GEOTECHNICAL RISK ASSESSMENT OF LANDSLIDES ON NATURAL SLOPES

Milinda Prasad Amarasinghe

218092G

Doctor of Philosophy

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

October 2025

GEOTECHNICAL RISK ASSESSMENT OF LANDSLIDES ON NATURAL SLOPES

Milinda Prasad Amarasinghe

218092G

Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree
Doctor of Philosophy

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

October 2025

DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: 16/03/2026

The above candidate has carried out research for the PhD thesis under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Emeritus Professor S. A. S. Kulathilaka

Signature of the Supervisor: Date: 16/3/2026

ABSTRACT

Landslides are one of the most frequent natural hazards that affect humans, causing significant damage to properties and resulting in fatalities and injuries. Rainfall has been identified as the major triggering factor for landslides, and the tropical region is severely affected due to heavy rainfalls and favourable geological and hydrological conditions prevailing in these regions. Moreover, the landslide impact tends to be severe due to the high economic, political and social vulnerability in the region. However, limited studies have delved into the complex conditions that prevail in these regions. In this thesis, an extensive review was conducted on landslide risk assessment and management. Special emphasis was placed on Sri Lanka as a representative tropical country where landslides are prevalent due to rainfall, complex subsurface conditions, and it is still developing, where many challenges exist, and limited studies have been conducted. This study aimed to assess the landslide susceptibility and hazard for regions with limited data, integrating heuristic methods, process-based methods and machine learning (ML) for landslide prediction, zonation and threshold development. Initially, the applicability of well-established process-based methods was investigated using case studies to predict landslides. Then, using these methods, the critical slopes within a catchment area were identified, and process-based slope stability analysis was conducted, identifying the failure initiation area with extreme event rainfall conditions. Then the runout area for these critical slopes was determined using process-based runout assessment with the initiation area identified. Finally, a framework was developed based on process-based parametric analysis integrated with ML for slope scale prediction of failure and zonation as a quick tool for predicting the landslide hazards. This research delivers robust, scalable, and data-efficient regional landslide risk assessment tools, particularly valuable in data-scarce or resource-constrained settings. Its strong predictive capability and practical adaptability enhance its potential for integration into landslide risk management.

Keywords: landslides, susceptibility, hazard, limit equilibrium, machine learning, transient seepage

DEDICATION

This thesis is dedicated to my beloved family, whose unwavering support, patience, and encouragement have carried me through every challenge and your belief in me has been my greatest strength.

To my teachers and supervisors, for your wisdom, patience, and belief in my potential. Your encouragement lit the path when I struggled to see it myself.

This work is a tribute to the kind-hearted people of my beautiful island nation, Sri Lanka, for their resilience and generosity. Your commitment to free education, funded through your hard-earned taxes, has given me and countless others the chance to dream beyond our circumstances. Amidst hardship and uncertainty, you have built bridges of opportunity. I carry your spirit and pride with me in every word of this thesis.

ACKNOWLEDGEMENT

I wish to express my gratitude to my supervisors for the project, Emeritus Professor S. A. S. Kulathilaka from University of Moratuwa, Sri Lanka; Professor Dilan Robert and Professor Annan Zhou from RMIT University, Australia; and Dr H.A.G. Jayathissa from National Building Research Organisation, Sri Lanka, for their unwavering support, guidance and supervision throughout the PhD journey. Their patience with my mistakes, willingness to listen to my endless questions and thoughts on different aspects of research, supporting me through hard times and encouraging me all the way up to this point is invaluable.

I sincerely appreciate the Department of Civil Engineering, University of Moratuwa, Department of Civil and Infrastructure Engineering, School of Engineering of RMIT University, for granting me the opportunity to undertake this PhD program and providing me with the research scholarship that enabled me to pursue this journey. I am incredibly thankful for the two principal supervisors from the two institutions, Emeritus Professor S.A.S. Kulathilaka and Professor Dilan Robert, for generously adjusting their busy schedules for weekly discussions and offering the flexibility I needed to pursue this work. I would like to extend my sincere thanks to Professor U.P. Nawagamuwa and Professor L.I.N. De Silva of the Department of Civil Engineering, University of Moratuwa, for their valuable feedback and insightful comments that helped improve the quality of this project. Their constant encouragement has been instrumental in motivating me to pursue and stay committed to this path. I thank the non-academic staff of the Geotechnical Engineering laboratory of the Department of Civil Engineering, University of Moratuwa, for their facilitation and assistance with the laboratory work.

I greatly appreciate the support from the National Building Research Organisation for their role as the industry partner in the project. Without their support, this work could not have been a success. I would like to convey my utmost respect and appreciation to the Director General of NBRO, Dr Asiri Karunawardene, for his steadfast support for this project. I extend my sincere thanks to the Director of the Geotechnical Engineering Division of NBRO, Mr K.N. Bandara, for his invaluable guidance and assistance in organising field investigations and facilitating essential resources even under strict economic restrictions due to the economic crisis prevailed in Sri Lanka. His continued support has been a blessing for this program. Special thanks should go to Mr. Suranga Dissanayake for his flexibility in arranging the field investigation teams for the research work at the times I needed. I thank Mrs. Hasali Hemasinghe for providing me with guidance on the GIS platform and the required data for the project. I thank my colleagues at NBRO Lilanka, Buddhika, Wathsala, Thamali, Gangani, Aruna, Mihira, Sanchitha, Manuja, Raneesha, Darsha, Dileesha, Lasanda and Lahiru for their consistent support, encouragement, and help with accessing critical project data. Moreover, the laboratory staff and field investigation team of the NBRO, Sri Lanka, are greatly appreciated for their support and for facilitating me in sample collection and laboratory experiments.

To my father, Sirimewan Amarasinghe, and my mother, Chandrika Nissanka, who I owe everything. Their unwavering love and belief in me have been my foundation. Their support in good times and bad times, knowing that they are there to catch me if I fall, has been the strength in my life. I thank my sister, Gayani Amarasinghe, her husband, Lakshan Dissanayake and my brother, Kalana Amarasinghe, for being with me throughout the journey, encouraging me to pursue this path. I also thank my parents-in-law, relatives and my extended family for always supporting me, encouraging me and cheering me on to my success. Thanks to the many friends who supported me, whether in Sri Lanka, Australia, or across the world, for your words of encouragement, late-night conversations, and gestures that kept me going.

Most importantly, I express my heartfelt gratitude to my beloved wife, Bimali Dilhara. Her unwavering support, countless sacrifices, and constant reassurance during the most difficult moments have made this achievement possible. She put aside her own dreams and career to stand by me, and for that, I am forever grateful.

I extend my deepest respect to all my teachers and lecturers who have contributed to my academic and personal development over the years. I am eternally indebted to the people of Sri Lanka, whose support through free education and healthcare empowered me to pursue this path. It is through this system that I was given the wings to fly. Finally, I extend my heartfelt thanks to everyone who has been part of my life's journey. Each of you has shaped me in your own way, and I carry a piece of that with me always.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ALARP	As Low As Reasonably Practical
ALE	Arbitrary Lagrangian–Eulerian
ALiDAR	Airborne Light Detection and Ranging
ANN	Artificial Neural Network
APoF	Annual probability of failure
AUC	Area Under the Curve
BH	Borehole
CEL	Coupled Eulerian–Lagrangian
CNN	Convolutional Neural Network
CoV	Coefficient of Variation
CWR	Completely Weathered Rock
DEM	Digital Elevation Model
DNN	Deep Neural Network
DQN	Deep Q-Network
DT	Decision Tree
EF	Efficient Factor
EFGM	Element-Free Galerkin Method
EM-DAT	Emergancy Event Database
FE	Finite Element
FN	False Negative
f-N	frequency- consequence
F-N	cumulative frequency-consequence
FORM	First-Order Reliability Method
FoS	Factor of safety

FP	False Positive
GbLiDAR	Ground based Light Detection and Ranging
GBM	Gradient Boosting Machine
GbSAR	Ground based Synthetic Aparture Radar
GFLD	Global Fatal Landslide Database
GIS	Geographic Information System
GLC	Global Landslide Catalog
GLE	General Limit Equilibrium
GNSS	Global Navigation Satellite System
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GS	GeoStudio
HC	Highland Complex
HCF	Hydraulic Conductivity Function
HDPE	High Density Polyethylene
InSAR	Interferometric Synthetic Aparture Radar
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
KC	Kadugannwa Complex
KNN	K-Nearest Neighbors
KTP	Kithulgala Test Pit
LA	Limit Analysis
LE	Limit Equilibrium
LEWS	Landslide Early Warning Systems
LHZM	Likely High Hazard Zone Mapping
LiDAR	Light Detection and Ranging
LR	Logistic Regression

LSTM	Long Short-Term Memory
MCS	Monte Carlo Simulation
ML	Machine Learning
MPM	Material Point Method
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NB	Naive Bayes
NBRO	National Building Research Organisation
OOB	Out-of-Bag
PL	PLAXIS
PLL	Possible life loss
PoF	Probability of failure
PTSD	Post Traumatic Stress Disorder
QGIS	Quantum Geographic Information System
RAF	Random Forest
ReLU	Rectified Linear Unit
RF	Rainfall Pattern
RFEM	Random Finite Element Method
RMSE	Root Mean Square Error
ROC	Receiver Operating Characteristic
RT	Random Tree
SAC	Soft Actor-Critic
SHALTSTAB	Shallow Landsliding STABility Model
Sigmoid	Sigmoid Function
SINMAP	Stability Index Mapping
SORM	Second-Order Reliability Method

SPH	Smooth Particle Hydrodynamics
SPT	Standard Penetration Test
STP	Sobasiripura Test Pit
SVM	Support Vector Machine
SWCC	Soil Water Characteristic Curve
Tanh	Hyperbolic Tangent
TDR	Time Domain Reflectometry
TN	True Negative
TP	True Positive
TRIGRS	Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Model
TWI	Topographic Wetness Index
UAV	Unmanned Arial Vehicle
UGLD	Unified Global Landslide Database
USCS	Unified Soil Classification System
VC	Vijayan Complex
WC	Wanni Complex