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Space-Time Behavior of Klang Valley Region Slope Failures

(Perilaku Ruang dan Masa Kegagalan Cerun di Kawasan Lembah Klang)

P. THANAPACKIAM*, O.S. KHAIRULMAINI & A.G. FAUZA

ABSTRACT

In the last decade slope failure intensity and frequency has increased. This article investigates slope failure distribution and trend change and the tendency of spatial direction of slope failures in the Klang Valley Region (KVR) of Malaysia. The change in land cover especially for urbanization and population pressure has notably influenced spatial and temporal variations in slope failure occurrences in the KVR. This study recognized two significant impacts of slope failures: increase in intensity and frequency of slope failures from 1991 to November 2011 and spatial direction of slope failures in the KVR. Both of these effects create severe stresses on the population of the KVR. The study observed that the temporal and spatial advances of slope failures would continue to increase in intensity and frequency in the not so distant future as the environment would become more stressful as a result of urbanization. The knowledge generated from the work would be valuable to all stakeholders affected by slope failures in the KVR and lead the way towards achieving a more sustainable slope development planning in the future.

Keywords: *Slope failures; spatial direction; sustainable development; temporal direction*

ABSTRAK

Kadar kegagalan cerun semakin meningkat sejak sedekad yang lalu. Makalah ini melaporkan taburan dan trend kegagalan cerun serta arah kecenderungan daripada segi ruangan kejadian kegagalan cerun di Kawasan Lembah Klang (KVR) di Malaysia. Perubahan ciri liputan bumi terutamanya diakibatkan oleh perbandaran dan tekanan penduduk mempengaruhi kejadian kegagalan cerun daripada segi ruangan dan masa. Kajian ini mengenal pasti dua impak signifikan dalam kejadian kegagalan cerun: pertambahan kejadian kegagalan cerun dari 1991 ke November 2011 dan perkembangan arah kegagalan cerun. Kajian ini mendapati hala masa dan ruang kegagalan cerun semakin meningkat memandangkan tekanan persekitaran yang meningkat akibat perbandaran. Kajian ini diharap dapat menyumbangkan ilmu untuk pembangunan cerun yang mampan pada masa hadapan.

Kata kunci: Hala masa; hala ruang; kegagalan cerun; pembangunan mampan

INTRODUCTION

Statistics on slope failure disaster in the world showed that 3154 deaths from a total of 28 devastating slope failures occurred in 2010 (The International Disaster Database [EM-DAT] 2011). In Malaysia, increase in slope failure was observed for the past decades. Among these failures were the recent slope failure with devastating impact which occurred in Kampung Sungai Ruil, Cameron Highlands on 7 August 2011 while another major slope failure in Hulu Langat occurred on 21 May 2011. The recent pattern on slope failure showed a concentration in the urban areas especially on reworked slopes such as in the Klang Valley Region (KVR). It was identified as having frequent slope failures in the last 10 years (Thanapackiam & Khairulmaini 2008).

Slope failures are defined as the sudden movement of slope materials under the influence of gravity. Slope material consists of consolidated and unconsolidated materials such as soil, rock, artificial filling or a combination of the above (United States Geological Survey [USGS] 2004). The terms mass movements or landslides were used to refer to slope failures in many scholarly researches. In categorizing slope failures, Varnes (1984) grouped types of slope failures according to material and types of movements. Varnes regarded slope failure as *landslide* and included creep as a type of slope failure (however in this study creep is not considered as a type of slope failure). In the present study, slope failures are categorized as gravity induced sudden movements of slope material that include flows, slides, falls, lateral spreads, topples and subsidence.

Distribution and trend of slope failures characteristics differ due to various generic and specific factors. These factors consist of rainfall, vegetation, over burden loads, morphology, geological structures, weathered materials and undercutting of slopes (Khairulmaini & Tengku Adeline 2006). Crozier (1986) considered these factors were able to apply transient forces in overcoming the inherent marginal stability of slopes. In Malaysia, the wet tropical climatic conditions constantly expose slope materials to weathering activities (Tan 1995) and develop thick layers of weathered unconsolidated materials. In line with this, Raj (2000) in a study along the Kuala Lumpur

- Karak Highway of Peninsular Malaysia found that weathered granitic bedrocks in cut-slopes were less strong than consolidated materials. Therefore, weathering is able to reduce reworked slope stability and slope morphology also markedly influenced slope failures (Fernandes et al. 2004). A study in Cameron Highlands, Malaysia showed that 20° to 34° slopes are highly prone to slope failures (Sharifah et al. 2004). Steeper slopes have been found to contain shallower soil profile as it depends on the slope's resistance to downslope movement (Crozier 1986; Selby 1979) and are subjected to rapid slope failures since they are weakly bounded. Changes on slope gradients due to slope alteration such as in urban areas and heavy materials on top of undercutting slopes with weak materials have significant impact on slope failure occurrences in Penang, Malaysia (Chan 1998). Frequent slope failures were noted on cut-slopes with heights more than 5 to 10 m (Chau et al. 2002).

Rainfall is the other variable that has marked influence on slope failure occurrences. Slope failure distribution and trend is notably related with rainfall intensity and amount (Cardinali et al. 2006; Dai & Lee 2001). Slope failure distributions were more frequent during rainy seasons (Chang & Chiang 2009; Dai & Lee 2001) or due to successive rainfall during rainy periods (Chatterjea 2009; Department of Irrigation and Drainage 2008). Heavy rainfall during the monsoon season, for example, applies extra stress on the modified slopes.

Slope failure distributions and trend were influenced by vegetation cover. Vegetation protects and binds unconsolidated materials on slope surfaces (Collinson & Anderson 1996; Gao & Maro 2010) but also could cause rockfalls on consolidated slope materials (Thanapackiam & Khairulmaini 2008). In addition, slope failure is often aggravated by urban development activities such as construction of buildings, telecommunications and transportation systems. These activities are able to increase loads (Knapen et al. 2006; Schuster & Highland 2007) and artificial vibrations on the surface of slopes which eventually would intensify slope instability in urban areas.

This brief review of literature shows that localized differences in space and time behavior of slope failures are greatly affected by correlation of many causal factors. Many scholarly works studied the differences of slope failure space and time in the developed countries (Fuchs et al. 2007; Papathoma-Köhle et al. 2007; Schuster & Highland 2007); however there is a lack of studies on slope failure distribution and trend of slope failure threat in developing countries (Papathoma-Köhle et al. 2007) such as Malaysia. Gap of knowledge in slope failures in urban areas as identified by Hufschmidt (2011) is also acknowledged in this present study. This study was carried out with the aim to investigate spatial distribution and temporal trend of slope failure in the KVR of Malaysia. The findings and knowledge generated from this study are expected to assist in future sustainable urban development, besides guiding disaster managers and stakeholders in the KVR in taking proactive measures to tackle slope failure threat in the future.

STUDY AREA

The KVR is located between 3° 0'N - 3° 15'N latitude and 101° 23'E - 101° 51'E; 3° 0'N longitude in Peninsular Malaysia (Figure 1). KVR occupies 2831 km^2 (Department of Agriculture Malaysia (DOA) 2004) and comprises 5 administrative areas: Federal Territory Kuala Lumpur (FT Kuala Lumpur), Gombak, Klang, Petaling and Ulu Langat (districts in Selangor) (Department of Prime Minister [DPM] 2008).

In this study region, Klang River and its 9 tributaries flow across towards the Straits of Malacca in the west. In the east of KVR terrain of more than 914 meters (JUPEM 2004) are located. Many watercourses of the Klang River begin from this higher terrain area where the Titiwangsa

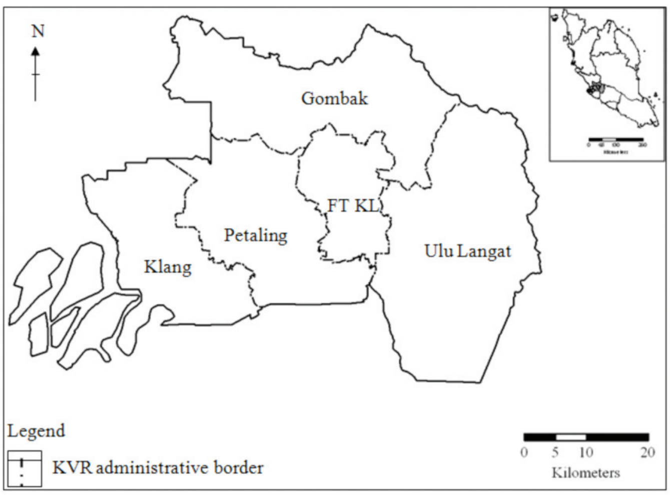

FIGURE 1. Location of the Klang Valley Region (KVR)

Range is located. In addition, slopes in the study region are also environmentally fragile to climatic variables such as rain and temperature as the region is situated in a wet equatorial climatic region. KVR receives annual rainfall of more than 2540 mm and its mean temperature is between 25 and 28°C (Malaysian Meteorological Department [MMD] 2009).

URBAN AREA

This study found that KVR is exposed to more human activities as urban areas cover 37.6% of the total land of the region (Department of Agriculture Malaysia (DOA) 2008). Permanent forest reservation covers only 20% of the land in the KVR. Urban population growth is found to be more rapid than in rural areas in Malaysia (Khoo & Van 1996) thus the population concentration in the region has caused immense increase in loads on slope surfaces. This region is also under artificial vibration due to urban related activities such as construction, transportation and telecommunication as well as quarrying activities.

SOCIO-ECONOMIC CONDITIONS

The total population of KVR is 5.89 million (2010), accounting for 20.5% of the population in Malaysia. The average annual population growth rate is 2.0% for the period 2000-2010 (Department of Statistics Malaysia [DOS] 2011). Population growth is greatly influenced by economic activities in the region. The Gross Domestic Product of KVR is MYR 67,747 million in 2000 and thus become a factor for population concentration. High density of population distribution is identified in economically elevated areas such as FT Kuala Lumpur.

METHODS

SLOPE FAILURE THREAT

This study gathered data on slope failures occurring from 1991 to November 2011. In identifying slope failure locations, causal factors and impacts, slope failure reports were used in this study. These reports were documented by agencies such as the Public Works Department Malaysia (PWD) and Department of Mineral and Geosciences (DMG); however these agencies have not documented many small slope failure with minimal danger to the safety of the populace. Thus, the study collected data from publications in journals and conference proceedings by engineers or geologists who were directly involved in investigating slope failures in the KVR. Archival data especially from news media were also used to identify frequency of slope failures in the KVR. These slope failures were then used to generate a slope failure database for the KVR.

In this database, the coordinates of locations, causal factors and impacts were included. The slope failure coordinates and environmental factors were determined through field visits. In addition, primary and secondary data were collected also from various agencies related to slope failure management and other agencies. Rainfall data were gathered from the Department of Irrigation and Drainage (DID) and Malaysia Meteorological Department (MMD). The data were used to identify the influence of rainfall on slope failure events. Terrain maps from Department of Mapping (JUPEM) assisted in determining elevation while gradient map by the Department of Agriculture were used to identify slope gradients in this study region. The population density and population growth in this region were determined to increase in population pressures. The population data was acquired from the Department of Statistics Malaysia. The study used these physical and population data to plot digital maps whereby the administrative border of KVR is provided by the Department of the Prime Minister. Additional information of causal factors which influenced distribution and trend of slope failure were acquired by analyzing these data. In this paper, spatial direction and temporal threats of slope failures were presented in graphs and maps. Population vulnerability to slope failure was investigated after slope failure location and level of risk had been determined.

SAMPLING PROCEDURES

This study used exhaustive sampling method as the number of slope failure victims differ between slope failures threatened locations. Figure 2 shows the sampling procedures applied in this present study. A total of 172 slope failures that occurred from 1991 to November 2011 were mapped and then analyzed for spatial and temporal threats. The spatial direction of slope failures was projected using this data and displayed in graphs. Population vulnerability to slope failures was examined using slope failures that occurred during 2006 to 2008. These locations were visited to identify environmental and human vulnerability to slope failures in the KVR.

RESULTS AND DISCUSSION

Two significant effects identified are the increasing intensity – frequency of slope failure impacts on the populace and the direction of the slope failure in the KVR.

SLOPE FAILURE FREQUENCY AND INTENSITY

Findings show significant increase in intensity – frequency of slope failures in the KVR. Slope failure data base of this study showed that 172 slope failures were recorded from 1991 to November 2011 in the KVR. Figure 3 displays the intensity and frequencies of yearly slope failures in the study region. Figure 3 shows that the peaks of slope failure frequencies were recorded in 1993, 2001 and 2008. In 1993, 8 slope failures were identified and a devastating slope failure occurred in 2008. In this incident 5 people were killed in the Taman Bukit Mewah slope failure. The study found that after a peak year of slope failures less frequent slope failure occurrences were identified. This

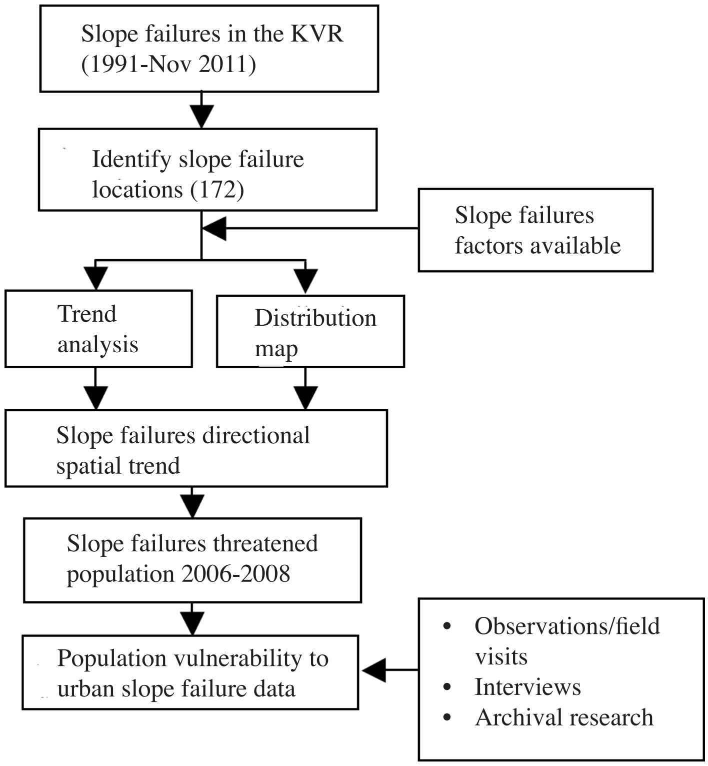

FIGURE 2. Sampling procedures

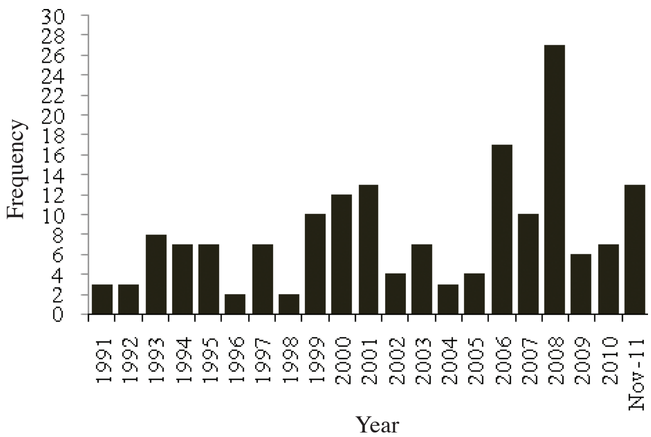

FIGURE 3. Slope failure intensity and frequency 1991 – November 2011

could due to the improvement of mitigation measures and reworked slopes maintenance.

Findings in this study showed fluctuation of slope failure occurrences from 1991 to November 2011. The general pattern however displayed increase in intensity and frequencies over the years. Figures 4(a) and 4(b) show increase in future slope failures trend line of the KVR ($y = 23.5x + 10.33$; $r^2 = 0.95$). The study forecasted the trend for the future for 3 time periods. Findings of the future slope failures intensity projection shows that 106 slope failures will occur during the period 2012-2018 and will increase to 130 slope failures in the period of 2019-2025. The frequency – intensity will further rise to 154 slope failures incidences from 2026-2032. The study suggests that slope failure will record a significant rise in the future and these slope failures are an impending threat to the urban populace in the KVR.

SLOPE FAILURE SPATIAL DIRECTION

Results of slope failures spatial distributions are shown in Figure 5. The spatial distribution shows that most slope failures were clustered around the center of KVR. Significant numbers of slope failures occurred in the Federal Territory Kuala Lumpur and Petaling district from 1991 to 1997 (Figure 5(a)). Similar trend continues for the time period 1998 to 2004 whereby clustered slope failures were identified in the Federal Territory

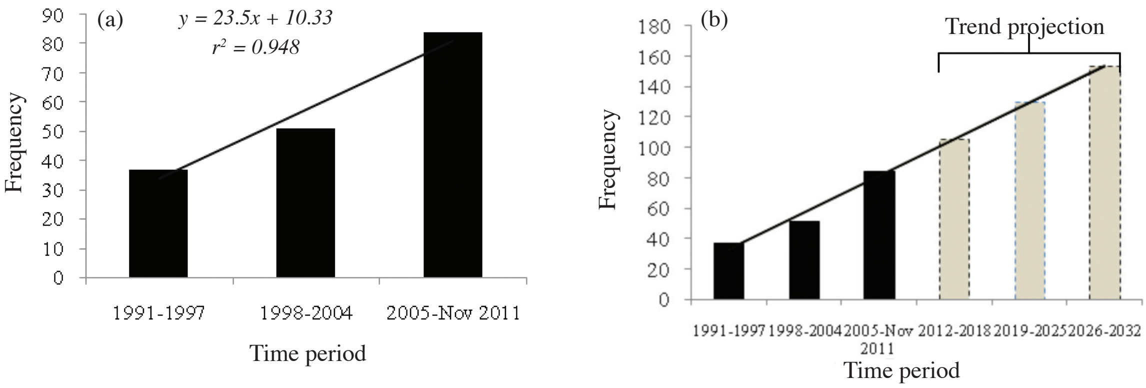

FIGURE 4. Slope failure current and future trend projection a) Slope failure trend 1991 - November 2011 and b) Slope failure future trend projections

Kuala Lumpur. The trend of slope failures distribution has widened towards Ulu Langat from the eastern part of FT Kuala Lumpur. Several slope failures were also identified in the northern part of KVR. The findings of slope failures spatial distributions in 2005 to November 2011 (Figure 5(c)) shows that slope failures increased markedly from the previous time and expanded from the center of KVR toward all directions. The spread of slope failures distributions was related to other factors such as generic factors (slope morphology, weathering, slope materials, geological structures) and anthropogenic factors (urban activities, artificial vibrations and planted vegetation). The generic factors act in amalgamation in reducing slope stability whereas trigger of sudden slope failures were due to slope failure specific factors. This study found that rain has notable influence on reworked slopes stability; however, mitigation measures on urban slopes enhance slope stability. Hence, the role of urban activities and population pressure were investigated to its influence on occurrences of future slope failures in the KVR.

Urban impact on slope failures This study found that urban development has markedly affected slope failures of the KVR. Comparison of urban development and slope failure distributions in this study indicated that significantly intense slope failures occurred in urban land (94.2%) from 1991 to Nov 2011 (Figure 6). This study also found notable increase in slope failures temporal trend with a significant correlation (r^2 = 0.97). Slope failure occurrences increased from 32 urban slope failures from 1991-1998 to 82 urban slope failures from 2005 to November 2011. The increase in urban slope failures shows that slope stability was reduced due to over burden loads on reworked slopes.

Population pressures Population increase is in line with development of urban activities in the KVR. Population increase and concentration in this region have contributed to population pressures on the fragile reworked slopes in the KVR. This study found that population density has increased from 629 people per km^2 (1980) to 1962 people per km^2 in 2006. In addition, findings show that Federal Territory Kuala Lumpur has the highest population density (7,089 people per km^2) while population density of Petaling district is 3,012 people per km^2. Population density in Ulu Langat district is 369 people per km^2 and Gombak has 1,085 people per km^2 (DOS 2011) for this time period. Population pressures too have augmented loads on reworked slopes in this study region and similarly have increased vulnerability of population to slope failure threats.

Many scholars have investigated space and time behavior of slope failures mostly focusing on macro level (Hufschmidt 2011). Studies were carried out in a whole island such as Singapore (Chatterjea 2009) and Lantau Island (Zhao et al. 2002) while Sarkar et al. (2000) compared slope failure occurrences in different regions. The aim of these previous researchers was to investigate slope failure on a wider scale but this present study was carried out in a focused study area that is in the KVR.

Slope failure clustering is identified in the center of the KVR but in a previous study Griffiths et al. (2005) found that slope failures were clustered in river capture sites in a catchment area of the Rio Aguas Catchment in South-East Spain. In this study, slope failure occurrences were related to influence of water source with slope failures. In the KVR, rainfall influenced slope stability and prolonged rain in tropical wet countries could weaken reworked slope stability (Raj 1998). This could affect the distribution of slope failures in the KVR. In this present study, clustered slope failure distributions as well as increase in slope failure frequencies and intensities were related to decrease in inherent capacity of slopes and increase in stresses on slopes. This is due to various causal factors and lack of slope maintenance. Reworked slopes will weaken over time with inadequate maintenance (Terzaghi et al. 1996) and thus need constant monitoring. Slope failure fluctuations in the KVR are related to the efficiency of slope stability measures. Slope failure maintenance and proper measures can reduce the impact of slope failures in the KVR. In general, the rise in slope

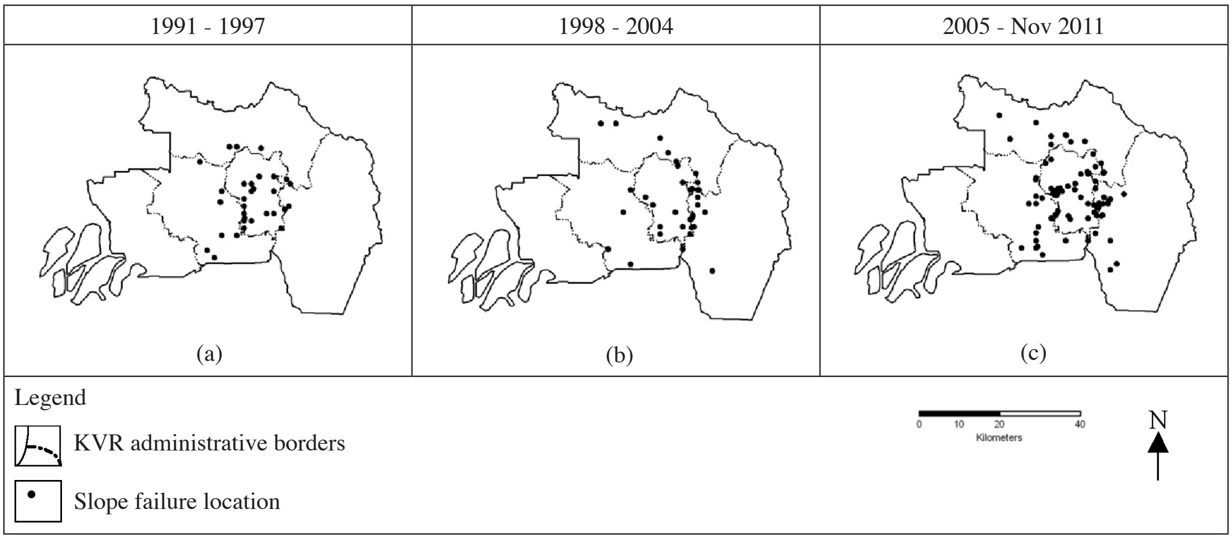

FIGURE 5. Spatial direction of slope failures 1991-Nov 2011

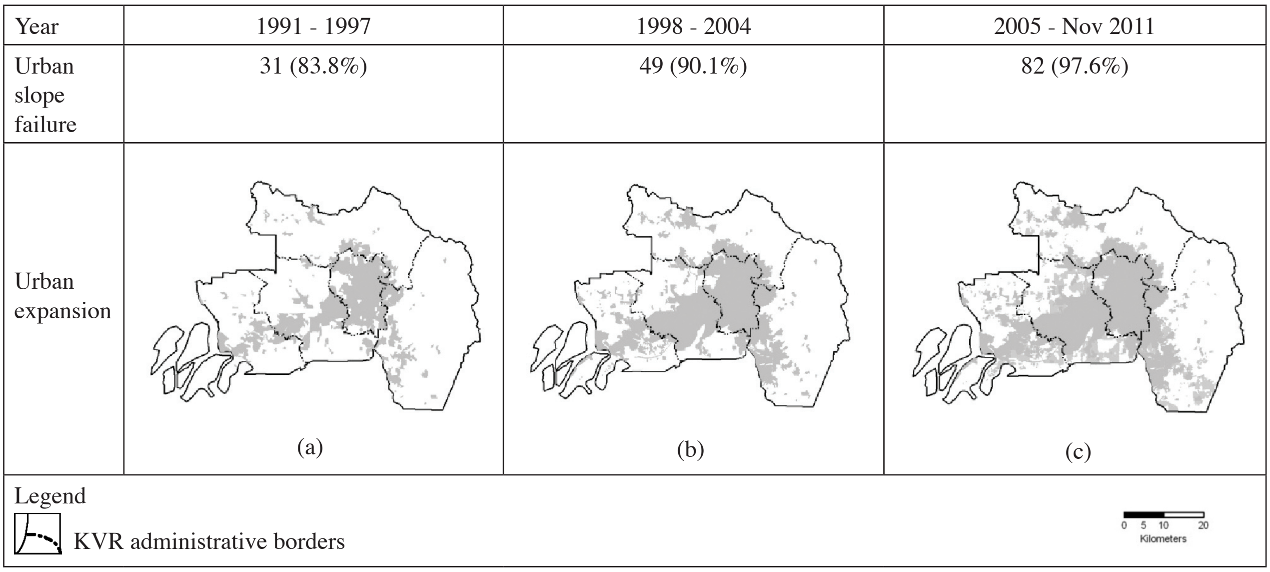

FIGURE 6. Urban land cover in the KVR

failure frequency and intensity is associated with intense urban activities and load increase in this study region.

In the KVR, urban development has contributed to population concentration as well as load increase. Load increases were caused by construction of structures such as buildings, telecommunication and transportation systems. These conditions have caused load increase and also rise of artificial vibrations which weaken reworked slope stability (Knapen et al. 2006; Polemio & Petrucci 2000; Saldivar-Sali & Einstein 2007). Various intensive economic activities would cause slope failures (Szabó 2003) as increase in loads on reworked slopes cause slope materials to be dislodged (Polemio & Petrucci 2000). In this present study region, slopes were exposed to various slope stress increasing factors on top of overburden loads and artificial vibrations (Figure 7). These factors have weakened slope stability and contributed to increase in slope failure frequencies and intensities over time. The decrease in inherent capacities of urban slopes has eventually raised spatial and temporal occurrences of slope failure in the KVR.

These increases in slope failures have affected the safety of the population as well. This study revealed that slope failures have significantly augmented the threat amongst the vulnerable urban dwellers. The space and time behavior of slope failures displays significant increase in slope failures from 1991 to November 2011, and the projection of these slope failures shows notable increase in future ($r^2 = 0.95$). Hence to reduce slope failure impact, sustainable habitation is pertinent in future urban development projects in the KVR.

In order to reduce the spatial and temporal slope instability, various slope management measures are

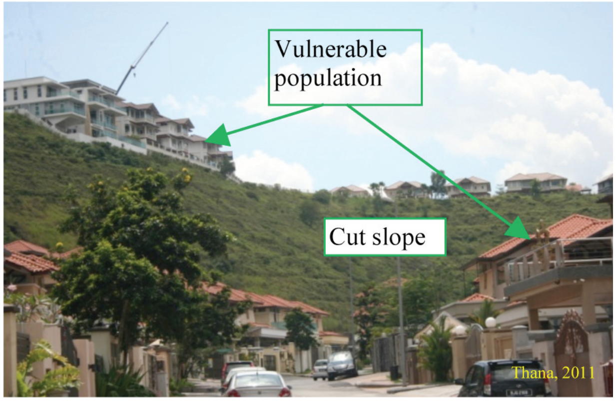

FIGURE 7. Slope failure threat to urban dwellings

carried out in the KVR. These measures vary from short to long-term mitigation measures which consists of hard management approaches and soft management approaches (Thanapackiam 2012). Hard management approaches include strengthening of slope stability and managing drainage on slopes while soft approaches include educating the public to participate in slope management measures. The slope failure threatened populace therefore needs to be more aware of the threat they are facing and be able to monitor slope instability in their surroundings.

CONCLUSION

This study on space and time behavior of slope failures has identified increase in slope failure in the KVR since the last decades. The spatial distributions are associated with load increase due to urban activities and population pressures in the KVR. Slope instability caused by human activities is also the causal factor for safety threat amongst the urban population in this study region. Furthermore, spatial direction shows significant occurrences of slope failures in densely populated areas which in future would expose the urban dwellers to more intense slope failures. Therefore, this study suggests for a sustainable habitation to reduce the frequency and intensity of slope failure in the coming years. Besides slope mitigation measures to strengthen urban slopes, establishment of a people centric slope failure early warning system is equally essential in reducing population vulnerability to slope failure threat in the KVR (Thanapackiam et al. 2011). Awareness of slope failure threat will enable the urban population to be more proactive in increasing their adaptive capacity to the impending slope failure risk (Thanapackiam et al. 2012). In addition, this population can participate in monitoring slope stability in their surroundings and alerting the authority of any sign of slope instability as soon it is detected. The knowledge generated from the work would be valuable to all stakeholders affected by slope failures in the KVR. This will pave the way to a more sustainable slope development planning in future especially through establishing a people-friendly slope failure, early warning system which encompasses not only technological components in management but human components as well.

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Department of Geography
University of Malaya
50603 Kuala Lumpur
Malaysia

*Corresponding author; email: tnpba@yahoo.com

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