Gypsum induced Landsides in Ollon, Switzerland

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This abstract presents a comprehensive case study of landslides in Ollon, Switzerland, emphasizing the complex geological and topographic factors contributing to these geotechnical hazards. Through historical analysis, geotechnical investigations, and geological assessments, the study aims to uncover the underlying causes and mechanisms of the landslides. The study area, situated in the "Bois de la Glaive" region of Ollon, features a challenging terrain characterized by karstified gypsum rock cover, which hinders surface runoff. Steep slopes, coupled with a dense root system, further complicate the stability of the area. Landslides in Ollon involve a debris mass consisting of soil and gypsum blocks, resulting from a complex interplay of geological and environmental factors. Geotechnical analysis involves evaluating slope stability, soil properties, and groundwater conditions. Field investigations and laboratory tests provide crucial insights into shear strength, permeability, and deformation behavior. Geological analysis explores the lithological composition, geological structure, and tectonic history of the region, aiming to understand how geological processes interact with external forces like weathering and erosion. The study also highlights the role of water content in destabilizing the terrain. Rainwater infiltration, especially in the context of gypsum's impermeability, plays a significant role in slope instability.

Keywords: Landslide, Gypsum, Geotechnics, Switzerland, Rainfall

Introduction

Landslides are prominent geotechnical hazards in Switzerland, primarily due to its complex geological and topographic characteristics. Understanding the mechanisms and factors contributing to landslides is essential for mitigating their impact on infrastructure and ensuring human safety. This paper presents a comprehensive case study focused on landslides in the village of Ollon, situated in the Canton of Vaud, Switzerland.

The study employs a multidisciplinary approach, including historical analysis, geotechnical investigations, geological assessments, and consideration of environmental factors. The objective is to uncover the underlying causes and mechanisms of landslides in Ollon, with a specific focus on its geological, geotechnical, and environmental aspects.

Ollon's geological features play a significant role in slope instability. It is characterized by karstified gypsum rock cover, which hinders surface runoff. Steep slopes and a dense root system further complicate stability. Landslides in Ollon involve a debris mass consisting of soil and gypsum blocks, resulting from complex geological and environmental interactions.

The geotechnical analysis involves assessing slope stability, soil properties, and groundwater conditions. Field investigations and laboratory tests provide critical insights into shear strength, permeability, and deformation behavior, contributing to a comprehensive understanding of the terrain's stability.

Additionally, the study considers the environmental factors, such as the impermeable nature of gypsum rock and the role of vegetation, including the dense root system, in slope stability.

Historical analysis utilizes aerial photographs to track landslide events over time, revealing patterns and trends in past occurrences. Pluviometry data is analyzed to examine the relationship between precipitation patterns and landslide events.
The laboratory results provide further insights into the composition and properties of the soil and rock in Ollon, enhancing our understanding of the terrain's behavior.
This paper aims to shed light on the complex interactions between geological, geotechnical, environmental, and climatic factors that contribute to landslides in Ollon. The findings have practical implications for predicting and mitigating future slope failures in the region.

Methodology

The investigation into landslides in Ollon employed a multidisciplinary approach, encompassing geological, geotechnical, environmental, historical, and climatic considerations. For this study, only the 30 January, 2021's one has been sampled.
The study area's geological features were thoroughly characterized, with geological mapping, rock sampling, and mineral identification forming the foundation. An exploration of the region's tectonic history provided insights into the geological processes that have shaped the area.
Environmental elements were integral to the analysis. The presence of karstified gypsum rock cover, impeding surface runoff, was examined, along with the impermeable nature of gypsum and its impact on water infiltration. Additionally, the role of vegetation, specifically the dense root system, was observed and assessed concerning slope stability.
A historical investigation was conducted using aerial photographs dating from 1938 to the present day. These images were analyzed to track the evolution of slope displacements and past landslide occurrences, identifying patterns and trends in historical events.
Precipitation data from nearby observation stations, including MétéoSuisse (Swiss Federal Office of Meteorology) and the Canton of Vaud, underwent analysis. This examination focused on understanding the relationship between precipitation patterns and landslide events, with particular attention to the duration and intensity of rainfall leading up to landslides.
Detailed investigations were conducted to assess slope stability. This included comprehensive slope stability analyses, taking into account factors such as slope angle, soil properties, and groundwater conditions. Soil samples collected from key locations underwent laboratory testing to determine their properties, including Unified Soil Classification System (USCS) classification, bulk density, granulometry, and Atterberg limits. Additionally, experiments were conducted to ascertain gypsum dissolution times.
This comprehensive and integrated methodology facilitated a holistic understanding of the complex interactions and contributing factors influencing landslides in the area.

Results

A historical study was conducted using aerial photographs sourced from the Swiss Confederation's database (map.geo.admin).
Since 1938 (Photo A, Figure 1), photography has enabled the observation of slope movements and various associated landslide events. Already, a landslide (highlighted in red) occurred a few meters away from the one in 2021. Further to the west, another larger unstable area is noticeable (highlighted in yellow), providing evidence that the region has been subjected to these events for nearly a century, at the very least.
In 2004 (Photo B, Figure 1), it is clearly evident that a detachment niche is forming on the upper part of the slope. Rockfall events appear to have increased in intensity, nearly reaching the road below during one of the events (highlighted in yellow). The landslide from 1938 (highlighted in red) has been completely absorbed by vegetation.

The 2010 photograph (Photo C, Figure 1) depicts the upper part of the slope completely devoid of vegetation due to a significant number of rockfall events since 2007.
On January 22, 2018 (Photo D, Figure 1), a new landslide (highlighted in red) occurs at the same location as in 1938, precisely 80 years later and likely under similar conditions. Vegetation is starting to reclaim its territory in the vicinity of the rockfall zone (highlighted in yellow).

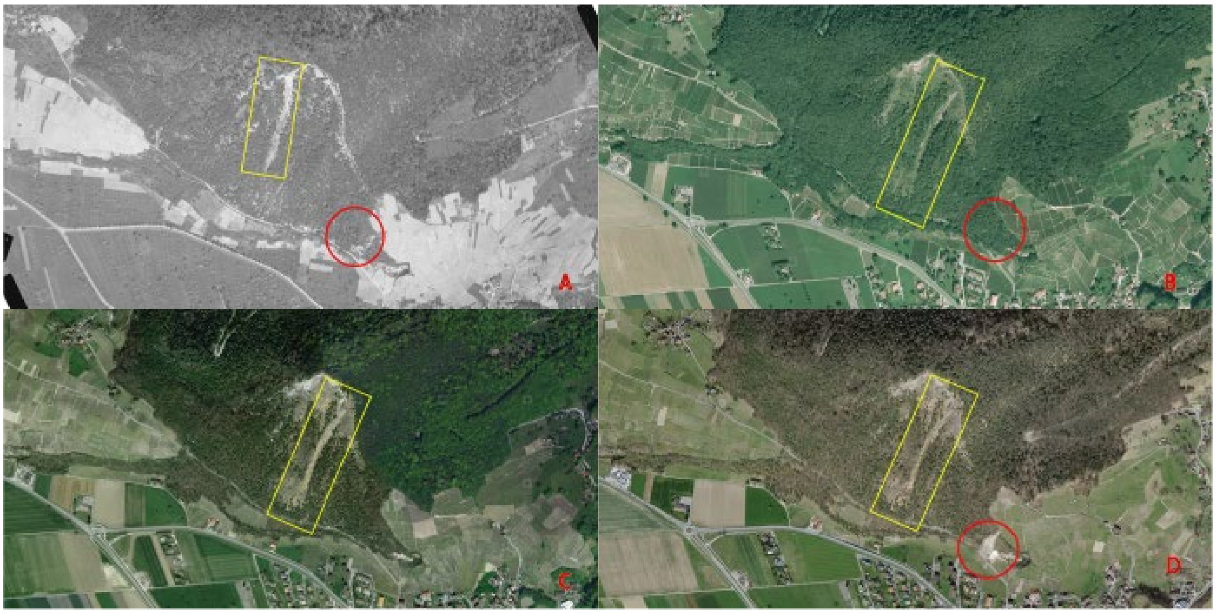

Figure 1. Aerial photographs. A: 1938; B: 2004; C: 2010; D:2018 (modified after map.geo.admin)

The precipitation data related to the two most recent events in the region were collected from public meteorological authorities and have been compiled in Figure 2.

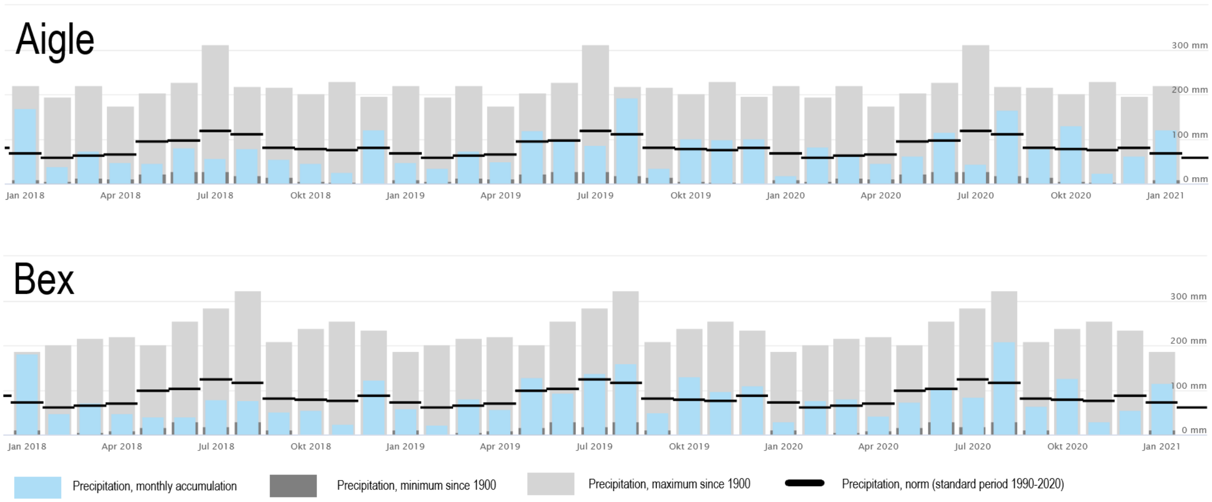

Figure 2 Precipitation data according to two nearby stations (modified after MétéoSuisse)

The laboratory analyses presented here were conducted on three samples collected from various key locations on the last landslide. The following table summarize the results of particle size analysis and Atterberg limits obtained according to the Unified Soil Classification System (USCS).

Table 1. Unified Soil Classification System for three samples

Sample	Fines %	Gravel %	Sand %	Liquid Limit %	Plastic Limit %	USCS
1	46.9	24.3	28.8	47.5	8.0	SM
2	45.6	25.4	29.0	48.0	3.3	SM
3	50.3	26.7	23.0	44.0	4.0	ML

Discussion

Gypsum's impermeable nature is a fundamental factor contributing to slope instability. This mineral inhibits surface runoff and hampers effective water infiltration, thereby disrupting the normal hydrological processes of the terrain. This disruption, in conjunction with the steep slopes commonly found in the area, sets the stage for instability. As water infiltrates the surface layer, it encounters the impermeable gypsum stratum, creating a saturation boundary. This boundary leads to an increase in pore pressure within the soil, ultimately compromising the soil's shear strength.

Moreover, gypsum's susceptibility to dissolution near the surface is another critical aspect to consider. When gypsum is exposed to water, it can undergo rapid dissolution, which alters its volume and properties. This dissolution process introduces variations in specific volumes, causing expansions and contractions within the rock. These volume changes, coupled with gypsum's tendency to deform under stress, contribute significantly to the overall instability of the slopes.

Analytical results from soil samples collected in the area reveal that the predominant soil type is Silty-Medium. Silty soils have moderate water retention capabilities and tend to compact easily when saturated, leading to reduced permeability. This reduction in permeability can result in poor drainage, particularly problematic in this area because of the particularly steep slope (around 43°).

Silty soils also typically exhibit low shear strength, which means they have a reduced ability to resist shearing forces. In slope stability analysis, this reduced shear strength can significantly elevate the risk of landslides or slope failures, particularly in regions with steep terrain.

While silty soils possess cohesion due to their fine particles, their friction angle is low. Cohesion provides some strength to the soil, but the lower friction angle makes silty soils more susceptible to sliding along failure planes. Altogether, these soil characteristics underscore the heightened vulnerability of the terrain to landslides, particularly when combined with the geological influence of gypsum, as observed in the area.

Conclusion

The comprehensive investigation into landslides in Ollon, Switzerland, has revealed the intricate web of factors contributing to these geotechnical hazards. The geological composition, characterized by gypsum-rich karst formations, plays a fundamental role in slope instability. Water, with its capacity to increase soil weight and generate shear forces, is a significant driver of landslides. Collectively, these findings underscore the vulnerability of the region to landslides and emphasize the need for an interdisciplinary approach to address these complex geotechnical challenges. This study highlights the critical importance of holistic geotechnical hazard analysis in safeguarding the region's infrastructure and enhancing the safety of its inhabitants. Hence, new investigations must be conducted with the aim of precisely determining the return periods of these events in the context of an acceleration of intense climatic phenomena.