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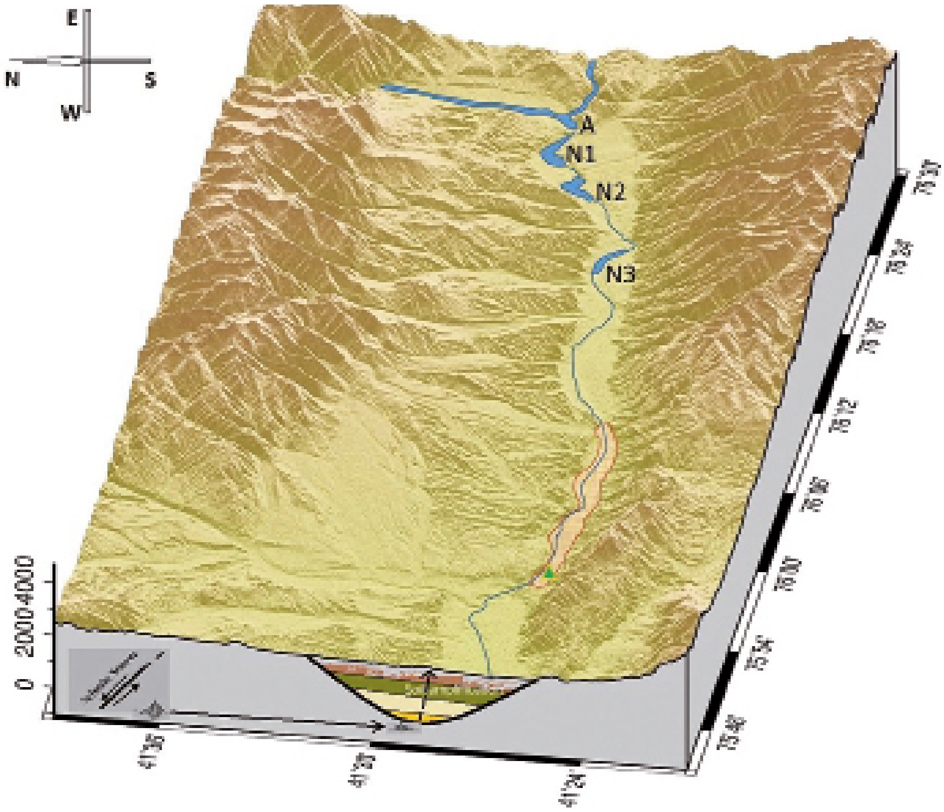

Figure 1: Calculated 3D topography map (1-arcsec) for the Naryn region, with filled reservoirs. Red line indicates territory of Naryn town, a green triangle indicates UCA campus. A indicates Ak-Bulun hydro-power station (HPS), N1indicates Naryn HPS-1, N2 indicates Naryn HPS-2, and N3 indicates Naryn HPS3.

Assessing Earthquake Hazard Near Dams in Kyrgyzstan's Upper Naryn Region

Accurately assessing earthquake hazards from large earthquakes in Kyrgyzstan is difficult.

However the task is urgent because of the planned construction of a cascade of dams in the Upper-Naryn region (**Figure 1**).

Information about seismic hazards is needed to inform the design of these dams and ensure that they can withstand earthquakes of certain magnitudes, preventing the potentially disastrous results of dam failure. Recent seismic activity in the Naryn region has been moderate, but data show that stronger earthquakes have occurred there in the past, and are possible again in the future. Therefore, an accurate assessment of earthquake hazard is needed. New methods that do not rely on instrumental data have made the study of ancient earthquakes possible, and are useful in creating a more comprehensive map of earthquake hazard which other instrumental method cannot fully provide. New research has revealed that although the maximum possible intensity of seismic activity in the Upper-Naryn area is higher than previously thought, it does not exceed the maximum seismic intensity that the planned dams are capable of withstanding.

Key Messages

- New research shows that maximum possible seismic intensity in the Upper-Naryn area is 8.9 on the MSK-64 scale, a value higher than previously thought. Planned dams have been designed to withstand earthquakes of intensity 9.0. This means that no safety margin exists, and that the quality of dam construction is critical for safety during an earthquake of high magnitude.
- New methods of assessing earthquake hazard, using local data and inexpensive methods, are effective and can be recommended for use in earthquake-prone areas where the level of potential seismic activity is unclear, and where local instrumental data do not exist.
- A multiplicative effect could occur during earthquakes if the cascade of closely located dams is exposed to strong seismic impact. The possible consequences of such an effect should be examined carefully.

New methods can provide important information about earthquake and seismic hazard.

It is impossible to predict earthquakes. However, historical data can provide important information and can indicate what earthquake magnitudes are likely, and approximately when they could occur. Earthquake hazard is measured using a number of techniques. Most commonly, instrumental data is used to record seismic activity. For this, sometimes even long-term data sets (hundreds of years) are inadequate to assess earthquake hazards. Nonetheless, understanding earthquake hazard is vital for infrastructure planning. In regions such as Central Asia where instrumental data sets are incomplete or absent, other methods will be more useful and appropriate in assessing earthquake hazard.

Assessing seismic hazard (the local effects of earthquakes) is simpler than assessing overall earthquake hazard. New methods are available for examining seismic hazard in the Naryn region in Kyrgyzstan, and should be presented, verified, and applied (see Case Study).

Accurate maps of earthquake hazard are important for infrastructure planning in the Naryn region.

Large dam projects are planned for earthquake-prone areas in the Upper-Naryn region in Kyrgyzstan. Risk of a potential dam breach entails flood risk for the city of Naryn. Therefore, possible seismic risk should be carefully considered and should inform dam construction. However, the magnitude of possible earthquakes in the region is very unclear, creating problems for planning. The results of seismic monitoring in the Naryn region suggests a moderate level of seismic activity (maximum earthquake magnitude of 5.4), whereas new results from other data (Peak Ground velocity data, see Case Study) show that earthquakes of much higher magnitude have occurred there in the past (e.g. seismic intensity of 9), and could therefore occur again in the future. Although the proposed dams have been designed to withstand earthquake intensities of 9, this means that no safety margin exists, and that the safety of the dam during earthquakes will rely heavily on the quality of the dam construction.

Potential earthquake magnitude should be carefully assessed in areas where the level of seismic danger is unclear and consequences of dam breaches include the danger of flooding in areas of high population density. It is important that state and local administration, investors and the general public have access to accurate risk maps so they can adequately plan and mitigate risk.

Planning should consider multiplicative effects in the event of an earthquake.

The most devastating dam breaches often result from the multiplicative effect of interacting factors. These are typical of complex natural and man-made systems.

The proposed Upper-Naryn dam cascade is an example of a complex natural and man-made system, and the multiplicative effect in case of a disaster, such as an earthquake, appears to be quite possible. Because of this, in the case of a flood wave generated from a potential earthquake impact, the side effects in areas where the dam is located, the potential of reservoir overflow, and change of inflow from the main river tributaries should be examined carefully. Furthermore, an estimation of possible human and economic loss is necessary for state administration and investors to plan appropriately for mitigating risk.

Case Study: Seismic Hazard in the Naryn Region

CAARF fellow Sagynbek Orunbaev investigated seismic hazard in the Naryn region in Kyrgyzstan, using a new method to improve understanding of seismic activity in the area (**Figure 2**). To do this, local rock dislocations and shifts were studied. Rock dislocations occur due to strong seismic impacts. The cases under review included displacements that occurred after strong earthquakes in the 20th century and paleoseismic dislocations that were observed in the crustal rocks in the Upper-Naryn (Naryn region) area along active faults. The aim of the study was to determine parameters of the paleoseismic events in terms of seismic intensity (I), which is essentially equal to Peak Ground Velocity (PGV). Two independent methods were used: (1) estimation of site effects for assessing ground soil, estimated at a depth of 30 metres from the surface (described as Vs30), with reference to instrumental measurements and to the current DEM model of this territory; and (2) assessment of physical characteristics of disturbances of particular types and habitus and fixed values of displacements of rock blocks. Numerous local disturbances with significant rock shifts were systematically reviewed and used as a set of standard models. Using this data, the values of mass velocities of seismic impacts (PGV), which caused the rock dislocations, were calculated. In many cases, PGV values were around 0.5 - 0.9 m/s, corresponding to a seismic intensity of 9. This is considerably higher (I=0.5-1.0) than values conventionally accepted (I=8).

In order to prepare for high intensity earthquakes, it is necessary to understand the site characteristics of large areas across administrative districts and at the location of hydropower dams. The use of Peak Ground Velocity Estimation (PGVEM) results coupled with results from site-effect examination provides a robust seismic assessment for the area. In addition, the average shear-wave velocity from the surface to a certain depth is correlated with the PGVEM of strong motion. The study also highlighted the need for a research focus on seismic risk analysis, including vulnerability of existing infrastructure and flood risk.

Figure 2: CAARF fellow Sagynbek Orunbaev during fieldwork in the Naryn region. He is standing in an area where there has been an active seismic fault. **Photo: Mikhail Rodkin**

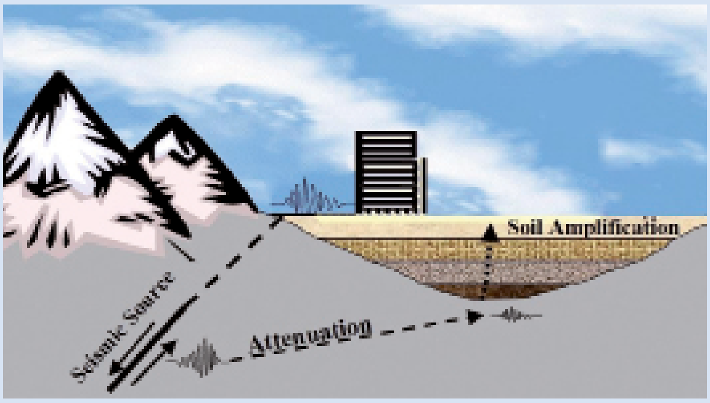

Figure 3: Hazard analysis is based on seismic source modelling, wave attenuation, and local ground amplification.

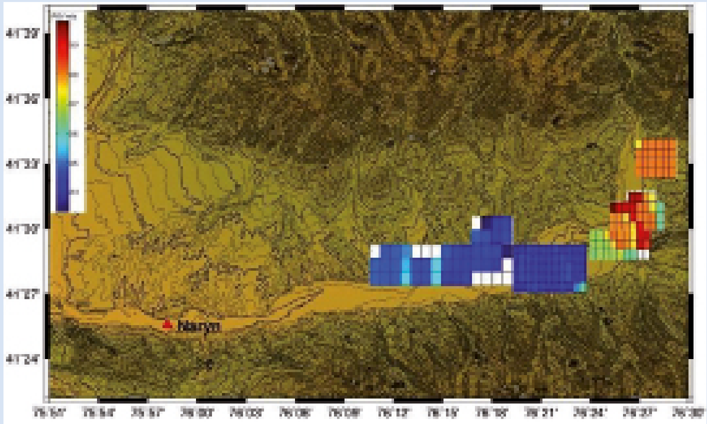

Figure 4: Map of the study area in the Upper Naryn region in Kyrgyzstan, showing the mean Peak Ground Velocity values (white cells correspond to insufficient data). The red triangle indicates the location of Naryn city.

Hazard analysis is the process of quantitatively estimating the ground motion at a site or region of interest, based on the characteristics of surrounding seismic sources **(Figure 3)**. It falls primarily within the disciplines of geology and seismology with input from civil engineering. In this respect, the term seismic hazard has a technical meaning restricted to the behaviour of the ground, aside from any effects on the built environment. The basic methodology of hazard analysis is comprised of source modelling, wave attenuation, and local ground amplification. This method of seismic hazard analysis has not previously been applied to the Naryn region in Kyrgyzstan.

The Peak Ground Velocity Estimation Method (PGVEM) was used for seismic assessment of the area where the Upper-Naryn Cascade of hydropower plants is planned. Previously the PGVEM method was applied to examine source zones of ancient earthquakes in the Russian sector of Fennoscandia, and to investigate field data from the source zones of strong earthquakes that occurred on the territory of the Kyrgyz Republic: Susamyr (19.08.1992, Ms = 7.3) and Kemin (03.01.1911, Ms = 7.9). The PGVEM enables the estimation of Peak Ground Velocities (PGVs) occurring during strong earthquakes in the past. The PGVEM can provide valid estimation in cases where appropriate statistical data is collected about rock blocks likely displaced during strong earthquakes.

Fieldwork was conducted during 2014-2015 in the Upper Naryn area, near the location of the planned dams and reservoirs of the Upper Naryn hydrocascade. More than 280 cases of rock block displacements that could be connected with strong historical earthquakes were found. This data allows the possibility of estimating the possible peak ground velocity (PGV) values that could cause these displacements. Results indicated that in the upper part of the studied area the mean PGV values are 0.5-0.9 m/s, corresponding to a seismic intensity I = 9 and higher. In the lower part of the studied area the mean PGV values decreased, approaching 0.4-0.60 m/s and less **(Figure 4)**.

All obtained PGVEM findings were found to be in a good agreement with the results from other methods used to study earthquakes, and agree on a maximum seismic intensity (I = 9) around which the hydro-cascade has been designed. Note, however, that no safety margin exists in the upper part of the cascade under construction.

Figure 5 A & B: Examples of rock failure and displacement along an active fault line in Naryn region, Kyrygzstan. Measurements from these displacements can reveal information about peak ground velocity (PGV) during historical earthquakes. **Photo: Sagynbek Orunbaev**

Definitions

Seismic hazard: The probability of an earthquake occurring in a specific location at a specific time, with a ground motion intensity above a certain threshold.

Seismic risk: The risk of damage from seismic activity, including earthquakes, to infrastructure, systems, and other entities, which encompasses social, environmental, and economic consequences.

Peak ground velocity (PGV): The greatest ground speed (velocity) reached during a seismic event, e.g. an earthquake.

Benefits and challenges of the PGVEM method

As described, the PGVEM method makes it possible to estimate typical PGV values experienced during strong earthquakes in the historical past. This method is based on the examination of cases of rock block failure and displacement, which can be caused by strong seismic impact or by other factors **(Figures 5 & 6)**. If there is a large number (e.g. dozens) of rock displacements, researchers can hope to reveal features typical of earthquakes and to estimate the mean PGV values typical for the area during historical earthquakes.

The advantage of the PGVEM is that it makes possible obtaining a quantitative estimate of PGV. Most other indicators of historical seismic activity can indicate approximate earthquake occurrence but do not allow parameterization of the event. For example, we were able see the indicators of presumably seismogenic dislocations in soft rocks **(Figure 6),** but we have no statistical data that is needed for parameterization of the event. Another marked benefit of the PGVEM is that it allows cost-effective investigations in areas with limited instrumental data or seismic records, and also enables the option of conducting cost-effective areal macroseismic studies.

Figure 6: An example of possible seismic dislocations in soft rock in the trench wall, located near the temporal base for hydrocascade construction. The slanting wedges in the wall are presumably indications of seismogenic dislocations during historical earthquake events. **Photo: Sagynbek Orunbaev**

Further Reading

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Central Asia and Afghanistan Research Fellowships (CAARF) were awarded by the University of Central Asia's Mountain Societies Research Institute to qualified researchers from Afghanistan, the Kyrgyz Republic, and Tajikistan. Fellows' research was centred around learning from and for sustainable development in mountain societies of the Tien Shan, Pamir and Hindu Kush ranges in Central Asia, with a special focus on environmental change, natural resources governance, and the social and economic impacts of mountain development.

Mountain Societies Research Institute

The University of Central Asia Graduate School of Development's Mountain Societies Research Institute (MSRI) is an interdisciplinary research institute dedicated to addressing the challenges and opportunities within Central Asian mountain communities and environments. MSRI's goal is to support and enhance the resilience and quality of life of mountain societies through the generation and application of sound research.

MSRI has five objectives: To generate knowledge on mountain societies through original scientific research; to serve as a knowledge hub for scholars, development practitioners, and policy makers; to enhance regional capacity to conduct sound research relevant to mountain societies; to inform policy and practice through engagement with key development partners; and to disseminate knowledge among mountain stakeholders, including the co-development and co-teaching of UCA's academic programmes. MSRI, together with its partners, actively works to transfer knowledge to policy and practice aimed at improving the quality of life for people of the mountain areas in Central Asia. For more information on MSRI, please visit: http://www.ucentralasia.org/msri.

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