Cataloguing of rock glaciers in dissimilar regions of the Mackenzie Mountains: Testing for possible semi-automated detection of rock glaciers using topographic data

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We acknowledge that The University of Lethbridge is located on the traditional territory of the Blackfoot Confederacy. We recognize and honor the past, present, and future generations of Indigenous peoples who have lived on this land since time immemorial.

ABSTRACT

Rock glaciers have been the subject of extensive research in recent years, due to their potential to serve as indicators of past and present climate conditions and their potential impacts on water resources. Compilation and analysis of collected data on the location, size, and characteristics of rock glaciers within the Mackenzie Mountains was used to build a rock glacier catalogue that will serve as a valuable resource for future research and monitoring efforts. The research also aims to map the spatial distribution of rock glaciers using optical imagery and to develop a semi-automated detection model using Generalized Additive Models (GAMs) in R. The model will incorporate attribute data, such as solar radiation, aspect, topographic position index, slope, elevation, and lithology as controls for rock glacier development. Topographic data was collected in multiple regions of the Mackenzie Mountains and extracted using a 30m digital elevation model (DEM). The results of this study have the potential to improve our understanding of rock glacier distribution and dynamics in the Mackenzie Mountains and could also be applied to similar mountainous regions.

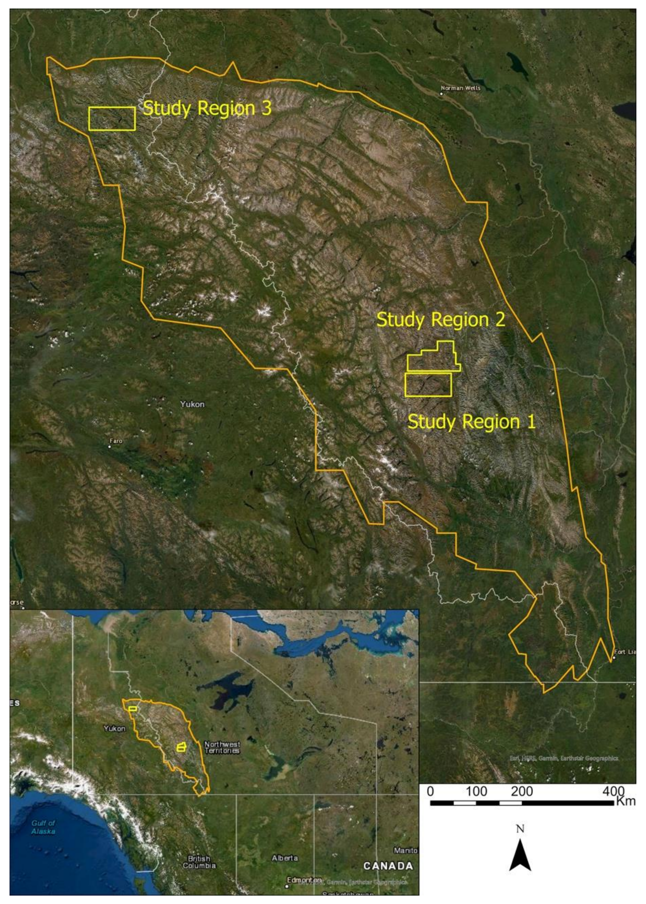

Figure 1: Three defined regions within the Mackenzie Mountains, which border the NT and YT in northern Canada. Each region is approximately 5000 km^2.

OBJECTIVES

1. Identify rock glaciers in selected study regions within the Mackenzie Mountains using previously developed classification methods.

2. Analyze rock glacier morphological attributes, extracted from digital elevation models (DEMs)

3. Test a potential semi-automated detection model using a statistical approach. Striving for a semi-automated model that will determine the likelihood of rock glaciers in adjacent regions.

METHODS

The international permafrost association (IPA) has established guidelines for the inventory and mapping of rock glaciers, which provide a framework for the use of optical imagery in the identification of rock glaciers (RGIK, 2022). The morphological features discussed in this study, follow these guidelines, and include utilizing identification criteria including vegetation patterns, color, ridge, and furrow features. This framework was implemented to manually identify rock glaciers from satellite imagery, within an ArcGIS Pro 2.9.3 environment (ESRI Inc. 2021), Google Earth 7.3.6 (Google Earth 2022) Pro and Sentinel Hub.

Features confidently identified as rock glaciers were recorded using datapoints labeled RG (Rock glacier) while features that were identified as debris covered glaciers (DCGs), embryonic rock glaciers, protalus lobes, protalus ramparts, talus cones and rockslides were recorded as features of interest (FOI). To overcome subjectivity issues a consensus-based method was used (Way et al, 2021).

The spatial distribution of rock glaciers can be modeled using generalized additive models (GAMs) in R (R version 4.2.2). In this study multiple GAM models were created in R with restricted maximum likelihood (REML) method. These models help to better understand the spatial distribution of rock glaciers as a binary dependent variable, '0' and '1' absence and presence, respectively. In the stepwise GAM model termed 'StepGAM1,' six independent variables were included: 'slope,' 'eastness,' 'northness,' 'topographic position index,' 'elevation,' and 'solar radiation." To prevent issues with maintaining consistency among variables that are distributed radially, the aspect was transformed into two linear variables that represent the direction of "northness" and "eastness" (Pearson et al, 2007). Lithology was not included in the StepGAM1 model as a predictor variable because including categorical predictors with many levels, such as lithology, can lead to overfitting, which can result in poor model performance on new data (Wood, 2017). A second GAM model 'StepGAM2' was created to test the differences between the models when including the lithology variables.

Figure 2: Active rock glacier, SA3, ESRI World imagery base layer (ArcGIS Pro, version 2.9.3) with defined, steep terminus and lateral margins. Ridge and furrow topography indicative of flow also apparent, 1:10,000.

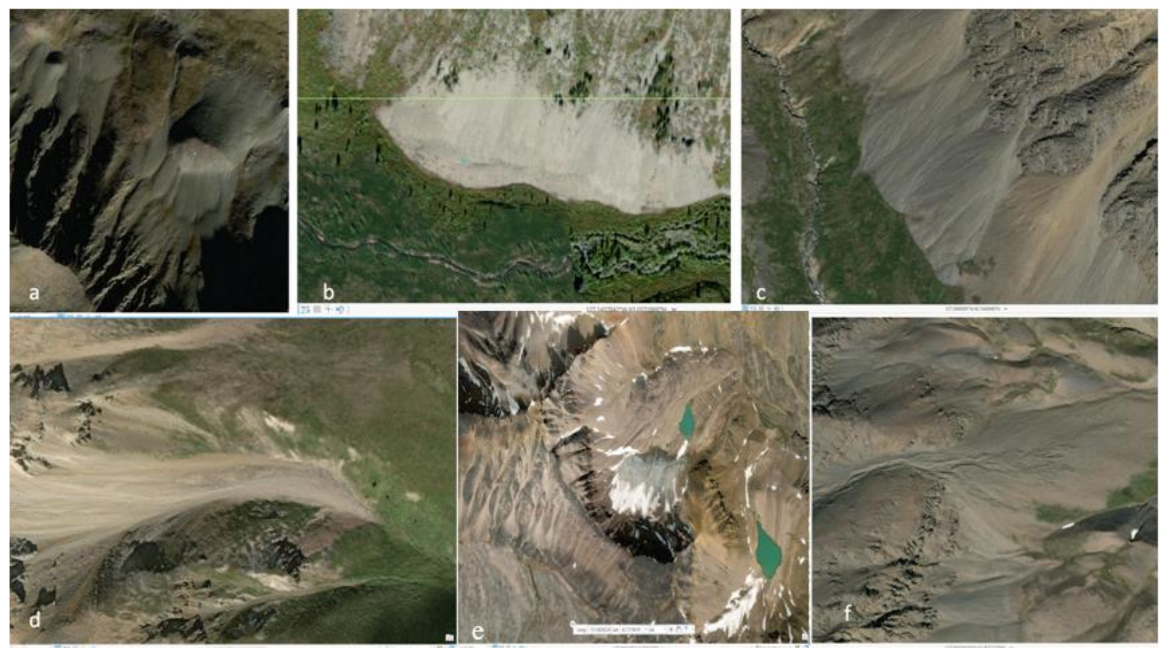

Figure 3: Landforms found in periglacial environments that can be considered embryonic rock glaciers (a) FOI; embryonic rock glacier (protalus lobe) from SA3, northern Mackenzie Mountains. ESRI world imagery base layer (EWIBL), 1:10,000 (b) protalus rampart, SA2,(EWIBL), 1:5,000; features that can be mistaken for rock glaciers (c) talus cones, SA1, ESRI World Imagery Base Layer, 1:5,000 (d) rockslide, SA2, ESRI (WIBL), 1:5,000 (e) debris covered glacier, SA1, ESRI (WIBL), 1:15,000 and (f) fluvial erosion over a talus slope,SA1, ESRI WIBL, 1:5,000. (ArcGIS Pro, version 2.9.3).

RESULTS

StepGAM1

variable	AIC	R2	Step
Sol_Rad	1018.683	-0.00125	1
Sol_Rad+SLOPE	919.728	0.135434	2
Sol_Rad+SLOPE+Eastness	898.9516	0.158932	3
Sol_Rad+SLOPE+Eastness+Northness	900.9068	0.157878	4
Sol_Rad+SLOPE+Eastness+Northness+ELEV	865.4432	0.195075	5
Sol_Rad+SLOPE+Eastness+Northness+ELEV+TPI	517.6669	0.551742	6

	Predicted Positive	Predicted Negative
Actual Positive	122	34
Actual Negative	26	130
Total Diagnol	252	
Total	312	
Accuracy (%)	80.77	

StepGAM2:

variable	AIC	R2	Step
Sol_Rad	1018.683	-0.00125	1
Sol_Rad+SLOPE	919.728	0.135434	2
Sol_Rad+SLOPE+Eastness	898.9516	0.158932	3
Sol_Rad+SLOPE+Eastness+Northness	900.9068	0.157878	4
Sol_Rad+SLOPE+Eastness+Northness+ELEV	865.4432	0.195075	5
Sol_Rad+SLOPE+Eastness+Northness+ELEV+TPI	517.6669	0.551742	6
Sol_Rad+SLOPE+Eastness+Northness+ELEV+TPI+Lithology	501.8854	0.590138	7

	Predicted positive	Predicted Negative
Actual Positive	120	36
Actual Negative	25	131
Total Diagonal	251	
Total	312	
Accuracy (%)	80.45	

The rock glacier inventory results show that there are a total of 536 rock glaciers total within the three regions. 477 categorized as active and 59 as inactive. The area covered by rock glaciers in each study region is 121.62 km2 in region 1, 60.66 km2 in region 2, and 88.07 km2 in region 3. The mean elevation of rock glaciers in all regions is 1608.6 meters, with a mean slope of 17.6 degrees and a mean aspect of 168.7 degrees. The mean TPI (Topographic Position Index) is -40.3, indicating that rock glaciers are generally lower in elevation than their surroundings. The mean solar radiation is 231.2 W/m2, which may contribute to the formation and maintenance of rock glaciers. The occurrence of different types of geology in each study region is also presented, with sandstone, dolostone, and siltstone being the most common rock types among the rock glaciers while shale, dolostone and limestone are the most predominant rock types of the entire study area.

CONCLUSIONS

In conclusion, the catalogue results provide valuable information for understanding the distribution and characteristics of rock glaciers in the study regions, as well as their potential impacts on the surrounding landscape. The generalized additive model with a binomial family and a logit link function provides significant predictors for the outcome variable and explains a moderate amount of variance in the data. The inclusion of lithology as a predictor in the model provides additional information that helps explain more of the variation in the response variable compared to the second model that does not include lithology. However, the second model still explains a substantial portion of the variation in the response variable. The confusion matrices show that both models have similar accuracy and F1 scores, but Model 1 has a higher precision score indicating better performance in correctly identifying positive cases. It may be worthwhile to further evaluate the model's performance through cross-validation or other methods, such as a random forest model. The data collected will also be used to create a probability surface in ArcGIS Pro. This surface will provide a visual representation of the model's results and better illustrate the probability of different outcomes. The probability surface is created by overlaying the model results on a geographic map, in order to see the spatial distribution of the model predictions. This information can be invaluable in making informed decisions and identifying areas of higher likelihood of rock glacier presence, therefore reducing the time, and labor constraints, as well as subjectivity that are currently encountered when composing a rock glacier inventory at large regional scales.

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