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Effect of land use on the development of slope instability in the Neka-Rood Watershed, Iran

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ABSTRACT

Land use can be considered as one of the most important parameters in the development of slope instability. It is a factor that continuously changes the land surface condition with time. Therefore, it should be considered when analysing the potential of slope instability and preparing a landslide hazard zonation map. Land use influences the characteristics of land surface and may cause changes in its behaviour towards the processes such as weathering and erosion affecting the inherent properties of the ground.

The results show that between 1955 and 1993 more than 30% of the land has been converted from forestland to pastureland in the Neka-Rood Watershed of Iran. This conversion accelerated the slope instabilities in the watershed, where 90% of landslides were recorded in the pastureland and only 8% in the forestland. It was also noted that the geological conditions have greatly influenced the potential of land erosion and consequently the type of land use.

INTRODUCTION

For the last three decades, the population growth in Iran has been very high. In the study area, in particular, a population growth of over 60 per cent is reported (Safaei 1998), hence more agricultural and building land is demanded for development and expansion of construction projects in the area. This results in a change in land use and invariably leads to landscape changes that cause various types of environmental hazard such as landslides and floods. The effect was manifested as a huge flash flood in the Neka-Rood basin on 30 July 1999, which was responsible for the loss of 50 lives and great damage to the property.

Lee (1996) stated that the role of a geologist has become very important owing to the new land use changes that demand for the knowledge of regional geology to a land use planner. Mulder (1996) also stressed the need of considering the geological factors for urban development.

The aim of this paper is to investigate the effect of land use on the development of slope instability, to evaluate the potential of land erosion with respect to the type of land use, to identify the role of land use on the landslide hazard zonation, and to propose the best type of land use for regional development projects.

In this regard, various methods of landslide hazard zonation are reviewed and two commonly used techniques are described. In order to clarify the role of land use on the development of slope instability, a correlation between land use and geological setting, land use and slope angle, and land use and surface erosion is made.

PHYSIOGRAPHY

The Neka-Rood Watershed is part of the Mazandaran Province in northern Iran (Fig. 1), and is situated in the northern side of the Alborz Mountains, between 1,640 and 2,420 m above mean sea level. The watershed has a surface area of about 22 km^2, and consists of three sub-watersheds named as the Al-Arz, Kiassar, and Metkazin, (Fig. 2). The Gravilus coefficient (G_c) for each sub-region is 1.4, 1.52, and 1.27, respectively. The coefficients show that the watershed has an elongated shape. The mean annual precipitation is 550 mm and it mostly falls as snow. The temperatures vary between 40° C and -15° C during the summer and winter, respectively.

GEOLOGICAL SETTING

It is recognised that the surface geology has a major control on the development of slope instability. The generalised geological map of the area is shown in Fig. 3, whereas the geological age, composition, and surface distribution of the lithological units are shown in Table 1. Based on their susceptibility to mass movements, the lithological units can be combined into the following three groups:

- middle and late Cretaceous carbonate rocks containing laminated limestone with intervals of marlstone and marly limestone (generally appearing as high mountains);
- detritic unit, which is divided into the Palaeocene silty marlstone and marly limestone, and Miocene conglomerate, sandstone, marlstone, and thin layers of gypsum in the upper part (very vulnerable to sliding, weathering, and erosion); and
- quaternary deposits containing mainly loose deposits of cover soil and alluvium (sporadically distributed in the area).

The Alborz Mountains are part of the Alpine-Himalayan mountain belt with high seismicity. The area is surrounded

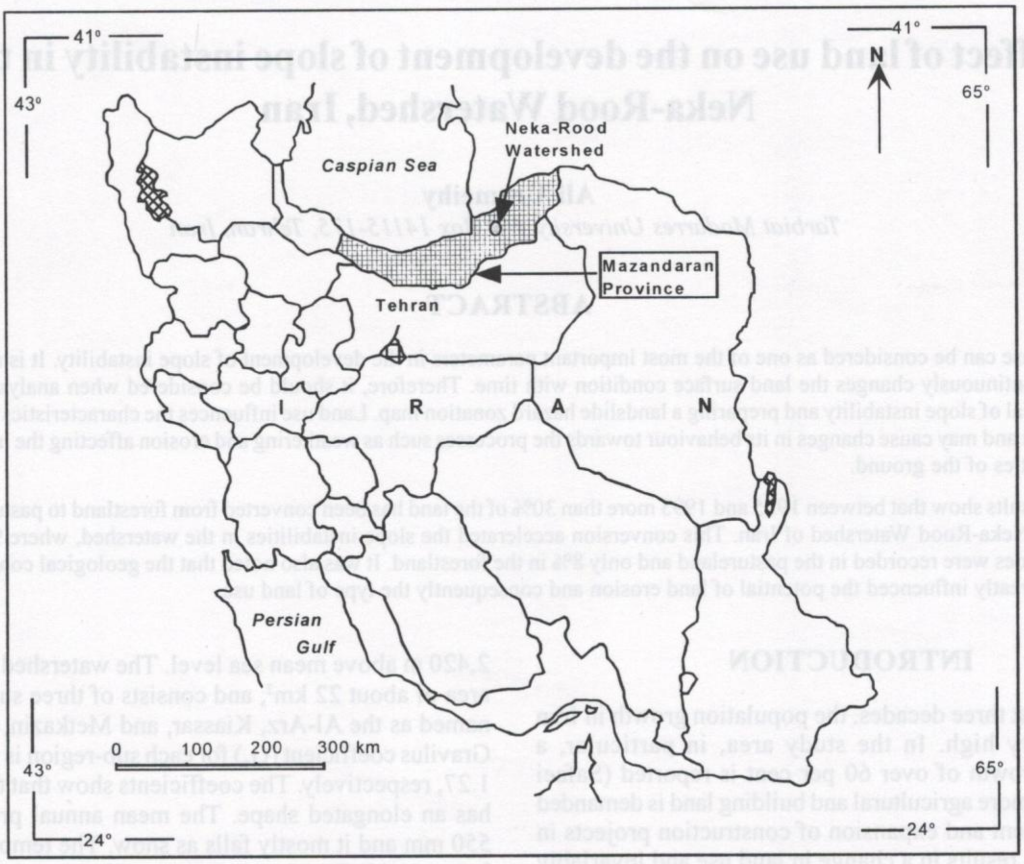

Fig. 1: Location of the Neka-Rood Watershed in the Mazanadaran Province, Iran

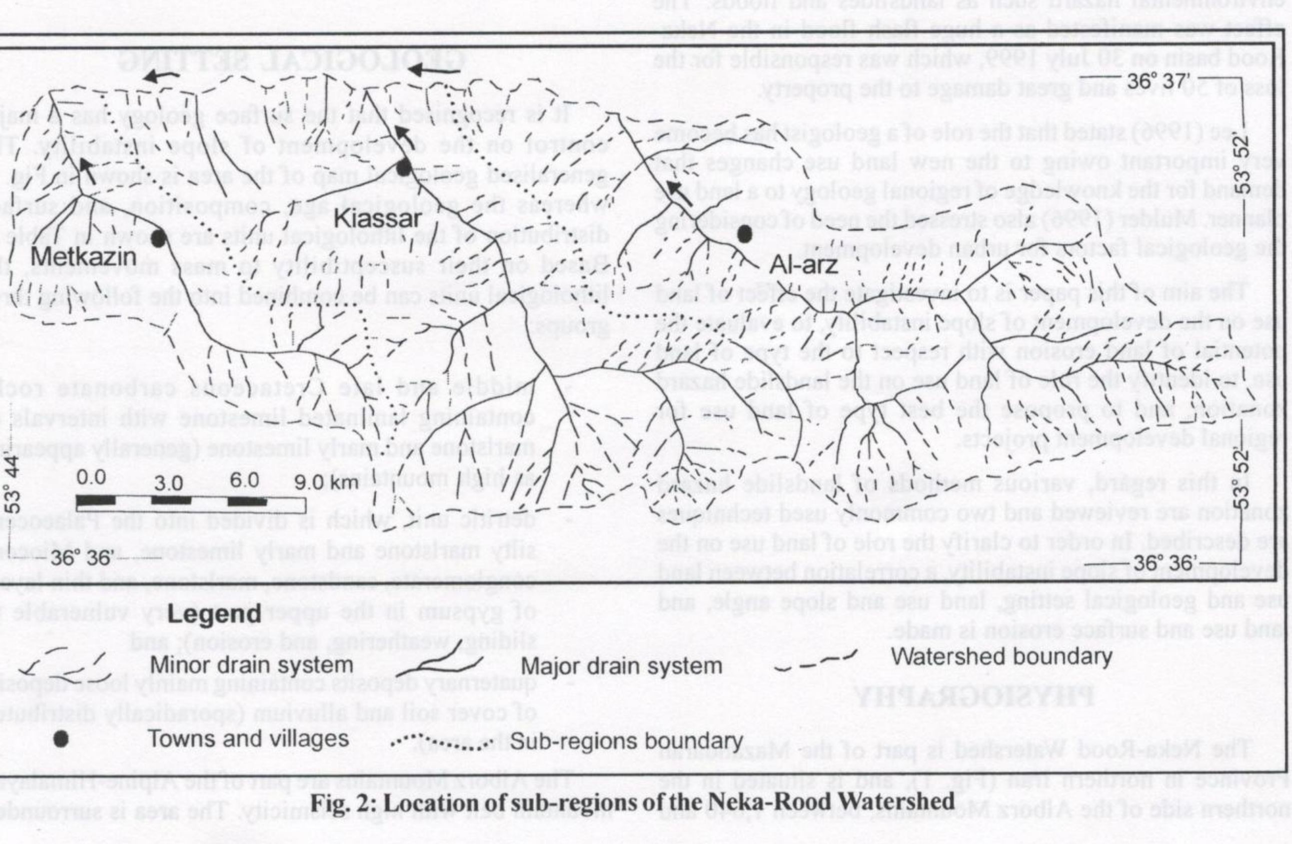

Fig. 2: Location of sub-regions of the Neka-Rood Watershed

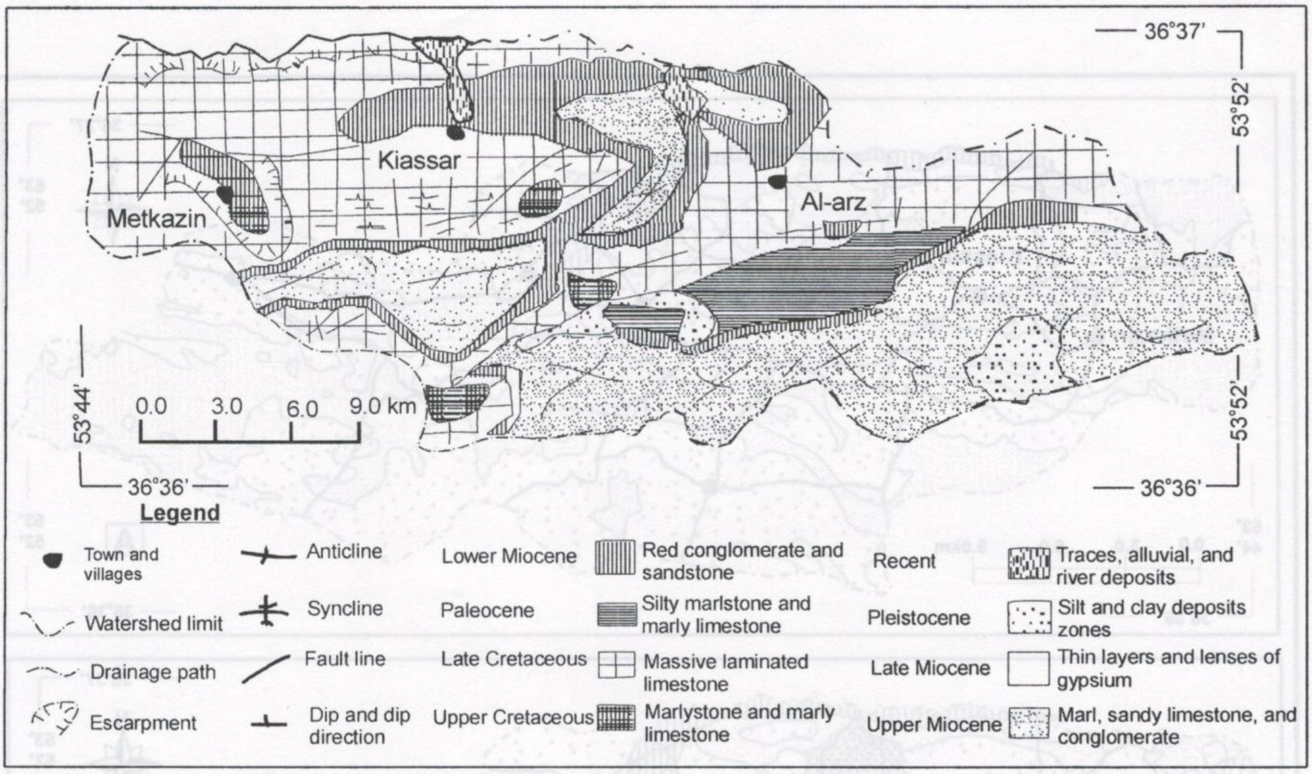

Fig. 3: General geological map of the Neka-Rood Watershed

Table 1: Geological age and surface distribution of the lithological units

Geological age	Lithology	Surface distribution in %
Recent	River deposits, alluvial fans, traces	-
Pleistocene	Zones of silt and clay deposits	4.1
Late Miocene	Lenses and thin layers of gypsum	30
Middle Miocene	Marl, sandy limestone, and conglomerate	1.8
Early Miocene	Red conglomerate and sandstone	11.7
Palaeocene	Silty marlstone, and marly limestone	2.6
Late Cretaceous	Massive laminated limestone	46.4
Middle Cretaceous	Marlstone and marly limestone	2.2

by the two main thrust faults: the North Alborz Fault and the Khazar Fault. They are located some 4 and 10 km south and north of the study area, respectively. The main thrust faults and the axes of folds in the area trend due N40°E. There are a number of local faults and fractures, which crosscut the folds and main faults.

LAND USE CHANGE

Any changes in the environment may have unexpected effects on the conditions of ground. The land use change has a very important influence upon slope stability in areas where forests are removed from hill slopes for agricultural development. The overall effect of trees on hill slopes with shallow soils is to increase soil shear strength by 60 per cent or more (Selby 1993). These effects are in accordance with the observations that the landslides are far less common on forestland than on adjacent cultivated slopes or grassland.

The land use maps of 1955 and 1993 are shown in Fig. 4A and 4B, respectively. The types of land use in 1955 and 1993 are summarised in Table 2. It shows that more than 30 per cent of the forestland has been converted into the agricultural land and pastureland during the last 38 years. Most of the converted land has the slope angle of less than 20 degrees. This change in land use accelerated the rate of erosion and caused most of the slope instabilities in the area.

Table 2: Distribution of various land use types in 1955 and 1993

Year	Land use type			
	Forest	Woods	Agriculture	Pasture
1955	46%	-	2%	52%
1993	29%	1%	3%	67%

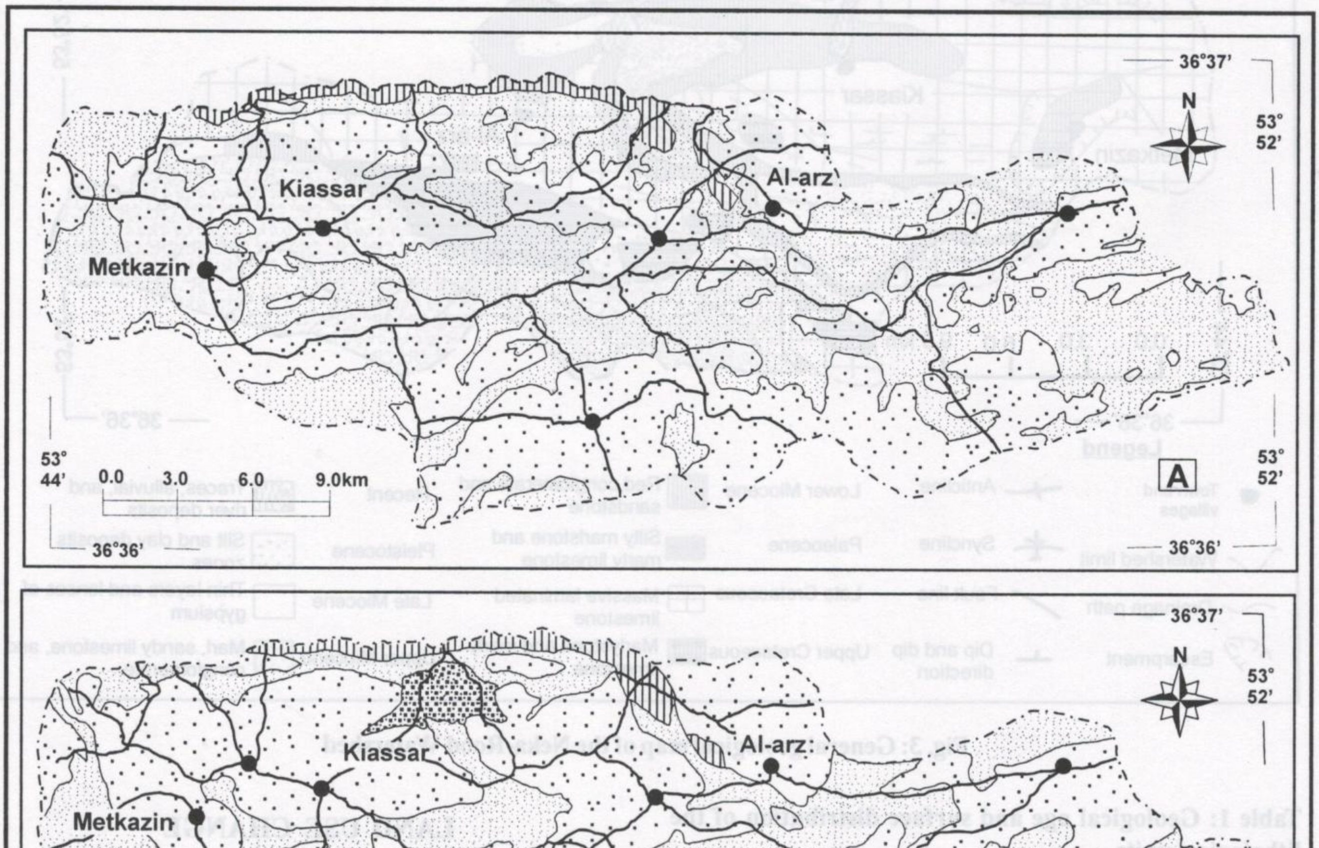

Fig. 4: Land use maps of the Neka-Rood Watershed. A: Land use map of 1955; B: Land use map of 1993

SLOPE ANGLE

The area is mostly mountainous with steep slopes and rugged terrain. The area contains three types of landform, which are identified as mountains, hills, and plains with surface distribution of 70, 28, and 2%, respectively. The various slope categories of the study area are presented in Fig. 5 and Table 3.

There is a close relationship between slope angle and geology of the area. The slope angle also affects the type of land use in the area. Steep slopes restrict the agricultural use, and consequently most of the agricultural land is located along main rivers and streams. Pastureland is widely distributed in the area and can be found in different types of ground morphology. The vegetation in the pastureland is very little, and hence it is very prone to erosion and slope instability. Most landslides occur in the area with high relative relief and larger slope angle.

SURFACE EROSION

Erosion hazard is not easily recognised because the process takes a long time. The rate of surface erosion in the study area is generally controlled by three factors. These are the type of land use, slope angle, and geology. The pastureland shows higher degree of erosion than the forestland or agricultural land. The rate of erosion is higher on steep slopes. The geological units such as massive laminated limestone and well-cemented conglomerate and sandstone show higher resistance to erosion than weak rocks such as marlstone, silty marlstone, and weakly cemented sandstone. The rate of erosion in the area is illustrated in Fig. 6.

LANDSLIDE HAZARD ZONATION

The landslide hazard mapping indicates areas vulnerable to sliding and divides the land into zones of varying degree of stability. The landslide hazard mapping invokes a multidisciplinary approach, integrating all the influencing factors on slope instability in the study area. Various techniques of landslide hazard mapping have been developed in recent years. Examples of some techniques are presented by Hansen (1984), Varnes (1984), Hearn and Fulton (1987), Dearman (1987), and TC4 (1993).

Table 3: Slope categories and their distribution in the area

Class of slope	Slope angle	Distribution	Surface morphology
1	0° – 5°	1.0%	plain
2	5° –10°	1.0%	
3	10° –15°	6.0%	hills
4	15° –0°	22.0%	
5	20° –0°	54.0%	mountainous
6	40° –0°	12.0%	
7	> 60°	4.0%	

According to the main contributing factors, two techniques of landslide hazard zonation (LHZ) mapping are used in this paper. A comparison of the results is made to evaluate the effect of land use on the development of slope instability in the area.

Method I

This method was used for zoning the slope instabilities in the Kanagawa Prefecture, Japan (KPG 1986). In this method, seven factors are considered. These factors and their ratings are given in Table 4. It can be noted that the main emphasis is given to the seismic activity, which has a rating of 40%. The summation of influencing factors for each cell indicates the susceptibility of that cell for sliding:

$$W = W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7.$$

Since the study area is situated within the seismically active Alborz mountain belt, the Kanagawa method is found to be useful for preparing a LHZ map. For this purpose, the area was divided into the grids of 500 m x 500 m on the map at 1:50,000 scale. The rating of each individual contributing factor was calculated using the proposed rating scheme. General description of this technique is given in TC4 (1993).

Method II

This method is based on Wagner (1981), Wagner et al. (1987), Deoja et al. (1991), Anbalagan et al. (1993), and Anbalagan and Singh (1996). In this method, the slopes are divided into a number of facets, which are mostly restricted by ridges and rivers. A facet is part of hill slope that has almost a similar character of slope showing consistence slope direction and inclination. The main influencing factors of this method and their ratings are summarised in Table 5. It can be noticed that the land use has been considered as one of the main factors, and its rating is similar to those of other factors such as lithology, morphology, and discontinuities.

Based on the procedure of the described methods, landslide hazard zonation maps for the study area are prepared. The maps are shown in Fig. 7. According to this method, about 70% of the area falls in the high hazard zone and over. While, Method I shows that only 29% of the area falls in the high hazard zone (Uromeihy and Safaie 1998). A

Table 4: Factors and their ratings for Method I (after KPG 1986)

Main influencing factors		Maximum rating	Weight in %
Maximum surface acceleration	W_1	2.754	40
Length of contour line	W_2	0.696	10
Relative relief	W_3	1.431	21
Length of fault	W_4	0.191	3
Ground hardness	W_5	0.710	11
Artificial slope	W_6	0.845	12
Natural slope	W_7	0.207	3

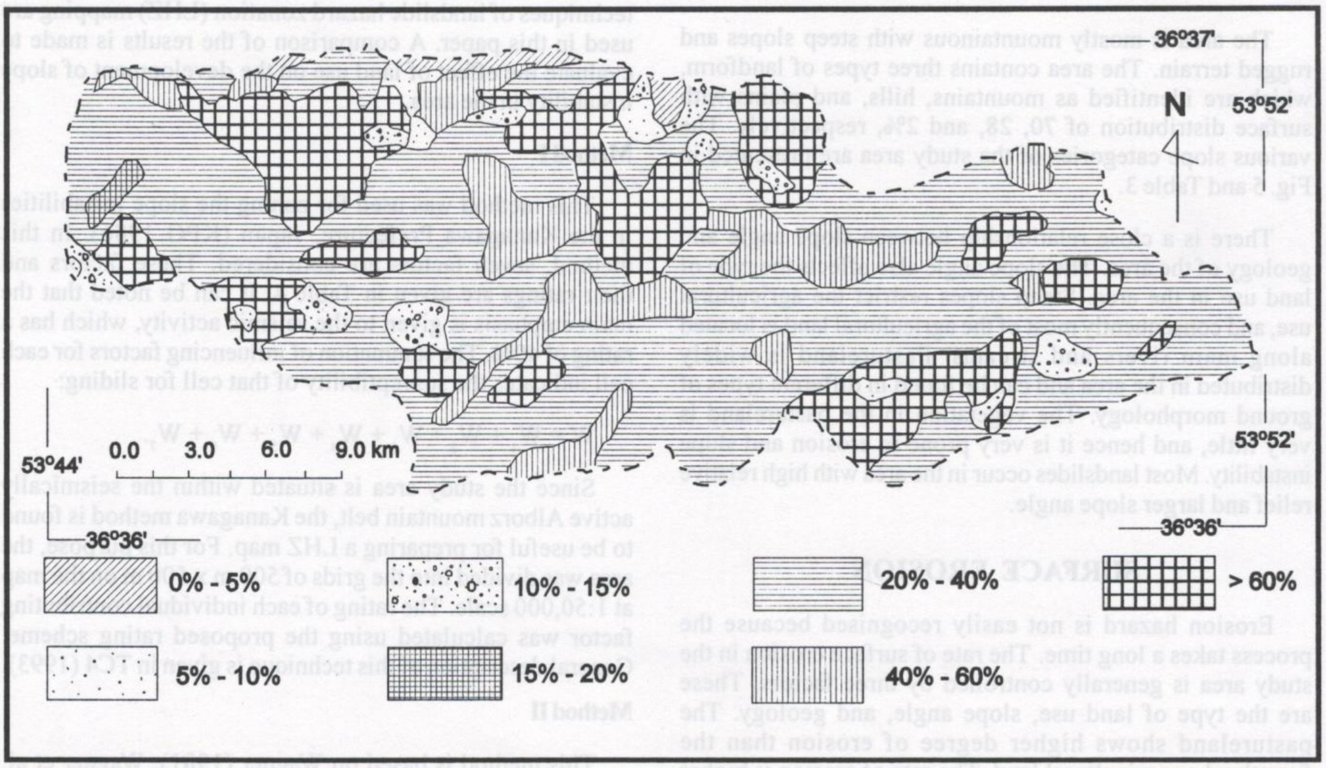

Fig. 5: Slope map of the Neka-Rood Watershed

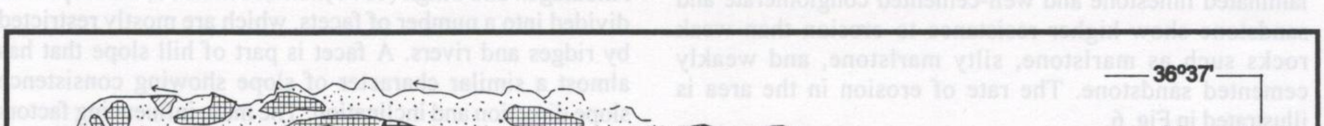

Fig. 6: Erosion hazard zonation map of the pastureland in the Neka-Rood Watershed

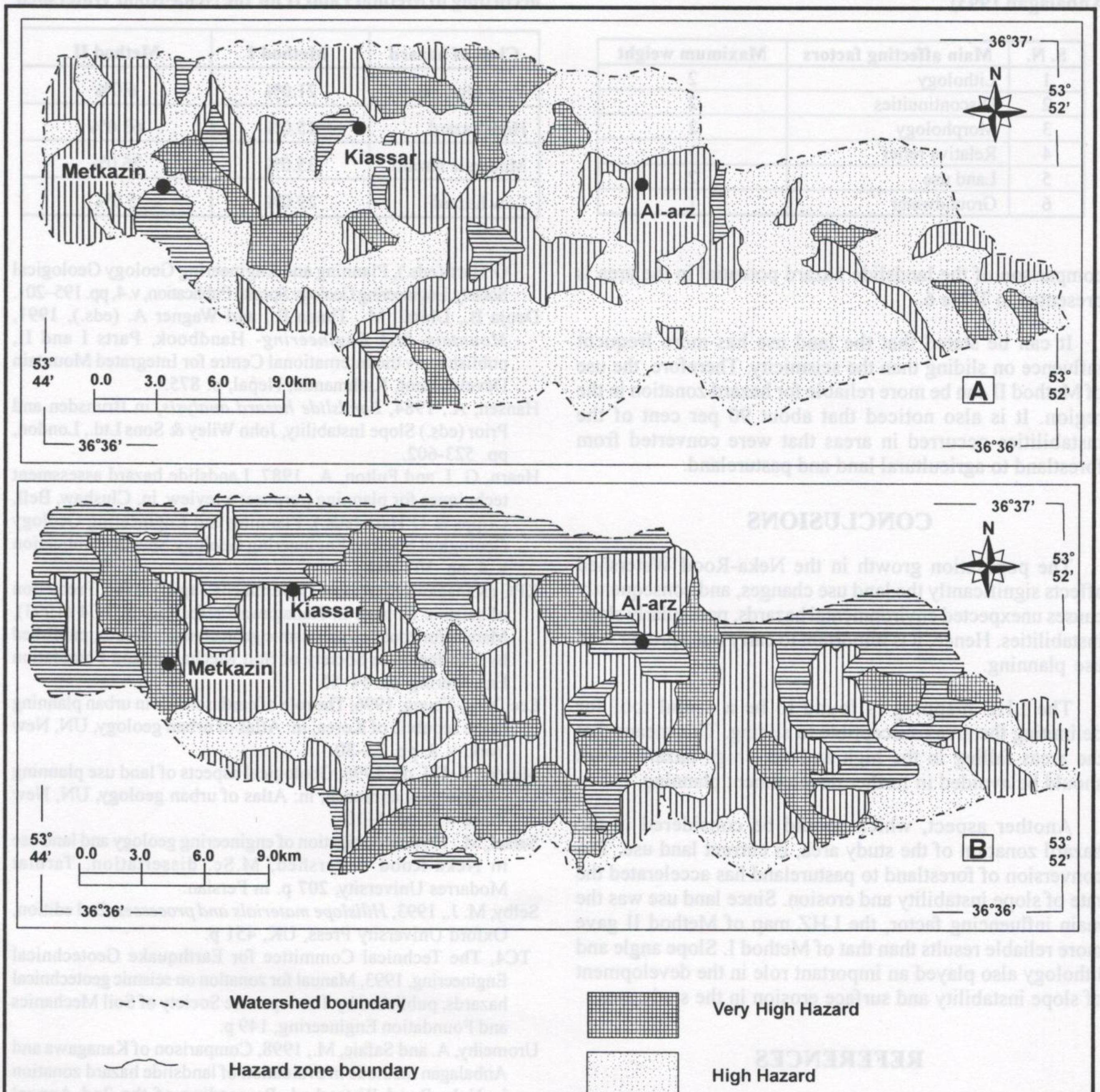

Fig. 7: Landslide hazard zonation maps of the Neka-Rood Watershed. A: According to Method II; B: According to Method I

Table 5: Factors and their ratings for Method II (after Anbalagan 1993)

S. N.	Main affecting factors	Maximum weight
1	Lithology	2
2	Discontinuities	2
3	Morphology	2
4	Relative relief	1
5	Land use	2
6	Groundwater	1

Table 6: A comparison of the landslide hazard potentials according to Method I and II for the Neka-Rood Watershed

Class of hazard	Method I	Method II
Very high hazard	21.0%	6.0%
High hazard	15.0%	63.0%
Moderate hazard	35.0%	26.0%
Low hazard	29.0%	5.0%

comparison of the landslide hazard potential in the area is presented in Table 6.

It can be stated that the land use has more frequent influence on sliding than the seismicity. Therefore, the use of Method II can be more reliable for hazard zonation in the region. It is also noticed that about 90 per cent of the instabilities occurred in areas that were converted from forestland to agricultural land and pastureland.

CONCLUSIONS

The population growth in the Neka-Rood Watershed affects significantly the land use changes, and consequently causes unexpected environmental hazards, particularly slope instabilities. Hence, it is important to carry out a proper land use planning.

The LHZ mapping is found to be a useful tool for delimiting the areas susceptible to sliding. This means that the areas falling in the high and very high hazard zones should be avoided in further development planning.

Another aspect, which should be considered in the hazard zonation of the study area, is current land use. The conversion of forestland to pastureland has accelerated the rate of slope instability and erosion. Since land use was the main influencing factor, the LHZ map of Method II gave more reliable results than that of Method I. Slope angle and lithology also played an important role in the development of slope instability and surface erosion in the study area.

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