



Overview of modelling techniques for Geo Hazard Risk Assessment

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***Abstract:** The occurrence of disasters both natural and man-made is inescapable. For this reason, the key to successful disaster resilience is preparation. Climatic and Anthropogenic distortions and the increasing population have impacted the environment and increased the probabilities of disaster events in the Central Asia region. Water resources in Central Asia are generated at high mountains with snow and glacier melt dominating the flow regime. Increasing temperatures at higher elevations will have an impact on the snow and glacier melting process and this will change the flow regime of Central Asian rivers. A combination of different modeling techniques, including regional climate monitoring, hydrological, hydro-geological, river hydraulics, geotechnical, debris flows, landslides, Artificial Neural Networks (ANN) modeling tools are helpful for prediction analysis and disaster event preparation activities. Some these modeling techniques are reviewed in this article.*

Keywords: Central Asia, climate change, hydrological change, geo hazards.

Introduction, current Central Asian problems in geo hazard predictions

Floods and droughts are getting more devastating in many regions in Central Asia. Many researchers relate these events to anthropogenic nature distortions, climate change, and engineering construction [1, 2]. Moreover, according to UN experts, “only 4% of the estimated \$10 billion in annual humanitarian assistance is devoted to prevention, and yet every dollar spent on risk reduction saves between \$5 and \$10 in economic losses from disasters” [3]. Snow and glacier melt is essential for the water supply of a number of counties in Central Asia with about 90% of this water being used for irrigation. With regional temperatures rising due to climate change along the Tien Shan, Central Asia's largest mountain range, glaciers have lost 27 percent of their mass and 18 percent of their area during the last 50 years [4]. More extreme climatic variations will likely increase the incidence of geohazards, floods, landslides, earthquakes by inducing even more extreme weather conditions. The Intergovernmental Panel on Climate Change (IPCC) extensive report published in 2012 [5], reconfirmed by [6], predicts with high confidence that future changes in heat waves, glacial retreat, and/or permafrost degradation will increase the occurrence of landslides. Also, there has been an increase in the number of large rock slides during the past

two decades, and especially during the first years of the 21st century [7]. The most frequent causes of natural disasters are: spring floods and rain floods, constituting about 30% of the total number of disasters. Most of the Central Asian regions are at a high risk of flooding and mudslides. Moreover, the Central Asian region is situated in the earthquake area: particular dangers are quasi strong and devastating earthquakes have occurred. Many problems and disasters are interconnected, so a multidisciplinary approach should be applied for the causes and potential disaster identification. Earthquakes, monitoring sites-dam-reservoirs crash, hurricane, floods and fires could happen in a simultaneous chain of actions. Most of the Central Asian countries lack advanced flood-drought monitoring and early warning technologies. Quite often the local Central Asian people do not have time to react properly in advance of emergency events. A combination of different modeling techniques, including regional climate monitoring, hydrological, hydro-geological, geotechnical, river hydraulics, debris flows, landslide, ANN modeling tools will be helpful for the prediction analysis and disaster preparation activities in Central Asia.

A taxonomy of various modeling techniques, including Climate scenarios, regional climate, hydrological, hydro-geological, river hydraulics, geotechnical, debris flows, landslides, ANN modeling tools

“All models are wrong, but some are useful.” This common aphorism by George Box could be applicable for this chapter [8]. None of the modeling tools are perfect, because all of them have some limitations. By developing different modeling tools, researchers imitate the natural processes by adding limitations to their models. The connected chain of the different modeling techniques, which can be useful for geohazard assessments could be classified into several larger categories including:

- 2.1. Hydro-meteorological monitoring, Climate scenarios
- 2.2. Hydrological, hydro-geological and hydraulic modeling
- 2.3. Extreme events forecasting, geotechnical modeling, including landslides
- 2.4. Artificial Neural networks (ANN)

2.1. Hydro-meteorological monitoring, Climate scenarios

For various current and future predictions of the local and regional hydro-meteorological monitoring applications, many researchers use the climate scenarios data from the IPCC [9]. For example, CMIP5 climate scenarios for the time period of 1950 to 2100 years can be used to assess possible climate projections in the Central Asia. In the previous work of authors, daily CMIP5 climate data for precipitation, temperature, relative humidity and solar radiation were prepared to assess climate impact assessment in some watersheds of Central Asia. The expansion of research work in Central Asia can benefit from previous research where this data with daily temporal resolution were already tested [10,11]. There are several models that run different representative concentration pathways (rcp2.6, rcp4.5, rcp6.0 and rcp8.5). For the climate impact assessment in the future research areas, temperature and precipitation changes in the future relative to control period needs to be considered from all models to identify plausible changes in the future. Raw climate scenarios are delivered as grid based datasets and

the size of each grid cell is very coarse (100-200 km) in order to be applied directly for climate impact assessments. In order to make them applicable for studies in basin scale, it is important to conduct the bias correction. There are different approaches for conducting bias correction which utilize past observed climate records for statistical bias correction of future climate projections. Conducting bias correction allows for the statistical downscaling of climate records down to the location of stations which enables future projection for the climate records at these station locations. Therefore, it is important to consider observed climate records from meteorological stations located in or in the vicinity of the research areas. Another example of the regional climate model is PRECIS (HadRM3P), which is based on the atmospheric component of the UK Meteorological Office HadCM3 (Hadley Centre Coupled Model version 3) model [12]. PRECIS has horizontal resolution of 25 or 50km and outputs over 130 meteorological variables at sub-daily, daily, monthly and annual temporal frequencies. The PRECIS regional climate modeling system has a user friendly graphical interface and free provision of several GCMs (including state-of-the-art HadGEM2-ES from the latest CMIP5 ensemble) as input data. Model projections may be used in the development of climate projections for selected regions.

2.2. Hydrological, hydro-geological and hydraulic modeling

Once the statistically downscaled and bias corrected climate records are established for the future, hydrological models can be applied that use future climate projections and simulate possible river flow. This allows assessment of changes in the river flow regime of the research areas. Depending on the availability of data, different types of hydrological, hydro-geological, hydraulic models can be applied such as a conceptual model such HBV [10], a distributed model such as WASA [13, 14], Soil Water Assessment Tool (SWAT) [15], GMS ModFlow [16, 17], DHI MIKE SHE, MIKE Hydro, MIKE 21, and MIKE 11 [18]. Distributed hydrological models describe hydrological processes more in detail but at the cost of more data requirement. The conceptual hydrological models simulate water balance in a coarse resolution and thus do not require much data. The simulation of future river flow using hydrological models also allows the assessment of changes of individual discharge components: snowmelt, glacier melt, rain or groundwater contribution to total discharge. The results of simulated river flow changes give insight into possible changes in the future based on which water related strategies can be developed to mitigate negative impact of warming climate on socio-economy in the research areas.

2.3. Extreme events forecasting, geotechnical modeling, including debris flows and landslides

Debris flows and avalanches are some of the major natural hazards in Central Asian countries, where they cause several casualties every year. Hence, sound modelling of the propagation of the debris is crucial for improving the current capabilities to assess the risk posed by landslides. Experts in numerical methods develop related modeling tools, including Discrete Element Methods, FEM in large displacements, meshless methods, and SPH applicable for the modelling of landslide induced debris flows. The Discrete Element Method (DEM) is increasingly employed in the scientific community to model landslide events in rock slopes

where the behavior is ruled by the presence of discontinuities, e.g. joints, beddings, faults, and in granular materials. In this case, it is important to correctly model rock blocks of non-circular and non-spherical shapes, for 2D modelling of rock slides, and the more realistic 3D modelling [19,20] implemented in the open source code YADE. Innovative developments have been brought to the open source DEM code YADE. In particular, concerning the modelling of fractured rock mass systems, the developments consist of the definition of pre-existing discontinuities as a Discrete Fracture Network (DFN) initially plugged into a set of discrete elements combined with the use of a modified contact logic which provides an explicit representation of rock joints. Both fracturing of intact material and yielding within discontinuities can therefore be reproduced, depending on the loading conditions and material strength. DFN in association with DEM constitutes an essential tool to understand and predict instabilities leading to the failure of fractured rock slopes. Finite Element (FE) is nowadays the primary numerical tool employed by geotechnical engineers to analyze actions on the ground and to design geotechnical strategies to mitigate geohazards, protections against landslides, and seismically proof infrastructure. There are many situations where traditional finite element analyses cannot cope with issues such as the presence of localized and diffuse soil failure modes, or the modelling of the propagation of debris and mud flows. Advanced finite element techniques are being developed to tackle these types of problems. As models encompass more and more degrees of freedom and scales of analysis, unprecedented numerical issues related to algorithm convergence and stability need to be addressed [21, 22]. The geomechanical community is also facing an increasing need for expertise in coupling numerical codes [23, 24] and modelling the transition between discrete and continuum media [25, 26]. Material Point Method (MPM), a finite element method, combined with Lagrangian interpolation points (FEM-LIP), are applied for slope stability modeling with analyses of the large deformations, both permanent and reversible, to simulate damage in unsaturated rock subject to thermo-hydro-mechanical stress paths [27]. This technique works in combination with the nonlinear Finite Elements and various models of discontinuities, including free surfaces, interfaces, cohesive zones, in order to simulate the coupled evolution of discontinuities at different scales.

2.4. Artificial Neural Networks (ANN) in Hydrological Modeling

Artificial Neural Networks (ANN) is a modeling technique which simulates complex processes with a large amount of data. ANN adapts to the changes in real time and makes permanent improvement with error minimization. Originally ANN techniques were based on the simulation of the human brain: “The human brain is a complex, non-linear, parallel information processing system, the performance of which can't compare with a modern computer. An example of one of these task is the human eye; the brain recognizes the images at a rate of about 100-200 milliseconds. The ability to collect and analyze the experience, allows the human brain to achieve such results. A neural network is a machine that simulates the way the brain processes a specific task” [28]. ANN methods are applied for floods, mudflows and earthquake prediction [29]. ANN can be also used as a geohazard risk

assessment tool [30] and can be applicable for flood prediction and disaster damage assessment [31]. As an example of using ANN for the Central Asian region, author Atanov worked on the “Kalkuran river flow forecasting using artificial intelligence technologies” project [32]. For this study, the ANN was applied to predict water discharge of the Kalkutan River, which is the main tributary of the Esil River flowing within the Astana city area, the capital of Kazakhstan. The aim of the study was to develop a model for forecasting flow in the river during the spring flood, based on the ANN approach. The discharge station data from the Kalkutan river is used for calibration. KazHydroMed provided required hydro-meteorological data for the ANN modeling, including: precipitation, snow-water equivalent, and temperature. The self-organizing neural networks with back propagation of the error was applied within the ANN program, which is one of the universal types of neural networks for modeling complex dependencies. As a result of the work, a model was developed for predicting water flow in the river during the spring flood, with an accuracy of 89% (Fig. 1). Thus, the correlation between the actual measurements and the predicted value was 0.894 [32].

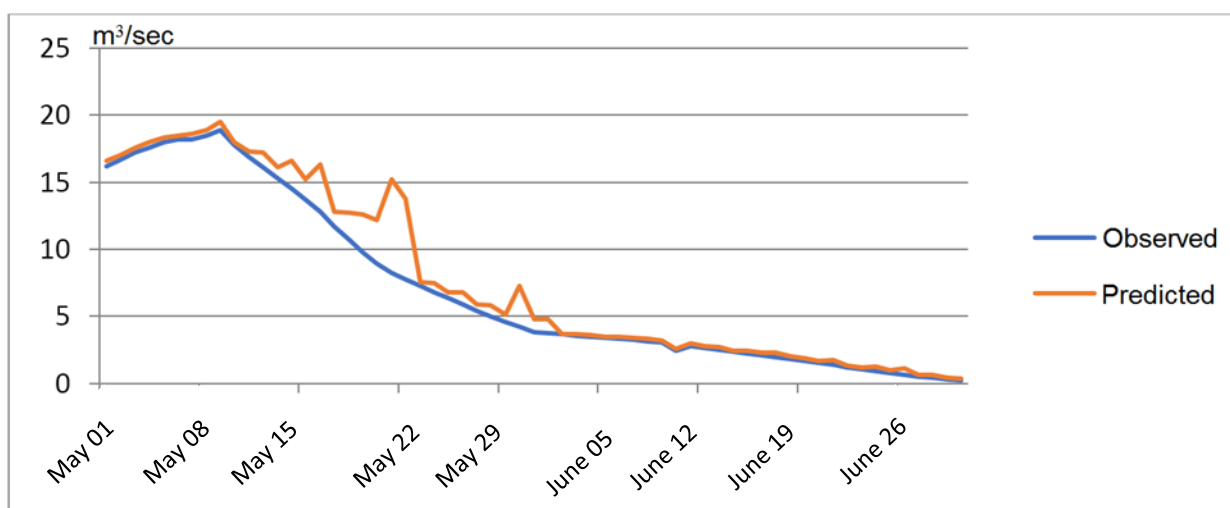


Fig. 1. Hydrograph of water discharge in Kalkutan river

Conclusion, future studies and research work

Central Asian countries should increase emphasis, support and should create incentives for activities and projects related to disaster mitigation, disaster preparation, proactive actions, and problem identification. The UN and organizations such as FEMA recommend investing more on proactive actions related to disaster risk mitigation since “every dollar spent on risk reduction saves between \$5 and \$10 in economic losses from disasters” [3].

Central Asian countries lack common data sharing. Geo spatial data collection is a very time consuming task, and many researchers duplicate other researcher’s work. It is reasonable to develop more open source databases, as it is well developed in many countries. Moreover, the geoinformation system similar to Canadian Multi-Agency Situational Awareness System (MASAS) is a reasonable model for development [33]. On the next level, by using the collected data, and available open geo databases, different modeling tools could be applied,

some of which were presented in this article. All these project activities and disaster preparation efforts require consistent funding. It is necessary to properly calculate all the potential expenses and future losses. For this purpose, USA and Canada apply HAZUS, which could be adapted for Central Asia [34, 35]. These are effective current and future research works that can be readily be applied in Central Asia.

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