CORRELATION OF ROCK QUALITY DESIGNATION AND RESISTIVITY USING UNMANNED AERIAL VEHICLE AND TWO-DIMENSIONAL ELECTRICAL RESISTIVITY TOMOGRAPHY

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DEDICATION

This thesis is dedicated to 230 million Pakistani who paid the cost of this thesis, I am greatly indebted to them.

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ABSTRACT

Rock Quality Designation (RQD) is a widely applied rock mass classification system for quantifying rock mass quality because it is simple and easily obtained compared to other rock mass classification systems. The rock mass quality using RQD can be identified from drill cores and scanline surveys. However, the calculation of RQD from core samples is expensive and directional-dependent. On the other hand, the scanline survey of obtaining RQD, provides point base information, is time-consuming, and is not practicable in large areas. In addition, the information by scanline survey is limited to the rock outcrop only, and subsurface rock mass quality remains unidentified. For subsurface investigation of rock mass conditions, 2D Electrical Resistivity Tomography (2D ERT) has been extensively applied; however, no comprehensive and detailed correlation of RQD and resistivity values exists to date. This study utilised an integrated Unmanned Aerial Vehicle survey (UAV) and 2D ERT survey at two sites with similar geological formations and aims to establish the correlation between resistivity and RQD indexes. The UAV survey enables the reconstruction of 3D point cloud that calculates the RQD on the surface indirectly from 1 m × 1 m block utilizing Volumetric Joint Count (Jv). This was achieved in ShapeMetrix (SMX) software. At the same time, the 2D ERT survey allows extracting the corresponding resistivity values for each RQD indexes from the same block using ZonRes2D software. A series of Linear Regression (LR) analysis and k-Nearest Neighbour (k-NN) algorithm were performed in Python to obtain continuous projections of RQD and rock resistivity and assigned resistivity values to respective RQD indexes. Two hundred twenty-three data points were obtained representing RQD and corresponding resistivity values. These data points successfully provide a continuous projection of RQD with resistivity using LR analyses, and it was confirmed that the resistivity of rock mass increases 30 Ωm for each unit increase in RQD index. Whereas the k-NN efficiently assigned resistivity values to various RQD indexes, the very poor rock shows a resistivity value of less than 350 Ωm; for poor rock, it ranges from 350-1150 Ωm. While for fair rock, the resistivity varies between 1150 to 1850 Ωm, for good rock, the resistivity ranges from 1850 to 2500 Ωm, and excellent rock has a resistivity value greater than 2400 Ωm. The established correlation of RQD obtained via k-NN characterize the surface and subsurface rock mass quality along the slope in RQD mapping. It was found that the subsurface rock mass quality was at higher quality compared to the surface at both sites. It can be concluded that the integrated UAV and 2D ERT have been successfully applied in this study. In addition, the established correlation will help in obtaining the RQD values using expeditious, inexpensive, and environmental non-destructive approach.

ABSTRAK

Rock Quality Designation (RQD) adalah sistem pengelasan jisim batuan yang digunakan secara meluas untuk mengukur kualiti jisim batuan kerana ia senang digunakan dan mudah diperolehi berbanding sistem pengelasan yang lain. Kualiti jisim batuan menggunakan RQD boleh dikenal pasti daripada teras gerudi dan juga tinjauan garis imbasan. Walau bagaimanapun, pengiraan RQD daripada sampel teras adalah mahal dan bergantung kepada arah. Sebaliknya, tinjauan garis imbasan untuk mendapatkan nilai RQD, hanya menyediakan maklumat pada titik lokasi tertumpu, mengambil masa yang lama dan tidak sesuai dipraktikkan di kawasan yang besar. Di samping itu, maklumat melalui tinjauan garis imbasan adalah terhad kepada singkapan batuan sahaja, dan kualiti jisim batuan di bawah permukaan masih tidak dapat dikenalpasti. Untuk penyiasatan keadaan jisim batuan bawah permukaan, keadaan jisim batuan 2-Dimensi Tomografi Kerintangan Elektrik (2D ERT) telah digunakan secara meluas, namun tiada korelasi komprehensif dan terperinci antara RQD dan nilai kerintangan wujud sehingga kini. Kajian ini menggunakan Tinjauan Kenderaan Udara Tanpa Pemandu (UAV) dan tinjauan 2D ERT di dua tapak dengan pembentukan geologi yang serupa, bertujuan untuk mewujudkan korelasi antara kerintangan dan indeks RQD. Tinjauan UAV membolehkan pembinaan semula titik awan 3D bagi pengiraan nilai RQD pada permukaan secara tidak langsung daripada blok 1 m × 1 m menggunakan Kiraan Bersama Volumetrik (Jv). Ini dicapai dalam perisian ShapeMetrix (SMX). Pada masa yang sama, tinjauan 2D ERT membolehkan pengekstrakan nilai kerintangan yang sepadan untuk setiap indeks RQD dari blok yang sama dengan menggunakan perisian ZonRes2D. Satu siri analisis Regresi Linear (LR) dan algoritma *k-Nearest Neighbor* (k-NN) telah dilakukan di dalam Python untuk mendapatkan unjuran berterusan RQD dengan kerintangan batuan dan memberikan nilai kerintangan kepada indeks RQD masing-masing. Dua ratus dua puluh tiga titik data diperolehi yang mewakili RQD dan nilai kerintangan yang sepadan. Titik data ini berjaya memberikan unjuran berterusan nilai RQD dengan kerintangan menggunakan analisis LR, dan telah disahkan bahawa kerintangan jisim batuan meningkat sebanyak 30 Ωm untuk setiap peningkatan unit dalam indeks RQD. Manakala k-NN dapat memberikan nilai kerintangan kepada pelbagai indeks RQD dengan lebih efisien, di mana batuan yang sangat lemah menunjukkan nilai kerintangan kurang daripada 350 Ωm; untuk batuan lemah, ia berkisar antara 350-1150 Ωm. Seterusnya, bagi batuan saksama, kerintangan berbeza antara 1150 hingga 1850 Ωm, untuk batuan yang baik, kerintangan antara 1850 hingga 2500 Ωm, dan batuan yang sangat baik mempunyai nilai kerintangan lebih daripada 2400 Ωm. Korelasi bagi RQD yang diperolehi melalui k-NN mencirikan kualiti jisim batuan permukaan dan bawah permukaan di sepanjang cerun dalam pemetaan RQD. Ia didapati, kualiti jisim batuan bawah permukaan adalah lebih tinggi berbanding permukaan di kedua-dua tapak. Jadi, dapat disimpulkan bahawa pengunaan kaedah UAV dan 2D ERT secara bersepadu telah berjaya diaplikasikan dalam kajian ini. Di samping itu, korelasi yang disediakan ini akan membantu dalam mendapatkan nilai RQD menggunakan pendekatan yang lebih cepat, murah dan tidak merosakkan alam sekitar.

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LIST OF ABBREVIATIONS

RQD	-	Rock Quality Designation
UAV	-	Unmanned Aerial Vehicle
2D ERT	-	Two-Dimensional Electrical Resistivity Tomography
SMX	-	ShapeMetriX
ML	-	Machine Learning
SLR	-	Simple Linear Regression
MLR	-	Multiple Linear Regression
UTM	-	Universal Transverse Merricator
k-NN	-	k Nearest Neighbour
IDW	-	Inverse Distance Weightage
UCS	-	Unconfined Compressive Strength
RSR	-	Rock Structure Rating
RMR	-	Rock Mass Rating
MRMRSMR	-	Modified Rock Mass Rating
SMR	-	Slope Mass Rating
GSI	-	Geological Strength Index
TLS	-	Terrestrial Laser Scanner
LiDAR	-	Light detection and Ranging
CT	-	Classification Tree
SVM	-	Support vector Machine
NN	-	Nearest Neighbour

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent decades, slope stability assessment has been getting greater interest in response to the construction of extensive road networks and residential areas in the hilly and mountainous region due to population expansion and socio-economic development. Malaysia is also among the countries having 25% of the terrain hilly and mountainous [5]. Consequently, a substantial portion of highways and residential areas in Malaysia are exposed to the threat of slope failure. Slope failure contributes to 8.3% of all-natural disasters in Malaysia, causing 500 fatalities to date [6]. Therefore, a comprehensive rock slope stability assessment is crucial to mitigate rock slope failure, particularly along the roadside, thus reducing the loss of life, property damage, and socio-economic impact.

A comprehensive and robust rock slope stability assessment is needed to understand several parameters. These parameters include the understanding of analysis of geologic discontinuities and physical characteristics of the rock slope. Measurements of geological discontinuities involve orientations, persistence, spacing, and roughness of joints and faults. In contrast, the physical characteristics encompass the slope height, slope length, face angle, identification of various lithological features, and measuring the magnitude of driving and resistive forces [7-10].

Rock slope stability assessment techniques are broadly categorized as kinematic analysis, numerical modeling, limit equilibrium analysis, and empirical methods [11]. This research work mainly emphasized the empirical technique for slope stability assessment. The empirical method or rock mass classification system quantitively describe the engineering behaviour of rock mass condition [12]. Numerous rock mass classifications systems such as Terzaghi, Rock Quality

Designation (RQD), Rock Structure Rating (RSR), Rock Mass Rating (RMR), Modified Rock Mass rating (MRMR), Q-system, Slope Mass Rating (SMR) and Geological Strength Index (GSI) are in practiced for slope stability assessment [13, 14].

Rock Quality Designation (RQD) is a standard technique in mining and geotechnical investigation for quantifying the quality and degree of jointing of rock mass based on the RQD index [15]. RQD index is the indicator of the rock mass quality that represents the degree of fracturing of the rock mass [15]. The application of RQD for the characterization of rock mass quality dates to Deer’s work in 1963 [8, 13, 16]. The widespread application of RQD for rock engineering is because it can be simply, inexpensively, and rapidly obtained compared to other rock mass classification systems [16, 17]. The use of RQD as primary parameters in various rock mass classification systems such as RMR, Q-system, GSI, and SMR also demonstrate its importance [16, 18, 19]. The correlation of RQD with rock mass deformability and unconfined compressive strength also signifies its importance [20-22]. The rock mass quality using RQD can be identified from drill cores and scanline surveys [16].

The primary limitation of the coring method is that rock cores give different values of RQD for same location when samples are obtained from cores with varying drilling orientations [23]. To overcome this, Hudson and Priest recommended to acquire three cores in different directions to obtain information on the three-dimensional (3D) jointing in a rock mass. However, such practice is costly and time-consuming [24, 25]. The other limitation of coring is that the storing of cores requires a significant amount of space and is mostly waisted, which prevents future inspections [18]. This leads to the modification of the RQD classification system by indirectly measuring the degree of fracturing of rock mass from fracture frequency (λ) and Volumetric Joint Count (Jv) for numerous engineering applications [26]. Due to low cost, simplicity, and reproducibility, the indirect way resulted in the quick development of the RQD for evaluating rock mass quality for various engineering applications such as slope stability, mining engineering, and tunnels [27]. The indirect calculation of RQD using Jv is more reliable compared to fracture frequency because RQD may be sensitive to the directions of the scanline. In contrast, the sampling direction does not influence the Jv.

Various remote sensing techniques such as Interferometric Synthetic Aperture Radar (InSAR), Light Detection and Ranging (LiDAR), Unmanned Aerial Vehicle (UAV) and Terrestrial Laser Scanning (TLS) provide a promising approach to indirectly (Jv) quantify rock mass quality using RQD [28-30]. These techniques cover a larger area in a short time and provide aerial images and high-resolution 3D point cloud without direct contact with rock slope as opposed to manual geological mapping. Currently, UAV has proven its significance for slope stability assessment because it is inexpensive compared to InSAR and LiDAR and more efficient than TLS, especially on steep rock slopes [31]. Although UAV is a well-established technique for rock slope stability assessment, the information provided by UAV is limited to rock outcrop only and the subsurface rock mass quality remains unidentified. In addition, although UAV itself is rapid technique but the quantification of rock mass conditions based on Jv from UAV point cloud is time-consuming specially for larger area.

For rapid subsurface investigation of rock mass quality, 2D Electrical Resistivity Tomography (2D ERT) has been extensively applied [32-35]. The stability of the rock slope is highly influenced by the fracturing, weathering and presence of water and clay content in the rock mass. This makes 2D ERT an attractive technique for slope stability assessment because the resistivity of the rock mass is highly sensitive to the fracturing, weathering, and presence of water and clay content [32, 36, 37]. The increasing interest in the application of 2D ERT for geotechnical investigation is due to its lightweight, easy portability, technological advance data collection and interpretation and non-destructive data gathering ability [38]. However, as discussed above 2D ERT is extensively applied for various rock engineering applications, but very little work is carried out to quantify rock mass quality based on RQD using 2D ERT. This is because of the lack of comprehensive and detail correlation of resistivity for all RQD indexes to date.

1.2 Problem Statement

RQD has widespread application such as geotechnical investigation, rock slope stability assessment, rock mass deformability prediction and tunnel support designing. However, the traditional way of calculation of RQD suffers several limitations. Firstly, rock cores yield different values for a given location when samples are extracted with varying orientations of drilling [23]. In addition, the coring technique is costly and time-consuming, and many steep areas are inaccessible for shifting heavy drilling equipment [24, 25]. Furthermore, storing cores requires a significant amount of space and is mostly waisted, which prevents future inspections [18]. To overcome this, the indirect calculation of RQD by measuring the degree of rock mass fracturing was introduced [26]. However, the indirect calculation of RQD provide point-based information, is directional dependent, and time-consuming especially on a large slope [10, 39-41].

To overcome the above-mentioned shortcoming of RQD calculation, few researchers attempted to correlate RQD and resistivity values in granitic rock [1-4]. However, their correlation of RQD and resistivity values provided previously possesses certain deficiencies. The primary limitation of previous research works on correlation of RQD, and resistivity is that it provides the spotted correlation of RQD and resistivity values, thus lacks a continuous projection of RQD and resistivity for all RQD indexes. Additionally, all the previous work integrates 2D ERT and boreholes, which is considered an expensive and time-consuming approach.

This research work deploys an integrated UAV and 2D ERT surveys to calculate RQD and the corresponding resistivity values. This will allow to obtain a continuous projection of RQD and corresponding resistivity values, thus enable to assigned resistivity values to all RQD indexes. The approach presented in this research work is cost-effective, expeditious and environmentally non-destructive as opposed to previous researchers.

1.3 Significance of the Research

UAV is widely applied for geotechnical assessments, particularly rock slope stability assessment. These techniques provide a promising approach for rapidly assessing the rock slope's stability. UAVs provide 3D point cloud of rock slope surface over a large area quickly. However, the information provided by UAV is limited to the outcrop. Whereas the rock mass is heterogeneous, therefore not necessary that the rock behaves the same as represented on the outcrop. Thus, for a detailed assessment of the rock slope, the surface and subsurface kinematics are required simultaneously. To expose, subsurface lithology, 2D ERT, an indirect geophysical technique is an efficient, inexpensive, and rapid approach.

This research work will integrate the surface information obtained by UAV with the subsurface interpretation of 2D ERT. The combined information such as RQD and resistivity obtained by these techniques will be correlated to improve the RQD classification system by assigning the resistivity values to various RQD indexes in the RQD classification system. Thus, the outcome of this research work will provide an inexpensive, rapid and efficient rock mass quality assessment approach.

1.4 Research Objectives

The research study aims to establish a correlation of resistivity with RQD by incorporating resistivity values to various RQD indexes. This can be achieved by obtaining the following objectives.

I. To determine RQD and corresponding resistivity values using UAV and 2D ERT survey

II. To establish continuous projection of RQD and resistivity and assign resistivity values to RQD indexes using simple linear regression and k-Nearest Neighbours (k-NN) classifiers.

III. To compare the effect Jv and resistivity with RQD using multiple linear regression.

IV. To characterize rock mass quality along both sites using established correlation.

1.5 Scope of the Study

The focus of this study is on the rock mass characterization base on RQD. Based on the RQD Index, the RQD employs a single parameter to evaluate the rock mass quality. In this study, the RQD was calculated indirectly using Jv. Two study sites have opted for data acquisition: rocks slope along the PLUS expressway (KM 258.17, Jelapang, Perak) and Bukit Ayam, Pengerang, Johor, having granite formations. UAV surveys at both sites were performed using DJI Phantom 4 v2.0 Quadcopter UAV system. The acquired UAV images were processed in shapeMetrix (SMX) software to reconstruct 3D Point cloud. A 1 m*1 m flat block were drawn on 3D point cloud and RQD was calculated indirectly using Jv to correlate with subsurface resistivity values. The resistivity of rock mass is influenced by the saturation of the water content in the joints of rock mass. Knowing that, the resistivity filed data in this research was performed in dry and hot season. The corresponding subsurface resistivity values for various RQD indexes were calculated by carrying 2D ERT survey using ABEM LS Tetrameter utilizing ZondRes2D software. Thus, the integrated UAV and 2D ERT survey enable to obtained RQD and corresponding resistivity values.

To establish a continuous projection of resistivity and RQD, simple linear regression analysis modelling was performed using python. After establishing a continuous projection of RQD and resistivity values, k-NN modelling was performed in python to assign the resistivity values to various RQD indexes. In line with this, the multiple linear aggression analysis was also performed using python to study the compare the effect of Jv and resistivity on RQD. Finally, the surface and subsurface rock quality along the slope was characterized by constructing RQD mapping in ArcGIS using the inverse distance weightage (IDW) interpolation technique.

1.6 Thesis Outline

The report of this research work is presented in seven chapters. Every chapter provide comprehensive discussion and explanation about the research. A summary of each chapter is as follow.

Chapter 1, the chapter discusses the background of the study that serves a guidance for the reader to know what research has been done previously. The chapter also explain the problem statement, scope of the research, research aims, objectives of the research and significance of the research.

Chapter 2, this chapter presents detail literature review of previous research work. Discussions and comments of the contribution of previous research is also provided in this chapter. The chapter outlines detail information on rock mass classification system particularly RQD, various remote sensing techniques especially UAV survey and geophysical techniques specifically 2D ERT.

Chapter 3, this chapter provide detail explanation on research methodology, which covers description about the study area, various approaches deployed for data collection and processing such as UAV and 2D ERT survey. The chapter also explain the calculation of RQD from UAV point cloud and extraction of corresponding resistivity values from 2D ERT interpretation.

Chapter 4 presents the results obtained from various survey works such as 2D ERT and UAV. This chapter presents the outcome of UAV and 2D ERT survey in the form 3D point cloud and resistivity tomograph respectively. Furthermore, 2D ERT survey is authenticated in various ways including comparison the outcome of 2D ERT interpretation at multiple electrodes spacing. In addition, discussion on the 2D ERT interpretations achieved by the two different software is also presented to validate the 2D ERT interpretation.

Chapter 5 provides the detail of various sections and 1 m* 1 m block used to calculate RQD and corresponding resistivity values. The detail of the number of joints identified at both sites is also provided. The obtained RQD and corresponding resistivity values is also tabulated in this chapter.

Chapter 6 highlights the finding of the research work in relation to the objectives. The continuous projection of the RQD and corresponding resistivity values obtained using simple linear regression analysis is presented in this chapter. In addition, the outcome of k-NN modelling and its application of assigning resistivity values to RQD indexes is also discussed. The effect of Jv and resistivity on RQD studied using multiple linear regression is also explained in this chapter. The obtained characterization of rock mass quality along both rock slope is also provided in this chapter.

Chapter 7, this chapter provide the concluding remarks on the research outcomes. The chapter also suggest the possible extension of this research work.

REFERENCES

1. Olona, J., J.A. Pulgar, G. Fernández-Viejo, C. López-Fernández, and J.M. González-Cortina, *Weathering variations in a granitic massif and related geotechnical properties through seismic and electrical resistivity methods.* Near Surface Geophysics, 2010. **8**(6): p. 585-599.
2. Lin, D., R. Yuan, X. Lin, X. Lin, C. Lou, Y. Cai, J. Yu, R. Qiu, X. Su, and H. Wang, *Disturbed granite identification by integrating rock mass geophysical properties.* International Journal of Rock Mechanics and Mining Sciences, 2021. **138**: p. 104596.
3. Ishak, M.F., M.I. Zaini, M. Zolkepli, M. Wahap, J.J. Sidek, A.M. Yasin, M. Zolkepli, M.M. Sidik, K.M. Arof, and Z.A. Talib, *Granite Exploration by using Electrical Resistivity Imaging (ERI): A Case Study in Johor.* International Journal of Integrated Engineering, 2020. **12**(8): p. 328-347.
4. Azwin, I., R. Saad, M. Saidin, M. Nordiana, A.A. Bery, and I. Hidayah. *Combined analysis of 2-D electrical resistivity, seismic refraction and geotechnical investigations for Bukit Bunuh complex crater*. in *IOP Conference Series: Earth and Environmental Science*. 2015. IOP Publishing.
5. Haliza Abdul Rahmana, J.M., *Landslides Disaster in Malaysia: an Overview.* Health and the Environment Journal, 2017. **8**(1): p. 13.
6. Rahman, H.A. and J. Mapjabil, *Landslides disaster in Malaysia: an overview.* Health, 2017. **8**(1): p. 58-71.
7. Sadeghi, S., E.S. Teshnizi, and B. Ghoreishi, *Correlations between various rock mass classification/characterization systems for the Zagros tunnel-W Iran.* Journal of Mountain Science, 2020. **17**(7): p. 1790-1806.
8. Azarafza, M., Y.A. Nanehkaran, L. Rajabion, H. Akgün, J. Rahnamarad, R. Derakhshani, and A. Raoof, *Application of the modified Q-slope classification system for sedimentary rock slope stability assessment in Iran.* Engineering Geology, 2020. **264**: p. 105349.
9. Erguler, Z.A., H. Karakuş, İ.G. Ediz, and C. Şensöğüt, *Assessment of design parameters and the slope stability analysis of weak clay-bearing rock masses*

and associated spoil piles at Tunçbilek basin. Arabian Journal of Geosciences, 2020. **13**(1): p. 1-11.

10. Khanna, R. and R. Dubey, *Comparative assessment of slope stability along road-cuts through rock slope classification systems in Kullu Himalayas, Himachal Pradesh, India.* Bulletin of Engineering Geology and the Environment, 2021. **80**(2): p. 993-1017.
11. Gurocak, Z., S. Alemdag, and M.M. Zaman, *Rock slope stability and excavatability assessment of rocks at the Kapikaya dam site, Turkey.* Engineering Geology, 2008. **96**(1-2): p. 17-27.
12. Morales, M., K.K. Panthi, and K. Botsialas, *Slope stability assessment of an open pit mine using three-dimensional rock mass modeling.* Bulletin of Engineering Geology and the Environment, 2019. **78**(2): p. 1249-1264.
13. Basahel, H. and H. Mitri, *Application of rock mass classification systems to rock slope stability assessment: A case study.* Journal of rock mechanics and geotechnical engineering, 2017. **9**(6): p. 993-1009.
14. Pantelidis, L., *Rock slope stability assessment through rock mass classification systems.* International Journal of Rock Mechanics and Mining Sciences, 2009. **46**(2): p. 315-325.
15. Haldar, S., *Mineral exploration.* Mineral Exploration, 2013: p. 193-222.
16. Zheng, J., X. Yang, Q. Lü, Y. Zhao, J. Deng, and Z. Ding, *A new perspective for the directivity of rock quality designation (RQD) and an anisotropy index of jointing degree for rock masses.* Engineering geology, 2018. **240**: p. 81-94.
17. Zhang, L. and H. Einstein, *Using RQD to estimate the deformation modulus of rock masses.* International journal of rock mechanics and mining sciences (1997), 2004. **41**(2): p. 337-341.
18. Olson, L., C. Samson, and S. McKinnon, *3-D laser imaging of drill core for fracture detection and rock quality designation.* International Journal of Rock Mechanics and Mining Sciences, 2015. **73**: p. 156-164.
19. He, M., Z. Zhang, and N. Li, *Prediction of fracture frequency and RQD for the fractured rock mass using drilling logging data.* Bulletin of Engineering Geology and the Environment, 2021: p. 1-11.
20. Jiang, X.-W., L. Wan, X.-S. Wang, X. Wu, and X. Zhang, *Estimation of rock mass deformation modulus using variations in transmissivity and RQD with*

depth. International Journal of Rock Mechanics and Mining Sciences, 2009. **46**(8): p. 1370-1377.

21. Khabbazi, A., M. Ghafoori, G.R. Lashkaripour, and A. Cheshomi, *Estimation of the rock mass deformation modulus using a rock classification system.* Geomechanics and Geoengineering, 2013. **8**(1): p. 46-52.
22. Zhang, L., *Determination and applications of rock quality designation (RQD).* Journal of Rock Mechanics and Geotechnical Engineering, 2016. **8**(3): p. 389-397.
23. Choi, S. and H. Park, *Variation of rock quality designation (RQD) with scanline orientation and length: a case study in Korea.* International Journal of Rock Mechanics and Mining Sciences, 2004. **41**(2): p. 207-221.
24. Azimian, A., *A new method for improving the RQD determination of rock core in borehole.* Rock mechanics and rock engineering, 2016. **49**(4): p. 1559-1566.
25. Kring, K. and S. Chatterjee, *Uncertainty quantification of structural and geotechnical parameter by geostatistical simulations applied to a stability analysis case study with limited exploration data.* International Journal of Rock Mechanics and Mining Sciences, 2020. **125**: p. 104157.
26. Zhang, W., Q. Wang, J.-p. Chen, C. Tan, and X.-q. Yuan, *Determination of the optimal threshold and length measurements for RQD calculations.* International journal of rock mechanics and mining sciences (1997), 2012. **51**: p. 1-12.
27. Haftani, M., H.A. Chehreh, A. Mehinrad, and K. Binazadeh, *Practical investigations on use of weighted joint density to decrease the limitations of RQD measurements.* Rock Mechanics and Rock Engineering, 2016. **49**(4): p. 1551-1558.
28. Zeybek, M. and İ. Şanlıoğlu, *Accurate determination of the Taşkent (Konya, Turkey) landslide using a long-range terrestrial laser scanner.* Bulletin of Engineering Geology and the Environment, 2015. **74**(1): p. 61-76.
29. Telling, J., A. Lyda, P. Hartzell, and C. Glennie, *Review of earth science research using terrestrial laser scanning.* Earth-Science Reviews, 2017. **169**: p. 35-68.
30. Wang, M., K. Liu, G. Yang, and J. Xie, *Three-dimensional slope stability analysis using laser scanning and numerical simulation.* Geomatics, Natural Hazards and Risk, 2017. **8**(2): p. 997-1011.

31. Guisado-Pintado, E., D.W. Jackson, and D. Rogers, *3D mapping efficacy of a drone and terrestrial laser scanner over a temperate beach-dune zone.* Geomorphology, 2019. **328**: p. 157-172.
32. Khan, M.S., S. Hossain, A. Ahmed, and M. Faysal, *Investigation of a shallow slope failure on expansive clay in Texas.* Engineering Geology, 2017. **219**: p. 118-129.
33. Naudet, V., M. Lazzari, A. Perrone, A. Loperte, S. Piscitelli, and V. Lapenna, *Integrated geophysical and geomorphological approach to investigate the snowmelt-triggered landslide of Bosco Piccolo village (Basilicata, southern Italy).* Engineering Geology, 2008. **98**(3-4): p. 156-167.
34. Coulibaly, Y., T. Belem, and L. Cheng, *Numerical analysis and geophysical monitoring for stability assessment of the Northwest tailings dam at Westwood Mine.* International Journal of Mining Science and Technology, 2017. **27**(4): p. 701-710.
35. Falae, P.O., D. Kanungo, P. Chauhan, and R.K. Dash, *Recent trends in application of electrical resistivity tomography for landslide study*, in *Renewable Energy and its Innovative Technologies*. 2019, Springer. p. 195-204.
36. Boyle, A., P.B. Wilkinson, J.E. Chambers, P.I. Meldrum, S. Uhlemann, and A. Adler, *Jointly reconstructing ground motion and resistivity for ERT-based slope stability monitoring.* Geophysical Journal International, 2017. **212**(2): p. 1167-1182.
37. Asriza, S., T. Kristyanto, T. Indra, R. Syahputra, and A. Tempessy, *Determination of the landslide slip surface using electrical resistivity tomography (ERT) technique.* Advancing Culture of Living with Landslides: Volume 2 Advances in Landslide Science, 2017: p. 53.
38. Bharti, A.K., S. Pal, P. Priyam, V.K. Pathak, R. Kumar, and S.K. Ranjan, *Detection of illegal mine voids using electrical resistivity tomography: The case-study of Raniganj coalfield (India).* Engineering geology, 2016. **213**: p. 120-132.
39. Alameda-Hernández, P., R. El Hamdouni, C. Irigaray, and J. Chacón, *Weak foliated rock slope stability analysis with ultra-close-range terrestrial digital photogrammetry.* Bulletin of Engineering Geology and the Environment, 2019. **78**(2): p. 1157-1171.

40. Nanda, A.M., M. Yousuf, Z.U. Islam, P. Ahmed, and T. Kanth, *Slope Stability Analysis along NH 1D from Sonamarg to Kargil, J&K, India: Implications for Landslide Risk Reduction.* Journal of the Geological Society of India, 2020. **96**(5): p. 499-506.
41. Singh, H.O., T.A. Ansari, T. Singh, and K. Singh, *Analytical and numerical stability analysis of road cut slopes in Garhwal Himalaya, India.* Geotechnical and Geological Engineering, 2020. **38**: p. 4811-4829.
42. Tan, S.N.M.A., E.T. Mohamad, R. Saad, and M.F. bin Md, *integration of geophysical interrogation and geomechanical assessment for sedimentary rock mass classification, iskandar puteri, johor, malaysia.* malaysian construction research journal (MCRJ): p. 180.
43. Palmstrom, A., *Measurements of and correlations between block size and rock quality designation (RQD).* Tunnelling and Underground Space Technology, 2005. **20**(4): p. 362-377.
44. Chen, Q. and T. Yin, *Should the use of rock quality designation be discontinued in the rock mass rating system?* Rock Mechanics and Rock Engineering, 2019. **52**(4): p. 1075-1094.
45. Bieniawski, Z. *Geomechanics classification of rock masses and its application in tunneling*. in *Proc. 3rd Int. Congress on Rock Mechanics*. 1974.
46. Kirkaldie, L. *Rock classification systems for engineering purposes*. in *Symposium on Rock Classification Systems for Engineering Purposes, 1987, Cincinnati, Ohio, USA*. 1988.
47. Adjiski, V., Z. Panov, R. Popovski, and R. Karanakova Stefanovska, *Application of photogrammetry for determination of volumetric joint count as a measure for improved rock quality designation (RQD) index.* Sustainable Extraction and Processing of Raw Materials Journal (SEPRM), 2021. **2**(1): p. 12-20.
48. Pells, P., Z. Bieniawski, S. Hencher, and S. Pells, *Rock quality designation (RQD): time to rest in peace.* Canadian Geotechnical Journal, 2017. **54**(6): p. 825-834.
49. Hoek, E., P. Kaiser, and W. Bawden, *Support of Underground Excavations in Hard Rock AA BALKEMA.* Rotterdam/Brookfield, 1995.
50. Alghamdi, M.A., *Rock quality risk (RQR) of Assukhairah Village, Taif, Saudi Arabia.* Arabian Journal of Geosciences, 2021. **14**(24): p. 1-9.

51. Zhang, L., *Evaluation of rock mass deformability using empirical methods–A review*. Underground Space, 2017. **2**(1): p. 1-15.

52. He, M., Z. Zhang, and N. Li, *Prediction of fracture frequency and RQD for the fractured rock mass using drilling logging data.* Bulletin of Engineering Geology and the Environment, 2021. **80**(6): p. 4547-4557.

53. Merritt, A.H. *Geologic prediction for underground excavations*. in *N Am Rapid Excav & Tunnelling Conf Proc*. 1972.

54. CECIL III, O.S., *Correlations of Rock Bolt-Shotcrete Support and Rock Quality Parametersin Scandinavian Tunnels*. 1970: University of Illinois at Urbana-Champaign.

55. Gardner, W.S. *Design of drilled piers in the Atlantic Piedmont*. in *Foundations and excavations in decomposed rock of the Piedmont province*. 1987. ASCE.

56. Zhang, L. and H. Einstein. *Estimating the deformation modulus of rock masses*. in *4th North American Rock Mechanics Symposium*. 2000. OnePetro.

57. Kulhawy, F. and R. Goodman, *Foundations in rock*. 1987, Butterworth Scientific, Guilford. p. 55.

58. Kulhawy, F. and R. Goodman, *Foundations in rock*. 1987, Butterworths, London. p. 55-1.

59. AASHTO, R.D.G., *American Association of State Highway and Transportation Officials.* Washington, DC, 1996.

60. Zhang, L., *Estimating the strength of jointed rock masses.* Rock mechanics and rock engineering, 2010. **43**(4): p. 391-402.

61. Deere, D., *The rock quality designation (RQD) index in practice*, in *Rock classification systems for engineering purposes*. 1988, ASTM International.

62. Deere, D.U., R.F. Coon, and A.H. Merritt, *Engineering classification of in-situ rock*. 1969, illinois univ at urbana dept of civil engineering.

63. Cording, E. and D. Deere. *Rock tunnel supports and field measurements*. in *N Am Rapid Excav & Tunneling Conf Proc*. 1972.

64. Koutsoftas, D.C., *Discussion of "Rock quality designation (RQD): Time to rest in peace".* Canadian Geotechnical Journal, 2018. **55**(4): p. 584-592.

65. Mahmoodzadeh, A., M. Mohammadi, H.H. Ibrahim, T.A. Rashid, A.H.M. Aldalwie, H.F.H. Ali, and A. Daraei, *Tunnel geomechanical parameters prediction using Gaussian process regression.* Machine Learning with Applications, 2021. **3**: p. 100020.

66. Mahmoodzadeh, A., M. Mohammadi, H.F.H. Ali, S.N. Abdulhamid, H.H. Ibrahim, and K.M.G. Noori, *Dynamic prediction models of rock quality designation in tunneling projects.* Transportation Geotechnics, 2021. **27**: p. 100497.
67. Ismail, M.A.M., T.A. Majid, C.O. Goh, S.P. Lim, and C.G. Tan, *Geological assessment for tunnel excavation under river with shallow overburden using surface site investigation data and electrical resistivity tomography.* Measurement, 2019. **144**: p. 260-274.
68. Bisso, D., S.M. Ntomba, R.C. Mengbwa, R.C.M. Takamte, and J.M. Ondoa, *Geological and geotechnical characteristics of Ntem formations: Insight of its applications in the Memve'ele dam construction (Southern Cameroon).* Geotechnical and Geological Engineering, 2020. **38**(5): p. 4585-4601.
69. Lewis, J.R., *Design and Installation of Micropile Foundations for a Suspension Bridge*, in *IFCEE 2018*. 2018. p. 173-183.
70. Yasrebi, A., A. Hezarkhani, P. Afzal, and N. Madani, *Application of an Inverse Distance Weighted Anisotropic Method for Rock Quality Designation distribution in Eastern Kahang deposit, Central Iran.* Journal of Mining and Metallurgy A: Mining, 2019. **55**(1): p. 1-15.
71. Deere, D., A. Hendron, F. Patton, and E. Cording. *Design of surface and near-surface construction in rock*. in *The 8th US symposium on rock mechanics (USRMS)*. 1966. OnePetro.
72. Deere, D.U. and D.W. Deere, *Rock Quality Designation (RQD) after Twenty Years*. 1989, Deere (don u) consultant gainesville fl.
73. Hudson, J. and S. Priest. *Discontinuity frequency in rock masses*. in *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*. 1983. Elsevier.
74. Awang, H., A. Salmanfarsi, A. Misbahuddin, and M. Ali. *Slope stability analysis of rock mass using Rock Mass Rating and Slope Mass Rating*. in *IOP Conference Series: Earth and Environmental Science*. 2021. IOP Publishing.
75. Rusydy, I., T.F. Fathani, N. Al-Huda, K. Iqbal, K. Jamaluddin, and E. Meilianda, *Integrated approach in studying rock and soil slope stability in a tropical and active tectonic country.* Environmental Earth Sciences, 2021. **80**(2): p. 1-20.

76. Zheng, J., X. Wang, Q. Lü, J. Liu, J. Guo, T. Liu, and J. Deng, *A Contribution to Relationship Between Volumetric Joint Count (J v) and Rock Quality Designation (RQD) in Three-Dimensional (3-D) Space.* Rock Mechanics and Rock Engineering, 2020. **53**(3): p. 1485-1494.

77. Palmström, A., *Characterizing rock masses by the RMi for use in practical rock engineering: Part 1: The development of the Rock Mass index (RMi).* Tunnelling and underground space technology, 1996. **11**(2): p. 175-188.

78. Albarelli, D., O. Mavrouli, and P. Nyktas, *Identification of potential rockfall sources using UAV-derived point cloud.* Bulletin of Engineering Geology and the Environment, 2021: p. 1-23.

79. Shahbazi, M., G. Sohn, J. Théau, and P. Ménard, *UAV-based point cloud generation for open-pit mine modelling.* International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 2015. **40**.

80. Seabra Nogueira Alves Albarelli, D., *Rockfall susceptibility assessment on UAV based 3D point clouds*. 2020, University of Twente.

81. Ziegler, M., R. Colldeweih, A. Wolter, and A. Loprieno-Gnirs, *Rock mass quality and preliminary analysis of the stability of ancient rock-cut Theban tombs at Sheikh 'Abd el-Qurna, Egypt.* Bulletin of Engineering Geology and the Environment, 2019. **78**(8): p. 6179-6205.

82. Farmakis, I., V. Marinos, and N. Vlachopoulos. *Assessment of the GSI along rock slopes based on LiDAR and photogrammetry point clouds*. in *53rd US Rock Mechanics/Geomechanics Symposium*. 2019. OnePetro.

83. Walton, G., G. Mills, G. Fotopoulos, R. Radovanovic, and R. Stancliffe, *An approach for automated lithological classification of point clouds.* Geosphere, 2016. **12**(6): p. 1833-1841.

84. Casagli, N., S. Morelli, W. Frodella, E. Intrieri, and V. Tofani, *TXT-tool 2.039-3.2 Ground-Based Remote Sensing Techniques for Landslides Mapping, Monitoring and Early Warning*, in *Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools*. 2018, Springer. p. 255-274.

85. Sturzenegger, M., M. Yan, D. Stead, and D. Elmo. *Application and limitations of ground-based laser scanning in rock slope characterization*. in *Proceedings of the first Canadian US rock mechanics symposium*. 2007.

86. Zeng, Q., W. Lu, R. Zhang, J. Zhao, P. Ren, and B. Wang, *LIDAR-based fracture characterization and controlling factors analysis: An outcrop case*

from Kuqa Depression, NW China. Journal of Petroleum Science and Engineering, 2018. **161**: p. 445-457.

87. Lemmens, M., *Terrestrial Laser Scanning*, in *Geo-information: Technologies, Applications and the Environment*. 2011, Springer Netherlands: Dordrecht. p. 101-121.

88. Ekinci, A., T. Muturi, and P.M.V. Ferreira, *Aerial Close-Range Photogrammetry to Quantify Deformations of the Pile Retaining Walls.* Journal of the Indian Society of Remote Sensing, 2021. **49**(5): p. 1051-1066.

89. Sadeghzadeh, I. and Y. Zhang, *A review on fault-tolerant control for unmanned aerial vehicles (UAVs)*, in *Infotech@ Aerospace 2011*. 2011. p. 1472.

90. Lee, S. and Y. Choi, *Reviews of unmanned aerial vehicle (drone) technology trends and its applications in the mining industry.* Geosystem Engineering, 2016. **19**(4): p. 197-204.

91. Pagano, M., B. Palma, A. Ruocco, and M. Parise, *Discontinuity Characterization of Rock Masses through Terrestrial Laser Scanner and Unmanned Aerial Vehicle Techniques Aimed at Slope Stability Assessment.* Applied Sciences, 2020. **10**(8): p. 2960.

92. Roşca, S., J. Suomalainen, H. Bartholomeus, and M. Herold, *Comparing terrestrial laser scanning and unmanned aerial vehicle structure from motion to assess top of canopy structure in tropical forests.* Interface focus, 2018. **8**(2): p. 20170038.

93. Kekeç, B., N. Bilim, E. Karakaya, and D. Ghiloufi, *Applications of Terrestrial Laser Scanning (TLS) in Mining: A Review.* Turkey Lidar Journal. **3**(1): p. 31-38.

94. Noor, N.M., Z. Kamaruddin, A. Abdullah, A.A. Abdullah, S.S. Eusoff, and M.H. Mustafa, *Using terrestrial laser scanner for Malay heritage documentation: preliminary approach to Istana Balai Besar, Kelantan.* International Journal of Development and Sustainability, 2018. **7**(6): p. 1886-1897.

95. aniwa. *Terrestrial laser scanners (TLS): guide and product selection*. 2021; Available from: https://www.aniwaa.com/buyers-guide/3d-scanners/terrestrial-laser-scanners-long-range/.

96. Bienert, A., S. Scheller, E. Keane, G. Mullooly, and F. Mohan, *Application of terrestrial laser scanners for the determination of forest inventory parameters.*

International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2006. **36**(5): p. 1-5.

97. Ramirez, F.A., R.P. Armitage, and F.M. Danson, *Testing the application of terrestrial laser scanning to measure forest canopy gap fraction.* Remote Sensing, 2013. **5**(6): p. 3037-3056.

98. Labelle, E.R., J.B. Heppelmann, and H. Borchert, *Application of Terrestrial Laser Scanner to Evaluate the Influence of Root Collar Geometry on Stump Height after Mechanized Forest Operations.* Forests, 2018. **9**(11): p. 709.

99. Moudrý, V., K. Gdulová, M. Fogl, P. Klápště, R. Urban, J. Komárek, L. Moudrá, M. Štroner, V. Barták, and M. Solský, *Comparison of leaf-off and leaf-on combined UAV imagery and airborne LiDAR for assessment of a post-mining site terrain and vegetation structure: Prospects for monitoring hazards and restoration success.* Applied geography, 2019. **104**: p. 32-41.

100. Hofierka, J., M. Gallay, P. Bandura, and J. Šašak, *Identification of karst sinkholes in a forested karst landscape using airborne laser scanning data and water flow analysis.* Geomorphology, 2018. **308**: p. 265-277.

101. Beland, M., G. Parker, B. Sparrow, D. Harding, L. Chasmer, S. Phinn, A. Antonarakis, and A. Strahler, *On promoting the use of lidar systems in forest ecosystem research.* Forest Ecology and Management, 2019. **450**: p. 117484.

102. Renslow, M., P. Greenfield, and T. Guay, *Evaluation of multi-return LIDAR for forestry applications.* US Department of Agriculture Forest Service-Engineering, Remote Sensing Applications. http://www. ndep. gov/USDAFS/LIDAR. pdf [Consulta: 12 de marzo de 2009], 2000.

103. Wingtra. *Drone photogrammetry vs. LIDAR: what sensor to choose for a given application*. 2021; Available from: https://wingtra.com/drone-photogrammetry-vs-lidar/.

104. Doyle, T.B. and C.D. Woodroffe, *The application of LiDAR to investigate foredune morphology and vegetation.* Geomorphology, 2018. **303**: p. 106-121.

105. Inomata, T., D. Triadan, F. Pinzón, M. Burham, J.L. Ranchos, K. Aoyama, and T. Haraguchi, *Archaeological application of airborne LiDAR to examine social changes in the Ceibal region of the Maya lowlands.* PloS one, 2018. **13**(2): p. e0191619.

106. Son, S.W., D.W. Kim, W.G. Sung, and J.J. Yu, *Integrating UAV and TLS approaches for environmental management: A case study of a waste stockpile area.* Remote Sensing, 2020. **12**(10): p. 1615.

107. Mesas-Carrascosa, F.-J., M.D. Notario García, J.E. Meroño de Larriva, and A. García-Ferrer, *An analysis of the influence of flight parameters in the generation of unmanned aerial vehicle (UAV) orthomosaicks to survey archaeological areas.* Sensors, 2016. **16**(11): p. 1838.

108. Agüera-Vega, F., F. Carvajal-Ramírez, and P. Martínez-Carricondo, *Assessment of photogrammetric mapping accuracy based on variation ground control points number using unmanned aerial vehicle.* Measurement, 2017. **98**: p. 221-227.

109. Wingtra, *Drone photogrammetry vs. LIDAR: what sensor to choose for a given application*. 2021.

110. Mesas-Carrascosa, F.-J., J. Torres-Sánchez, I. Clavero-Rumbao, A. García-Ferrer, J.-M. Peña, I. Borra-Serrano, and F. López-Granados, *Assessing optimal flight parameters for generating accurate multispectral orthomosaicks by UAV to support site-specific crop management.* Remote Sensing, 2015. **7**(10): p. 12793-12814.

111. Dandois, J.P., M. Olano, and E.C. Ellis, *Optimal altitude, overlap, and weather conditions for computer vision UAV estimates of forest structure.* Remote Sensing, 2015. **7**(10): p. 13895-13920.

112. Colomina, I. and P. Molina, *Unmanned aerial systems for photogrammetry and remote sensing: A review.* ISPRS Journal of photogrammetry and remote sensing, 2014. **92**: p. 79-97.

113. Siebert, S. and J. Teizer, *Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system.* Automation in construction, 2014. **41**: p. 1-14.

114. Light, D.L. and J.R. Jensen, *Photogrammetric and remote sensing considerations.* Manual of geospatial science and technology, 2001. **233**.

115. Nex, F. and F. Remondino, *UAV for 3D mapping applications: a review.* Applied geomatics, 2014. **6**(1): p. 1-15.

116. González-Jorge, H., J. Martínez-Sánchez, and M. Bueno, *Unmanned aerial systems for civil applications: A review.* Drones, 2017. **1**(1): p. 2.

117. Fawcett, D., B. Azlan, T.C. Hill, L.K. Kho, J. Bennie, and K. Anderson, *Unmanned aerial vehicle (UAV) derived structure-from-motion photogrammetry point clouds for oil palm (Elaeis guineensis) canopy segmentation and height estimation.* International Journal of Remote Sensing, 2019. **40**(19): p. 7538-7560.

118. Singh, K.K. and A.E. Frazier, *A meta-analysis and review of unmanned aircraft system (UAS) imagery for terrestrial applications.* International Journal of Remote Sensing, 2018. **39**(15-16): p. 5078-5098.

119. Domingo, D., H.O. Ørka, E. Næsset, D. Kachamba, and T. Gobakken, *Effects of UAV image resolution, camera type, and image overlap on accuracy of biomass predictions in a tropical woodland.* Remote Sensing, 2019. **11**(8): p. 948.

120. Chesley, J., A. Leier, S. White, and R. Torres, *Using unmanned aerial vehicles and structure-from-motion photogrammetry to characterize sedimentary outcrops: An example from the Morrison Formation, Utah, USA.* Sedimentary Geology, 2017. **354**: p. 1-8.

121. Aerotas. Available from: https://www.aerotas.com/overlap-flight-pattern.

122. Tusat, E., *A comparison of the accuracy of VRS and static GPS measurement results for production of topographic map and spatial data: a case study on CORS-TR.* Tehnički vjesnik, 2018. **25**(1): p. 158-163.

123. Vivat, A., K. Tretyak, I. Savchyn, O. Lano, and M. Navodych. *Analysis and comparison of static and RTK measurements: case study for GNSS network of the Dnister PSPP*. in *International Conference of Young Professionals «GeoTerrace-2021»*. 2021. European Association of Geoscientists & Engineers.

124. Mahato, S., A. Santra, S. Dan, P. Rakshit, P. Banerjee, and A. Bose. *Preliminary Results on the Performance of Cost-effective GNSS Receivers for RTK*. in *2019 URSI Asia-Pacific Radio Science Conference (AP-RASC)*. 2019. IEEE.

125. Upadhyaya, S., G. Pettygrove, J. Oliveira, and B. Jahn, *An introduction–global positioning system*. 2008, Technical report.

126. El-Mowafy, A. and M. Al-Musawa. *Machine automation using RTK GPS positioning*. in *2009 6th International Symposium on Mechatronics and its Applications*. 2009. IEEE.

127. Xiang, J., J. Chen, G. Sofia, Y. Tian, and P. Tarolli, *Open-pit mine geomorphic changes analysis using multi-temporal UAV survey.* Environmental earth sciences, 2018. **77**(6): p. 220.

128. Zulkipli, M.A. and K.N. Tahar, *Multirotor UAV-based photogrammetric mapping for road design.* International Journal of Optics, 2018. **2018**.

129. AL-Qadri, M. and J.-C. Cheng. *Accuracy Assessment for Geometric Features Extraction from Multirotor UAV's Images*. in *Proceedings of the 2020 The 4th International Conference on Graphics and Signal Processing*. 2020.

130. Deliry, S.I. and U. Avdan, *Accuracy of Unmanned Aerial Systems Photogrammetry and Structure from Motion in Surveying and Mapping: A Review.* Journal of the Indian Society of Remote Sensing, 2021: p. 1-21.

131. Greenwood, W.W., J.P. Lynch, and D. Zekkos, *Applications of UAVs in civil infrastructure.* Journal of infrastructure systems, 2019. **25**(2): p. 04019002.

132. Cabreira, T.M., L.B. Brisolara, and P.R. Ferreira Jr, *Survey on coverage path planning with unmanned aerial vehicles.* Drones, 2019. **3**(1): p. 4.

133. Han, X., J.A. Thomasson, G.C. Bagnall, N. Pugh, D.W. Horne, W.L. Rooney, J. Jung, A. Chang, L. Malambo, and S.C. Popescu, *Measurement and calibration of plant-height from fixed-wing UAV images.* Sensors, 2018. **18**(12): p. 4092.

134. Jurić Kaćunić, D., M. Car, L. Librić, and D. Gajski, *Application of Unmanned Aerial Vehicles in Engineering Practice.* Engineering Power: Bulletin of the Croatian Academy of Engineering, 2018. **13**(3.): p. 18-24.

135. Li, X., D.K. Giles, J.T. Andaloro, R. Long, E.B. Lang, L.J. Watson, and I. Qandah, *Comparison of UAV and fixed-wing aerial application for alfalfa insect pest control: evaluating efficacy, residues, and spray quality.* Pest Management Science, 2021. **77**(11): p. 4980-4992.

136. Jayathunga, S., T. Owari, and S. Tsuyuki, *Evaluating the performance of photogrammetric products using fixed-wing UAV imagery over a mixed conifer–broadleaf forest: comparison with airborne laser scanning.* Remote Sensing, 2018. **10**(2): p. 187.

137. Kanellakis, C. and G. Nikolakopoulos, *Survey on computer vision for UAVs: Current developments and trends.* Journal of Intelligent & Robotic Systems, 2017. **87**(1): p. 141-168.

138. Brito, R.C., M.C. Lorencena, J.F. Loureiro, F. Favarim, and E. Todt. *A comparative approach on the use of unmanned aerial vehicles kind of fixed-wing and rotative wing applied to the precision agriculture scenario*. in *2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC)*. 2019. IEEE.

139. Bian, J., X. Wang, and S. Gao, *Experimental aeromagnetic survey using a rotary-wing aircraft system: A case study in Heizhugou, Sichuan, China.* Journal of Applied Geophysics, 2021. **184**: p. 104245.

140. Xiang, J., J. Chen, G. Sofia, Y. Tian, and P. Tarolli, *Open-pit mine geomorphic changes analysis using multi-temporal UAV survey.* Environmental earth sciences, 2018. **77**(6): p. 1-18.

141. Tziavou, O., S. Pytharouli, and J. Souter, *Unmanned Aerial Vehicle (UAV) based mapping in engineering geological surveys: Considerations for optimum results.* Engineering Geology, 2018. **232**: p. 12-21.

142. He, J., Y. Li, and K. Zhang, *Research of UAV flight planning parameters.* 2012.

143. Ali, H. and F. Abed. *The impact of UAV flight planning parameters on topographic mapping quality control*. in *IOP Conference Series: Materials Science and Engineering*. 2019. IOP Publishing.

144. Stöcker, C., F. Nex, M. Koeva, and M. Gerke, *Uav-based cadastral mapping: an assessment of the impact of flight parameters and ground truth measurements on the absolute accuracy of derived orthoimages*. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 2019.

145. Saroglou, C., V. Kallimogiannis, N. Bar, G. Manousakis, and D. Zekkos. *Analysis of slope instabilities in the Corinth Canal using UAV-enabled mapping*. in *Proceedings of the ICONHIC 2nd International Conference on Natural Hazards & Infrastructure, Chania, Greece*. 2019.

146. Mokhtar, M.R.M., A.N. Matori, K.W. Yusof, A.M. Embong, and M.I. Jamaludin. *Assessing UAV landslide mapping using unmanned aerial vehicle (UAV) for landslide mapping activity*. in *Applied Mechanics and Materials*. 2014. Trans Tech Publ.

147. Rafek, A.G. and T.L. Goh, *Correlation of joint roughness coefficient (JRC) and peak friction angles of discontinuities of Malaysian Schists.* Earth Science Research, 2012. **1**(1): p. 57.

148. Yaacob, M.L.M., A.S.A. Rashid, A. Ismail, R. Sa'ari, M. Mustaffar, N.M. Yusof, and N. Abd Rahaman. *Rock slope monitoring using drone based multispectral and thermal images*. in *IOP Conference Series: Earth and Environmental Science*. 2020. IOP Publishing.

149. Qi, C. and X. Tang, *Slope stability prediction using integrated metaheuristic and machine learning approaches: a comparative study.* Computers & Industrial Engineering, 2018. **118**: p. 112-122.

150. Nieminski, N.M. and S.A. Graham, *Modeling stratigraphic architecture using small unmanned aerial vehicles and photogrammetry: Examples from the Miocene East Coast Basin, New Zealand.* Journal of Sedimentary Research, 2017. **87**(2): p. 126-132.

151. Zhou, W., F. Chen, H. Guo, M. Hu, Q. Li, P. Tang, W. Zheng, J.a. Liu, R. Luo, and K. Yan, *UAV Laser scanning technology: A potential cost-effective tool for micro-topography detection over wooded areas for archaeological prospection.* International Journal of Digital Earth, 2020. **13**(11): p. 1279-1301.

152. Orsini, C., E. Benozzi, V. Williams, P. Rossi, and F. Mancini, *UAV Photogrammetry and GIS Interpretations of Extended Archaeological Contexts: The Case of Tacuil in the Calchaquí Area (Argentina).* Drones, 2022. **6**(2): p. 31.

153. Rossi, P., F. Mancini, M. Dubbini, F. Mazzone, and A. Capra, *Combining nadir and oblique UAV imagery to reconstruct quarry topography: methodology and feasibility analysis.* European Journal of Remote Sensing, 2017. **50**(1): p. 211-221.

154. Bar, N., M. Kostadinovski, M. Tucker, G. Byng, R. Rachmatullah, A. Maldonado, M. Pötsch, A. Gaich, A. McQuillan, and T. Yacoub, *Rapid and robust slope failure appraisal using aerial photogrammetry and 3D slope stability models.* International Journal of Mining Science and Technology, 2020.

155. Török, Á., G. Bögöly, Á. Somogyi, and T. Lovas, *Application of UAV in Topographic Modelling and Structural Geological Mapping of Quarries and Their Surroundings—Delineation of Fault-Bordered Raw Material Reserves.* Sensors, 2020. **20**(2): p. 489.

156. Barlow, J., J. Gilham, and I. Ibarra Cofrã, *Kinematic analysis of sea cliff stability using UAV photogrammetry*. International Journal of Remote Sensing, 2017. **38**(8-10): p. 2464-2479.

157. Wang, S.H., Ahmed, Z.H.H. Z, and W. Pengy, *Cliff face rock slope stability analysis based on unmanned arial vehicle (UAV) photogrammetry.* Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 2019. **5**(4): p. 333-344.

158. Melis, M.T., S. Da Pelo, I. Erbì, M. Loche, G. Deiana, V. Demurtas, M.A. Meloni, F. Dessì, A. Funedda, and M. Scaioni, *Thermal remote sensing from UAVs: A review on methods in coastal cliffs prone to landslides.* Remote Sensing, 2020. **12**(12): p. 1971.

159. Fazio, N., M. Perrotti, G. Andriani, F. Mancini, P. Rossi, C. Castagnetti, and P. Lollino, *A new methodological approach to assess the stability of discontinuous rocky cliffs using in-situ surveys supported by UAV-based techniques and 3-D finite element model: a case study.* Engineering Geology, 2019. **260**: p. 105205.

160. Kumar, S. and H.K. Pandey, *Slope Stability Analysis Based on Rock Mass Rating, Geological Strength Index and Kinematic Analysis in Vindhyan Rock Formation.* Journal of the Geological Society of India, 2021. **97**(2): p. 145-150.

161. Wang, S., Z. Zhang, C. Wang, C. Zhu, and Y. Ren, *Multistep rocky slope stability analysis based on unmanned aerial vehicle photogrammetry.* Environmental earth sciences, 2019. **78**(8): p. 1-16.

162. Bar, N., M. Kostadinovski, M. Tucker, G. Byng, R. Rachmatullah, A. Maldonado, M. Pötsch, A. Gaich, A. McQuillan, and T. Yacoub, *Rapid and robust slope failure appraisal using aerial photogrammetry and 3D slope stability models.* International Journal of Mining Science and Technology, 2020. **30**(5): p. 651-658.

163. Tahar, K.N., *Multi rotor UAV at different altitudes for slope mapping studies.* The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2015. **40**(1): p. 9.

164. Török, Á., Á. Barsi, G. Bögöly, T. Lovas, Á. Somogyi, and P. Görög, *Slope stability and rockfall assessment of volcanic tuffs using RPAS with 2-D FEM slope modelling.* Natural Hazards and Earth System Sciences, 2018. **18**(2): p. 583-597.

165. Rusnák, M., J. Sládek, J. Buša, and V. Greif, *Suitability of digital elevation models generated by UAV photogrammetry for slope stability assessment (case study of landslide in Svätý Anton, Slovakia).* Acta Scientiarum Polonorum. Formatio Circumiectus, 2016. **15**(4): p. 439.

166. O'Banion, M.S., M.J. Olsen, C. Rault, J. Wartman, and K. Cunningham, *Suitability of structure from motion for rock-slope assessment.* The Photogrammetric Record, 2018. **33**(162): p. 217-242.

167. Salvini, R., C. Vanneschi, J.S. Coggan, and G. Mastrorocco, *Evaluation of the Use of UAV Photogrammetry for Rock Discontinuity Roughness Characterization.* Rock Mechanics and Rock Engineering, 2020.

168. Török, Á., Á. Barsi, G. Bögöly, T. Lovas, Á. Somogyi, and P. Görög, *Slope stability and rockfall assessment of volcanic tuffs using RPAS with 2-D FEM slope modelling.* Natural Hazards & Earth System Sciences, 2018. **18**(2).

169. Siebert, S. and J. Teizer. *Mobile 3D mapping for surveying earthwork using an unmanned aerial vehicle (UAV).* in *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*. 2013. Citeseer.

170. Abuzied, S.M., M.F. Kaiser, E.-A.H. Shendi, and M.I. Abdel-Fattah, *Multi-criteria decision support for geothermal resources exploration based on remote sensing, GIS and geophysical techniques along the Gulf of Suez coastal area, Egypt.* Geothermics, 2020. **88**: p. 101893.

171. Kannaujiya, S., S.L. Chattoraj, D. Jayalath, K. Bajaj, S. Podali, and M. Bisht, *Integration of satellite remote sensing and geophysical techniques (electrical resistivity tomography and ground penetrating radar) for landslide characterization at Kunjethi (Kalimath), Garhwal Himalaya, India.* Natural Hazards, 2019. **97**(3): p. 1191-1208.

172. Hussain, Y., R. Uagoda, W. Borges, R. Prado, O. Hamza, M. Cárdenas-Soto, H.-B. Havenith, and J. Dou, *Detection of cover collapse doline and other Epikarst features by multiple geophysical techniques, case study of Tarimba cave, Brazil.* Water, 2020. **12**(10): p. 2835.

173. Magiera, T., B. Żogała, A. Łukasik, and J. Pierwoła, *Application of different geophysical techniques to study Technosol developed on metallurgical wastes.* Land Degradation & Development, 2021. **32**(5): p. 1927-1937.

174. Bhattacharya, B.B., *Application of Geophysical Techniques in Groundwater Management,* in *Groundwater Development and Management*. 2019, Springer. p. 43-75.

175. Kana, J.D., N. Djongyang, D. Raïdandi, P.N. Nouck, and A. Dadjé, *A review of geophysical methods for geothermal exploration.* Renewable and Sustainable Energy Reviews, 2015. **44**: p. 87-95.

176. Knödel, K., G. Lange, and H.-J. Voigt, *Environmental geology: Handbook of field methods and case studies*. 2007: Springer Science & Business Media.

177. Lucius, J.E., W.H. Langer, and K. Ellefsen, *An introduction to using surface geophysics to characterize sand and gravel deposits*. 2007: US Geological Survey.

178. Parasnis, D.S., *Principles of applied geophysics*. 2012: Springer Science & Business Media.

179. Sheriff, R.E., *Encyclopedic dictionary of applied geophysics*. 2002: Society of exploration geophysicists.

180. Erkan, K., *A comparative overview of geophysical methods*. 2008, Ohio State University. Division of Geodetic Science.

181. Meju, M.A., *Geoelectromagnetic Exploration For Natural Resources: Models, Case Studies And Challenges.* Surveys in Geophysics, 2002. **23**(2): p. 133-206.

182. Rucker, D.F., N. Crook, D. Glaser, and M.H. Loke, *Pilot-scale field validation of the long electrode electrical resistivity tomography method.* Geophysical Prospecting, 2012. **60**(6): p. 1150-1166.

183. Frederick D. Day-Lewis, C.D.J., Kamini Singha, and John W. Lane, Jr., *Best practice in Electrical Resistivity Imaging: Data collection and processing, and application to data from corinna, MAINE.* An administrative report for EPA region: p. 227.

184. Salisbury, M. and D. Snyder, *Application of seismic methods to mineral exploration.* Mineral deposits of Canada: A synthesis of major deposit types, district metallogeny, the evolution of geological provinces, and exploration methods: Geological Association of Canada, Mineral Deposits Division, Special Publication, 2007. **5**: p. 971-982.

185. Milkereit, B., E. Berrer, A.R. King, A.H. Watts, B. Roberts, E. Adam, D.W. Eaton, J. Wu, and M.H. Salisbury, *Development of 3-D seismic exploration*

technology for deep nickel-copper deposits—A case history from the Sudbury basin, Canada. Geophysics, 2000. **65**(6): p. 1890-1899.

186. Salisbury, M.H., B. Milkereit, G. Ascough, R. Adair, L. Matthews, D.R. Schmitt, J. Mwenifumbo, D.W. Eaton, and J. Wu, *Physical properties and seismic imaging of massive sulfides.* Geophysics, 2000. **65**(6): p. 1882-1889.

187. Al-Anezi, G.T., A.M. Al-Amri, and H. Zaman, *Investigation of the weathering layer using seismic refraction and high-resolution seismic reflection methods, NE of Riyadh city.* Arabian Journal of Geosciences, 2012. **5**(6): p. 1347-1358.

188. Sengbush, R.L., *Seismic exploration methods*. 2012: Springer Science & Business Media.

189. Lelièvre, P.G., C.G. Farquharson, and C.A. Hurich, *Joint inversion of seismic traveltimes and gravity data on unstructured grids with application to mineral exploration.* Geophysics, 2012. **77**(1): p. K1-K15.

190. Macnae, J., *Applications of geophysics for the detection and exploration of kimberlites and lamproites.* Journal of Geochemical Exploration, 1995. **53**(1-3): p. 213-243.

191. Spies, B.R., *Depth of investigation in electromagnetic sounding methods.* Geophysics, 1989. **54**(7): p. 872-888.

192. Gough, D.I., *Electromagnetic exploration for fluids in the Earth's crust.* Earth-Science Reviews, 1992. **32**(1-2): p. 3-18.

193. Karlık, G. and M.A. Kaya, *Investigation of groundwater contamination using electric and electromagnetic methods at an open waste-disposal site: a case study from Isparta, Turkey.* Environmental Geology, 2001. **40**(6): p. 725-731.

194. West, G. and J. Macnae, *Physics of the electromagnetic induction exploration method*, in *Electromagnetic Methods in Applied Geophysics: Volume 2, Application, Parts A and B*. 1991, Society of Exploration Geophysicists. p. 5-46.

195. Leaman, D.E., *Applied geophysics in Tasmania: Part 2. Use, effectiveness and reliability of methods.* Exploration Geophysics, 1973. **4**(3): p. 59-77.

196. Carmichael, R.S. and G. Henry Jr, *Gravity exploration for groundwater and bedrock topography in glaciated areas.* Geophysics, 1977. **42**(4): p. 850-859.

197. Ali, H. and R. Whiteley, *Gravity exploration for groundwater in the Bara Basin, Sudan.* Geoexploration, 1981. **19**(2): p. 127-141.

198. Reynolds, J.M., *An introduction to applied and environmental geophysics*. 2011: John Wiley & Sons.

199. Aboud, E., E.S. Selim, and A. El Bishlawy, *Contribution of gravity and magnetic data in delineating the subsurface structure of Hammam Faroun area, Gulf of Suez, Egypt.* Arabian Journal of Geosciences, 2011. **4**(1): p. 249-257.

200. Hinze, W.J., *The role of gravity and magnetic methods in engineering and environmental studies*, in *Geotechnical an Environmental Geophysics: Volume I: Review and Tutorial*. 1990, Society of Exploration Geophysicists. p. 75-126.

201. Thomas, e.a., *Exploration geophysics for intrusion-hosted rare metals.* Geophysical Prospecting, 2016. **64**(5): p. 1275-1304.

202. McClenaghan, M.B., *Overview of common processing methods for recovery of indicator minerals from sediment and bedrock in mineral exploration.* Geochemistry: Exploration, Environment, Analysis, 2011. **11**(4): p. 265-278.

203. Clark, D., *Comments on magnetic petrophysics.* Exploration Geophysics, 1983. **14**(2): p. 49-62.

204. Telford, W.M., W. Telford, L. Geldart, and R.E. Sheriff, *Applied geophysics*. Vol. 1. 1990: Cambridge university press.

205. Dahlin, T., *2D resistivity surveying for environmental and engineering applications.* First break, 1996. **14**(7): p. 275-283.

206. Loke, M., *Electrical imaging surveys for environmental and engineering studies.* A practical guide to, 1999. **2**.

207. Samouelian, A., I. Cousin, A. Tabbagh, A. Bruand, and G. Richard, *Electrical resistivity survey in soil science: a review.* Soil & Tillage Research, 2005. **83**(2): p. 173-193.

208. Maganti, D., *Subsurface investigations using high resolution resistivity*. 2008, The University of Texas at Arlington.

209. Guinea, A., E. Playà, L. Rivero, and J.M. Salvany, *Geoelectrical prospecting of glauberite deposits in the Ebro basin (Spain).* Engineering geology, 2014. **174**: p. 73-86.

210. Hsu, H.L., B.J. Yanites, C.C. Chen, and Y.G. Chen, *Bedrock detection using 2D electrical resistivity imaging along the Peikang River, central Taiwan.* Geomorphology, 2010. **114**(3): p. 406-414.

211. Junaid, M., R.A. Abdullah, R. Sa'ari, W. Ali, H. Rehman, M.N.A. Alel, and U. Ghani, *2d electrical resistivity tomography an advance and expeditious exploration technique for current challenges to mineral industry.* Journal of Himalayan Earth Sciences, 2021. **54**(1): p. 11-32.

212. Perrone, A., V. Lapenna, and S. Piscitelli, *Electrical resistivity tomography technique for landslide investigation: A review.* Earth-Science Reviews, 2014. **135**: p. 65-82.

213. Loke, M., J. Chambers, D. Rucker, O. Kuras, and P. Wilkinson, *Recent developments in the direct-current geoelectrical imaging method.* Journal of applied geophysics, 2013. **95**: p. 135-156.

214. Abudeif, A., M. Mohammed, R. Fat-Helbary, H. El-Khashab, and M. Masoud, *Integration of 2D geoelectrical resistivity imaging and boreholes as rapid tools for geotechnical characterization of construction sites: a case study of New Akhmim city, Sohag, Egypt.* Journal of African Earth Sciences, 2020. **163**: p. 103734.

215. Dahlin, T. and B. Zhou, *A numerical comparison of 2D resistivity imaging with 10 electrode arrays.* Geophysical prospecting, 2004. **52**(5): p. 379-398.

216. Metwaly, M. and F. AlFouzan, *Application of 2-D geoelectrical resistivity tomography for subsurface cavity detection in the eastern part of Saudi Arabia.* Geoscience Frontiers, 2013. **4**(4): p. 469-476.

217. Falae, P.O., D.P. Kanungo, P.K.S. Chauhan, and R.K. Dash, *Electrical resistivity tomography (ERT) based subsurface characterisation of Pakhi Landslide, Garhwal Himalayas, India.* Environmental Earth Sciences, 2019. **78**(14): p. 430.

218. Aristodemou, E. and A. Thomas-Betts, *DC resistivity and induced polarisation investigations at a waste disposal site and its environments.* Journal of Applied Geophysics, 2000. **44**(2): p. 275-302.

219. Coulibaly, e.a., *Numerical analysis and geophysical monitoring for stability assessment of the Northwest tailings dam at Westwood Mine.* International Journal of Mining Science and Technology, 2017.

220. Martinez, J., J. Rey, M.C. Hidalgo, J. Garrido, and D. Rojas, *Influence of measurement conditions on the resolution of electrical resistivity imaging: The example of abandoned mining dams in the La Carolina District (Southern Spain).* International Journal of Mineral Processing, 2014. **133**: p. 67-72.

221. Martínez-Pagán, P., Á. Faz Cano, E. Aracil, and J.M. Arocena, *Electrical resistivity imaging revealed the spatial properties of mine tailing ponds in the Sierra Minera of Southeast Spain.* Journal of Environmental & Engineering Geophysics, 2009. **14**(2): p. 63-76.

222. Ramirez, A., W. Daily, D. Labrecque, E. Owen, and D. Chesnut, *Monitoring an Underground Steam Injection Process Using Electrical-Resistance Tomography.* Water Resources Research, 1993. **29**(1): p. 73-87.

223. Longo, V., V. Testone, G. Oggiano, and A. Testa, *Prospecting for clay minerals within volcanic successions: application of electrical resistivity tomography to characterise bentonite deposits in northern Sardinia (Italy).* Journal of Applied Geophysics, 2014. **111**: p. 21-32.

224. Olayinka, A. and U. Yaramanci, *Use of block inversion in the 2-D interpretation of apparent resistivity data and its comparison with smooth inversion.* Journal of Applied Geophysics, 2000. **45**(2): p. 63-81.

225. Mojica, A., T. Pérez, J. Toral, R. Miranda, P. Franceschi, C. Calderón, and F. Vergara, *Shallow electrical resistivity imaging of the Limón fault, Chagres River Watershed, Panama Canal.* Journal of Applied Geophysics, 2017. **138**: p. 135-142.

226. Galdon, J.M., J. Rey, J. Martinez, and M.C. Hidalgo, *Application of geophysical prospecting techniques to evaluate geological-mining heritage: The Sinapismo mine (La Carolina, Southern Spain).* Engineering Geology, 2017. **218**: p. 152-161.

227. Lapenna, V., P. Lorenzo, A. Perrone, S. Piscitelli, E. Rizzo, and F. Sdao, *2D electrical resistivity imaging of some complex landslides in Lucanian Apennine chain, southern Italy.* Geophysics, 2005. **70**(3): p. B11-B18.

228. Loke, M. and J.W. Lane Jr, *Inversion of data from electrical resistivity imaging surveys in water-covered areas.* Exploration Geophysics, 2004. **35**(4): p. 266-271.

229. Stan, D. and I. Stan-Kłeczek, *Application of electrical resistivity tomography to map lithological differences and subsurface structures (Eastern Sudetes, Czech Republic).* Geomorphology, 2014. **221**: p. 113-123.

230. Bufford, K.M., E.A. Atekwana, M.G. Abdelsalam, E. Shemang, E.A. Atekwana, K. Mickus, M. Moidaki, M.P. Modisi, and L. Molwalefhe, *Geometry and faults tectonic activity of the Okavango Rift Zone, Botswana:*

Evidence from magnetotelluric and electrical resistivity tomography imaging. Journal of African Earth Sciences, 2012. **65**: p. 61-71.

231. Hirsch, M., L.R. Bentley, and P. Dietrich, *A comparison of electrical resistivity, ground penetrating radar and seismic refraction results at a river terrace site.* Journal of Environmental & Engineering Geophysics, 2008. **13**(4): p. 325-333.
232. Cardarelli, E. and F. Fischanger, *2D data modelling by electrical resistivity tomography for complex subsurface geology.* Geophysical Prospecting, 2006. **54**(2): p. 121-133.
233. Di Maio, R. and E. Piegari, *A study of the stability analysis of pyroclastic covers based on electrical resistivity measurements.* Journal of Geophysics and Engineering, 2012. **9**(2): p. 191.
234. Glover, P.W., *Archie's law–a reappraisal.* Solid Earth, 2016. **7**(4): p. 1157-1169.
235. Davis, S.N., *Porosity and permeability of natural materials.* Flow through porous media, 1969: p. 54-89.
236. Sk, M., N. Ramanujam, V. Champoil, S.K. Biswas, Q.A. Rasool, and C. Ojha, *Identification of Groundwater in Hard Rock Terrain Using 2D Electrical Resistivity Tomography Imaging Technique: Securing Water Scarcity at the Time of Seasonal Rainfall Failure, South Andaman.* International Journal of Geosciences, 2018. **9**(01): p. 59.
237. Llera, F.J., M. Sato, K. Nakatsuka, and H. Yokoyama, *Temperature dependence of the electrical resistivity of water-saturated rocks.* Geophysics, 1990. **55**(5): p. 576-585.
238. Loke, M., *Electrical imaging surveys for environmental and engineering studies.* A practical guide to, 1999. **2**: p. 70.
239. Zumr, D., V. David, J. Jeřábek, N. Noreika, and J. Krása, *Monitoring of the soil moisture regime of an earth-filled dam by means of electrical resistance tomography, close range photogrammetry, and thermal imaging.* Environmental Earth Sciences, 2020. **79**(12): p. 1-11.
240. Camarero, P.L., C.A. Moreira, and H.G. Pereira, *Analysis of the physical integrity of earth dams from electrical resistivity tomography (ERT) in Brazil.* Pure and Applied Geophysics, 2019. **176**(12): p. 5363-5375.

241. Aizebeokhai, A.P., O. Ogungbade, and K.D. Oyeyemi, *Application of geoelectrical resistivity for delineating crystalline basement aquifers in Basiri, Ado-Ekiti, Southwestern Nigeria.* Arabian Journal of Geosciences, 2021. **14**(1): p. 1-13.

242. Manu, E., W.A. Agyekum, A.A. Duah, R. Tagoe, and K. Preko, *Application of vertical electrical sounding for groundwater exploration of Cape coast municipality in the central region of Ghana.* Arabian Journal of Geosciences, 2019. **12**(6): p. 1-11.

243. Aizebeokhai, A.P., K.D. Oyeyemi, and E.S. Joel, *Groundwater potential assessment in a sedimentary terrain, southwestern Nigeria.* Arabian Journal of Geosciences, 2016. **9**(7): p. 1-15.

244. Urban, J., T. Pánek, J. Hradecký, and P. Tábořík, *Deep structures of slopes connected with sandstone crags in the upland area of the Świętokrzyskie (Holy Cross) Mountains, Central Poland.* Geomorphology, 2015. **246**: p. 519-530.

245. Pánek, T., P. Tábořík, J. Klimeš, V. Komárková, J. Hradecký, and M. Šťastný, *Deep-seated gravitational slope deformations in the highest parts of the Czech Flysch Carpathians: Evolutionary model based on kinematic analysis, electrical imaging and trenching.* Geomorphology, 2011. **129**(1-2): p. 92-112.

246. Carrión-Mero, P., J. Briones-Bitar, F. Morante-Carballo, D. Stay-Coello, R. Blanco-Torrens, and E. Berrezueta, *Evaluation of Slope Stability in an Urban Area as a Basis for Territorial Planning: A Case Study.* Applied Sciences, 2021. **11**(11): p. 5013.

247. Buša, J., M. Rusnák, D. Kušnirák, V. Greif, M. Bednarik, R. Putiška, I. Dostál, J. Sládek, and D. Rusnáková, *Urban landslide monitoring by combined use of multiple methodologies-a case study on Sv. Anton town, Slovakia.* Physical Geography, 2020. **41**(2): p. 169-194.

248. Gemail, K., S. Shebl, M. Attwa, S.A. Soliman, A. Azab, and M. Farag, *Geotechnical assessment of fractured limestone bedrock using DC resistivity method: a case study at New Minia City, Egypt.* NRIAG Journal of Astronomy and Geophysics, 2020. **9**(1): p. 272-279.

249. Chalupa, V., T. Pánek, P. Tábořík, J. Klimeš, F. Hartvich, and R. Grygar, *Deep-seated gravitational slope deformations controlled by the structure of flysch nappe outliers: Insights from large-scale electrical resistivity tomography survey and LiDAR mapping.* Geomorphology, 2018. **321**: p. 174-187.

250. Pasierb, B., M. Grodecki, and R. Gwóźdź, *Geophysical and geotechnical approach to a landslide stability assessment: a case study.* Acta Geophysica, 2019. **67**(6): p. 1823-1834.

251. Suryo, E., Y. Zaika, C. Gallage, and B. Trigunarsyah, *A non-destructive method for investigating soil layers of an individual vulnerable slope.* international journal of geomate, 2020. **18**(69): p. 1-8.

252. Huntley, D., P. Bobrowsky, M. Hendry, R. Macciotta, and M. Best, *Multi-technique geophysical investigation of a very slow-moving landslide near Ashcroft, British Columbia, Canada.* Journal of Environmental and Engineering Geophysics, 2019. **24**(1): p. 87-110.

253. Castro, J., M.P. Asta, J.P. Galve, and J.M. Azañón, *Formation of Clay-Rich Layers at The Slip Surface of Slope Instabilities: The Role of Groundwater.* Water, 2020. **12**(9): p. 2639.

254. Perrone, A., F. Canora, G. Calamita, J. Bellanova, V. Serlenga, S. Panebianco, N. Tragni, S. Piscitelli, L. Vignola, and A. Doglioni, *A multidisciplinary approach for landslide residual risk assessment: the Pomarico landslide (Basilicata Region, Southern Italy) case study.* Landslides, 2020: p. 1-13.

255. Mezerreg, N.E.H., F. Kessasra, Y. Bouftouha, H. Bouabdallah, N. Bollot, A. Baghdad, and R. Bougdal, *Integrated geotechnical and geophysical investigations in a landslide site at Jijel, Algeria.* Journal of African Earth Sciences, 2019. **160**: p. 103633.

256. Samodra, G., M.F. Ramadhan, J. Sartohadi, and M. Anggri, *Characterization of displacement and internal structure of landslides from multitemporal UAV and ERT imaging.*

257. Hasan, M., Y. Shang, H. Meng, P. Shao, and X. Yi, *Application of electrical resistivity tomography (ERT) for rock mass quality evaluation.* Scientific Reports, 2021. **11**(1): p. 1-19.

258. Ündül, Ö., A. Tuğrul, Ş. Özyalın, and İ.H. Zarif, *Identifying the changes of geo-engineering properties of dunites due to weathering utilizing electrical resistivity tomography (ERT).* Journal of Geophysics and Engineering, 2015. **12**(2): p. 273-281.

259. Morgenroth, J., U.T. Khan, and M.A. Perras, *An overview of opportunities for machine learning methods in underground rock engineering design.* Geosciences, 2019. **9**(12): p. 504.

260. Cao, J., Z. Zhang, J. Du, L. Zhang, Y. Song, and G. Sun, *Multi-geohazards susceptibility mapping based on machine learning—a case study in Jiuzhaigou, China.* Natural Hazards, 2020. **102**(3): p. 851-871.

261. Yang, B., D. Elmo, and D. Stead, *Revisiting Rock Engineering Empirical Standards in the Era of Machine Learning to Benefit the Mineral Resources Sector in British Columbia.*

262. Cracknell, M.J. and A.M. Reading, *Geological mapping using remote sensing data: A comparison of five machine learning algorithms, their response to variations in the spatial distribution of training data and the use of explicit spatial information.* Computers & Geosciences, 2014. **63**: p. 22-33.

263. e Sousa, L.R., T. Miranda, R.L. e Sousa, and J. Tinoco, *The use of data mining techniques in rockburst risk assessment.* Engineering, 2017. **3**(4): p. 552-558.

264. Weidner, L., G. Walton, and R. Kromer, *Classification methods for point clouds in rock slope monitoring: A novel machine learning approach and comparative analysis.* Engineering Geology, 2019. **263**: p. 105326.

265. Weidner, L., G. Walton, and R. Kromer. *Automated rock slope material classification using machine learning*. in *54th US Rock Mechanics/Geomechanics Symposium*. 2020. OnePetro.

266. Tien Bui, D., H. Moayedi, M. Gör, A. Jaafari, and L.K. Foong, *Predicting slope stability failure through machine learning paradigms.* ISPRS International Journal of Geo-Information, 2019. **8**(9): p. 395.

267. Du, S., G. Feng, J. Wang, S. Feng, R. Malekian, and Z. Li, *A new machine-learning prediction model for slope deformation of an open-pit mine: an evaluation of field data.* Energies, 2019. **12**(7): p. 1288.

268. Kang, F., J. Li, S. Zhao, and Y. Wang, *Structural health monitoring of concrete dams using long-term air temperature for thermal effect simulation.* Engineering Structures, 2019. **180**: p. 642-653.

269. Montgomery, D.C., E.A. Peck, and G.G. Vining, *Introduction to linear regression analysis*. 2021: John Wiley & Sons.

270. Maulud, D. and A.M. Abdulazeez, *A Review on Linear Regression Comprehensive in Machine Learning.* Journal of Applied Science and Technology Trends, 2020. **1**(4): p. 140-147.

271. Schmidt, A.F. and C. Finan, *Linear regression and the normality assumption.* Journal of clinical epidemiology, 2018. **98**: p. 146-151.

272. Bazdaric, K., D. Sverko, I. Salaric, A. Martinović, and M. Lucijanic, *The ABC of linear regression analysis: What every author and editor should know.* European Science Editing, 2021. **47**: p. e63780.

273. Aggarwal, R. and P. Ranganathan, *Common pitfalls in statistical analysis: Linear regression analysis.* Perspectives in clinical research, 2017. **8**(2): p. 100.

274. Somvanshi, M., P. Chavan, S. Tambade, and S. Shinde. *A review of machine learning techniques using decision tree and support vector machine*. in *2016 international conference on computing communication control and automation (ICCUBEA)*. 2016. IEEE.

275. Chen, L.-S. and J.-Y. Lin. *A study on review manipulation classification using decision tree*. in *2013 10th international conference on service systems and service management*. 2013. IEEE.

276. Stephens, D. and M. Diesing, *A comparison of supervised classification methods for the prediction of substrate type using multibeam acoustic and legacy grain-size data.* PloS one, 2014. **9**(4): p. e93950.

277. Huang, Y. and L. Zhao, *Review on landslide susceptibility mapping using support vector machines.* Catena, 2018. **165**: p. 520-529.

278. Statininfer. Available from: https://statinfer.com/204-6-8-svm-advantages-disadvantages-applications/.

279. Maltarollo, V.G., T. Kronenberger, G.Z. Espinoza, P.R. Oliveira, and K.M. Honorio, *Advances with support vector machines for novel drug discovery.* Expert opinion on drug discovery, 2019. **14**(1): p. 23-33.

280. Kodinariya, T.M. and P.R. Makwana, *Review on determining number of Cluster in K-Means Clustering.* International Journal, 2013. **1**(6): p. 90-95.

281. Salman, S., K. Muhammad, A. Khan, and H.J. Glass, *A Block Aggregation Method for Short-Term Planning of Open Pit Mining with Multiple Processing Destinations.* Minerals, 2021. **11**(3): p. 288.

282. Javadi, S., S. Hashemy, K. Mohammadi, K. Howard, and A. Neshat, *Classification of aquifer vulnerability using K-means cluster analysis.* Journal of hydrology, 2017. **549**: p. 27-37.

283. Arun, P.V., *A comparative analysis of different DEM interpolation methods.* The Egyptian Journal of Remote Sensing and Space Science, 2013. **16**(2): p. 133-139.

284. Shiode, N. and S. Shiode, *Street-level spatial interpolation using network-based IDW and ordinary kriging.* Transactions in GIS, 2011. **15**(4): p. 457-477.

285. Wu, Y. and M.-C. Hung, *Comparison of spatial interpolation techniques using visualization and quantitative assessment.* Applications of Spatial Statistics, 2016: p. 17-34.

286. Goovaerts, P., *Kriging Interpolation.* he Geographic Information Science & Technology Body of Knowledge (4th Quarter 2019 Edition, 2019.

287. Shukla, K., P. Kumar, G.S. Mann, and M. Khare, *Mapping spatial distribution of particulate matter using Kriging and Inverse Distance Weighting at supersites of megacity Delhi.* Sustainable cities and society, 2020. **54**: p. 101997.

288. Achilleos, G., *The Inverse Distance Weighted interpolation method and error propagation mechanism–creating a DEM from an analogue topographical map.* Journal of spatial Science, 2011. **56**(2): p. 283-304.

289. Malaysia, P.; Available from: https://www.klia2.info/trips/highways/plus-expressway-north-south-expressway/.

290. Nuhu, H., S. Hashim, M. Aziz Saleh, M. Syazwan Mohd Sanusi, A. Hussein Alomari, M.H. Jamal, R.A. Abdullah, and S.A. Hassan, *Soil gas radon and soil permeability assessment: Mapping radon risk areas in Perak State, Malaysia.* PloS one, 2021. **16**(7): p. e0254099.

291. Kong, T.B., *Engineering geology in Malaysia—some case studies.* 2017.

292. Abad, S.A.N.K., E. Mohamad, and I. Komoo, *Dominant weathering profiles of granite in southern Peninsular Malaysia.* Engineering geology, 2014. **183**: p. 208-215.

293. (JMG), M.a.G.d. *Geological map of peninsular Malaysia. (Peta Geologi Semenanjung).* 2014; Available from: https://www.jmg.gov.my/add_on/mt/smnjg/tiles/.

294. Baioumy, H.M., M. Nawawi, K. Wagner, and M.H. Arifin. *Geological setting and origin of non-volcanic hot springs in West Malaysia*. in *rd Annual International Conference on Geological & Earth Sciences (GEOS 2014), Singapore*. 2014.

295. CM, C., *Structural History of the Kinta Valley*. 2014, MSc Thesis, Geoscience Dept., Faculty of Geoscience and Petroleum ….

296. Akingboye, A.S. and A.C. Ogunyele, *Insight into seismic refraction and electrical resistivity tomography techniques in subsurface investigations.* Rudarsko-geološko-naftni zbornik (The Mining-Geological-Petroleum Engineering Bulletin), 2019. **34**(1).
297. 3GSM. Available from: https://3gsm.at/.
298. Zond. Available from: http://zond-geo.com/english/

LIST OF PUBLICATIONS

1. Junaid, M., R.A. Abdullah, R. Sa'ari, W. Ali, H. Rehman, M.N.A. Alel, and U. Ghani, *2D electrical resistivity tomography an advance and expeditious exploration technique for current challenges to mineral industry.* Journal of Himalayan Earth Sciences, 2021. **54**(1): p. 11-32.
2. Junaid, M., R.A. Abdullah, R. Saa'ri, and N.A. Alel, *An expeditious approach for slope stability assessment using integrated 2D electrical resistivity tomography and unmanned aerial vehicle survey.* Journal of Applied Geophysics, 2022: p. 104778.
3. Junaid, M., R.A. Abdullah, R. Sa’ari, W. Ali, H. Rehman, and M. Sari, *Water-saturated zone recognition using integrated 2D electrical resistivity tomography, borehole, and aerial photogrammetry in granite deposit, Malaysia.* Arabian Journal of Geosciences, 2022. **15**(14): p. 1-13.
4. Junaid, M., R.A. Abdullah, R. Sa’ari, H. Rehman, K.S. Shah, U. Rafi, M.N.A. Alel, I.Z. Zainal, and N.E. Zainuddin, *Quantification of Rock Mass Condition Based on Fracture Frequency Using Unmanned Aerial Vehicle Survey for Slope Stability Assessment.* Journal of the Indian Society of Remote Sensing, 2022.