EDUCATION FOR SUSTAINABLE DEVELOPMENT

WORKSHEETS ON CLIMATE CHANGE

The melting glaciers

Glacial lake outburst floods in Nepal and Switzerland

GERMANWATCH

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The spectacular worldwide shrinking of mountain glaciers that we have been observing since the middle of the 19th century is one of the surest signs of global climate change. Mountain glaciers are therefore seen as a kind of "global fever thermometer". And although the mean temperature increase of 0.85 °C between 1880 and 2012 may not seem all that much at first glance, its impact is enormous. Alone the Alpine glaciers have lost around a third of their surface area and half of their mass until the 1970s.

Of the estimated 130km^3 of ice reserves, another approximately 20% have been lost since the 1980s. In countries with mountainous regions, such developments are cause for worry, because when glaciers melt, the risk of glacier-related hazards increases. In the Alps and in the Himalayas, such hazards are due above all to glacial lake outburst floods (GLOFs), which can have very serious consequences. Such outbursts may take place when glacial lakes caused by melting glaciers form behind moraines and ice dams. These dams are comparatively unstable and may burst suddenly. When this happens, millions of cubic metres of water and large quantities of rubble may be released within only a few hours. This causes catastrophic flooding in the valleys with severe damage to human beings, property, forests, agriculture and infrastructure.

GLOFs are not a new phenomenon, however, with increasing temperatures and the worldwide glacier shrinking, the likelihood of them happening has risen in many mountainous regions. This phenomenon therefore clearly shows in dramatic terms the possible consequences of global climate change at local level. At the same time, it becomes apparent how different the situations of industrial and developing countries are concerning their ability to react to such occurrences, something that can be seen in the examples of Nepal and Switzerland. Both countries are increasingly being confronted with glacial hazards, but their options for dealing with these are very different.

Use in the classroom

Glacier shrinkage on our planet is a phenomenon that school pupils might have heard about in various media. They have perhaps even been confronted directly with the issue during a holiday in the Alps or other mountains. This teaching module not only looks into the problem of glacial melting, but also at the still largely unknown consequences of this development, such as glacial lake outburst floods. Using two case studies, the pupils examine more closely the impacts on and options for action open to an industrialised country (Switzerland) and a developing country (Nepal).

By way of an introduction to the topic, pictures of an Alpine glacier taken in different years are shown so that these can be compared **(M 1)**. The pupils will be able to see how the glacier tip has retreated and will be given the opportunity to develop an initial hypothesis. They will almost certainly refer to the anthropogenic greenhouse effect. And yet these (correct) assumptions must then be backed up by real proof.

With the help of the materials **M 2–M 6** and the Atlases, the pupils will develop a picture of the worldwide impacts of climate change on mountain glaciers and the significance of glaciers as an indicator or "fever thermometer" for the Earth.

After the pupils have worked out the basic meaning and dimensions of global glacier shrinkage, they will learn the phenomenon of glacial lake outburst floods.

As part of this exercise, the pupils work on the case studies Nepal and Switzerland in collaborative group work **(M 7–M 10)**.

What can and must be done? This is the question that the pupils should look at in the closing section. Using two text analyses, they should research into the options for action open to Switzerland and Nepal **(M 11 and M 12)**. Table **M 13** is to be used for a concluding comparison.

Thanks to its design, this teaching module can be used to repeat or practice text understanding and analysis.

Further reading:

Alean, J. and M. Hambrey: Glaciers Online - Photoglossary
http://www.swisseduc.ch/glaciers/index-en.html (Accessed 24.01.2014).

Bojanowski, A. (2013): Land O' Lakes: Melting Glaciers Transform Alpine Landscape. In: Spiegel Online.
http://www.spiegel.de/international/europe/melting-glaciers-turning-alps-into-lake-region-a-896729.html (Accessed 18.02.2014).

Goldenberg, S. (2011): Glacier lakes: Growing danger zones in the Himalayas. In: The Guardian.
http://www.theguardian.com/environment/2011/oct/10/glacier-lakes-melt-himalayas (Accessed 18.02.2014).

Horstmann, B. (2004): Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats due to Climate Change. Germanwatch, Bonn. http://germanwatch.org/en/2753 (Accessed 18.02.2014).

ICIMOD (2011): Glacial Lakes and Glacial Lake Outburst Floods in Nepal.
http://www.icimod.org/dvds/201104_GLOF/reports/final_report.pdf (Accessed 24.01.2014).

IPCC (2013): Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

UNEP (2011): Global Outlook for Ice and Snow. Chapter 6B.
http://www.unep.org/geo/geo_ice/PDF/GEO_C6_B_LowRes.pdf (Accessed 18.02.2014)

Germanwatch

Following the motto "Observing, Analysing, Acting", Germanwatch has been actively promoting global equity and the preservation of livelihoods since 1991. In doing so, we focus on the politics and economics of the North and their worldwide consequences. The situation of marginalised people in the South is the starting point of our work. Together with our members and supporters as well as with other actors in civil society, we intend to represent a strong lobby for sustainable development.

We attempt to approach our goals by advocating for the prevention of dangerous climate change, food security, and compliance of companies with human rights.

Germanwatch is funded by membership fees, donations, grants from the "Stiftung Zukunftsfähigkeit" (Foundation for Sustainability) as well as grants from various other public and private donors.

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Within the series of *Worksheets on Climate Change* the following publications are available in English:

- Global climate change – General issues
- The melting glaciers – Glacial lake outburst floods in Nepal and Switzerland
- Sea level rise – Consequences for coastal and lowland areas: Bangladesh and the Netherlands
- Going under! The threat of rising sea levels for the small island nation of Tuvalu
- The threat to tropical rainforests and international climate protection
- Climate change and food security – Trends and key challenges
- Extreme events and climate change – Insurances for developing countries

See: www.germanwatch.org/en/worksheets

All worksheets are also available in German.

GERMANWATCH

Observing. Analysing. Acting.
For Global Equity and the Preservation of Livelihoods.

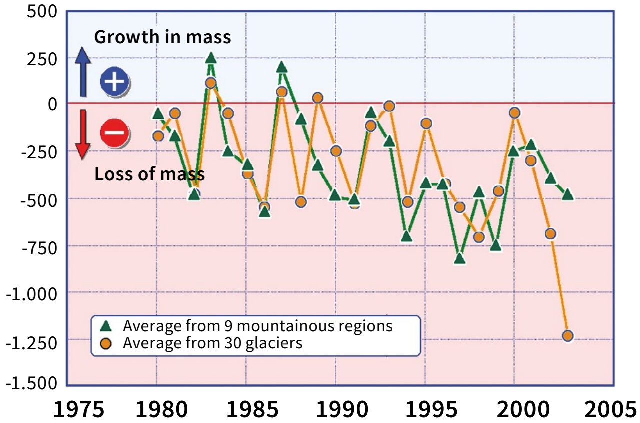
M 1 The Morteratsch glacier – a comparison over time

Frontal view of the Morteratsch glacier in Oberengadin, Switzerland. The first picture shows a hand-painted postcard, presumably from the year 1900. The second is a photo from the year 2012.

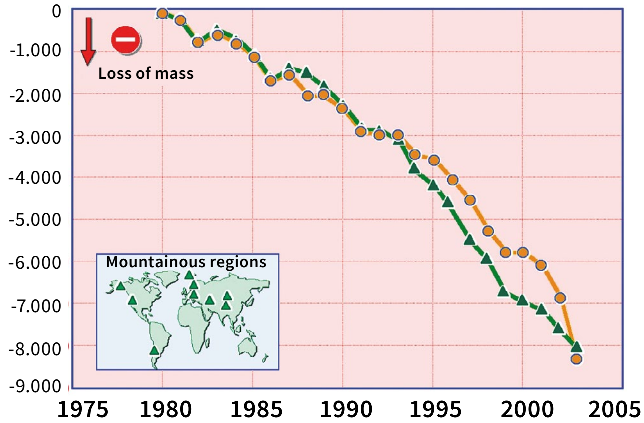
(Source: http://www.swisseduc.ch/glaciers/morteratsch/repeat_photos_1972_2012/morteratsch_chuenetta/index-en.html, accessed 24.01.2014)

M 2 Mass balance of glaciers and 9 mountainous regions on Earth (1975 – 2003)

Mean annual mass balance (mm)



Mean accumulated mass balance (mm)



(Source: Maisch, M. and W. Haeberli (2003): Die rezente Erwärmung der Atmosphäre - Folgen für die Schweizer Gletscher. In: Geographische Rundschau 55(2), p. 8, acc. to data from the WGMS, World Glacier Monitoring Service, Zürich; updated to 2003.)

M 3 Glacier melting

Since the end of the Second World War, mass balances of glaciers have been measured on a yearly basis worldwide. Alone in the period between 2003 and 2009, a loss of mass (not including the Antarctic and Greenland ice) of around 350 kg per square metre and year was identified. Recent measurements in Switzerland tie in with this trend.

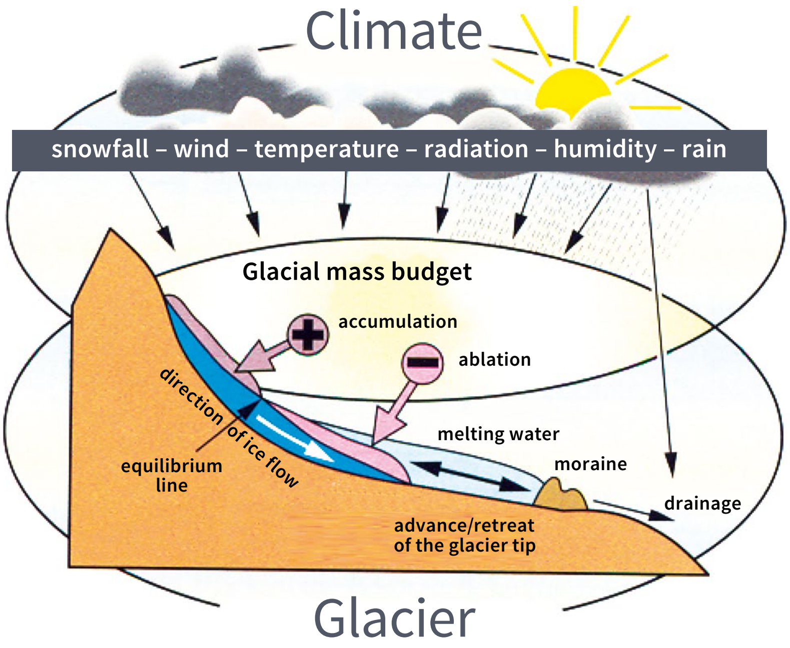
“The values ascertained for the 2010/2011 period show that the glaciers in Switzerland continue to retreat rapidly. “A total of 93 from 97 glaciers observed have lost in both length and mass. Three of them did not change their position and only one glacier – the Glacier du Mont Durand in Valais – moved forward 23 metres. Around three quarters of the measured values were between minus 1 and minus 30 metres” wrote ETH glaciologist Andreas Bauder [...]. The national retreat record was broken in the most recent measuring period by the Roseg Glacier. In only one year, it lost 1,305 metres in length. This means that the Grisons glacier has retreated from 6,711 to 2,567 metres since measurements began (1855). This is apparent from the newest data from the Swiss Academy of Sciences (Scnat) [...]. The report also states that the Alpine glaciers are currently losing around two to three percent of their surface area each year (in 2011 this was around 1,800 km^2) and their volume (in 2011 this was around 80 ± 20 km^3).”

(Sources: IPCC (2013): Climate Change 2013: The Physical Science Basis. Working Group 1 Contribution to the IPCC Fifth Assessment Report. Chapter 4 (draft); own translation of “Tagesanzeiger” 14.10.2012: Gletscherschmelze schreitet voran. http://www.tagesanzeiger.ch/wissen/natur/Gletscherschmelze-schreitet-voran/story/20714307, accessed 27.01.2014)

M 4 Increased melting of land ice

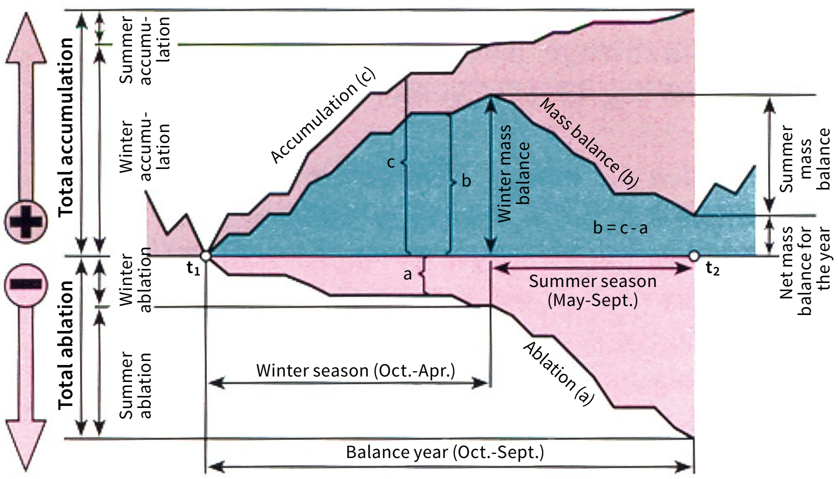
Ice, glaciers and snow are melting at an ever faster rate because of increasing average temperatures. Kilimanjaro in Tanzania, for example, has lost more than 85% of its glacial surface area to date; first measurements were taken in 1912. Snow cover on the planet as a whole has decreased by more than 10% since 1860. In Europe and Asia, snow cover on land has reached new record low levels every June since 2008 (ESA Envisat). The outcomes of this development are on the one hand a loss of drinking water reservoirs and, on the other hand, changes to the natural water supply. This often has more severe consequences in tropical and sub-tropical regions with sensitive ecosystems than in the north.

M 5 The glacial climate system



(Source: Falk, G.C. et al. (2002): Fundamente Kursthemen Physische Geographie. Gotha, p. 62.)

M 6 The glaciological year



(Source: Falk, G.C. et al. (2002): Fundamente Kursthemen Physische Geographie. Gotha. p. 63.)

EXERCISES

1. Interpret figure **M 2** with the help of **M 3.** Take into consideration the geographic zones named and use **M 4** and your atlas when reaching your conclusions.
2. Explain why the changes to the glacier equilibrium line can be used as an indicator for climate change **(M 5)**.
3. Use the figure showing the glaciological year to outline how increasing average temperatures impact a glacier **(M 6)**.

M 7 The Alps and climate change

"The hot summer of 2003 caused between 5 and 10 percent of the then existing ice mass to melt."

"Glaciologists forecast that at the most ten, but probably even five hot summers like the one from 2003 will lead the Alps to be largely free of ice. All that will remain are small residues on the largest valley glaciers, especially if they have thick moraine cover acting as an insulating layer."

"For many years now, protective films or fleeces have been spread over glaciers with a lot of tourist commerce in order to reduce the ablation. (…) Even if it seems to make sense to cover exposed parts, this is not technically feasible for larger surface areas."

Dangerous landslides and rockslides are happening more frequently due to climate change, both in glaciated and unglaciated regions, because the melting permafrost is often no longer able to hold the rocks in the fissures together. As such, in the year 2009, giant boulders plunged at great speed into the glacial lake of the Grindelwald glacier.:

(Source: Alean, J. (2010): Gletscher der Alpen, Haupt Verlag, Bern, p. 240, 249, abridged, supplemented.)

M 8 Glacial lake outbursts in Switzerland

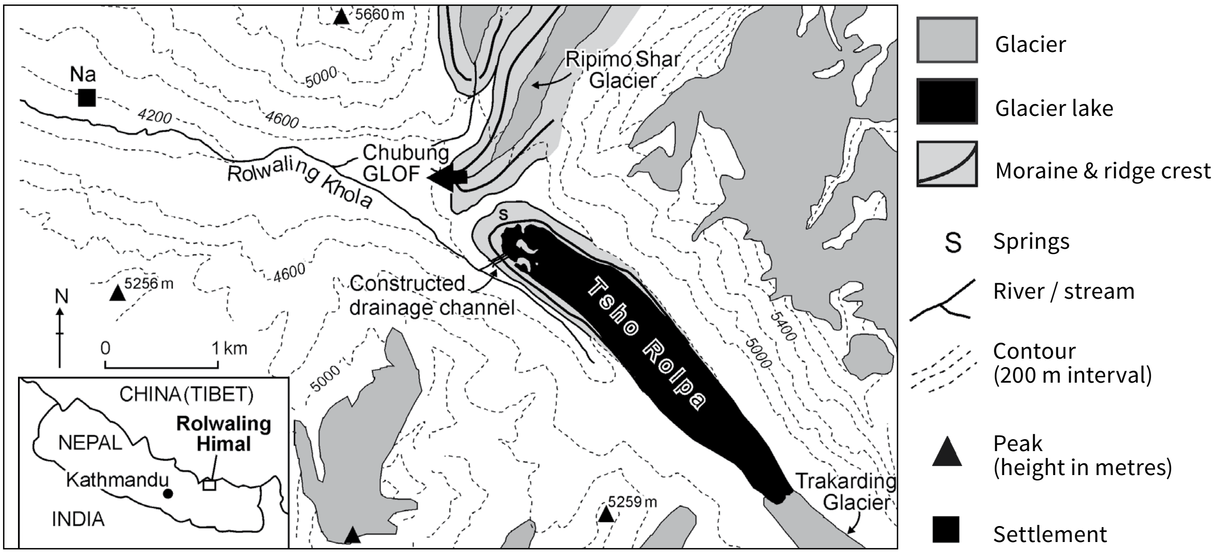
Since the end of the Little Ice Age (15th century till approximately 1850) more than 100 unusual (non-regular) glacier outburst floods have been observed in the Swiss Alps. Glacial lake outburst floods occur more frequently in the southern valleys of the canton of Valais, most often after the beginning of snow melting from June to August.

During the 20th century the minimum temperatures in Switzerland increased by 2 °C. The total rise in temperature in Switzerland has been around 1.7 °C since the beginning of industrialisation, and therefore distinctly higher than the global average (0.85 °C). Several new lakes have emerged as a result of glacial retreat and the thawing of permafrost. The number of glacial lakes will still increase and, according to estimates, a total number of 600 lakes will exist by 2100. One of the already existing lakes drained catastrophically in the summer of 1968, causing heavy damage in the village of Saas Balen. The outburst eroded about 400,000 m^3 of debris which is equivalent to about 1,000 detached family houses. Another similar event took place only two years later in summer 1970 when the same lake burst a second time. (...)

The outburst floods at Grubengletscher pinpoint one of the main problems Switzerland faces regarding the ongoing thawing of glaciers and permafrost. While the glacial lakes in Switzerland are relatively small, infrastructural facilities and residential settlements are close to the hazard zones. The hazard potential of existing and newly formed lakes and glacial risks in general can change rapidly, especially as in some areas of the Alps infrastructure and settlements have only been developed recently. Consequently even small glacial lake outburst floods can cause considerable damage. In one of the most populated mountain regions worldwide, this also has to do with the fact that infrastructure and settlements are spreading increasingly higher into Alpine regions. "The risks are exceeding what we have experienced before. Old chronicles and records suddenly turn out to be invalid and new threats can suddenly emerge at places that used to be safe. As a consequence, new local hazard maps have to be drawn and constant monitoring has to be carried out as the changes are happening so fast" Swiss glaciologist Wilfried Haeberli says.

(Source: Horstmann, B. (2004): Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats due to Climate Change. Germanwatch, Bonn, p. 6–8, altered.)

M 9 Survey map of Tsho Rolpa glacial lake



(Source: Horstmann, B. (2004): Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats due to Climate Change. Germanwatch, Bonn, p.4.)

M 10 Tsho Rolpa glacial lake in Nepal

In Nepal, already more than 24 glacial lake outburst floods have been documented out of a multiplicity of glacial lakes. The outburst at Dig-Tsho glacial lake on 4th August 1985 in particular sticks to mind; it caused the death of five people. The area of glacial lakes in the Himalaya enlarges annually by 25–35 ha.

Scientists from the United Nations Environment Programme (UNEP) and the International Centre for Integrated Mountain Development (ICIMOD) identified 1,466 (status 2012) glacial lakes in Nepal, of which they estimated around 21 to be potentially dangerous.

Among the identified critical lakes is Tsho Rolpa Lake. Tsho Rolpa is the lake of superlatives: in the Nepal Himalayas it is the largest moraine-dammed proglacial lake, the most studied and known as the most dangerous of its kind. Situated at an elevation of 4,580 metres above sea level, it is fed by the Tradkarding glacier, which is retreating at a rate of over 20 metres a year, and in some years within the last decade even 100 metres a year. This development poses a high risk to the people downstream as the amount of water released would be around 30 million cubic metres. “A flood from this lake could cause serious damage the village of Tribeni, which is 108 km downstream, threatening about 10,000 lives, thousands of cattle, agricultural land, bridges and other infrastructure,” said Pradeep Mool, remote sensing expert with the International Centre for Integrated Mountain Development (ICIMOD). Like the Dig Tsho outbreak in 1985, it also threatens a big hydroelectric project, the Khimti Hydropower – a 60 MW complex located about 80 km below Tsho Rolpa Lake. Its destruction could result in rebuilding costs of about US$ 22 million, plus the losses in electricity production.

But even small glacial lake outburst floods can be dangerous. Especially when they are above valley channels with steep slopes. Furthermore, some settlements are close to the glacial area and even above 4,000 metres touristic development takes place nearby glacial lakes.

(Source: Horstmann, B. (2004): Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats due to Climate Change. Germanwatch, Bonn, p. 6-8, altered.)

EXERCISE

4. Glacial lake outburst floods occur throughout the world. Collaborate to compare the example cases Switzerland and Nepal **(M 7 and M 8–M 10)**. Pay special attention to potential hazards and the extent of the glacial lake outburst flood.

M 11 How did people react in Switzerland?

In reaction to these catastrophic events, flood prevention was introduced in Switzerland. The measures proved to be successful during a period of glacier growth in the 1970s and early 1980s. New problems, however, developed when glacier thinning started to accelerate again.

Preventive measures had to be applied anew to avoid the development of dangerous situations. A hazard mitigation scheme was developed with the authorities, the Community of Saas Balen, the Canton of Valais and the Swiss Confederation. “Finally, we had to drain one of the lakes completely as it became increasingly dangerous”, remembers Andreas Kääb, specialist in the observation of glacial hazards and chair of the International Working Group on Glacier and Permafrost Hazards in Mountains. “The lake was a real beauty. Its disappearance left our research team with mixed feelings of relief and regret”. At the moment, there is no immediate risk from the remaining lakes for the communities situated downstream. The levels of the lakes were lowered by channels, ditches and even gates that can be regulated. A continued or even accelerated warming, however, could thin the tongue of the Gruben glacier beyond available experience or could even cause its complete disappearance. As a consequence, large volumes of water could collect again. “Such a potentially hazardous development would be without historical precedent but could be identified at an early stage with the help of an adequate observation system,” says Haeberli. For instance, at this stage the glacial lake at the Triftgletscher is controlled by cameras, sending their images day and night to a monitoring station in Zurich. Since 2010, the maximum height of the Grindelwald glacier can be regulated because a two kilometre long sloping tunnel was installed to drain the excess water.

“All in all, the damaging events at the Gruben glacier incurred costs of around 20 million Swiss francs. However, the costs for monitoring, field investigations, etc. would be less than 10% of the damage sum.” To forecast when and how a GLOF event will take place is difficult and needs detailed and multi-disciplinary investigations of the total environment of the lakes and associated factors in the surroundings as a whole. The Swiss living in one of the world’s most intensively studied mountainous region have sufficient organisational and financial options available for potential further measures.

(Source: Horstmann, B. (2004): Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats due to Climate Change. Germanwatch, Bonn, p.7f., altered, supplemented.)

M 12 How did people react in Nepal?

An early warning system was already installed at Tsho Rolpa Lake in 1998 in order to warn the population when critical levels are reached. However, this warning system no longer works because of a failure to carry out maintenance work and because of the theft of important technical components. And even when it was working, most people did not pay any attention to warnings, as there were a great number of false alarms. The installation and maintenance of modern satellite and radio-supported early warning systems would be highly expensive. The World Bank already provided US$ 1 million to install the now defective system. The government of the Netherlands has also co-financed projects in Nepal, for example, to create an open canal that led Tsho Rolpa Lake to sink by 3 m which, however, is not nearly enough according to estimates.

The lack of links to the infrastructure and the difficult geological profile pose a considerable problem for glaciological studies. What is more, from 1815 to 1945, Nepal was subject to an entry ban for travellers from outside, which restricted research expeditions by foreign experts for a long time. The result is that there are several gaps in the measurement data for Nepal. And the glaciers in the mountainous regions of Southern Asia are also very underrepresented in global statistics.

Progress in mapping the dangers has happened, however, as modern remote studies from outside using satellites can also be carried out for Nepal. Hazard maps initiated by the government are limited almost completely to Kathmandu Valley, which is economically important and densely populated. In addition, hardly any data exists for glacial lakes that are particularly dangerous because they are concealed or not visible to the eye.

Local organisations have introduced several measures in close cooperation with NGOs in order to reduce the dangers. However, technical equipment at the moraine dam cannot completely rule out the risk of a glacial lake outburst flood, but only reduce it. The population also does not consider the technical measures to be sufficiently effective. Furthermore, people are of the opinion that the valuable resources could be better used elsewhere. Another factor is that construction workers are exposed to great risks when building facilities.

There are some state regulations designed to reduce the dangers, among which only the National Adaptation Programme of Action from 2010 and the climate change Policy from 2011 refer specifically to glacial lake outburst floods. These regulations state, for example, that potentially dangerous lakes should be identified, preparations made in downstream settlements and the particularly vulnerable settlements should be given support.

In the 1990s, the government converted some individual bridges, changed some road routes, straightened some steep river sections and built dams in order to protect roads and settlements. As the aforementioned measures were the only ones carried out over a long period of time, standards have been laid down concerning aid payments and compensation funds for survivors of catastrophes; these are however very low. The reasons for the limited success of government measures are a lack of funds, not enough know-how about technical equipment, bad management and legal provisions. What is more, corruption and nepotism also make many measures more difficult to implement.

Despite the number of national regulations, the rescue operations and aid work following catastrophes is generally restricted to only temporary measures that are insufficient. As such, the population often has to rely on help from neighbouring communities or on self-help. In addition, poorer groups are often forced to settle in dangerous living environments because of rapid population growth. This means that, in most cases, the only thing that can be done is to rebuild houses that are at risk elsewhere and repurpose former residential areas.

(Sources: Horstmann, B. (2004): Glacial Lake Outburst Floods in Nepal and Switzerland. New Threats due to Climate Change. Germanwatch, Bonn, p.4f., altered; ICIMOD (2011): Glacial Lakes and Glacial Lake Outburst Floods in Nepal. http://www.icimod.org/dvds/201104_GLOF/reports/final_report.pdf, accessed 24.01.2014; Iturrizaga, L. (2012): Gletscherseen und ihr regionales Gefahrenpotenzial in der Himalaya-Region. In: Geographische Rundschau 2012(4), p. 18-25; Titz, A. (2011): Naturgefahren und Naturgefahrenmanagement in Nepal. In: Geographische Rundschau 2011(1), p. 58-60.)

M 13 Nepal and Switzerland in comparison

	Nepal	Switzerland
CO_2 emissions per capita (2011)[1]	0.1 tonnes	5.1 tonnes
Gross National Product (US$) (2011)[2]	19.1 billion	657.4 billion
Official development aid (ODA) (US$) (2011)	Received: 892.3 billion[3]	Donated: 3.1 billion[4]
Population (2011)[1]	30.5 billion	7.9 billion
Surface area	147,200 km^2	41,290 km^2

(Sources:
1 International Energy Agency (2013): CO_2 Emissions from Fuel Combustion. http://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2013.pdf, accessed 24.01.2014;
2 World Bank: http://data.worldbank.org/indicator/NY.GDP.MKTP.CD, accessed 24.01.2014;
3 World Bank: http://data.worldbank.org/indicator/DT.ODA.ALLD.CD accessed 24.01.2014;
4 OECD: http://www.oecd.org/dac/aidstatistics/50060310.pdf, accessed 24.01.2014.)

EXERCISES

5. Collaborate to find out what measures have been met in Nepal and in Switzerland to reduce the dangers posed by glacial lake outbursts **(M 11 and M 12)**.

6. Use **M 13** to make a concluding comparison of the two countries.

7. The glaciers act as water reservoirs that supply many of the Earth's large rivers. When glaciers retreat, stronger fluctuations in river levels are to be expected locally. Taking this into consideration, think about what economic impacts might be expected in the Rhine region from the melting of the Alpine glaciers. Where appropriate, use a different example of an important river and its associated area.