DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

Proceedings
of the 7th International Conference

Chengdu, China, 23–27 September 2024

Edited by
S.S. Chernomorets, K. Hu, K.S. Viskhadzhieva

Geomarketing LLC
Moscow
2024

СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

Труды
7-й Международной конференции

Чэнду, Китай, 23–27 сентября 2024 г.

Ответственные редакторы
С.С. Черноморец, К. Ху, К.С. Висхаджиева

ООО «Геомаркетинг»
Москва
2024

泥石流：

灾害、风险、预测、防治

会議記錄

第七届国际会议

中国成都, 2024年9月23日至27日

編輯者
S.S. Chernomorets, K. Hu, K. Viskhadzhieva

Geomarketing LLC
莫斯科
2024

УДК 551.311.8
ББК 26.823
С29

Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 7th International Conference (Chengdu, China). – Ed. by S.S. Chernomorets, K. Hu, K.S. Viskhadzhieva. – Moscow: Geomarketing LLC. 622 p.

Селевые потоки: катастрофы, риск, прогноз, защита. Труды 7-й Международной конференции (Чэнду, Китай). – Отв. ред. С.С. Черноморец, К. Ху, К.С. Висхаджиева. – Москва: ООО «Геомаркетинг», 2024. 622 с.

泥石流：灾害、风险、预测、防治. 會議記錄 第七届国际会议. 中国成都. 編輯者 S.S. Chernomorets, K. Hu, K.S. Viskhadzhieva. – 莫斯科: Geomarketing LLC. 622 p.

ISBN 978-5-6050369-6-8

Ответственные редакторы: С.С. Черноморец (МГУ имени М.В. Ломоносова), К. Ху (Институт горных опасностей и окружающей среды Китайской академии наук), К.С. Висхаджиева (МГУ имени М.В. Ломоносова).

Edited by S.S. Chernomorets (Lomonosov Moscow State University), K. Hu (Institute of Mountain Hazards and Environment, CAS), K.S. Viskhadzhieva (Lomonosov Moscow State University).

При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).

Conference logo is based on a figure from S.M. Fleishman’s book on Debris Flows (Moscow: Geografgiz, 1951, p. 51).

Evaluation of decadal rainfall variability's effect on debris flow intensity and frequency in the Brep Area of Chitral, Pakistan

N. Uddin, L. Ali, Z. Uddin

Branch of the Aga Khan Agency for Habitat in Pakistan, Islamabad, Pakistan, nasiruddin.shah@akdn.org

Abstract. Debris flows are a significant natural hazard, causing severe casualties and property damage. This study explores the relationship between rainfall conditions and debris flows in the Chitral District of northern Pakistan, focusing on the Brep region. Utilizing rainfall and temperature data from the weather monitoring post (WMP) installed by the Aga Khan Agency for Habitat, historical debris flow records, and GIS mapping, the study examines the impact of climatic variations on debris flow frequency and intensity.
The study aims to identify changing climatic conditions that lead to changes in precipitation patterns by analyzing temperature and rainfall data collected over ten years. Findings indicate a significant rise in temperatures from 2007 to 2023 and fluctuating rainfall intensities. Historical data reveals an increasing trend in debris flow damage, with affected areas expanding markedly over time. The results underscore the dynamic nature of climatic patterns and their influence on debris flows. By understanding the link between rainfall patterns and debris flow intensification, the research contributes to developing effective disaster prediction and early warning systems.

***Key words**: debris flow, intensity, rainfall, hazard, impact*

Cite this article: Uddin N., Ali L., Uddin Z. Evaluation of decadal rainfall variability's effect on debris flow intensity and frequency in the Brep Area of Chitral, Pakistan. In: Chernomorets S.S., Hu K., Viskhadzhieva K.S. (eds.) Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 7th International Conference (Chengdu, China). Moscow: Geomarketing LLC, 2024, p. 511–516.

Влияние десятилетней изменчивости осадков на интенсивность и частоту селевых потоков в районе Бреп (округ Читрал, Пакистан)

Н. Уддин, Л. Али, З. Уддин

Филиал Агентства Ага Хана по Хабитат в Пакистане, Исламабад, Пакистан, nasiruddin.shah@akdn.org

Аннотация. Селевые потоки представляют собой значительную природную опасность, приводящую к серьезным жертвам и материальному ущербу. В данном исследовании изучается связь между количеством осадков и селевыми потоками в районе Читрал на севере Пакистана, в основном в районе Бреп. Используя данные о количестве осадков и температуре с поста метеорологического мониторинга (ПММ), установленного Агентством Ага Хана по вопросам среды обитания, исторические данные о селевых потоках и картографию ГИС, в исследовании рассматривается влияние климатических колебаний на частоту и интенсивность селевых потоков.
Исследование направлено на выявление меняющихся климатических условий, которые приводят к изменению характера осадков, путем анализа данных о температуре и количестве осадков, собранных за десять лет. Полученные данные свидетельствуют о значительном повышении температуры с 2007 по 2023 г. и колебаниях интенсивности осадков. Исторические данные свидетельствуют о тенденции к увеличению ущерба от селевых потоков, причем пострадавшие районы заметно расширяются с течением времени. Полученные результаты подчеркивают динамичность климатических моделей и их влияние на селевые потоки. Понимание связи между характером осадков и интенсивностью селевых потоков способствует

разработке эффективных систем прогнозирования и раннего оповещения о стихийных бедствиях.

Ключевые слова: *селевые потоки, интенсивность, осадки, опасность, воздействие*

Ссылка для цитирования: Уддин Н., Али Л., Уддин З. Влияние десятилетней изменчивости осадков на интенсивность и частоту селевых потоков в районе Бреп (округ Читрал, Пакистан). В сб.: Селевые потоки: катастрофы, риск, прогноз, защита. Труды 7-й Международной конференции (Чэнду, Китай). – Отв. ред. С.С. Черноморец, К. Ху, К.С. Висхаджиева. – М.: ООО «Геомаркетинг», 2024, с. 511–516.

Introduction

Debris flows are major components of many natural disasters, causing severe casualties and significant damage to public and private properties. Rainfall is widely recognized as a critical factor in triggering debris flows [*Prenner et al., 2018*]. Regional rainfall destabilizes hillsides, increasing erosion and triggering debris flows as rainfall intensity rises [*Thouret et al., 2020*]. Understanding the relationship between rainfall and debris flows is crucial for comprehending their mechanisms, predicting disasters, and developing early warning systems.

Determining rainfall thresholds is a common method for analyzing how debris flows respond to rainfall [*Banihabib and Tanhapour, 2020*]. These thresholds are defined using various parameters [*Segoni et al., 2018*], including rainfall intensity [*Marin et al., 2020*], rainfall duration [*Peres and Cancelliere, 2014*], cumulative rainfall over a specific period [*Kean et al., 2011*], daily rainfall, and antecedent rainfall index [*Monsieurs et al., 2019*]. Rainfall thresholds for debris flows are typically derived from rainfall gauge observations.

In the Chitral region, rainfall-induced debris flows are a persistent hazard due to a combination of diverse conditioning factors, such as varying climates, complex terrains, and active geological movements [*Haq, 2007*]. In this area, rainfall data from gauge stations serve as the primary source for determining debris flow rainfall thresholds. Data on daily rainfall from 33 weather monitoring stations, covering the period from 2014 to the present, are accessed through the Aga Khan Agency for Habitat Regional office.

Study Area

Surrounded by some of the tallest and highly glaciated mountains, the Chitral District of northern Pakistan lies in the eastern Hindu Kush Range. Geographically, it extends from 71°2' – 73°8' E longitude to 35°3' – 36°9' N latitude (Fig. 1). The district has an area of 15,000 km^2 and spans within an elevation range from 1000 m to 7700 m above sea level. A common geomorphic feature of the Chitral region is valley facing slopes associated with high relief Mountains, which merge into broad, relatively flat floodplains. At least a dozen human casualties are associated with snow avalanches, floods and debris flows in the eastern Hindu Kush every year [*Khan et al., 2012*].

The Yarkhoon Valley is possessed by three of most noteworthy mountain networks of the earth. The Hindu Kush extend in the west, Hindu Raj go in the east and in the middle of is the Shandhur Karakorum run. Brep is situated in the lower yarkhoon northern part of Chitral District. The climate there is temperate. type with warm summer and very cold winter. Mean summer temperature ranges from 22°C to 24 °C while winter temperature ranges from -4°C to -6°C. Debris flow is the major and dominant hazard in the study area and the events in 2005, 2015 and 2022 damaged more than 100 households and washout major portion of the village.

Brief review of the problem

The problem under consideration revolves around the observed changes in rainfall patterns over the last decades, coupled with an increase in the frequency and intensity of debris flow events. Despite these significant shifts, there has been a notable absence of research exploring the potential correlation between changing rainfall patterns and the intensification of debris flow events. This research gap is concerning as it restricts our ability to understand and mitigate the risks associated with these natural hazards effectively. Addressing this gap is crucial for developing proactive measures to safeguard vulnerable communities and ecosystems against the growing threats posed by changing environmental conditions.

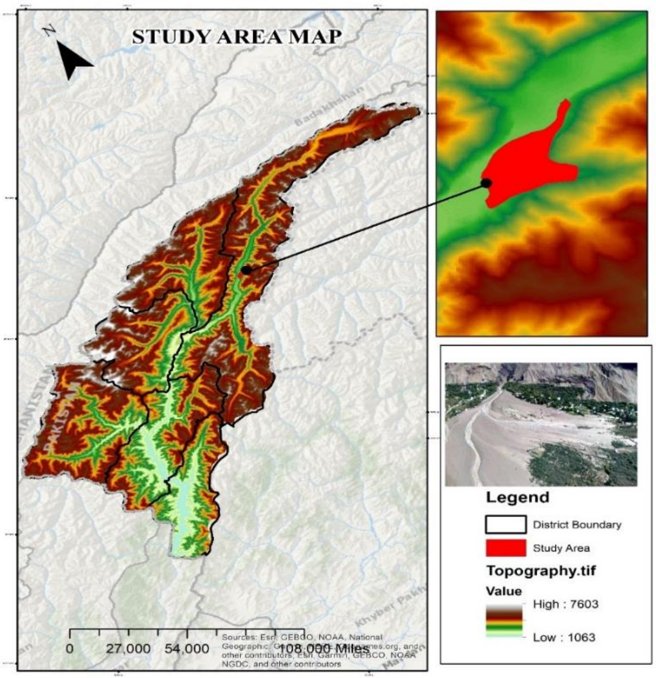

Fig. 13. The study area location map

Methods

The article employed several methodologies. Initially, rainfall and temperature data were gathered from weather monitoring posts set up by the Aga Khan Agency for Habitat. This data was then analyzed through the creation of various bar charts to observe changes in rainfall intensity and temperature variation. Subsequently, a field visit was conducted in the study area to develop risk reduction maps and verify changes in impact areas during the last three debris flow events. GIS footprints were utilized to produce maps illustrating variations in debris flow impact across the same three events.

Data

The data utilized in this study comprised three main sources:

1. Rainfall and temperature data: Data on rainfall intensity and temperature variations were collected from weather monitoring posts (WMPs) deployed by the Aga Khan Agency for Habitat within the study area. These records provided crucial information for analyzing climatic patterns and their potential influence on debris flow occurrences.
2. Historical data of debris flow: Historical records detailing previous debris flow events in the study area were compiled. Additionally, hazard and risk mapping data were generated through field visits, enabling the identification and assessment of vulnerable areas prone to debris flow hazards.
3. GIS footprints: Geographic Information System (GIS) footprints were utilized to analyze and visualize the impact areas of debris flow during the three most recent events.

This spatial data facilitated the creation of hazard and risk maps, offering insights into the extent and severity of debris flow occurrences over time.

Analysis

The analysis conducted in this study sheds light on the relationship between decadal rainfall variability and the intensity and frequency of debris flows in the Brep area of Chitral, Pakistan. Three key findings emerged from the examination of temperature and rainfall data, historical records, and impact area mapping:

- temperature Variation: The bar graphs constructed to analyze temperature variation over the years reveal a notable increase in temperatures from 2007 to 2023. In 2007, the temperature was recorded at less than 30 degrees Celsius, which rose to 32 degrees Celsius in 2014 and further increased to 35 degrees Celsius in 2023. This upward trend in temperatures suggests a potential warming effect over the past decade;
- rainfall Intensity Fluctuation: The analysis of rainfall data for the months of July and August illustrates variability in precipitation levels over the years. In 2004, rainfall measured 20 mm, which increased to 34 mm in 2007 and further rose to 38 mm in 2023. This fluctuation in rainfall intensity underscores the dynamic nature of climatic patterns in the region;
- historical Damage Assessment: Historical data collected during field visits indicates a concerning trend of increasing damages caused by debris flow events over time. The damages recorded in 2007 were relatively minimal compared to those in 2014 and 2023, suggesting a progressive escalation in the severity of debris flow impacts;
- impact Area Mapping: The mapping of impact areas for the three events further reinforces the escalating trend observed in historical data. In 2007, approximately 2000 square meters were affected, whereas in 2014, the impacted area expanded to 5000 square meters. By 2023, the impact area had significantly increased to 8000 square meters, highlighting the growing magnitude of debris flow occurrences.

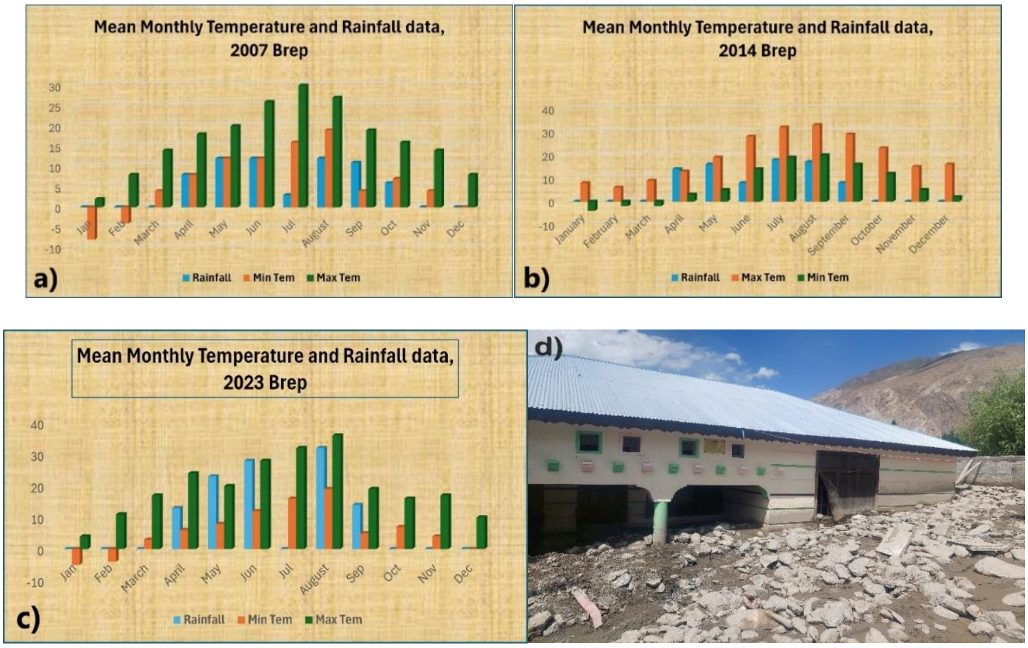

Fig. 14. Temperature and rainfall data: a – 2007 mean temperature and rain fall data variation; b – 2014 mean temperature and rain fall data variation c) 2022 mean temperature and rain fall data variation d) field photograph of 2022 debris flow incident

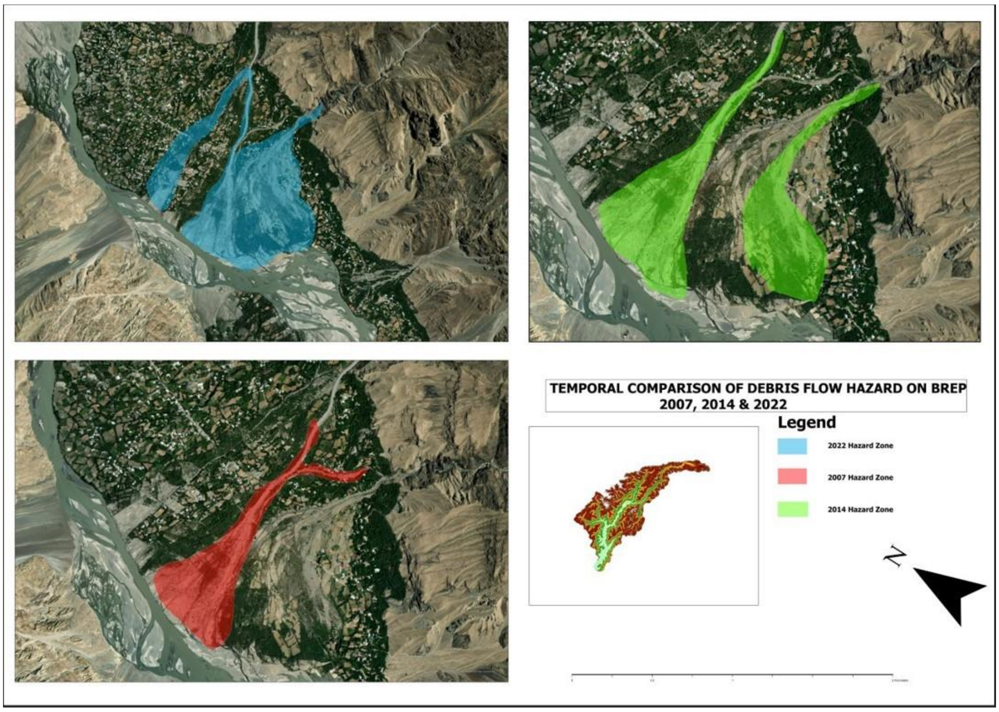

Fig. 15. Comparison of debris flow intensity in last one decade

Conclusions

The study presents compelling evidence linking decadal rainfall variability to the intensity and frequency of debris flows in the Brep area of Chitral, Pakistan. Through meticulous analysis of temperature and rainfall data, historical records, and impact area mapping, significant trends have emerged.

The observed rise in temperatures over the past decade, coupled with fluctuating rainfall intensities, underscores the dynamic nature of climatic patterns in the region. Moreover, the progressive escalation in damages caused by debris flow events, as evidenced by historical data and impact area mapping, highlights the growing vulnerability of communities to these hazards.

These findings emphasize the urgent need for robust risk management strategies to address the increasing risks posed by debris flows. By incorporating climate resilience measures, enhancing early warning systems, and implementing sustainable land-use practices, communities can better prepare for and mitigate the impacts of future debris flow events.

Ultimately, this study contributes valuable insights to the field of natural hazard management, advocating for proactive measures to build resilience and safeguard lives and livelihoods in hazard-prone regions like Brep, Chitral.

Acknowledgements

We would like to thank for all kind of support including technical assistance and field support provided by Aga Khan Agency for Habitat Pakistan to compile and write this article at every step throughout the completion of this article.

We also acknowledge the contributions of Ms. Asma Sherbaz, Weather Monitoring Post (WMP) In charge for providing accurate data of rainfall and temperature of the study area.

References

Banihabib, M. E., & Tanhapour, M. (2020). An empirical equation to determine the threshold for rainfall-induced landslides developing to debris flows. Landslides, 17(9), 2055–2065.

Haq, I. (2007). Community response to climatic hazards in northern Pakistan. Mountain Research and Development, 27(4). http://dx.doi.org/10.1659/mrd.0947

Kean, J. W., Staley, D. M., & Cannon, S. H. (2011). In situ measurements of post-fire debris flows in southern California: Comparisons of the timing and magnitude of 24 debris-flow events with rainfall and soil moisture conditions. Journal of Geophysical Research: Earth Surface, 116, F04019.

Khan, M. A., Haneef, M., Khan, A. S., & Tahirkheli, T. (2012). Debris-flow hazards on tributary-junction fans, Chitral, Hindu Kush Ranges, northern Pakistan. Journal of Asian Earth Sciences, 62, 720–733.

Marin, R. J., Garcia, E. F., & Aristizabal, E. (2020). Effect of basin morphometric parameters on physically based rainfall thresholds for shallow landslides. Engineering Geology, 278, 105855.

Monsieurs, E., Dewitte, O., Depicker, A., & Demoulin, A. (2019). Towards a transferable antecedent rainfall-susceptibility threshold approach for landsliding. Water, 11(10), 2202.

Peres, D. J., & Cancelliere, A. (2014). Derivation and evaluation of landslide-triggering thresholds by a Monte Carlo approach. Hydrology and Earth System Sciences, 18(12), 4913–4931.

Prenner, D., Kaitna, R., Mostbauer, K., & Hrachowitz, M. (2018). The value of using multiple hydrometeorological variables to predict temporal debris flow susceptibility in an alpine environment. Water Resources Research, 54(9), 6822–6843.

Segoni, S., Piciullo, L., & Gariano, S. L. (2018). A review of the recent literature on rainfall thresholds for landslide occurrence. Landslides, 15(8), 1483–1501.

Thouret, J. C., Antoine, S., Magill, C., & Ollier, C. (2020). Lahars and debris flows: Characteristics and impacts. Earth-Science Reviews, 201, 103003.