DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

Proceedings
of the 5th International Conference

Tbilisi, Georgia, 1-5 October 2018

Editors
S.S. Chernomorets, G.V. Gavardashvili

Publishing House “Universal”
Tbilisi   2018

СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

Труды
5-й Международной конференции

Тбилиси, Грузия, 1-5 октября 2018 г.

Ответственные редакторы
С.С. Черноморец, Г.В. Гавардашвили

Издательство Универсал
Тбилиси 2018

ღვარცოფები: კატასტროფები, რისკი, პროგნოზი, დაცვა

მე–5 საერთაშორისო კონფერენციის
მასალები

თბილისი, საქართველო, 1–5 ოქტომბერი, 2018

რედაქტორები
ს.ს. ჩერნომორეც, გ.ვ. გავარდაშვილი

გამომცემლობა "უნივერსალი"
თბილისი 2018

УДК 551.311.8
ББК 26.823

Селевые потоки: катастрофы, риск, прогноз, защита. Труды 5-й Международной конференции. Тбилиси, Грузия, 1-5 октября 2018 г. – Отв. ред. С.С. Черноморец, Г.В. Гавардашвили. – Тбилиси: Универсал, 2018, 671 с.

Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 5th International Conference. Tbilisi, Georgia, 1-5 October 2018. – Ed. by S.S. Chernomorets, G.V. Gavardashvili. – Tbilisi: Publishing House “Universal”, 2018, 671 p.

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Ответственные редакторы С.С. Черноморец, Г.В. Гавардашвили
Edited by S.S. Chernomorets, G.V. Gavardashvili

Верстка: С.С. Черноморец, К.С. Висхаджиева, Е.А. Савернюк
Page-proofs: S.S. Chernomorets, K.S. Viskhadzhieva, E.A. Savernyuk

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).

ISBN 978-9941-26-283-8

Climate change and flash floods in Himalayan region

R.K. Isaac[1], S. Shakti[2], M. Hardeep[2], M. Isaac[3]

[1]Vaugh Institute of Agriculture Technology, Sam Higginbottom University of Agriculture Technology and Sciences, Allahabad, U.P. India, Isaac_rk@hotmail.com

[2]SIET Sam Higginbottom University of Agriculture Technology and Sciences, Allahabad, U.P. India

[3]Center of Biotechnology, Ewing Christian College, University of Allahabad, U.P. India

Flash floods are being commonly observed in many parts of world. Uttarakhand state of India is highly vulnerable to climate mediated risks. The study analyses the last 35 years climatological changes and historical flash flood events in the Uttarakhand state of India. Change in land forms and loss of soil has been assessed for the years of major flash flood events by using Remote sensing images. Study shows that the large amount of soil displacement from higher slopes due to flash flood impacts. Sudden rise and rapid fall of water levels, as well as the high flow velocities combined with large sediment, transports large amount of debris at the lower reaches causing heavy amount of soil losses. Excess rainfall events are the major cause of receding glaciers and upwardly moving snowline and depleting natural resources. Erratic rainfall events leading to flash floods, induces changes in water resources and causes landslides to glacial melt in the Himalayas. Increased flood events are affecting water resources and are increasing the chances of deteriorating water quality and quantity within the next few decades. Study shows that the debris flow control, flood control and flood risk management demands area specific special procedures for disaster mitigation and Management.

flash floods, climatological changes, debris flow, Himalayas

Изменения климата и селевые паводки в Гималайском регионе

Р.К. Айзек[1], С. Шакти[2], М. Хардип[2], М. Айзек[3]

[1]Институт сельскохозяйственных технологий имени Вауха, Университет сельскохозяйственных технологий и наук имени Сэма Хиггинботтома, Аллахабад, Индия, isaac_rk@hotmail.com

[2]Университет сельскохозяйственных технологий и наук имени Сэма Хиггинботтома, Аллахабад, Индия

[3]Центр биотехнологий, Эвинг Кристиан Колледж, Университет Аллахабада, Аллахабад, Индия, monisha.isaac@gmail.com

Селевые паводки наблюдаются во многих частях мира. Штат Уттаракханд, Индия очень уязвим для рисков, связанных с климатом. В исследовании анализируются последние климатические изменения и исторические события селевых паводков в штате Уттаракханд за 35 лет. Изменение морфологии рельефа и потери почвы были оценены за несколько лет крупных селевых событий, используя изображения дистанционного зондирования. Исследование показало, что большое количество обвалов и оползней из-за внезапного наводнения вызывает подъем и последующее быстрое падение уровня воды, а также высокие скорости течения. Большое количество рыхлого материала переносится селевыми паводками в нижнее течение, что приводит к значительному снижению качеств почвы. Экстремальные осадки являются основной причиной отступания ледников, быстрого смещения снеговой линии и истощения природных ресурсов. Неожиданные осадки, ведущие к внезапным наводнениям, вызывают изменения водных ресурсов и приводят к оползням и таянию ледников в Гималаях. Возрастающее количество наводнений влияет на водные ресурсы и усиливает ухудшение качества и количества воды в течение последующих нескольких десятилетий. Исследование показывает, что контроль селей и селевых паводков и управление рисками наводнений требуют особых специальных процедур для смягчения последствий бедствий и для управления.

селевые паводки, изменения климата, сель, Гималаи

Introduction

Flash floods are being commonly observed in many parts of world. Large-magnitude debris flows in alpine basins are widely documented in the scientific and technical literature. Past flash floods and debris flow events have often caused high numbers of casualties [*Alcoverro et al. 1999*], A flash flood is defined as a flood which follows shortly (i.e. within a few hours) after a heavy or excessive rainfall event [*Georgakakos, 1986; Sweeney, 1992; Borga et al., 2007*] and consequently, the important hydrologic processes are occurring on the same spatial and temporal scale as the intense precipitation. These kinds of events represent an important problem in Europe, especially in many Mediterranean catchments, as well as in many other temperate areas in the world, resulting from severe rain clouds, which can produce thunderstorms or [*Doswell III et al., 1996*] mainly of convective origin that occur locally, typical in these regions.

Flash floods causes serious damages and economic losses. [*Huet et al., 2003*], Importantly, flash floods and debris flow also pose a serious risk to people, as water depths and velocities can increase within a short time. Past flash floods and debris flow have often caused high numbers of casualties; over 80 people, for example, lost their lives in the 1996 Biescas flood in Spain [*Alcoverro et al., 1999*].

Hydrogeomorphologic processes are a key driver of sediment transfer in mountain watersheds [*Stoffel and Wilford, 2012*]. In many parts of the world, flash floods are the most destructive natural hazard often resulting in a large amount of damage and fatalities. Approximately 40% of the flood-related deaths in Europe between 1950 and 2006 were linked to flash floods [*Barredo, 2007*]. 2 people died in the flash flood and debris flow on Cable Canyon in San Bernardino County in California in 2003 [*Restrepo et al. 2009*] and 19000 people were killed in the Cordillera de la Costa, Vargas (Venezuela) flash flood and debris flow disaster in 1999 [*Larsen et al. 2002*].

Flash floods are caused by short duration, high intensity, localized rainfall events. They differ from most other fluvial floods in that the lead time for warnings is generally very limited (e.g. often much less than two hours). They usually occur on catchments draining less than 1,000 km² with response times of a few hours or less [*Borga et al., 2008; Gaume and Borga, 2008*].

Brief Review of Problem

Uttarakhand state of India is highly vulnerable to climate mediated risks. These events represent an important problem in Uttrakhand hilly areas, consequently having sudden increase in water depths and flow velocities, causing serious damages and economic losses and large amount of debris is collected at the lower ends. Most of the slopes are poorly vegetated and, consequently, rainfall that is normally absorbed by vegetation can run off almost instantly. All these characteristics make those catchments prone to flash flood formation, as demonstrated by events that occurred in the area flood prone areas. Putting together the available meteorological and hydrological data a better insight of temporal and spatial variability of the rain storm, the soil moisture conditions and flash flood can be obtained. Further, GIS tools can be a used to calculate debris in the lower catchments.

Methods and Data Analysis

Uttarakhand is one of the hilly states in the Indian Himalaya. It lies in the northern part of India between the latitudes 28°43′ N and 31°27′ N and longitudes 77°34′ E and 81°02′ E, Fig. 1. The elevation ranges from 210 to 7817 m. The state shares its border with China (Tibet) in the north, Nepal in the east, inter-state boundaries with Himachal Pradesh in the west and north-west and UP in the south. Precipitation is received mostly in the form of monsoon rainfall from June to September. However higher reaches experience snowfall in the months of December, January and February. The average rainfall of the region is between 1250mm and 2000mm and of this maximum is recorded in the elevation zone of 1000 to 2000 m. The average annual temperature of region ranges from 25° celsius in the south to sub-zero in the north.

Fig. 1. Map of Uttrakhand state, India

Forests covers 62.54 per cent of the total reported area of the state in Uttarakhand. A significant proportion of land (5.55%) is agricultural wasteland, which together with fallow lands can be brought under cultivation. The agricultural in the hill region has small and fragmented land holdings, small-sized terraced fields. The state has very low availability of irrigation, little use of modern technological inputs like power, fertilizer and high yielding varieties of seeds.

The study was conducted for Upalda and Pauri areas of Garwal Hills. The past study shows that Pauri has received three flash flood events in 2010. No major and minor flood event has been reported from 2011 to 2014. The climatic parameters of 35 years 1979 to 2014 was analysed. Runoff for the area was estimated by curve number method.

The remote sensing images of 2009 and 2014 of Upalda for resource satellite, LISS III of spatial resolution 23.5 m, was analyzed and classified. Rainfall, temperature and humidity data of Pauri, latitude 30° 08' 49.62" N and longitude 78° 46' 28.34" E, 1688 m Elevation was analysed and correlated with the debris collected Uphalda, latitude, 30° 12' 47.22" N and longitude,78° 45' 19.49" E, 587 m Elevation.

Results

The study analyses the last 35 years climatological changes and historical flash flood events in the Uttarakhand state of India. The climate of this relatively small state varies from tropical to alpine. This wide range of climatic conditions is present mainly due to altitudinal variation but degree and direction of slope, the vegetal cover and presence of water bodies also make substantial impact on rapid and unpredictable change in micro-climate and local weather.

Climate Change in Himalayan Region

The temperature and rainfall, the two most prominent climatic factors, show large spatial variation over the region as well as from valley bottom to hilltop within the same region. Fig 2 shows the total annual precipitation of Pauri for 35 years. A total increase of 06.7 % have been reported in 35 years. Figure shows that total rainfall in 2010 was exceptionally high. The study shows that configuration and altitudinal peculiarities of mountain ranges of the Himalaya are responsible for the variation of climate within the mountain province itself. Fig 3. Shows the analysis of daily maximum precipitation from 1979 to 2014 shows that there are three major years of events in last 35 years 1994, 2000 and 2010 in the Pauri area of Uttrakhand. Three major flood events of flash flood have been reported in 2010.

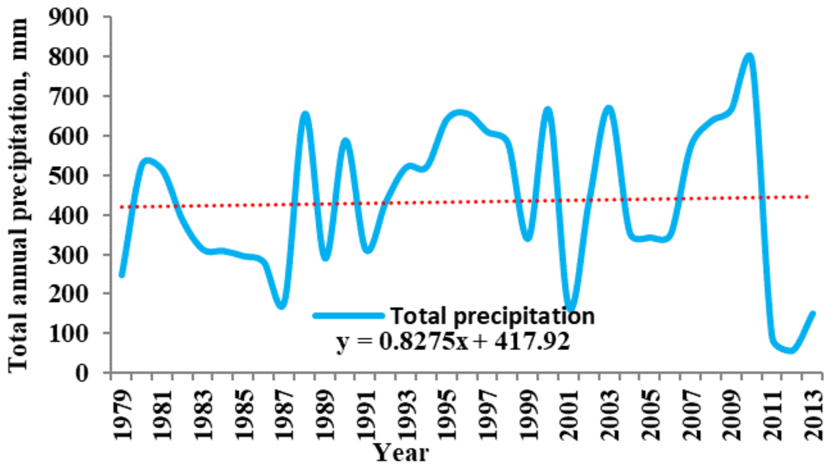

Fig. 2. Total annual precipitation at Pauri

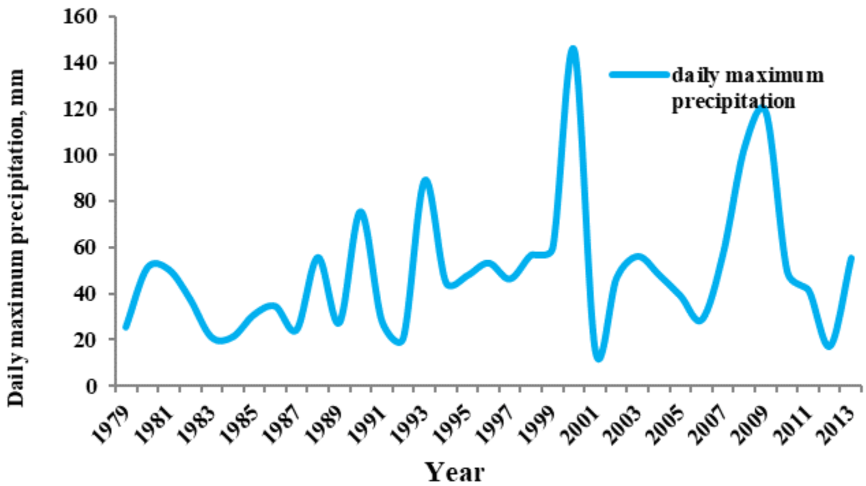

Fig. 3. Daily maximum precipitation at Pauri

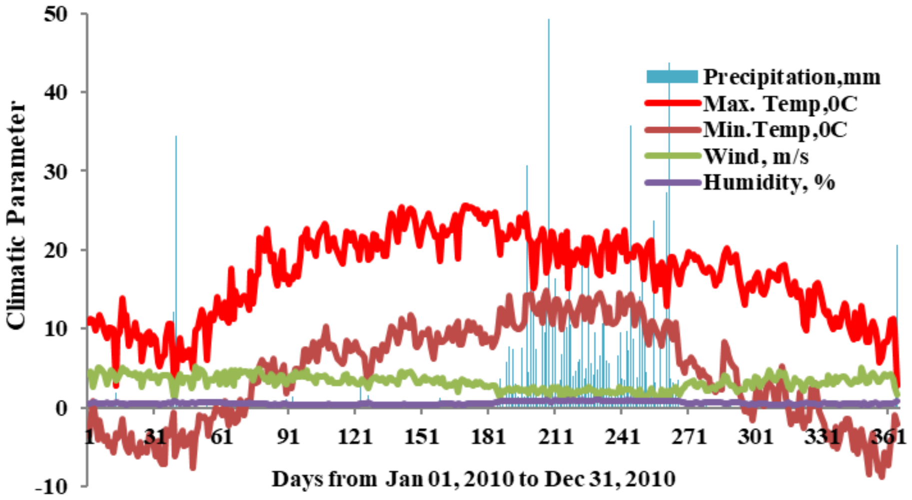

Fig. 4. Variation in climatic parameters of 2010

Flash floods and Antecedent Moisture Conditions

Fig. 4. shows the Variation in all climatic parameters in 2010. It is evident that maximum temperature for the duration have been reduced whereas the minimum temperature has been increased. Nearly 95% of rainfall has been occurred from July 01 to September 30, causing higher rate of soil saturation. Low wind velocity and high humidity were the normal features for that duration. Figure5. Shows that the continuous precipitation during three months duration in 2010 followed be higher 5 days antecedent moisture conditions for at least 5times and again with high rainfall events has caused the 3 major flash flood events in the area. The elevation difference of 1101 m has increased the flood velocity and very high rate of debris movement from the higher reaches was seen.

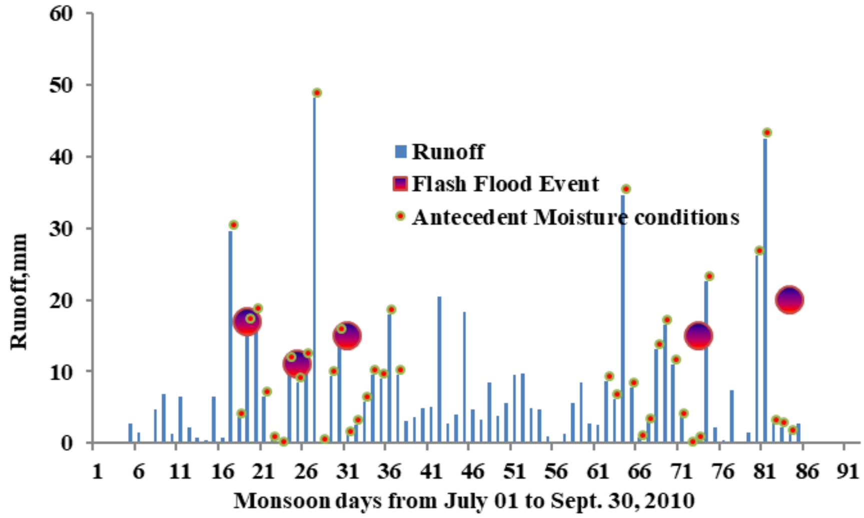

Fig. 5. Flash flood and runoff at varying antecedent moisture conditions

Debris collection and Change in Land forms

Change in land forms and loss of soil has been assessed for the years of major flash flood events by using Remote sensing images. Study shows that the large amount of soil displacement from higher slopes due to flash flood impacts. Sudden rise and rapid fall of water levels due to very high antecedent moisture conditions, as well as the high flow velocities combined with large sediment, transports large amount of debris at the lower reaches causing heavy amount of soil losses in the area. It is evident from the Fig. 6. and Fig. 7. that remarkable change has been taken place at the lower reach after the flash flood events of 2010. Table 1. Shows the change in land use at lower reaches. Study show that the 3 major flash flood events followed by high runoff throughout the season has efficiently contributed to soil loss. Sediment loss has been increased to 65% followed by increase in barren area to 402%.

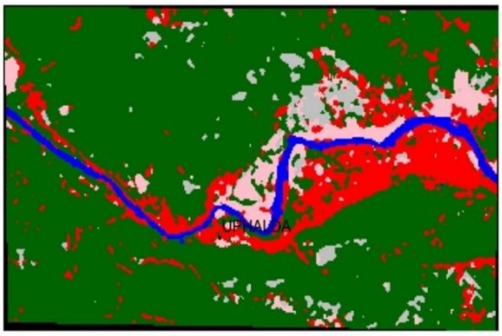

Fig. 6. Remote sensing Image of Uphalda 2009.

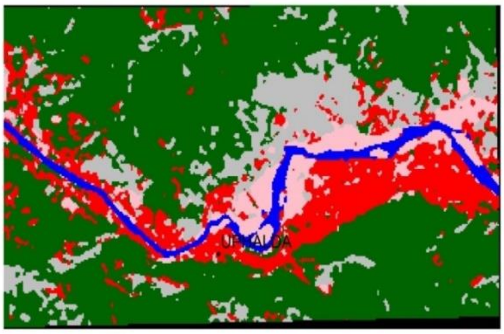

Fig. 7. Remote sensing Image of Uphalda 2014.

Table 1. Land Use classification for Uphalda, Uttrakhand.

	2009	**2014**	
class	**Area (m^2)**	**Area (m^2)**	**% increase**
River	45026	47370.5	05.207
Build-up area	207881	220900	06.2627
Forest	1123230	827505.5	-26.328
Sedimentation	85657.5	141564	65.2675
Barren land	55765.5	280220	402.4971
Total	1517560	1517560	0

Need for Ecological Sustainability

Experience with extreme floods during recent years has shown that structural measures alone cannot guarantee sufficient protection, however, and new approaches are needed Manfred *Spreafico* (2006). There is substantial increase in damage potential in the selected area as well as other hill areas. due to intense land use and increase in economic value, in channelized rivers runoff concentration time is affected, often causes higher flood peaks; a lack of space and retention areas to manage large-scale events; poor maintenance of structures and river beds and changes in runoff as a result of climate change and variations contributes more to potentials impact.

A sustainable flood protection policy has therefore been suggested for land-use planning, maintenance of the systems and to implement structural measures, Figure 6. It has been suggested that environmental concerns, flood protection and soil conservation measures, economic factors and participatory management must be included in the planning process for early benefits.

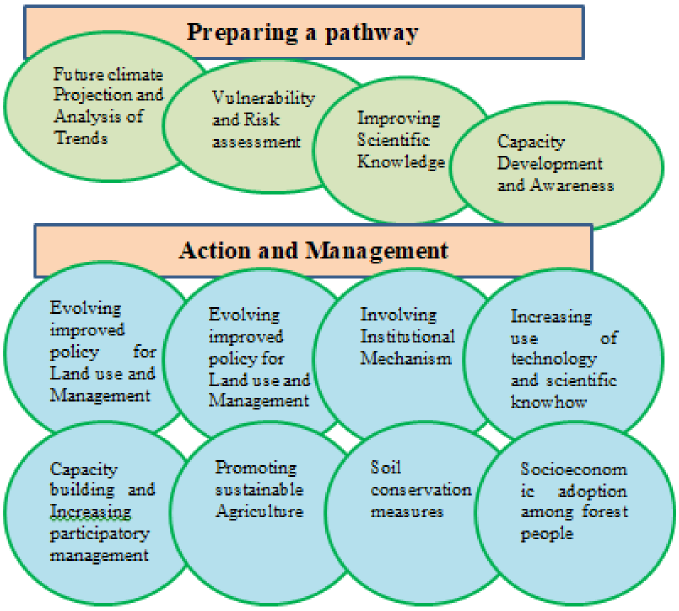

Fig. 6. Policy Action Plan for sustainable Development.

Conclusions

It was observed that excess rainfall events followed by high antecedent moisture conditions for more than 5 days are the major cause of flash floods in the area. Receding glaciers and upwardly moving snowline and depleting natural resources further contribute to the events. Erratic rainfall events leading to loosening of soil, induces changes in water resources, causes landslides and glacial melt in the Himalayas. Increased flood events are affecting water resources and are increasing the chances of deteriorating water quality and quantity within the next few decades. The debris flow control, flood control and flood risk management demand area specific special procedures for disaster mitigation and Management.

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