



Article

Quantitative Analysis of Tectonic Geomorphology Research Based on Web of Science from 1981 to 2021

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Abstract: Tectonic geomorphology is an important research area that uses multisource data to quantify the landscape response induced by the interaction between the tectonic uplift and climate changes. In this study, a comprehensive and quantitative analysis using bibliometric and scientometrics based on the research areas, countries, institutions, journals, authors, keywords, and citations is carried out, which provides an exhaustive history of tectonic geomorphology, and points out the hotspots and trends in the research area. A total of 2796 papers and 110,111 references from 1981 to 2021 are collected from Science Citation Index-Expanded (SCI-E) as the main data source. The results show that with the development of remote sensing, tectonic geomorphology, and the improvement of instruments and equipment, the amount of tectonic geomorphology analysis has been increasing. The journal *Geomorphology* is one of the most popular journals in this field. Through the co-occurrence network analysis, 12 clusters are identified in which the most popular research hotspot in tectonic geomorphology research is how to constrain the rates of active faulting using geomorphic indices. Through literature co-citation analysis, 13 research directions are extracted in which an important trend is to investigate the response of drainage divide migration to the fault slip rates. With the help of remote sensing data, physical attributes, and contextual knowledge, the reliability of measuring uplift rates under tectonic and climate changes has been increased. A future suggestion is to use multi-source heterogeneous data fusion to conduct quantitative analysis for tectonic geomorphology research.

Keywords: tectonic geomorphology; bibliometrics analysis; Web of Science; global trends; fluvial landforms



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1. Introduction

The fluvial process is one of the main manifestations of tectonic movements reshaping the surface morphology, mainly in the form of river erosion, sediment transport, and material deposition [1–3], which has prompted researchers to use fluvial geomorphology to study the bedrock uplift in active orogenic belts [4–6]. For example, uplift of bedrock or base-level fall can accelerate river erosion and migrate upstream by anadromous erosion, resulting in the channel slope and width changes [7–10]. Rivers take a long time, sometimes tens of millions of years, to make the landscape return to its original equilibrium. The disequilibrium leads to the formation of transient geomorphic marker points, namely, knickpoint, which is used to show the slope difference on both sides of the knickpoint induced by the base-level fall [4,11–13]. With the advent of remote sensing, the dynamic monitoring and assessment of the global landscape's evolution caused by tectonics and climate have greatly accelerated the process of field sampling and have become important research components in tectonic geology.

Tectonic geomorphology is a multidisciplinary research area, which combines physical geography, geomorphology, tectonic geology, chronology, petrology, etc. Considering the limitations of predicting the long-term changes in active faulting based on transient landscape response, many new areas in tectonic geomorphology have been studied in recent years that combine fluvial landform theories and stream power incision model (SPIM), e.g., drainage divide migration [14–17], height and age of fluvial terrace [18], stream power [2,7], boundary shear stress [7], and rock strength [16], etc. Multi-sensor data sources, such as optical satellite images, aerial remote sensing images, high-resolution drone airborne images, SAR satellites images, LiDAR, and ground observations, help calculate river incision and tectonic uplift rates [19–22]. The increase in data sources and resolution has led to significant improvement in the methods and accuracy of tectonic geomorphic indices acquisition. Through the continuous observation from remote sensing, the field investigation time can be greatly shortened, and the measurement accuracy of tectonic uplift rates can be improved. As a result, tectonic geomorphology has become an important tool for regional tectonic evolution study and disaster forecast analysis. Although the tectonic geomorphology studies are increasing, not all of them can constrain the uplift rate or reveal the geomorphic evolution causes, even predict the trends of tectonic stress. How to select the cutting-edge research hotspots from these studies is the critical choice that researchers should consider. Therefore, there is a need to sort out the hotspots and trends in tectonic landform research.

Bibliometrics and scientometrics are quantitative tools that help researchers quickly sort out research hotspots and trends by systematically visualizing the co-occurrence network of articles, categories, journals, countries, authors, institutions, and citations, etc. [23–25]. These tools integrate computing, big data, and statistics to analyse research hotspots and trends [26–28]. Specifically, scientometrics can analyse the current research hotspots based on keyword clustering, while bibliometrics can predict the future research trends based on the knowledge map of references [25,29–31]. Nevertheless, these tools have a high demand for the literature and citations to be included in the analysis, which needs to be reasonably selected to obtain a reliable understanding.

In this study, with the help of Biblioshiny, Citespace, and VOSviewer software, the status, development, hotspots, and trends of the tectonic geomorphology research are analyzed using the articles collected from the Web of Science in 1981–2021. The main contributions of this study: (1) identifying the hotspots of the tectonic geomorphology research; (2) predicting the trends of the tectonic geomorphology research; (3) making reasonable suggestions for tectonic geomorphology research.

2. Data Collection

As the Web of Science offers citation indexing of the natural and social sciences in the whole world, we choose the Web of Science Core Collection as the main data source. After expert consulting and extensive literature reading, we select the tectonic geomorphology research to conduct the bibliometrics and scientometrics analysis. We conduct an anonymous questionnaire to extract the keywords with high frequency from 20 representative professors who major in tectonic geomorphology research in China. We also select some tectonic geomorphology articles and reviews with high citations according to the suggestion from the questionnaire. As the keywords can often represent and generalize, the frequency statistics and analysis of keywords can be used to reflect the hotspots and trends of the specific research [32]. According to the questionnaire and literature reading, the keywords with top frequency are counted to form the search strategy in this study, which is determined as “Tectonic geomorphology or Tectonic landforms or Structural landform or Morphotectonic or Transient landscape or Drainage landscape”. The database was updated on 31 December 2021, and a refined selection was made. The language of these articles and documents was chosen as English. The records of this database include the title, author, affiliation, abstract, keywords, manuscript, and references.

Each document can be classified into the corresponding categories according to the article, author, journal, countries, journals, and citation, etc.

3. Method

We selected the R 4.1.3, CiteSpace 6.1.R2, and VOSviewer 1.6.18 software as the main analysis tools to show and visualize the results. Firstly, based on the R language, a useful web interface named “Biblioshiny” was produced by K-Synth Team [33]. This tool is interactive and can visualize the relationship and distribution of the sources, authors, keywords, institutions, countries, and citations, etc. Biblioshiny also provides some useful metrics and functions, for example, the strength link between the two items in the co-occurrence network is used to calculate the frequency of the keywords and show the research hotspots, and the total local citation is used to show the citations in the current database, while the collaboration networks of authors are used to display how authors relate to others in a research area. Additionally, this tool uses Bradford’s Law to show the correlation and spatial distribution of the journals [34], which can help researchers choose the most suitable journals. In Bradford’s Law, if the journals are arranged in decreasing order according to the number of articles published in a particular discipline, then the journals can be divided into core, relevant and non-relevant journals, with a relationship of 1: n: n² [34]. Furthermore, this tool also uses the H index, G index, and M index to highlight the impact of the articles [35,36]. Specifically, the H index indicates that the N articles of the researchers have been cited at least h times, while the other (N–h) articles have no more than h citations each [35]. The G index is the top g articles that received at least g² citations [36]. The M index is the H index divided by the difference between the start and end years [35], which has not stopped studying this research in the period since the first article is published. Therefore, this interface can help researchers a clear understanding of the hotspots.

CiteSpace was developed to analyse and visualize the research hotspots and trends according to the disciplines and citations [29]. With CiteSpace, research hotspots are dynamically visualised from a large number of articles over a long time, thus reflecting the trends of the research [37]. CiteSpace provides the cluster and timeline maps for analysing the relationship between keywords and citations of an article, which can cluster into co-occurrence networks and show the knowledge structure of their topics [30,38]. Moreover, the keywords that best represent the cluster can be extracted using the log-likelihood ratio (LLR) algorithm as the labels [32], which helps researchers seek the hotspots of the research. The timeline map can also show the trends of the clusters in different timescales [29], and reveal how clusters relate to each other. CiteSpace provides burst detection to show trends over a short period [38], as well as tools to calculate the node centrality [39]. The centrality of a node is an index guided by the structural hole theory to show the importance and position of the article in a co-occurrence network [40]. It calculates the probability of a node going through in a network and find the most valuable nodes along an arbitrary path [29,30]. Thus, the links between the papers are effectively highlighted. A node with a higher centrality means that it is located more to the middle of the networks. In CiteSpace [29,30], a purple ring is often used to reflect the centrality of a node. The centrality is:

$$\text{Centrality}(\text{node}_i) = \sum_{i \neq j \neq k} \frac{\rho_{jk}(i)}{\rho_{jk}} \quad (1)$$

where the ρ_{jk} is the shortest path from node_j to node_k. The $\rho_{jk}(i)$ is the number of paths that pass through the node_i.

VOSviewer is a software tool developed by van Eck and Waltman [41] to create and visualise bibliometric networks. Based on the node similarity, this tool provides 3 kinds of maps (network, overlay, and density) to show the hotspots and trends of a research area [42]. The density map can visualise the relationship and the weights of the nodes [41]. The clusters are formed by the keywords, which can help researchers seek the hotspots

along the co-occurrence line and the colours. In this study, the research area, countries, institutions, journals, authors, keywords, and citations were systematically obtained and analysed by using the aforementioned software tools.

4. Results

4.1. Basic Results

To obtain the data and results, the literature were collected using the search strategy. As a result, 2796 documents and 11,0111 references were collected, where the earliest article “Morphotectonic analysis of the Hazara arc region of the Himalayas, north Pakistan and northwest India” was published in the journal *Tectonophysics* [43]. The annual publications reached 70 articles/year on tectonic geomorphology research (Table 1), and the mean citations per article is 25.96, showing the rapid development of tectonic geomorphology research (Figure 1). As shown in Figure 1a, the number of annual documents (y) on the tectonic geomorphology research increases from 1981 to 2021, showing a polynomial trend with the year (x). The average number of annual articles increase from 31 (1997–2009) to 156 (2010–2021). Since 2010, the average annual number of published articles has exceeded 100. However, the average citation per article or year does not show a similar trend, where increasing since 1981 and decreased since 2000. Due to the continuous improvement and the use of remote sensing technology, more and more researchers have been using remote sensing data and techniques to explore the response of fluvial landforms to the changes in active faulting, which has led to a gradual rise and focus on tectonic geomorphology research since 2010. However, as regional landforms are not formed by tectonics alone, this has led to an inconsistent focus among researchers, resulting in multiple clusters. For example, Chen et al. [18] used the height and response time of the river terrace to reveal the river incision. Zhang et al. [44] used the hypsometric integral (HI), the ratio of valley floor width to height (VF), and basin shape (Bs) to reveal the tectonic uplift in the active mountain belt). Liu et al. [45] used the knickpoints on river longitudinal profiles to constrain the slip rates induced by active faulting. Although these studies all focus on tectonic geomorphology in Qianhe Basin, China, the main concerns are different. Whereas Chen et al. [18] focus on the river terrace, Zhang et al. [44] are concerned with geomorphology indexes, while Liu et al. [45] pay more attention to the river slope. Due to the different impact factors of the journals, the citations per article are different, which are six, 20, and 14, respectively (updated on 6 October 2022). The total articles for the top ten different countries are also included (Figure 1b) and show a similar increasing trend with the number of annual documents in Figure 1a. Although the total number of articles in China has not yet surpassed that of the United States, the growth rate for China has ranked second (0.938). suggesting that more Chinese researchers have started to focus on tectonic geomorphology research. The whole database includes 8089 authors, with 240 documents having a single author. Furthermore, there are a total of 6546 keywords generated by these articles (Table 1).

Table 1. Basic results are derived from the search strategy in the Web of Science database.

Type	Value/Number
Timescale	1981–2021
Articles	2796
Annual Growth Rate (%)	7.15
Annual article per year	70
Average citations per article	25.96
Journals	370
References	110,111
Keywords plus (ID)	6546

Table 1. Cont.

Type	Value/Number
Author's keywords (DE)	6723
Authors	8089
Authors of single-authored articles	209
Single-authored articles	240
Co-Authors per articles	4.28
International co-authorships (%)	33.37

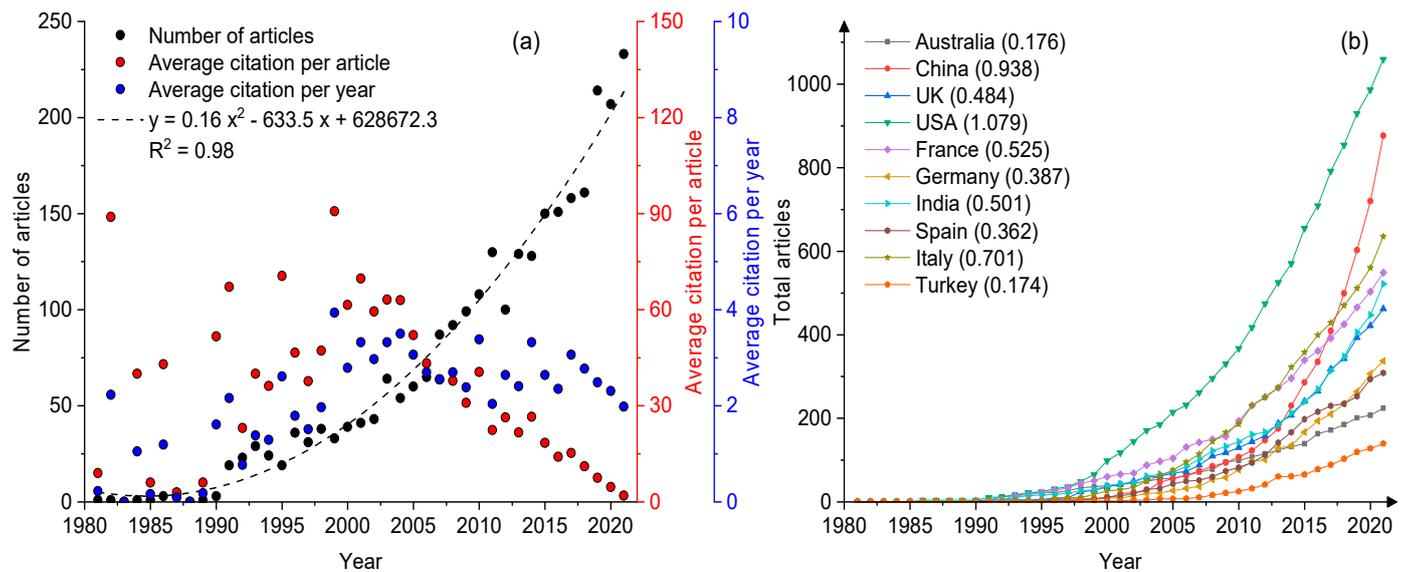


Figure 1. (a) Temporal changes in transient tectonic geomorphology research from 1981 to 2021, (b) the total article difference between the countries for tectonic geomorphology research from 1981 to 2021.

4.2. Research Areas

The research areas of tectonic geomorphology are determined using the Web of Science category field, showing an increase from three to 95. As shown in Figure 2a, these articles mainly focused on the evolution, deformation, basin, tectonics, uplift, active tectonics, geomorphology, faults, earthquake, model, erosion, tectonic evolution, and landscape evolution, etc. Moreover, the total number of articles in these areas is 2174, accounting for 77.7% of the total articles (Figure 2b). Specifically, some of the indices, e.g., hypsometric integral (HI), the ratio of valley floor width to height (VF), and basin shape (Bs) are proposed and conducted to reveal the tectonic uplift in the active mountain belt [44,46,47]. Other studies focused on the transient changes in river longitudinal profiles (e.g., the steepness index and knickpoints) to estimate the rates of active faulting [11,45,48,49]. Furthermore, some studies concerned the climate, tectonic, lithologies, and erosion influence on the fluvial morphology evolution [50,51].

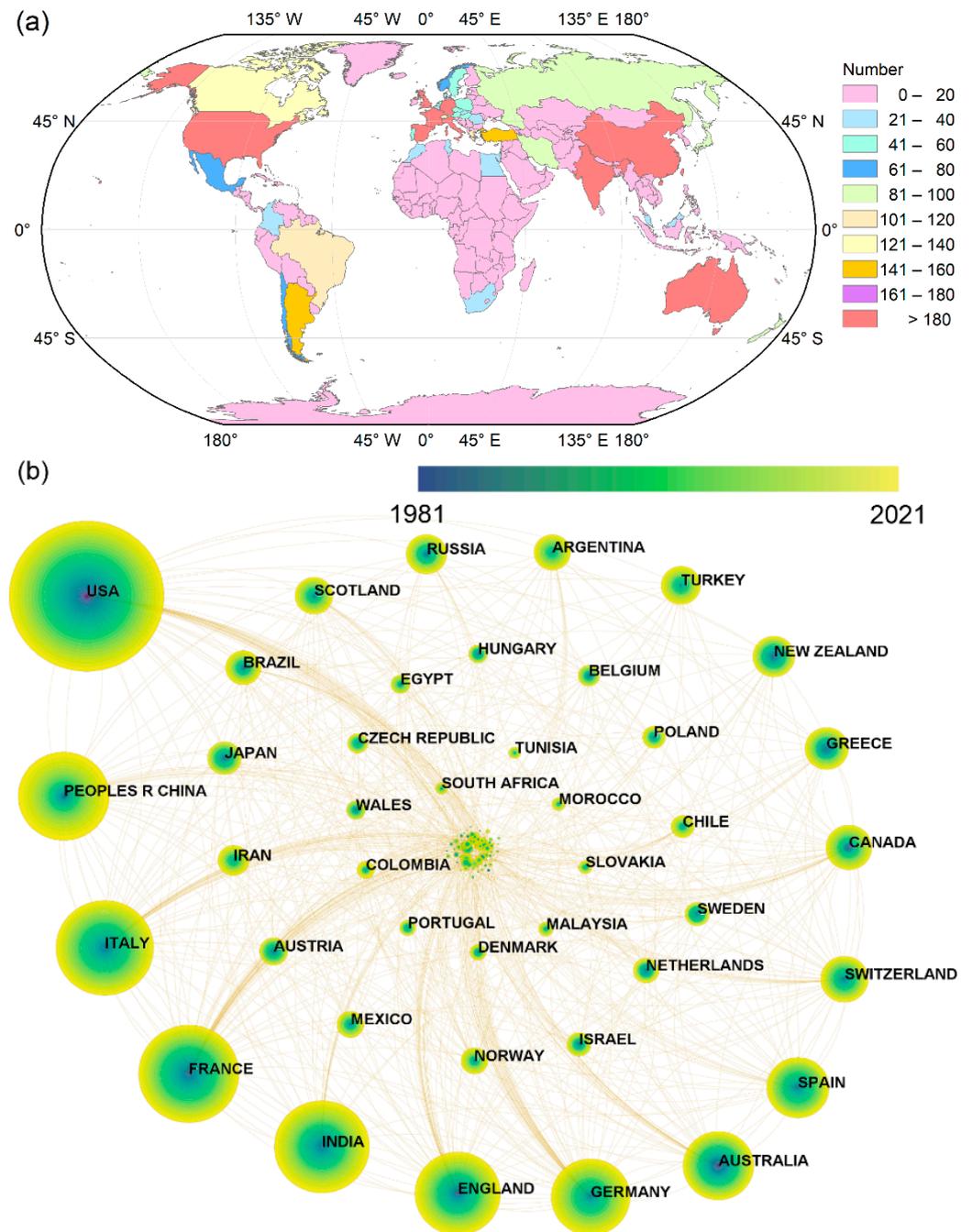


Figure 3. (a) The number of articles per country in tectonic geomorphology research, (b) the national cooperation between different countries in tectonic geomorphology research from 1981 to 2021.

4.4. Institutions

There are 2214 institutions concerning tectonic geomorphology research. The top 10 most influential institutions have published a total of 409 articles (Table 2). Among them, the number of studies from the China University of Geosciences (76) is higher than other institutions, followed by the University of California Santa Barbara (52), Wadia Institute of Himalayan Geology (42), National Autonomous University of Mexico (41), the University of Texas at Austin (37), Aix-Marseille University (35), University of Potsdam (35), University of Buenos Aires (31), Durham University (31), and University of Cambridge (29). Italy has published 635 articles and ranked third globally (Figure 3a). However, its relative institutions are hardly ranked in the top 10 institutions from 1981 to 2021 (Table 2). China

University of Geosciences (76), China University of Petroleum (27), Chengdu University of Technology (24), Nanjing University (22), Sun Yat-sen University (21), and Lanzhou University (20) are the top five institutions for this research in China.

Table 2. Top 10 institutions on tectonic geomorphology in 1981–2021.

Affiliations	Total Number of Articles	Countries
China University of Geosciences	76	China
University of California Santa Barbara	52	USA
Wadia Institute of Himalayan Geology	42	India
National Autonomous University of Mexico	41	Mexico
University of Texas at Austin	37	USA
Aix-Marseille University	35	France
University of Potsdam	35	Germany
University of Buenos Aires	31	Argentina
Durham University	31	UK
University of Cambridge	29	UK

4.5. Journals

The studies about tectonic geomorphology research have been published in 370 journals (Table 1). There is an increasing trend of journal numbers per year, ranging from four to 21 since 1981. The top 20 journals concerning tectonic geomorphology research have published 1330 articles (5.4%), accounting for 47.6% of the total articles (Table 3). Each of these 20 journals has published more than 27 articles until 2021. Nevertheless, 291 journals (10.4%) only published 1–5 articles about tectonic geomorphology research. The average impact factor of the top five journals is 3.947, showing the high impact of the tectonic geomorphology research. Therefore, these journals can be recognised as the most powerful source and reference to conduct new tectonic geomorphology research. Moreover, based on Bradford’s Law [34], the core journals are concentrated in the top 10 journals (Table 3). As shown in Figure 4, the journal *Geomorphology* is an attractive journal with the fastest growth rate. Additionally, as shown in Table 3, the citations of the top five journals are 10,809, 4737, 4719, 3596, and 2801, respectively, showing the international impact of journals. These results provide effective help to publish and share the main findings in this research area.

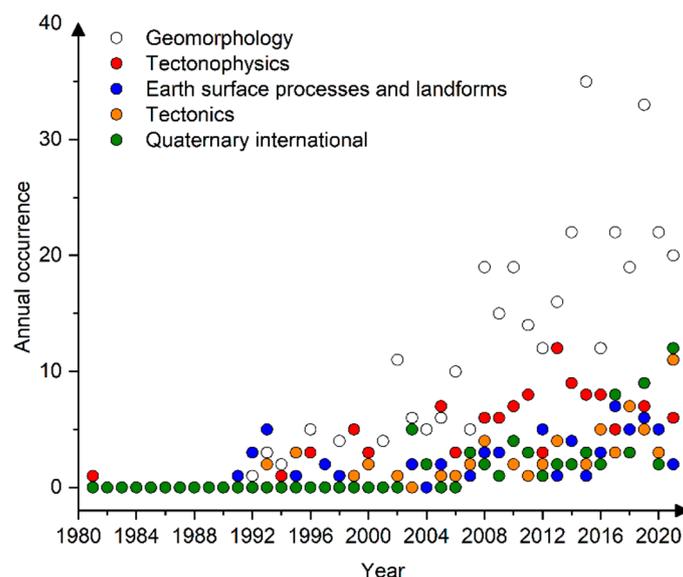


Figure 4. Dynamic analysis of the top 10 journals in tectonic geomorphology research from 1981 to 2021.

Table 3. Top 20 journals in the tectonic geomorphology research in 1981–2021.

Journals	NA	TLC	HI	GI	MI	PYS	ACPY	IF
Geomorphology	354	10,809	49	83	1.531	1991	348.7	4.406
Tectonophysics	132	4719	37	63	0.881	1981	115.1	3.660
Earth surface processes and landforms	73	1982	23	42	0.719	1991	63.9	3.956
Tectonics	67	2801	26	52	0.867	1993	96.6	5.261
Quaternary international	64	1192	20	32	1.000	2003	62.7	2.454
Earth and planetary science letters	54	3596	31	54	0.969	1991	116.0	5.785
Journal of the geological society of India	52	585	13	22	0.419	1992	19.5	1.466
Journal of Asian earth sciences	51	1154	19	32	1.000	2004	64.1	3.374
Journal of maps	50	471	12	18	0.857	2009	36.2	2.657
Journal of geophysical research-earth surface	48	1192	25	44	1.316	2004	66.2	4.418
Journal of south American earth sciences	45	515	13	21	0.448	1994	18.4	2.453
Journal of geophysical research-solid earth	44	4737	27	44	0.900	1993	163.3	4.390
Quaternary science reviews	42	1247	20	35	0.741	1996	48.0	4.456
Zeitschrift fur geomorphologie	42	442	12	19	0.387	1992	14.7	1.571
Marine and petroleum geology	39	599	13	23	0.520	1998	25.0	5.361
Marine geology	39	1517	18	38	0.581	1992	50.6	3.627
Geological society of America bulletin	36	2650	24	36	0.585	1982	66.3	5.410
Geology	36	2599	20	36	0.667	1993	89.6	6.324
Arabian journal of geosciences	35	206	9	11	0.750	2011	18.7	1.827
Basin Research	27	853	13	26	0.481	1996	32.8	4.100

where NA, TLC, HI, GI, MI, PYS, ACPY, IF are number of articles, total local cited sources, h index, g index, m index published year started, average citation per year, and impact factor in 2021, respectively.

4.6. Authors

There are 8089 authors are focusing on tectonic geomorphology in the dataset (Table 1). The top 20 most active and productive authors are ranked in Table 4. The top 10 authors are Whipple K.X. (19), Miccadei E. (20), Caputo R. (14), Kothyari G.C. (22), Piacentini T. (19), Ritz J.F. (15), Strecker M.R. (15), Tucker G.E. (12), Chamyal L.S. (17), and Monaco C. (11), who have published 164 articles. Whipple K.X. has been ranked first and cited 4804 times. The average citation of Whipple K.X. is 9.5 times higher than Miccadei E. Keller E.A. is the first and most productive author since 1982. According to Lotka's Law [52] and the M index, Strecker M.R. (0.80), Whipple K.X. (0.79), Kothyari G.C. (0.75), Miccadei E. (0.65), and Whittaker A.C. (0.63) are the top five authors who started to study tectonic geomorphology research. According to the H index, Whipple K.X., Miccadei E., Caputo R., Kothyari G.C., Piacentini T., Ritz J.F., Strecker M.R., and Tucker G.E are the core authors in tectonic geomorphology research, with an average h index of 13 (Table 4). Although USA, China, and Germany are the top 10 productive countries, there is only one author in these countries ranked in the top 20. Additionally, as shown in Table 1, there are a total of 240 single-authored articles in tectonic geomorphology research which are generated by 209 authors. The remaining articles are co-authored, with a co-author index per article of 4.28, indicating that the tectonic geomorphology studies need more authors cooperate to achieve an international impact (Figure 5).

Table 4. Top 20 authors in tectonic geomorphology research in 1981–2021.

Author	TN	TLC	AC	HI	GI	MI	TS	Institution	Country
Whipple K.X.	19	4804	252.8	19	19	0.79	1999	University of Oxford	UK
Miccadei E.	20	529	26.5	13	20	0.65	2003	Universita' degli Studi 'G. d'Annunzio' Chieti-Pescara	Italy
Caputo R.	14	575	41.1	12	14	0.40	1993	University of Ferrara	Italy
Kothyari G.C.	22	289	13.1	12	16	0.75	2007	Institute of Seismological Research	India
Piacentini T.	19	420	22.1	12	19	0.60	2003	Universita' degli Studi 'G. d'Annunzio' Chieti-Pescara	Italy
Ritz J.F.	15	502	33.5	12	15	0.50	1999	University of Montpellier	France
Strecker M.R.	15	531	35.4	12	15	0.80	2008	Universität Potsdam	Germany
Tucker G.E.	12	3659	304.9	12	12	0.44	1996	University of Oxford	UK
Chamyal L.S.	17	389	22.9	10	17	0.33	1993	M.S. University of Baroda	India
Monaco C.	11	451	41.0	10	11	0.37	1996	University of Catania	Italy
Whittaker A.C.	13	882	67.8	10	13	0.63	2007	Imperial College London	UK
Xu X.W.	11	478	43.5	10	11	0.53	2004	Oceanic University of China	China
Ascione A.	11	351	31.9	9	11	0.38	1999	University of Naples Federico II	Italy
Braucher R.	14	383	27.4	9	14	0.41	2001	Aix-Marseille University	France
Delcaillau B.	12	412	34.3	9	12	0.36	1998	Morphodynamique Continentale et Côtière	France
Finkel R.C.	9	642	71.3	9	9	0.38	1999	Lawrence Livermore National Laboratory	USA
Jackson J.	11	456	41.5	9	11	0.36	1998	University of Cambridge	UK
Keller E.A.	10	857	85.7	9	10	0.22	1982	University of California	USA
Maurya D.M.	15	358	23.9	9	15	0.38	1999	M. S. University of Baroda	India
Pant C.C.	11	184	16.7	9	11	0.56	2007	Kumaun University	India

where TN, TLC, AC, HI, GI, MI, TS, are total number of articles, total local citation, average citation, h index, g index, m index, time starts, respectively.

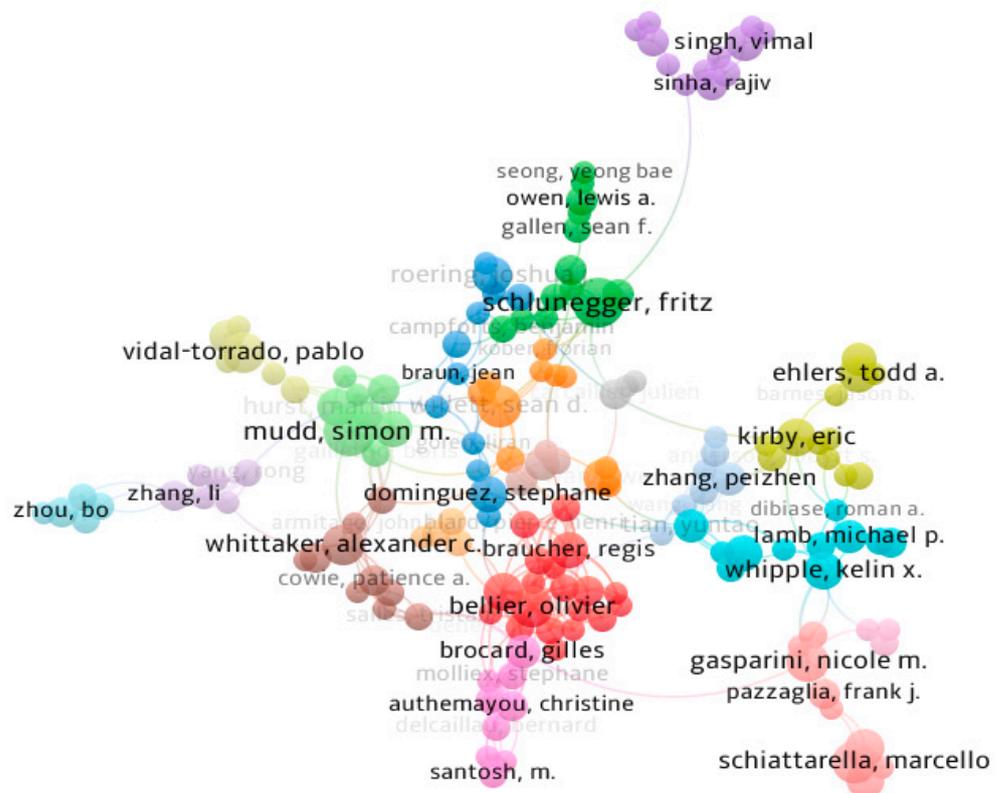


Figure 5. Authors network on tectonic geomorphology research in 1981–2021.

4.7. Keywords

In the past four decades, a total of 6546 keywords (Table 1) are extracted from the dataset and clustered into a co-occurrence network by the weights link and the total link strength (Figure 6). All the clusters are grouped into different colours. The larger the cluster node, the bigger the keyword's contribution to the group. The thicker the connecting line between two clusters, the closer the interaction between the two keywords. As shown in Table 5, the top 20 keywords are extracted by the co-occurrence in these articles, showing that they are related to four research areas: (1) tectonic evolution processes (Evolution, Deformation, Tectonic evolution, Landscape evolution, Constraints), (2) tectonic geomorphology (Basin, Geomorphology, Erosion, River, Landscape response), (3) tectonics (Tectonics, Uplift, Active tectonics, Fault, Earthquake, Earthquakes), and (4) tectonic structure (Model, History, System, Region).

Table 5. Top 20 keywords on tectonic geomorphology research in 1981–2021.

No	Keywords	Number of Articles	Average Cluster	Weight Links	Weight Total Link Strength
1	Evolution	622	11	771	3504
2	Deformation	262	2	540	1592
3	Basin	243	1	477	1310
4	Tectonics	204	10	446	1155
5	Uplift	166	5	398	1024
6	Active tectonics	157	2	405	994
7	Geomorphology	153	4	373	871
8	Fault	127	9	337	746
9	Earthquake	124	2	298	673
10	Model	116	5	284	669
11	Erosion	116	5	310	767
12	Tectonic evolution	112	3	342	586
13	Landscape evolution	103	5	292	636
14	River	101	1	268	574
15	History	94	8	264	513
16	System	88	2	247	499
17	Region	81	11	242	424
18	Earthquakes	81	2	231	456
19	Constraints	81	7	246	494
20	Landscape response	78	5	236	543

Additionally, the key clusters can also help researchers to understand the relationship between the different hotspots. The top 12 clusters are detected and visualized with different colours (Figure 6), and labelled by the numbers and co-occurrences (Table 6). Cluster 11 “Evolution” has the most occurrence (622) and links (771), and the highest weight total link strength with the other clusters (3504). We zoomed in the keywords network to show the relation to other clusters (Figure 7). As shown in Table 6, the top two keywords with the most links and highest strength are “Evolution” and “Deformation”, which are consistent with Web of Science. The links and strengths of these keywords are 1311 and 5096, respectively, showing that these keywords are the main hotspots in tectonic geomorphology research (Figure 7). The keywords with the top link strength to the keyword “Evolution” are “Basin” (Cluster1-92), “Deformation” (Cluster2-75), “Tectonics” (Cluster10-74), “Uplift” (Cluster5-63), and “Active tectonics” (Cluster2-54), respectively. The keywords with the top link strength to the keyword “Tectonic Evolution” are “Deformation” (Cluster2-13), “Basin” (Cluster1-10), “Constraints” (Cluster7-9), “Morphotectonic evolution” (Cluster3-6), and “River” (Cluster1-6). Although the names of the clusters are similar, the components and relation are different, indicating that tectonic geomorphology is a multidisciplinary research area.

Table 6. Keywords cluster on tectonic geomorphology research in 1981–2021.

ID	CM	C	Name	O	WL	WTLS	Top 10 Keywords
1	154	Red	Basin	243	477	1310	Basin, river, area, topography, morphology, growth, landscape, sea, patterns, dynamics
2	152	Green	Deformation	262	540	1592	Deformation, active tectonics, earthquake system, Earthquakes, zone, seismicity, kinematics, extension, new-zealand, tectonic geomorphology
3	127	Blue	Tectonic evolution	112	342	586	Tectonic evolution, morphotectonic evolution, plateau, Tibetan plateau, strike-slip, China, belt, tectonic uplift, fission-track thermochronology, apatite
4	101	Yellow	Geomorphology	153	373	871	Geomorphology, margin, stratigraphy, sedimentation, continental-margin, architecture, sea-level, sequence stratigraphy, seismic geomorphology, slope
5	89	Purple	Uplift	166	398	1024	Uplift, erosion, model, landscape evolution, landscape response, rates, river incision, mountains, climate-change, erosion rates
6	85	Light blue	Valley	59	196	334	Valley, California, drainage, late Pleistocene, India, GPS measurements, foreland basin, thrust, alluvial fans, neotectonics
7	75	Orange	Constraints	81	246	494	Constraints, subduction, fore-arc, insights, arc, collision, Miocene, lithosphere, mid-atlantic ridge, plate boundary
8	69	Brown	History	94	264	513	History, climate, origin, deposits, structural evolution, flow, landforms, age, record, sediments
9	49	Pink	Fault	127	337	746	Fault, quaternary, thrust belt, morphotectonic analysis, central Andes, late Miocene, stream-gradient, geomorphic indexes, northern Chile, south-America
10	49	Light pink	Tectonics	204	446	1155	Tectonics, exhumation, stress, field, magnitude, Pleistocene, landslides, movements, Himalaya, ages
11	28	Light green	Evolution	622	771	3504	Evolution, region, geometry, slip, faults, displacement, volcanism, gravity, mars, fold-thrust belt
12	22	Light grey	Example	51	156	308	Example, profiles, late quaternary, drainage-basin, ground-penetrating radar, fault system, Gujarat, Kutch, river profiles, Mississippi embayment

where CM, C, O, WL, WTLS are cluster members, colour in Figure 6, occurrences, weight links, weight total link strength, respectively.

4.8. Citations

Based on the co-citation analysis, the top five references with the most frequency from 1981 to 2021 are shown in Table 7. The frequency can show the academic influence of a specific article. The top article with the highest frequency (54) and centrality (0.12) is that of Kirby and Whipple [53], showing the importance and position in the co-occurrence network. Based on the SPIM, these researchers use the river long profiles to show the positive and monotonic relationships between channel steepness index and erosion rate at equilibrium. They also find that the knickpoint can be regarded as a marker to show variations induced by active faulting, in which the slope-break knickpoint in the channel long profiles can reveal the transient response induced by the tectonic uplift, while the vertical-step knickpoint does not show the tectonic significance but locate the fault position. Compared with the method based on the geomorphic index, the details of slope deformation are more specific and quantifiable from remote sensing data, therefore, more and more researchers are focusing on slope change. This work establishes the position in the co-occurrence network in tectonic geomorphology studies and is closely linked to other subsequent studies, e.g., the channel width analysis [7]. Based on the steady-state form of the SPIM, Perron and Royden [54] propose an alternative index called chi plots (χ) to identify erosional signals in transient longitudinal profiles. Furthermore, Lague [55] provides new insights concerning the role of incision with channel width, and also uses a threshold-stochastic simulation model with width (composite transient dynamics) to

explain the shortcomings and deficiencies of SPIM, where width may not sensitive to incision rate. Willett et al. [56] consider the drainage divide migration which can reshape basins and change the topology through river capture. They also use the chi plots to demonstrate the horizontal motion of drainage divides, which complement the dynamic reorganization theory of basins and provide a basis for analysing the interactions between tectonics, erosion, and climate. Whipple et al. [14] find that the changes in river profiles resulting from drainage divide migration are comparable to the tectonic, climate, and rock properties. They also introduce a nondimensional divide migration number, ND_m , to assess the feedback mechanisms of migration. Furthermore, they find that the interpretation of river profile changes in terms of drainage area associated with divide migration and network reorganization may be inappropriate in tectonically active regions. These findings point out the research hotspots and trends in the tectonic geomorphology research, i.e., how to use the fluvial geomorphic indices and drainage divide migration to quantify the tectonic uplift.

Table 7. Top 5 citations in tectonic geomorphology research from 1981 to 2021.

No.	Authors	Journal	Title	Frequency	Centrality
1	Kirby and Whipple [53]	Journal of Structural Geology	Expression of active tectonics in erosional landscapes	54	0.12
2	Willett, McCoy, Perron, Goren and Chen [56]	Science	Tectonic control of Yarlung Tsangpo Gorge revealed by a buried canyon in Southern Tibet	45	0.08
3	Perron and Royden [54]	Earth Surface Processes and Landforms	An integral approach to bedrock river profile analysis	37	0.09
4	Whipple, Forte, DiBiase, Gasparini and Ouimet [14]	Journal of Geophysical Research: Earth Surface	Timescales of landscape response to divide migration and drainage capture: Implications for the role of divide mobility in landscape evolution	27	0.04
5	Lague [55]	Catena	The stream power river incision model: evidence, theory and beyond	24	0.03

As shown in Figure 8, the references are clustered and shown by using LLR algorithm in the timeline view. Ten clusters representing the research trends in tectonic geomorphology research are numbered, coloured, and listed according to their co-citations and keywords, where the top cluster being the newest research hotspots and trends. Moreover, each cluster lasts a different timeline. The colourful curves are the co-citation lines linked the two corresponding years. The cluster #0 “Divide migration” has 115 references, while the smallest cluster #19 “Mud volcanoes” only contains five references (Table 8). There are also some big nodes with red tree rings, which represent the articles with high citations. For example, the node with Boulton and Whittaker [57] is smaller than the node with Whittaker and Boulton [50], showing that the former citation has fewer citations, even though the authors are same. Additionally, previous studies have shown that the visualization of clusters is better and the nodes in the cluster are homogeneous when the silhouette is >0.5 [29,30,32]. As shown in Table 8, the silhouette value of all clusters is larger than 0.85, showing that the cluster is reliable.

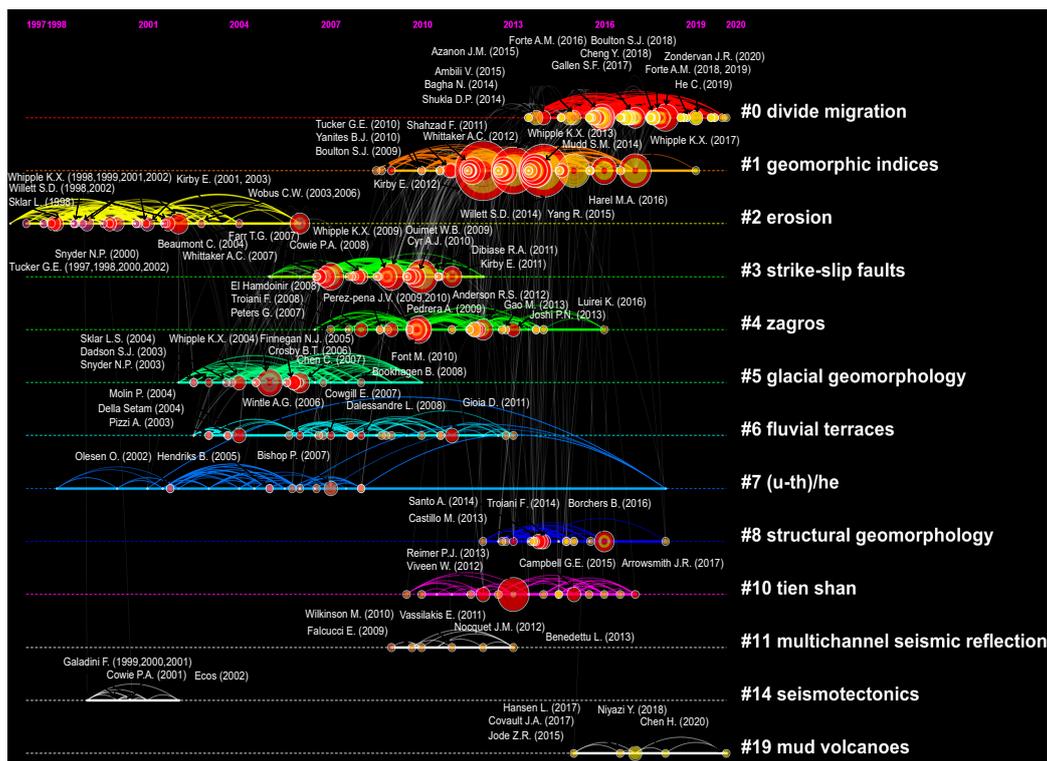


Figure 8. Cluster visualization in timeline view of the tectonic geomorphology research in 1981–2021. The horizontal axis is the timeline (years). The nodes are the cited reference with a frequency and read circles represent the burst. The line between the nodes is the timeline of the reference, and the thickness is the strength [29,30].

Table 8. Reference cluster on tectonic geomorphology research in 1981–2021.

Cluster ID	Size	Silhouette	Start Year	End Year	Duration	Mean (Year)	Label (LLR)
0	115	0.890	2014	2020	7	2017	Divide migration
1	91	0.854	2009	2019	11	2013	Geomorphic indices
2	70	0.978	1997	2006	10	2000	Erosion
3	61	0.920	2005	2012	8	2008	Strike-slip faults
4	57	0.923	2007	2016	10	2011	Zagros
5	54	0.989	2002	2010	9	2005	Glacial geomorphology
6	44	0.940	2003	2013	11	2007	Fluvial terraces
7	37	0.940	1998	2018	21	2004	(U-Th)He
8	29	0.915	2012	2018	7	2014	Structural geomorphology
10	19	0.964	2010	2017	8	2013	Tien Shan
11	9	1.000	2009	2013	5	2010	Multichannel seismic reflection
14	7	1.000	1999	2002	4	2000	Seismotectonics
19	5	0.998	2015	2020	6	2017	Mudd volcanoes

Specifically, the largest node to cluster #0 is Forte and Whipple [15], which mainly provides a series of MATLAB tools to simulate the landscape evolution and show how the drainage divide migrates under different conditions (e.g., climate, tectonic, rock erodibility, etc.). They also find that cross-divide contrasts in chi plots can represent current divide migration when the surrounding conditions are similar. The nodes to cluster #0 mainly result from cluster #1 “Geomorphic indices” with 91 nodes. The silhouette value of cluster #1 is 0.854 and the biggest node is Kirby and Whipple [53]. In view of their work, more studies start to focus on the geomorphic indices (channel steepness and wideness) extracted from the DEM to determine the interaction of climate, tectonic, and lithology. These nodes overlap and show high impact (i.e., larger nodes and red burst rings) in the timeline view.

Therefore, the cluster #0 and #1 are the hotspots in tectonic geomorphology research to date. However, there are some differences between these two clusters. The geomorphic indices are mainly focusing on the extraction of transient geomorphic indices while the divide migration concerned the long-term changes in landforms. Additionally, there are also some links between cluster #3 “strike-slip faults” and the top 2 clusters (cluster #0 and #1), showing a strong correlation between them. Cluster #3 has 61 members and a silhouette value of 0.92. The active period of this cluster is from 2007 to 2011. The most representative node to cluster #3 is Whittaker, et al. [58], as they find that the loss of hydraulic scaling is an intrinsic response to tectonic forcing.

The third-largest cluster #2 “Erosion” has 70 members, and the silhouette value is 0.978. Through the timeline view, it is interesting to see that clusters #0, #1, #3, and #4 started at the end of cluster #2. Previous studies have shown that the interaction between erosion and active tectonics has driven researchers to explore the erosion rates by using the tectonic uplift difference from channel morphological features, such as k_{sn} , k_{wm} , HI, VF, and Bs, etc. [11,44,45,59,60]. These members and links imply that the clusters #0, #1, #3, and #4 may start or generate from cluster #2.

Clusters #5 (labeled glacial geomorphology), #6 (labeled fluvial terraces), and #7 (labeled (u-th)/he) are mainly focused on using current landform extrapolating the ancient morphology. Therefore, the start time of these clusters is similar. Specifically, our previous work [45] chose the time measured by optical stimulated luminescence (OSL) dating from the paleosol along the river terraces [18] as the knickpoint formation time to estimate the fault initiation. These clusters support and complement each other in tectonic geomorphology research.

Based on the burst analysis [29,30], the top 25 references are extracted and ranked by strength (Figure 9). These studies are mainly focused on the changes in fluvial landforms induced by the active faulting and climate, where 13 burst articles (52%) focus on cluster #1 (Table 9). These works can help researchers find the hotspots and trends in the tectonic geomorphology research, understand the paleoclimatic state of the study area, and achieve the goal of prediction and dynamic monitoring of geological hazards.

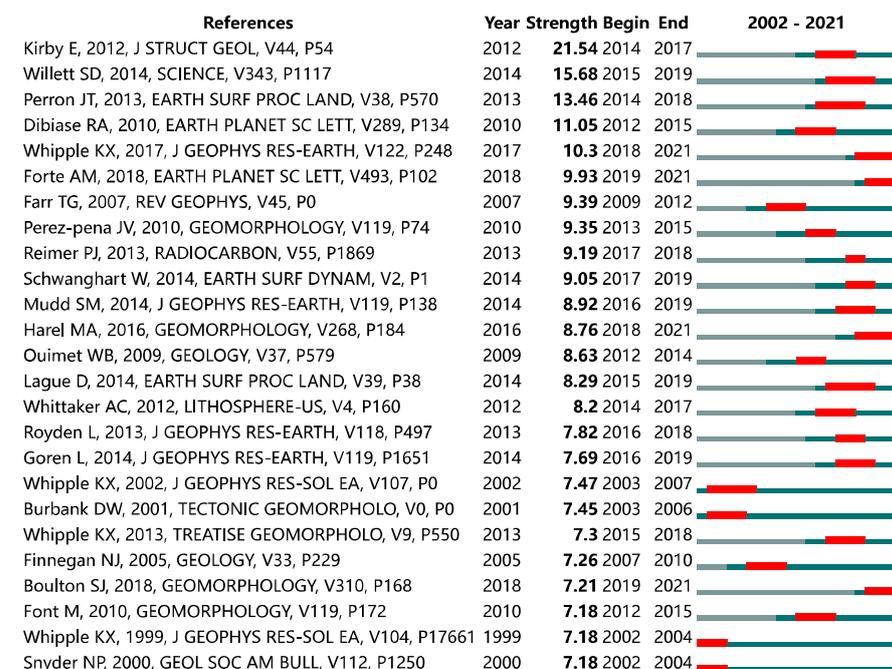


Figure 9. Top 25 references with the strongest citation in tectonic geomorphology research. Each reference is listed with the author names, year, journal name, volume, pages, and strength. The red lines are the timelines.

Table 9. The nodes in the Burst analysis.

Cluster ID	Labels (LLR Algorithms)	References
0	Divide migration	[15,19]
1	Geomorphic indices	[14,50,53–56,61–67]
2	Erosion	[2,68,69]
3	Strike-slip faults	[70–72]
4	Zagros	[73,74]
5	Glacial geomorphology	[75]
6	Fluvial terraces	/
7	(U-Th)He	/
8	Structural geomorphology	/
10	Tien Shan	[76]
11	Multichannel seismic reflection	/
14	Seismotectonics	/
19	Mudd volcanoes	/

5. Discussion

5.1. What Are the Main Hotspots in Tectonic Geomorphology Research?

According to the co-occurrence network and cluster analysis, the integral results show that tectonic geomorphology research mainly focuses on the following hotspots.

5.1.1. How to Reveal the Basin Changes?

The fluvial geomorphology and evolution often result from plateau uplift in an active orogenic belt. Some tectonic geomorphological indices are proposed to quantitatively analyse the landform formation and changes. The keywords of these clusters about the basin changes (labelled Basin and Valley) are the river, area, topography, morphology, and growth (Table 6). Therefore, some tectonic geomorphology research was conducted on these clusters by exploring the relationship between fluvial geomorphology and active faulting to understand the tectonic uplift mechanisms [44,77,78]. Especially in the Chinese Loess Plateau, which covers the thick Quaternary Loess, the geomorphic evolution history and its response derived by the geomorphology indices to the uplifting process are effective choice [44,47,59]. Therefore, the fluvial morphologic indices generated from the DEMs, e.g., HI, VF, and Bs, etc., are greatly used. However, these indices can hardly calculate the uplift rates and only reflect the geomorphic uplift from a macroscopic perspective. Therefore, this hotspot is often used to provide adequate evidence on the regional uplift history.

5.1.2. How to Constrain the Rates of Active Faulting?

The tectonic uplift causes the river channel slope, resulting in a channel steepening in the river longitudinal profile. Therefore, more studies have successfully used the channel steepness index, knickpoint, and chi plots to describe the landform response to active faulting [58,69,79,80], resulting in the node to cluster #1 is bigger than the other clusters. With the development of remote sensing, researchers are not only concerning the channel slope, but the cross-sectional variations (channel width), which achieving a significant advance in temporal and spatial observation. Similar to the channel steepness index (k_{sn}), some studies have used the channel wideness index (K_{wn} , Equation (2)) based on SPIM to explore the response mechanisms of channel width to tectonic uplift. For example, Zhang et al. [7] use the laser rangefinder (precision ~1 cm) to measure the channel width in the Daxia catchment and estimate shear stress, unit stream power, and bed load transport rate. They find that no significant narrowing of the channels from slowly eroding to rapidly eroding. Li et al. [81] use the laser rangefinder at ~100 m intervals along the tributaries to derive the channel width for the Heihe River and find that the differential rock uplift exists both cross strike and along strike in the Qilian Mountains. Li et al. [60] extract the channel width from Google Earth images to analyse the Cenozoic tectonic deformation in the Madong Shan, to find that the bedrock channel form and river incision are mainly

controlled by the tectonic uplift, followed by the lithology. These studies are helpful to understand the stress transfer of the fault.

$$k_{wn} = WA^{-b_{ref}} \quad (2)$$

where the W and A are the channel width and drainage area, respectively. The b_{ref} is the referenced index, ranging from 0.3 to 0.5.

Changes in river width limit the boundaries and potential for river erosion while being a response to changes in steepness, which both control the erosion system [82]. Additionally, changes in channel width cause potential energy to accumulate near the fault, resulting in river incisions. Previous studies have shown that channels generally become narrower at high rates of uplift while wider at low rates of uplift [82]. However, not all the channels obey this pattern [83] as the variations in rock strength act as a first-order control on mountain landscapes [80,84], indicating that the rock strength can also control the channel width. Furthermore, rainfall increases the river flow and accelerates the bedrock erosion on both sides of rivers, resulting in a wider channel. Therefore, only considering changes in river morphology from a tectonic perspective may ignore the competing effects of lithology and climate.

Additionally, previous studies have shown that channel width adjustment is usually much shorter than slope adjustment [82], so channel steepening is the main adjustment way to channel morphology at the transient moment of tectonic uplift. As the channel incision becomes larger and the river incision is enhanced, width gradually becomes the dominant adjustment in channel morphology. Although the channel width is now a research hotspot to the cluster “geomorphologic indices” in tectonic geomorphology research, the mechanism of tectonic uplift adjustment to channel width is still not clear.

With the improvement of remote sensing imagery resolution, the field measurement time for channel width has been greatly reduced. However, limited to the vegetation coverage and cloud/snow on the optical images, existing channel width extraction algorithms based on remote sensing still need further enhancement, especially regarding how to improve the extraction accuracy while reducing the impact of noise, such as mountain shadows. Furthermore, SAR satellites can solve problems such as vegetation cover on optical images due to their strong penetrating ability. This data source has been widely used in geosciences, e.g., SRTM is often used to extract HI and k_{sn} . However, the grayscale and texture features of river channels on SAR images are not fully exploited, especially since adjacent channel centerpoints have similar grayscale and texture features. A further research hotspot on channel width extraction concerns how to extract the grayscale and texture features from SAR images.

5.2. What Are the Future Research Frontiers in Tectonic Geomorphology Research?

According to the co-citation analysis, the integral results show that the tectonic geomorphology research mainly focuses on the following trends.

5.2.1. Drainage Divide Migration

Through the co-citation network analysis, divide migration was extracted and ranked the top 1 cluster in tectonic geomorphology research (Figure 8). As an important marker of the asymmetric mountain ranges, the drainage divide (Figure 10a) records the disequilibrium state and signals of the landscape through migration [16,17,56]. For example, Bernard et al. [80] use the FastScape model [85] to describe the drainage divide location changes in response to the basement rocks' exhumation and channel morphology. When uplift begins, the river responds through incision, headward erosion, and drainage divide migration. The stability and location of the drainage divide can be used to study the changes in tectonic uplift. When the area in the orogenic belt has similar uplift, lithology, and precipitation, the main drainage divide will stabilize in the geometric center of the orogenic belt. When the orogenic belt experiences asymmetric uplift, the main divide will migrate to the side with a higher uplift until the orogenic belt eventually reaches a stable

state again (Figure 10b). When the uplift rate decreases, the divide will migrate to the geometric center of the orogenic belt again [17] (Figure 10c). However, not all drainage divide migrates toward higher uplift rates as climate and lithology interact with tectonics as well [17]. Therefore, the divide migration represents a change in uplift rates and has become a scientific and technological tool to explore plate movements, climate change, and biodiversity.

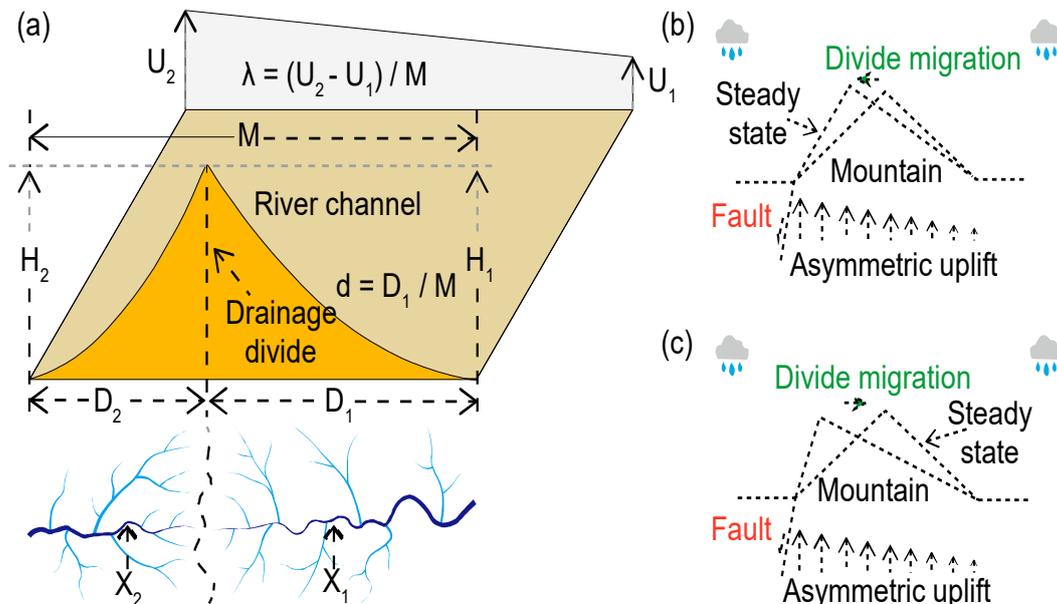


Figure 10. Drainage divide migration modified from [86,87]. (a) drainage divide, U_1 and U_2 are the uplift rates on both sides of the mountain belt, and D_1 and D_2 are the horizontal distances from the drainage divide to both sides, respectively. X_1 and X_2 are the upstream distances of the channel along the divide-normal direction, respectively. M is the mountain width. H_1 and H_2 are the channel heights above the base levels. λ and d are the gradients of the uplift rate and divide location, respectively. (b,c) are the migration of the drainage divide.

Previous studies have shown that the drainage divide limits the upstream migration boundary of the knickpoint [4]. The difference in knickpoint retreat rate on either side of the drainage divide also predicts the migration trend of the drainage divide, indicating that the migration rates can be derived from the knickpoints. However, active orogenic belts are often asymmetrical, showing that using the knickpoint retreat rate difference directly as the divide migration rate may be inappropriate. To address this concern, some previous studies have used numerical simulation to derive the migration process of the drainage divide [17,86]. Moreover, to predict the steady-state position of the drainage divide in an asymmetric mountain belt, Zhou et al. [86] derived a cross-divide contrast index (C) as Equations (3) and (4).

To address the question above, some previous studies have used numerical simulation to derive the migration process of the drainage divide [17,86]. Moreover, to predict the steady-state position of the drainage divide in an asymmetric mountain belt, Zhou et al. [86] derived a cross-divide contrast index (C) as follows:

$$C = \frac{\int_0^{D_1 - X_c} [U_1 + \frac{X'}{D_1 + D_2} (U_1 - U_2)]^{\frac{1}{n}} (D_1 - X')^{-\frac{bm}{n}} dx'}{\int_0^{D_2 - X_c} [U_2 + \frac{X'}{D_1 + D_2} (U_1 - U_2)]^{\frac{1}{n}} (D_2 - X')^{-\frac{bm}{n}} dx'} \quad (3)$$

With

$$C = \left(\frac{K_1}{K_2}\right)^{\frac{1}{n}} \left(\frac{H_1}{H_2}\right) \left(\frac{T_1}{T_2}\right)^{\frac{mb}{n}-1} \left(\frac{k_1}{k_2}\right)^{\frac{m}{n}} \quad (4)$$

where, assuming n and b are uniform across the divide, respectively, X_c is the distance between the channel head and the divide. X' is the upstream distance of the channel along the divide-normal direction. m and n are the area and slope exponents, respectively. k and b are the Hack's coefficient and exponent. K_1 and K_2 are the erosion coefficient, respectively. T is the channel tortuosity coefficient [86].

Numerical simulation is an important tool to predict the drainage divide location at a different time [88]. Since the drainage divide formation is influenced by a combination of lithology, channel erosion, horizontal convection, etc. [17], the massive simulation results for drainage divide location have not been efficiently used. With the rapid development of artificial intelligence, geomorphic analysis models based on the neural network have been used for tectonic analysis [89]. However, current geomorphology studies based on the neural network are mainly focused on landslide prediction. The historical uplift issue affects the current drainage divide location, indicating that previous drainage divide locations in millions of years can be regarded as time series to predict the future location. Taking the channel height, uplift, and drainage divide location as the input data, the future drainage divide can be predicted and located by using the recurrent neural networks. Therefore, using the neural network model to predict the drainage divide location will deepen the understanding and knowledge of the geomorphological response to tectonic uplift.

5.2.2. Fluvial Terrace

River degradation terraces can also provide valuable geomorphic markers for fault displacement and can be used to measure the rate and direction of fault slip over time [90]. To measure the slip rate of faults using terrace displacement, we need to understand how these alluvial features interact with rivers and faults, and when they begin to record fault slip. Previous studies have shown that the timing and magnitude of a terrace displacement are commonly uncertain [91,92], but the oldest terrace can give a minimum age for the graben. Some studies have used magnetostratigraphy to get the time of each river terrace in Qianhe Graben [18], therefore, we find that clusters labelled "Fluvial terraces" and "(U-Th)He" are recognised as the hotspots and trends in Table 8 and Figure 8. However, due to the cost and time of chronological measurement, researchers have rarely paid as much attention to this cluster as to the divide migration and geomorphic indices.

We also noted that the uncertainty remains in the determination of the different terrace boundaries. Although Chen et al. [18] use features of river terraces on DEM and slope analysis to delineate the T_1 – T_5 terraces in the Qianhe Graben, anthropogenic background knowledge can lead to differences in the final height results. In addition to height and slope, the same terrace has a similar texture, grayscale, shape, etc. If these features can be expressed by using multivariate heterogeneous data, the method of terrace delineation can be further explored while shortening the time of field measurement.

Tectonic geomorphology allows us to integrate results derived from remote sensing data to conduct relative research in active orogenic belts. For example, Abdelkareem and El-Baz [93] used Landsat-7 Enhanced Thematic Mapper (ETM+) images to show the structural and geomorphic features in the west of the Nile River (Egypt), where Radarsat-1 satellite data is used to show the geomorphology details of the area. They also used the ASTER DEM generated by a stereo-pair of image bands (3N and 3B) to reveal the terrain changes. Additionally, with the Sentinel-2 and Sentinel-1A data, Qureshi and Khan [94] acquired the land cover classification maps and the displacement rate along faults of the Manzai Ranges in Western Pakistan, and extracted the geomorphological index using the Tandem-X data. These results show that multi-sensor remote sensing data can be integrated to reveal the details of geomorphology induced by tectonic or climate in a macro or micro view.

Although the remote sensing data (e.g., images, UAV stereo images, Radar Laser Point Cloud, etc) has become the main data in quantifying the landscape response (e.g., the

relief, channel steep, channel width, river terrace, drainage divide, etc.) to the faulting and incision, further study is still needed regarding to reveal how the landforms evolve based on the current transient landform changes. Since changes in landforms are usually formed in tens of thousands or millions of years, the landform changes induced by tectonic uplift are transient. With the advent of computing, big data and machine learning, the way to extract the geomorphology indices has changed to extract the feature between the object and label from remote sensing data. Recently, with the development of multitemporal and hyperspectral remote sensing, continuous and dynamic measurement is possible. The tectonic research has progressed from field measurement, through the indices extraction of landform evolution based on remote sensing data, to tectonic geomorphology based on big data.

5.3. Limitations

We noted some limitations in this study. Firstly, the datasets are collected from Web of Science, and may lack comparison with other databases (i.e., Google Scholar, Scopus). This comparison allows us to discover the context of previous research and identify the current research hotspots. Secondly, although literature retrieval can help find more articles, this study still requires a more precise search process. Tectonic geomorphology is a diverse discipline that most of the articles in the database combine knowledge and perspectives from other different disciplines. Thirdly, the number of keywords varies in journals, where the journals *Geomorphology* and *Tectonophysics* require a maximum of six keywords, the journal *Earth surface processes and Landforms* requires at least five keywords, the journal *Basin research* requires 3–7 keywords, the *Journal of geophysical research-solid earth* requires a maximum of three keywords, while the journal *Geology* does not require keywords. The number of keywords also affects the clustering results. To address this challenge, we can use some useful tools, such as Term Frequency Counter (<https://key-content.com/word-frequency-counter/>, accessed on 6 October 2022), Word Frequency Counter (<https://ezcalc.me/word-frequency-counter/>, accessed on 6 October 2022), Word Counter (<https://wordcounter.ai/>, accessed on 6 October 2022), etc., to count the word/term frequency in the articles and cluster to the keywords, which can help researchers find the hotspots and trends for the tectonic geomorphology research in the future. Finally, quantifying the articles by the citations may ignore the content of the article as some authors cite themselves. Therefore, how to make a scientific and objective assessment of article quality will be one of the most important research trends in the future.

6. Conclusions

To analyse the hotspots and trends of the tectonic geomorphology research, we use bibliometrics and scientometrics to visualise the co-occurrence network of research areas, authors, countries journals, institutions, keywords, and citations from 1981 to 2021. Over the past four decades, tectonic geomorphology research has shown tremendous growth, with an annual rate of 7.15%. With the rapid development of remote sensing, researchers have mainly focused on using remote sensing data to show and quantify the response of the fluvial landforms to active faulting. Through the co-occurrence network analysis, the hotspot of the tectonic geomorphology research is how to constrain the rates of active faulting using geomorphic indices. Through the literature co-citation analysis, the trend of tectonic geomorphology research is to investigate the response of drainage divide migration to the fault slip rates. Geomorphological analysis based on multi-source remote sensing data is the way to analyse the tectonic uplift, but such analysis still requires human supervision and assistance. Therefore, it is necessary to use multi-source heterogeneous data to establish tectonic landform interpretation systems. To achieve the real-time monitoring and dynamic evaluation of tectonic uplift and provide reasonable and effective data for geological hazards monitoring, multidisciplinary interrelationships should be continuously established.

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