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Candan Gokceoglu · Ebru Sezer

A statistical assessment on international landslide literature (1945–2008)

Abstract In the present study, the analysis of the international landslide literature is aimed. The landslide is perhaps one of the most complex natural phenomena. Also, due to landslides, a considerable amount of loss of lives and economic losses is encountered throughout the world. Although a vast amount of landslide papers is published in international journals, a statistical assessment on this literature is not encountered. For this reason, this study is performed. For the assessment of the international landslide literature, the Science Citation Index Expanded (WOS; Web of Science) published by Institute of Scientific Information (now Thomson Scientific), USA for the period 1945–2008, is considered. A total of 3,468 publications are found and this data is stored into Oracle XE database and queried by using Structured Query Language and Procedural Language/Structured Query Language. In the following stages, some statistical analyses are performed and the possible trends are discussed.

Keywords Landslide · Earth surface process · Database · Scientometrics assessment

Introduction

According to Varnes (1978), the term “landslide” describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of them. This phenomenon is a natural earth surface process before the appearance of *Homo sapiens* on Earth. However, millions of years later, the human presence transformed the natural events into natural disasters (Alcantara-Ayala 2002). As a result of landslide activity throughout the world, in the period of 1990–1999, total 8,658 person died according to EM-DAT database. EM-DAT contains essential core data on the occurrence and effects of over 16,000 mass disasters in the world 1900 to present (<http://www.emdat.be>). Approximately 90% of these deaths occurred within the Circum Pacific Region (Aleotti and Chowdhury 1999). In other words, the global death toll due to natural disasters is concentrated in developing countries (also called Third World Countries), and it can be as high as 95% of the total toll (Alexander 1994). In addition to deaths, landslides have important detrimental effects on roads, buildings, lifelines, water quality of lakes, and rivers etc. It is evident that natural hazards cannot be prevented, but the understanding of the process and scientific methodologies to predict pattern of behavior of such processes can be powerful tools to help reduce natural vulnerability (Alcantara-Ayala 2002). Recently, a considerable increase in international landslide literature has been observed because scientific investment to decrease the losses sourced from landslides has been provided by decision makers. It is necessary to make a general assessment of this literature by scientometrics methods. For this reason, the main goals of the present study are

to analyze international landslide literature by statistical and scientometrics methods, and to discuss the trends in the landslide literature. For the purpose of the study, the data was compiled from the Science Citation Index Expanded (WOS; Web of Science) published by Institute of Scientific Information (now Thomson Scientific), USA for the period 1945–2008 (Web of Science 2008). Then, these data was stored to Oracle database and some necessary queries and procedures were developed. In the following stages, some statistical analyses were performed and the results were discussed.

Method

For the assessment of the international landslide literature, the Science Citation Index Expanded (Web of Science) published by Institute of Scientific Information (now Thomson Scientific), USA for the period 1945–2008, was used. Before the search process, the keywords were selected to collect the landslide literature from WOS. They were taken from the classification proposed by Varnes (1978). These keywords are “landslide”, “rock fall”, “rotational slump”, “planar block slide”, “rock slide”, “earth flow”, and “debris flow”. In the first stage of the search, the data searched using these keywords were downloaded from the ISI website (www.isinet.com). Table 1 shows number of records of each keyword. As a result of this search, a total of 3,721 records were obtained. However, some records can be obtained from different keywords and some records were obtained from different keywords more than once, means “duplication”. To eliminate these duplications, similar records were reduced into one record. As a result of this process, a total of 3,468 records were obtained for the analysis. We estimate that our data contains over 95% of the international landslide publications in the period 1945–2008. The complete data set was put into a database, the Oracle. To perform the analyses, some queries and procedures were developed. Statistical results were obtained by using Structured Query Language, SQL queries. Some attributes of WOS records were organized as comma-separated as AU meaning authors and DE meaning keywords. They were fragmented by using Procedural Language/Structured Query Language, PL/SQL procedures. PL/SQL is a procedural extension of SQL used in Oracle databases. Especially, when applying keyword fragmentation, many different writing styles of the keywords were observed. They were put into the high style by manual editing to get correct statistical results including them.

There are three main tables are related with each other, such as publications, authors, and keywords. Each publication was stored with unique ID, each author was stored with his/her publications IDs and each keyword was stored with publications IDs where it was published. The queries and procedures developed in the present study were stored into scripts.

Table 1 Number of records of the search key words used in the study (the period of 1945–2008)

Keyword	Number of record
Landslide	2,823
Rock fall	302
Rotational slump	28
Planar block slide	5
Rock slide	127
Earth flow	46
Debris flow	390

Analysis

Trend in number of publication

In the period of 1945–1974, the annual average number of publication about landslide is only one. The first jumping in the average number of landslide publication is observed in 1975. In this year, a total of 11 papers were published. Between the years of 1975–1986, the annual average number of publication is 11. After 1987, a sharp increase exists to present, and the annual average reaches 150 (Fig. 1). In general, this pattern of changes in the international landslide literature over the years is similar to that of the total publication output from the world.

Publication platform

Total 3,468 papers were published in 606 different publication platform. The journals publishing landslide papers mostly are listed in Table 2. “Geomorphology”, “Engineering Geology”, “Earth Surface Processes and Landforms”, “Landslides”, “Canadian Geotechnical Journal”, and “Environmental Geology” (Table 2). The total citations of the journals are also given in Table 2. According to this statistical assessment, the articles published in “Geomorphology”, “Engineering Geology”, “Earth Surface Processes and Landforms”, and “Geology” were mostly cited. However, this assessment shows the total citations. If making another assessment considering average citation per article, the articles in “Geology”, “Journal of Geophysical

Research”, and “Quaternary Science Reviews” have the higher impacts than the others (Table 2). Although “Landslides” journal is a directly thematic journal about landslides, the number of citations and the average citation per publication are highly low. The main cause of this situation is sourced from the publication date of the articles. This journal has been published since 2005. In other words, when comparing with the other journals, the articles published in Landslides are rather new. For this reason, in the next years, it may be expected that the total citations of the articles in “Landslides” increase. In Table 2, the average citations per landslide publications and the Journal Impact Factor (JIF) are shown. A linear relationship between the average citations per landslide publication and the JIF was found ($r=0.82$). This showed that the landslide publications provided important contribution to the JIF.

Key words

A total of 4,898 key words were used in the articles. Naturally, the mostly used keywords are landslide and debris flows. The other most frequently used key words are landslide hazard, GIS, slope stability, rock fall, earthquake, and landslide susceptibility. Especially, landslide hazard, GIS, and landslide susceptibility concepts have been used for the last decade depending on the development on digital cartography and information technologies. This part will be discussed in the subsequent chapter in detail.

Fig. 1 The annual number of landslide publications

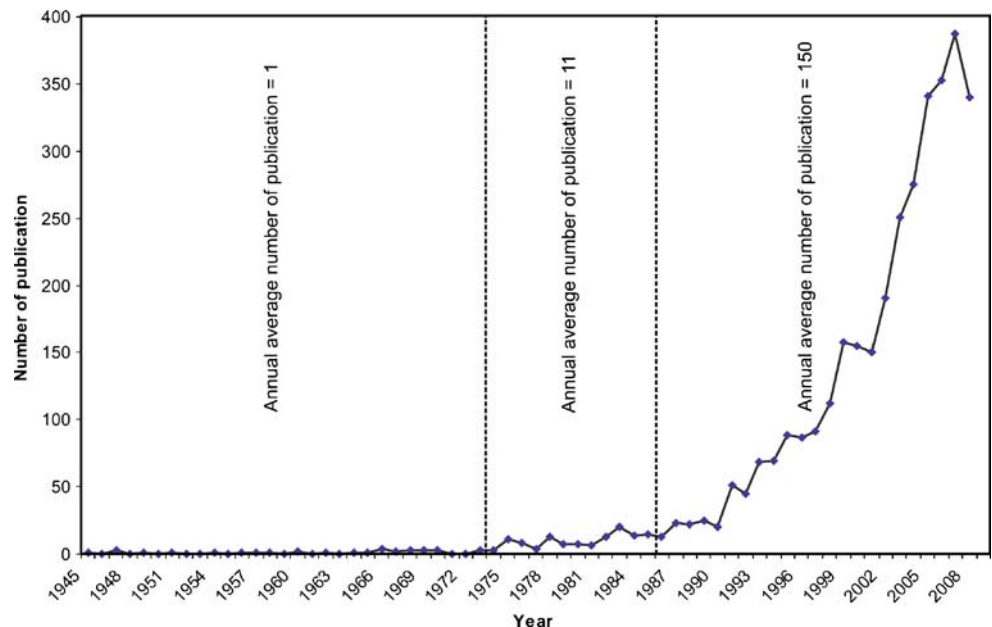


Table 2 The journals frequently used by the landslide researchers (the period of 1945–2008)

Journal	Total publications	Total citations	Average citations per pubs	Journal IF (2008)
Geomorphology	367	3,338	9.10	1.854
Engineering Geology	299	2,620	8.76	0.951
Landslides	132	147	1.11	0.986
Earth Surface Processes and Landforms	131	1,742	13.30	1.917
Canadian Geotechnical Journal	125	1,237	9.90	0.542
Environmental geology	104	622	5.98	0.722
Natural hazards	92	431	4.68	1.015
Natural hazards and earth system sciences	87	236	2.71	1.021
Environmental & Engineering Geoscience	56	298	5.32	0.271
Journal of Volcanology and Geothermal Research	48	892	18.58	1.742
Marine Geology	41	553	13.49	1.975
Geology	40	960	24.00	3.754
Journal of Geophysical Research-Solid Earth	39	892	22.87	2.953
Geophysical Research Letters	37	422	11.41	2.744
Quarterly Journal of Engineering Geology and Hydrogeology	37	114	3.08	0.685
Zeitschrift fur Geomorphologie	34	260	7.65	1.250
Geological Society of America Bulletin	32	570	17.81	3.354
International Journal of Remote Sensing	30	175	5.83	0.987
Bulletin of the Seismological Society of America	29	270	9.31	1.743
Catena	29	241	8.31	1.346
Quaternary International	28	124	4.43	1.468
Earth and Planetary Science Letters	27	352	13.04	3.873
Pure and Applied Geophysics	27	247	9.15	0.860
Quaternary Science Reviews	26	533	20.50	4.110
Bulletin of Volcanology	26	419	16.12	2.065
Bulletin of Engineering Geology and the Environment	26	32	1.23	0.463
Hydrological Processes	25	241	9.64	1.798
Current Science	25	29	1.16	0.800
Soils and Foundations	25	12	0.48	0.560

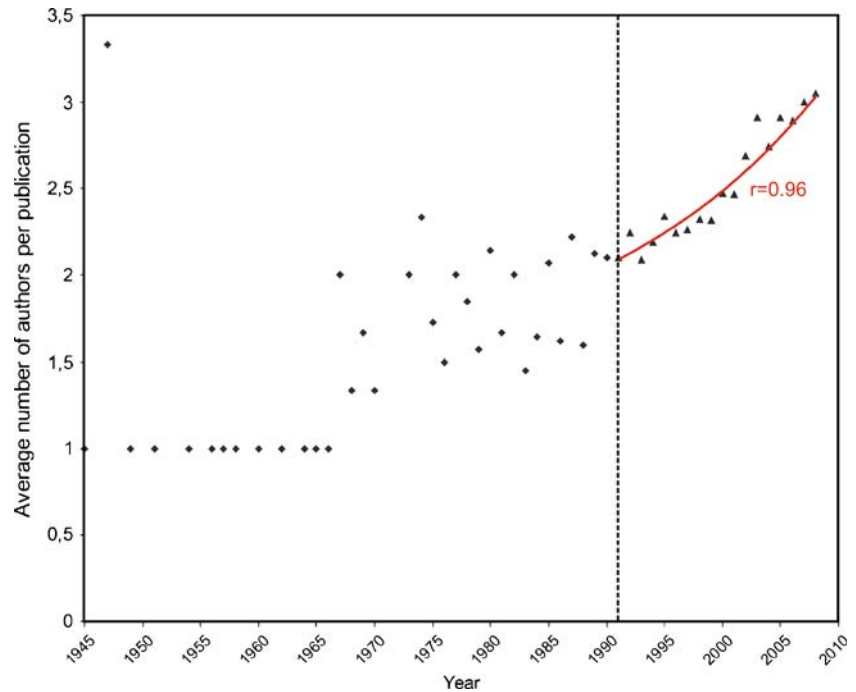
Authors

An author analysis was performed in the present study. In the world landslide literature in the period of 1945–2008, a total of 6,650 authors have published the articles about the landslides. To assess the authorship, the Lotka's law is considered. Lotka's Law (Mehta 2005) describes the frequency of publication in a given field and it states that "... the number (of authors) making n contribution is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60%". This means that out of all the authors in a given field, 60% will have just one publication, and 15% will have two publications ($(1/2)^2 \times 60$), 7% authors will have three publications ($(1/3)^2 \times 60$), and so on (Mehta 2005). In the database used in this study, 5,055 authors have one publications and the share of these authors is 76.0% while those having two publications is 13.4%. Of all authors, 4.2% have three contributions. These values show a general agreement with the Lotka's Law. However, a slight deviation is observed between the authors having high number of publications and the values obtained from the Lotka's law.

The number of authors per publication and year graph is given in Fig. 2. In the first period (1945–1966), almost all papers were written by single author. In addition, in this period, number of the average yearly publication is only one. For this reason, it is impossible to perform a statistical analysis. In the second period (1967–1990), although a rough increasing trend in the number of the average author per article was observed, the data was clearly scattered. However, after 1990, a salient increasing in the number

of average authors per article was found. In 1991, the number of average authors per article is 2.09 while this value increases to 3.05. Between the years of 1991 and 2008, an exponential relationship between the number of average authors per publication and year, with a coefficient of correlation of 0.96, was obtained. In fact, as the other scientific research areas (e.g. hydrogen energy researches (Tsai 2008)), this shows the importance of team works and multidisciplinary studies. According to Abt (2007), the science fields have evolved rapidly into team efforts in which the average number of authors per paper is increasing rapidly. This is largely because research projects are becoming more complex and require the expertise of people of different capabilities (Abt 2007). In addition, the trend of increasing multi-authorship is a well-established phenomenon observed on the international level (e.g., Sampson 1995; Bird 1997; Gokceoglu et al. 2008). Our findings are in a good accordance with the findings of Abt (2007) and Tsai (2008). In the landslide literature, the most productive authors with their impacts are given in Table 3. A total of 44 authors having ten or more publications were detected in the landslide literature. Total citations of these authors are 7,313 while the minimum and maximum total citations are 11 and 489. F. Guzzetti from Italy is the most cited author. However, in this study, the average citation per publication was considered. According to this assessment, N. Hovius from England has the highest impact with the average citations per publication of 40.70. The average citation per publication of 44 most productive authors are between 1.10 and

Fig. 2 The graph between the average number of authors per landslide publication and the year



40.70. Among the most productive 44 authors, 11 authors from Italy; six authors from Canada; four authors from USA and France; three authors from Republic of China, Japan, England, and Spain; two authors from Switzerland; and one author from South Korea, Turkey, Scotland, Taiwan, and Belgium were detected (Table 3). When considering top ten authors having the highest impact, three authors from Italy and USA, two authors from England, and one author from Republic of China and Scotland were encountered. This result is not surprising for the most productive Italian researchers but it was interesting for the most productive USA researchers, because among the most productive 44 authors, four authors exist in the top ten authors having the highest impact list (Table 3). When considering these results, it is possible to say that the leading landslide researchers are from Italy, USA, and England.

Subject analysis

To display the trends in landslide literature, the yearly frequencies of key words were considered. However, each record in WOS does not include key words before 1990. For this reason, in the first stage, the key words of the articles in the period of 1990–2008 were compiled and the key words most frequently used were searched in titles and abstracts. The main reason of this process is to find the pioneer studies in the landslide literature. In the period of 1990–2008, the most frequently used key words are landslide, debris flow, landslide hazard, GIS, slope stability, rock fall, earthquake, landslide susceptibility, rainfall, tsunami, landslide risk, and natural hazard. Landslide, debris flow and rock fall are expected because these terms are among the search key words of the data used in this study. The key words of landslide hazard, landslide susceptibility, landslide risk, and natural hazard are the type of landslide assessment while GIS and slope stability are the analysis techniques. Earthquake and rainfall are the main landslide triggers while tsunami is consequence of submarine landslides. In the second stage, the frequently used key words in the period of 1990–

2008 were searched in titles and abstracts of all records, and the results obtained were assessed. The most frequently used words in the titles and the abstracts are slide, landslide, slope, area, model, flow, rock, fall, debris, and analysis. To encounter frequently these words are normal but this does not provide an idea about the trends of landslide studies, because these are classical terms in the landslide literature. In fact, to provide a realistic assessment on the trend of the landslide literature, the most cited articles should be considered.

Among the landslide publications, the article entitled “A physically-based model for the topographic control on shallow landsliding” (Montgomery and Dietrich 1994) is the most cited publication with a total citation of 221. This result was normal because this study was the first attempt to describe the analysis of shallow landsliding and these types of movements are encountered frequently. The second most cited article is published by Ancochea et al. (1990). However, its main subject is not directly related with the landslide. Its main subject is the volcanic evolution of the Island of Tenerife. When describing the volcanic evolution, the authors considered the debris avalanches created by volcanic activity. The main citation sources of this paper are the papers about volcanic activity. The other most cited articles were published by the same research group from Italy (Carrara et al. 1991; Guzzetti et al. 1999). Especially, the paper published by Carrara et al. (1991) is one of the pioneer studies in the landslide literature because the main subject of this paper was the use of GIS technique for landslide hazard zonation. The other most cited article published by the same research group (Guzzetti et al. 1999) is not a pioneer study but it is a highly comprehensive study for landslide hazard zonation studies. All most cited articles (total citation >100) are given in Table 4. According to Table 4, a total of 16 articles were taken at least 100 citations. Three of these articles were published in “Water Resources Researches” while two of them were published in “Earth Surface Processes and Landforms”. In general, three

Table 3 The most productive authors in the landslide literature

Author	Country	Total publications	Total citations	Average citations per pubs
Lee, CF	Republic of China	30	400	13.33
Lee, S	South Korea	27	365	13.52
Guzzetti, F	Italy	24	489	20.38
Sassa, K	Japan	21	60	2.86
Korup, O	Switzerland	20	124	6.20
Malet, JP	France	19	96	5.05
Reichenbach, P	Italy	17	414	24.35
Masson, DG	England	17	360	21.18
Hungr, O	Canada	17	199	11.71
Poesen, J	Belgium	16	80	5.00
Maquaire, O	France	16	133	8.31
Evans, SG	Canada	16	211	13.19
Stoffel, M	Switzerland	15	87	5.80
Pasuto, A	Italy	15	130	8.67
Watts, P	USA	14	330	23.57
Corominas, J	Spain	14	206	14.71
Petley, DN	England	13	48	3.69
Jakob, M	Canada	13	175	13.46
Gokceoglu, C	Turkey	13	135	10.38
Crosta, GB	Italy	13	70	5.38
Cardinali, M	Italy	13	289	22.23
Wasowski, J	Italy	12	43	3.58
Tinti, S	Italy	12	133	11.08
Sidle, RC	Japan	12	154	12.83
Parise, M	Italy	12	100	8.33
Jibson, RW	USA	12	153	12.75
Dai, FC	Republic of China	12	244	20.33
Cruden, DM	Canada	12	26	2.17
Clague, JJ	Canada	12	105	8.75
Casagli, N	Italy	12	91	7.58
Ballantyne, CK	Scotland	12	194	16.17
Silvano, S	Italy	11	82	7.45
Sauer, EK	Canada	11	86	7.82
Montgomery, DR	USA	11	241	21.91
Guglielmi, Y	France	11	55	5.00
Chen, H	Taiwan	11	82	7.45
Wang, SJ	Republic of China	10	11	1.10
Pieraccini, M	Italy	10	65	6.50
Marti, J	Spain	10	124	12.40
Hovius, N	England	10	407	40.70
Fukuoka, H	Japan	10	28	2.80
Dietrich, WE	USA	10	264	26.40
Delacourt, C	France	10	129	12.90
Cendrero, A	Spain	10	95	9.50

types of subjects are mostly cited in the landslide literature. The first one of these subjects is the regional landslide susceptibility and hazard assessments while the relationships between the landslides and geomorphology are the second hot topic. The last one is the effects of lithologic and tectonic features on the landslide development.

Results and discussions

The results and conclusions obtained from the present study can be summarized as follows:

1. When applying the trend analysis, the three periods were considered. In the first period, the average annual publication

was one while the average annual publication increased to 11 in the second period. In the last period, the average annual publications reached to 150. Generally, we expect that this pattern of changes in the international landslide literature over the years is similar to that of the total publication output from the world.

2. A total of 3,468 publications were published in 606 different publication platform. However, the journals of “Geomorphology”, “Engineering Geology”, “Earth Surface Processes and Landforms”, “Landslides”, “Canadian Geotechnical Journal”, and “Environmental Geology” are the platforms publishing the landslide papers frequently. In addition, the articles published in “Geomorphology”, “Engineering Geology”,

Table 4 The publications having more than 100 citations in the landslide literature

Total citations	Title	Authors	Journal	Year	Volume	Page numbers
221	A physically-based model for the topographic control on shallow landsliding	Montgomery, DR; Dietrich, WE	Water Resources Research	1994	30	1153–1171
206	Volcanic evolution of the island of Tenerife (Canary-Islands) in the light of New K-AR data	Ancochea, E; Fuster, JM; Ibarrola, E; Cendrero, A; Coello, J; Hernan, F; Cantagrel, JM; Jamond, C	Journal of Volcanology and Geothermal Research	1990	44	231–249
171	GIS Techniques and statistical-models in evaluating landslide hazard	Carrara, A; Cardinali, M; Detti, R; Guzzetti, F; Pasqui, V; Reichenbach, P	Earth Surface Processes and Landforms	1991	16	427–445
161	Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy	Guzzetti, F; Carrara, A; Cardinali, M; Reichenbach, P	Geomorphology	1999	31	181–216
155	Sediment flux from a mountain belt derived by landslide mapping	Hovius, N; Stark, CP; Allen, PA	Geology	1997	25	231–234
132	Analysis of erosion thresholds, channel networks, and landscape morphology using a digital terrain model	Dietrich, WE; Wilson, CJ; Montgomery, DR; McKean, J	Journal of Geology	1993	101	259–278
124	Stochastic forcing of sediment supply to channel networks from landsliding and debris flow	Benda, L; Dunne, T	Water Resources Research	1997	33	2849–2863
119	Debris-flow mobilization from landslides	Iverson, RM; Reid, ME; LaHusen, RG	Annual Review of Earth and Planetary Sciences	1997	25	85–138
109	The last glacial maximum of Svalbard and the Barents Sea area: Ice sheet extent and configuration	Landvik, JY; Bondevik, S; Elverhoi, A; Fjeldskaar, W; Mangerud, J; Salvigsen, O; Siegert, MJ; Svendsen, JI; Vorren, TO	Quaternary Science Reviews	1998	17	43–75
107	A distributed slope stability model for steep forested basins	WU, WM; SIDLE, RC	Water Resources Research	1995	31	2097–2110
107	Petrology of submarine lavas from Kilaueas Puna Ridge, Hawaii	Clague, DA; Moore, JG; Dixon, JE; Friesen, WB	Journal of Petrology	1995	36	299–349
106	Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in Western Oregon	Nakamura, F; Swanson, FJ	Earth Surface Processes and Landforms	1993	18	43–61
105	Corrugated slip surfaces formed at ridge-transform intersections on the Mid-Atlantic Ridge	Cann, JR; Blackman, DK; Smith, DK; McAllister, E; Janssen, B; Mello, S; Avgerinos, E; Pascoe, AR; Escartin, J	Nature	1997	385	329–332
105	Real-time landslide warning during heavy rainfall	Keefer, DK; Wilson, RC; Mark, RK; Brabb, EE; Brown, WM; Ellen, SD; Harp, EL; Wiczorek, GF; Alger, CS; Zarkin, RS	Science	1987	238	921–925
102	Supply and removal of sediment in a landslide-dominated mountain belt: Central Range, Taiwan	Hovius, N; Stark, CP; Chu, HT; Lin, JC	Journal of Geology	2000	108	73–89
101	A giant landslide on the north flank of Tenerife, Canary Islands	Watts, AB; Masson, DG	Journal of Geophysical Research-Solid Earth	1995	100	24487–24498

“Earth Surface Processes and Landforms”, and “Geology” were mostly cited. This shows that there is a good correlation between the number of publications and number of total citations for a journal.

- When considering the most cited papers of the international landslide literature, the papers published in “Water Resources Researches” and “Earth Surface Processes and Landforms” were generally mostly cited. These publications contribute the increase of the impact factor of journal.
- A key word analysis was performed to investigate the possible trends in the international landslide studies. The most frequently used key words are landslide, debris flow, landslide hazard, GIS, slope stability, rock fall, earthquake, landslide susceptibility, rainfall, tsunami, landslide risk, and natural hazard. This result shows that the increasing trend in the regional landslide susceptibility and hazard assessments is expected. The other main subject is the landslide evolution.

Regional assessment of landslide hazard and susceptibility contributes directly to landslide hazard mitigation. For this reason, to find some funds to work about these subjects is easy for the researchers when comparing the other subjects of the landslides.

- In the near future, the other innovative researches about the landslides may be expected. These researches are the assessment of landslide risk, prediction of runout and time of landslides, and early warning systems. To reach such type purposes, the anatomy and mechanisms of the landslides should be clearly known. For this reason, an increase in the studies on the landslide evolution may be expected. However, the landslide is perhaps one of the most complex natural phenomena in the nature. Due to this complexity, there is still a long way to understand this natural process. To reach the target and to minimize the losses caused by the landslides, the researchers should make much more investigation and publish

their results. Additionally, the extra funds throughout the world need to be provided.

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C. Gokceoglu

Department of Geological Engineering, Hacettepe University,
06800 Beytepe,
Ankara, Turkey
e-mail: cgokce@hacettepe.edu.tr

E. Sezer

Department of Computer Engineering, Hacettepe University,
06800 Beytepe,
Ankara, Turkey