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Evolution and Trend of Research on the Hydrogeomorphological Processes on Roads in the Last Decades: a Review

Evolução e Tendência das Pesquisas sobre Processos Hidrogeomorfológicos em Estradas nas Últimas Décadas: uma Revisão

Valdemir Antoneli, Jeferson Eslei Mazur, Edivaldo Lopes Thomaz & João Anésio Bednarz

Universidade Estadual do Centro-Oeste, Departamento de Geografia, Laboratorio de Erosão de Solos, Guarapuava, PR, Brasil
E-mail: vaantoneli@gmail.com; jeferson.mazur@gmail.com; thomaz@unicentro.br; joaogeo2013@gmail.com
Corresponding author: Valdemir Antoneli; vaantoneli@gmail.com

Abstract

Over time, roads have become an important study object. Several studies were carried out to understand the importance of roads on the hydrogeomorphological dynamics on hillslopes and watershed. Nonetheless, new gaps and new research methods emerged as research progressed on this subject. Therefore, to understand the evolution and new challenges of research on roads, a bibliographic review was prepared based on 300 articles searched in the Scopus platform considering the last two decades (2001–2010 and 2011–2020). We use keywords that refer to roads in the search field, e.g., soil erosion on roads, delivery rate, bank, rails, highways, abandoned roads, and road rehabilitation. The data were tabulated and separated according to the following themes: data collection method, study purposes, road types, and geographic location. Our main conclusions were a) in the 2000s, around 60% of surveys were carried out on unpaved roads and rural roads, mainly in roadbed features; b) In the 2010, occurred a decentralization on the research on rural roads from mainstream countries as US and Australia to Latin American countries e.g., Brazil and Middle East e.g., Iran; c) the studies in emerging countries, mostly tested known research methods in different landscapes of tropical climate; d) a new research perspective in recent decades have emerged, focusing on the influence of roads on the landscape's dynamics. Finally, roads are recognized as a human-made landscape signature and studies about nature and biodiversity conservation, particularly at watershed scale, must considered this anthropogenic feature.

Keywords: Bibliometry; Land use change; Fragmentation of the landscape

Resumo

Com o tempo, as estradas se tornaram um importante objeto de estudo. Vários estudos foram realizados para compreender a importância das estradas na dinâmica hidrogeomorfológica em encostas e bacias hidrográficas. No entanto, novas lacunas e novos métodos de pesquisa surgiram à medida que as pesquisas avançavam sobre o assunto. Portanto, para compreender a evolução e os novos desafios da pesquisa em estradas, foi elaborada uma revisão bibliográfica com base em 300 artigos pesquisados na plataforma Scopus considerando as duas últimas décadas (2001-2010 e 2011-2020). Usamos palavras-chave que se referem a estradas no campo de pesquisa, por exemplo, erosão do solo em estradas, taxa de entrega, banco, trilhos, rodovias, estradas abandonadas e reabilitação de estradas. Os dados foram tabulados e separados de acordo com os seguintes temas: método de coleta de dados, objetivos do estudo, tipos de estradas e localização geográfica. Nossas principais conclusões foram a) na década de 2000, cerca de 60% dos levantamentos foram realizados em estradas não pavimentadas e rurais, principalmente em características de leito de rodovias; b) Em 2010, ocorreu uma descentralização na pesquisa em estradas rurais de países tradicionais como EUA e Austrália para países da América Latina, por exemplo, Brasil e Oriente Médio, por exemplo, Irã; c) os estudos em países emergentes, em sua maioria testados métodos de pesquisa conhecidos em diferentes paisagens de clima tropical; d) uma nova perspectiva de pesquisa nas últimas décadas tem surgido, com foco na influência das estradas na dinâmica da paisagem. Por fim, as estradas são reconhecidas como uma assinatura da paisagem feita pelo homem e os estudos sobre a conservação da natureza e da biodiversidade, principalmente na escala de bacias hidrográficas, devem considerar essa característica antropogênica.

Palavras-chave: Bibliometria; Mudança no uso da terra; Fragmentação da paisagem

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1 Introduction

Roads emerged from the evolution of carriers, paths and trails, which are introduced into the landscape. Roads are part of human history and are currently ubiquitous elements on the planet. These paths were often opened to give access to remote locations, to allow the flow of production. With increasing population demand in recent decades, new roads were opened (Bochet, Garcia-Fayos & Tormo 2010). However, many of these roads were opened without proper planning, increasing environmental problems. Over time, different approaches to hydrogeomorphological processes have been researched on roads, including the interaction between geomorphic processes (Wemple, Swanson & Jones 2001), hydrogeomorphological response (Thomaz & Ramos-Scharrón 2015), soil erosion (Ramos-Scharrón 2021), delivery rate between slopes and river channel (Benda et al. 2019; Thomaz & Perreto 2016), changing landscape water dynamics (Navarro-Hevia et al. 2015), river pollution (Colyer, Hoque & Fowler 2020), and increase river discharge (Kalantari et al. 2017), subsurface flow intercepted by rural roads (Cunha & Thomaz 2017), and traffic impact on soil loss (Antoneli & Thomaz 2016).

At the watershed level, roads play an important role in hydrogeomorphological dynamics and in the connectivity of slope sediments with rivers. From the opening of a new road, changes occur in the hydrogeomorphological processes at the opening sites and along the slopes (Wemple, Swanson & Jones 2001). Road soil compaction leads to water infiltration at very low levels (Yu et al. 2021), increasing runoff and sediment production (Cao, Wang & Liu 2021).

These changes in hydrogeomorphic processes can increase the rate of sediment delivery to streams (Yousefi et al. 2016), and deteriorating water quality (Nosrati & Collins 2019). The hydrogeomorphological processes refer to the interrelationship between hydrological and geomorphological processes acting in hydrographic basins (Sidle & Onda 2004), however, this interaction occurrence is not clear yet (Goerl, Kobiyama & Santos 2012).

Several reviews are found in the literature on the influence of roads on landscape dynamics, including soil erosion models (Fu, Newham & Ramos-Scharrón 2010), ecological issue (Cohen et al. 2021; Tiwari & Rachlin 2018), evolution of techniques of erosion control (Seutloali & Beckedahl 2015), delivery rate (Croke & Hairsine 2006), reduced sediment production (Burroughs & King 1989), remote sensing (Wang et al. 2016), heavy metals connectivity between highways and rivers (Schuler & Relyea 2018), rural road geometry (Roussiamanis et al. 2013), road paving (Bryce et al. 2017) and impact of roads on hydrological processes (Kastridis 2020), among others.

However, in recent decades, little has been discussed about the evolution and trends in research on highways around the world. In this context, the use of bibliometric research techniques is a form of integrated analysis of publications related to roads, in addition to allowing the assessment of emerging trends in road research and addressing possible research gaps.

Therefore, the objective of this article is to evaluate, through bibliometric analysis, how research has been on the hydrogeomorphological processes in roads in the last two decades (2001-2010 and 2011-2020) according the items: a) what data collection methods have been used, (b) what types of roads have received the most attention, (c) what are the methods for preventing and controlling land degradation in this time period, (d) what are the trends in future research on roads, and (e) what are the possible knowledge gaps to be considered in the future on roads. The bibliometric studies, which synthesize and discuss the scientific production of a given topic, significantly contribute to increasing the relevance and rigor of new research, in addition to supporting research decisions and project development (Romanelli et al. 2018).

2 Methodology

To analyze the evolution of research on roads in the last two decades, it was conducted a search for articles related to the topic on the Scopus platform. For this, it was used keywords that refer to roads in the search field, e.g., soil erosion on roads, sediment connectivity, ravines, rails, highways, abandoned roads, and road rehabilitation. A total of 150 articles published between 2001 and 2010 and 150 articles published between 2011 and 2020 were selected, totaling 300 articles for analysis.

The articles were tabulated and identified in relation to the data collection method (natural rain, simulated rain, or modeling) and types of roads, which have been divided into unpaved rural roads, paved rural roads (additional layer of gravel), forested roads, highways, road bank, trails, and abandoned roads (Figure 1). Trails refer to paths that do not receive constant traffic. Among them, it was highlight paths inside agricultural areas and forest trails to remove wood.

The objectives of these research were also identified, including soil erosion on roads, bank erosion, connectivity of road sediments with rivers, environmental impact of the opening of roads, and erosion control techniques. Finally, the VOSviewer software (Van Eck & Waltman 2013) was used to temporarily represent the bibliographic production on roads according to countries and indexed terms.

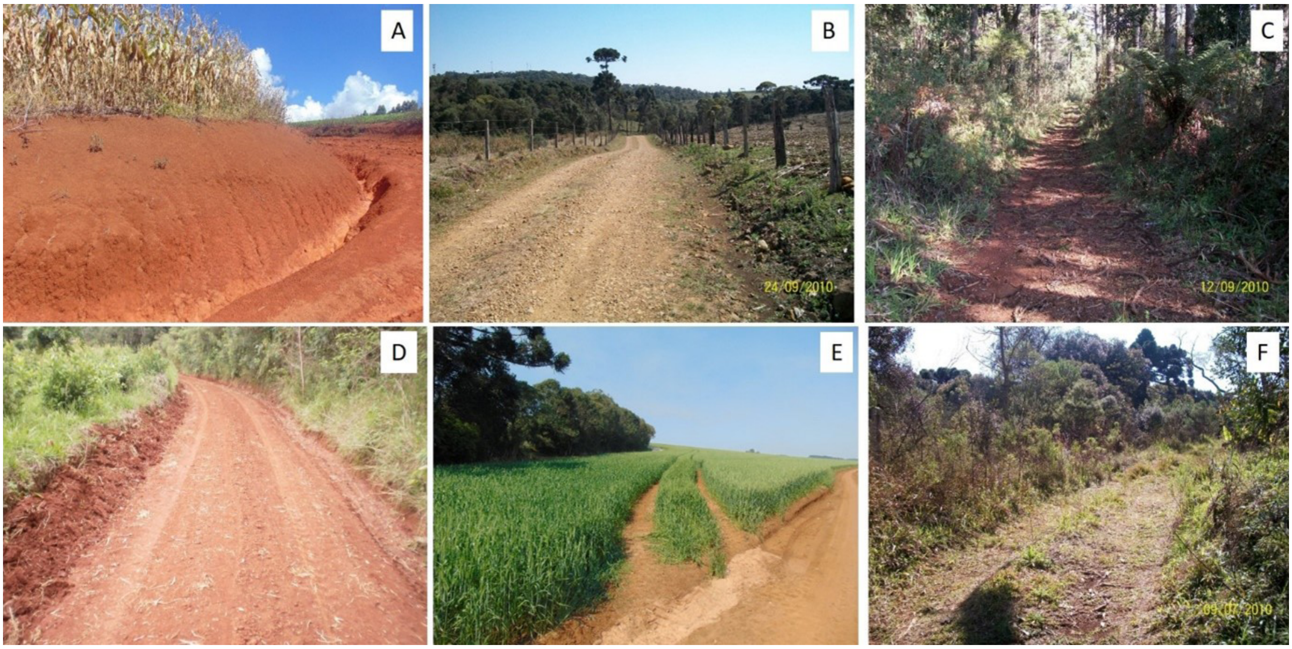

Figure 1 Types of roads. A. Unpaved rural road; B. Rural roads with gravel; C. Forest road; D. Road bank; E. Rails; F. Abandoned roads.

3 Results and Discussion

3.1 Evolution of Road Researches

The first research that were carried out under the influence of roads on landscape dynamics and delivery rate were based on the observations of Gilbert (1917), who recognized the role of roads as a source of sediments in Sierra Nevada, USA. However, research on the influence of roads on altering landscapes began in the 1950s. These researches appeared to assist in planning land use, aiming to decrease its degradation process (Navarro-Hevia et al. 2015).

Later, Hooven (1952) observed that the opening of roads for the cutting of wood affected the water quality because the opening of these roads caused disturbance in the soil. From then on, studies were carried out with the objective of understanding the dynamics of roads in the slopes and hydrographic basins until culminating recently with the influence of roads in the landscape. There is a gradual expansion of scale regarding the effect of roads (Figure 2).

In the 1970s and 1980s, researchers started observing roads as an important source of sediment in river basins. During this period, some research was carried out with the objective of identifying the influence of roads in different aspects, including soil erosion (Swanson & Dyrness 1975), sediment sources (Dunne 1979), use of road surface vegetation to reduce erosion (Monsen 1974), use of techniques to reduce roadbed erosion (Kidd & Kochenderfer 1973), influence of traffic on soil erosion (Reid & Dunne 1984), and addition of gravel layer to reduce erosion (Kochenderfer & Helvey 1987), among others.

In the 1990s, research on roads was intensified, covering several types and segments of roads, such as unpaved rural roads (Ramos-Scharrón 2010), gravel roads (Dacoregio et al. 2019), highways (Dong, Zhang & Guo 2012), and trails (Vinson et al. 2017). Currently, the hydrogeomorphological studies of roads are changing from empirical and physical studies related to surface runoff and sediment production at the scale of the terrain and the road segment to studies of sediment transfer at the river crossing level (Kastridis 2020).

In the mid-1990s, there was little research that aimed at quantifying soil erosion in specific sections of the road to assist in assessing its impacts (Elliot, Foltz & Luce 1995). When the loss of soil was noted and the factors interfering with these losses became known, the modeling emerged as a new research gap in soil erosion on roads (Cao, Wang & Liu 2021).

Soil erosion models range from simplified procedures, such as the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) (Seutloali & Beckedahl 2015), to more complex methods that require a series physical and morphological parameters, such as the Water Erosion Prediction Project (WEPP) (Oliveira, Wendland & Nearing 2013). USLE and RUSLE calculate the average annual soil loss caused by rill and inter-rill

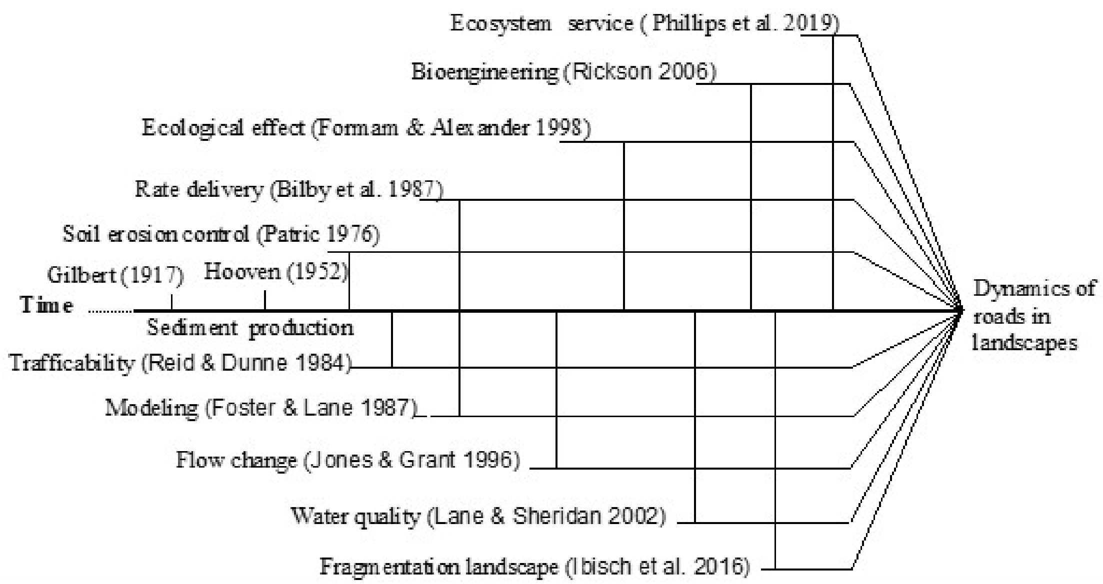

Figure 2 Simplified evolution of research on roads and related topics.

multiplying natural and anthropogenic factors. However, the use of this model is generally based on erosion rates in the landscape and may indicate different soil erosion rates when comparing road parcels (Riedel & Vose 2003).

The WEPP model was developed to provide a spatial and temporal distribution of soil loss (Baird et al. 2012). This model indicates a better adjustment in the estimate of soil loss on roads since it includes some characteristics of the road, such as road surface, cut slope, ditch, and embankment slope, among others (Cao et al. 2013). These characteristics are modeled separately, and they are defined as different elements of surface flow with unique parameters of soil and vegetation assigned (Fu, Newham & Ramos-Scharrón 2010).

The application of these models to estimate the rates of soil loss on roads may indicate problems, such as overestimation of erosion (Ou et al. 2021). Models were often developed based on data derived from the edaphoclimatic conditions of the United States or Europe, and the application of these models in different climatic and management conditions in other regions has leveraged new research applied to roads. As a result, other gaps were opened, such as delivery rate (Bilby, Sullivan & Duncan 1989; Jacobson & Primm 1997), alteration in the aquatic habitat (Goode, Luce & Buffington 2012), ecological effect (Forman et al. 2003), change in river flow (Jones & Grant 1996; La Marche & Lettenmaier 2001), connectivity of unpaved roads to rivers in urbanized areas (Nelson & Booth 2002), use of the fingerprinting technique (Collins & Walling 2002; Melquiades et al. 2019) and tracers (Thomaz & Melquiades 2009), both used to identify sources of sediment in river basins.

In the last decade (2011–2020), research began to emphasize the influence of on landscape fragmentation (Ibisch et al. 2016) and ecosystem services (Xu et al. 2020). In this context, the road was started to be studied as an agent that transforms landscapes. Additional current topics include infrastructure works, slope management, and restoration of vegetation on the roadsides. These techniques are efficient in reducing sediment production (Henderson, Smith & Fitch 2016) and in making decisions for opening new roads.

As research on roads has progressed, new perspectives have emerged with the opening of new research gaps. When roads were started to be important sources of sediment, investigations were intensified, to the point that soil erosion and its connectivity with rivers became popular. However, research on soil erosion and on-site connectivity requires greater effort to monitor variables. With the repository of information about soil erosion on roads, there was an intensification of the application of models that were useful in predicting and evaluating soil losses in road erosion (Yu et al. 2021).

From the application of models, it appears that the erosion of roads and their connectivity become clearer, and roads are then considered an integral part of the landscape (Ibisch et al. 2016). New insights have emerged, which were mainly related to water quality (Lane & Sheridan 2002), ecosystem services (Phillips et al. 2019) and ecology (Wang, Liu & Pang 2021). Therefore, nowadays roads are an important element in the dynamics of the landscape, due to its spatial representativeness and for causing soil degradation, aquatic ecosystems contamination, and landscape fragmentation.

3.2 Geographical Distribution of Road Surveys in the Past Two Decades

Due to the large number of researches on hydrogeomorphological processes on roads in the last two decades (4.3 times higher than the previous two decades) (Figure 3), it is observed that there was a more detailed understanding of the potential of roads to cause environmental degradation. It is estimated that approximately 1.5% of the Earth's surface is affected by the impacts of roads, which can degrade the landscape, fragment habitat (Avon et al. 2010), alter ecological flows (Sitzia, Campagnaro & Grigolato 2016) and increase erosion, indirectly affecting almost 25% of the planet (Cheng et al. 2015). Through the functions that roads have, and the rapid economic and population growth, it is estimated that by 2050 about 1–2 million km of roads will be opened every decade to meet social and economic demands (Faiz et al. 2012). Moreover, it is estimated that at least 25 million km of new roads are expected by 2050 around the world, accounting to an increase of 60% in the total of roads in relation to the 2010s (Laurance et al. 2014). The increased opening of new roads becomes an ecological threat to habitats, through soil losses (Cao et al. 2013), various forms of pollution (Leonard & Hochuli 2017), contamination of water resources (Zhang et al. 2021), both leading to landscape degradation (Martín et al. 2016).

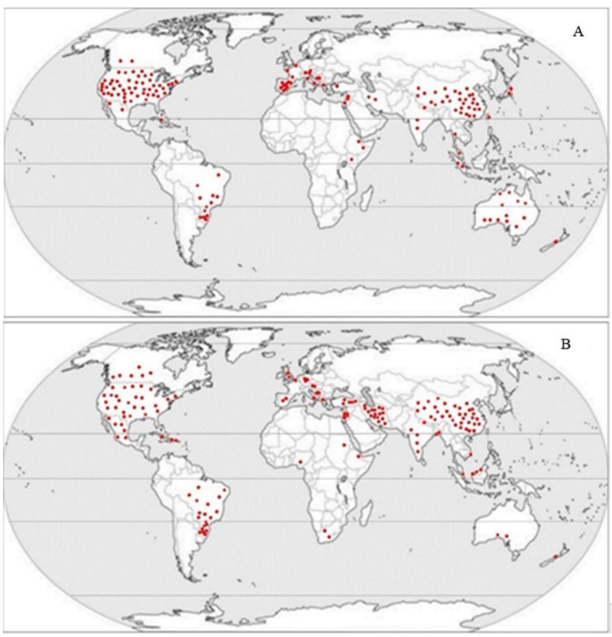

Figure 3 Geographical distribution of research around the world. A. Research carried out in the 2000s; B. Research carried out in the 2010s. The red dots represent the locations where searches were performed.

Most research on environmental impacts on roads is focused on temperate countries. Among them, the United States and China stand out, which have become references in research on the topic (Figure 3). The variations in the number of surveys between countries interfered with the distribution between continents. Asia had 116 articles in the interstice (38 .6%), and North America had 87 articles (29%), followed by Europe (12.3%) and South America (10.3%). In other continents, the contribution was less than 5%.

In the 2000s, the largest number of researches (33.7%) analyzed in this article were carried out in the United States, while 20% of researches were carried out in China (Table 1). Of the total articles researched, only 18% (27 articles) were developed in tropical countries, with 44% (12 articles) being carried out in Brazil.

Table 1 Distribution of resources in each country. Ranking of the 10 countries with the highest number of research. The other countries indicated less than five research in the two decades. Source: articles extracted from the Scopus platform using the keywords indicated in the methodology.

Countries	Decade	
	2000	2010
United States	49	24
China	30	35
Brazil	12	19
Iran	2	16
Australia	12	2
Spain	10	2
Canada	2	5
Mexico	1	6
Israel	1	5
Turkey	0	5

In the 2010s, there was a reduction in research in some countries compared to the previous decade, for example, a 51.3% research reduction in the United States, five times reduction in Spain, and six times reduction in Australia. However, some countries have seen an increase in the number of research, such as Brazil (41.6% increase), Canada (2.5 times), and Mexico (5 times). The greatest increase was seen in the Middle East, with Iran producing eight times more articles in the 2010s than in the 2000s. Israel and Turkey also indicated a considerable increase between the two periods (four and five times respectively).

Therefore, in the last decade, there has been a reduction in research in countries that over time have become a reference in research on roads. For this reason, the displacement of research areas from countries such as the United States and some European countries to countries in the Middle East, Africa, and Latin America, where the change in land use is occurring at alarming rates, increasing soil erosion (Aneseyee et al. 2020; Rodrigues et al. 2021). The opening of new research frontiers in emerging countries results from the little knowledge of the dynamics of roads in other terrestrial landscapes, thus leading to a little delay in the research carried out in these countries.

3.3 Types of Road Segments Studied

In the past two decades, research have been carried out on several types of road segment (Table 2). However, forest roads and unpaved roads in rural areas continue to be the study subjects in most research, accounting for 49% of the total research conducted.

Unpaved roads were the subject of 50 research studies in the 2000s; however, there was an 89% reduction in the 2010s. A similar situation occurred on forest roads and highways, with a reduction of 55 % and 85%, respectively. In the last decade, we observed an increase in the number of searches in some segments of roads, such as gravel roads (115.2%), road bank (93.3%), trails (113.0%), and abandoned roads (100%).

It was observed that highways and road bank have become the study subjects in several research in the last decade. This increase may be associated with the development of the road network in recent years around the world. However, the control of soil erosion in highway bank and railroad bank is almost negligible (Seutloali & Beckedahl 2015). Several research point to the addition of a vegetation cover in these banks, aiming to reduce environmental problems (Rivera et al. 2014), but the compaction and erosion of these banks hinder the rapid establishment of vegetation (Hobbs & Norton 1996).

Despite the increase in research on abandoned roads, little attention has been given to the recovery and reuse of these roads. Some research has been carried out to observe the hydrosedimentological behavior in the reopening of abandoned roads. However, the results are inconclusive as to the time required for soil conditions to improve. Foltz, Copeland and Elliot (2009) observed that 30 years without traffic and vegetation regeneration was not enough to allow the recovery of the infiltration to values similar to an intact forest. Therefore, the recovery of vegetation cover may be like that of conditions without roads (Lloyd, Lohse & Ferré 2013), but little is still known regarding the recovery of hydrological and geomorphological characteristics at the top of the soil on these roads.

Therefore, the reduction in research on unpaved roads and forest roads in the last decade is mainly due to the detailed understanding of the erosive dynamics of this type of road (Seutloali & Beckedahl 2015). As a result, new road segments have been used for new research, in addition to testing new methods of data collection.

3.4 Objectives of Studies on Road Segments in the Past Two Decades

Over time, the focus of research has shifted, but road surface erosion still seems to be the main objective of research in the past two decades. Among all the articles evaluated in this study, 48.3% quantified the erosion of the road surface (Table 3).

Table 2 Road segments used as a study object in the last two decades.

Decades	Unpaved roads	Forest roads	Gravel roads	Highways	Road bank	Trails	Abandoned roads
2000	50	41	12	23	15	8	2
2010	28	28	29	14	29	17	4
Total	78	69	41	37	44	25	6
%	26.0	23.0	13.7	12.3	14.7	8.3	2.0

Table 3 Distribution of research related to the research objective.

Decades	Surface erosion	Bank erosion	Delivery rate	Impact on landscapes	Prevention
2000	78	8	17	16	34
2010	67	3	30	27	21
Total	145	11	47	43	55
%	48.3	3.6	15.6	14.2	18.2

Issues such as sediment connectivity and the influence of roads on the landscape have stood out among road surveys in the past decade. The advance in the knowledge of the connectivity of road sediments with water bodies has broadened the understanding of the influence on landscape dynamics. Understanding connectivity helps to mitigate the adverse impacts on the environment (Jaafari et al. 2015; Ramos-Scharrón 2021).

Therefore, soil erosion, although well documented over time, still seems to be the most used research object in recent decades. This fact is related to the decentralization of research from central countries to emerging countries (Figure 4). The opening of new research fronts on roads in emerging countries results from the increase in the opening of new roads, use of established methodologies to observe how they behave in different edaphoclimatic conditions, and internationalization of research institutions and research partnerships with central countries.

3.5 Methods used for Data Collection

The change in the objective of research carried out on roads permeates the methods adopted and/or developed. Even so, research with natural rain accounted to 43.3% of the total. In the 2000s, 55.3% of the surveys were conducted with natural rain, while in the following decade, there was a 76% reduction in the number of research with natural rain. This reduction is attributed to the increase in research using simulated rain, which increased by 70.6% in the 2010s (Table 4).

With the increase in research using rain simulation, there is also an increase in the application of models to identify the influence of roads on the landscape dynamics. Road erosion models are relatively less developed than erosion models in agricultural areas, which have been a focus of research and development over the past half century (Dubé, Megahan & Mccalmon 2004). However, when evaluating the results of the model, it should be kept in mind that the output is an estimate and not a precise value (Jaafari et al. 2015).

The increased use of rain modeling and simulation can be attributed to the ease of collecting and generating data, monitoring in the field with natural rain demands a lot of effort from the researcher. The evolution of road modeling can also be related to the development of new technologies for collecting information associated with remote sensing.

As technology advanced, several models were created and used to analyze both quantitatively and qualitatively the rate of soil erosion on roads. However, in recent years researchers have used geostatistical methods to collect information about environmental processes on roads (Ezekwesili & Agunwamba 2021; Igwe et al. 2020) (see keywords in Figure 5).

3.6 Current Trends

Studies on road erosion have intensified since the 1970s, a time when rural and urban land planning began to be implemented to prevent the degradation of ecosystem (Navarro-Hevia et al. 2015). The purpose of these studies was to investigate the importance of road surfaces in soil erosion in different agricultural and nonagricultural scenarios around the world (Cao et al. 2013). With this, there was a more detailed understanding of soil erosion on rural roads and its controlling factors, e.g., slope, type of road surface, ramp length, trafficability, and edaphoclimatic conditions. Currently, there seems to be a refinement of research in relation to roads such as water repellency (Papierowska et al. 2020), shear strength (Ubido, Ogbonnaya & Ukah 2020), and air pollution through traffic (Wawer et al. 2020), among other studies, which describe roads as an element of the landscape. Currently, roads are analyzed holistically and they are part of an integrated landscape system, characterized as an open system, with continuous material and energy exchanges with the environment (Phillips 1999).

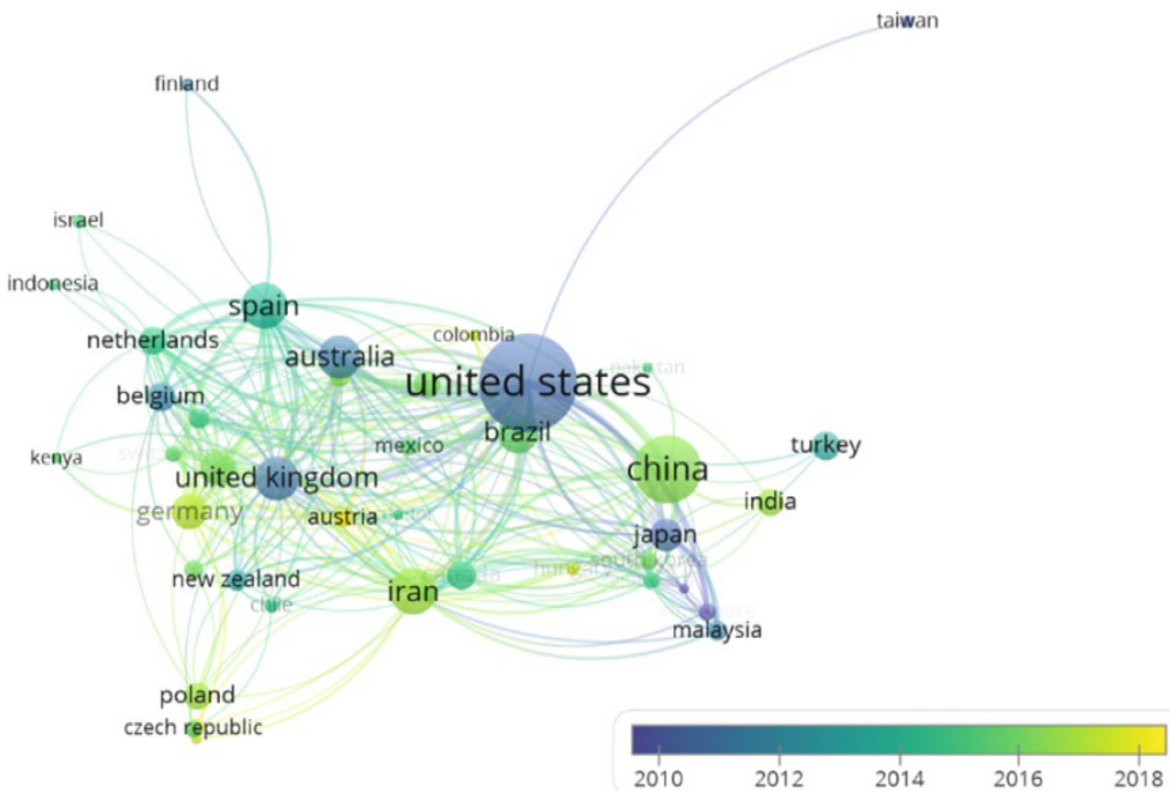

Figure 4 Bibliographic production on environmental processes on roads.

Table 4 Method used for data collection on roads in the last two decades.

Decades	Modeling	Rain simulation	Natural rain
2000	33	34	83
2010	45	58	47
Total	78	92	130
%	26.0	30.6	43.3

The more in-depth knowledge of environmental degradation promoted by roads has enhanced the application of modeling, primarily with the current technological advance, such as the use of Terrestrial Laser Scanning and Digital Elevation Models (DEMs), which are both used to detail the surface dynamics of roads and erosion processes (Cao, Wang & Liu 2021). Temporally, studies have progressed on road segments, mathematical models, dust production, and particulate matter linked the longest to the United States. Recent studies have been carried out on suspended sediments, sediment analysis, and soil conservation in a watershed scale approach (Figure 5).

Future research should focus on themes that have been underemphasized over time, such as the application of effective methods to reduce environmental degradation promoted by roads, planning to open new roads, proximity of the results of the various studies carried out on roads over time with public managers who effectively carry out road maintenance, and training of public managers responsible for the maintenance and opening of new roads.

Roads have become the most ubiquitous elements in terrestrial landscapes. Therefore, the presence and dynamics of roads must be considered not only from the economic point of view and circulation of goods and human development but also in territorial planning, conservation of natural resources, and maintenance of ecosystem services in hydrographic basins.

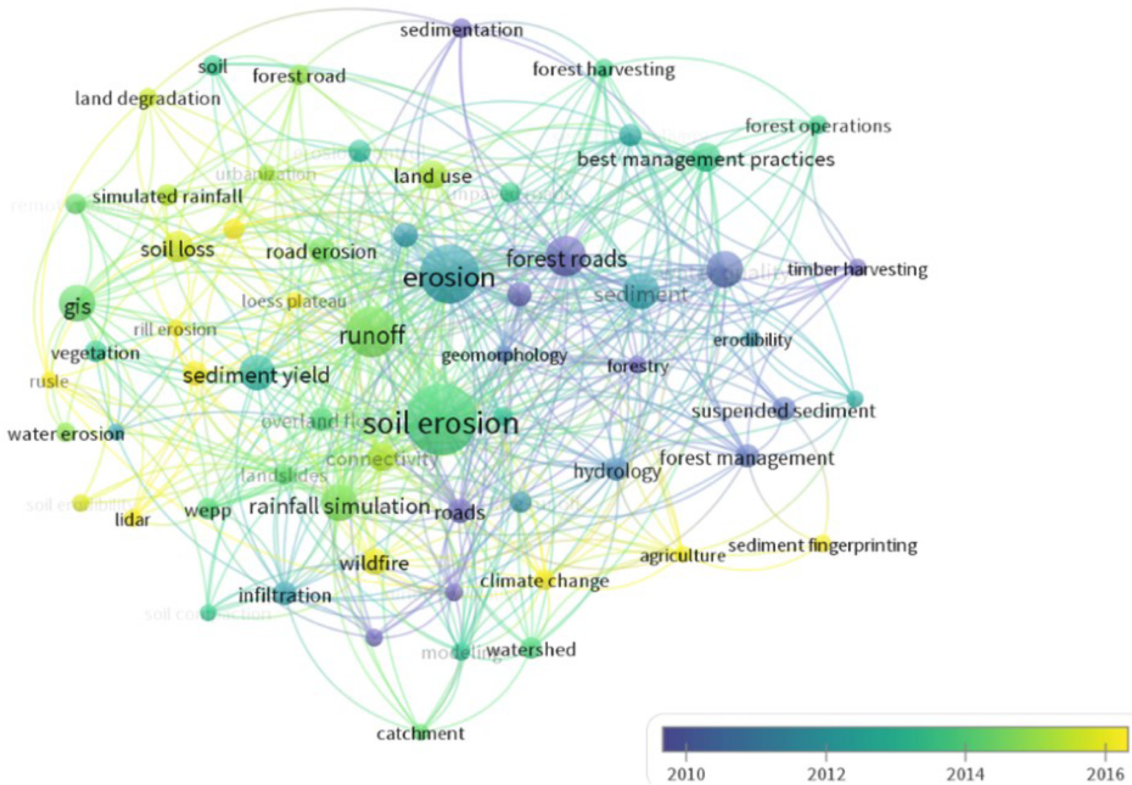

Figure 5 Temporal evolution of indexing words related to the study of roads.

4 Conclusion

During the study period, there was a change in the research objective regarding hydrogeomorphological processes. In the 2000s, around 60% of surveys were carried out on unpaved roads and rural roads. In the following decade, this scenario changed, new research perspectives emerged, focusing on other road segments such as gravel roads and road bank. Along with these new research perspectives, new research gaps such as the delivery rate and the impact of roads on the landscape have opened up. However, surface erosion of roads is still one of the main research objectives, despite a significant increase in rainfall modeling and simulation for data collection.

In recent decades, there has been decentralization of research on rural roads. Countries such as the United States, Spain, and Australia, which have become a reference on this topic, have reduced their research. In contrast, China, which has also been considered a reference in road studies, increased the number of surveys from the 2000s to the 2010s. Surveys have been decentralized in some Latin American countries like Brazil and Mexico and in the Middle East like Iran and Israel, on the international road research scene.

The opening of new research frontiers in emerging countries may be conditioned to some factors, such as testing known research methods in different landscapes of tropical climate, increase in the road and rail network in these countries, and insertion and partnerships between institutions in these developing countries and institutions in developed countries. However, the opening of new roads in developing countries includes many regions that support exceptional biodiversity and ecosystem services vital to the planet, and the fragmentation of these habitats due to the opening of new roads leads to environmental degradation.

Environmental processes are well known and has been the subject of studies in recent decades. This suggests that much research only replicate known methods and techniques with little advance in knowledge. However, new research perspectives have emerged, primarily focusing on the influence of roads on the dynamics of landscapes.

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Author contributions

Valdemir Antoneli: conceptualization; methodology; validation; writing-original draft; writing – review and editing. **Jefferson Eslei Mazur:** methodology; formal analysis; validation. **Edivaldo Lopes Thomaz:** conceptualization; validation; writing-original draft; writing – review and editing. **João Anesio Bednarz:** conceptualization; formal analysis; writing-original draft.

Conflict of interest

The authors declare no potential conflict of interest.

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