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.

ღვარცოფები: კატასტროფები, რისკი, პროგნოზი, დაცვა. მე–5 საერთაშორისო კონფერენციის მასალები. თბილისი, საქართველო, 1–5 ოქტომბერი, 2018. გამომცემლობა "უნივერსალი", თბილისი 2018, 671 გვ. პასუხისმგებელი რედაქტორები ს.ს. ჩერნომორეც, გ.ვ. გავარდაშვილი.

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

Change in water environment and aquatic ecology of Himalayan region

M. Isaac[1], A.K. Pathak[2], R.K. Isaac[3], U. Sharma[4]

[1]Center of Biotechnology, Ewing Christian College, University of Allahabad, Allahabad, India, monisha.isaac@gmail.com

[2]ICAR-National Bureau of Fish Genetic Research, Lucknow, India, pathakajey@rediffmail.com

[3]Vaugh Institute of Agriculture Technology, Sam Higginbottom University of Agriculture Technology and Sciences, Allahabad, India, isaac_rk@hotmail.com

[4]Babasaheb Bhimrao Ambedkar University, Lucknow, India, urvashisharma33@gmail.com

High rainfalls, climatological changes are the normal phenomenon at the Himalayan region. Freshwater ecosystems contain water and sediment subsystems which support several communities. The high runoff, debris flow and sediment deposition caused due to flash floods at lower reaches is a natural phenomenon. Suspended and deposited sediments impact the aquatic habitats directly through physical effects or indirectly through effects on water clarity or the habitat that rely on for feeding, cover, or reproduction. Elevated levels of suspended sediments can impact fish by physically damaging tissues and organs or by decreasing light penetration and visual clarity in the water, which can cause a range of effects from behavioral changes to mortality. Appearance and disappearance analysis of major water bodies after the major flash flood event of 2013 was conducted for Uttrakhand State of India. The analysis of remote sensing images shows the deposition and movements of large amount of debris to the water bodies at the lower reaches. It has been observed that high velocity of runoff caused during the event, changes the shape of water bodies impacting the habitats life cycle. The severity of the impact may depend on several factors, including sediment concentration, duration or frequency of exposure, particle size and shape, associated pollutants, species, and life stage at time of exposure. It is essential to take sufficient mitigation and protection measures for the fresh water bodies containing habitat in hilly regions for sustainable ecosystem.

aquatic ecology, sediment, debris flow, Himalayan region

Изменение водной среды и водной экологии в Гималайском регионе

М. Айзек[1], А.К. Патхак[2], Р.К. Айзек[3], У. Шарма[4]

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

[2]ICAR-Национальное бюро рыбно-генетических исследований, Лукнов, Индия, pathakajey@rediffmail.com

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

[4] Университет имени Бабасахеба Бхимрао Амбедкара, Лукнов, Индия, urvashisharma33@gmail.com

Высокие осадки и изменения климата являются нормальным явлением в Гималайском регионе. Пресноводные экосистемы содержат подсистемы воды и осадконакопления, которые поддерживают некоторые общины. Высокие расходы паводков, селевые потоки и отложение рыхлого материала, вызывают мощные наводнения в низовьях. Взвешенные и осажденные наносы воздействуют на водные среды обитания непосредственно через физические эффекты или косвенно через воздействие на прозрачность воды или среду обитания, в которой происходят питание и размножение рыб. Повышенные уровни взвешенных наносов могут воздействовать на рыбу физически, повреждая ткани и органы или уменьшая проникновение света и прозрачность воды, что может вызвать ряд эффектов от поведенческих изменений до гибели. Анализ состояния и исчезновения основных водных объектов после крупного прорывного паводка 2013 года был проведен для штата Уттракханд, Индия. Анализ изображений дистанционного зондирования показывает осаждение и перемещение большого количества обломков в водоемы в нижнем течении. Было зафиксировано, что высокая скорость потока во время события изменяет форму водоемов, влияющих на жизненный цикл среды обитания. Тяжесть нагрузки может зависеть от нескольких факторов, включая концентрацию наносов, продолжительность или частоту воздействия, размер и форму частиц, связанные с ними загрязнители, виды и фазу жизни организмов во время воздействия. Для устойчивости экосистемы крайне важно принять достаточные меры по смягчению и защите для пресноводных объектов, включающих среду обитания в холмистых районах.

водная экология, отложения, сель, Гималайский регион

Introduction

The aquatic habitats situated in mountains are some of the most sensitive indicators of environmental change [*Williamson et al., 2008*]. Their high elevation leads to increased exposure to ultraviolet radiation as well as a shortened growing season that aggravates plankton populations due to both temperature and light limitations [*Sommaruga, 2001*]. Plankton are considered indicators of the different trophic status of a water body, their study provides basic information about entire ecology of pond [Vollenweider, 1968] and they used for pollution surveillance [*Prescott, 1939; Lund, 1962; Brook, 1965*]. Apart from primary production, phytoplankton act as biological indicators of water quality in pollution studies while, zooplankton occupy a vital role in the trophic structure of an aquatic ecosystem and play a key role in the energy transfer. Freshwater ecosystems contain water and sediment subsystems which support several communities. Sediment with but seasonal fluctuations and catastrophic events markedly affect the physical, chemical and biological structure and integrity of aquatic habitats.

High rainfalls, climatological changes are the normal phenomenon at the Himalayan region. The high runoff, debris flow and, suspended and deposited sediment impacts the aquatic habitats directly through physical effects or indirectly through effects on water clarity or the habitat that rely on for feeding, cover, or reproduction. Elevated levels of suspended sediments can impact fish by physically damaging tissues and organs or by decreasing light penetration and visual clarity in the water, which can cause a range of effects from behavioral changes to mortality.

Many studies have been done on the fish species diversity [*Cowley, 2006; Cowley et al., 2007; Hoeinghaus et al., 2007; Haxton and Findlay, 2007; Light and Marchetti, 2007*]. The freshwater ecosystem of Himalaya is highly diverse, that is important for the variation of aquatic population. Various studies have been done on the ecology and fish faunal diversity of the hill stream fishes [*Kumar et al.,2006, Rautela et al.,2006, Sahu et al., 2006 Haxton and Findlay, 2008*].

Life in the aquatic environment is largely governed by physico-chemical characteristics and their stability. Limnological studies of water bodies also provide information about the trophic status which may help in management and conservation [*Marchetto et al., 1995*]. The ponds are infested with macrophytic vegetation. The ponds receive glacial melt water besides runoff from the surrounding areas. These ponds are subject to high anthropogenic pressure by both local and tourists.

Brief Review of Problem

Ponds are useful for monitoring long-term changes in freshwater ecosystems caused by a warming climate. It is easier to measure the species richness in ponds than in other freshwater ecosystems because they have clear boundaries, are relatively small in size and are sensitive to environmental changes, such as those caused by climate change. Climate changes has significant impact on high-mountain glacial environment. Rapid melting of snow/ice and heavy rainfall have considerable effects on fresh water ecosystems by adding un precedent amounts of sediment and debris causing danger to fish life. Appearance and disappearance analysis of major water bodies after the major flash flood event of 2013 was conducted for Uttrakhand State of India. The study considers the loss of biodiversity due to physical changes in high elevation Ponds due to disaster from heavy rainfall on 16 to 17 June 2013. It caused burst of moraine dammed Chorabari lake causing flooding of Saraswati and Mandakini Rivers in Rudraprayag district of Uttarakhand. The WIHG meteorological observatory at Chorabari Glacier camp (3820 m a.s.l.) recorded 210 mm rainfall in 12 hours between 15 June and 16 June 2013. The heavy rainfall together with melting of snow in the surrounding Chorabari Lake washed off both the banks of the Mandakini River causing massive devastation to the Kedarnath town.

Methods and Data Analysis

The study was conducted for the small ponds situated at Latitude 30°44'35.54"N 30°44'42.30"N, Longitude 79°29'39.19"E 79°29'43.25"E, and Altitude of 3,415 m and 3,422 m at Badrinath, Uttrakhand India. Fig. 1, 2 and 3 shows the location of project site and ponds. Both the selected ponds were situated at high altitude Himalayan region near Indo-Tibet boarder in Chamoli district of Uttarakhand. The place is popularly known as Badrinath (an important holly place of India). The Badrinath town is situated in the cold climatic condition of Garhwal hills, on the banks of the Alaknanda River at an elevation of 415 meters. The town lies between the Nar and Narayana mountain ranges and in the shadow of Nilkantha peak, most of the period it was covered by snow. The location and important features of both the ponds have been mentioned in Table 1.

Fig. 1. Location of Uttrakhand in India.

Fig. 2. Location of Ponds at Badrinath, GoogleEarth image (a) September 2011 and (b) March 2014

Table 1. Some important feature of the selected ponds at Badrinath

	Pond - 1	**Pond - 2**
Type	Natural	Natural
Latitude	30°44'35.54"N	30°44'42.30"N
Longitude	79°29'39.19"E	79°29'43.25"E
Altitude (m)	3,415	3,422
Maximum length (m)	144	92
Minimum width (m)	62	85
Maximum depth (m)	1	1.5
Average depth (m)	0.5	0.5
Source of water	Rain water, Ice melts	

Remote sensing Imagery was used and analyzed in Arc view. Land Sat 5, 30m resolution thematic map before flood event (May 2011) and Landsat 8 imagery after flood (May 2014) was chosen for change Analysis of Classified image was done using NDSI classification.

Daily rainfall and Minimum and Maximum Temperature data from Jan 01, 2013 to December 31, 2013 was used to for analysis. Worldwide literature was reviewed and cited to analyse the possible impact determines the overall role of anthropogenic pressure on select glacial fed ponds.

Results

Climatic Changes and Rainfall

Mean Annual Rainfall of Himalayan Region is 1175 mm. The Badrinath receives mean annual rainfall from 2000 mm to 2700 mm. In the year of disaster, the annual rainfall was 2681 mm. The most of the rainfall occurs in June to September. Fig. 3. shows the annual distribution of rainfall and Minimum and maximum temperatures. TRMM rainfall measured in eight days from June 10-17, 2018 was observed 391.4 mm. The high rainfall has led to heavy disaster at Badrinath due to bursting of The Chorabari Lake at 2 km upstream of Kedarnath.

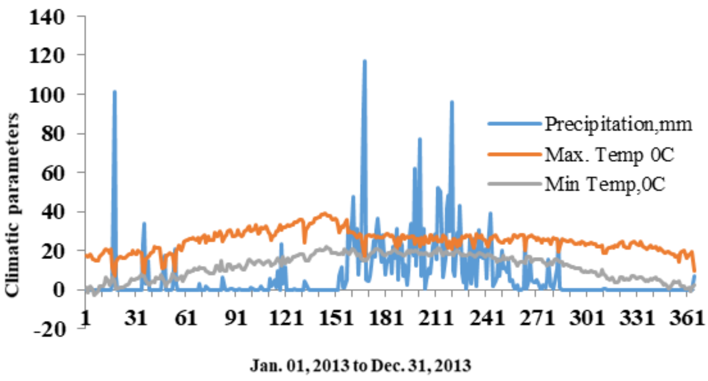

Fig. 3. Variation of climatic parameters in 2013

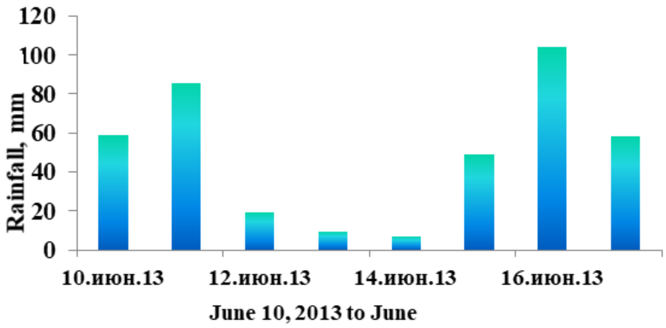

Fig. 4. TRMM Rinfall measured at Badrinath on June 16-17,13 leading to disaster. Source: [*Allen et al., 2015*].

Change in Ponds area

The present study focuses the change analysis study done for assessment of different land use pattern in and around two major freshwater lakes for Uttrakhand state of India before and after the devastating flash flood event of 2013 using the Landsat images of two different periods before and after flash flood event (May 2011 and May 2014).

The findings from 22.05-hectare area of study including the two freshwater lakes shows 6.3% area increase in deposition of debris, 20.8% area increase in vegetation, 39.2% area conversion in fragmented water patches (Table 2). Further, overall decrease in the lake area and change in shape was also observed. The analysis shows that due to large amount of debris flow in to the ponds the overall classified land shape has been changed. Since there has been sufficient time passed after the flood event the vegetation has been established on the are having large amount of debris. Since the estimated slope towards the pond 1 and Pond 2 was observed to 36% and 45%, the flow velocity at the time of heavy rainfall may have positively supported towards the movement of heavy debris. The remote sensing images shows the deposition and movements of large amount of debris to the water bodies at the lower reaches. It has been observed that high velocity of runoff caused during the event, changes the shape of water bodies impacting the habitats life cycle. The severity of the impact may depend on several factors, including sediment concentration, duration or frequency of exposure, particle size and shape, associated pollutants, species, and life stage at time of exposure.

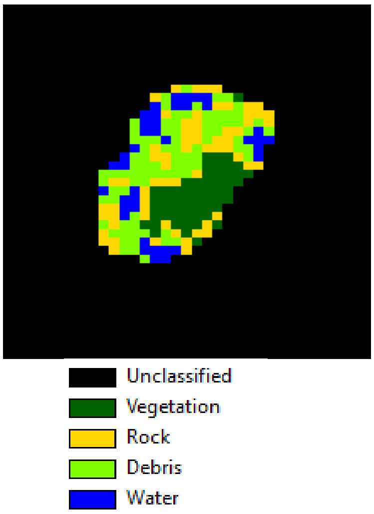

Fig. 5. Change analysis of Classified Image,

May 2011

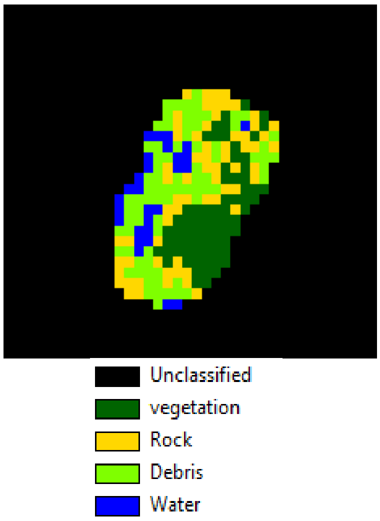

Fig. 6. Change analysis of Classified Image,

May 2014

Table 2. Classified changes in ponds area

Components	Percentage change after flood
Vegetation	20.833
Rockey area	1.515
Debris	6.329
Water Patches	-39.286

Debris and sediment Deposition and impact on water habitat

In the ecological studies the factors which affect the species richness are important. The growth and survival of fish fauna depends on the food availability in the water resource. Zooplankton and phytoplankton are the prime food stuffs for the fishes. Not only the food but the physico-chemical conditions of the water, also play a major role in survival of fish faunal diversity. Many ecologists mentioned that the richness and occurrence of fish faunal diversity of any aquatic ecosystem conflicts with the environmental factors surrounding it [*Jackson et al., 2001*]. Table 3. Shows the impact of suspended sediment on fish species. Elevated levels of suspended sediments can impact fish by physically damaging tissues and organs or by decreasing light penetration and visual clarity in the water, which can cause a range of effects from behavioural changes to mortality. The severity of the impact may depend on several factors, including sediment concentration, duration or frequency of exposure, particle size and shape, associated pollutants, species, and life stage at time of exposure [*Collins et al., 2011; Kemp et al. 2011*]. Most direct effects are caused by the scouring and abrasive action of suspended particles, which damages gill tissues or reduces respiration by clogging gills, leading to decreased resistance to infection or disease, reduced growth, or mortality [*Ryan, 1991; Wood & Armitage, 1997*]. Small, angular sediment particles can be more damaging to gills than larger or rounded ones (e.g. [*Lake & Hinch, 1999*]).

The physiological stress caused by exposure to elevated concentrations of suspended sediments over time can make fish more susceptible to infection, parasitism and disease (e.g. fin rot; *Herbert & Merkens 1961*]. Studies have shown consistent declines in growth rates [*Kumar et al., 2012*], has indicate the significant role of anthropogenic activity for growth of planktonic diversity and their distribution. species recorded during investigation were the classic indicators of a shift from oligotrophic (Low productivity) conditions to eutrophic (High productivity) conditions of both the ponds.

Severe gill damage, gill thickening, and clogging tend to occur at relatively high levels of suspended sediments (i.e. >500 mg/L), but this level can differ between species and life stages, with minimal to no damage reported for some species at very high concentrations (e.g. arctic grayling; [McLeay et al. 1987]). The effects of deposited sediments on fish have been shown to be mostly related to habitat degradation and loss – mainly through declines in the quantity and quality of spawning areas, and reduced food supply. High or continuous levels of sedimentation on streambeds can lead to alterations in fish presence and community structure, reduced reproductive success, and increased rates of mortality, particularly of eggs and larvae [*Wood & Armitage, 1997; Kemp et al., 2011*]. As sedimentation increases, fish may relocate temporarily causing short-term declines in population sizes or may lead to more permanent changes in community composition over time (e.g. [*Jowett & Boustead, 2001*]).

Conclusions

Climatic factors and environmental degradation have sizable impact on aquatic life. Observed ponds have shown sufficient decrease in size due to increased debris and vegetative area. Literature shows that suspended and deposited sediment either reduces growth or affects the survival of fish.

It is essential to take sufficient mitigation and protection measures for the fresh water bodies containing habitat in hilly regions for sustainable ecosystem.

There is limited information to set robust guideline values for acceptable sediment concentrations. Most of international guidelines indicated that effects on fish growth occur between 5 and 15 NTU. It is required to setup a standard guideline for deposited and suspended sediments which may be harmful for aquatic populations [*Haxton and Findlay, 2007*].

Table 3 Summary of the direct effects of suspended sediment (SS) on fish, reported in either turbidity or suspended sediment concentration. The SS measure (concentration or NTU – Nephelometric Turbidity Units) reflects the level at which significant effects were observed. Studies are ordered by increasing SS measure within effect type (e.g. gill damage, growth). (Source: [*Cavandagh et al., 2014*]

Taxon	**SS measure**	**Duration**	**Method**	**Effect**	**Country**	**Reference**
Gill damage						
Whitetail shiner	100–500 mg/L	21 d	Lab tank	Thickening of gill lamellae	USA	*Sutherland & Meyer* [2007]
Brown trout	810 mg/L	21 d	Lab tank	Gill thickening	England	*Herbert & Merkens* [1961]
Rainbow trout	4887 mg/L	64 d	Lab tank	Slight gill thickening	Canada	*Goldes et al.* [1988]
Redbreast tilapia	35000 mg/L	1–48 h	Lab tank	Severely clogged gills (juveniles)	South Africa	*Buermann et al.* [1997]
Coho salmon	40000 mg/L	4 d	Lab tank	Damage to gill filaments	Canada	*Lake & Hinch* [1999]
Redbreast tilapia	60000 mg/L	1–48 h	Lab tank	Severely clogged gills (adults)	South Africa	*Buermann et al.* [1997]
Various species	104000 mg/L	1 d	In-stream	Gill clogging	Bolivia	*Swinkel et al.* [2014]
Arctic grayling	250000 mg/L	4 d	Lab tank	No gill damage	Canada	*McLeay et al.* [1987]
Growth						

Taxon	SS measure	Duration	Method	Effect	Country	Reference
Brook trout	10–40 NTU	12 h	Artificial channel	Reduced growth rate	USA	*Sweka & Hartman* [2001a]
Long steelheads	25 NTU	14–21 d	Lab channel	Reduced growth	USA	*Sigler et al.* [1984]
Arctic grayling	100 mg/L		Lab tank	Reduced growth	Canada	*McLeay et al.* [1984]
Spotfin chub	500 mg/L	21 d	Lab tank	Reduced growth rate	USA	*Sutherland & Meyer* [2007]
Disease						
Steelhead	2500 mg/L	11 d	Lab tank	Increased susceptibility to pathogen	USA	*Redding et al.* [1987]
Survival						
Coho salmon	100 mg/L	4 d	Lab tank	Increased mortality	Canada	*Lake & Hinch* [1999]
Smelt	3000 mg/L	24 h	Lab tank	LC50	New Zealand	*Rowe et al.* [2009]
Redbreast tilapia	21 000– 24 000 mg/L	1–48 h	Lab tank	LC50 (juveniles)	South Africa	*Buermann et al.* [1997]
Redbreast tilapia	42 000– 48 000 mg/L	1–48 h	Lab tank	LC50 (adults)	South Africa	*Buermann et al.* [1997]
Banded kōkopu	43 000 mg/L	24 h	Lab tank	Survival not affected	New Zealand	*Rowe et al.* [2009]
Īnanga	43 000 mg/L	24 h	Lab tank	Survival not affected	New Zealand	*Rowe et al.* [2009]
Various species	104 000 mg/L	1d	In-stream	High % mortality	Bolivia	*Swinkel et al.* [2014]

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