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Seismic activity on the territory of Slovakia in 2022

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Abstract: The National Network of Seismic Stations of Slovakia (NNSS) consists of eight short period and six broadband permanent seismic stations and a data centre located at the Earth Science Institute of the Slovak Academy of Sciences (ESI SAS). The NNSS recorded and detected 11996 seismic events from all epicentral distances in 2022. Totally 76 earthquakes originated in the territory of Slovakia in 2022. This paper provides basic information on the configuration of the NNSS, routine data processing, seismic activity on the territory of Slovakia in 2022 as well as macroseismic observations collected in 2022.

Key words: Slovakia, National Network of Seismic Stations, seismicity, macroseismic observations

1. Introduction

The seismic activity on the territory of Slovakia and adjacent areas has been reported on the daily basis by the so-called Seismo Reports published on the web sites of the Department of Seismology, ESI SAS `http://www.seismology.sk/Seismo_Reports/reports.html` and in annual reports as a part of the project Partial monitoring system – Geological factors (*Liščák et al., 2023*) which is solved with a contract between ESI SAS and State Geological Institute of Dionýz Štúr. The aim of this paper is to provide a quick overview of earthquakes which originated on the territory of Slovakia or were macroseismically felt on the territory of Slovakia in 2022.

2. Seismic stations operating in 2022

The seismic monitoring of the Slovak territory is provided by the NNSS

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operated by the ESI SAS (*ESI SAS, 2004; Csicsay et al., 2018*), *Local Seismic Network in Eastern Slovakia* operated by the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava and local network of seismic stations around NPPs Jaslovské Bohunice and Mochovce operated by Progseis Ltd. company. The networks of seismic stations cooperate, and the exchange of data is on the regular basis. The positions of the seismic stations on the territory of Slovakia are shown in Fig. 1.

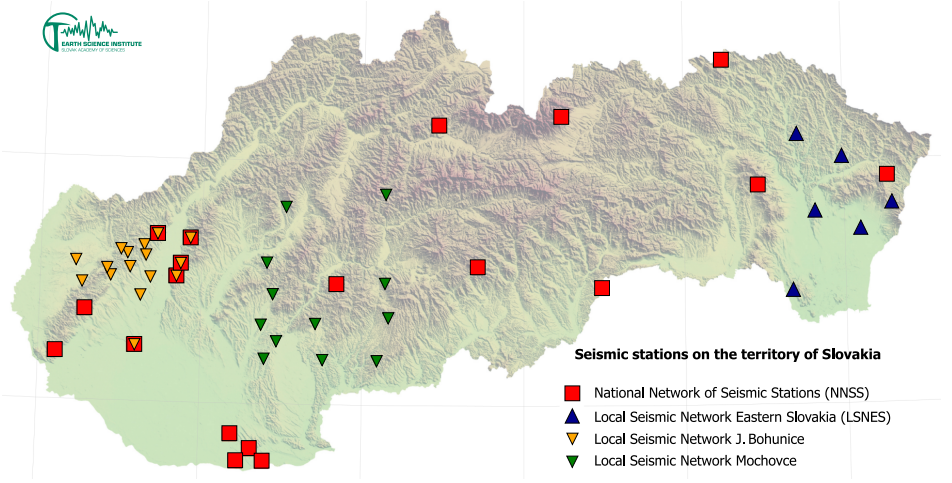

Fig. 1. Seismic stations operational on the territory of Slovakia in 2022.

In 2022 the NNSS consisted of fourteen permanent seismic stations, from which eight are short period and six are broadband. Broadband stations are: Izabela (IZAB), Kolonické sedlo (KOLS), Liptovská Anna (LANS), Modra (MODS), Skalnaté pleso (SPC), Vyhne (VYHS) and Bratislava – Železná studnička (ZST). Short period stations are: Hurbanovo (HRB), Iža (SRO1), Kečovo (KECS), Moča (SRO2), Stebnícka Huta (STHS), Šrobárová (SRO). The HRB is the oldest NNSS seismic station that has been in operation since 1909 (*Pajdušák, 1997; Csicsay and Luby, 2021*). Broadband station Červenica (CRVS) located in Slanské Hills has been temporarily out of operation since 2018. After finding an alternative suitable location, the seismic station will be relocated and put back into operation.

The NNSS permanent seismic stations and their instrumentation are summarized in Table 1. More details can be found on the web page `http://`

www.seismology.sk/National_Network.

Four additional short period seismic stations have been operated on the jointly bases of ESI SAS and other institutions. The seismic stations Banka (BAN), Jalšové (JAL), Podolie (POD) and Tematín (TEMA) located in the Little Carpathians and Považský Inovec Mts. have been operated in cooperation with Progseis Ltd. company and the Institute of Rock Structure and Mechanics of the Czech Academy of Sciences (IRSM CAS) (*Fojtíková et al., 2015*). These stations have been installed as temporary seismic stations.

At the beginning of November 2022, in cooperation ISRM CAS, the Zbyňov Seismic Station (ZBNS) was installed nearby Žilina in the Rajecká dolina and put into trial operation. The seismic station is equipped with a broadband seismometer. After the successful completion of the trial operation, the ZBNS seismic station will be included in the NNSS.

Table 1. Equipment of seismic stations of the NNSS operating in 2021.

Station	**ISC code**	**Lat. [°N]**	**Long. [°E]**	**Alt. [m]**	**Sensor**	**DAS**	**Sampl. freq.**	**Data format**
Bratislava Žel. Studnička	ZST	48.196	17.102	250	Metrozet	Wave32	100/sec	mSEED
Vyhne	VYHS	48.493	18.836	450	STS-2	Wave24	100/sec	mSEED
Modra-Piesok	MODS	48.373	17.277	520	STS-2	Wave32	100/sec	mSEED
Hurbanovo	HRB	47.873	18.192	115	2× Mainka	Analog	–	smoked paper
Izabela	IZAB	48.569	19.713	450	Guralp-40T-60s	Gaia	100/sec	mSEED
Iža	SRO1	47.7622	18.2328	111	LE3D	PCM	20/sec	mSEED
Kečovo	KECS	48.483	20.486	345	LE3D	Wave24	100/sec	mSEED
Kolonické sedlo	KOLS	48.933	22.273	460	Guralp-6T-30s	Wave32	100/sec	mSEED
Liptovská Anna	LANS	49.151	19.468	710	Metrozet	Wave32	100/sec	mSEED
Moča	SRO2	47.763	18.394	109	Guralp-40T-1s	Wave24	100/sec	mSEED
Stebnícka Huta	STHS	49.417	21.244	534	LE3D	Wave24	100/sec	mSEED
Šrobárová	SRO	47.813	18.313	150	3× SKM-3	Wave24	100/sec	mSEED
Skalnaté Pleso	SPC	49.189	20.234	1751	Guralp-40T-30s	SeisComp EarthData	100/sec	mSEED

3. Data processing

Digital data from all NNSS stations (except the analog seismic station HRB) are transferred in real-time to the data centre at the ESI SAS either by the internet or satellite telemetry. Software package SeisComp3 (*Weber at al., 2007*) and SeedLink server are used for data acquisition and exchange.

Beside observations from the NNSS stations the data centre at ESI SAS also use the data from the above-mentioned local networks of seismic stations in Slovakia and observations from networks of neighbouring countries: Austrian Seismic Network (*ZAMG – Zentralanstalt für Meterologie und Geodynamik, 1987*), Czech Regional Seismic Network (*Institute of Geophysics, Academy of Sciences of the Czech Republic, 1973*), Hungarian National Seismological Network (*Kövesligethy Radó Seismological Observatory, 1992*), Local seismological network for monitoring NPP Dukovany (*Institute of Physics of the Earth Masaryk University, 2014*), GEOFON Seismic Network (*GEOFON Data Center, 1993*), *Polish Seismological Network*. These stations form a so-called Regional Virtual Network of ESI SAS that consists of approximately 55 seismic stations.

Routine analysis of the digital recordings at the ESI SAS has been performed by the Unix package Seismic handler (*Stammler, 1993*). Interactive locations of seismic events within Seismic Handler are performed by external program LocSat. The collected digital observations are manually processed on the daily basis. The epicentre locations are based on the IASP91 traveltime curves. Local magnitudes have been determined from the maximum vertical trace amplitudes of Sg waves, using the pre-defined Seismic Handler formula for local events. Continuous raw seismic data from the NNSS are stored in a local archive and seismic data interpretations (together with information on equipment of stations) are stored in a web accessible database.

4. Seismic activity in 2022

The NNSS analysed 11996 local, regional and teleseismic events in 2022. More than 39000 seismic phases were determined. Seismic events identified as quarry blasts were excluded from further processing and were not included in the event statistics. All events recorded by the NNSS and analyses at the data centre at ESI SAS has been reported in the so-called Seismo

Reports and published on the above-mentioned web sites of the Department of Seismology, ESI SAS.

Altogether 76 seismic events located by the NNSS originated on the territory of Slovakia in 2022 (Fig. 2). Known quarry blasts are not included in this number. Twenty-three earthquakes reached local magnitude 1.0 or more and are listed in Table 2. The strongest earthquake occurred on April 6 at 17:04 UTC in Upper Hron River region with local magnitude M_L 2.1.

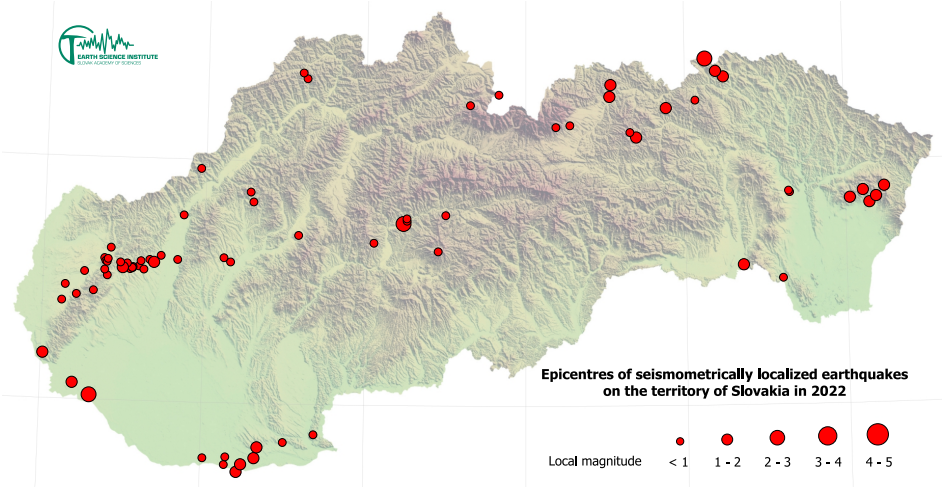

Fig. 2. Map of epicentres of local earthquakes originated on the territory of Slovakia in 2022. Diameters of the circles are proportional to local magnitudes.

Table 2. List of earthquakes originated on the territory of Slovakia in 2022 with $M_L \geq 1.0$.

Date [YYYY-MM-DD]	**Origin Time (UTC) [HH:MM:SS]**	**Lat. [°N]**	**Lon. [°E]**	**Depth [km]**	M_L **[NNSS]**	I_0 **[°EMS]**	**Region**
2022-02-15	02:13:36.99	48.07	17.20	0	1.3		Šamorín – Komárno – Štúrovo
2022-03-02	17:27:26.79	49.27	20.53	4	1.4		Spiš Magura
2022-03-21	18:05:23.34	47.77	18.33	2	1.2		Šamorín – Komárno – Štúrovo
2022-03-30	20:58:33.11	48.19	17.01	0	1.0		Little Carpathians
2022-04-06	17:04:04.62	48.75	19.24	0	2.1	4	Upper Hron River region

Table 2. Continued from the previous page.

Date [YYYY-MM-DD]	**Origin Time (UTC) [HH:MM:SS]**	**Lat. [°N]**	**Lon. [°E]**	**Depth [km]**	M_L **[NNSS]**	I_0 **[°EMS]**	**Region**
2022-04-14	12:03:08.85	47.82	18.35	0	1.6	3	Šamorín – Komárno – Štúrovo
2022-04-17	15:17:03.78	48.85	22.03	8	1.2		Vihorlat Mts.
2022-04-20	10:09:32.69	49.11	20.69	3	1.7		Levoča Mountains
2022-05-01	20:46:32.16	48.88	22.11	5	1.1		Vihorlat Mts.
2022-05-25	15:47:27.15	49.23	20.88	0	1.4		Spiš-Šariš Intermontane
2022-06-02	19:36:00.74	48.83	22.15	3	1.1	3	Vihorlat Mts.
2022-06-17	16:13:58.15	48.85	22.19	4	1.2		Vihorlat Mts.
2022-06-22	12:15:34.50	49.32	20.54	0	1.8		Spiš Magura
2022-06-25	06:08:36.57	47.72	18.22	0	1.0		Šamorín – Komárno – Štúrovo
2022-07-05	04:37:25.80	47.75	18.25	1	1.2		Šamorín – Komárno – Štúrovo
2022-07-21	11:13:08.49	48.58	21.36	0	1.7		Slanské Hills
2022-09-22	16:16:42.35	48.89	22.25	3	1.8		Vihorlat Mts.
2022-09-30	12:53:53.71	49.38	21.20	4	1.4		Low Beskids
2022-09-30	13:04:17.30	49.35	21.25	2	1.6		Low Beskids
2022-09-30	14:42:23.48	49.43	21.13	4	2.0		Low Beskids
2022-10-28	03:49:54.64	48.55	17.49	1	1.2		Little Carpathians
2022-11-03	03:46:44.41	48.57	17.69	1	1.8		Little Carpathians
2022-11-25	02:45:43.72	48.02	17.31	3	2.1		Šamorín – Komárno – Štúrovo

The seismicity of the Slovak territory is dominated by the Little Carpathians and Komárno seismic source zones (*Hók et al., 2016*). The strongest earthquake in the Little Carpathians source zone was detected on the Novem-

ber 3 at 03:46 UTC with local magnitude M_L 1.8. The strongest earthquake in the Komárno source zone was detected on the April 14 at 12:03 UTC with local magnitude M_L 1.6. Although the low level of seismic activity from the last decades remained unchanged also in 2022, these two source zones remain of the primary interest for the monitoring of seismic activity within the territory of Slovakia.

5. Macroseismic observations

Four earthquakes were macroseismically felt on the territory of Slovakia in 2022 (Table 3), three of them with the epicentre on the territory of Slovakia (Fig. 3) and one of them on the territory of Bosnia and Herzegovina. All of these four earthquakes were also seismometrically observed and processed. Intensities were estimated by the European Macroseismic Scale 1998 (EMS-98) introduced by *Grünthal (1998)*.

Table 3. List of macroseismically observed earthquakes on the territory of Slovakia in 2022.

Date [YYYY-MM-DD]	**Origin Time (UTC) [HH:MM:SS]**	**Lat. [°N]**	**Lon. [°E]**	**Depth [km]**	**M_L [NNSS]**	**I_0 [°EMS]**	**Region**
2022-04-06	17:04:04.6	48.75	19.24	0	2.1	4	Upper Hron River region
2022-04-14	12:03:08.8	47.82	18.35	0	1.6	3	Komárno
2022-04-22	21:07:49.1	43.07	18.16	5	5.7	3*	Bosnia and Herzegovina
2022-06-02	19:36:00.7	48.83	22.15	3	1.1	3	Vihorlat Mts.

* highest macroseismic intensity on the territory of Slovakia

The earthquake on April 6 at 17:04 UTC with epicentre in Upper Hron River region between Banská Bystrica and Slovenská Ľupča and local magnitude 2.1 was macroseismically felt on 21 locations (Table 4). Subsequently, 101 macroseimic questionnaires were filled. The epicentral intensity was determined at 4° EMS-98. The event was described as a weak trembling. Some people reported acoustic effects what were compared to light or medium rumble or detonation. In some cases the observers reported shaking of light furniture and rattling of china and glasses too.

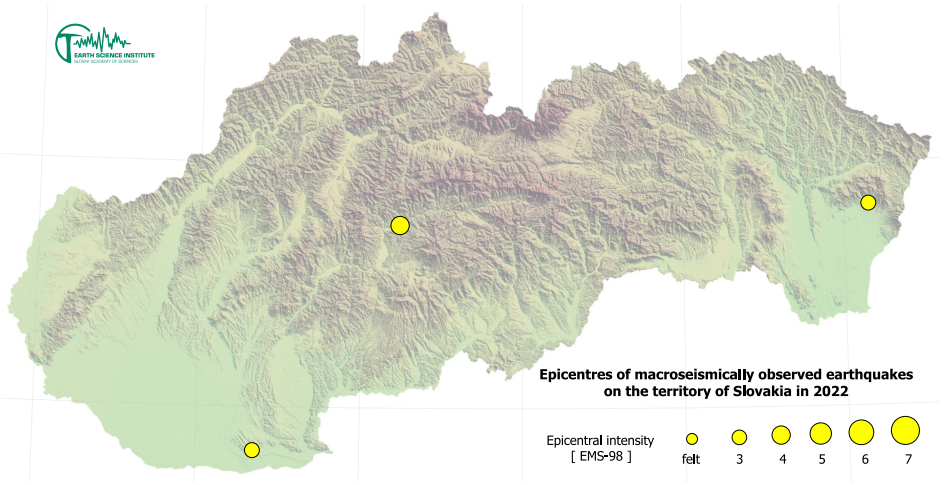

Fig. 3. Map of epicentres of macroseismically observed earthquakes on the territory of Slovakia in 2022. Diameters of the circles are proportional to epicentral intensity.

Table 4. Macroseismic observations for April 6, 2022 earthquake, 17:04 UTC.

Locality	**Lat.** [°**N**]	**Lon.** [°**E**]	**No. of questionnaires**	***I*** [°**EMS-98**]
Priechod	48.782	19.236	1	4
Banská Bystrica	48.733	19.143	28	3
Sásová	48.756	19.158	12	3
Slovenská Ľupča	48.763	19.271	11	3
Selce	48.763	19.21	9	3
Horná Mičiná	48.697	19.213	6	3
Ľubietová	48.741	19.381	6	3
Poniky	48.701	19.308	5	3
Môlča	48.72	19.225	3	3
Nemce	48.765	19.185	3	3
Ponická Lehôtka	48.721	19.299	3	3
Strelníky	48.722	19.397	3	3
Podkonice	48.8	19.257	2	3
Baláže	48.814	19.197	1	3
Čerín	48.663	19.251	1	3
Detva	48.557	19.416	1	3

Table 4. Continued from the previous page.

Locality	**Lat.** [°**N**]	**Lon.** [°**E**]	**No. of questionnaires**	***I*** [°**EMS-98**]
Dolná Mičiná	48.674	19.222	1	3
Hrochoť	48.655	19.374	1	3
Medzibrod	48.792	19.354	1	3
Podkriváň	48.531	19.499	1	3
Oravce	48.685	19.265	2	felt

The earthquake on April 14 at 12:03 UTC with epicentre in the Komárno seismic source zone near municipality Modrany and local magnitude 1.6 was macroseismically felt on 1 location (Table 5). One macroseimic questionnaire was filled. The epicentral intensity was determined at 3° EMS.

Table 5. Macroseismic observations for April 14, 2022 earthquake, 12:03 UTC.

Locality	**Lat.** [°**N**]	**Lon.** [°**E**]	**No. of questionnaires**	***I*** [°**EMS-98**]
Modrany	47.823	18.354	1	3

The earthquake on April 22 at 21:07 UTC with epicentre near Herzegovinian village of Strupići and local magnitude 5.7 was macroseismically felt on 2 locations within the territory of Slovakia (Table 6). Two macroseismic questionnaires were filled. The maximum intensity on the territory of Slovakia was determined at 3° EMS-98.

The earthquake on June 2 at 19:36 UTC with epicentre in Vihorlat Mts. and local magnitude 1.1 was macroseismically felt on 1 location (Ta-

Table 6. Macroseismic observations for April 22, 2022 earthquake, 21:07 UTC.

Locality	**Lat.** [°**N**]	**Lon.** [°**E**]	**No. of questionnaires**	***I*** [°**EMS-98**]
Bystričany-Chalmová	48.693	18.458	1	3
Nitra	48.314	18.092	1	3

Table 7. Macroseismic observations for June 2, 2022 earthquake, 19:36 UTC.

Locality	**Lat.** [°**N**]	**Lon.** [°**E**]	**No. of questionnaires**	***I*** [°**EMS-98**]
Jasenov	48.797	22.173	1	3

ble 7). One macroseimic questionnaire was filled. The epicentral intensity was determined at 3° EMS-98.

6. Conclusion and discussion

The NNSS is operated by the ESI SAS, Bratislava. Data from all stations (except station HRB) are transferred in real-time to the data centre at Bratislava. Data processing and routine analysis are performed digitally by interactive seismological software Seismic Handler. Digital data are accessible both on-line and off-line in standard data format. So called Seismo Reports of seismic events recorded by NNSS are published on the web page of the ESI SAS `http://www.seismology.sk/Seismo_Reports/reports.html`.

Maintenance of seismic stations in year 2022 was influenced by Covid-19 pandemics but not on such large extent as in the previous two years.

We continued with the successful cooperation CE^{3}RN (*Lenhardt et al., 2021*) and with co-maintenance of temporary seismic stations in the cooperation PACASE (*Hetényi et al., 2019; Schlömer et al., 2024*) too. Temporary broadband seismic stations installed during the international cooperation PACASE (*Hetényi et al., 2019; Schlömer et al., 2024*) have become a part of the AdriaArray multi-national effort.

Epicentres and local magnitudes were determined for 76 earthquakes originated on the territory of Slovakia in 2022. Weak seismic activity was recorded from several seismic source zones: Little Carpathians, Komárno, Vihorlat Mts., Spiš Magura, Levoča Mountains and Low Beskids.

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