ABSTRACT

of the thesis work of Mkilima Timoth «Aspects of embankment dams stability considering the impact of land use changes and climatic conditions in catchments», submitted for the degree of Doctor of Philosophy (PhD) in the specialty «8D07329 – Civil Engineering»

The goal of the thesis research

Assessment of the potential influence of land use changes, extreme events, and loading conditions on the slope stability of an embankment dam.

Research objectives

• To assess the potential applicability of GIS methods for dam site characterization and selection.

• To assess the rate of urbanization based on the trend of land use/land cover changes in the study catchments.

• To estimate stormwater runoff in the study catchments using the SCS curve number method based on the surface cover and extreme events.

• To assess the rate of runoff changes in the study catchments as influenced by the changes in land use/land cover.

• To assess the potential effects of runoff changes on the flow characteristics in the study dams.

• To assess the potential effect of the flow characteristics changes on the stability of the study embankment dams.

Research methods

A combination of Geographical Information System approaches and numerical modeling investigated different case studies' problems. The Soil Conservation Services Curve Number (SCS-CN) method, widely known as the Natural Resources Conservation Service curve number (NRCS-CN), was used to estimate flow conditions in the catchment. At the same time, numerical modeling was used to investigate the influence of the flow conditions on the slope stability of the study embankments. Virtual models and case studies (Msimbazi, Ndembera, Nura-Sarysu, Ural-Caspian, and Aral-Syrdarya) were investigated in this study.

The main provisions (proven scientific hypotheses and other conclusions that are new knowledge) introduced for the defense

As a result of the changes in land use/land cover and extreme events, the design flows and reservoirs' depths changed significantly with time. Furthermore, due to the flow variations in the catchments, this study demonstrated that long-term water levels and loading conditions had a substantial impact on the slope stability of embankment dams. Based on the facts, it is vital to evaluate the state of the catchment in terms of land surface cover and climatic variables during the design phase of an embankment dam to achieve safe and sustainable dams.

Description of the main results of the research

As a consequence of the land use and land cover change analysis in the Ndembera catchment, land use classifications for water, wetland, dense forest, developed low intensity, developed medium intensity, and developed high intensity were produced. In 1990, wetlands constituted the bulk of the Ndembera watershed,

accounting for around 56.57% of the entire area; however, high-intensity development covered just about 0.86% of the total area, while medium-intensity development covered 13.9%. However, in 2011, medium intensity development encompassed the majority of the catchment, accounting for 54.7% of the total area. A similar phenomenon was also observed in the Chardara catchment in Kazakhstan, whereby a large part of the catchment by 2011 was transformed into high-intensity development.

As a result of the changes in land use/land cover and extreme events, the catchment modeled flows and reservoirs' depths changed significantly with time. Furthermore, as a result of flow variations in the catchments, this study demonstrated that long-term water levels and loading conditions had a substantial impact on the slope stability of embankment dams.

With the help of numerical modeling, the possible impact of changes in long-term water level on the slope stability of an embankment under rapid drawdown conditions was explored in the first virtual model. Three possible long-term water levels (ten, eight, and six meters) were considered. The findings of the investigation show that as the long-term operational water level changes, the factor of safety values changes as well. When the water level was dropped from 10 m to 6 m for a 13 m high embankment, the steady-state factor of safety was shown to be decreasing with the reduction in water level, with the steady-state factor of safety reducing by roughly 13.44 %. While the upstream slope became more stable as the long-term water level dropped under rapid drawdown scenarios, the downstream slope became more unstable. The research work also demonstrated that an embankment freeboard can have a significant impact on the steady-state factor of safety. Changes in long-term operating water levels also influenced the minimum values of the factor of safety, with the highest minimum factor of safety value obtained from a 6 m water level under a 5 days drawdown rate and the lowest minimum factor of safety value obtained from a combination of 10 m water level and instantaneous drawdown scenario.

In the second virtual model, the impact of the size of a toe drain on the slope stability of an embankment dam during rapid drawdown conditions has been studied. According to the findings, pore-water pressures at the upstream face of the embankment decreased as the toe drain size increased, whereas pore-water pressures at the downstream toe increased. Changes in the toe drain size were also discovered to alter the factor of safety values. The derived results in this study revealed that when an embankment is subjected to a rapid drawdown situation, there is a substantial potential association between toe drain size and factor of safety.

From the Samarkand dam, a minimum factor of safety of 2.149 was found when the embankment was subjected to a 1 m per day draw-down rate; the minimum factor of safety value was reached on the fourth day of the drawdown. The factor of safety calculated from a 1 m per day drawdown rate is 8.32% lower than that calculated from a long-term steady state. Furthermore, the factor of safety calculated using the instantaneous drawdown rate is 32.85% smaller than that calculated using long-term steady-state conditions.

From the Ndembera or Lugoda dam, when the hydraulic conductivity value changed to 10-7 m/s, the lowest minimal factor of safety value was attained, with a value of 0.901, which is less than 1. The phenomenon suggests that if the hydraulic conductivity value is less than 10-6 m/s, the embankment could fail at a pace of 1 meter per day to half of the maximum water level. If the hydraulic conductivity value must be less than 10-6 m/s, a lower drawdown rate must be used to avoid the possibility of failure. The derived results in this study demonstrated that slope stability and the combination of a drawdown rate and embankment material characteristics have a strong relationship.

From the Aktobe dam in Kazakhstan, when the embankment was subjected to a 1 m per day drawdown rate, a minimum factor of safety value of 1.486 was calculated. The factor of safety value is 3.7 % higher than the 10 days drawdown rate, 8.3 % higher than the 5 days drawdown rate, and 48.6% higher than the instantaneous drawdown rate.

In the case of the Chardara dam in Kazakhstan's Syrdarya basin, the effect of long-term water level variations and loading circumstances on the slope stability of an embankment dam was studied. Based on the piezometric lines, it was discovered that the pore-water pressures in the embankment remain rather high even after the reservoir has been completely emptied. With a difference of up to 54.4%, the factor of safety values from long-term steady-state settings were generally greater than those from fast drawdown conditions. As a result, the findings imply that it is critical to study the potential impact of drawdown scenarios on slope stability at various embankment heights.

In that matter, it is significantly important to investigate the state of the catchment in terms of land surface cover and climatic variables during the design phase of an embankment dam in order to achieve safe and sustainable dams.

Rationale for the novelty and significance of the results

The most important and crucial factor in whether a dam will be subjected to failure is the amount of water that it has to retain. The current approach of dam design and construction is based on the state of the watershed at the time at which the dam has to be constructed. However, this approach ignores land surface cover as one of the crucial factors that have a high potential to determine the state of a watershed or catchment with time. Therefore, when the landscape is changed especially with the development of impervious surfaces, it can have a big impact on how quickly stormwater is either absorbed into the ground surface or runs off toward the dam located downstream. In general, investigation of how changes in land surface cover can be a significant threat to a dam located in an urbanizing catchment can help design highly sustainable dams in the future. Unfortunately, previous works have not comprehensively captured the combination of land use changes and extreme events on slope stability of embankment dams, making it difficult to appropriately incorporate these factors during the design phase of an embankment dam. The results derived in this study have a significant potential to bridge the knowledge gap that has been existing for a long time, leading to the many embankment stability issues resulting from changes in flow characteristics within a catchment as a function of land use land cover changes.

Compliance with the directions of development of science or state programs

Land use and land cover change analysis is an important aspect of soil and water conservation because it can reveal a region's pattern of human land use. Land use patterns must be studied in order to cope with global climate change and achieve sustainable development. On the other hand, stormwater system modeling is a useful approach for determining flooding susceptibility and identifying possible flood-reduction strategies. These phenomena are important in determining the flow characteristics of a watershed, as well as the stability of an embankment dam. Slope stability analysis is also used to assess the safe design of man-made or natural slopes (such as embankments, road cuts, open-pit mining, excavations, landfills, and so on), as well as the equilibrium conditions.

It's also worth noting that dam engineers' lack of awareness of land use and land cover issues has been connected to an increase in the number of embankment dam failures around the world. Civil Engineers must understand the nature and behavior of land cover change within a catchment, flow characteristics in relation to changes in land use and land cover, and embankment stability problems related to flow characteristic issues in order to design highly sustainable dams.

Description of the contribution of the candidate to each publication

11 research articles were published on the topic of the research work, including:

5 – articles in peer-reviewed scientific journals recommended by the Committee for Quality Assurance in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan:

1. The potential effects caused by long-term water level changes on embankment slope stability under rapid drawdown / A.K. Aldungarova, Ye.B. Utepov, **T. Mkilima**, A.S. Tulebekova, Sh.Zh. Zharassov // Bulletin of Kazakh Leading Academy of Architecture and Construction. — 2022. — Vol. 83, No. 1. — P. 107–119. https://doi.org/10.51488/1680-080X/2022.1-01.

2. The influence of land use and land cover change on stormwater runoff in a highly urbanizing catchment. A case of Msimbazi catchment in Dar es Salaam city, Tanzania / **T. Mkilima** // Journal of Geography and Environmental Management. — 2021. — Vol. 63, No. 4. https://doi.org/10.26577/JGEM.2021.v63.i4.03.

3. Defining the boundaries and area of the Samarkand Reservoir catchment based on digital elevation models / A. Aldungarova, Y. Utepov, **T. Mkilima**, A. Tulebekova, Sh. Zharassov, A. Abisheva // Journal of Geography and Environmental Management. — 2021. — Vol. 62, No. 3. https://doi.org/10.26577/JGEM.2021.v62.i3.03.

4. Linear interpolation effectiveness on Terzaghi’s bearing capacity factors for shallow foundations / Ye.B. Utepov, **T. Mkilima**, A.S. Tulebekova, A.B. Kazkeyev // VESTNIK KazNRTU. Ser. Technical Sciences. — 2020. — Vol. 141, No. 5. — P. 515–520.

5. Combination of GIS and remote sensing as a tool in civil engineering. A case of Maibalyk reservoir, Kazakhstan / **T. Mkilima**, Ye.B. Utepov // News of Kazakhstan Science. — 2020. — Vol. 147, No. 4. — P. 31–40.

3 – articles in the proceedings of international and national conferences held in Kazakhstan and abroad:

6. Development of GIS-based workflow on Dam design and analysis under changing land surface and climatic conditions / A.S. Tulebekova, **T. Mkilima**, Ye.B. Utepov // Proceedings of International Scientific and Methodological Conference MODERN TRENDS IN ARCHITECTURE AND CONSTRUCTION: ENERGY EFFICIENCY, ENERGY SAVING, BIM TECHNOLOGIES, PROBLEMS OF THE URBAN ENVIRONMENT. — Almaty, Kazakhstan: International Education Corporation, 2020. — P. 240–246.

7. Potential dam site characterization using geographical information system / **T. Mkilima** // Proceedings of 2. INTERNATIONAL TURKIC WORLD CONGRESS on SCIENCE and ENGINEERING. — Nur-Sultan, Kazakhstan: L.N. Gumilyov Eurasian National University, 2020. — P. 380–387.

8. Reservoir routing for a peak flow reduction in a floods-impacted catchment / **T. Mkilima**, Ye.B. Utepov // Proceedings of the XX Annual Republican Scientific Student Conference STUDENT AND SCIENCE: A LOOK INTO THE FUTURE: Vol. 2. — Almaty, Kazakhstan: Kazakh State Academy of Architecture and Civil Engineering, 2020. — P. 294–299.

3 – articles in international peer-reviewed scientific journals with a percentile by CiteScore of at least 25 (twenty-five) in the Scopus database:

9. Dynamics of Embankment Slope Stability under Combination of Operating Water Levels and Drawdown Conditions / Ye.B. Utepov, A.K. Aldungarova, **T. Mkilima**, I.M. Pidal, A.S. Tulebekova, Sh.Zh. Zharassov, A. Abisheva // Infrastructures. — 2022. — Vol. 7, No. 5. — P. 65. https://doi.org/10.3390/infrastructures7050065. CiteScore: 2.5, процентиль: 58%.

10. The influence of material characteristics on dam stability under rapid drawdown conditions / Y. Utepov, Z. Lechowicz, A. Zhussupbekov, Z. Skutnik, A. Aldungarova, **T. Mkilima** // Archives of Civil Engineering. — 2022. — Vol. LXVIII, No. 1. — P. 539–553. https://doi.org/10.24425/ACE.2022.140184. CiteScore: 1.0, процентиль: 25%.

11. Potential Impact of Land-Use Changes on River Basin Hydraulic Parameters Subjected to Rapid Urbanization / Ye.B. Utepov, A. Aniskin, **T. Mkilima**, Zh.A. Shakhmov, G. Kozina // Tehnicki vjesnik - Technical Gazette. — 2021. — Vol. 28, No. 5. — P. 1519–1525. https://doi.org/10.17559/TV-20200808134641. CiteScore: 1.5, процентиль: 51%.

Structure and scope of work

Thesis consists of Introduction, five chapters, Conclusion, References and Appendices. It is presented on 302 pages, and contains 170 figures and 50 tables. This work was carried out at the Department of «Civil Engineering» of L.N. Gumilyov ENU (Nur-Sultan, Kazakhstan), the staff of which is highly appreciated for their support during the studies. The author expresses his sincere gratitude to scientific advisors PhD, Associate Professor Utepov Ye.B. (L.N. Gumilyov ENU, Nur-Sultan, Kazakhstan) and Professor Zbigniew Lechowicz (Warsaw University of Life Sciences, Warsaw, Poland) for their assistance and valuable advises during the studies and the thesis preparation.