COMPARISON OF THE HYDROLOGICAL AND METEOROLOGICAL PROJECT IMPLEMENTATIONS IN THE DIFFERENT COUNTRIES

Zhanay Sagintayev
Nazarbayev University, Astana

Climatic and anthropogenic distortions have impacted the enviroment and increased the probabilities of disaster events worldwide, including Kazakhstan. 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 Kazakhstan, Central Asian Rivers. A combination of different modeling techniques, including regional climate monitoring, hydrological, hydro-geological, river hydraulics, geothechnical, debris flows, landslides, Artificial Neural Networks (ANN) modeling tools are helpful for prediction analysis and disaster event preparation activities. Some of these modeling techniques are reviewed in this article.

The article outline:

1) Introduction, current Kazakhstan, Central Asian problems with geo hazard predictions

2) A taxonomy of various modeling techniques, including climate scenarious, regional climate, hydrological, hydro-geological, river hydraulics, geothechnical, debris flows, landslides, and ANN modeling tools

3) Conclusion, future studies, research work

1. Introduction

Floods and droughts are getting more devastating in many regions in Kazakhstan, Central Asia. Many researchers relate these events to anthropogenic nature distortions, climate change, and engineering construction [1; 2]. Moreover, according to UN, "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 countries 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, geothechnical, river hydraulics, debris flows, landslide, ANN modeling tools will be helpful for the prediction analysis and disaster preparation activities in Kazakhstan, Central Asia.

2. A taxonomy of various modeling techniques, including Climate scenarious, regional climate, hydrological, hydro-geological, river hydraulics, geothechnical, debris flows, landslides, ANN modeling tools

"All modela are wrong, but some are useful." This common aphorim 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, reseachers imitate the natural processes by adding limitations to their models. The connected chain of the different modeling techniques, which can be useful for geohazard assessement could be classified into several larger categories including:

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

2.1. Hydro-meteorological monitoring, Climate scenarious

For various current and future predictions of the local and regional hydro-meterological monitoring applications, many researchers use the climate scenarious data from the ГРСС [9]. For example, СМГР5 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 CMTP5 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. There are several models that run different representative concentration pathways (rcp2.6, rcp4.5, гср6.О 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 course (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 reserach 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 [10]. 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 HBV as applied already in Central Asia [11], a distributed model such as WASA [12], Soil Water Assessment Tool (SWAT) [13], GMS ModFlow [14;15], DHI MIKE SHE, MIKE Hydro, MIKE 21, and MIKE 11 [16]. 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 course 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, and 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, modeling, including mudflow and landslides

Mudflow and avalanches are some of the major natural hazards in Central Asian countries, where they cause several casualties every year. Hence, sound modeling 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 modeling 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 [17; 18] implemented in the open source code YADE. Innovative developments have been brought to the open source DEM code YADE. In particular, concerning the modeling 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 modeling 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 [19; 20]. The geomechanical community is also facing an increasing need for expertise in coupling numerical codes [21; 22] and modeling the transition between discrete and continuum media [23; 24]. Material Point Method (MPM), a finite element method, combined with Lagrangian interpolation points (FEMLIP), 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 [25]. 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 premanent 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" [26]. ANN methods are applied for floods, mudflows and earthquake prediction [27]. ANN can be also used as a geohard risk assessment tool [28] and can be applicable for flood prediction and disaster damage assessment [29].

3. *Conclusion, future studies and research work*

Kazakhstan, Central Asian countries should increase emphasizes and 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 realated to disaster risk mitigation since "every dollar spent on risk reduction saves between $5 and $10 in economic losses from disasters" [3]. Kazakhstan, Central Asian countires lack common data sharing. Geospatial data collection is a very time consuming task, and many researchers duplicate other researcher's work. It is resonable to develop more open source databases, as it is well developed in many countries. Application of remote sensing data in this region should be promoted. Examples for evaluation of remote sensing data and its operational application were tested for snow cover data [30;31]. Moreover, the geoinformation system similar to Canadian Mulit-Agency Situational Awareness System (MASAS) is a reasonable model for development [32]. On the next level, by using the collected data, and available open geo databases, different modeling tools coud be applied, some of which were presented in this article. All these project activities and disaster preparation efforts require consistent funding. It is neccessary to properly calculate all the potentical expenses and future losses. For this purpose USA and Canada apply HAZUS, which could be adapted for Kazakhstan [33; 34]. These are effective current and future research work that can be readily be applied in Kazakhstan, Central Asia.

References

1. DFO, 2017, Dartmouth Flood Observatory (DFO Flood Events), http ://floodobservatory.Colorado .edu/Events/2017Kazakhstan4465/2017Kazakhstan4465 .html;
2. NASA, 2017, Earth Observatory NASA, Natural Hazards Central Asia, https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=17369
3. Schwarz, E., 2006, "A Needless Toll of Natural Disasters", UN Secretary General's Deputy Special Envoy, Op-Ed .*The Boston Globe.* boston.com/news/globe/editorial_opinion/oped/articles/2006/03/23/
4. Farinotti, D., Longuevergne, L., Moholdt, G., Duethmann, D., Molg, T., Bolch, T., Vorogushyn, S. and Guntner, A., 2015. Substantial glacier mass loss in the Tien Shan over the past 50 years, *Nature Geoscience,* 8, 716-722, 2015, doi:10.1038/ngeo2513
5. IPCC, 2012, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.
6. IPCC, 2014, *Climate Change 2014: Impact, Adaptation and Vulnerability. Summary for policy makers.* Working Group II of the Intergovernmental Panel on Climate Change, AR5
7. Ravanel L. and Deline P. 2011. Climate influence on rockfalls in High-Alpine steep rock walls: The north side of the Aiguilles de Chamonix (Mont Blanc massif) since the end of the 'Little Ice Age'. *The Holocene,* 21(2):357- 365.
8. DDC IPCC, 2017, Intergovermental Panel on Climate Change (IPCC), http://www.ipcc-data.org/
9. *Box, G. E. P., 1976,* "Science and Statistics", Journal of the American Statistical Association, *71(356): 791-799,* doi: 10.1080/01621459.1976.10480949
10. 10.PRECIS, 2017, PRECIS: a regional climate modelling system, http://www.metoffice.gov.uk/research/applied/international-development/precis
11. Gafurov, A., Goetzinger, J. and Bardossy, A., 2006. Hydrological modeling for meso scale catchments using globally available data, *Hydrology and Earth System Sciences Discussion,* 3(4): 2209-2242.
12. Guenter, A. and Bronstert. A., 2004. Representation of landscape variability and lateral redistribution processes for a large-scale hydrological modeling in semi-arid areas. Journal of Hydrology 297 (1-4)436-161. DOI: 10.1016/j.jhydrol.2004.04.008
13. Sagintayev, Z, Sultan, M., Khan, S. D., Khan, A. S., Mahmood, K., Yan,E., Milewski, A., and Marsala, P., 2011, Remote Sensing Contributions to Hydrologic Modeling in Arid and Inaccessible Watersheds, Pishin Lora Basin, Pakistan. *Journal of Hydrological Processes* 26(1), doi/10.1002/hyp.8114/full

14. Sagintayev, J., Z. Yerikuly, S. Zhaparkhanov, V. Panichkin, O. Miroshnichenko, and S. Mashtayeva. 2015. Groundwater inflow modeling for a Kazakhstan copper ore deposit, *Journal of Environmental Hydrology,* 1 (23) Paper 9.

15. Sagintayev, J., Salybekova V., Kalitov D., Zavaley V., and Rakhimov T. 2016. Numerical Modeling of the Intensification Processes of Groundwater Treatment for Hexavalent Chromium Using In Situ Technology, *Journal of Environmental Hydrology,* 24 (Paper 4: 1-13.

16. DHI, 2017, DHI MIKE is the global organization dedicated to solving challenges in water environments worldwide, https://www.mikepoweredbydhi.com/

17. Boon CW., Houlsby GT. and Utili S. 2012. A new algorithm for contact detection between convex polygonal and polyhedral particles in the discrete element method. *Computers and Geotechnics,* 44: 73-82. DOI: 10.1016/j.compgeo.2012.03.012

18. Boon CW., Houlsby GT. and Utili S. 2013. A new contact detection algorithm for three dimensional non- spherical particles. *Powder Technology.*248: 94-102. http://dx.doi.Org/10.1016/j.powtec.2012.12.040

19. Sloan, S. W., and Abbo, A. J. 1999. Biot consolidation analysis with automatic time stepping and error control Part 1: theory and implementation. *International Journal for Numerical and Analytical Methods in Geomechanics,* 23(6): 467-492. DOI: 10.1002/(SICI)1096-9853(199905)23:6<467

20. Tamagnini, C, Castellanza, R., and Nova, R. 2002. A generalized backward Euler algorithm for the numerical integration of an isotropic hardening elastoplastic model for mechanical and chemical degradation of bonded geomaterials. International Journal for Numerical and Analytical Methods in Geomechanics, 26(10): 963-1004. DOI: 10.1002/nag.231

21. Collin F., Laloui L., and Charlier R. (2005). Unified approach of coupled constitutive laws. *Revue Europeenne de Genie Civil,* 9, 713-723.

22. Kim J., Moridis G, Yang D. and Rutqvist J., 2012, Numerical studies on two-way coupled fluid flow and geomechanics in hydrate deposits. *Society of Petroleum Engineers Journal,* 17(2): 485-501.

23. Sibille, L., Donze, F. V., Nicot, F., Chareyre, B., & Darve, F. 2008. From bifurcation to failure in a granular material: a DEM analysis. *Acta Geotechnica,* 3(1): 15-24.

24. Andrade JE., Avila CF., Hall SA., Lenoir N., and Viggiani G, 2011, Multiscale modeling and characterization of granular matter: from grain kinematics to continuum mechanics. *Journal of the Mechanics and Physics of Solids,* 59(2), 237-250 http://doi.Org/10.1016/j.jmps.2010.10.009

25. Gatmiri B., and Arson C, 2008. Theta-Stock, a powerful tool for thermohydromechanical behavior and damage modelling of unsaturated porous media. *Computers and Geotechnics,* 35(6): 890-915. DOI: 10.1016/j.compgeo.2008.08.008

26. Haykin, S. O. 2009. *Neural Networks and Learning Machines 3rd Ed.* NY: NYL Pearson Prentice Hall. https://cours.etsmtl.ca/sys843/REFS/Books/ebook_Haykin09.pdf

27. Elsafi, S., 2014, Artificial Neural Networks (ANNs) for flood forecasting at Dongola Station in the River Nile, Sudan, Alexandria Engineering Journal 53(3): 655-663 http://doi.Org/10.1016/j.aej.2014.06.010

28. Ercanoglu, M., 2005, Landslide susceptibility assessment of SE Bartin (West Black Sea region, Turkey) by artificial neural networks, *Natural Hazards and Earth Sciences* (5): 979 - 992.

29. Al-Azzam, O., Sarsar, D., Seifu, K., and Mekni, M. 2014, Flood Prediction and Risk Assessment Using Advanced Geo-Visualization and Data Mining Techniques: A Case Study in the Red-Lake Valley, *Applied Computational Science* .http://www.wseas.us/e-librarv/conferences/2014/Malavsia/ACACOS/ACACOS-02.pdf

30. MASAS, 2017, Canada's Multi-Agency Awareness System (MASAS), http://www.canops.org/?page=AboutMASAS

31. Gafurov, A., Kriegel, D., Vorogushyn, S. and Merz, B. 2013. Evaluation of remotely sensed snow cover product in Central Asia. Hydrology Research 44(3), 506-522. DOI: 10.2166/nh.2012.094

32. Gafurov, A., Liidtke, S., Unger-Shayesteh, K, Vorogushyn, S., Schone, T., Schmidt, S., Kalashnikova, O., and Merz, B. 2016, MODSNOW-Tool: an operational tool for daily snow cover monitoring using MODIS data. *Environmental Earth Sciences 75:* 1078, DOI: 10.1007/sl2665-016-5869-x

33. HAZUS, 2017, FEMA Multi-Hazards Loss Estimation (HAZUS), https://www.fema.gov/hazus-software

34. HAZUSCANADA, 2017, HAZUS Canada Using natural disaster scenarios for better planning and response, http://hazuscanada.ca/