A Preliminary Investigation of the Feasibility of Predicting Landslide Risk Using Active Microwave Remote Sensing

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ABSTRACT: Landslides are a major natural hazard in mountainous areas, which can result in substantial damage to property and human lives. Many such areas in Sri Lanka are constantly subjected to rainfall triggered landslides. It is essential to take remedial action prior to the occurrence of a landslide in order to prevent loss of lives and minimize property damage. Therefore, timely prediction of landslide occurrence is of utmost importance. With the advancement of technology, the use of remote sensing techniques for detection of landslides has become viable. Thus, this research focuses on the potential use of high resolution remote sensing systems for early detection of landslides. Out of several indicators which can be used for the prediction of landslides remotely, this research focuses on using active microwave remote sensing to estimate the rapid variation in surface soil moisture. Soil surface moisture can be correlated to soil subsurface moisture, which is a major cause of landslides. Microwave scattering parameters can be derived from microwave satellite imagery. This paper demonstrates the feasibility of correlating the remotely sensed microwave scattering parameters to soil surface moisture content using analytical modeling.

1 INTRODUCTION

Rainfall triggered landslides cause a considerable property damage and loss of human lives in Sri Lanka. This damage could be minimized by implementing an accurate landslide forecasting system. The current system of predicting landslides in Sri Lanka is based on monitoring the rainfall intensity. The risk of landslide is predicted when the rainfall intensity reaches a threshold value.

With the advancement of technology, use of satellite imagery for the prediction of natural hazards has gained significant popularity. There are several indicators which can be used for the forecasting of landslides remotely: (1) significant displacements within known landslide locations which can be monitored with high resolution optical satellite images and the use of image processing techniques, (2) surface fissures, the development and propagation of which can be monitored from optical satellite images since image processing techniques can be used to monitor the fissure widths with time, (3) loss of vegetation, which can be mapped based on optical satellite images with time in suspected landslide locations, and (4) rapid variation in surface soil moisture content which can be estimated with active microwave remote sensing and co-related to the subsurface moisture variation using analytical models. Out of these methods, this research focuses on the use of active microwave remote sensing for the prediction of soil surface moisture. The increase of soil surface moisture is an indicator of the rise of the groundwater table, which could lead to slope instability.

Significant research efforts have been focused on determining the feasibility of active microwave remote sensing for the prediction of landslides. Using statistical modeling, Ray et al. (2007) observed that there exists a close relationship between soil moisture obtained from AMSR-E microwave images, pre-landslide precipitation data obtained remotely from TRMM sensor and the occurrence of landslide events. In addition, Ray et al (2010) were able to develop landslide susceptibility maps for Cleveland Corral, California using remotely sensed AMSR-E data.

2 THEORITICAL BACKGROUND

2.1 *Active Microwave Remote Sensing*

Microwaves belong to the 300MHz to 300GHz frequency range of the electromagnetic spectrum. Microwave remote sensing can be categorized into two areas: (1)active microwave remote sensing (2) passive microwave remote sensing. In the former category, a microwave pulse is sent to an object on the ground by a satellite mounted sensor. In the latter category, a sensor would sense the microwave emissions coming from objects on earth. This research will be based on active microwave remote sensing.

When a microwave pulse sent by a microwave sensor comes to contact with an object on earth, part of the energy is reflected back, another part is scattered while the third part is absorbed (Bohren, 1983) as shown in Fig. 1.

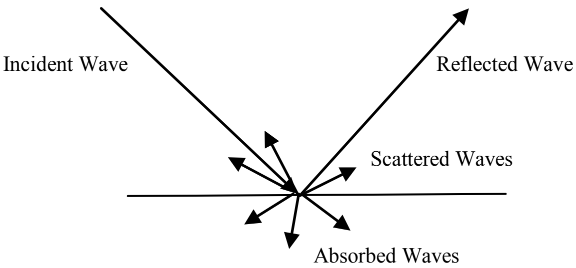

Fig. 1 Illustration of the incident, reflected, scattered and absorbed waves

The level of scatter depends on several factors which are related to the object on which microwave radiation is incident and the properties of the incident wave itself. Some of these factors are the soil moisture content, soil surface roughness, vegetation cover, incidence angle and frequency. Hence, the scattering of microwave radiation is an important parameter which could be used to remotely sense the properties of land surface.

Scattering is quantified using a parameter known as the backscatter coefficient. There are several models which are used for the calculation of the backscatter coefficient. Out of several models, small perturbation surface backscattering model (Fung, 2010) is used in this research.

2.2 *Small Perturbation Surface Backscattering Model*

The small perturbation surface backscattering model is used to calculate the backscatter coefficient (σ) when the surface roughness is small. The backscatter coefficient is defined in terms of the wave number of the incident microwave (k), the incident angle (θ), surface height standard deviation(σ), surface correlation length (L), magnetic permeability (μ_r) and effective permittivity(dielectric constant)of the surface material (ε_r).The wave number of the incident wave is defined as,

$$k = \frac{2\pi}{\lambda} \tag{1}$$

where λ is the incident wavelength. In order to apply this model, the surface parameters should conform to the following:

$k\sigma < 0.3$, $(\sigma / L) < 0.3$, $kL < 3$

The surface is defined in terms of its surface height standard deviation and correlation length. Finally, the backscatter coefficient is quantified as,

$$\sigma = (4k^4\sigma^2\cos^4\theta)\left|(\varepsilon_r-1)[\mu_r\varepsilon_r-\sin^2\theta]+\varepsilon_r^2(\mu_r-1)\right|^2 \frac{W(2k\sin\theta,0)}{[\pi(\varepsilon_r\cos\theta+\sqrt{\mu_r\varepsilon_r-\sin\theta^2}]^4} \tag{2}$$

Where W is the surface spectra evaluated at different spectral values, which is the surface height autocorrelation function defined in the wavelength domain using a two dimensional Fourier Transform.

The permittivity of the surface material is dependent upon its constituents such as soil particles, water and air voids. Effective permittivity of wet soil is an important parameter in this model, which leads to the determination of soil water content using the backscatter coefficient derived from satellite imagery. Several dielectric mixing models which are used for deriving the effective dielectric constant of a medium in terms of the dielectric constants of its constituent materials are available. Out of them, the authors have used the Rayleigh Mixing formula (Sihvola, 1999).

2.3 *Rayleigh Mixing Formula*

According to the Rayleigh mixing formula, the effective permittivity of a sparse mixture with homogeneous, spherical inclusions can be defined as,

$$\frac{\varepsilon_{eff}-\varepsilon_0}{\varepsilon_{eff}+2\varepsilon_0+v(\varepsilon_{eff}-\varepsilon_0)} = \sum f_i \frac{\varepsilon_i-\varepsilon_0}{\varepsilon_i+2\varepsilon_0+v(\varepsilon_{eff}-\varepsilon_0)} \tag{3}$$

Where ε_{eff} is the effective permittivity of the mixture, ε_0 is the permittivity of the base material, ε_i is the permittivity of the i^{th} constituent of the mixture and f_i is the volume fraction of the i^{th} constituent and ν is a free parameter. The parameter ν accounts for the effect of the polarization of a particle from its neighboring particles. ν can be quantized using the percentages of sand, silt, clay, moisture and the microwave frequency in the following manner (Behari, 2005):

$$v = -0.00525 \times \text{Sand} + 0.021627 \times \text{Silt} - 0.02642 \times \text{Clay} + 0.1095 \times \text{Moisture} + 0.007001 \times \text{Frequency} + 3.976294 \quad (4)$$

3 CASE STUDY

A case study was performed on a soil surface which has a surface topography represented by a Gaussian distribution with zero mean and standard deviation of 1. The surface was prepared by performing a Monte-Carlo simulation assuming a mean height and a standard deviation (Fig. 2).

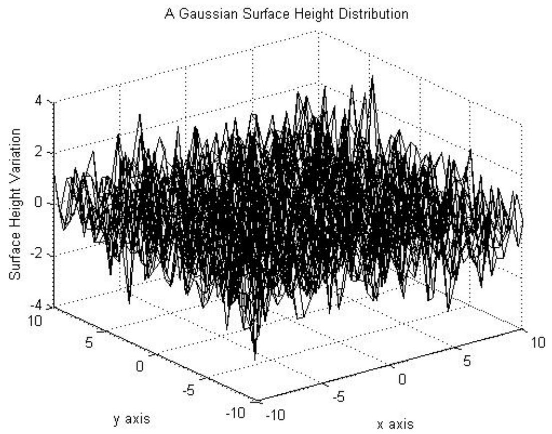

Fig. 2 Surface height variation obtained by performing a Monte-Carlo simulation on a 2D Gaussian height distribution

The surface height autocorrelation function was obtained for the derived surface (Fig. 3) and a 2D Fourier Transform was performed on the surface to transform the function from the space domain to the wavelength domain (Fig. 4).

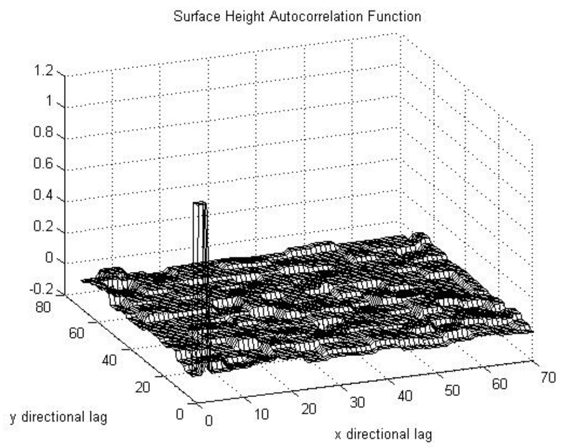

Fig. 3 Plot of the surface height autocorrelation function

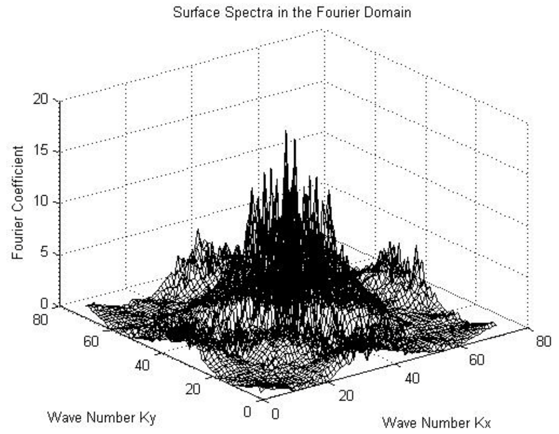

Fig. 4 Surface height autocorrelation function represented in the wave number domain

The surface spectra required at the levels specified by the small perturbation surface backscattering model could be obtained from the transformed function. Then the variation of the surface backscatter coefficient with the effective permittivity could be observed by using the small perturbation surface backscattering model.

The Rayleigh mixing formula was used to determine the variation of soil effective permittivity with the moisture content. A sandy soil site was selected for the case study which comprises 3 phases: (1) dry soil, (2) water and (3) air with a porosity of 0.4. The relative permittivity of dry sand was considered 4.7 and that of water was considered 88. Finally, the variation of effective permittivity with soil moisture content was observed.

4 RESULTS OF THE CASE STUDY

The backscatter coefficient which is determined using small perturbation surface backscattering model displayed an increasing trend with the increase of the effective permittivity.

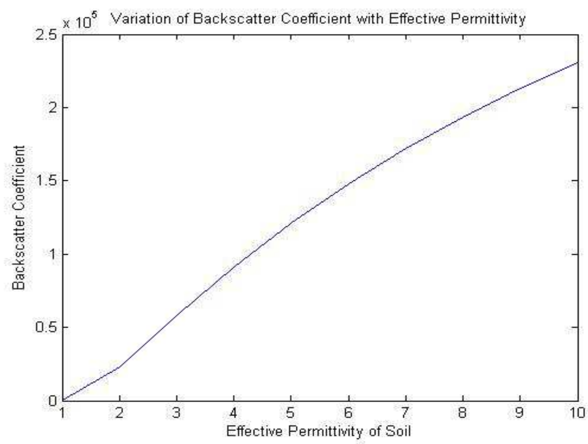

Fig. 5 Variation of backscatter coefficient with the effective permittivity of soil

Furthermore, the behavior of the effective permittivity of soil with moisture content was observed, which demonstrated an increasing trend with the increase of moisture content.

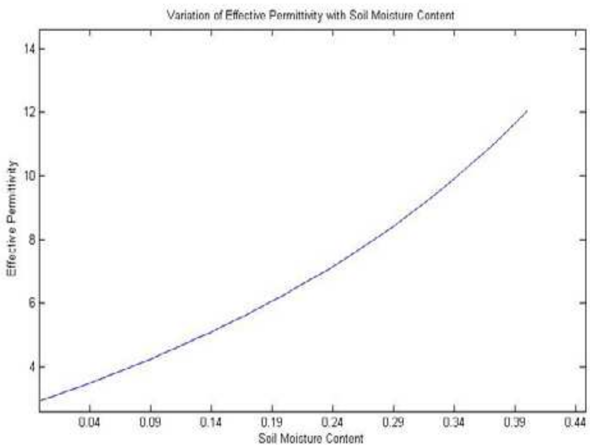

Fig. 6 Variation of effective permittivity with soil moisture content

5 CONCLUSIONS

This paper describes a preliminary investigation on the feasibility of using active microwave remote sensing to detect excessive soil moisture levels that could trigger landslides. Methodology that can be used to determine the effective permittivity using remotely sensed backscatter coefficients was demonstrated through a case study. Moreover, another theoretical model was used to demonstrate the variation of effective permittivity with soil moisture content. The results showed an increasing trend of backscatter coefficient with the increase of soil surface moisture, which can be attributed to the large difference in dielectric constant between water and dry soil. Hence, the remotely sensed backscatter coefficient, which can be obtained from radar images, does demonstrate significant sensitivity to the soil moisture content. Thus, it can indeed be used as a useful parameter for detection of landslides.

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