Landslide Susceptibility Map of Canada

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Abstract

Landslides are especially damaging in Canada and despite their extensive occurrence, the exact location of instability depends on several factors and is therefore not homogeneous across the country.

The 1:6 million scale landslide susceptibility map of Canada presented here is a first approximation for those individuals interested in pursuing more detailed investigations. The map has been constructed based primarily on GIS, by considering digital layers of relevant national information including: slope angle, aspect, precipitation, permafrost, surficial geology, vegetation, distance to rivers, distance to coast (lakes and oceans) and bedrock lithology. These variables have been categorized into several classes depending on their greater or lesser favourability to influence slope instabilities. The values assigned to each class are not equal for the whole country and vary depending on the region considered (Canadian Shield, Hudson Bay Lowlands, or the remaining area). Broad patterns in slope instability are apparent at the national scale.

Background

Within Natural Resources Canada (Geological Survey of Canada), one objective of the Public Safety Geoscience Program is the provision of broad, high level information that summarizes the likelihood of threat from a variety of natural hazards to Canada's citizens and infrastructure. Landslides are especially important in this regard. In Canada, during the past century and a half, more individuals have died from landslides than all other natural hazards combined (Evans 1999). Moreover, landslides are estimated to cost (direct and indirect) the country ~ $200 - $400 million annually (Clague and Bobrowsky 2010). Unfortunately there is no publically available, pan-Canadian expression of the potential threat from landslides.

This map provides Canadians a means to compare regional differences in landslide susceptibility. It should be used as a guide to direct more specific and detailed studies.

Methodology

The methodology used in this work includes the following several steps: 1) GIS database creation and digital data layers collection, 2) derived Digital Terrain Models creation, 3) relief differentiation of large areas in the country, 4) landscape reclassification, 5) assignment of susceptibility ranking for each data layer based on large areas and variable distribution, and 6) final data information analysis, cross correlation and construction of the susceptibility model.

A digital dataset was created with a Geographical Information System (GIS) (ArcGIS v. 9.2 ESRI). Vector data stored in the database consist of several thematic layers comprising precipitation, permafrost distribution, surficial geology, vegetation, bedrock lithology, rivers and coasts (lakes and oceans) and elevation. These data represent parameters that influence slope stability in Canada to varying degrees. Unfortunately the accuracy, precision and reliability of the data used are not equal, not systematic and cannot be evaluated for reliability.

Raster data consisted of a 1 km pixel value Digital Elevation Model (DEM) and other digital derived models. To construct the final susceptibility map it was also necessary to transform the vector layers to raster format (1 km precision). All of the data layers used in this synthesis were obtained from various agencies, departments and ministry websites hosted in Canada. Several of the sources are open to public access, whereas some of the information resides within the data confines of the Geological Survey of Canada (see Dominguez and Bobrowsky 2012 for greater detail on the methodology).

Existing knowledge of slope instability type, style and distribution for all of Canada suggests that for this analysis we can distinguish a few large areas by considering regional variations in landslide attributes. For the purposes of this work, four substantially large regions are recognized: 1) the vast territory (> 4 millions km2) occupied by the Canadian Shield (CS), a very stable environment where instability problems are not as abundant as in other areas; 2) an area up to 300,000 km2 located in the middle of the country, directly south of the Hudson Bay (Hudson Bay lowlands, HBL). Finally, the remaining terrain has been distinguished between: 3) the areas where the slope is less than 1 degree as interpreted by 1 km2 pixels (low relief areas, L) and 4) those parts of the country where the slope is greater than 1 degree are considered as high relief areas (H).

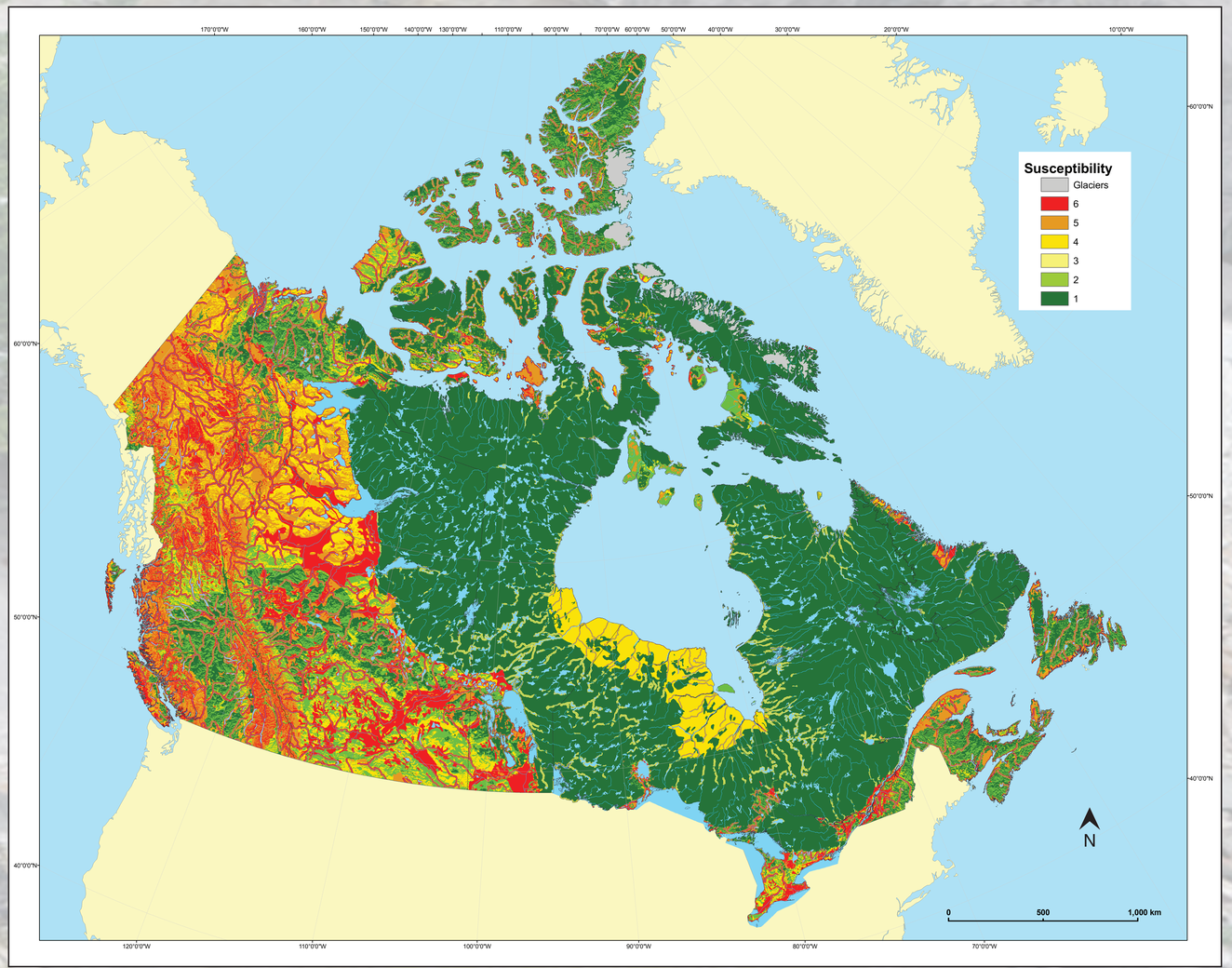
After compiling information for all of the mentioned variables into the GIS, we classified the Canadian landscape by taking into account the different distribution of terrain elements across the country. Each of the parameters used in this study was then divided into appropriate classes as summarized in Table 1. To establish the susceptibility ranking of specific data layers, expert opinion was obtained during a workshop at which GSC landslide experts relied on their personal experience and professional knowledge as input to the attribute and parameter relevance regarding landslide hazards. Attributes within each parameter were assessed and classified (semi-quantitatively) according to six categories of significance (1-low to 6-high).

These categories vary depending on which one of the large areas previously defined was considered: 1) the Canadian Shield, 2) the Hudson Bay Lowlands, and 3) the remaining Canadian territory for Low and High relief terrain. The H and L relief terrain are not shown on this image given the size of the map representation. As a result three susceptibility ranking tables have been constructed. Susceptibility values shown in Table 1 have been applied to the three areas.

The Hudson Bay Lowlands (HBL) and the Canadian Shield (CS) are recognized as special areas from a landslide susceptibility point of view. These two regions are relatively flat areas, with thin drift cover so that instabilities in these two regions are linked to those conditions where there is some slope, and usually close to rivers or coast. However, distance to water bodies alone was insufficient and the presence of key surficial deposits was also considered (glaciolacustrine and lacustrine, glaciomarine and marine, lacustrine and marine deposits).

Susceptibility classes applied to HBL and CS are shown in Tables 2 and 3. The reason other data attributes are not considered in the HBL and CS areas is because their susceptibility ranking by experts was generally low.

The final map classifies the landscape of Canada from highly susceptible (hot colours) to least susceptible (cool colours); regarding the threat of landslide hazards.



Conclusions

The methodology and baseline digital data layers (availability, quality, resolution) employed in any susceptibility map strongly influence the final product. Different methods will generate different final maps using the same primary data. The final map shows regional landslide susceptibility on a hot (red) to cold (dark green) color scheme which corresponds to a high (6) to low (1) susceptibility ranking. With respect to this susceptibility map it is important to highlight that most susceptibility terrains are located in western Canada. That is consistent with the known distribution of high relief and mountainous areas. The St Lawrence River Valley corridor, in southeastern Canada is another area that displays a greater number of orange and red pixels on the map. Again this is expected given the presence of Leda clays and the historic record of instability in the region (Quinn et al. 2010). The third region of high potential corresponds to the river valleys and glaciolacustrine and lacustrine sediments present in the prairies of west-central Canada.

In general, the rest of the country could be considered to be of lower landslide susceptibility, although local and site specific assessments cannot be reliably extracted from such a national scale map and therefore more diligent study and interpretation on a case by case basis is advised for detailed needs.

		Susceptibility RANKING					
		1	2	3	4	5	6
SLOPE	< 1°	L					
	1° - 18°	H					
	18° - 30°					H	
	> 30°						H
ASPECT	North	HBL					
	South		HL				
	Flat	HBL					
TOTAL ANNUAL PPT	> 3000 mm			HL			
	2700 – 3000		HL				
	< 2700	HBL					
PERMAFROST	Continuous	HBL					
	Extensive Discontinuous			HL			
	Sporadic Discontinuous			HL			
	Isolated Patches		HL				
	No Permafrost	HL					
SURFICIAL GEOLOGY	Alluvial	HL					
	Colluvial			HL			
	Colluvial deposits			HL			
	Glacial deposits	HBL					
	Glaciers						
	Glaciofluvial deposits		HL				
	Glaciolacustrine and lacustrine deposits				CS	HBL	H L
	Glaciomarine and marine deposits				CS	HBL	H L
	Lacustrine deposits				CS	HBL	H L
	Marine deposits				CS	HBL	H L
	Rock	L				H	
	Water						
VEGETATION (e.g. Landuse)	Broadleaf Forest		HL				
	Coniferous Forest		HL				
	Cropland				HL		
	Forest land/Shrub land		HL				
	Grassland				HL		
	Mixed Forest		HL				
	Snow/Ice						
	Tundra			HL			
	Urban and Built-up			HL			
	Wetland/Shrubland			HL			
	Water						
DISTANCE FROM RIVERS	< 1 km						HL
	1- 3 km					HL	
	3 - 5 km				HL		
DISTANCE FROM COAST	< 1 km						HL
	1- 2 km					HL	
	2 - 3 km				HL		
DISTANCE FROM LAKES	< 1 km						HL
	1- 2 km					HL	
	2 - 3 km				HL		

Table 1. Susceptibility values applied to the Canadian landscape (H – highlands, L – lowlands, CS – Canadian Shield and HBL – Hudson Bay Lowlands) (see text for explanation of acronyms).

		SG1	SG2			
DISTANCE FROM RIVERS	< 1 km	CS				CS
	1 - 2 km	CS		CS		
	3 - 5 km	CS	CS			
	> 5 km	CS	CS	CS	CS	
DISTANCE FROM COAST	< 1 km	CS				CS
	1 - 2 km	CS		CS		
	2 - 3 km	CS	CS			
	> 3 km	CS	CS	CS	CS	
DISTANCE FROM LAKES	< 1 km	CS				CS
	1 - 2 km	CS		CS		
	2 - 3 km	CS	CS			
	> 3 km	CS	CS	CS	CS	

Table 2. Susceptibility values applied to the Canadian Shield area. (SG1 = Alluvial or Colluvial or Glacial or Glaciofluvial deposits or Rocks. SG2 = Glaciolacustrine or Lacustrine or Glaciomarine or Marine deposits).

		SG1	SG2			
DISTANCE FROM RIVERS	< 1 km	HBL				HBL
	1 - 3 km	HBL		HBL		
	3 - 5 km	HBL	HBL			
	> 5 km	HBL	HBL	HBL	HBL	
DISTANCE FROM COAST	< 1 km	HBL				HBL
	1 - 2 km	HBL		HBL		
	2 - 3 km	HBL	HBL			
	> 3 km	HBL	HBL	HBL	HBL	
DISTANCE FROM LAKES	< 1 km	HBL				HBL
	1 - 2 km	HBL		HBL		
	2 - 3 km	HBL	HBL			
	> 3 km	HBL	HBL	HBL	HBL	

Table 3. Susceptibility values applied to Hudson Bay Lowlands territory. (See Table 2 for explanation of acronyms SG1and SG2).

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The Data on this map are intended to convey regional trends and should be used as a guide only. The Data should not be used for planning purposes, design or construction at any specific location, nor are the Data to be used as a replacement for the types of site specific geotechnical investigations required by law across Canada."

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