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Risk Assessment of Land Subsidence in Kathmandu Valley, Nepal

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Abstract

Land subsidence is an environmental geological phenomenon that causes slow lowering of ground surface elevation. With this slow deformation in land comes great risks to buildings and infrastructures resulting in significant economic losses and in worst case scenarios loss of human life as well. Therefore, it is important to assess risk beforehand for proper risk management.

The objective of this research is to assess risk in the areas affected by land subsidence in Kathmandu Valley, Nepal using Geographic Information System (GIS) processing. A land subsidence map of Kathmandu valley (from 2007 to 2010) has been generated using Differential synthetic aperture radar interferometry (D-InSAR) technique. Geophysical data, that includes the subsidence volume, land subsidence velocity and groundwater exploitation intensity of the affected area will be utilized to estimate the future land subsidence. Social data, that includes population density, gross domestic product/km^2 and construction land proportion will be utilized to estimate the vulnerability. Finally, the estimated land subsidence and estimated vulnerability will be combined together to obtain a land subsidence risk map. Different cases with and without governmental prevention and reduction policy or action will also be employed to compare the differences.

This result is expected to be useful for the government and interested stakeholders for better understanding of the prevailing situation and the changes that can be brought through interventions. The generated result will also be helpful for disaster prevention policy-making

Keywords

Land Subsidence; Risk Assessment; Kathmandu Valley; D-InSAR; GIS

1. Introduction

Kathmandu Valley, the capital city of Nepal is the largest urban agglomerate in terms of economic activities and population. The ever increasing dense population and economic growth induces the intensive exploitation of land and water resources. This haphazard exploitation along with the geologic setting of the valley makes it prone to land subsidence. Land subsidence is an environmental geological phenomenon that causes slow lowering of ground surface elevation (Hu, et al., 2009). The problem of land subsidence was first included by the UNESCO program of the International Hydrological Decade(IHD), 1965-74. Since then this problem has been documented throughout the globe. Some of the places suffering from land subsidence are Tokyo, Japan (Yamaguchi, 1969), Mexico (Adrian et al., 1999), Houston- Galveston Region, TX, USA (Gabrysch and Neighbors 2000), Jakarta, Indonesia (Abidin et al., 2001), Ravenna, Italy (Teatini et al., 2005), Pingtung Plain, Taiwan (Hu et al., 2006) and China (Xu et al. 2008). Land subsidence can induce geological disasters, damage infrastructure, and contribute to economic loss that could directly affect the sustainable development.

In case of Kathmandu valley, the first land subsidence map was generated for the period of 2007 to 2010 prior to this research. The results showed areas of subsidence in densely populated areas and areas with high economic activities. Land subsidence is just a geological phenomenon either triggered by natural or anthropogenic activities but when this phenomenon has the probability of resulting harmful consequences or the expected loss (of lives, property, livelihoods, economic activities or environment) then it is considered as risk. (Hu et al., 2009). Risk factors are compounded by the rapid increase in the urban population and economic development (Wang et al., 2012). Therefore, it is necessary to assess land subsidence risk for decision and policy makers to prevent a huge potential disaster.

The several approaches for land subsidence risk assessment include statistical models and expert system methods. These models include neuro-fuzzy inference system (ANFIS) (Park et al. 2012), artificial neural network (ANN) (Kim et al., 2009; Choi et al., 2010), weight of evidence (WOE) (Oh and Lee, 2010), multi-criteria decision model (Mancini et al., 2009), frequency ratio (FR) (Oh et al. 2011; Suh et al., 2013) and analytic hierarchy process (AHP) (Putra et al., 2011; Jiang et al., 2012; Huang et al., 2012). However, most of these models were adopted to study land subsidence resulted from coal mining.

In this study, three factors (hazard, vulnerability and capability of disaster prevention and reduction) were selected for quantitative evaluation. The main objective of this research is to assess land subsidence risk in Kathmandu valley, Nepal using the Risk Index method, ArcGIS Spatial Analyst and the Analytic Hierarchy Process.

2. Methods and Materials

2.1. Study Area

The Kathmandu valley, the capital and the largest urban agglomerate of Nepal is located in the central part of the country between 27°32'13” and 27°49'10” N latitudes and 85°11'31” and 85°31'38” E longitudes. It covers an area of 569.8 km^2 and has a population density of 19,250 per km^2 as per 2012 census. The area is relatively flat with slopes less than 1º with soil having predominantly loamy and boulder texture. It stands at an elevation of approximately 1,400 m (4,600 ft). The city has two principle landforms: alluvial and flood plains along river and slightly more elevated river terraces. The valley is bowl shaped with draining towards the center of the basin.

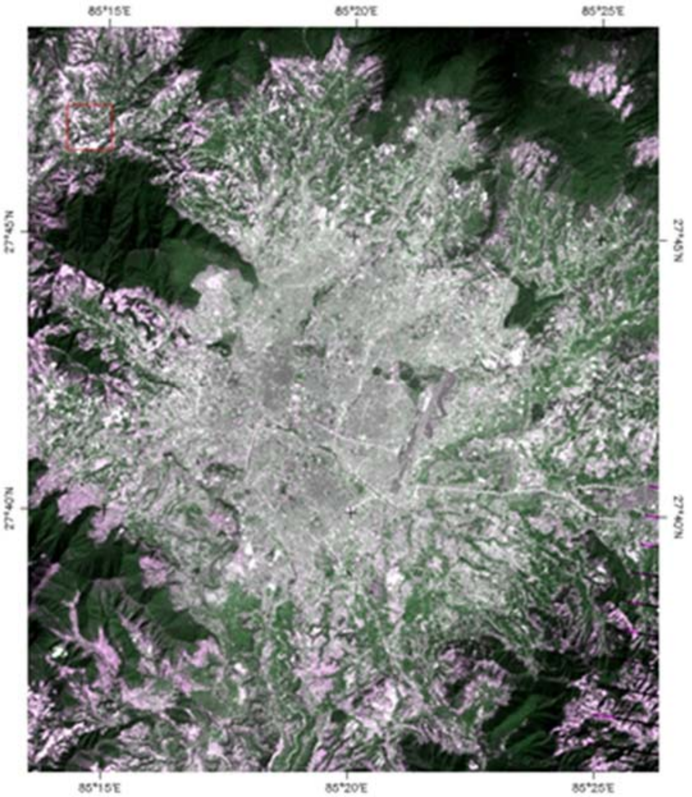

Figure 1. Landsat Image of Kathmandu Valley (2013)

2.2. Methodology

Three factors, hazard, vulnerability and the capability of disaster prevention and reduction will be considered for the quantitative evaluation of risk. The Risk Index Method, ArcGIS Spatial Analyst and the Analytic Hierarchy Process will be employed to assess the risk of land subsidence.

Risk Index Method: This method will be employed for the quantitative estimation of risk by following the underneath relationship (Lirer and Vitelli, 1998)

$$D_R = f(H, V, R) \qquad (1)$$

where, D_R is the disaster risk
H is the Hazard
V is the Vulnerability
R is the capability of disaster prevention and reduction.

Hazard is the probability that disaster will occur in a given area within a given period of time. Similarly, vulnerability is a measure of susceptibility to physical harm or damage due to a disaster.

ArcGIS Spatial Analyst: The tools like spline interpolation, reclassification and raster calculator tool in the ArcGIS will be used for the analysis. Spline interpolation helps to create a raster surface on the basis of subsidence volume and velocity.

Reclassification as well as raster calculator tool deals with the different aspects of evaluation indices.

Analytic Hierarchy Process: This process will be employed for the criteria weighting. Analytic Hierarchy Process is a multi-criteria mathematical evaluation method used for decision making. Here, hierarchical structures are used to quantify relative priorities for a given set of elements on a ratio scale set by the user.

A simple flowchart for the methodology is shown in **Figure 2** below. Geophysical data, that includes the subsidence volume, land subsidence velocity and groundwater exploitation intensity of the affected area will be utilized to estimate the future land subsidence i.e. Hazard. Different from sudden disasters, land subsidence is a slow-onset geohazard and is accumulated over years. Therefore, the accumulative subsidence volume is the key indicator in evaluating the land subsidence hazard (Wang 2006; Wei, 2006). Land subsidence velocity is included as the hazard evaluating indicator to demonstrate the trend of subsidence. The ground water exploitation intensity is also used as an indicator because groundwater extraction is considered as the primary cause of subsidence in the area.

Social data, that includes population density, gross domestic product/km^2 and construction land proportion will be utilized to estimate the vulnerability. The level of socioeconomic development is directly proportional to vulnerability; the more developed the economy and the more dense the population the more the changes of damage and physical harm. The estimated land subsidence and estimated vulnerability will be combined together to obtain a land subsidence risk map. Different cases with and without governmental prevention and reduction policy or action will also be employed to compare the differences. Case 1 is with no governmental prevention and reduction policy or action whereas Case 2 is with government action to reduce ground water exploitation and finally Case 3 is with government action to prevent/reduce construction land proportion. Finally, three different land subsidence risk map will be obtained by employing these three different cases.

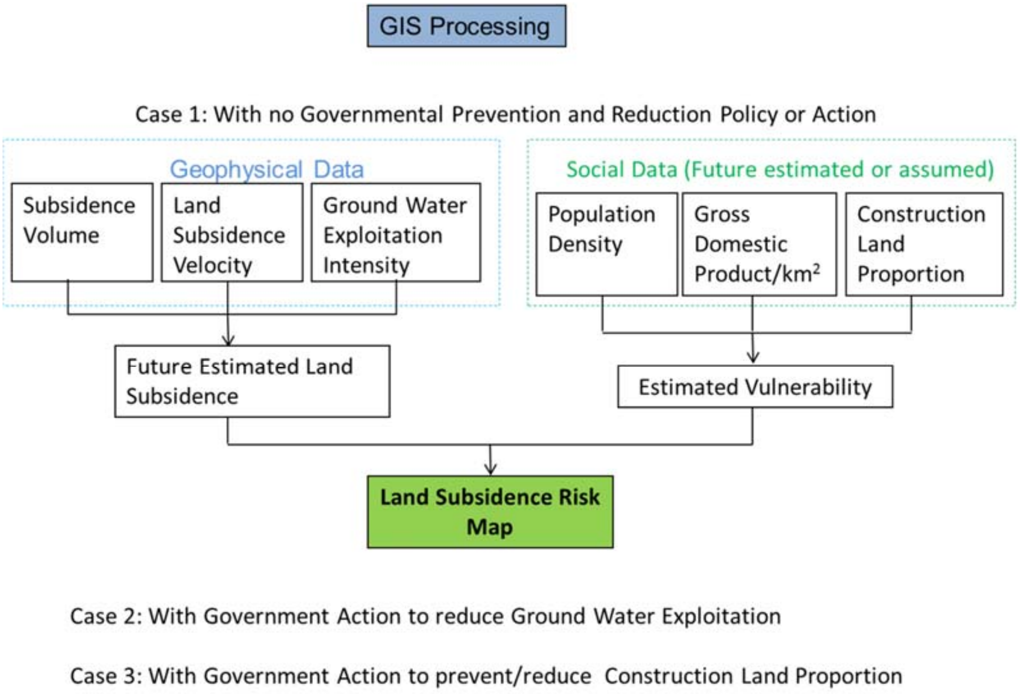

Figure 2. Methodology Flowchart

3. Expected Result

This is an ongoing research; therefore, the results are not obtained yet. But, eventually, after applying the above mentioned method; a land subsidence hazard map, a land subsidence vulnerability map and finally three different risk maps is expected to be obtained. The result map will be zoned in terms of very high, high, medium, low and very low risk/hazard/vulnerability areas.

This result is expected to be useful for the government and interested stakeholders for better understanding of the prevailing situation and the changes that can be brought through interventions. The generated result will also be helpful for disaster prevention policy-making

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