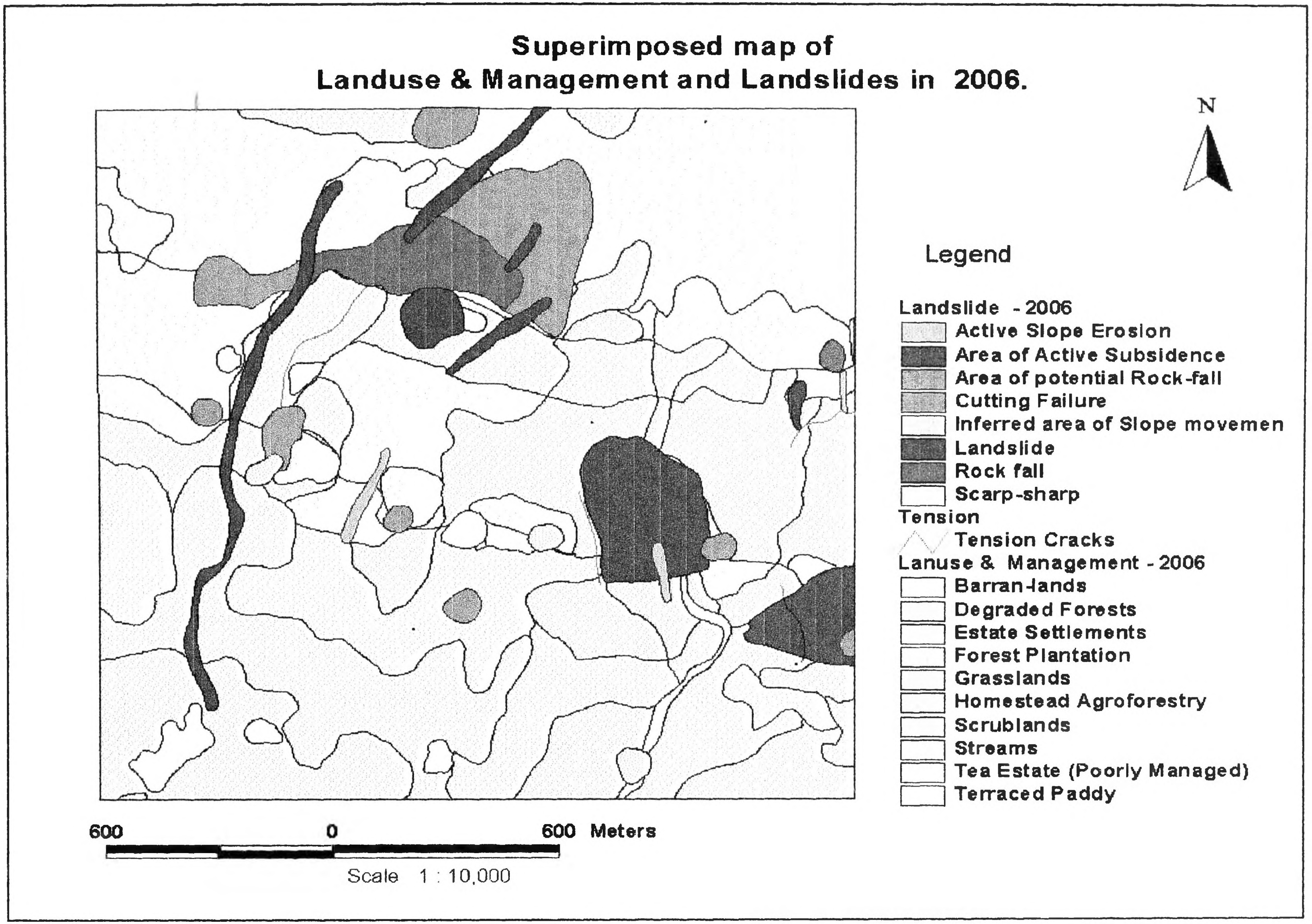

Figure 4.11 : - Land-use & Management and Landslides map in year the 2006

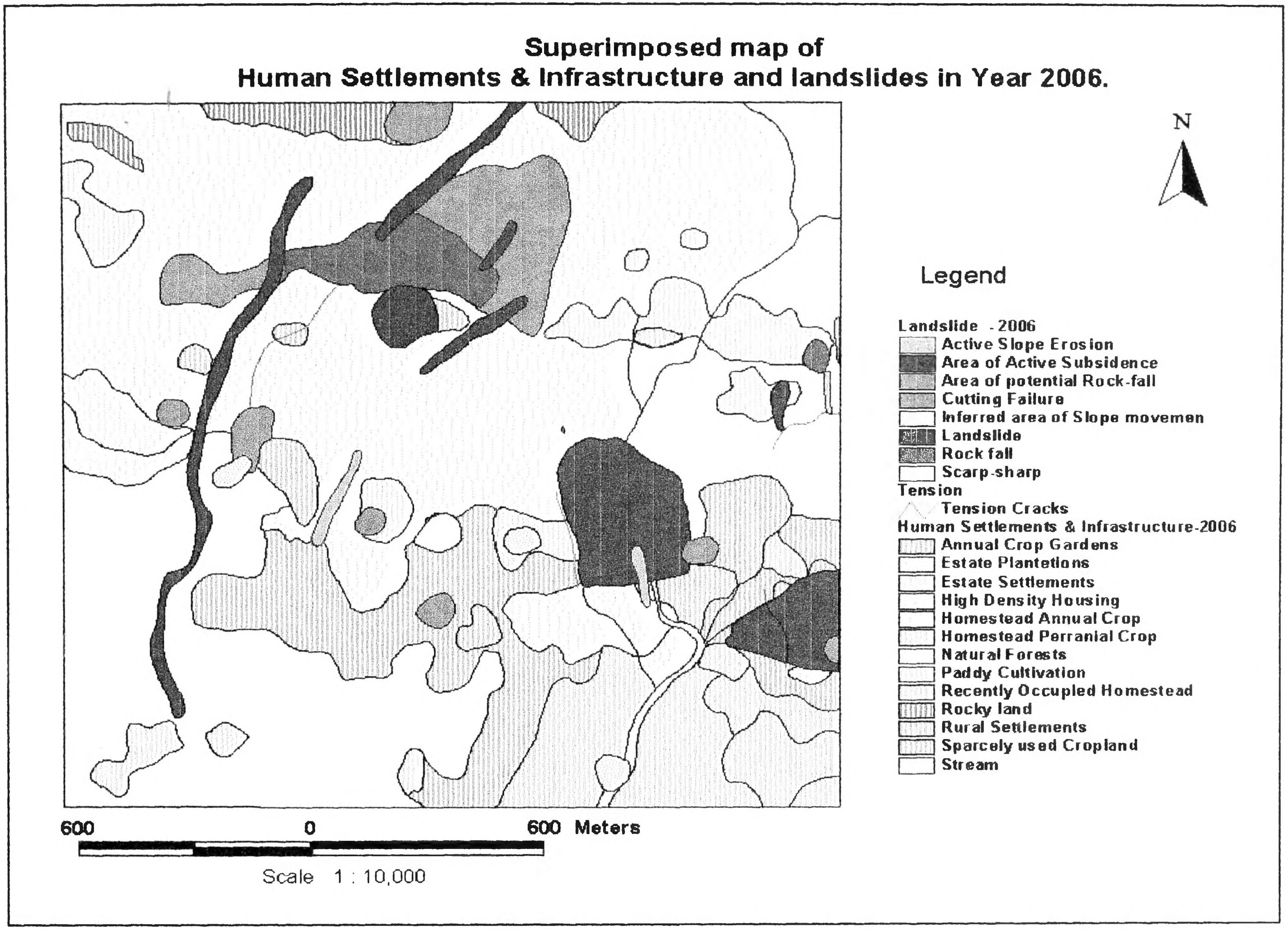

Figure 4.12 : - Human Settlement & Infrastructure and Landslides map in the year 2006

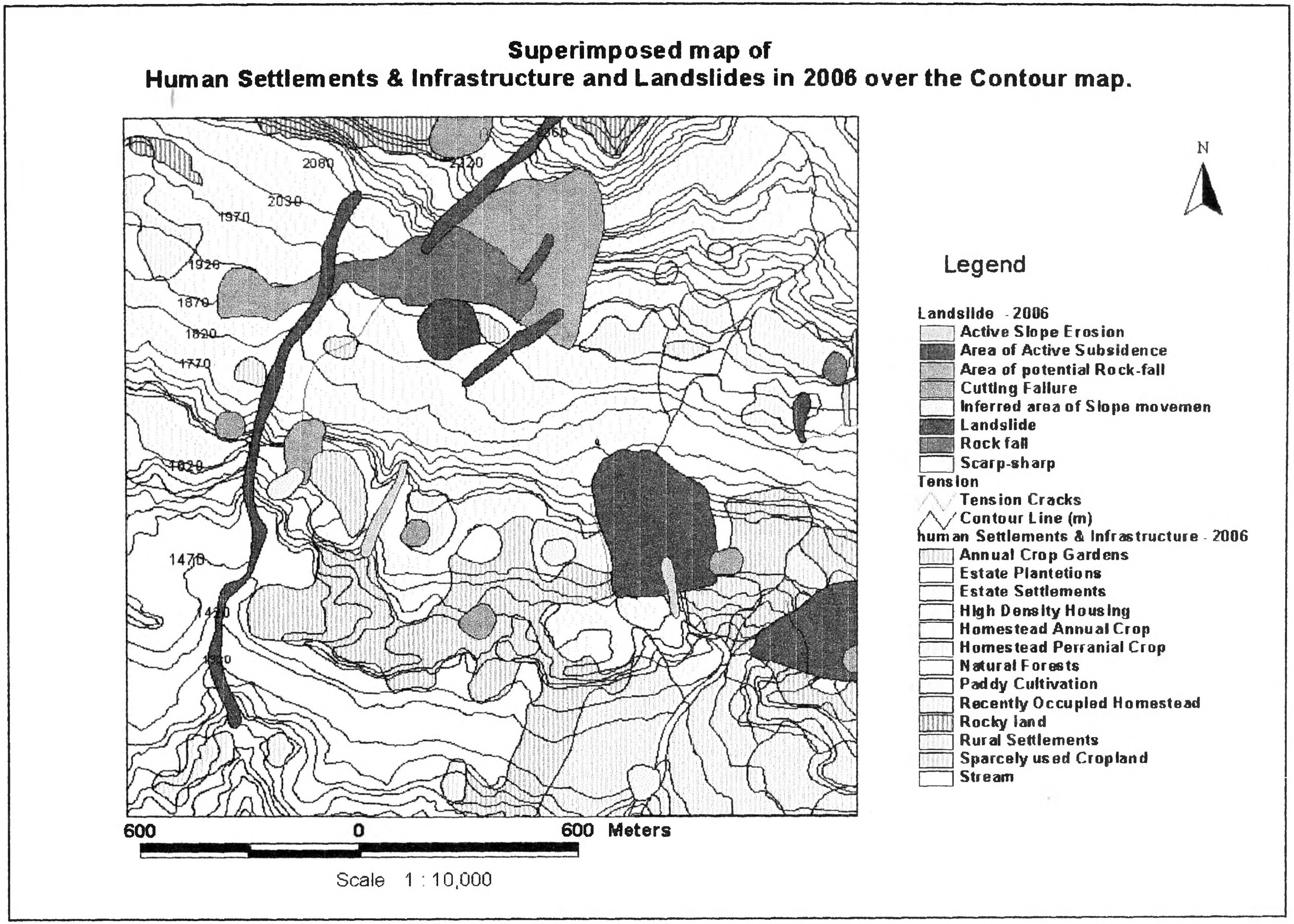

Figure 4.13 : - Human Settlement & Infrastructure and Landslides over Contour map in the year 2006

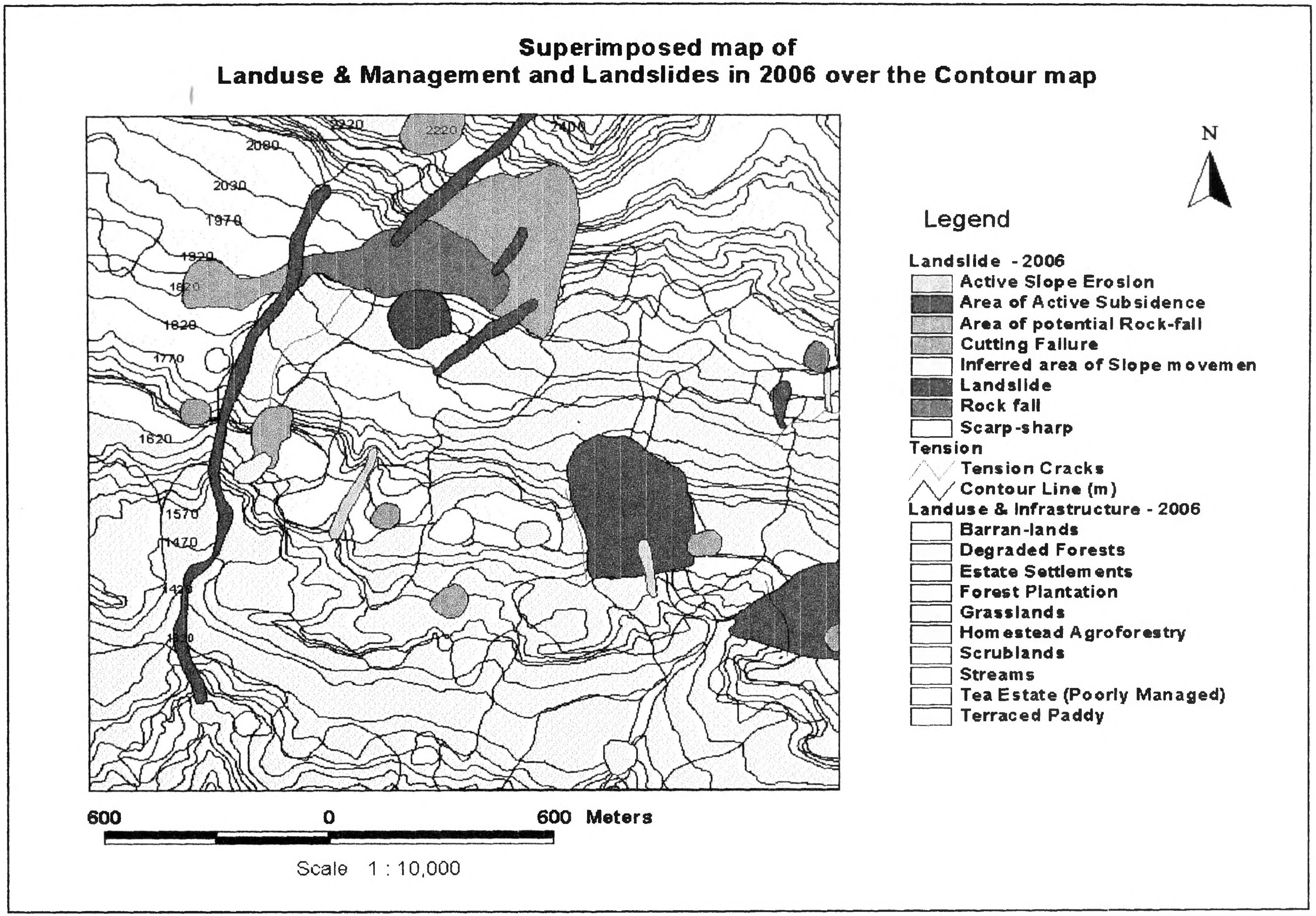

Figure 4.14 : - Land-use & Management and Landslides over Contour map in the year 2006

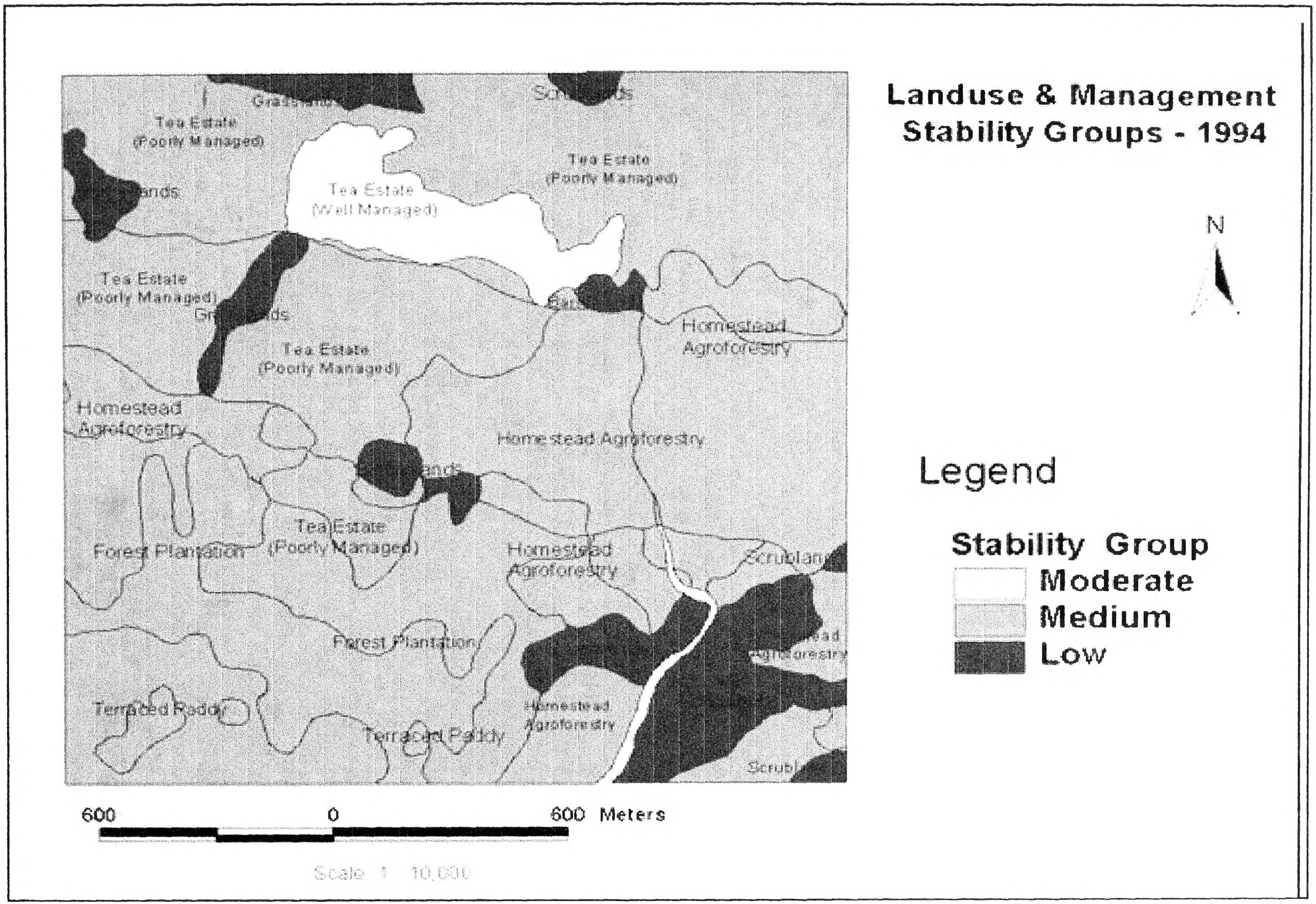

Figure 4.15. Stability parameter analysis for the Land-use & Management in the year 1994.

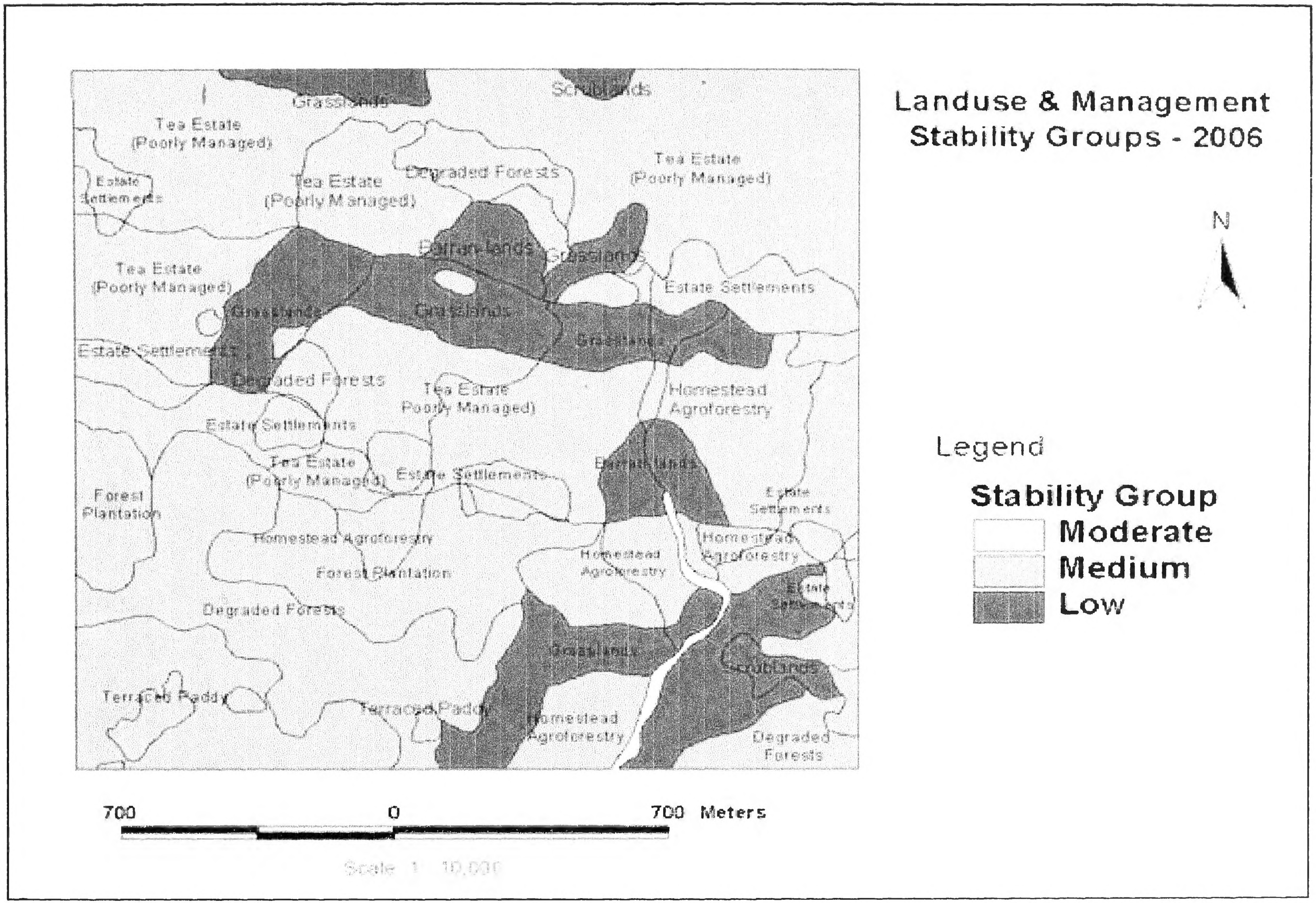

Figure 4.16 . Stability parameter analysis for the Land-use & Management in the year 2006.

Based on the above results, it is apparent that there is an influence of land-use practices and human settlements on landslides. Most of the areas that were stable in 1994 have become unstable in 2006. Most of these newly observed Landslides sites show a change in its land-use pattern and human settlements.

The results also indicate that land-use categories such as poorly managed, Chena cultivation and annual crop cultivations have an influence on destabilizing the slopes. Human settlements, which are part and parcel of deep slope cuttings and non-compacted fillings, also aggravate the stability of the slopes.

CHAPTER 5

5. Conclusion & Further Studies

5.1 Conclusion

The objective of this study was to evaluate anthropogenic influences on creating landslides observed in a 4 square Km area in Viharagala Division, Badulla district.

This study was conducted with a desk-study with maps of Human settlements & Infrastructure, Land-use & management and Landslides prepared by NBRO. The studied maps represent the situation observed in 1994. The present state of the location, in year 2006, had been examined by the field investigation. Those two distinct states of year 1994, and year 2006, were contrasted by interpreting State-of-Nature maps and field records as well. It may need to indicate the modern GIS software, provides an excellent tool to correlate the data spatially and generate and analyze maps & other forms of thematic information.

Majority of Landslides occur as a result of rainfall and consequently water is the main cause of Landslides. Within 1993-1994, this study area had experienced a major Landslide, which triggered with high intensity of rainfall. The affected area had been covered with homestead agriculture, especially Homestead annual crop cultivations (Tobacco), Estate tea plantations and Rural settlements. Field records reveal that, this slopes has poor surface water drainage systems. Thus, it is imperative that control of surface water by appropriate draining techniques is required to minimize the occurrence of landslides. The category for stability of most land-use types in the year 2006 compared with 1994 has gradually increased by giving a high risk to the people living in this area.

The conclusion stated that the incidence of Landslides and potential slope failures has a direct link with human involvement. With the extension of population, they have to extend their land area to build their settlements but the land is limited. This study reveals that, the people encroaching the land towards the steeper slopes by applying unprotected deep cuts, land fillings and land degradation. Due to these activities, the acceleration of Landslides hazards and related other environmental degradation is prominent. Even during this period from 1994 to 2006, inappropriate agricultural practices have been rapidly increased. Those activities will continue with direct and indirect influence by both state and private sectors.

5.2 Suggestions for Further Studies

To reduce or to avoid the hazard of landslides, educating the villagers, on the issues such as the human influence in creating landslides and the good practice of land use, is a must. Further, by introducing proper surface water draining methods, avoiding unprotected deep cuts and slope cutting, slope failures can be mitigated and future research needs to be carried out on the low cost mitigatory measures suitable for our country.

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Appendices

Appendix 1

Classification System of Human Settlement & Infrastructure

Level 1	Level 2	Level 3 (Criteria)
1.0 Settlements	1.1 High density housing	High concentration of dwelling units with little or no space for agricultural activities.
	1.2 Rural Settlements	Medium concentration of residential, non-residential and public or private building.
	1.3 Estate Settlements	Bungalows, Labour lines and factories, etc...
2.0 Residential cum Small holder agriculture	2.1 Homestead and perennial crop cultivation	Major portion of the land cover by perennial crops (no possibility for any significant second stage cultivation)
	2.2 Homestead and annual crop cultivation	With little or no perennial crop, cover land is mainly assigned to cultivation of annual crops with visible or not visible parceling pattern
	2.3 Recently occupied homestead.	Recently occupied land undergoing process of settlement without usual established patterns. (Ground cover < 20%)
3.0 Small holder Agriculture	3.1 Annual crop gardens	Annual crop cultivated on land with or without visible parceling patterns, indicating the ownership of land.
	3.2 paddy Cultivation	Irrigated or rain fed paddy cultivation
	3.3 Sparsely used cropland	Areas cultivated from time to time (mainly chena cultivation)
4.0 Other major uses	4.1 Natural forests	Nature managed
	4.2 Grasslands	Nature managed
	4.3 Rocky land	Rock outcrops, Erosional remnants
	4.2 Plantations	State or Estate managed.

Appendix 2

Classification System of Land-use and Management

Level 1	Level 2	Level 3 (Criteria)
1.0 State/Estate plantation	1.1 Tea Estate (Well Managed)	Tea Estate (70 – 90 % Cover)
	1.2 Tea Estate (Poorly Managed)	Tea Estate (20 – 70 % Cover)
	1.3 Forest Plantations	Broodiest and Pinus varieties.
2.0 Small holder village agriculture	2.4 Homestead and agro forestry	Mixed tree crops.
	2.2 Terraced paddy	Paddy Cultivation
3.0 Natural Woodlands	3.1 Degraded natural forests	Degraded forests
	3.2 Secondary forests / Scrublands.	Scrubland
4.0 Natural grass and barren-lands.	4.1 Natural Grasslands and patinas	Pathana / Grassland
	4.2 Barran-lands / Escarpments.	Erosional Remnants
5.0 Urban / Rural human Settlements.	5.1 Estate Settlements	Estate Settlements.

Appendix 3

The Legend and Stability of Land-use & Management categories according to their stability parameters.

Level 1	Land use Map unit (Level 2)	Stability Group
1.0 State/Estate plantation	1.1 Tea Estate (Well Managed)	1
	1.2 Tea Estate (Poorly Managed)	2
	1.4 Forest Plantations (Pinus Spp.)	2
2.0 Small holder village Agriculture	2.5 Homestead and agro forestry	2
	2.2 Terraced paddy	2
3.0 Natural Woodlands	3.3 Degraded natural Forests	2
	3.4 Secondary forests / Scrublands.	3
4.0 Natural grass & Barren-lands.	4.3 Natural Grasslands and patinas	3
	4.4 Barren-lands / Escarpments.	3
5.0 Urban / Rural Human Settlements.	5.1 Estate Settlements	2

Stability Group Attributes.

1. Low Stability - 1
2. Moderate Stability - 2
3. High Stability - 3

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