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Linguistic Summarization for Analyzing Earthquake Impact: A Study on the 2023 Kahramanmaraş Earthquakes in Türkiye

Sena AYDOGAN[1,*], Nazmiye ELIGUZEL[2]

[1]Gazi University, Faculty of Engineering, Department of Industrial Engineering, 06570, Ankara, Türkiye
[2]Gaziantep Islam, Science & Technology University, Faculty of Engineering, Department of Industrial Engineering, 27010, Gaziantep, Türkiye

Highlights

- Analyzes complex datasets from 11 provinces affected by the earthquakes by linguistic summarization.
- Creates concise, insightful summaries to support policymakers in disaster response and planning.
- Investigates numerous factors to identify patterns and provide actionable insights.

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Abstract

A disaster is an event or a series of events that greatly disrupt the usual flow of daily activity. The earthquakes that struck Kahramanmaraş in 2023 impacted eleven provinces across Türkiye. These earthquakes resulted in the deaths of over 50,000 individuals, caused destruction to more than 500,000 structures including communication and energy facilities, and resulted in substantial economic damages. This study investigated the possible use of linguistic summarization to analyze 11 provinces located in an earthquake-prone area, using data that is peculiar to these provinces. The aim of the study is to transform raw data into intricate descriptions that exhibit linguistic complexity, employing a specific technique known as linguistic summarization. The objective of this research is to examine patterns in each province by taking into account various factors, including the proportion of earthquake-affected provinces in the gross domestic product (GDP) and subsectors data, the total number of buildings in earthquake-affected provinces, data on house damage, data on disaster housing planning, the overall damage to companies by provinces, and data on the damage status of tourism facilities. The main objective of the study is to offer brief and readily understandable information about regions prone to earthquakes, so improving the comprehension of decision-makers and policymakers to enable well-informed decision-making. Analysis indicates that economic recovery may depend on sectors with limited structural damage yet significant GDP contribution, highlighting the necessity of targeted actions to alleviate the enduring effects of disruptions in real estate and the public sector.

1. INTRODUCTION

Türkiye is located on the geologically active Anatolian Plate, which has experienced numerous significant earthquakes throughout its history. Between 1900 and 2023, Türkiye encountered 269 earthquakes, resulting in human casualties and considerable economic damage [1]. Two significant earthquakes occurred in Türkiye on February 6th, 2023. The epicenters were located in Pazarcık (Mw 7.7; focal depth: 8.6 km) and Elbistan (Mw 7.6; focal depth: 7 km) districts of Kahramanmaraş. The earthquakes took place at 04:17 and 13:24 local time, respectively. These earthquakes, which are unprecedented in recent history both in terms of their severity and extent, resulted in significant destruction over a total of 11 provinces, which are Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Malatya, Kahramanmaraş, Şanlıurfa, Kilis, and Osmaniye [1]. These earthquakes resulted in 50,339 deaths and 107,200 injuries [2]. According to official data at the governorate level (see Figure 1), the geographical distribution of displaced people outside the affected provinces shows that at least 1.1 million people, mostly Turkish citizens, have moved to various parts of the country. This number includes the 2.7 million people who have been displaced within the 11 provinces [3].

*Corresponding author, e-mail: senaaydogan@gazi.edu.tr

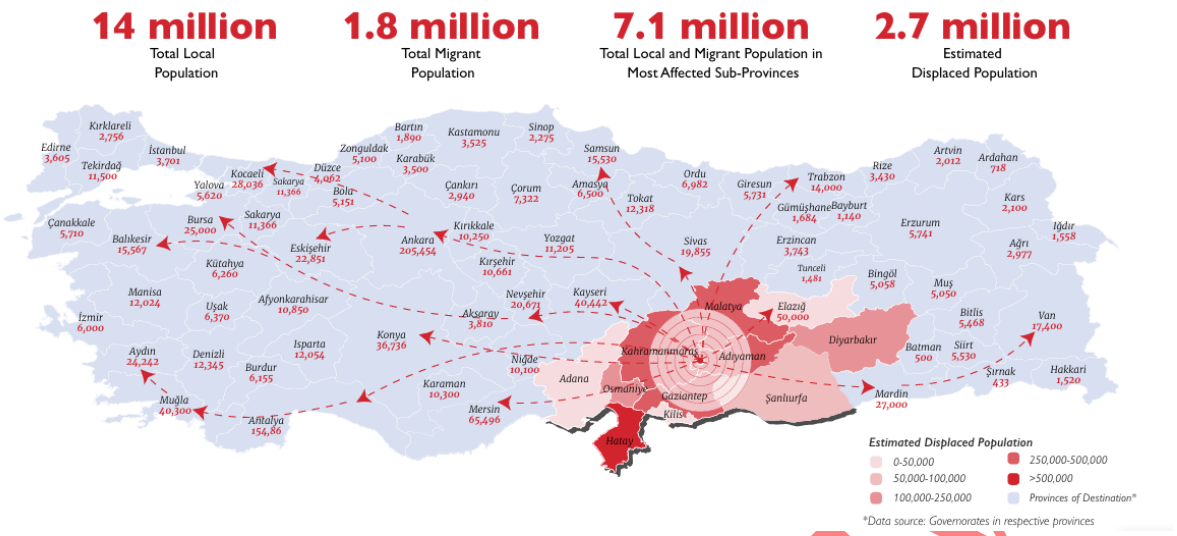

Figure 1. *Overview of Earthquake Displacement [3]*

There are 14 million local inhabitants and 1.8 million migrants located in the affected region, with 7.1 million residing in hard-hit areas (6.3 million locals and 0.8 million migrants) [3]. These data illustrate the destructive intensity of earthquakes and the extent of their geographical impact.

After examination of the literature on the Kahramanmaraş earthquake, it is clear that the majority of the studies are predictive models in fields such as Earth and Planetary Sciences [4-6], forecasting models [7], environmental sciences [8,9] etc. In contrast to the existing literature, we proposed to use a descriptive model, namely linguistic summarization. This study aims to utilize the linguistic summarization technique to examine the earthquake's impact on 11 provinces. Consequently, it may guide prediction models. Linguistic Summarization is a technique introduced by Yager [10] and has been successfully applied in different fields, including sustainability [11], healthcare [12], business [13], human resources [14], time series [15-17], international trade network [18], knowledge discovery [19].

In the current study, data unique to 11 provinces in an earthquake-prone area were used to analyze the possible use of linguistic summarization. The objective of the research is to convert the unprocessed data into detailed descriptions that are linguistically sophisticated, using a unique approach called linguistic summarization. This research aims to analyze patterns in each province by considering several factors, such as the proportion of earthquake-affected provinces in the GDP and subsectors data, the total number of buildings in earthquake-affected provinces, the data on house damage, the data on disaster housing planning, the overall damage to companies, and the data on the damage status of tourism facilities. The primary goal is to provide concise and easily comprehensible information regarding earthquake-prone areas, enhancing the understanding of decision-makers and policymakers to facilitate informed decision-making.

The framework for the subsequent sections of the research is as follows. The methodology, which incorporates linguistic summarization, is explained in the second section. The problem definition, results, and discussions are presented in the third section, and the study is concluded in section 4.

2. MATERIALS AND METHOD

As proposed by Yager [10], fuzzy linguistic summarization is a descriptive process that condenses large volumes of numerical data into shorter, easy-to-understand summaries that capture essential information about the data. Before introducing linguistic summarization, fuzzy sets are described briefly in the following subsections.

2.1. Fuzzy Sets

Fuzzy set theory extends regular set theory by allowing partial membership, making it a more flexible and realistic approach to dealing with imprecise information. Its mathematical tools and operations help reasoning and decision-making in uncertain environments [20]. A characteristic function of an element belonging to a set takes a value in {0,1} in classical set theory, while it takes a value in [0,1] in fuzzy set theory. On universal set X, a fuzzy subset A is defined as $A = \{x, \mu_A(x) | x \in X\}$ where the characteristic function of x is a mapping from universal set to the unit interval, $\mu_A(x): X \rightarrow [0,1]$. For two fuzzy subsets A_1 and A_2 of universal set X, the intersection of them is defined as $\mu_{A_1 \cap A_2}(x) = \min(\mu_{A_1}(x), \mu_{A_2}(x))$ and union of them is described as $\mu_{A_1 \cup A_2}(x) = \max(\mu_{A_1}(x), \mu_{A_2}(x))$.

To convert fuzzy sets into crisp sets, α −cut is used. The crisp set of A is defined as $A_\alpha = \{x \in X | \mu_A(x) \geq \alpha\}$. If any fuzzy subset is normal (i.e., $\sup_{x \in X}\{\mu_A(x)\} = 1$) and convex, then the fuzzy set is also named a fuzzy number. The two most common fuzzy numbers, triangular and trapezoidal, are defined in Equation (1) – Equation (2) and depicted in Figure 2 (a) and Figure 2 (b), respectively

$$Triangular_{a,b,c}(x) = \begin{cases} (x-a)/(b-a) & a \leq x \leq b \\ (c-x)/(c-b) & b < x \leq c \\ 0 & otherwise \end{cases} \quad (1)$$

$$Trapezoidal_{a,b,c,d}(x) = \begin{cases} (x-a)/(b-a) & a \leq x \leq b \\ 1 & b < x \leq c \\ (d-x)/(d-c) & c < x \leq d \\ 0 & otherwise \end{cases}. \quad (2)$$

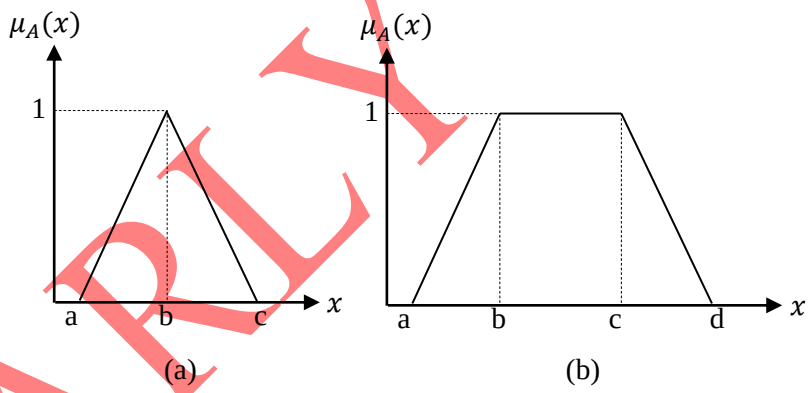

Figure 2. *(a) Triangular fuzzy number, (b) trapezoidal fuzzy number*

2.2. Linguistic Summarization

Summarization is one of the descriptive techniques in data mining [21]. Statistical summarization allows us to export knowledge narrowly, including only mean, standard deviation, etc. However, the power of natural language statements can ease the understanding and enrich the generated summaries by linguistic summarization.

In linguistic summarization, sentences are generated adhering to predefined protoform structures proposed by Zadeh [22] and are associated with the degrees of accuracy of the generated summaries. Two basic protoforms are described below.

Let Y be the set of objects, Q be a linguistic quantifier, A be a summarizer, and T be the corresponding truth degree, then the type-I protoform is formed as "$Q\ Y\ A\ [T]$". For example, "Most earthquake victim city have low economic contribution of financial insurance activities to GDP [1.00]" is a type-I protoform generated from the dataset in which most is the quantifier, earthquake victim city is the object, low

economic contribution of financial insurance activities to GDP is the summarizer, and 1.00 is the truth degree of the summary.

In addition to the type-I protoform, let B be a pre-summarizer, then the type-II protoform is formed as "$Q\ B\ Y\ A\ [T]$". For example, "Most high machinery damage to companies earthquake victim city have low economic contribution of financial insurance activities to GDP [1.00]" is a type-II protoform generated from the dataset in which high machinery damage to companies is the pre-summarizer.

Truth degrees (T) related to type-I protoform and type-II protoform are given in Equations (3) and (4), respectively [23]. Higher T values mean that the summary represents the dataset better

$$T = \mu_Q\left(\sum_{m=1}^{M} \mu_A(v_k^m)\right) \tag{3}$$

$$T = \mu_Q\left(\frac{\sum_{m=1}^{M}(\mu_A(v_{k_1}^m)\otimes\mu_B(v_{k_2}^m))}{\sum_{m=1}^{M}\mu_B(v_{k_2}^m)}\right). \tag{4}$$

In Equation (3), v_k^m shows the value of k^{th} attribute for m^{th} object, $\mu_A(v_k^m)$ shows the membership degree of that value to fuzzy set A, μ_Q represents the membership degree of inner parenthesis to the fuzzy quantifier Q. Equation (4), in addition to the definitions mentioned earlier, $\otimes$ shows any t-norm operator for the intersection of two fuzzy sets; the minimum operator is applied in this study. Please see [24] for detailed information on evaluation methods.

3. APPLICATION

3.1. Problem Definition

We collected the data from the Kahramanmaraş and Hatay Earthquakes Report. [1]. The report considered the most recent dates for the available data. Data includes information on the "Proportion of GDP and subsectors affected by earthquakes in various provinces", "Number of Total Buildings in Earthquake-Affected Provinces", "Damage Control Report by Province", "Disaster Houses Programme", "Total Damage to Companies by Province", and "Damage Status of Tourism Facilities in Earthquake-Affected Regions". The provided data also contains subtitles.

In the final dataset, 11 provinces (Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Malatya, Kahramanmaraş, Şanlıurfa, Kilis, and Osmaniye) and related 29 features under the six main titles are present. The features and related subfeatures are presented in Table 1.

First, the values based on six titles are clustered using the fuzzy c-means algorithm to determine fuzzy linguistic summarizers/pre-summarizers to be used in protoforms [25]. Three fuzzy linguistic summarizers (low-medium-high) for each feature and their membership functions are presented in Figure 3. Second, Q is defined by a trapezoidal fuzzy membership function (0.5;0.75;1;1) for fuzzy linguistic quantifier component of to be generated protoforms.

Table 1. *Features and related subfeatures*

Feature		Subfeature	
x_1	Economic contribution to GDP	$x_{1,1}$	Agriculture, forestry and fishery
		$x_{1,2}$	Industry
		$x_{1,3}$	Manufacturing industry
		$x_{1,4}$	Construction
		$x_{1,5}$	Services
		$x_{1,6}$	Information and communication
		$x_{1,7}$	Financial and insurance activities
		$x_{1,8}$	Real estate activities
		$x_{1,9}$	Professional, administrative and support service activities
		$x_{1,10}$	Public administration, education, human health and social work activities
		$x_{1,11}$	Other service activities
		$x_{1,12}$	GDP
x_2	Number of buildings affected by the earthquake	$x_{2,1}$	Resident
		$x_{2,2}$	Workplace
		$x_{2,3}$	Public
		$x_{2,4}$	Other
x_3	Number of damaged houses	$x_{3,1}$	Urgent/severely damaged or collapsed
		$x_{3,2}$	Moderately damaged
		$x_{3,3}$	Lightly damaged
x_4	Number of damaged tourism facilities	$x_{4,1}$	Collapsed
		$x_{4,2}$	Severely damaged
		$x_{4,3}$	Moderately damaged
		$x_{4,4}$	Lightly damaged
x_5	Total estimated damage to companies (in a million TRY)	$x_{5,1}$	Infrastructural damage
		$x_{5,2}$	Building damage
		$x_{5,3}$	Machinery damage
		$x_{5,4}$	Stock damage
x_6	Number of planned houses	$x_{6,1}$	House
		$x_{6,2}$	Village house

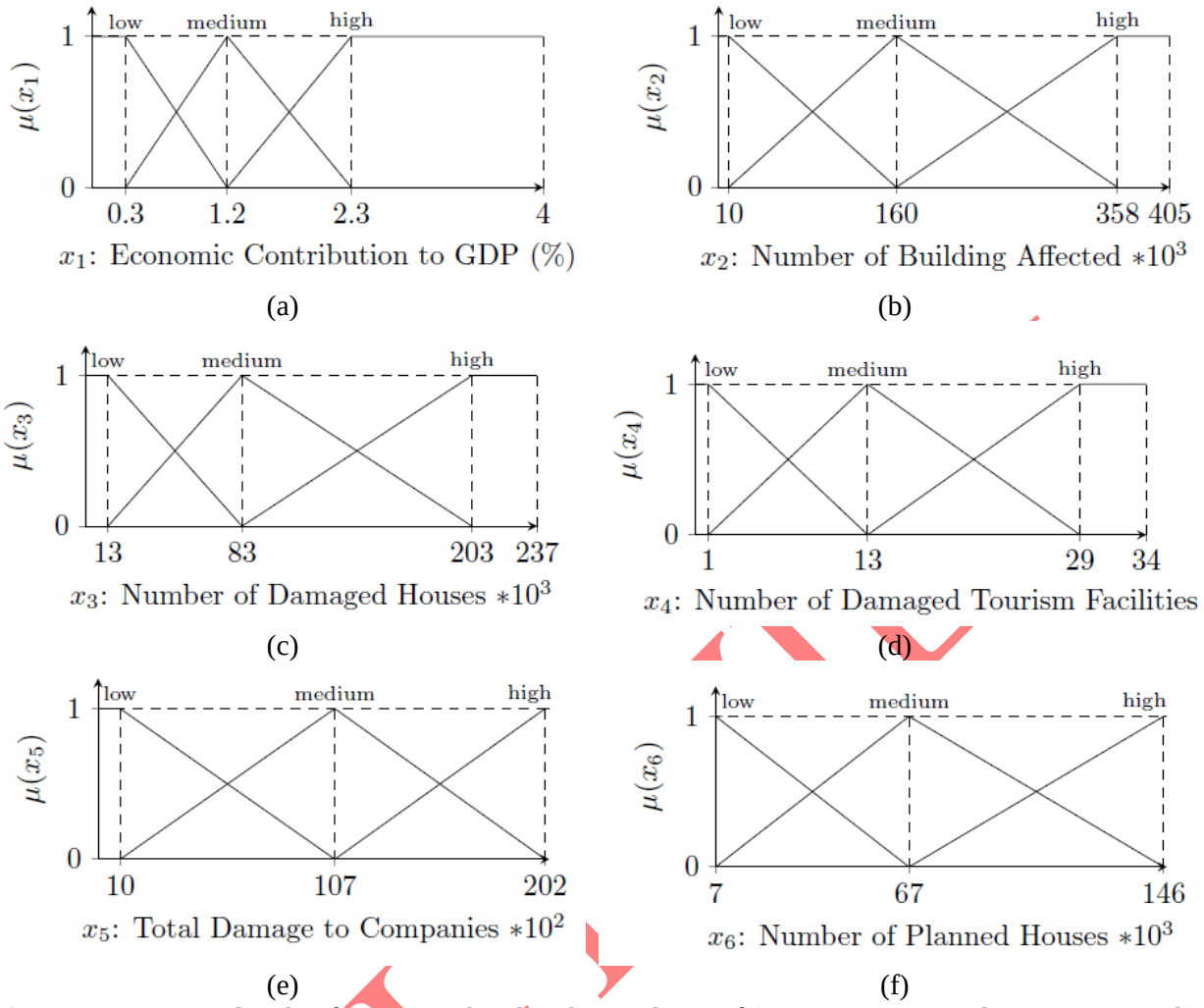

Figure 3. *Fuzzy membership functions related to the attributes of (a) Economic contribution to GDP, (b) Number of buildings affected, (c) Number of damaged houses, (d) Number of damaged tourism facilities, (e) Total damage to companies, and (f) Number of planned houses*

Third, type-I fuzzy linguistic summaries are generated for each province separately by taking summarizers from the subfeatures set. Last, type-II fuzzy linguistic summaries are generated for overall provinces using summarizers and pre-summarizers from the subfeatures set.

3.2. Results and Discussion

The proposed paper aims to extract information about earthquake provinces from various perspectives, such as their economic contribution to GDP, affected tourism facilities, total damage to companies, and so on. The threshold value for accurate summaries is defined as 0.7. We select linguistic summaries with truth degrees greater than 0.7 to include in the results. Word clouds are generated to graphically emphasize frequently recurring terms within the text. Word clouds are favored for emphasizing summaries by taking into account the truth degrees of the sentences instead of word frequency. Figure 4 illustrates the province-based summary results through word clouds.

Figure 4. *Word clouds of province-based linguistic summaries*

The critical interpretations for provinces are given below.

Adana: The economy of Adana is predominantly reliant on agriculture, industry, manufacturing, and public services, all of which provide substantial contributions to the GDP. The financial and other service activities

provide a moderate economic contribution. Although the region's economy is performing well, a significant number of residential buildings are impacted by earthquakes, while the damage to workplaces, public buildings, and other structures is minimal. The tourism industry remains virtually unscathed, with minimal harm to firm infrastructure and assets. The quantity of proposed residences, encompassing both village dwellings, must be increased. This indicates a requirement for heightened attention towards enhancing the ability of residential buildings to withstand seismic events and even reevaluating housing construction plans to ensure better preparedness for future earthquakes.

Adıyaman: Adıyaman's economy has a minimal contribution from critical sectors, including industry, manufacturing, construction, services, information and communication, financial activities, real estate, and professional services. This signifies a comparatively feeble and undeveloped economy. Analyzing the data on post-earthquake destruction in Adıyaman using absolute numbers may seem relatively less than in other provinces. Nevertheless, taking into account the demographic and geographical attributes of the provinces of the earthquake region, it becomes apparent that this devastation is indeed more severe.

Diyarbakır: The economy of Diyarbakır is distinguished by a substantial involvement in agriculture and forestry, together with noteworthy activity in the building and real estate industries. Nevertheless, the industrial, manufacturing, and service sectors have a comparatively minor impact on the GDP. The public sector has a substantial effect on the economy. Regarding post-earthquake impact, Diyarbakır experiences moderate to low damage across different types of buildings, with a notable effect on residential structures. The tourism sector also faces challenges, with varying degrees of damage to tourism facilities. However, the overall effect on companies and infrastructure remains relatively minimal.

Elazığ: The economy of Elazığ is mainly defined by a low contribution from diverse sectors such as industry, manufacturing, services, real estate, and financial activities. Nevertheless, the public sector activities make a significant but not excessive contribution. The city's contribution to its GDP is small. Elazığ sustains modest damage to various types of buildings and has a negligible effect on public and commercial infrastructure in the aftermath of the earthquake. The extent of harm to residential and tourism facilities is now restricted, and the influence on businesses and infrastructure is relatively small.

Gaziantep: The economy of Gaziantep is characterized by a well-balanced contribution from multiple sectors, with a significant focus on industry, manufacturing, and services. The city's substantial contribution to the overall GDP indicates its robust economic activity. Gaziantep shows modest damage to many structures after an earthquake, with negligible effects on public, commercial, and residential infrastructure. The extent of harm to residential and tourism facilities is restricted, and the influence on businesses and infrastructure is relatively low. Although particular areas in Gaziantep have experienced severe destruction, it may be perceived as relatively minimal when evaluating the overall impact based on absolute numbers. However, when considering the limited scope of the damage, especially in certain districts or neighborhoods, the seriousness of the issue becomes more evident.

Hatay: In Hatay, the agricultural, construction, services, and real estate sectors make a minor contribution to the economy. However, the earthquake has had a substantial impact. Residential structures, specifically, have encountered extensive destruction, with many residences being seriously impacted. The tourism industry has also experienced significant repercussions, with different levels of harm observed in various establishments. Moreover, organizations have experienced substantial damage to their infrastructure and assets.

Malatya: The economy of Malatya is predominantly dependent on public services, with industries and industrial sectors making only marginal contributions. The earthquake's aftermath is evident, with substantial destruction to residential structures and tourism infrastructure. Nevertheless, the effect on commercial infrastructure and organizations is relatively minimal.

Kahramanmaraş: The economy of Kahramanmaraş is distinguished by a harmonious and equitable contribution from the agricultural, industrial, and manufacturing sectors. Nevertheless, the service sector's contribution is relatively low, indicating the possibility of expansion in this domain. The earthquake's

aftermath is substantial since extensive destruction is evident in residential structures and tourism establishments. Additionally, there is significant harm to the company's infrastructure and assets.

The results for type-II fuzzy linguistic summaries (LSs) for overall provinces are listed in Table 2.

Table 2. *Linguistic summaries for overall provinces*

LS	*Q*	*B*	*Y*	*A*	*T*
1	Most	High Building Damage to Companies	Provinces also have	Medium Economic Contribution of GDP to GDP	0.80
2	Most	High Building Damage to Companies	Provinces also have	Medium Economic Contribution of Industry to GDP	0.87
3	Most	High Building Damage to Companies	Provinces also have	Low Economic Contribution of Information Communication to GDP	1
4	Most	High Building Damage to Companies	Provinces also have	Low Economic Contribution of Financial Insurance Activities to GDP	1
5	Most	High Economic Contribution Of Industry To GDP	Provinces also have	"High Number of Resident Building Affected", "Low Number of Public Buildings Affected"	1
6	Most	High Economic Contribution Of Real Estate Activities To GDP	Provinces also have	"High Number of Resident Building Affected", "Low Number of Public Building Affected", "Low Number of Collapsed Tourism Facilities", "Medium Building Damage to Companies"	1
7	Most	High Economic Contribution Of Public Administration Education, Human Health, Social Work Activities To GDP	Provinces also have	"Low Number of Workplace Building Affected", "Low Number of Public Building Affected", "Low Number of Other Building Affected", "Low Number of Urgent Severely Damaged Collapsed Houses", "Low Number of Urgent Moderately Damaged Collapsed Houses"," Low Number of Collapsed Tourism Facilities", "Low Number of Severely Damaged Tourism Facilities", "Low Number of Moderately Damaged Tourism Facilities", "Low Number of Lightly Damaged Tourism Facilities", "Low Infrastructural Damage To Companies", "Low Building Damage to Companies", "Low Machinery Damage to Companies", "Low Stock Damage to Companies"	0.78-1
8	Most	Medium Number Of Urgent Severely Damaged Collapsed Houses	Provinces also have	Low Economic Contribution Of Financial Insurance Activities To GDP	1
9	Most	Low Economic Contribution Of Construction To GDP	Provinces also have	"Low Number of Workplace Building Affected", "Low Number of Public Building Affected", "Low Number of Other Building Affected", "Low Number of Moderately Damaged Houses", Low Number of Collapsed Tourism Facilities", "Low Number of Severely Damaged Tourism Facilities", "Low Number Of Moderately Damaged Tourism Facilities", "Low	0.78-1

	Infrastructural Damage to Companies", "Low Building Damage to Companies", "Low Machinery Damage to Companies", "Low Stock Damage to Companies"

LS1: Companies that experience significant construction damage often contribute moderately to the GDP. Nevertheless, its contribution will likely continue to decline due to the substantial structural damage. This is because structural damage immediately impacts the economic activity in these sectors, which might result in decreased productivity and economic output.

LS2: The economic impact on the industry from sectors experiencing significant building damage is moderate. Nevertheless, due to the substantial structural damage, its contribution is expected to continue declining. This is because the damage has a direct effect on the operating capacities of these sectors, resulting in decreased production and economic output.

LS3: Companies with significant building damage make minimal economic contributions to information and communication technologies. Nevertheless, due to the substantial structural damage, its contribution is expected to continue declining.

LS4: Companies with significant building damage have a minimal economic impact on financial insurance activity. Nevertheless, due to the substantial structural damage, its contribution is expected to continue declining.

LS5: The economic contribution to the industry from sectors with high economic impact is significant. While there are many affected residential buildings, public buildings are less impacted. A high GDP can help alleviate the adverse effects of building damage on residential buildings, making significant economic contributions and ensuring a faster and more efficient recovery.

LS6: In provinces where real estate activities make a substantial economic contribution, there is significant damage to numerous residential properties, while the impact on public buildings is relatively small. Furthermore, a limited number of tourism facilities have been demolished. In addition, building damage to companies is moderate. The real estate sector is an essential part of the economy. Still, it is encountering considerable obstacles due to the large number of residential structures and tourism facilities that have been adversely damaged or collapsed.

LS7: In provinces where public administration, education, human health, and social work activities provide a substantial economic contribution, minimal damage is reported in various areas such as workplace buildings, public buildings, companies, tourism facilities, etc. This shows that investments in these sectors cannot experience any negative impact.

LS8: In provinces with a medium number of urgent, severely damaged, and collapsed houses, the impact of financial insurance activities on GDP is low. We expect this rate to decrease further due to heavily damaged houses.

LS9: In provinces where the construction sector contributes less to GDP, buildings generally have low damage. This indicates that the investment in the industry will remain unaffected.

4. CONCLUSION

This study explores the use of linguistic summarization to assess the effects of the 2023 Kahramanmaraş earthquakes in Türkiye, which significantly impacted eleven provinces. The study seeks to convert unprocessed data into intricate language descriptions with the purpose of offering clear and concise information to assist decision-makers in comprehending the impact of the earthquake on different industries and locations. The examination of each province uncovered distinctive patterns and varying degrees of economic and infrastructural devastation. Adıyaman, Gaziantep, Hatay, Kahramanmaraş, and Malatya are

the provinces that were most significantly impacted by the earthquake. Adıyaman, while its lesser economy, suffered significant destruction considering its population and geographical characteristics. Gaziantep experienced localized vulnerability, resulting in catastrophic destruction in specific locations. However, the overall impact was minor. The economy of Hatay was greatly affected as both the residential and tourism industries suffered substantial damage. Malatya and Kahramanmaraş experienced substantial damage to their residential and tourism facilities, which had a considerable impact on their economic operations.

Linguistic summarization offered insights into the relationship between economic contributions and structural damage. Industries that make significant contributions to the GDP are expected to see decreases as a result of structural damage, which may cause a negative influence on productivity and economic production. On the other hand, industries that have suffered little damage and make a significant contribution to the GDP may help speed up the process of economic recovery. The implications of real estate and public sector activities have been diverse, highlighting the necessity of focused efforts to alleviate potential problems in the future.

To summarize, this research highlights the significance of linguistic summarization in analyzing the impact of disasters. It offers essential data to improve preparedness, response, and recovery plans, guaranteeing stronger infrastructure and thriving economic activities in locations prone to earthquakes. This approach could be further developed in future research by incorporating a wider range of data sources and sophisticated analytical techniques to enhance disaster management and policy-making. Infrastructure failure data (bridge collapses, etc.) and agriculture loss statistics could be incorporated into the current dataset. Future research could focus on creating comparative summaries for similar disasters occurring in different regions to identify best practices and common challenges.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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