

Landslides in Central Asia: a review of papers published in 2000-2020 with a particular focus on the importance of GIS and remote sensing techniques

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Abstract

Landslides are among the major environmental hazards with large-scale socio-economic and environmental impacts that jeopardize socio-economic wellbeing in mountainous regions. Landslides are due to the interaction of several complex factors such as local or regional geology, geomorphology, topography, and seismic motions. The goal of this study is to review published articles on causes and effects of landslides in Central Asia throughout 2000-2020. In line with this goal, we have collected (using Scopus database), reviewed, and analyzed 79 papers published during 2000-2020. Our results revealed an increasing number of landslide studies in Central Asia during the period under investigation, with authors from Belgium dominating in the published outcomes (28% of total), followed by authors from Central-Asian countries. After then, the paper analyses the mostly applied models and frequently identified driving conditions and triggers of landsliding, such as aspect, altitude, soil types, precipitation, earthquakes and human interventions. Geographic information system (GIS) and remote sensing (RS) had not commonly been used in the papers between 2000 and 2010, and they have progressively been applied in landslide studies in Central Asia in the last decade. According to our analysis, geotechnical, geophysical and statistical methods were preferably used for the landslide studies in Central Asia.

Keywords

Landslide,
Central Asia,
Geo-information
Systems,
Remote Sensing,
Conditioning factors,
Models

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Highlights for public administration, management and planning:

- In total, 79 Scopus-indexed papers were published between 2000 and 2020 on landslides in Central Asia, with an increasing frequency during the last 10 years.
- Geotechnical, geophysical and statistical methods were mainly used in landslide studies and since 2013 the role of geoinformation systems and remote sensing has escalated.
- The main conditions and factors considered in landslide studies were slope, soil type and past mass movements for conditions, and earthquakes for triggers.

1 Introduction

Landslides are considered as one of the potential hazards with large-scale socio-economic and environmental impacts (Pourghasemi et al. 2018; Juliev et al. 2017). Landslides are predominantly owing to the interaction of complex factors such as either local or regional geology, geomorphology, topography, and seismic motion. These factors are divided into two major groups, conditioning and triggering factors (Havenith et al. 2000; Mavlyanov et al. 2008; Juliev et al. 2017). To a great extent, slope inclination (slope in further text) and aspect, altitude, lithology, drainage density, land use, and soils are regarded as conditioning factors. Contrastingly, precipitation, earthquakes, and human interventions are deemed as triggering factors (Evans et al. 2006; Haberland et al. 2011; Pánek et al. 2016). Appraising the complexity and difficulty of projecting the landslide occurrence, the landslide susceptibility assessment is one of the most important issues in the international literature (Aleshin & Torgoev 2013). Consequently, different methods and techniques have been introduced for modeling landslide susceptibility and its assessment (Baimakhan et al. 2011; Aleshin & Torgoev 2014; Baimakhan et al. 2020). The main goal of the landslide susceptibility analysis is to get deeper insight into the interrelationship between landslide site and its related factors in order to spatially locate the most prone areas using statistical and geostatistical (or GIS) methods (Sidle & Ochiai 2006; Pourghasemi et al. 2018). The Soil Thematic Strategy has pinpointed landslides as one of the eight soil threats and encourages the identification of areas vulnerable to landslides in the European Union (Havenith et al. 2015; Kadirhodjaev et al. 2020).

Sufficient understanding of the actual tendency and scientifically sound methodology and techniques for predicting occurrence and activity of landslide can help to improve adaptive and mitigation capacity of landslides prevention (Sanhueza-Pino et al. 2011; Strom & Abdrakhmatov 2019). Throughout the past two decades, studies and research on landslides have increased in regard to the development of remote sensing (RS), simulation approaches, and geographic information systems (GIS) (Torgoev et al. 2006, 2012; Torgoev & Havenith 2013).

In Central Asia mountainous regions, the main trigger of the landslides are earthquakes. The largest seismic excitatory center is deep-focus (around 100–300 km) Pamir-Hindu Kush (Niyazov & Nurtaev 2013). Many sequential landslides could oc-

cur after strong local/regional earthquake; however, these cases are insignificant in Turkmenistan and Uzbekistan. Many landslide events registered once as a consequence of earthquake occur in large mountainous area of Central Asia (Sabitova et al. 2020). The most recent strong earthquake that occurred on June 26, 2016 (M-6.4 H = 28 km) with maximum shock intensity, caused concurrent landslide formations at 27 different sites of the region and large landslides were simultaneously formed on 2–3 sites (Alshembari et al. 2020). Additionally, there are potential sites such as Maylusuu, Baypaza, Altynbel, and Naugarzan prone to landslides, where the rock displacement accelerated and repeated through fixed years (Haberland et al. 2011). Ostensibly, apart from the earthquakes, the occurrence of landslides in Central Asia depends on its climate condition, terrain morphology and seismic activity when the slope of local areas reach the critical stability. Hence, it is urgent to enhance landslides control in this region. Reflecting the past landslide research is one of the essential steps in this effort since it may identify research gaps and stimulate research agenda and funding.

Considering all the above, this study aims to review published articles on the issue of the term of landslides in Central Asia throughout 2000–2020. Aligning with this aim, we have collected, reviewed, and analyzed 79 published papers in the Scopus database during 2000–2020, which has a generally broader scope and includes more journals published outside of the Western regional domain than Clarivate Web of Science.

1.1 Methodology

In this paper, we proceeded to the selection of publications regarding the regional knowledge of the conducted research. A total of 79 publications throughout 2000–2020 were downloaded and reviewed from the Scopus database using landslide and Central Asian countries (Fig. 1), including Kazakhstan, Kyrgyzstan, Turkmenistan, Tajikistan and Uzbekistan as the keywords.

Next, papers were categorized according to the year of publication. Afterwards, a database was compiled for all reviewed papers including the year and type of publication, author's names, affiliated country, journal name, citations, type of models applied to estimate landslide, and conditioning and triggering factors included in the model. Lastly, the landslides review database for Central Asia was used to analyze different relations among the journals publishing landslide papers for Central Asia during the period 2000–2020, utilized mod-

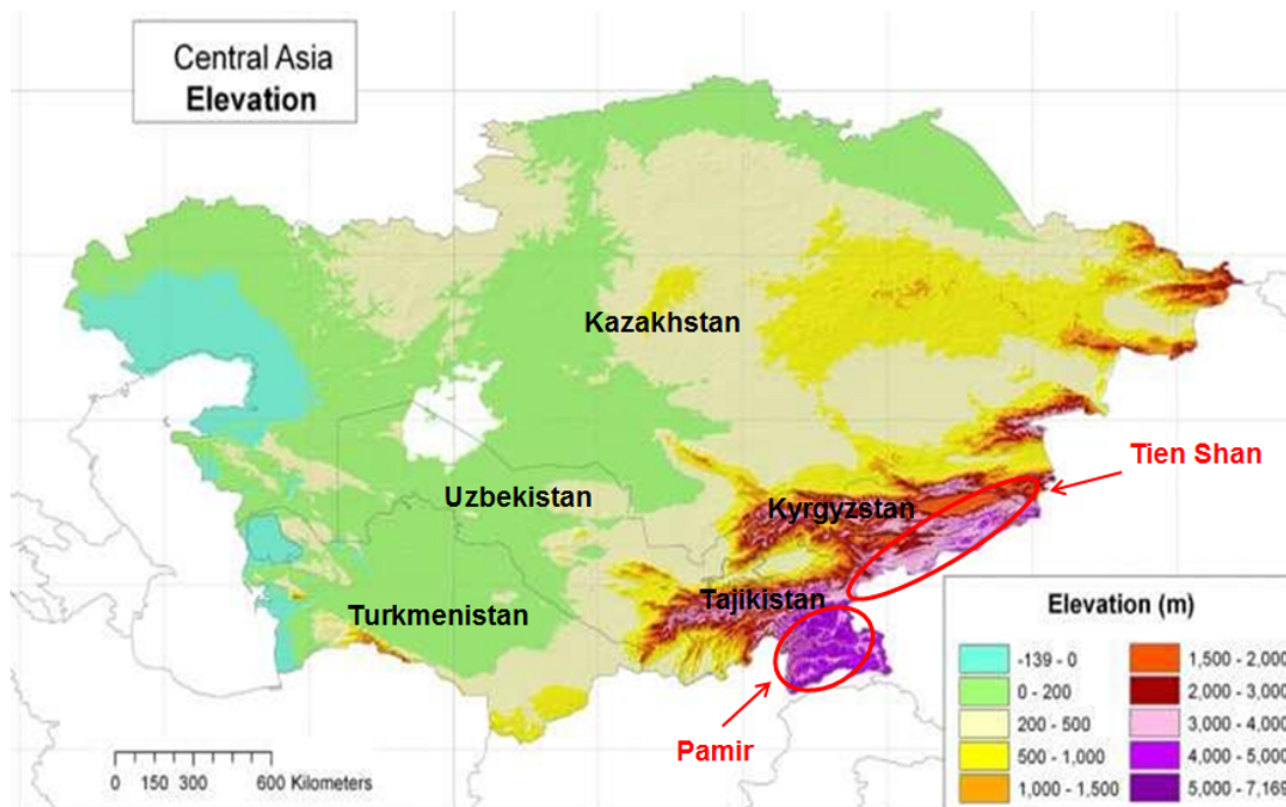


Fig. 1 Central Asia: Digital Elevation Model (source: De Pauw 2008)

els in landslide prone areas identification, and factors deemed in landslide assessment. In some cases, this analysis was undertaken in those two periods: 2000–2010 and 2011–2020 for two reasons: (1) for establishment of comparative analyses in terms of the number of papers published; and (2) for the trend development per journal and country. In the text, specific attention is paid to the importance of GIS and RS in the landslide assessment.

2 Results and discussion

2.1 Trend of publications

Of the total 79 papers published between 2000 and 2020 on landslides in Central Asia (Fig. 2), an overall 24 articles were published within 13 years during 2000–2012, whereas in 2013 there was a sharp increase, reaching an annual number of 13 articles throughout the study period. Between 2013 and 2020, on average, approximately seven articles were published per year (55 in total from 2013 to 2020). Our results further proved that, until 2013, there has been a decreasing number of pa-

pers published in international journals, followed by a significant upward trend afterward (Fig. 2). Moreover, our study reveals that the majority (32) or 41% of 79 papers were research articles, followed by 31 (39%) articles in conference proceedings, 11 (14%) book chapters, two (3%) review papers, and one survey, a scientific note and a textbook (Fig. 3).

2.2 Tendency of publishing sources and citations

Of the 79 articles reviewed for the period 2000–2020, 52 international journals and proceedings are listed and indexed in the Scopus abstract's database (Fig. 4): landslide in Central Asia indexed papers materialized mostly in Landslides, IAMG 2006 Proceedings, Landslide Science and Practice, E3S Web of Conferences, Landslide Science for a Safer Geoenvironment, and the Proceedings of 14th Asian Regional Conference on Soil Mechanics. Those six journals and proceedings have published 31.64% of the papers related to landslides in Central Asia during the period 2000–2020. Besides that, it was shown that, Landslides and IAMG 2006 Proceedings have solely

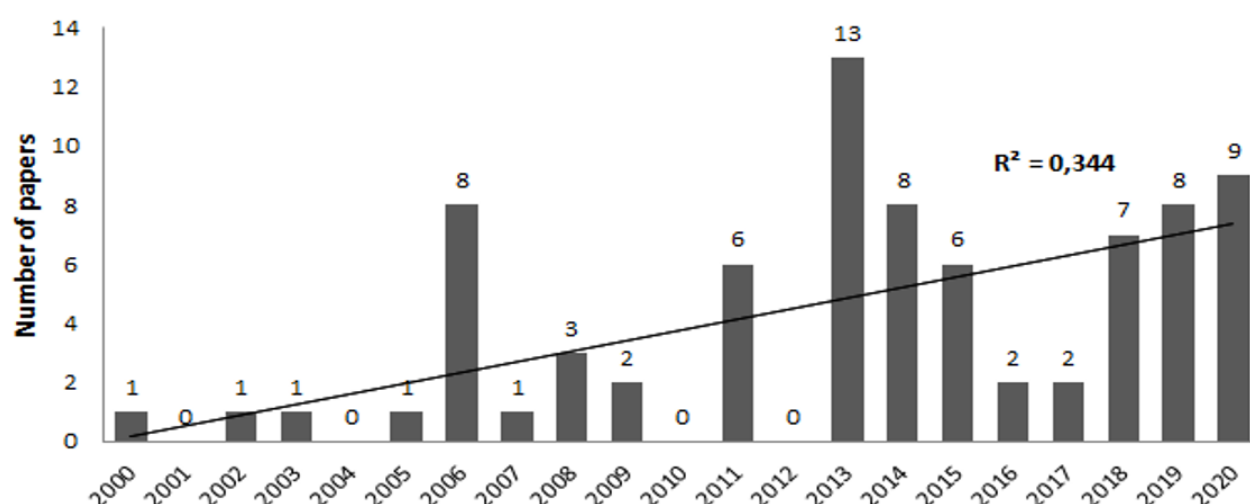


Fig. 2 Number of papers under the topic of landslides in Central Asia arranged by the year of publication)

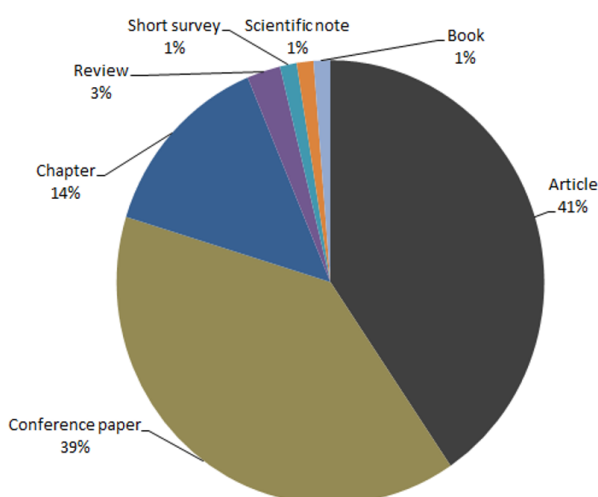


Fig. 3 Type of reviewed publications

published 13% of these papers. The average impact factor of the journals with the highest number of articles was 0.38. The number of publications showed an increasing trend in Natural Hazards, Landslides, Arabian Journal of Geosciences, Catena, and Bulletin of Engineering, Geology and the Environment between the two periods of investigations (Fig. 4). However, more citations were given to the papers published in Landslides than the publications in IAMG 2006–11th International Congress, accounted for more than 120 citations. Three articles in 14th Asian Regional Conference on soil Mechanics were published with four citations. Furthermore, there are Natural Hazards

and Earth System Science, Geomorphology, Landslide Science and Practice Complex, Geotechnical Engineering for Disaster Mitigation, FOG-Freiberg Online Geoscience, Landslides: Global Risk Preparedness, Landslides Science for a safer Geoenvironment, and ICSMGE 2017–19 International Conference, in which two papers for each were published in 2000–2020. Among those, only papers in Natural Hazards and Earth System Science had more citations, equivalent to roughly 70. In the remaining 38 sources, published paper was quite few, which was one paper for each source. However, out of those 38 sources, Engineering Geology had more citations, equivalent to more than 80 citations (Fig. 4).

As we witnessed through this analysis, majority of works were published in conference series rather than peer reviewed sources. For example, four conference proceedings out of six sources, which have at least three or more papers published, have 16 papers in contrast to peer reviewed journals publishing nine papers. Through these conference papers we can only see the shallow results with limited factors rather than in-depth analysis of their rationale. Therefore, despite having a such number of papers in these conference series, they have been cited few times rather than journal papers because of their lower significance and contribution.

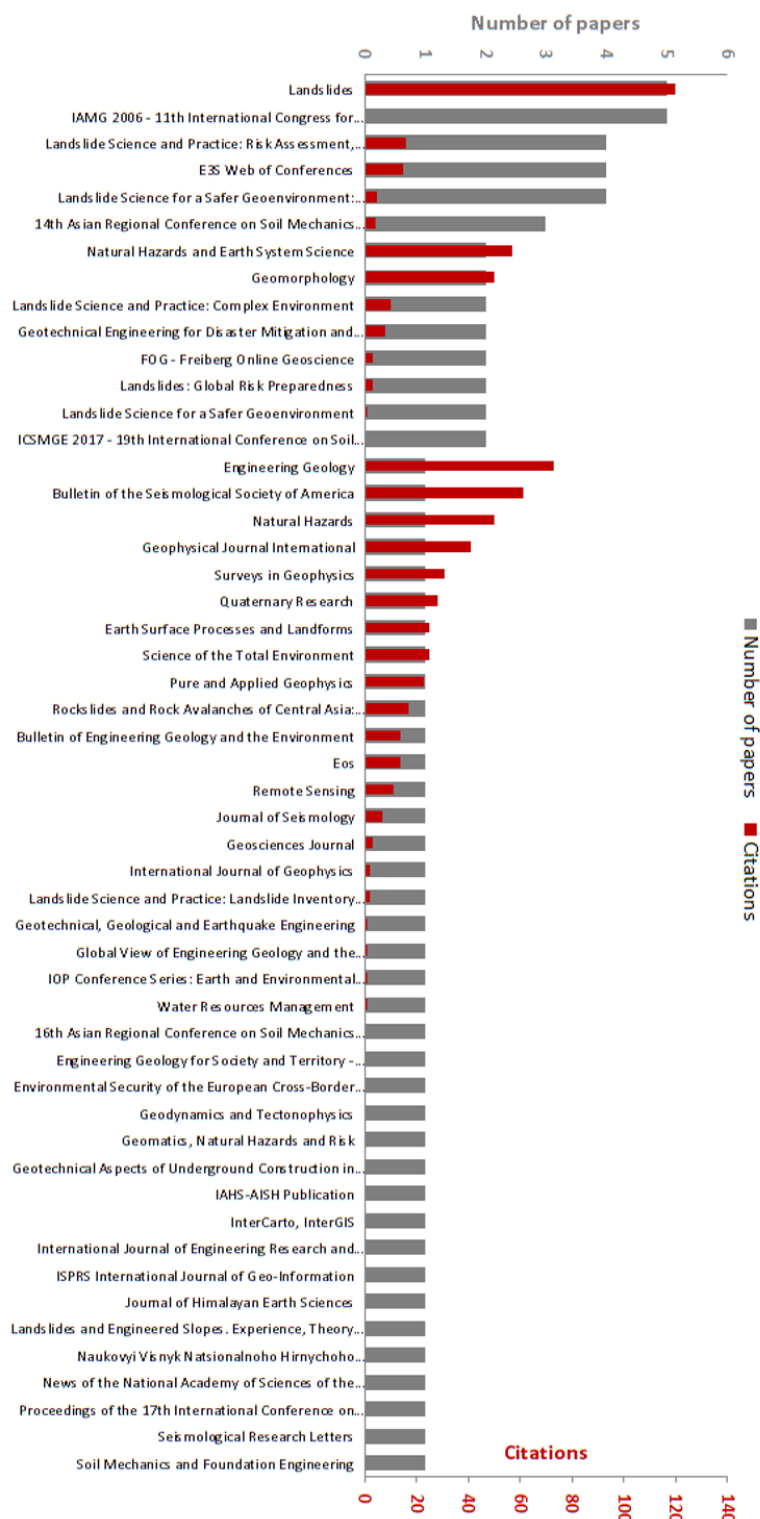


Fig. 4 Tendency of publishing source and citations in 2000–2020

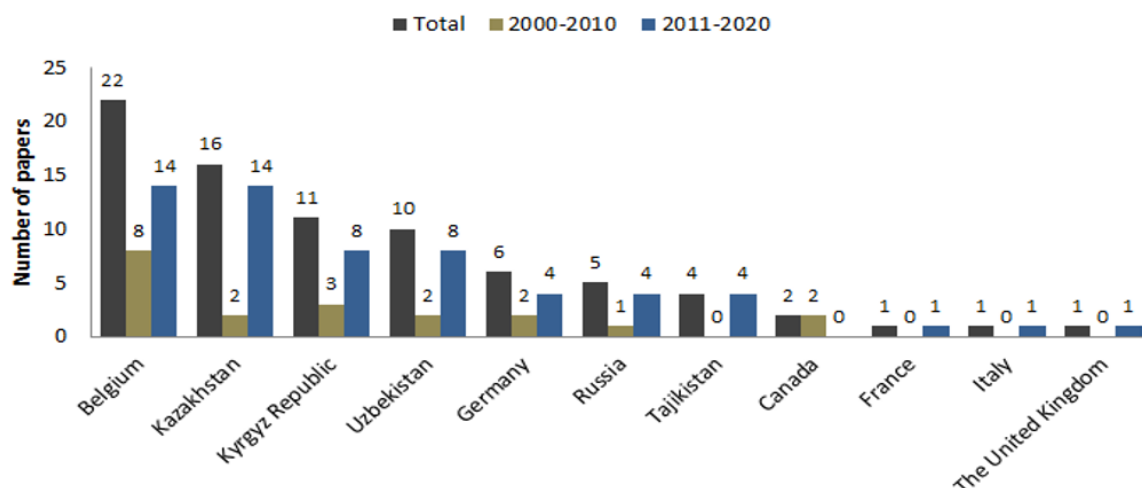


Fig. 5 Number publications per country during 2000–2020.

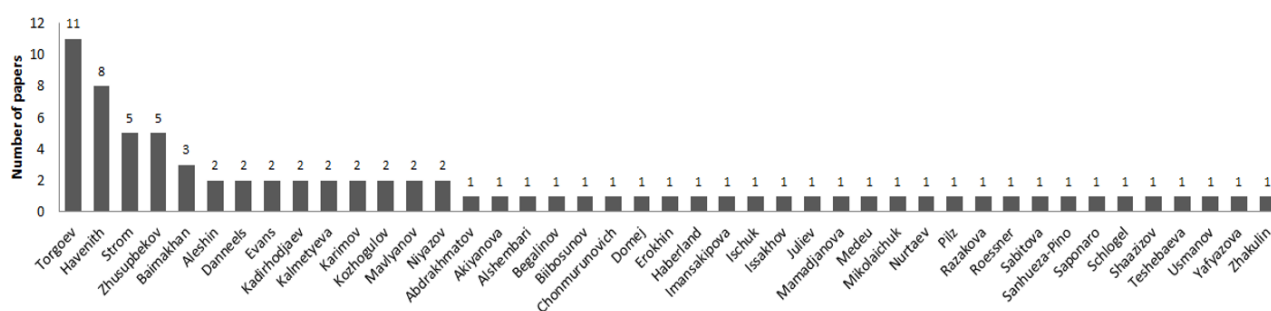


Fig. 6 Number written articles per author in 2000–2020 according to the first author.

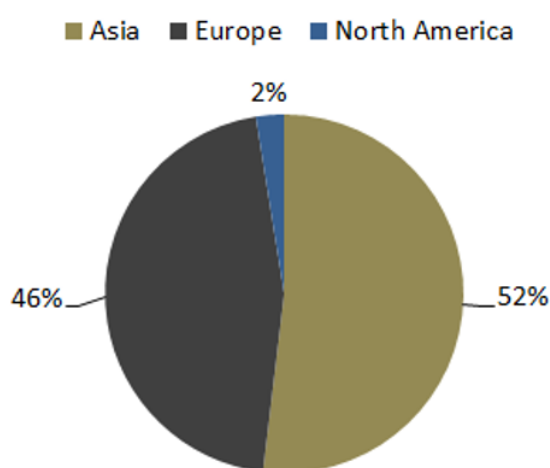


Fig. 7 Articles published by geographic regions.

2.3 Authors and their affiliated country

Our analysis showed that 43 authors from 11 countries conducted research on landslides during 2000–2020. The authors and their affiliated countries were selected to determine the number of publications according to the first author of the papers. Among them, Torgoev dominated with 11 publications, followed by Havenith with eight papers, Strom and Zhusupbekov with five papers, and Baimankhan with three research papers. Further nine authors authored two articles on landslides in Central Asia. Out of 43 researchers, 29 of them wrote one article within 2000–2020 (Fig. 6). It was identified that 11 countries, including Belgium, Kazakhstan, Kyrgyz Republic, Uzbekistan, Germany, Russia, Tajikistan, Canada, France, Italy, and The United Kingdom conducted research on landslides in Central Asia. The results showed that prevalence of affiliated countries is related to funding of the large funding schemes and programmes. For Belgium, for instance, Havenith was a coordinator of a number of projects in Kyrgyzs-

tan and Tajikistan (e.g. NIDECO, FP6 INC, NATO SFP) and had more articles than authors from other countries; in 2000–2010, eight papers were published, and during 2011–2020, there were 14 publications (Fig. 5). Scientists from Kazakhstan published 16 papers in total in two decades, two articles in the first decade, and 14 publications in the latter decade, respectively. In case of Kyrgyzstan, there were 11 articles, including three articles in 2000–2010, and eight papers in 2011–2020. During two decades, researchers from Uzbekistan published 10 articles; two publications in the first decade, and eight articles in the second decade (Fig. 5). German scientists published two and four papers in 2000–2010 and 2011–2020, correspondingly, whereas Russian researchers published five articles in two decades (Fig. 5). In the first decade, Tajikistan, France, Italy, and The United Kingdom had no articles published at all, whereas in the second decade there was only one article for each. Only Canadian scientists had not published any article on landslide in 2011–2020, but they had two articles published in the first decade (Fig. 5).

According to geographical references of the publications, similar share can be observed for countries in Asia (52%) and Europe (46%), whereas there was a negligible publication frequency by North American authors (2%) (Fig. 7).

In the second decade, there was a growth in the number of papers in Belgium, since numerous scientists from Central Asia affiliated with Belgian organizations have increased their research output. The reason behind this increase is the existing and ongoing scientific cooperation between Belgium and Central Asian countries.

In total, 723 citations were given to 79 publications published on landslide study by 11 countries in the last 20 years. It was found that Belgium was again dominant with 330 citations given to 22 publications. Noteworthy, papers with first authors from Germany received 140 citation for six papers (on average of 23 citations for each publications), whereas this figure was even better in the case

of Canada (123 citations received by two papers). Moreover, ten articles published by scientists from Uzbekistan had 49 citations in total, and each has around four to five citations in average. Publications by researchers from Kyrgyz Republic, Russia, Kazakhstan, Tajikistan, and the United Kingdom had a total of 38, 21, 16, four and two citations, correspondingly (Fig. 8).

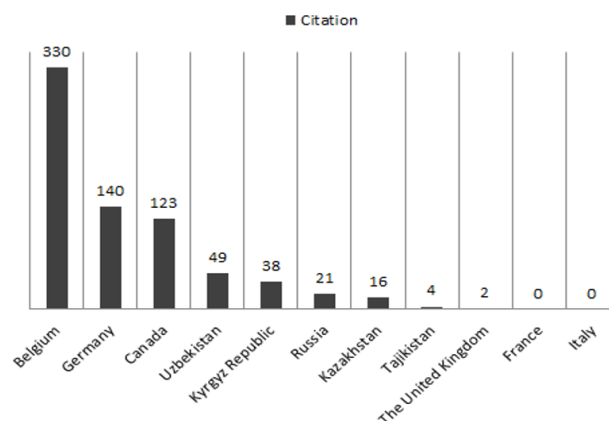


Fig. 8 Number of citations received by papers.

2.4 Methods used for landslide studies

Our evaluation showed that around 60–65% of the reviewed publications focused on the landslide studies of Kyrgyzstan. From the (Fig. 4) we can see that the main authors for the landslide studies in Central Asia are from Kyrgyzstan or authors coordinating different projects on landslide studies in Kyrgyzstan. The main reason for this, because 92% the territory of Kyrgyzstan occupied by Tien Shan and Pamir Alai mountain ranges. Therefore, this territory is very interesting study area for the foreign researchers. Several joint projects conducted during the last 2–3 decades funded by the several organizations. Given publications are the results of the projects held in Kyr-

Table 1 Methods employed in landslide studies in Central Asia

Methods	Description	Triggering factor	Types of landslide
Geotechnical	Soil characteristics, slope stability analysis	Mining activity and urbanization	Slides and flows
Geophysical	Seismic refraction, electrical resistivity tomography	Seismic and tectonic activity, man-made dams	Rockslides, rockfalls, debris flows, mudflows
Statistical	Landslide susceptibility mapping	Nuclear waste tailing dams, seismic and tectonic activity, precipitation, Glacial lake outburst floods (GLOFs)	Slides and flows

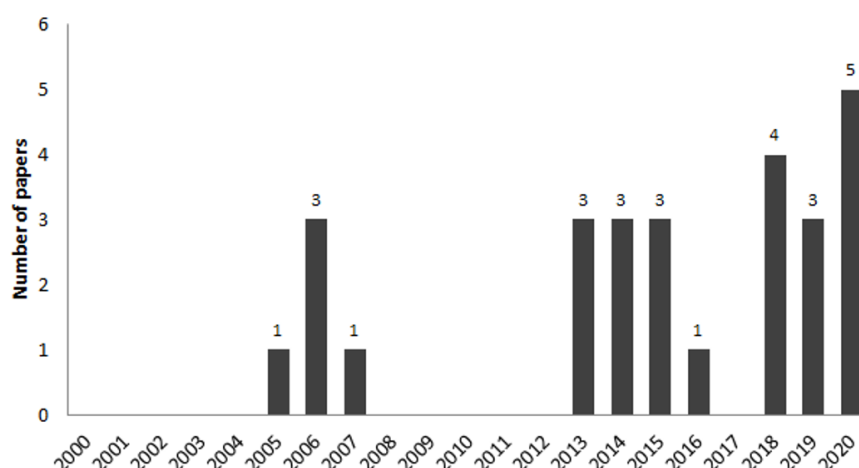


Fig. 9 Role of GIS and Remote Sensing in landslide studies during 2000–2020.

gyzstan. Mailuu-Suu is the main area for conducting the landslide studies shown in reviewed publications. Mailuu-Suu is a former uranium mining area at the border of the Fergana Basin. This area is prone to landslide occurrences (Havenith et al. 2006; Torgoev & Havenith 2013; Aleshin & Torgoev 2014). Given papers declaring the most deposits being involved to landslide activities are quaternary loess units (Torgoev et al. 2006; Nurtaev & Niyazov 2014; Juliev et al. 2019).

We have divided methods used for the landslide studies in Central Asia into three main groups: geotechnical, geophysical and statistical (Table 1). Geotechnical methods are mainly related to the soil characteristics and properties and their impact to the slope failure processes (Baimakhan et al. 2008; Kojogulov & Nikolskay 2008; Strom & Abdrakhmatov 2009; Zhusupbekov & Bogomolov 2009; Zhusupbekov et al. 2011a,b).

Geophysical methods are widely used in landslide studies. Seismic refraction and electrical resistivity tomography are the main geophysical methods employed for the seismic and tectonically active zones (Havenith et al. 2000, 2003; Danneels et al. 2008; Haberland et al. 2011; Torgoev & Havenith 2013; Nurtaev & Niyazov 2014; Havenith et al. 2015). Here we highlighted the importance of the Pamir Hindukush earthquake zone and its impact on the landslide occurrences in Central Asia region (Niyazov & Nurtaev 2013; Torgoev & Havenith 2013; Nurtaev & Niyazov 2014). According to Niyazov and Nurtaev (2013) most of large landslide events in Central Asia related to Pamir Hindukush earthquake zone.

Statistical methods mainly related with spatial analysis using GIS and RS techniques. Authors who

worked on the landslide susceptibility mapping using statistical methods frequently mentioned the issue of the data scarcity for the Central Asia region (Saponaro et al. 2015; Juliev et al. 2019). Several studies (70–85%) conducted on landslide susceptibility mapping used different statistical methods (Torgoev & Havenith 2013; Havenith et al. 2015; Saponaro et al. 2015; Kadirhodjaev et al. 2018; Juliev et al. 2019; Kadirhodjaev et al. 2020). Among the landslide triggers earthquakes and human intervention dominate, but glacial lake outburst floods (GLOFs) induced by climate change has also been widely studies in Tien Shan mountainous areas (Table 1; see also Section 3.6).

2.5 Role of GIS and RS in landslide studies

GIS and RS was not widely used in landslide studies until 2005, and they were used in five papers in 2005–2007; however, they were not used at all in papers published during 2008–2012. Researchers have started using GIS and remote sensing in their research since 2013, and these accounted for ten papers in our analysis. Scientists did not employ GIS and remote sensing in their landslide research during 2017; however, they were used in 12 articles during 2018–2020 (Fig. 9). Overall, it can be claimed that GIS and remote sensing have not been used at all in articles published for 11 years, and they have only recently been widely used in articles included in nine years of two decades.

As we discussed several methods in landslide studies, through 2000–2010 there was a restricted application of GIS and RS and geotechnical, geophysical and statistical methods were mainly used.

Fortunately, recent advances of GIS and RS technologies have accelerated the investigation process of landslides. This statement was proven in studies where GIS/RS was integrated with the three methods listed above (Table 1) and now the application of GIS/RS technologies has become inseparable with other methods.

2.6 Factors in landslide studies

Our analysis showed 56 conditions and factors affecting the occurrence and movement of landslides identified in 79 papers published in 2000–2020. The most commonly used factor was slope, which was considered in 42 publications (Table 2). Furthermore, earthquake was the second frequently considered factor in publications (18 papers). During the two decades, soil type was used in 15 articles, followed by previous mass movements (13 papers), precipitation and water dams (11 publications) (Roessner et al. 2005; Ischuk 2013). Moreover, rockfalls factor was observed in 10 articles, and researchers also explored land topography as a main factor in nine papers. Flooding, lithology and mudflow were only sparsely considered as factor in landslide research, each of them was appearing in seven articles during 2000–2020 (Strom & Abdrakhmatov 2014; Torgoev et al. 2014). Additionally, aspect and land use/land cover were taken as factor influencing landslide process, and each of those factors was used in five publications, whereas air temperature, distance to roads, mountain glaciers and seismicity were employed in over all 16 publications (Havenith et al. 2002; Zhusupbekov et al. 2013; Kalmet'eva et al. 2019; Alshembari et al. 2020; Zhakulin et al. 2020). Each of 11 factors, such as altitude, bedrock, curvature, terrain morphology, elevation, glacier erosion, ground motions, river distance, soil texture, unstable masses, and vibration, were used in three papers within 2000–2020 (Danneels et al. 2006, 2008; Torgoev & Havenith 2013; Torgoev et al. 2014; Torgoev & Havenith 2016; Zhakulin et al. 2020). Besides that, each of 12 factors were used once in two papers, whereas each of the remaining 16 factor was observed once in only one publication from 2000 to 2020. Out of 56 factors, researcher mostly used the first 11 factors shown in their landslide studies (Table 2).

Clearly, almost 60% of studies and investigations of landslides were considering slope a dominating factor for landslides. Evidently, this is the initial factor that needs to be considered for studying slides and flows in mountainous regions and while assessing landslide susceptibility zones. Notably, several

papers used various names for factors such as altitude, elevation and DEM. Our suggestion would be to refine the terminology for avoiding confusion across the disciplines.

Table 2 Factors in landslide studies in Central Asia

Factor	# of papers	Factor	# of papers
Slope	42	Anisotropy	2
Earthquake	18	Distance to faults	2
Soil type	15	Elastic deformations	2
Mass movement	13	Electrical tomography	2
Precipitation	11	Explosion	2
Water dams	11	Gravitational energy	2
Rockfalls	10	Permafrost rocks	2
Land topography	9	Seismic shaking	2
Flooding	7	Seismic tomography	2
Lithology	7	Shear-wave velocity	2
Mudflow	7	Site effects	2
Aspect	5	Soil moisture	2
Land use/	5	Concavity	1
Land cover		Convexity	1
Air temperature	4	Ground failure	1
Distance to roads	4	Ground thickness	1
Mountain glaciers	4	Groundwater pressure	1
Seismicity	4	Irrigation	1
Altitude	3	NDVI	1
Bedrock	3	Synchronicity	1
Curvature	3	Tectonics	1
DEM	3	Teleseismic events	1
Elevation	3	Topographic wetness index	1
Glacial erosion	3	Valley depth	1
Ground motions	3	Water movement	1
River distance	3	Water table	1
Soil texture	3	Wave	1
Unstable masses	3	Wave spectra impact	1
Vibration	3		

3 Conclusion

Reviewed publications on landslide studies in Central Asia has increased considerably since 2013, averagely two articles per year between 2000 and 2010 to nearly six articles between 2011 and 2020, giving a 300% growth. This increase could potentially be owing to the advances of GIS and remote sensing, diverse model approaches, open data source availability, and the raised awareness of the importance of scientific stake on locating such risky areas for improved land planning and mitigating or averting a negative aftermath of landslides. To discern the trends of the promotion of GIS and RS in landslide studies in Central Asia was one of our objectives in this paper. Evidently, GIS and remote sensing had not been much used at all in articles published between 2000 and 2010, and they have progressively been used in studies included in last nine years. Consequently, it is affirmative to witness that the role of GIS and RS is gradually increasing, meaning that the regional scientists come to follow the track gone behind globally. As 56 conditions and factors considered in landslide studies in Central Asia between 2000 and 2020, slope factor was deemed as a dominant condition for landslides, followed by earthquake, soil type, and mass movement. Since these phenomena are observed in mountainous landscapes and tectonically active zones, Central Asia is one of the potential areas, reasonable to consider these two factors, whereas applicability of other listed factors is yet in debate in the example of Central Asia. To conclude, 79 papers for five different nations within 20 years are not sufficient to cover the entire problem related to landslide studies. Therefore, it is highly recommended to create additional research environment around this regional problem in the short-term.

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