

Local Tsunamigenic Sources In Greece, Identified By Pattern Recognition

Novikova O.V

Institute of Earthquake Prediction Theory and Mathematical Geophysics

Gorshkov A.I. (✉ gorshkov@mitp.ru)

Institute of Earthquake Prediction Theory and Mathematical Geophysics

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Abstract

This study is an attempt to determine potential tsunamigenic morphostructural nodes in mainland Greece using pattern recognition algorithms. The earthquakes that have produced local tsunamis in the region were confined to morphostructural nodes whose locations were found by morphostructural zoning. The recognition problem consisted in separating all nodes in the region into the tsunamigenic class and the non-tsunamigenic class based mainly on the geomorphologic parameters of the nodes. The data on tsunamigenic earthquakes in Greece for training the Cora-3 algorithm were taken from the GHTD global historical catalog of tsunamigenic events (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml). The recognition procedure resulted in determining 27 tsunamigenic nodes, with most of these being situated in the southern tip of the Peloponnese Peninsula, as well as in the gulfs of Corinth and Patras. Three tsunamigenic nodes were identified in the area of the Malian Gulf on the Aegean coast of Greece. According to the relevant literature, most local tsunamis in Greece were initiated by submarine slides and slumps due to earthquakes. According to the characteristic geomorphologic features derived in this study, the tsunamigenic nodes are situated in settings of contrasting relief characterized by steep slopes. This favors submarine landslides when subjected to earthquake excitation. The results reported in this paper form a basis for developing a methodology to be used in long-term tsunami hazard assessment, supplying information on local potential tsunamigenic sources required for tsunami regionalization of coastal areas in Greece.

Highlights

The earthquakes that have produced local tsunamis in Greece are confined to morphostructural nodes whose locations were found by morphostructural zoning.

The recognition procedure performed has determined 27 tsunamigenic nodes, most of which are situated in the southern edge of the Peloponnese Peninsula, as well as in the gulfs of Corinth and Patras.

Inferred the characteristic geomorphologic features indicate that the tsunamigenic nodes are situated in settings of contrasting relief characterized by steep slopes. This favors submarine landslides when subjected to earthquake excitation.

The results reported in this paper form a basis for developing a methodology to be used in long-term tsunami hazard assessment, supplying information on local potential tsunamigenic sources required for tsunami regionalization of coastal areas in Greece.

Introduction

The Mediterranean region is characterized by a high level of seismicity (Grünthal and Wahlström 2012) due to the ongoing interaction between the African and Eurasian plates (McKenzie 1970). The seismic events occurring in offshore areas of the Mediterranean occasionally generate tsunamis of varying

intensities that have been recorded there since antiquity. According to Shchetnikov (1981), the Mediterranean region has generated 12% of all world tsunamis.

Tsunamis have been documented for most seismic areas in the Mediterranean (Guidoboni et al. 1994, 2005; Soloviev 1990; Soloviev et al. 2020; Tinti et al. 2001), including Greece (Ebeling et al. 2012; Papadopoulos and Chalkis 1984; Papadopoulos 2001, 2003; Papadopoulos et al. 2007, 2014a, 2014b). Tsunamis are caused by earthquakes of varying size; the mean magnitude of the tsunamigenic earthquakes in the Mediterranean region is $M=6.8\pm 0.15$ (Soloviev 1990). Nevertheless, tsunamigenic earthquakes are rather rare events there. Estimated periodicities of strong tsunamis vary between different areas of the Mediterranean; in particular, the estimate for the eastern Mediterranean is 142 years (Papadopoulos et al. 2007).

The coastal areas of Greece were affected by tsunamis due both to distant earthquakes, mostly those which occur in the active zone of the Hellenic arc, and to local earthquakes that occur in mainland Greece, in particular, in the southern tip of the Peloponnese (Papadopoulos 2001; Papadopoulos et al. 2007, 2014a, 2014b) and in the Gulf Corinth in central Greece (Papadopoulos 2003; Kortekaas et al. 2011). Fig. 1 shows a map of tsunamigenic earthquakes for the entire Mediterranean based on the Global Historical Tsunami Database (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml). The study area is outlined in Fig. 1.

Although the Mediterranean tsunamis have lower intensities than their Pacific counterparts (Soloviev 1990), they can still cause considerable damage to coastal infrastructure, primarily that in harbors and resorts. For this reason, the assessment of tsunami hazard is necessary and obligatory for design of structures to be built in the coastal strip and for determining coastal areas that can pose threat to the residents (Bernard 1998; Mofjeld et al. 1999).

The problem of long-term tsunami hazard assessment is similar to that of earthquake hazard (Gusakov 2016). By analogy with the PSHA (Probabilistic Seismic Hazard Assessment) (see, e.g., Shedlock et al. 2000), the prediction of tsunami hazard is to be based on a probabilistic seismotectonic approach PTHA (Probabilistic Tsunami Hazard Assessment), which aims at developing general and detailed maps of tsunami hazard (Power and Downes 2009; Gonzales et al. 2009; Leonard et al. 2014; Knighton and Bastidas 2015; Grezio et al. 2021; Sørensen et al. 2012).

The locations of potential tsunami sources should be known in order to develop an effective strategy of reducing tsunami losses and predicting them. The goal of the present study is to develop an approach to the determination of local potential tsunami sources; we deal with the identification of local tsunami sources and determine their geomorphologic features for mainland Greece. The approach is based on a methodology used to recognize possible locations of large earthquakes (Gelfand et al. 1972), which has been in use for many years for seismic regions worldwide and showed a sufficiently high efficiency for identification of potential earthquake locations (Soloviev et al. 2014; Gorshkov and Novikova 2018). The earthquake-generating structures are assumed to be morphostructural nodes of fault zones (Gelfand et al. 1972; Rantsman 1979). We have already identified the locations of morphostructural nodes within

mainland Greece by doing morphostructural regionalization of Greece in order to recognize earthquake-generating nodes for M7+ earthquakes (Gorshkov et al. 2020).

The approach presented in this paper can furnish a methodological basis for dealing with the problem of long-term tsunami prediction and for assessment of tsunami hazard, while the results can be used immediately for tsunami zoning of mainland Greece.

Method

We used the approach based on a methodology for recognition of possible locations of future large earthquakes (Gelfand et al. 1972) in order to determine tsunamigenic sources; the methodology has been used for a long time to identify potential earthquake-generating nodes. The most recent review of applications of this methodology with a detailed discussion can be found in (Gorshkov and Soloviev 2021). The methodology is efficient, as has been proved by comparing recognition results in the regions of study with the actual relevant earthquakes which have occurred in the regions after the results were published (Gorshkov 2010; Soloviev et al. 2014; Gorshkov and Novikova 2018).

The methodology is based on the idea that large earthquakes tend to occur at nodes of fault zones. The procedure consists of two stages. The first stage involves the application of morphostructural zoning (MSZ) to find the locations of morphostructural nodes which are treated as earthquake-controlling structures (Alekseevskaya et al. 1977; Rantsman 1979).

Morphostructural zoning is based on the concept of a hierarchical block structure of the Earth's crust. The MSZ maps show blocks of three hierarchical levels. The lower level (the third rank) consists of blocks with similar values of information-bearing relief features (altitude level and the orientations of linear relief forms). The boundaries between blocks, or morphostructural lineaments, are assumed to run where at least one feature experiences a sharp and significant change. These blocks are combined to form megablocks that represent the second hierarchical level. If the values of information-bearing features change in a monotone manner from block to block, then the boundaries between megablocks are taken to be where this monotonicity breaks down. The largest zoning unit of the first rank, a mountain country, is an area having a uniform type of relief and the same type of orogenesis. The lineaments are assigned the rank of those morphostructures which they separate.

Morphostructural nodes are a special kind of morphostructures which are formed at intersections of morphostructural lineaments that separate crustal blocks. The natural boundaries of nodes can be determined by detailed field surveys (Rantsman 1979; Gvishiani et al. 1988). In cases where the natural intersection boundaries are not determined, then nodes are defined as vicinities of nodes of lineaments in a circle of some radius, approximately equal to the earthquake source size appropriate for the magnitude under consideration.

The second stage involves discrimination of the nodes found by MSZ into high and low seismicity ones relative to a specified magnitude threshold. Nodes are classified using methods of pattern recognition

(Bongard 1967). This is done using recognition algorithms, e.g., the Cora-3 logical-type learning algorithm (Gelfand et al. 1972; Gvishiani et al. 1988; Gorshkov et al. 2003).

The problem of identifying tsunamigenic nodes is formulated in this study similarly to the problem of recognizing high and low seismicity nodes. The objects of recognition are the nodes found by MSZ (Fig. 2). Tsunami-generating earthquakes can emanate from several of the nodes identified by MSZ in the region (Fig. 2). The problem is to find criteria (a decision rule) from geomorphologic parameters to distinguish tsunamigenic nodes (the **TsG** class) from non-tsunamigenic ones (the **NTsG** class). The decision rule is worked out during the training stage for the Cora-3 algorithm. The training sample for the **TsG** class is based on the information concerning documented tsunamigenic earthquakes. The decision rule separates all nodes into the **TsG** and **NTsG** classes.

2. The data set

2.1. The morphostructural nodes in mainland Greece

We determined the morphostructural nodes in the region of study earlier to deal with the recognition of earthquake-generating nodes where M7+ earthquakes can occur (Gorshkov et al. 2020). A MSZ map for mainland Greece to scale 1: 1 000 000 is shown in Fig. 2.

The relief of the territory is dominated by mountain ranges of the Hellenides mountain belt; their structure and present-day configuration was formed by a complex interaction of the African and Eurasian plates (McKenzie 1970). The Hellenic belt divides into the northern part (the Pindus mountains) and the southern, which occupies the Peloponnese Peninsula (see Fig. 2). They are separated by the Gulf of Corinth which fills the basin of a young Quaternary rift (Armijo et al. 1996). Lineaments of the first rank separate the Hellenides mountain country from the adjacent major geosstructures of the first rank. In the west, east, and south, lineaments of the first rank separate the Hellenides from the deep-sea basins of the Ionic, Aegean, and Cretan seas, respectively (Fig. 2). These lineament zones follow along the continental slope and include major tectonic faults (Kilias et al. 2002).

Lineaments of the second rank separate territorial units of the second rank (megablocks). Five megablocks have been identified with different altitude levels and the strikes of the large constituent relief elements. The mega-blocks are discussed in (Gorshkov et al. 2020). The megablock that includes the Peloponnese is separated from the mega-blocks of central Greece by a transverse lineament of the second rank which can be followed along the active southern side of the Gulf of Corinth (Armijo et al. 1996). The lineament extends westward across the Gulf of Patras.

Lineaments of the third rank separate blocks. They can be followed by observing sharp changes in the altitude and strike of large relief elements. The relief of the area of study is heavily dissected, so that a dense network of rank 3 transverse lineaments has been identified striking northeast and nearly east–west; they cut obliquely through the north–northwestern trend of the Hellenides mountain ranges (Fig. 2).

MSZ has identified 139 nodes (Fig. 2) whose boundaries are defined as circles of radius 30 km around intersections of lineaments.

2.2. The tsunamigenic earthquakes in Greece

The information on the tsunamigenic earthquakes in the region was taken from the Global Historical Tsunami Database (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml), which has a separate section on Mediterranean tsunamis. A description of the data base along with other tsunami data bases and the principles underlying their creation can be found in (Goff 2020).

This data base contains parameters of tsunamigenic earthquakes (date, geographic coordinates, magnitude, and depth of focus) and characteristics of the tsunamis themselves (intensity and runup). The reliability of the raw data on each event is given by a numeral on a scale from -1 to 4. Tsunami intensity is given on the Soloviev-Imamura scale (Soloviev 1972; Soloviev and Go 1974) based on average runup values on the coast that was the nearest to the epicenter. Each event is supplied with a reference to a source describing the event. The depths of focus in the data base are available for recent earthquakes only. Papadopoulos and Chalkis (1984) say that the absolute majority of tsunamigenic earthquakes in Greece were at depths of 10–15 km in the crust, and it was only occasionally that hypocentral depths could reach 70 km.

There is no unambiguous relationship between tsunami intensity and the magnitude of the responsible earthquake (Soloviev 1990; Levin et al. 2005). Smaller earthquakes occasionally give rise to greater tsunami intensities than events of higher magnitudes. Bearing this in mind, we selected the training material for the Cora-3 recognition algorithm to identify tsunamigenic nodes by relying on tsunami characteristics rather than the responsible earthquake. The Cora-3 algorithm was trained by earthquakes and associated tsunamis for which the reliability factor was greater than 1 and tsunami intensity was ≥ 3 . With this intensity, the mean wave height could reach 5.7 meters according to the Soloviev relation, which can pose immediate threat to coastal communities and infrastructure.

A list of events such as specified above is given in Table 1, and their epicenters are displayed in a map of morphostructural zoning (Fig. 2). It is apparent from this figure that the epicenters of these tsunamigenic earthquakes lie close to nodes of morphostructural lineaments to be treated as morphostructural nodes.

Table 1. The tsunamigenic earthquakes in Greece (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml)

Year	north latitude	east longitude	M	Intensity	Source
-426	38.9	22.7	Ms,7.1	5	Freitag and Reicherter 2019
-373	38.25	22.25	Ms, 7.3	5	Papadopoulos 2000
551	38.4	22.3	7.1	4	Ambraseys 2009
1402	38.11	22.41	7	5	Soloviev et al. 2000
1817	38.3	22.1	Ms, 6.8	3	Galanopoulos 1960
1861	38.2	22.2	7.3	4	Galanopoulos 1960
1866	36	23	Ms, 6	4	Ambraseys 1962
1867	36.4	22.2	Ms, 7.1	4	Ambraseys 1962
1881	38.4	21.4	6.5	3	Papadopoulos 2000
1894	38.7	23.1	Ms, 7	4	Galanopoulos 1960
1915	38.5	20.7	Ms, 6.7	3	Galanopoulos 1960
1948	38.53	20.42	Mw, 6.5	4	Galanopoulos 1960

2.3 The nodes parameters used for recognition

We did recognition of tsunamigenic nodes using those parameters which we employed to recognize those earthquake-generating nodes in mainland Greece which can produce M7+ earthquakes (Gorshkov et al. 2020). The parameters used to recognize tsunamigenic nodes (Table 2) include morphometric terrain indicators and the geometry of the lineament-and-block structure of the region under study as displayed in the map of morphostructural zoning shown in Fig. 2. We also included a parameter defined as the fraction of unconsolidated Quaternary deposits within an intersection. Taken as a whole, these parameters provide indirect data to characterize the intensity of tectonic movements and the degree of crustal fragmentation at nodes. The parameters were found by inspection of topographic and geological maps, as well as the MSZ map. The parameter values were measured in a circle of radius 30 km treated as a node and which is centered at the intersection.

Table 2. The parameters that were used for recognition of tsunamigenic nodes

Parameters	Discretization thresholds
<i>Morphometric parameters</i>	
Maximum relief altitude, m (Hmax)	1600
Minimum relief altitude, m (Hmin)	- 106
Altitude range, m (ΔH) (Hmax - Hmin)	1952
Distance between points of Hmax and Hmin, km (L)	32
Altitude gradient, ($\Delta H/L$)	63
<i>Geological parameter</i>	
Percentage of Quaternary deposits in % at a node (Q)	20
<i>Geometry of lineament-and -block structure</i>	
Highest rank of lineament at a node, (HR)	2
Number of lineaments that make an a node, (NL)	2
Distance between intersection and nearest lineament of first rank, km , (D1)	50
Distance between intersection and nearest lineament of second rank, km , (D2)	30
Distance to nearest intersection at adjacent intersection, km , (Dn)	21

The Cora-3 recognition algorithm used in this study (Bongard 1967; Gvishiani et al. 1988; Gorshkov et al. 2003; Gorshkov 2010) is applied to objects in the form of binary vectors. For this reason the application of the recognition algorithm is preceded by parameter discretization to divide the entire range of a parameter using discretization thresholds into two or three intervals so that each interval should contain approximately the same number of recognition objects. Afterwards, the algorithm deals, not with measured parameter values, but with the fact of falling in an interval: "small" and "large" in the case of two intervals, and "small", "intermediate", and "large" when there are three intervals. The discretization thresholds for each parameter are listed in Table 2. The discretization procedure is described in detail in (Gvishiani et al. 1988; Gorshkov et al. 2003).

3. Recognition Of Tsunamigenic Nodes

The training material for the Cora-3 algorithm was based on the information for the tsunamigenic earthquakes in the study region; see the list in Table 1.

The set of recognition objects for mainland Greece included 139 nodes. The training sample **TsG₀** of the tsunamigenic class had 12 nodes: 71, 72, 83, 84, 86, 90, 91, 98, 139,140, 145, and 150 (Fig.3). The

remaining 127 nodes made the training material **NTsG₀**.

Recognition results. The characteristic features for nodes in class **TsG** and class **NTsG** as selected by Cora-3 during the training phase are listed in Table 3. The intervals of parameter values in Table 3 are specified by the discretization thresholds.

The classification of nodes into classes **TsG** and **NTsG** was produced by Cora-3 using a voting procedure. For each intersection the algorithm counts the numbers of features for each class that a current intersection has. Tsunami-generating nodes are recognized to be those for which the difference between the number of features in class **TsG** and that in class **NTsG** was ≥ 1 . As a result, of the 139 nodes in the region, 27 were classified as being tsunamigenic ones, including the 12 that were used for training in class **TsG**.

Table 3. Characteristic features of tsunamigenic (**TsG**) and non-tsunamigenic (**NTsG**) nodes

PARAMETERS (for notation see Table 2)

FeatureN	Hmax, m	Hmin, m	L, km	dH, m	dH/L	Q, %	NL	D1 km	D2, km	Dn, km	HR
features of nodes in class TsG											
1		≤-106								>21	>2
2							>2	>50			≤2
3		≤-106	>32						≤30		
4	≤1600		>32						≤30		
5		≤-106				≤20		>50			
6	≤1600			>1952			>2				
7			>32		>63			≤2			
8		≤-106	≤32	>1952							
9	≤1600		>32		>63						
features of nodes in class NTsG											
1					≤63					≤21	
2			≤32						≤30		
3			≤32					>50			
4			≤32		>63						
5			≤32	≤1952							
6	>1600		≤32								
7		>-106									

The reliability of the resulting classification was checked by three control experiments (Gelfand et al. 1972; Gvishiani et al. 1988). In the first experiment, the training material **TsG₀** and **NTsG₀** consisted in the nodes recognized as being **TsG** and **NTsG** in the main variant shown in Fig. 3. Overall, the classifications obtained by the experiment were identical with the main variant. In the other two experiments, recognition objects were excluded one by one from the training, and in the same manner the parameters of these objects, one by one. The classifications obtained in these experiments show some insignificant departures from the main variant. The results of the experiments are adjudged to be positive, since less than 10% of the objects changed classification; this is consistent with the empirical criteria for

stability as formulated in (Gvishiani et al. 1988), and one can say that the resulting classification of nodes into tsunamigenic and non-tsunamigenic ones is stable.

Discussion And Conclusions

The recognition has determined potential tsunamigenic nodes in mainland Greece (Fig. 3) that can produce local earthquakes with subsequent tsunamis of intensity ≥ 3 . Structurally speaking, most identified tsunamigenic nodes lie at lineaments of the higher ranks, the first and the second, which separate the larger crustal blocks in the region. A large set of tsunamigenic nodes is related to the lineament of the first rank that separates the Peloponnese Peninsula from the deep-sea basins of the Ionic and Cretan seas. The lineament can be followed by a scarp in the continental slope characterized by a complex tortuous configuration and steepness. Another cluster of tsunamigenic nodes is in the Gulf of Corinth. This is the most active seismic region in Greece and one of those which pose high tsunami hazard in the Mediterranean Sea (Papadopoulos and Fokaefs 2005). West of the Peloponnese is a group of tsunamigenic nodes which are related, similarly to those in the Gulf of Corinth, to the lineament of the second rank that separates the Peloponnese from central Greece. Three tsunamigenic nodes have been identified in the offshore zone of the Aegean Sea in the Malian Gulf.

We note that the recognition involved all nodes in the region, including those which lie in inner areas far from the coast. No tsunamigenic nodes have been identified in inner areas of mainland Greece. This indicates that the characteristic features identified (Table 3) are proper to the tsunamigenic nodes situated in coastal areas.

The tsunamigenic nodes have not "large" values of maximum and minimum relief altitudes in combination with "large" values of altitude range and relief gradient. In addition, they typically have "large" areas of unconsolidated Quaternary deposits. This combination of these features of the tsunamigenic nodes provides evidence that they are situated in areas of dissected relief and persistent subsidence under a tensional setting, similarly to those which dominate both the Aegean Sea and mainland Greece (Armijo et al. 1996). The origin of local tsunamis both in the southern Peloponnese and in the Gulf of Corinth is explained by most researchers by submarine landslides due to earthquakes (Ebeling et al. 1996; Papadopoulos and Kortekaas 2003; Papadopoulos 2003). It is pointed out that the occurrence of submarine landslides in the Gulf of Corinth is favored by steep slopes of the surrounding mountains (Kortekaas et al. 2011; Papadopoulos 2003). The tsunamigenic nodes that are situated in the southern tip of the Peloponnese include steep parts of the continental slope. Papadopoulos et al. (2014a) emphasize that the historical tsunamis in the highly seismic region of the southwestern Peloponnese were local events and were caused by submarine landslides.

The characteristic features of tsunamigenic nodes obtained in this study are in agreement with the landslide origin of Greek tsunamis. The "large" values of relief gradient that are characteristic for identified tsunamigenic nodes situated both on segments of the continental slope around the southwestern Peloponnese and in the Gulf of Corinth indicate high contrasts and steepness in relief

within the tsunamigenic nodes. This makes the slopes at tsunamigenic nodes unstable and creates conditions for slides due to seismic excitation.

Papadopoulos et al. (2014b) determined tsunamigenic zones in the Mediterranean region, including Greece, based on documented sources for tsunamis and assessed the relative potential of those zones. Figure 3 shows the positions of the tsunamigenic zones found by Papadopoulos et al. (2014b). Comparison with the identified tsunamigenic nodes shows a consistency between the two.

The "high" potential zone (zone 1 in Fig. 3) in the southwestern tip of the Peloponnese contains our tsunamigenic nodes nos. 128, 129, 134, 143, 139, 140, 145, 147, 148, and 149. North of that zone, we identified a tsunamigenic node (no. 109) where no tsunamigenic events are known to have occurred by now.

A "very high" potential zone has been identified in the Gulf of Corinth (zone 2 in Fig. 3). It contains identified tsunamigenic nodes nos. 90, 91, 97, and 98. Note that our results indicate that the zone extends farther westward along the Gulf of Patras where tsunamigenic nodes nos. 83, 84, 85, 86, and 150 have been identified.

A "low" potential zone in the eastern coast of Greece (zone 3 in Fig. 3) in the Malian Gulf contains tsunamigenic nodes nos. 72 and 73. Tsunami-generating node no. 71 associated with the 426 BC event was identified west of these. Node no. 33 north of zone 3 was identified as a tsunamigenic one, although no tsunamigenic events have been recorded there so far.

Summing up, we can say that the recognition results are in a general agreement with the tsunamigenic zones identified by Papadopoulos et al. (2014b). As well, these results also indicate the existence of other tsunamigenic zones not identified in (Papadopoulos et al. 2014b). First of all, we should mention the long tsunamigenic zone in the Gulf of Patras area.

Gorshkov et al. (2020) used a MSZ map for mainland Greece to identify earthquake-generating nodes for M7+. Most tsunamigenic nodes identified in the present study are identical with the M7+ earthquake-generating nodes (Fig. 4). This primarily concerns the tsunamigenic nodes situated in the southwestern tip of the Peloponnese, as well as in the Corinthian and Malian gulfs. Comparison of the tsunamigenic nodes with the earthquake-generating ones shows that they are in zones of high seismic potential (Fig. 4).

Grey circles indicate tsunamigenic nodes, while dark grey circles show seismogenic nodes capable of M7+ according to Gorshkov et al. (2020). Lines are the same as in Fig. 2.

These results provide a methodological basis for dealing with the problem of long-term tsunami prediction and assessment of tsunami hazards. As well, the locations of identified tsunamigenic sources furnish necessary information for tsunami regionalization of coastal areas of Greece, as well as the gulfs of Corinth, Patras, and Malian Gulf.

Declarations

Ethical Statement

Authors of the manuscript “Local tsunamigenic sources in Greece identified by pattern recognition” by Novikova O.V. and Gorshkov A.I. confirm that the manuscript

- is not submitted to another journal for simultaneous consideration,
- is original and has not been published elsewhere in any form or language (partially or in full),
- is not a part of a larger study. The manuscript is an independent and completed research.
- Results are obtained using the objective geophysical and seismological data available for all scientific community.
- No data, text, or theories by others are presented as if they were our own.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Olga Novikova and Alexander Gorshkov. The first draft of the manuscript was written by Olga Novikova and Alexander Gorshkov. Both authors read and approved the final manuscript.

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Figures

Figure 1

The epicenters of tsunamigenic earthquakes in the Mediterranean based on Global Historical Tsunami Database (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml).

Figure 2

A morphostructural zoning map for mainland Greece.

The lines are lineaments. Line thickness corresponds with lineament rank: the thick ones represent the first rank; the medium ones show the second rank; and the thin lines represent the third rank. Solid curves mark longitudinal lineaments, dashed lines represent transverse ones. Filled circles mark the epicenters of tsunamigenic earthquakes.

Figure 3

The identified tsunamigenic nodes in mainland Greece.

Large grey circles mark the tsunamigenic nodes. The dots represent tsunamigenic earthquakes. Dotted lines enclose tsunamigenic zones 1-3 after Papadopoulos et al., (2014b). Numerals from 1 to 150 denote node identification numbers. The lines are the same as in Fig. 2.

Figure 4

Tsunamigenic and seismogenic nodes.

Grey circles indicate tsunamigenic nodes, while dark grey circles show seismogenic nodes capable of M7+ according to Gorshkov et al. (2020). Lines are the same as in Fig. 2.