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Mapping and monitoring subtle ground deformation in Sindos, Greece, with high precision digital leveling

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ABSTRACT

Several studies have focused on the ground displacement phenomena in the broader area of the Thessaloniki Plain, Greece. Although there is a general consensus on the diachronic occurrence of subsidence, there have been recent studies that also report considerable uplifts. In order to resolve some of these ambiguities and to further study and monitor the area, new, high-accuracy leveling measurements were conducted during 2018–2020 in the vicinity of the town of Sindos. Findings indicate a total vertical displacement of up to about −15 mm, whereas the continuation of a clear overall subsidence tendency rather than uplift has been verified.

KEYWORDS

subsidence; uplift; levelling; digital levelling; mapping; Sindos; Thessaloniki; Greece

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1. Introduction

Subsidence is a type of geological hazard that is generally subtle and imperceptible in real-time, typically necessitating at least a couple of years of observations to identify. Nevertheless, the consequent disaster may be particularly catastrophic, especially in the presence of certain conditions, e.g., when occurring in low-lying coastal urban centers, populated deltas or coastal protected areas. One of the factors contributing to subsidence is the uncontrolled pumping of water and oil from underground, which particularly escalated in the twentieth century and has led to significant economic and cultural losses (Bolt et al. 1977).

Climate change and associated sea level rise is expected to considerably aggravate the impact of such coastal subsidence geohazards in the years to come (Elias et al. 2020). This is due to the fact that the combined climate-induced sea-level rise and vertical land movements, including natural and human-induced subsidence in sedimentary lowlands, have a higher impact (up to four times faster), in terms of average relative sea-level rise, over coastal areas (Nicholls et al. 2021).

Such an example is the broader area of the Thessaloniki Plain, northern Greece, where several studies have detected vertical ground displacements since the 1960s. Especially at the eastern edge of the Plain, in the vicinity of the coastal front, the Sindos–Kalochori wider area has been the most interesting one and hence the focus of the majority of studies. The comparison between past leveling and Global Navigation Satellite System (GNSS) data indicates that sections of the plain of Thessaloniki, especially those close to the modern Galikos and Axios river mouths, have undergone subsidence of up to 4 m in the last 50 years (Stiros 2001; Psimoulis et al. 2007). Most researchers highlight the over-exploitation of groundwater as the main cause of subsidence phenomena (Hadzinakos, Rozos, and Apostolidis 1990; Andronopoulos, Rozos, and Hadzinakos 1991). However, a number of experts suggest alternative interpretations, such as the compaction of the shallow sediment layers and the synsedimentary deformation of the delta (Stiros 2001), the coastal erosion and the rise of sea level (Doukakis 2005), the combination of natural and anthropogenic factors (Psimoulis et al. 2007) and the compaction of unconsolidated silt-clay deposits near coastline (Dimopoulos, Stournaras, and Pavlopoulos 2005). Although groundwater exploitation in the area started in the early 1960s in order to facilitate industrial development, subsidence was not noticed until 1965, indirectly, manifesting as progressive marine water inflow (Raspini et al. 2014). In 1969, during a period of intensive rainfall, seawater reached the southern houses of the village (Mouratidis et al. 2010). Previous studies have exploited the archive of the ERS satellite Synthetic Aperture Radar (SAR) data (1991–2000), for implementing conventional and Persistent Scatterer (PS) SAR Interferometry (InSAR) measurements, as well as the equivalent part of the Envisat Advanced SAR (ASAR) data (2002–2010) for standard and elaborated InSAR processing (Raucoules et al. 2008; Costantini et al. 2016; Mouratidis 2017). According to these studies, the estimated subsidence rate in the vicinity of Sindos-Kalohori ranges between about 2 and 5 cm/yr (Costantini et al. 2016).

Nevertheless, some authors (Svigkas et al. 2016) contradict part of the aforementioned results and highlight a significant uplift signal in the area, suggesting a rebound phenomenon. More specifically, from 2003 to 2010, an uplift tendency of up to +12 mm/yr was reported in the Sindos-Kalohori area, as opposed to the 1992–2000 subsidence of more than 20 mm/yr. Regarding the spatial distribution of the uplifting pattern, the pixels in and around Sindos with uplift values close to the maximum are only slightly fewer than those recorded in the adjacent area of Kalochori (Svigkas et al. 2016), indicating a relatively isotropic phenomenon.

The most recent deformation measurements in the area of Sindos come from InSAR studies, in the era of Sentinel-1 SAR mission. These indicate subsidence rates of about 10 mm/yr for the period 2014–2019 (Elias et al. 2020) and 14 mm/yr during 2015–2019 (Svigkas et al. 2020).

In this context, the purpose of this study is twofold; a) to resolve any ambiguities regarding the current (2018–2020) status of Sindos in terms of vertical ground deformation (subsidence or uplift), by applying, for the first time in this area, sub-millimeter precision methods, and b) to establish a high precision monitoring network, in order to ensure the continuity of monitoring efforts with reliable in-situ observations in the near future either as a standalone approach or as a complementary (ground truth, calibration and validation data) to other monitoring/observational Remote Sensing methods (e.g. InSAR) and corresponding networks (e.g. Global Navigation Satellite Systems/GNSS).

2. Study Area

The study area is the broader region of the town of Sindos or Sinthos (older name, Tekeli) (Fig. 2). Sindos (40°40′0″ N 22°48′0″ E) lies about 14 km NW of the city of Thessaloniki, northern Greece, and belongs to the Municipality of Delta. It is an almost flat, low-elevation (5–10 m) region and covers an area of about 5 km^2, in the vicinity of four major rivers (Gallikos, Axios, Loudias, Aliakmonas). According to the 2011 census, there are 9289 inhabitants in the area, with agricultural activities being the primary occupation.

During the last decades, the area was gradually transformed into a suburban-industrial zone due to the expansion of the nearby city of Thessaloniki. In

1965, Sindos was designated as the Industrial Park of Thessaloniki. Nowadays, more than 300, mostly small, factories are operating in the area. In Sindos, there are also other important facilities besides those that define it as the Industrial Zone of Thessaloniki. These include the facilities of the International Hellenic University (IHU) and, in the wider area, the facilities of the city's water supply and sewerage company (EYATH) and biological wastewater treatment.

From a geological point of view, Sindos consists of Holocene deposits which are characterized as coastal deposits with fossils of gastropods. These deposits are unconsolidated to partly consolidated marine-lacustrine sediments, filling a NW–SE oriented tectonic graben, consisting mainly of sand and black silty clays (Rozos, Apostolidis, and Xatzinakos 2004; Hadzinakos, Rozos, and Apostolidis 1990). The

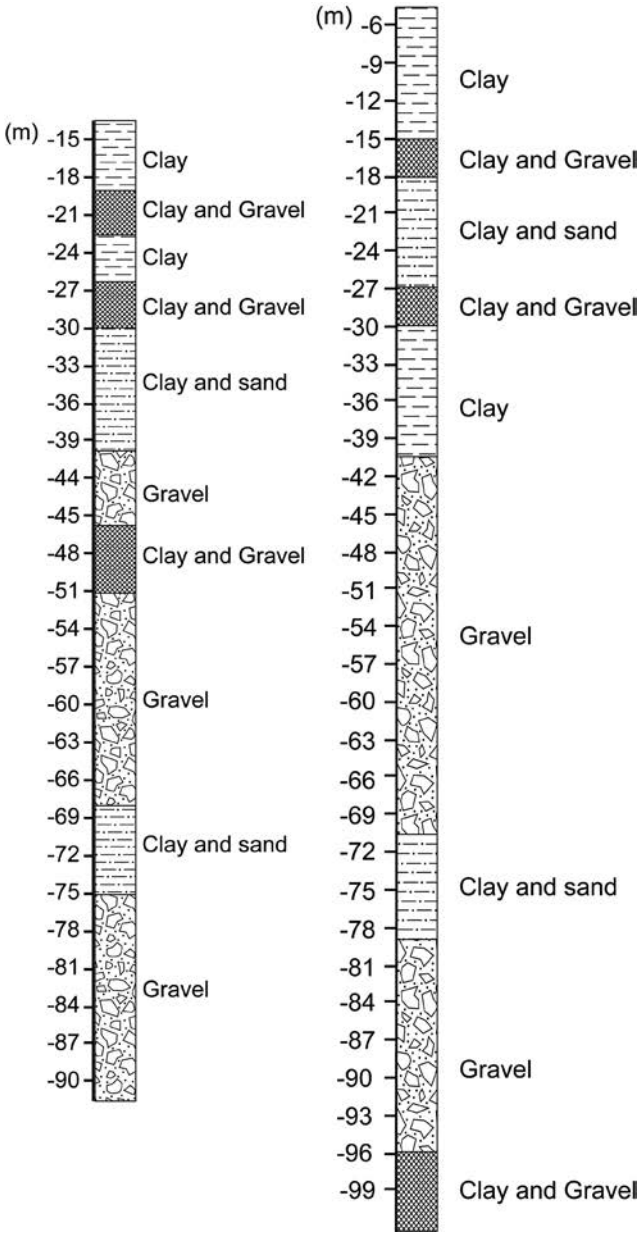

Fig. 1 Two recent, indicative stratigraphic columns of the broader area of Sindos (Tsourlos et al. 2007).

Neogene basement, buried by a 300–400 m thick sequence of Quaternary deposits, is represented by sandstones, red clays and outcrops in the north and in the north-east border of the area of interest (Raspini et al. 2014). The materials that are found are mainly sands, red clays with calcareous compositions, and conglomerates (Tsourlos et al. 2007) (Fig. 1). The existence of these elements in the area indicates that the plain of Thessaloniki probably was part of the Thermaikos gulf, and, at some point, Sindos used to be a coastal area (Ghilardi et al. 2008). Generally, the area is comprised of recent unconsolidated material, which form on multiple aquifer systems. Three main aquifers can be identified: one phreatic and two deep confined aquifers. The water level within these deposits was at an average depth of about 10–15 m below ground surface. The groundwater table is below sea level. The mean hydraulic conductivity was estimated to be $k = 6.5 \times 10^{-3} - 1.5 \times 10^{-2}$ m/min, Transmissivity (T) = 0.55–0.94 m^2/min, Storage coefficient (S) = 10^{-3} (Tsourlos et al. 2007). Further information about individual boreholes in the area can be found in additional studies (Mattas, Voudouris, and Panagopoulos 2014). According to climate data from the Meteorological station of Thessaloniki (40°03′ N, 22°58′ E) the mean annual temperature is 15.8 °C and the mean annual precipitation is 451.7 mm (Pateli et al. 2002).

The reasons for the occurrence of subsidence lie in both natural, as well as anthropogenic processes, related to the compaction of sediments and over-exploitation of aquifers (Astaras and Sotiriadis 1988).

3. Methodology

3.1 Method and Instrumentation

The most common methods for measuring subsidence and studying its spatial distribution are GNSS, InSAR and leveling, each of which has its advantages and drawbacks, while the combination of multiple techniques bears the potential of more enhanced results (Blasco et al. 2019; Del Soldato et al. 2018; Argyrakis et al. 2020).

In the spatial domain, spirit leveling, GNSS and extensometer measurements are relatively sparse, as these measurements can only be taken at a comparably restricted number of locations. InSAR measurements on the other hand are spatially dense, with their resolution (and thus density) depending on the pixel size of the SAR data used. Nevertheless, high-precision (mm) InSAR methods require, at the time of this writing, a few months of SAR observations, in order to accumulate a sufficient amount of data. Additionally, these InSAR results are provided in the form of a deformation rate (mm/yr), assuming a linear evolution of the phenomenon. Thus, potential variations within the considered time period may be

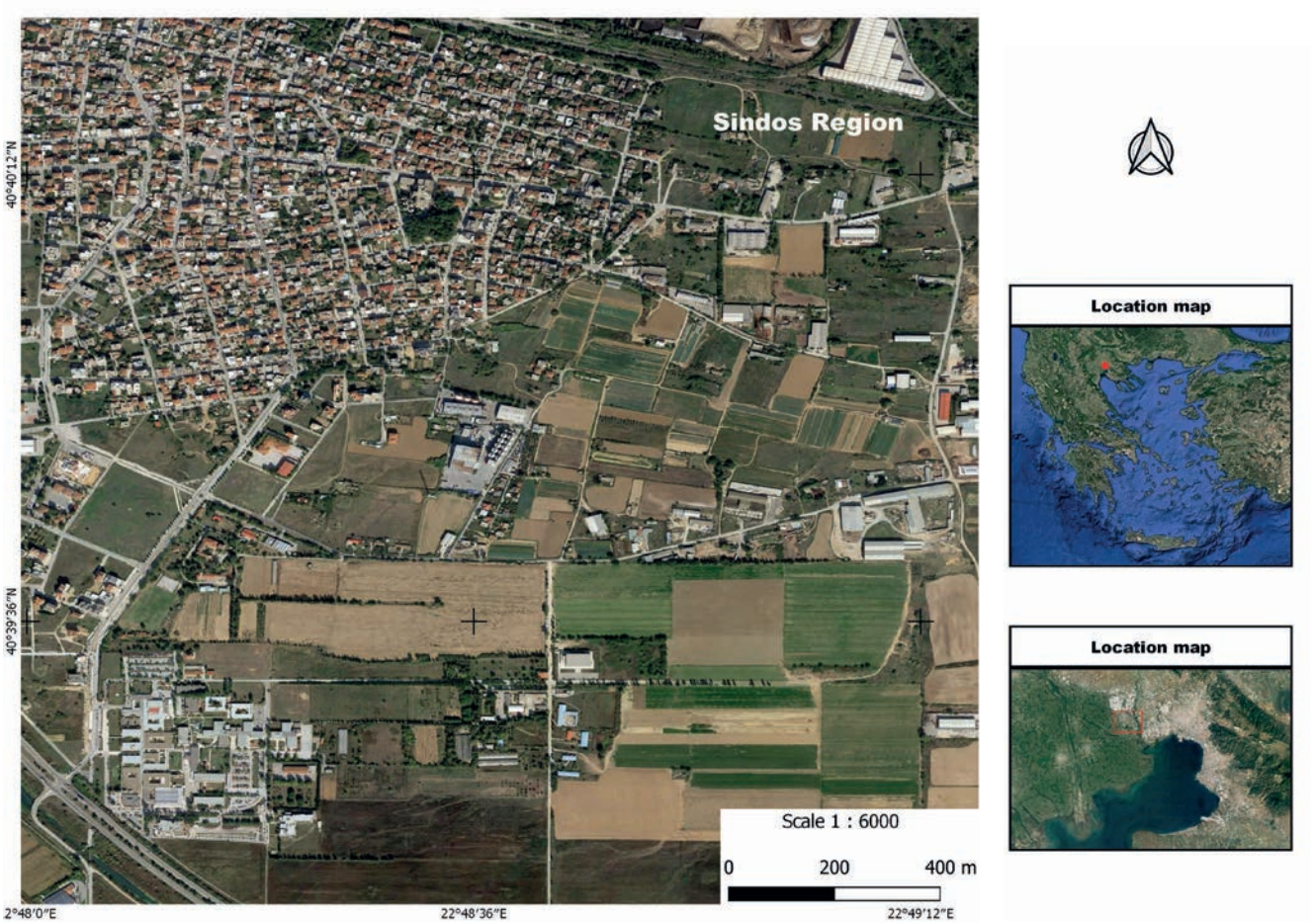

Fig. 2 Overview of the study area (Background source: Google™).

cancelled out, while a certain degree of in-situ validation is also typically desirable.

The frequency of measurement highly depends on the study objectives, the measurement methods, the available manpower and the expected order of magnitude of the subsidence rates. Very slow subsidence rates may not be possible to capture by GNSS measurements over a period of several years, due to the low signal-to-noise ratio (enough subsidence needs to occur between measurements to exceed the expected measurement error). In this case, a more accurate method, such as spirit leveling, may be necessary, in order to obtain meaningful results within a reasonable timeframe.

Overall, the most precise measurements are made using spirit-leveling surveys and extensometers. High precision leveling has been efficiently used e.g. for the purposes of monitoring crustal vertical deformation (Hao et al. 2014; Chen et al. 2021), post-glacial land uplift (Kall, Oja, and Tänavsuu 2014), inter-seismic deformation (Amighpey, Voosoghi, and Arabi 2016), in hydropower projects (Guanming et al. 2019), but also for calibrating or validating satellite-based land subsidence rates (Fryksten and Nilfouroushan 2019; Hung et al. 2018; USGS n.d.).

Taking into account these considerations and given the verified low deformation rates (whether subsidence or uplift) during the last two decades in the Sindos area (Svigkas et al. 2020; 2016; Elias et al. 2020), the method selected, in order to fulfil the objectives of this study, was spirit leveling.

The equipment used for the measurements was Leica DNA03™, which is a high precision digital level, with a nominal accuracy (Standard deviation per km double run) of ± 0.3 mm with invar staff or ± 1 mm with standard staff.

Fig. 3 The equipment, Leica DNA03™ and the staff (Professional 3000 series), that was used for the leveling measurements.

3.2 Network Design

The leveling network consisted of eleven points that cover the study area. The mean, maximum and total distance between all points is about 500 m,

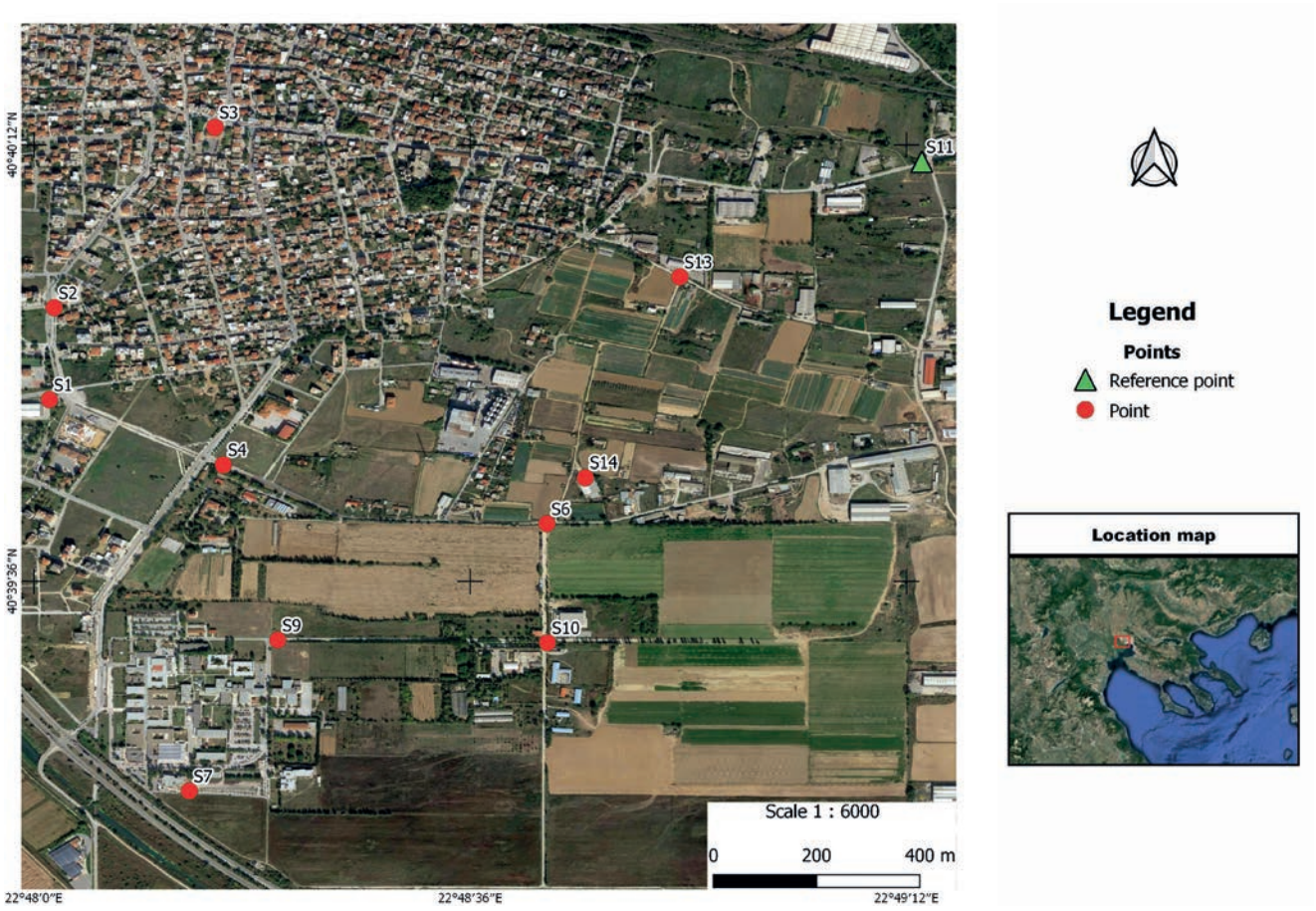

Fig. 4 The leveling network used in this study, including ten fixed points and the considered stable reference point (red dots and green triangle respectively).

1.4 km and 5 km respectively. The location of each point was carefully selected according to the following criteria:

- Coverage (including the approx. N-S and E-W boundaries of the study area).
- Accessibility.
- Minimum interference with public and (predominantly) private property.
- Conspicuity and durability.
- One of these points should be as far from the affected area as possible (given local conditions, total distance for leveling and safety regulations), in order to serve as the reference ("stable") point for all measurements.

Note that three additional points (namely S5, S8 and S12) were originally established in 2018, but

Tab. 1 The exact location and design details of each point of the established network are listed on the table below.

Point No.	Point Name	Lat	Lon	Description
1	S1	40.6641	22.8003	The westernmost point in the study area. It is located near the municipal gym of Sindos.
2	S2	40.6662	22.8004	Point facilitating the transition towards the center of Sindos. It is located near the 3rd elementary school.
3	S3	40.6704	22.8041	The northernmost point in the study area, located on the main square of Sindos Town.
4	S4	40.6626	22.8043	Located on the road, at the main entrance of Sindos.
5	S6	40.6613	22.8117	Point located at approximately the center of the study area.
6	S7	40.6551	22.8035	The southernmost point, located on the pavement, in the International Hellenic University (IHU) campus.
7	S9	40.6586	22.8055	Second point located in the main IHU campus.
8	S10	40.6585	22.8117	Point located on the road, near the IHU agricultural fields.
9	S11	40.6696	22.8203	The reference point, located in the NE boundary of the study area.
10	S13	40.6669	22.8148	Point located on the road, facilitating the transition towards the central point, S6.
11	S14	40.6623	22.8126	Point located on the road, facilitating the transition towards the central point, S6.

were eventually lost (destroyed due to external factors) by 2020.

Based on the diachronic InSAR measurements and other previous results (Mouratidis, Costantini, and Votsis 2011; Mouratidis et al. 2010; Raucoules et al. 2008; Costantini et al. 2016; Raspini et al. 2014; Svigkas et al. 2016) in the study area, the vertical displacement tends to zero towards the NE. At this point, it ought to be taken into account that Sindos is an industrial area, including highways, bridges, intense truck traffic and other heavy vehicles, combined with an inherent poor town/road planning. These create overall adverse field work conditions and imposes constrains related to safety of the people involved in the measurements. Given also the practical limitations in terms of distance that can be covered with leveling, point S11 (Fig. 4) was rendered as the best choice for a reference point. In fact, as indicated in some of the high-resolution results (Svigkas et al. 2016), the selected reference point is (marginally) located inside the stable area. It also has to be noted that these results refer to the period 1993–2000, when the subsidence rates were considerably higher (more than double) than in the post-millennial period. Therefore, S11 was already stable as early as 2000, when the overall subsidence rates in the broader area were much larger.

In order to secure the network as much as possible, but also to establish a reference for future studies (when significant deformation is expected to have accumulated), static, approximately hourly, GNSS measurements were conducted at each of the points. To this end, geodetic, dual (L1, L2) frequency Topcon Hiper pro™ GNSS receivers were used, at a sampling rate of 30 sec and with a cut-off angle of 5°. These measurements were coupled with equivalent, simultaneous GNSS observations outside the study area, at a distance well below 20 km (in Pylaia, Thessaloniki).

3.3 Data Collection and Processing

Spirit leveling was then performed in a double-run mode, between all consecutive network points, with several loops in-between (Fig. 6), in order to minimize blunders. Backsights and foresights were approximately equal in distance, ranging between 40–50 m, with an average of 42 m. The measurements were also carried out during similar periods of the year for three years (i.e., May–June 2018, 2019 and 2020), so as to avoid seasonality-related effects as much as possible.

As a first level of quality assurance, each double-run measurement that did not satisfy a closure of ±0.5 mm was executed again, until the desired threshold was achieved. The final height difference between two points was then calculated as the mean value

Fig. 5 Approximate distance between network of points and GNSS stable station at Pylaia.

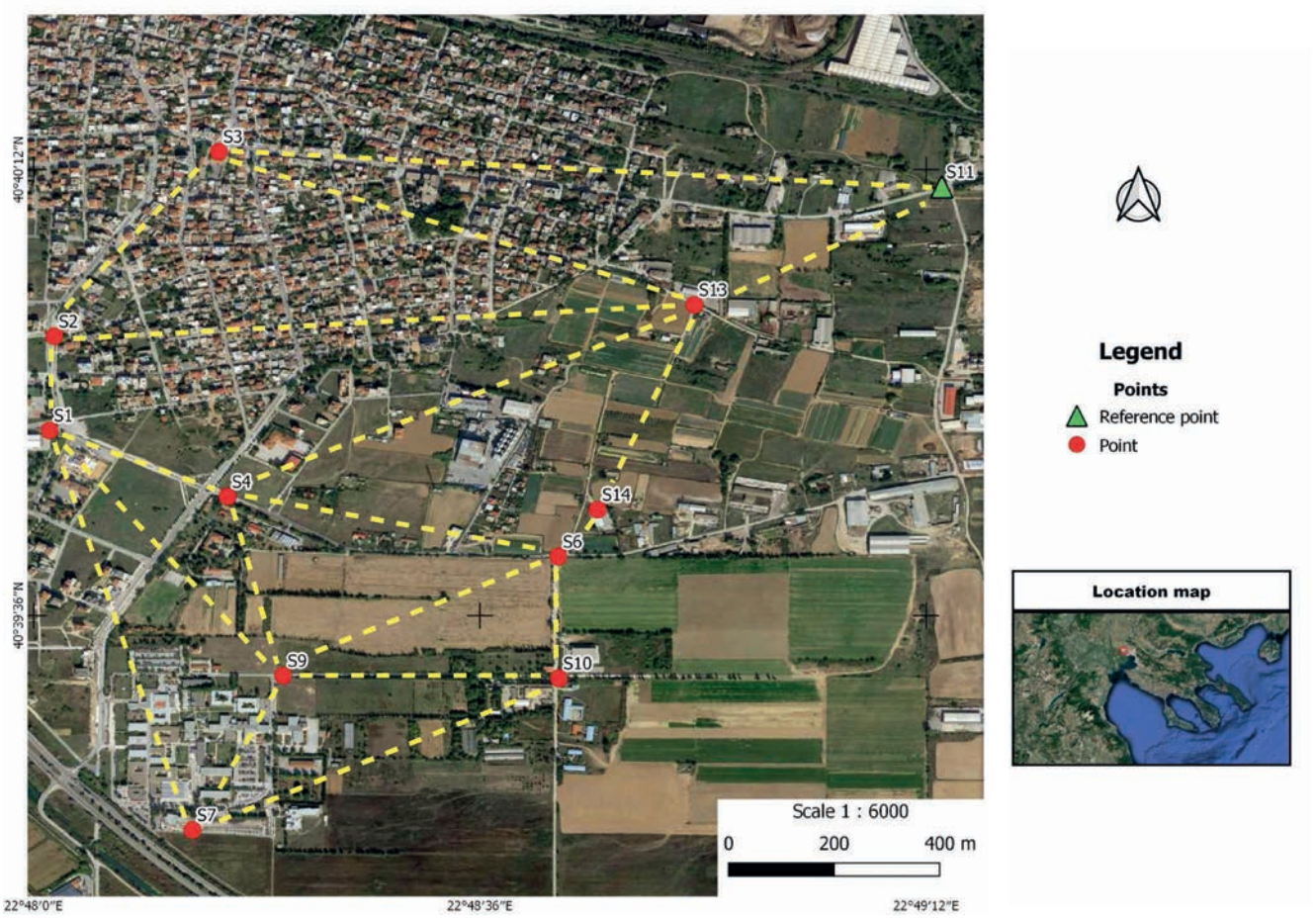

Fig. 6 Complete sketch of the leveling network, including the loops performed on an annual basis from 2018 to 2020.

between the double run measurements, fulfilling the threshold. To further ensure robustness against blunders, as well as to enable residual error redistribution, the leveling network was designed with multiple loops. An empirical threshold of the loop closure was set; If the loop closure was larger than ±15 mm, the double-run leveling for this particular loop was repeated.

Tab. 2 Summary of the conducted leveling main characteristics.

Vertical Deformation (mm)			
Point	**June 2018 – June 2019**	**June 2019 – June 2020**	**June 2018 – June 2020**
S1	−9.3 ± 0.73	−0.6 ± 0.75	−9.9 ± 0.74
S2	−7.3 ± 0.73	−3.4 ± 0.74	−10.7 ± 0.74
S3	−5.3 ± 0.71	−2.9 ± 0.71	−8.2 ± 0.72
S4	−8.8 ± 0.72	−0.4 ± 0.7	−9.2 ± 0.71
S6	−8.5 ± 0.69	0.7 ± 0.69	−7.8 ± 0.68
S7	−15.1 ± 0.75	0.8 ± 0.75	−14.3 ± 0.75
S9	−11.6 ± 0.71	0.7 ± 0.71	−10.9 ± 0.7
S10	−14.4 ± 0.71	−0.6 ± 0.71	−15.0 ± 0.71
S11	Reference Point		
S13	−2.9 ± 0.58	3.2 ± 0.57	0.3 ± 0.58
S14	−5.5 ± 0.67	3.0 ± 0.68	−2.5 ± 0.67

All of the collected leveling data were imported in a Geographical Information System (GIS) environment, specifically QGIS. For this process it was necessary to decode and transfer the data from the digital level to a readable PC format, as well as to pre-process them, in order to be fully and properly readable by the GIS software. The next step was to calculate the relative height difference of each point in relation to the reference point. Finally, the values calculated from the three datasets were subtracted (2019–2018, 2020–2019, 2020–2018), with the purpose of determining the relative vertical displacement of every point, always in relation to the reference point.

3.4 Quality Analysis of the established Vertical Network

The vertical network was solved by applying least squares adjustment for three successive years (2018, 2019, 2020), using the DeRos software (Dermanis and Rossikopoulos 1981). Specific rigorous criteria (double run and loop–closure controls, respectively) for the elimination of potential blunders were applied. The solution was based on minimum constraints (Koch 1999), fixing the reference point (which is laid far away from the area of interest). The outlier identification and rejection were realized by the application of the data-snooping method (Dermanis and

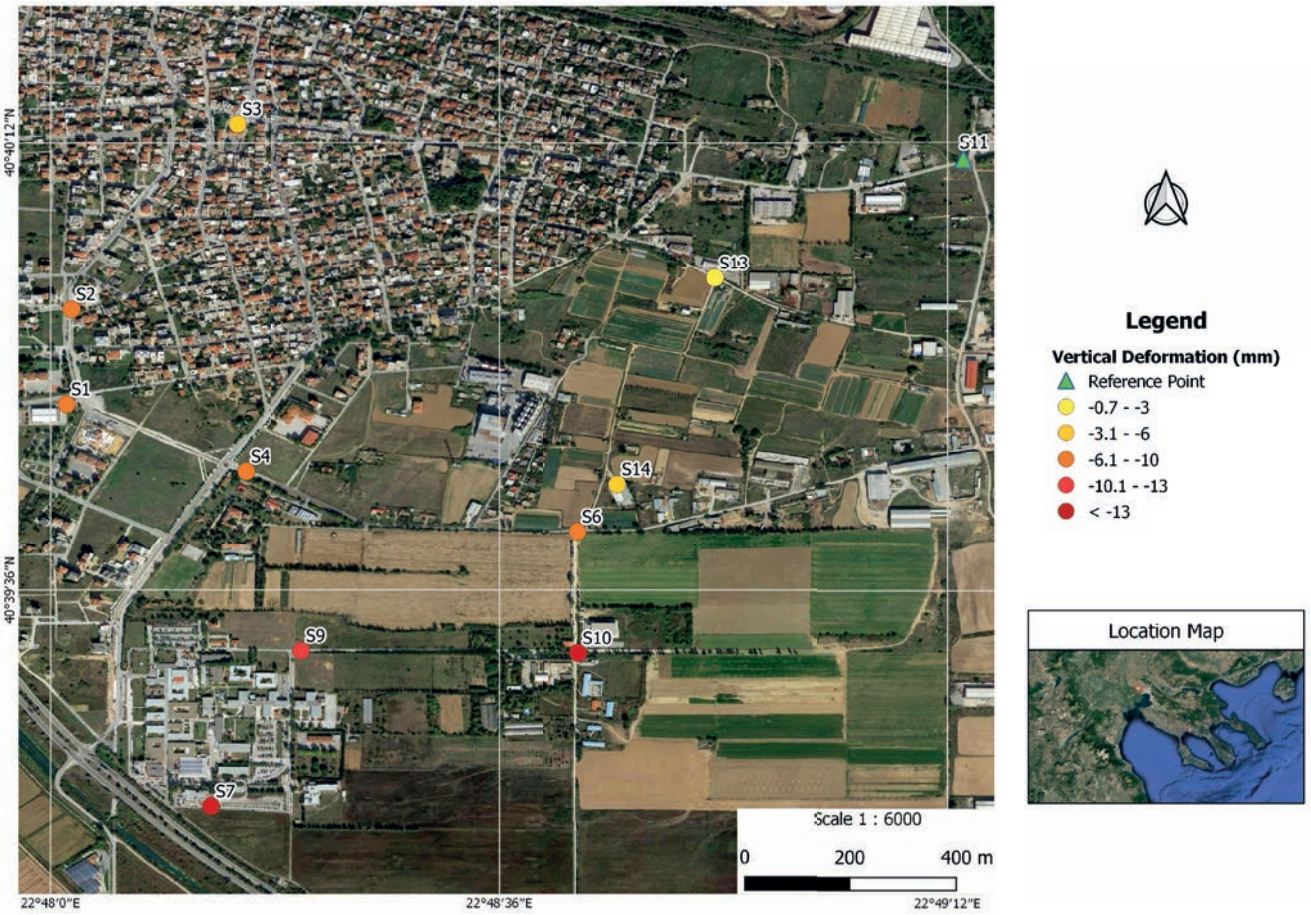

Fig. 7 Vertical displacements between June 2018 and June 2019.

Fotiou 1992; Rossikopoulos 1999). The t-test (Student's t-test) was implemented with a 95% level of confidence.

After performing adjustment on an annual basis, the estimation of the heights and their associated accuracies were obtained, for the respective years. In order to assess the significance of the estimated vertical displacement the following criterion was applied, pointwise (Dermanis 1986):

$$\frac{h_i^k - h_i^j}{\sqrt{\sigma^2{}_{h_i}{}^k + \sigma^2{}_{h_\xi}{}^k}} \leq Z^{a/2} \quad (1)$$

Where h_i^k, h_i^j, the estimated heights of an arbitrary point i for two successive years j and k, $\sigma^2{}_{h}{}^k{}_i$, $\sigma^2{}_{h}{}^k{}_\xi$ the estimated variances of the aforementioned heights and $z^{a/2}$ the value of the normal distribution, for a particular level of significance a. A level of confidence a = 0.05, thus $z^{a/2}$ = 1.96 was chosen. If equation (1) is fulfilled, the estimated displacement between two successive years is statistically insignificant. On the other hand, the failure of the test leads to the conclusion that the displacement and the uncertainty can be separated, meaning that the displacement can be measured with adequate confidence.

4. Results

4.1 Leveling measurements for the period 2018–2019

The leveling results between June 2018 and June 2019 are presented in Fig. 7. Starting from the reference point (S11), negative displacement on the z axis is increasing towards the SW side of the area of interest. This negative displacement indicates subsidence for every point of the dataset. Maximum subsidence value for this period is 15.1 ± 0.75 mm (S7), minimum is 2.9 ± 0.58 mm (S13) (Table 3). Therefore, for 2018–2019, only subsidence phenomena were observed over the study area.

4.2 Leveling measurements for the period 2019-2020

In this second set of results between June 2019 and June 2020, deformation seems to have a lower homogeneity (Fig. 8). More specifically, a significant number of points (5 out of 11) display values that are close to zero. These points are S1, S4, S6, S9, S10 and they are located in the middle of the area of interest, creating a cluster. Three out of eleven points seem to have an uplift trend. These points are S7, S13 and S14. The two

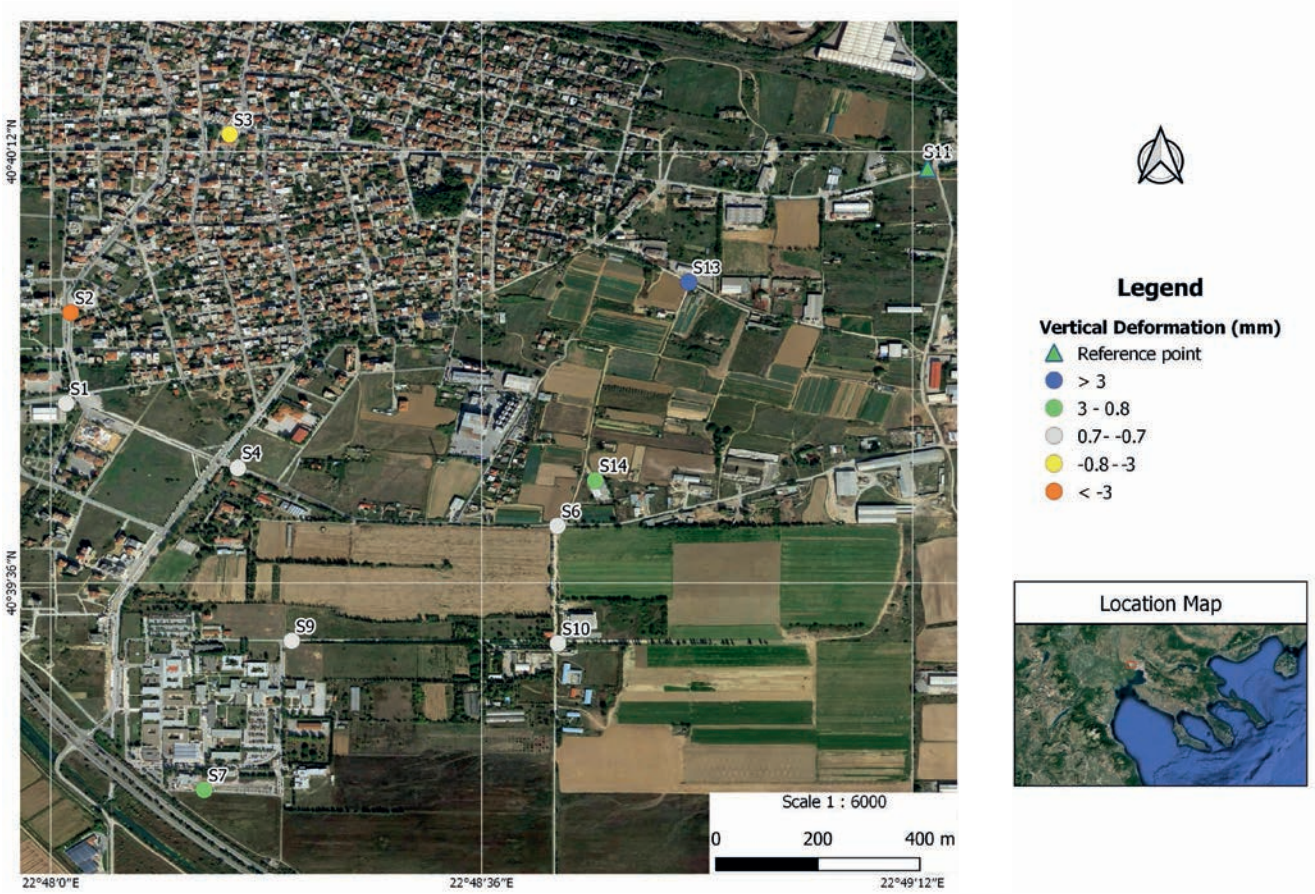

Fig. 8 Vertical displacements between June 2019 and June 2020.

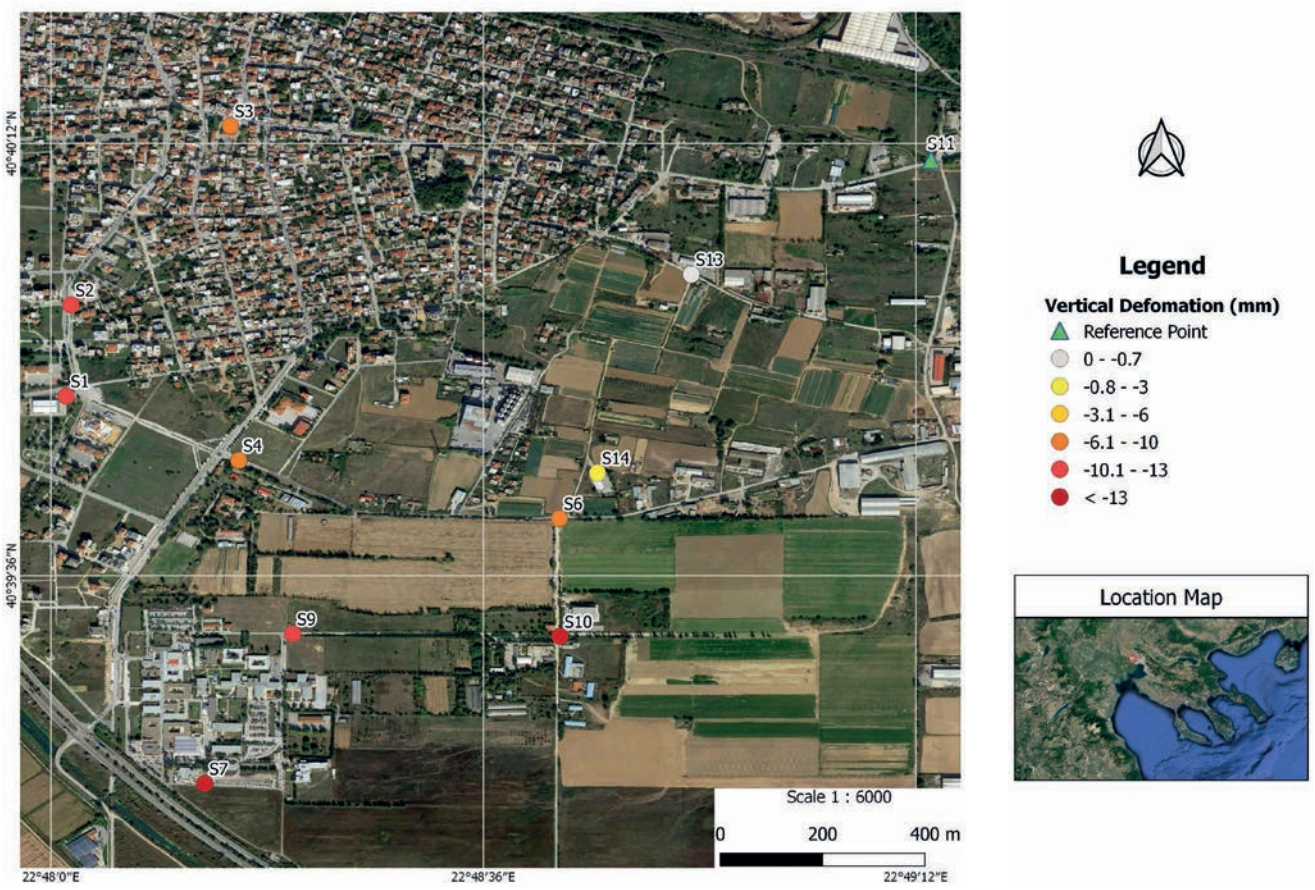

Fig. 9 Cumulative vertical displacements for the total study period (June 2018 – June 2020).

remaining points S2 and S3 seem to have a negative displacement (subsidence). Maximum subsidence value for this period is 3.4 ± 0.74 mm, while maximum uplift is 3.2 ± 0.57 mm (Tab. 3). Hence, in 2019–2020, both subsidence and uplift phenomena took place, but most of the points measured seem to be relatively stable.

4.3 Leveling measurements for the period 2018-2020

The third set of the measurements refers to the total difference between June 2018 and June 2020 (Fig. 9). One out of eleven points (S13), displays values that are close to zero, therefore it can be considered as overall stable. All other points of this dataset seem to have negative displacement (subsidence), which increases towards the SE part of the area. Maximum subsidence value for this period (which includes the total time range of the measurements) is 15.0 ± 0.71 mm (S10), minimum is 2.5 ± 0.67 mm (S14) (Tab. 3). In light of an overall interpretation, only subsidence phenomena appear to have taken place in the study area in this time frame. In this context, for a better overview of the ensemble deformation, a continuous surface was created by using the IDW (Inverse Distance Weighting) method.

Tab. 3 Summary of vertical deformation for every point of the established network, during each period of measurements. Subsidence/uplift are presented with negative/positive values respectively.

Loop	Loop closure 2018 (mm)	Loop closure 2019 (mm)	Loop closure 2020 (mm)
S3-S11-S13-S3		−0.2	0.5
S2-S13-S3-S2	−0.6	0.6	0.3
S1-S2-S13-S4-S1	−0.7	−0.2	−0.7
S4-S13-S14-S6-S4	0.5	−0.4	−0.4
S1-S4-S9-S1	0.2	−0.1	0.4
S1-S9-S7-S1	−0.4	0.3	0.6
S9-S4-S6-S9	−0.5	−0.4	0.3
S9-10-S6-S9	−0.2	0.1	−0.5
S7-S9-S10-S7	0.1	−0.3	−0.1

4.4 Control and Quality Analysis

The final closures for all measured loops, in accordance to Fig. 6, are presented, for each year, in Tab. 4.

Concerning quality analysis, all tests (according to Eq. 1) for the period 2018–2019 indicate statistically significant displacements. Conversely, for the period 2019–2020 half of the displacements identified

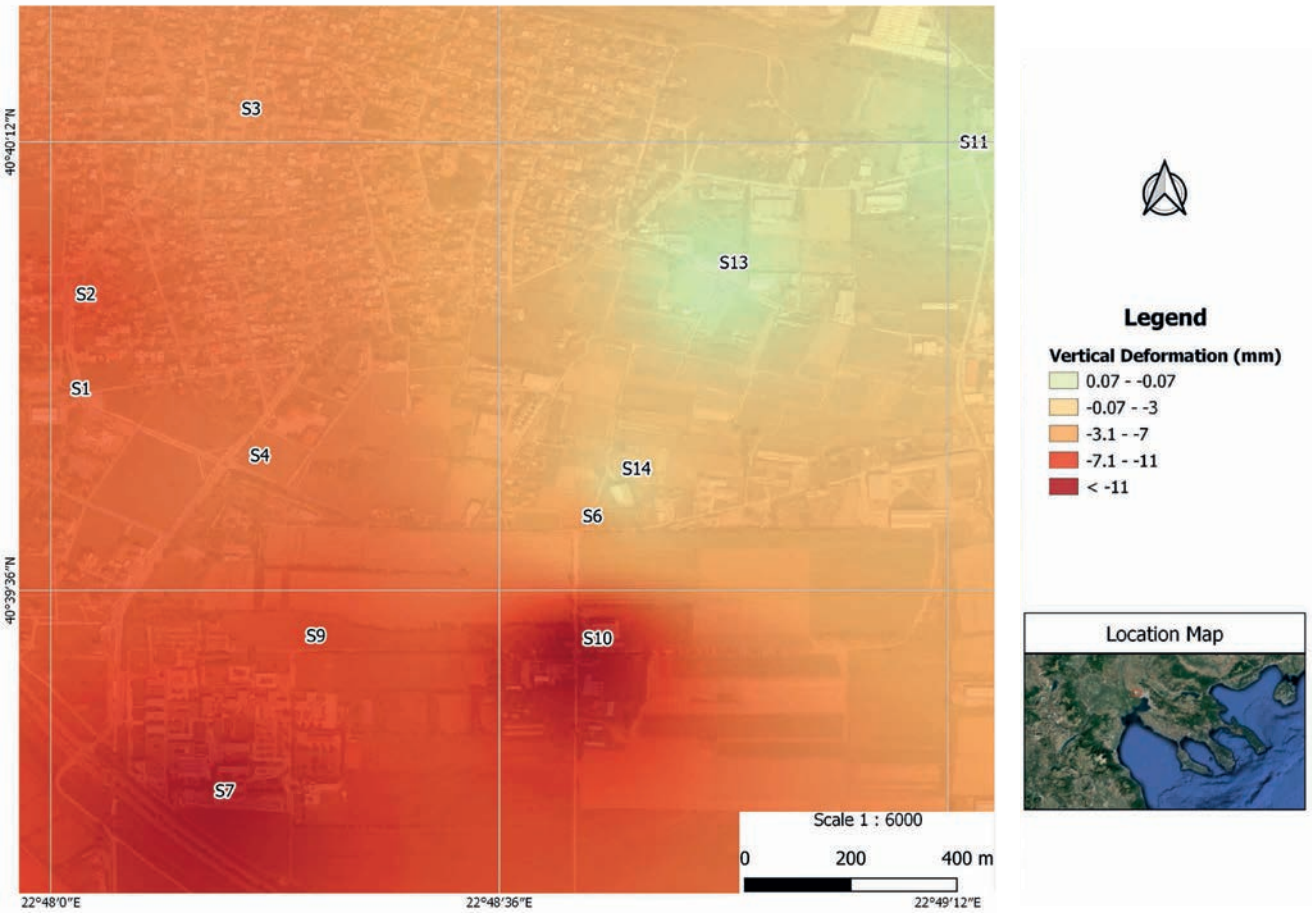

Fig. 10 Continuous surface of deformation for the period between 2018 to 2020, created by taking into account all eleven points of the dataset. This raster map is solely for visualization and qualitative interpretation purposes, hence the estimated values of deformation per pixel are indicative. As such, the map highlights an increasing subsidence towards the SW of the study area.

are statistically insignificant (S1, S4, S6, S9 and S10), while the total displacements between 2018–2020 are considered significant for all points except for S13.

After applying Least Squares (LS) adjustment, the accuracy (StD of the adjusted heights) ranged between 0.57 mm and 0.75 mm, with a mean value of about 0.7 mm.

Tab. 4 Loop closures for the 2018, 2019 and 2020 measurements.

Loop	Loop closure 2018 (mm)	Loop closure 2019 (mm)	Loop closure 2020 (mm)
S3-S11-S13-S3	0.4	−0.2	0.5
S2-S13-S3-S2	−0.6	0.6	0.3
S1-S2-S13-S4-S1	−0.7	−0.2	−0.7
S4-S13-S14-S6-S4	0.5	−0.4	−0.4
S1-S4-S9-S1	0.2	−0.1	0.4
S1-S9-S7-S1	−0.4	0.3	0.6
S9-S4-S6-S9	−0.5	−0.4	0.3
S9-10-S6-S9	−0.2	0.1	−0.5
S7-S9-S10-S7	0.1	−0.3	−0.1

5. Discussion

The three annual sets of high precision leveling measurements over the Sindos region have yielded reliable data – well below the mm level –, in order to ascertain the subtle vertical deformations occurring in the area.

The first set of measurements refers to the period between June 2018 and June 2019. For this timeframe, the displacement results over the ensemble network are negative, indicating a subsidence trend varying from 2.9 mm to 15.1 mm. Subsidence values seems to increase towards the SW part of the study area, i.e., to the south of Sindos and, in particular, in and around the facilities of the International Hellenic University (points S7 and S9). This increase of subsidence rate has been previously identified by several studies (Bolt et al. 1977; Mouratidis, Briole, and Ilieva 2010).

In the second dataset, for the period between June 2019 and June 2020, both negative (subsidence) and positive (uplift) deformation values have been recorded. Nevertheless, all of these values are much lower than those of 2018–2019, while five (i.e., almost 50%) of the measured points were determined to be stable. More specifically, points S1, S4, S6, S9 and S10, located at the center and towards the south of the study area, seem to be stable (deformation rate less then ± 0.7 mm). At the NW part of the study area, which also coincides with the denser urban environment of Sindos Town, negative values are recorded (points S2 and S3). The magnitude of subsidence over these two points is 2.9 mm and 3.4 mm respectively, for this second period of measurements. Finally, in the E–NE (S13 and S14) and far SW (S7) part of the study area, some positive displacement values have been measured. These correspond to an uplift of 3.2 mm, 3.0 mm and 0.8 mm, respectively. Taking into account the adjusted network accuracy of 0.7 mm, the uplift of S7 can be considered as marginally discernible. Given the geographic distribution of deformation during 2019–2020, S7 could be eventually considered as stable, given that all its nearest neighbors (S1, S4, S6, S9 and S10) are the points previously identified as stable as well.

Overall, during the full measurement timeframe, i.e., between June 2018 and June 2020, subsidence phenomena prevail over the whole study area, apart from one of the network points (S13), which is considered as stable, while no uplift signals have been recorded. The pattern of subsidence for these two years, is similar to the results for 2018–2019, i.e., values are maximized towards the S–SW (14.3 mm for S7 and 15.0 mm for S15).

As is evident from the individual (annual) results, a considerable difference in the deformation was identified between the two epochs (2018-2019 vs 2019–2020). In particular, the first year of measurements indicates clear subsidence (up to about 15 mm), whereas the second year is characterized by rather stable or significantly less perceptible displacements – whether uplift or subsidence – of about ± 3 mm. One possible explanation for these annual (or seasonal) differences may lie in the fact that changes of the aquifer level is followed by a proportional response detected at the surface (Raspini et al. 2014) and that sediments in the area are strongly affected by the underground water level (Raspini et al. 2014). These formations cover the majority of the study area and are indicative of high erosion and leaching. They are characterized by moderate to high permeability, frequently creating dynamic aquifers with evident water-level fluctuations. Additionally, according to (IGME 1993), phenomena of subsidence and soil displacement are observed as the direct result of urban expansion over these extensive sediment surfaces.

In order to investigate the correlation of subsidence trends with the aquifer level, aquifer level data over the study area was retrieved from the Thessaloniki Water Supply & Sewerage Company (EYATH S.A.). The data cover the period just before and right after the leveling measurements on a bi-annual basis from 2018 to 2020. The average aquifer level difference of all available borehole data, with reference to June 2018 – hence just before the start of the leveling campaigns – is presented in Fig. 11.

As it can be observed, the water level drops by more than 1m from June 2018 to May 2019 which is consistent to the observed clear subsidence during the same period. Conversely, during May 2019 – June 2020 the aquifer levels rise by about 0.35 m, which is again consistent with the more balanced behavior of the deformation phenomena in this time frame. Overall, the trend in the aquifer level changes

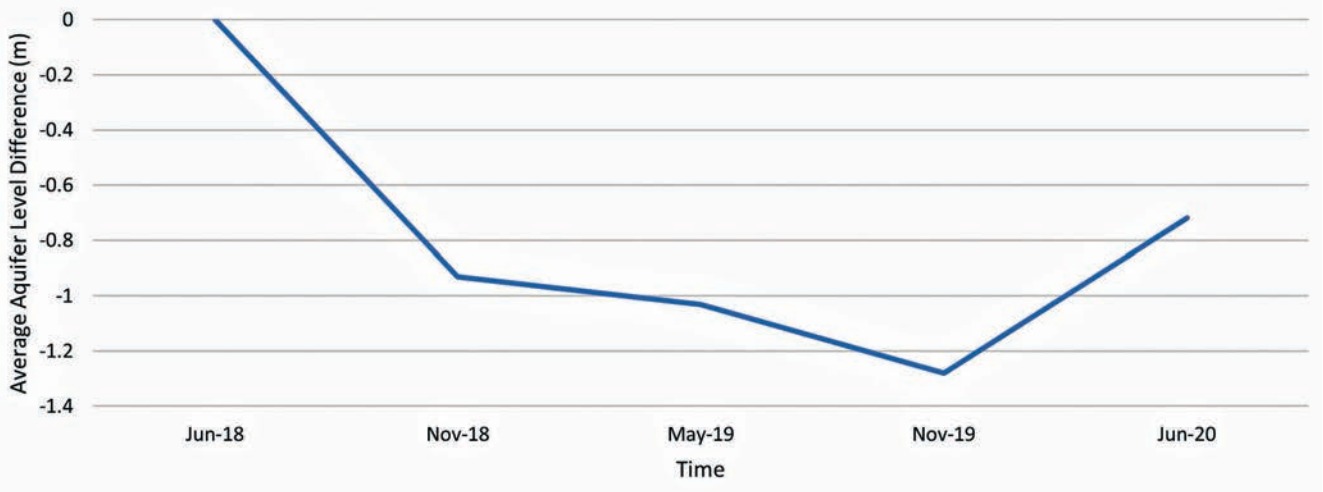

Fig. 11 Evolution of aquifer levels in the study area, during the period of the leveling measurements. All differences are presented with reference to June 2018 (source: EYATH S.A.).

resembles the pattern of the deformation phenomena, taking into account the time-lag between aquifer recharge and ground uplift mentioned in (Svigkas et al. 2016).

Additionally, monthly precipitation data of Sindos weather station were retrieved for the period 2018–2020 (apart from February 2020, for which the data were missing) (Meteo 2021). Subsequently, the total precipitation for the two individual time frames (June 2018 – May 2019 and June 2019 – May 2020) were calculated, yielding 342 mm and 528 mm respectively. This means that the precipitation of 2019–2020 was at least 54% more than that of 2018–2019, which may have slowed down or even partially reverted the subsidence phenomena for the specific year. Also, by retrieving all additional precipitation data from the Sindos weather station for previous years, dating back up to June 2015, the resulting average precipitation per year (June to May) is 420 mm. Interestingly enough, the minimum value (342 mm) is observed during the period between June 2018 – May 2019, i.e. coinciding with the clear subsidence trend measured; while the maximum value (528 mm) occurs between June 2019 – May 2020, i.e. coinciding with the more balanced deformation pattern identified in this period (Meteo 2021).

Compared to previous studies, which verified an ongoing decrease in the maximum subsidence rate per year, throughout the last three decades (Costantini et al. 2016), the current situation in Sindos seems to be following the same pattern. In particular, the rate of subsidence in the area continues to decline, from about 45 mm/yr in the period 1992–2001 (Raspini et al. 2014; Raucoules et al. 2008) and 34 mm/yr during 1993–2000 (Svigkas et al. 2016), to approximately 18 mm/yr during 2002–2007 (Mouratidis, Briole, and Ilieva 2010; Mouratidis et al. 2010) and 14 mm/yr for the period 2004–2010 (Costantini et al. 2016), to 10 mm/yr during 2014–2019 (Elias et al. 2020) and 14 mm/yr for 2015–2019 (Svigkas et al. 2020) and finally to about 7 mm/yr during 2018–2020 (from the results of this study). In contrast to this pattern, Svigkas et al. (Svigkas et al. 2016) reported an uplifting trend of about 12 mm/yr, for the period between 2003–2010 (Tab. 5 and Fig. 12). Note that all other studies were applied in broader area of Northern Greece, Thessaloniki region or specifically in Kalochori and Sindos regions. All the above-mentioned studies were based on InSAR methods (such as individual interferograms generation, Persistent Scatterer Interferometry and Small Baseline Subset approaches), hence, where appropriate, their results had to be converted from Line of Sight (LoS) deformation to vertical displacement (subsidence), in order to be comparable with the results of the current study.

Tab. 5 Rate of deformation in the broader area of Sindos based on all available relevant results.

Studies	Time Interval	Deformation Rate (mm/yr)
Raspini, F. et al. (2014), Raucoules, D. et al. (2008)	1992–2001	−45
Svigkas, N. et al. (2016)	1993–2000	−34
Mouratidis, A. et al. (2010)	2002–2007	−18
Costantini, F. et al. (2016)	2004–2010	−14
Svigkas, N. et al. (2020)	2003–2010	12
Elias, P. et al. (2020)	2014–2019	−10
This study	2018–2020	− 7

The main limitation of this study lies in the restrictions related to the distance that can be covered by leveling, in order to ensure that the reference point is clearly outside the deforming area, thus stable with respect to the other network points. Pre-existing information and literature as well as achieved results converge that S11 lies at the farthermost end of the least affected-by ground deformation-area. Thus, S11 was by evidence the optimum choice for a reference point for the purposes of this study.

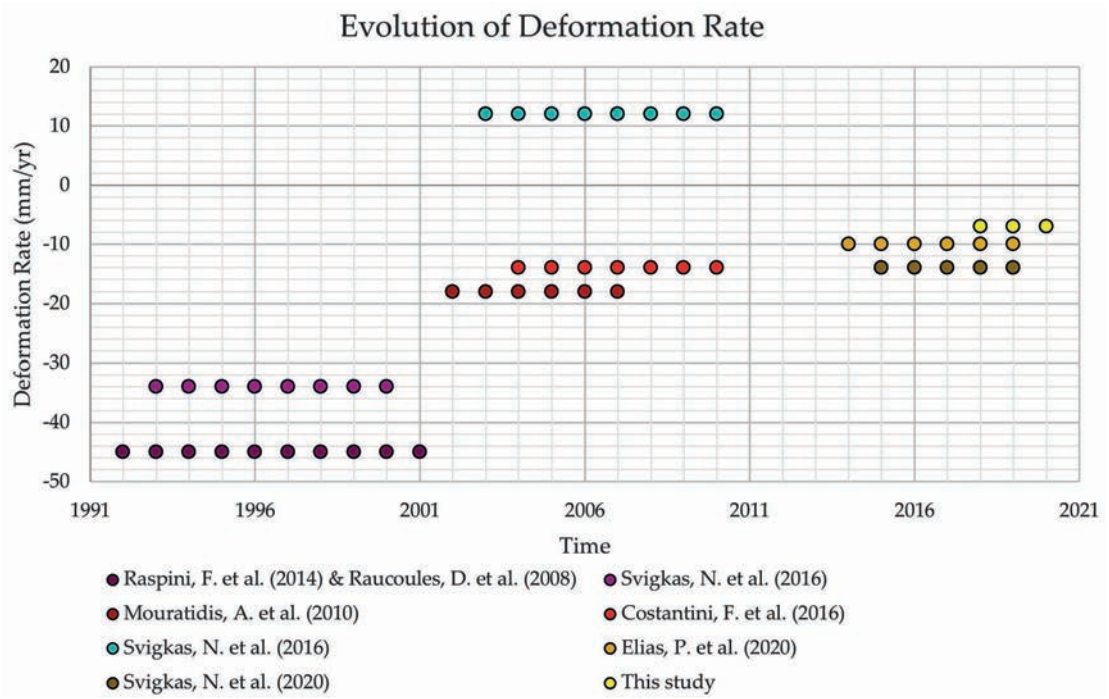

Fig. 12 Graphical representation of the evolution of the rate of deformation throughout the years in the broader area of Sindos region.

6. Conclusions

In this study, subtle vertical motions in the Sindos region, Thessaloniki, northern Greece, were measured three times, in three consecutive years (June of 2018, 2019 and 2020), by creating a high precision leveling network of eleven points over an area of about 5 km^2. Measured also with GNSS, this network comprises a scientific "investment" for the continual observation of vertical deformation in the study area, in the coming years or decades.

The first pair of measurements (June 2018 – June 2019) reveals considerable subsidence over the whole study area, while the second period (June 2019 – June 2020) is predominantly characterized by relative stability or significantly lower deformation – subsidence or uplift – values. Over the full two-year period (2018–2020), the area is clearly dominated by a subsidence trend, with a total maximum value of up to 15.0 mm. Although this value corresponds to a subsidence rate of about 8 mm/yr, special attention ought to be given to the non-linear nature of the phenomena involved, as verified by the year-to-year measurements. This phenomenon can be, by hard evidence, attributed to the different amounts of annual precipitation, the intensity of ground water exploitation and the consequent variations of the aquifer level.

The identified on-going subsidence at progressively lower rate is particularly evident and in line with the vast majority of previous relevant studies of the last three decades.

Overall, it is acknowledged that the current study investigates only a "temporal window" of a diachronic and dynamic phenomenon of deformation that has been quantitatively studied via reliable ground- and satellite-based methods (leveling, GNSS, InSAR) for more than three decades. As such, but also due to the considerable decrease of the subsidence rate and the consequent reduction of the signal/noise ratio during the last 10–15 years, it has been considered imperative to scale-up the precision of observations.

High precision leveling over such an extensive area requires a lot of properly trained human resources and engineering expertise, is very time-consuming, costly and tedious. Nevertheless, the resulting output was rather essential, in order to constrain and be able to map and monitor the current subtle deformation signal manifestations in the study area.

Apart from resolving the ambiguity of downward/upward displacements and the indication of non-linear deformation patterns, the established network and measurements shall serve as a basis for future monitoring. Additionally, they also constitute invaluable assets for the validation of alternative/complementary geodetic methods, such as those of GNSS and InSAR, or the synergistic use of all three approaches simultaneously. In fact, the study area has been monitored since 1991, almost continuously, with InSAR (apart from 2011–2013, due to the lack of SAR data), while the subsidence phenomena have been evolving. Thus, the leveling network as well as the GNSS measurements (to be periodically repeated in the future) will render this case study as an ideal test site for the cross validation of geodetic methods (InSAR, GNSS, leveling) and/or the optimization of their combined use. This is e.g., expected to contribute to the overall deterioration of opportunistic InSAR results (Hanssen 2003) and to overcoming the limitations of the individual geodetic methods.

In this context, it is of high scientific value that the research expands in space and time, in order to have a clear representation and understanding of the phenomenon and its progress throughout the years, as well as to ascertain the potential periodicity of ground deformation.

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The impact of the Covid-19 pandemic on cross-border cooperation between Czechia and Austria

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ABSTRACT
Cross-border cooperation plays an important role in deepening European integration. Thanks to the existence of cross-border cooperation, border regions can overcome negative effects of the border and the adverse impact on their development, which leads to improvements in the daily lives of local residents. The Covid-19 pandemic caused an unprecedented closure of borders between most EU countries, which meant that communication between cross-border actors became more difficult and many cross-border activities were cancelled. After the first waves of the pandemic subsided, twenty interviews were conducted with mayors of Austrian municipalities in the Czech-Austrian border region. The topic of these interviews was the level of cross-border cooperation with Czech entities (municipalities, schools, societies etc.) and the impact of the Covid-19 pandemic on cross-border cooperation. The main findings from the interviews are that cross-border cooperation is positively evaluated. More than half of the mayors see cross-border cooperation as slightly increasing in recent years and about a fifth as decreasing or not developing. The main obstacles to cross-border cooperation are bureaucracy and language barriers. There are many joint activities in the border area, some of them have a long tradition and take place every year. Due to the border closure, the organisation of these activities was first postponed and then cancelled in 2020. On a positive note, according to the mayors, most of the cross-border events were already taking place in 2021. It can be concluded, that the pandemic caused a one-year gap in cross-border activities.

KEYWORDS
borders; cross-border cooperation; Czech-Austrian borderland; Covid-19

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1. Cross-border cooperation

Cross-border cooperation can be defined as institutionalized cooperation between adjacent administrative units, which are at a lower level than the state, thus it is, in short, regional cooperation across a national border (Perkmann 2003). Cross-border cooperation is seen as a multifaceted and diverse process, which is related to the fact that the inhabitants of border areas are aware that the border line not only divides them but also unites them through identical challenges on both sides of the border (Del Bianco 2006).

Cross-border cooperation plays an increasingly important role in the regional development of border areas, whether as part of the internal potential of the territory or as part of European integration at the regional or local level. It is no longer only the state as the main political actor, but also the European Union acting externally on border areas, as well as, for example, the Euroregions, which represent one of the important forms of institutional anchoring of cross-border cooperation at the regional level (Havlíček et al. 2018). The European Union has 40 internal land border regions, which account for approximately 40% of its land area and where almost 30% of the EU population lives (Cross-border cooperation in the EU 2020).

Camagni et al. (2019) argue that legal and administrative barriers continue to affect the economic growth of European border regions, despite the creation of a single European market. It is estimated that the removal of legal and administrative barriers would allow European border regions to be about 9% richer than they currently are. Border regions generally have less access to public services such as hospitals and universities, and individuals, businesses and public authorities face specific difficulties in working between different administrative and legal systems (Cross-border cooperation in the EU 2020).

It can be argued that regions that progressively remove border barriers and establish contacts with neighbouring regions show a greater potential to progressively reduce the gap between the border periphery and the inland core. And while physically the border is removed relatively quickly, e.g. the fall of the Iron Curtain or the entry of a new country into the Schengen area, economic links develop gradually, over a period of years. But customs, prejudices, perceptions of neighbours and other socio-cultural characteristics change much more slowly (Scott 2012).

Although the European integration process has achieved significant results and helped to remove many obstacles in mutual cooperation, many barriers remain, mainly stemming from divergent legal and administrative provisions. It is cross-border cooperation that plays a major role in removing these barriers (Böhm and Kurowska-Pysz 2019), leading to an easier everyday life for the inhabitants of European border regions.

2. Czech-Austrian relations and the cross-border cooperation

The history of Czech-Austrian relations is long and rich. Similarly, the Czech-Austrian border has undergone a significant transformation and change of function. From the perspective of cross-border cooperation between Czechia and Austria, 1989 was a major turning point, when the Iron Curtain fell and the state borders were reopened. The political upheaval and the changes, which were his consequence, started a process of overcoming the bipolarity of Europe that had lasted for decades. Since 1989, the two border regions have been gradually connecting, re-establishing contacts, building new border crossings and getting to know each other (Šindelář 2019).

After 1989, the Czech-Austrian border region could be described as a bridge between the neighbouring states (Jeřábek et al. 2004). The Czech-Austrian border functioned in this so-called alienated border regime (Martinez 1994) after Czechia joined the European Union in 2004. EU enlargement accelerated the process of so-called debordering and contributed to a change in the function of the state border. From a partially open border it was possible to define the Czech-Austrian border as a contact border (Martinez 1994). After 2007, when border controls were completely abolished and thus the last restrictions fell, we started speaking of the border area as cooperative instead of fully open. This means that emergence and development of various forms of cross-border cooperation can be expected (Perkmann 2003).

The origin of cross-border cooperation between Czechia and Austria dates back to the immediate period after the fall of the Iron Curtain, at that time still in the form of individual contacts between citizens and later work abroad (Heintel and Weixlbaumer 2002). In the beginning, these were ad hoc contacts between municipalities, various associations (mainly cultural and sporting events) or schools. We are talking about a "wild" phase (1989–1992 initiated "from below". Later on, systemic cooperation was established and expanded – the so-called managed phase (1992–1995) promoted "from above" – especially in the field of tourism, cooperation in disaster management and in solving some common problems of the municipalities (Havlíček 2005).

A further impetus for the strengthening of cross-border cooperation came in 1995, when Austria joined the EU, which also allowed this part of the border region to be included in the EU pre-accession programme Phare CBC and the INTERREG programme, which in turn allowed the use of European subsidies (Heintel and Weixlbaumer 2002). The possibility to draw on subsidies was one of the main reasons for the establishment of cross-border structures between Czechia and Austria, which are the Pomoraví/Weinviertel/Zahorie Euroregion,

established in 1999 (renewed in 2021 after a passive phase), and the Euroregion Silva Nortica, operating since 2002. This period is known as the European phase (1995–2004).

In the period before Czechia accessed to the EU, other factors must be emphasised. Firstly, the fear of losing jobs in border areas played a role in Austria, so a restrictive transition period of up to seven years was negotiated on the issue of free movement of labour (the same was applied to new EU members by Germany), which ended in 2011, and secondly, Austrians protested against the launch of the Temelín NPP. The conflicting past remains present in the background of relations. The expulsion of Germans from Czechoslovakia and the subsequent settlement of the borderlands is still a controversial topic, especially for Germans from Bavaria and some Austrians (Šindelář 2019).

Apart from the impetus of the accession of Czechia to the EU and the possibility of drawing money from European funds, cross-border cooperation has seen greater development only with the launch of the Austria-Czech Republic Operational Programmes for the years 2007 to 2013, which continued in the period 2014–2020, and in the current Austria-Czech Republic Operational Programme 2021–2027, which was approved by the European Commission in June 2022 with a budget of approximately €86,000. This last fourth period, which lasts until today, is called the integration phase (2004+) (Havlíček 2005).

2.1 The main reasons for cross-border cooperation between Czechia and Austria

If we look at the main reasons for cross-border cooperation in the Central European region, the main ones are listed by Jeřábek, Dokoupil, Havlíček et al. (2004): firstly, overcoming mutual animosity and prejudices between people in border areas, which are considered as a historical heritage, i.e. establishing good neighbourliness. Secondly, reducing peripherality and isolation, promoting economic development and improving living standards. And thirdly, achieving rapid assimilation into an integrated Europe while maintaining the highest possible degree of autonomy.

Isolation and some peripherality are also mentioned by Heintel and Weixlbaumer (2002), who state that the northern belt of Lower Austria is the most economically weak region in the whole of Austria. The main reason for this is simply the distance from major centres of population (centres, core areas); other reasons may be the region's less accessible location and the associated population decline, the loss of economically active people, the lower level of civil society, etc. The same opinion is shared by Jurczek (2006), who adds that border regions have very little endogenous potential compared to the centre of the country, both from a material (e.g. infrastructure) and immaterial point of view (human capital).

How has the Czech-Austrian border area changed in recent years? The once closed borders have become open borders, and the isolated municipalities have become a space of mutual contacts, i.e. a "space of mediation" (Jeřábek et al. 2004). The region, which was long described as "dead", has been given a new chance to develop (Weixlbaumer 2005), and despite today's relatively large economic differences, there has been a certain economic convergence between these two countries. Compared to Austria, however, Czech municipalities have had to cope with a lag of several decades until today, as they were isolated from municipalities in neighbouring countries during the socialist era and their participation or involvement in any cross-border cooperation was practically excluded.

3. Covid-19 and its impact on the Czech-Austrian border region

The Covid-19 pandemic has caused many changes in Europe. One of its main consequences has been the temporary border closure in March 2020, which was introduced as a measure to prevent the uncontrolled spread of the disease and concerned the internal Schengen borders. National borders regained the role of a barrier to protect against a neighbour – implicitly suspected of being infected (Espinoza, Castillo-Chavez, and Perrings 2020). This had a major impact on cross-border cooperation, including the Czech-Austrian border region, among other things, as it dramatically reduced all flows across the border.

The most visible manifestation of the impact on the border is, of course, the temporary closure of the border and/or the introduction of extensive restrictions on the mobility of the population as a means of limiting the spread of the virus. However, border closures usually come too late. Once the virus is detected in a location, the subsequent border closure has a more limited epidemiological effect as well as significant economic and social impacts (Scott and Casaglia 2021). Subsequent waves of Covid-19 have brought back border closures as one of the favoured measures of EU member states. This has caused many difficulties in border regions where many citizens and businesses are fundamentally dependent on the other side of the border. It can be argued that border areas have been more affected by border closures than other territories (Ramírez 2020).

On the other hand, the majority of European citizens accepted the need for temporary border closures to protect public health. Even opinion polls conducted in Czechia during the first pandemic wave in spring 2020 showed that about a third of the Czech population would agree to closing the borders for a longer period of time and 5% would agree to closing the borders even permanently (National Pandemic Alert 2020).

The Covid-19 pandemic has exposed the social and economic vulnerability of nations, countries and societies. These factors are reflected in the patterns of border formation that have emerged with different impacts within societies: age, health, employment, level of job flexibility, housing conditions, etc. (Scott and Casaglia 2021). Another factor or complication is/was the 'dual' nature of the border. Each border regime between two countries resulted from their own entry procedures, which were mostly poorly coordinated with each other, complicating the situation of people who had to cross the border in both directions in their daily journey back and forth for work, education, etc. Moreover, the controls were often inappropriate, based on bureaucratic criteria such as nationality, not, for example, on health status, without taking into account the territorial reality of people's lives (Böhm 2021).

Moreover, during the closure of the borders, significant tendencies of so-called rebordering are evident, not least because most of the measures that were based on social distance were introduced on a strictly national basis, which is in exact contrast to the actions that the European institutions would have wished to see (Brunet-Jailly and Vannet 2020). These limitations made cross-border projects very difficult to implement. The pandemic has shown that national borders, already considered part of the European past, are firmly anchored in the minds of most politicians and citizens (Böhm 2021 in Castan Pinos and Radil 2020).

4. Analysis of structured interviews

In the autumn of 2021 and in the spring of 2022, a survey was conducted in the form of structured interviews with mayors and vice-mayors of Austrian municipalities. A total of 45 municipalities were approached, located within a distance of about 20 km from the Czech-Austrian border in the entire Austrian border area from Bad Leonfelden, located near Vyšší Brod, to Hohenau an der March, which lies in close proximity to the point of the contact of the Czech-Austrian-Slovak borders. By June 2022, 20 interviews had been carried out (Fig. 1), from which several findings emerged, which are presented in the next section of the article. The main questions or points of the interviews are as follows: How would mayors generally describe the cross-border cooperation so far? Is the trend of cross-border activities in recent years (independent of the Covid-19 pandemic) decreasing or increasing? What projects have been implemented in recent years? Are there any

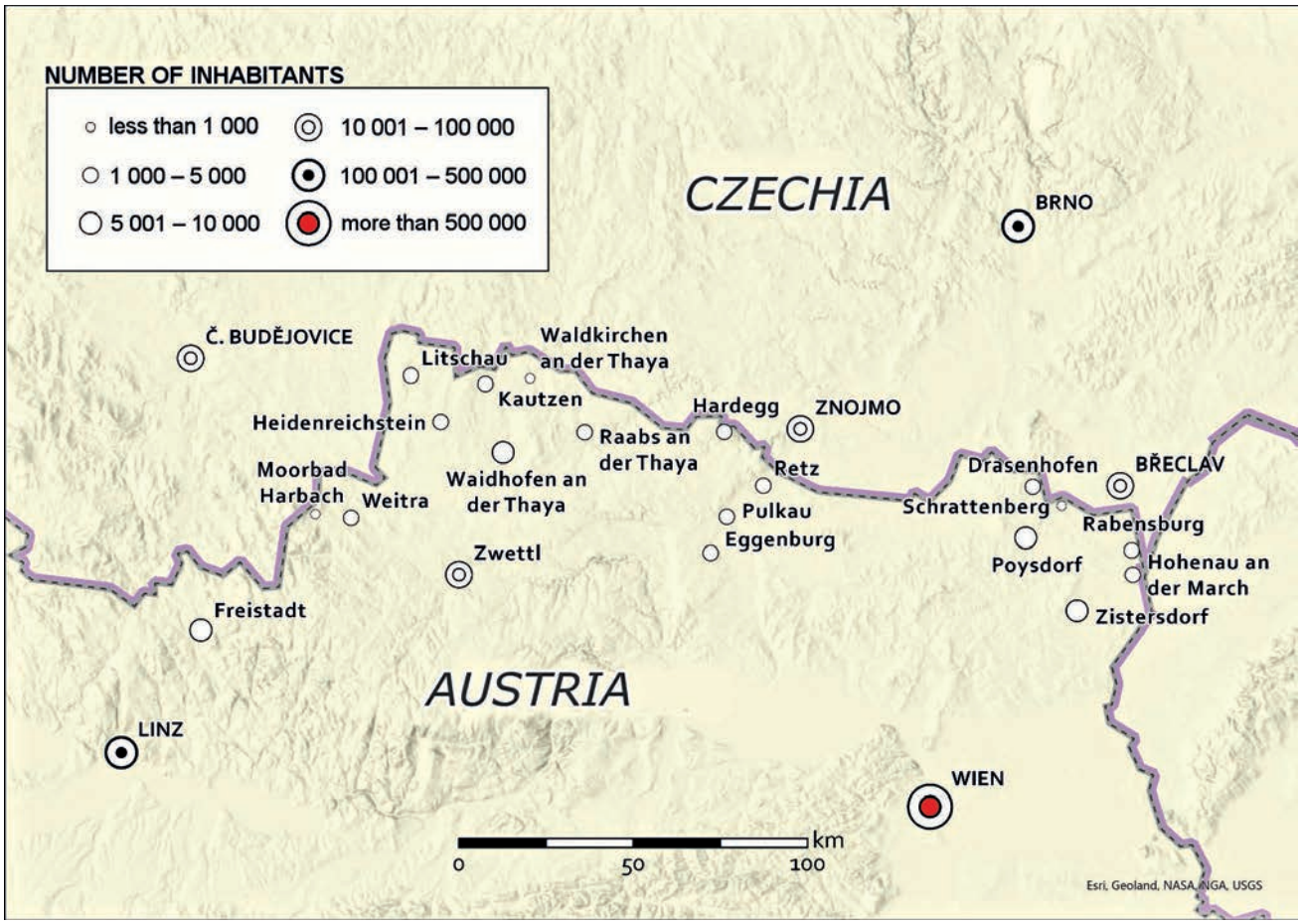

Fig. 1 Municipalities where interviews were conducted.
Source: D. Doležal

cross-border activities taking place in your municipality? What kind and how often? What are the barriers to further development of cross-border activities? And how much has the Covid-19 pandemic and the associated border closure affected cross-border cooperation? It must be emphasised that these are the answers of Austrian mayors.

4.1 Cross-border cooperation in general

As far as the evaluation of cross-border cooperation is concerned, it is generally described as good or very good, but several mayors believe that there is still room for improvement and intensification of cooperation. The administration of The Small Projects Fund (SPF) in Austria has been transferred to the regions, to the so-called Regionalbüros, which has greatly eased the bureaucratic complications of drawing down funds, was often mentioned and positively evaluated (in contrast, in Czechia is The Small Project Fund administered by individual Euroregions). The interviewed mayors are satisfied with this set-up. They praised the work of the Silva Nortica Euroregion, which is said to be very active, initiating various projects and also involved in their implementation. Cooperation within the Podyjí/Thayatal National Parks is also seen positively.

Other comments that were made on this topic are that as long as projects are taking place, whether between municipalities or associations, everything runs smoothly. Primarily it is about co-organising various cultural events and tourism assistance/consultation. However, the potential for cooperation is and has been far from exhausted.

Another view is that the Waldviertel and South Bohemia have very similar natural, cultural, historical assets that could be used even better together. There could also be more joint meetings, as the old border is still present in people's minds. Another mayor expressed the view that the world does not end at borders and that cross-border cooperation could lift the region in all directions.

Several positive references were made to the 2009 Lower Austrian Regional Exhibition held in Telč, Horn and Raabs an der Thaya with the motto: Czech-Austria: divided, separated, united/connected.

Another mayor added that from time to time there are various talks about possibilities and plans for the future, but at this stage the joint activity usually ends. Another mayor added that the cross-border cooperation works well and that it is mostly about invitations to various cultural events in some Czech municipality.

It should be stressed that cross-border cooperation does not only concern municipalities that are close to the national border, but also regions (Waldviertel, Weinviertel, South Bohemia Region, Vysočina Region, South Moravia Region), which often negotiate with each other and solve obstacles of cross-border cooperation.

In response to the next question, which asked whether the trend in cross-border cooperation is increasing or decreasing over the last 5 to 10 years, half of the mayors said that the trend has been upward in recent years. Another third thinks that the level of cross-border cooperation is stable and that it is about the same as before. And about a fifth of the mayors think that the trend is decreasing and that there are fewer joint projects than before, seeing the closure of the border in the context of the Covid-19 pandemic, during which many projects were interrupted or terminated and then not resumed, as one of the causes.

Another fact that was found in the answers to this question is that the size of the municipality or the distance from the state border does not play a very big role here. For example, the mayors of municipalities adjacent to the border with Czechia near border crossings, such as Schrattenberg (800 inhabitants) or Retz (4,200 inhabitants), see the level of cross-border cooperation as rising, the similarly situated municipality of Litschau (2,100 inhabitants) and Kautzen (1,100 inhabitants) describe it as declining and, conversely, in Zwettl (30 km from the border with Czechia, 10,700 inhabitants) there is a clear increase in cross-border activities, while in Mistelbach (33 km from the border, 11,700 inhabitants) the level is very low.

4.2 Examples of cross border projects related to covid-19

The following topics of the interviews are cross-border projects that have been implemented with Czech partners in recent years and the impact of the pandemic on these projects. Some mayors highlighted 2019, when many one-off events were held to mark the 30th anniversary of the opening of the border and the fall of the Iron Curtain. In 2020, the pandemic understandably made cooperation more difficult, few joint events could take place and even planning for others was negatively affected. At first, joint events were postponed indefinitely, then largely cancelled, but in a large number of cases resumed again in 2021. In the next section of the article, examples of projects/events in individual municipalities are given.

Every year since 2009, an event called the Young University of Waldviertel-Vysočina (Jung Universität) has been held in Raabs an der Thaya for around 100 schoolchildren from both states between the ages of 11 and 14 who participate in joint workshops, lectures and other activities. Due to the pandemic, this event was cancelled in 2020 and was postponed to 2021, and held as normal in 2022.

The partner municipality of Raabs in Czechia is Jemnice, whose new leadership was very keen to cooperate with the Austrians, but due to the border closure, the cooperation has been subdued for the time being.

In the village of Kautzen, the so-called Peace Trails (Friedenswege) have been connected in recent years thanks to the help of the SPF. Two are located on Austrian territory, two on Czech territory and two cross the state border. The trails deal with various themes, such as the Jewish element in the region or reconciliation between peoples. The trail between Kautzen and Nové Hrady focuses on the violent loss of the homeland after the World War II. These trails were opened in 2022; the pandemic did not affect their preparation.

In the district of Waidhofen an der Thaya, an association of fifteen municipalities called Future of the Thaya Valley (Zukunftsland Thayatal) has been established, which, in addition to regional development, also seeks cross-border cooperation with municipalities in Czechia. Specifically in the field of tourism and culture, smaller projects have already been implemented, including joint concerts of Thayaland music schools in Třešť or exhibitions of Czech artists in Dobersberg, which are always satisfactorily attended, according to the mayor.

With the help of the SPF, the Barefoot Trail project (Barfußweg) in Schrattenberg was implemented with the main partner Valtice, who have been cooperating for many years. The project has the function of a bridge between Czechia and Austria. The hiking trail also gives visitors a glimpse of the neighbouring country. Before the pandemic, around 15,000 people a year visited this marked route. In 2020, the border crossing on the trail was dammed, and from 2021, the entire length of about 5 km can be walked again.

In addition, a Feast (Kirtag) is held once a year in Schrattenberg. According to the mayor, this is a unique event in Europe, as a brass band from Czechia plays for dancing Austrian guests in Austria, so in his opinion the event cannot be more cross-border any more. Due to Covid-19, the already announced and prepared event was not held in 2020 and was cancelled, but in the following years the tradition was renewed again.

The cross-border cooperation between Moorbach-Harbach and Horní Stropnice is intensive. Every summer, the two municipalities jointly celebrate a Border celebration (Grenzfest), in 2019 named to Peace celebration (Friedensfest). Like other cross-border events, the border celebrations were cancelled in 2020, but they were held again in 2021, as well as in 2022.

For more than fifteen years, the international cultural festival Crossings (Übergänge) has been held every two years between Gmünd and České Velenice, with many guests from outside Czechia and Austria. The 2020 edition had to be postponed until 2021, when it could be held again to the satisfaction of the mayors.

The municipality of Weitra is involved in many activities with Czech partners, such as the Welcome Neighbours (Willkommen Nachbar) event, which organises various trips to Czechia, the Mensch und Fisch exhibition and the cross-border health trails (Grenzüberschreitende Gesundheitswege), co-organised by the municipality of Nové Hrady.

In the smaller municipalities close to the border, the role of the mayor and his relations and contacts on the other side of the border are again emphasised. There is often an exchange of schoolchildren, which is linked to cross-border cooperation between schools. There are also joint sporting (cross-border runs or bike rides) and musical events.

In Freistadt there are annual joint meetings of firefighters, in Hörschlag a meeting of schoolchildren and musical groups from both countries was organised and in Litschau bilingual information leaflets were produced and a cross-border map of cycle paths was created. A trans-regional project was the planning and implementation of one of the longest EuroVelo cycle routes, the Iron Curtain Trail.

On the other hand, the Twinning Days (Tage der Partnerstädte) of Znojmo and Retz, which are normally very active in cross-border activities, could not take place in 2020 and 2021 and were cancelled without compensation, and the mayors' debates could only take place online. The cooperation between the Music school in Retz and the Art school in Znojmo is long-standing, halted by the pandemic and then restored. The two towns also have a joint Facebook account so that they can inform Czechs and Austrians about events, such as Cross-border wanderings (Grenzüberschreitende Wanderung).

The INTERREG supported Portz Insel (Backsteinbrücke) project, which enabled the reconstruction of a 17th-century brick bridge near Mikulov, its connection to the cycle path leading to Drasenhofen and the creation of a nature trail in its surroundings, is worth mentioning. The municipality of Drasenhofen also organises a partnership ball with Mikulov.

The Thayaland/Podyjí National Park is also very active in cross-border cooperation. The park administration signed a declaration of cooperation with 28 other Austrian and Czech municipalities in June 2022 with the aim of nature conservation, tourism development, culture and educational projects. In previous years, the Castle Trail (Burgen- und Schlösserweg) and the Crafts along the River (Das Gewerbe am Fluss) have already been created.

4.3 Cross-border cooperation and its main obstacles

The next question asked about the main obstacles or barriers to cross-border cooperation with Czechia. The language barrier was identified as the main obstacle in almost every interview, which is already a permanent and long-standing problem that was already mentioned during the 2016 and 2017 surveys (Šindelář 2020). For this reason, sometimes an interpreter or translator has to be present at the meeting. Two of the mayors are of the opinion that the language barrier is mainly on the side of the Austrians, as the Czechs have some knowledge of German and

this leads to the fact that more initiatives come from the Czech side or that Czech mayors more often make the first step or look for a partner on the other side of the border.

Another identified obstacle was the amount of bureaucracy and the municipalities' own financial resources needed to pre-finance or co-finance projects. One barrier mentioned was the complicated common history and prejudices that are present among both Austrians and Czechs, but mostly only among older residents.

Furthermore, elections and the change of mayor or municipal council play a role, as cross-border activities are mostly based on personal acquaintances and relationships.

Mayor of Litschau complained about the lack of various funds or grants to help reduce the costs of cross-border activities. He said that there used to be a subsidy call in Austria called We are neighbours (Wir sind Nachbarn), from which one could get a one-off 500 Euro relatively uncomplicated for a cross-border activity of any kind. He adds that people have less and less time and desire to deal with complicated bureaucracy and therefore often any idea dies in the beginning due to lack of motivation or lack of funding or financial risk.

The last finding is that according to most of the mayors, cross-border cooperation is perceived by the local population to be quite low and the initiative usually comes from local people involved, from schools or from various interest groups. However, from their point of view, there is a lack of such actors who would be active and interact with similar actors on the other side of the border in the region.

5. Conclusion

The position of the Czech-Austrian border region has changed dramatically since 1989. From an isolated peripheral area divided by the Iron Curtain, it has become an open place for all kinds of contacts on the former Iron Curtain border without border controls and any restrictions. Nevertheless, the study region is rather at the beginning of this long-term process in terms of cross-border cooperation, and EU financial support has played an important role in bringing the Czech-Austrian border region closer together. The notion of the border as a development opportunity or a space of mediation (Jeřábek, Dokoupil, Havlíček et al. 2004) is illustrated by the increase in cross-border cooperation activities that has taken place in the Czech-Austrian borderland over the last 30 years.

The Covid-19 pandemic has had a major impact on individual states and especially on border regions (Klatt, 2020). The closure of internal borders during the first wave of the Covid-19 pandemic denied the basic narrative of European integration, i.e. freely permeable (internal Schengen) borders. The pandemic caused situations where decisions were made by nation states without coordination with neighbouring states at the European or regional level.

The main aim of this article was to evaluate cross-border cooperation in the Czech-Austrian border region and the impact of the pandemic on cross-border activities.

Twenty interviews with mayors of Austrian municipalities revealed that cross-border cooperation is positively evaluated, but could certainly be intensified. In some cases, mayors see no added value in cross-border projects, although the Small Projects Fund has always been positively evaluated. The person of the mayor and his/her commitment and acquaintances (the situation often changes after an election with a change of mayor) on the other side of the border also play a bigger role than the size of the municipality and its location near the national border.

The majority of mayors observe an increasing trend in cross-border activities, about one fifth of them consider it to be decreasing in recent years. The main obstacle to the development of cross-border cooperation is the language barrier, which was named by almost all mayors interviewed, and the same conclusion was also reached by a survey in the Czech-Austrian border region in 2016 and 2017 among the mayors and local population. For this reason, sometimes an interpreter or translator has to be present at the meeting/talks.

Various cross-border activities take place in the study region, some only sporadically, but many of them are annual. Due to the Covid-19 pandemic, almost all of these activities were first postponed, then cancelled in 2020. A positive finding is that this was a gap of about one year and that it can be observed that from 2021 onwards joint Czech-Austrian events can be organised again as in the years before the pandemic and that many mayors are willing and interested to plan, prepare and organise/co-organise these events.

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The role of social capital in empowering rural community for reducing environmental hazards: the case study of Khodabandeh, Iran

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ABSTRACT
Social capital approaches consider the empowerment of societies against disasters, which enable rural communities to recover from the negative effects of hazards. Social capital is a mediator for collective action and can help people build common property resources. Not only can social capital improve access to natural resources, it can also improve access to physical capital. Using the descriptive and analytical survey, this article analyzes the impact of social capital on managing an earthquake in the villages of Khodabandeh in northwest of Iran. The findings indicate that according to the single sample T test as well as the opinions of local authorities and household heads. The components of attitude and cohesion have the strongest direct effect on reducing vulnerability at the level of households and rural authorities, the component of trust has the strongest indirect effect, and the network component has no indirect effect on either level.

KEYWORDS
social capital; disaster management; village; Khorarood village

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1. Introduction

Looking at the world data testifies to the fact that within the last two decades, natural disasters have occurred more frequently than the past and have brought about devastating effects. According to a report by the International Disaster Database, during the years from 1980 to 1998 and 1999 to 2009, the number of reported disasters has increased from 1,690 to 3,886 (UNISDR 2008) whereas, within the same period, 140 natural disasters have been reported in Iran. However, it can be claimed that occurrence of a natural hazard is not automatically a disaster. But poor location of settlements, establishment of near-fault settlements, lack of warning systems, non-compliance with building codes, poor management systems, lack of public awareness can make natural hazards a disaster (UNISDR 2008). Meanwhile, earthquake is one of the most devastating natural disasters that threaten human settlements. Earthquakes are one of the most powerful natural phenomena that can impose substantial human and economic losses on societies (Kamranzad et al. 2020). The top five countries that have been most frequently affected by damaging earthquakes are China, Indonesia, Iran, Turkey, and Japan, with 16%, 10%, 8%, 4.5%, and 4% of all damaging earthquakes, respectively (OECD 2018; CRED 2020). According to the United Nations report, in 2003, Iran ranked first among the countries of the world for the number of earthquakes more intense than 5/5 Richter and it is one of the highest rated countries for being vulnerable to earthquake and the number of death tolls in this accident. Based on the same report, earthquake is the most prevalent among natural disasters in Iran and its testimony is the high magnitude earthquakes that occasionally shake various regions of this country resulting in irreparable financial and life damages (CRED UNISDR 2018; UN 2015). Iran is characterized by dispersed seismic activities, very large earthquakes with long return periods and large seismic gaps along multiple faults (Hamzezade and Mahood 2009; Kaljee and Chen 2011; Kais and Islam 2016). Besides, according to official reports, 17.6% of devastating earthquakes of the world belongs to Iran. Hence, in the context of the earthquake vulnerability, Iran can be classified as a country with high vulnerability to geophysical hazards, since 32% of the area, 70% of the population and 67% of the gross national product is exposed to the risk of earthquake natural disasters. Sustainable livelihood approach, as one of these paradigms, pays attention to empowering local communities instead of focusing solely on reducing damages with the purpose of creating communities that are able to withstand and recover from the adverse effects of hazardous events.

Over the past decades, the United Nations has also altered its paradigm in disaster management from relief and rescue operations after disaster to risk reduction and preparedness before disaster. One of these efforts is local empowerment and benefiting from the social capital of regions. Societies possessing this capital will provide a proper platform for the formation of a capable, accountable, and efficient civil society. In addition, democratic civil institutions will grow in such an environment. The social capital is so important that in its absence, other capitals will lose their effectiveness since without this capital, other capitals will not be optimally used and in the society that lacks sufficient social capital, other capitals will be wasted (Falk and Kilpatrick 2005; Flora 2001). However, due to the vulnerability of the country, especially in the rural areas, the role of social capital in this regard has not been considered and evidence suggests that in rural development planning, planners and policy makers of rural development do not pay attention to the issue of social capital. The role played by villages, especially in the event of a disaster, in fact, it is obvious that social capital is lacking in the rural development of this country. Regarding to the location of the Khararood village along the Great Soltanieh fault, and the existence of numerous main and secondary faults around this area, the susceptibility of the area to earthquakes, the purpose of the present research is to answer the following questions:

I) Is the existing social capital in the study area sufficient for the management of earthquake disaster?
II) Which dimensions of social capital play an effective role in reducing vulnerability in sample villages both at level of households and rural authorities of the region?

2. Theoretical foundations of the research

2.1 Social capital

Social capital is one of the latest conceptions of social sciences acting as a bridge between sociology, economics, planning and the policy underlying numerous interdisciplinary studies. It is the effective functioning of social groups through interpersonal relationships.

Over the past two decades, the concept of social capital has been accepted as a highly popular term used in a number of social sciences and definitions of social capital have been provided by various fields of study in different ways (Xue 2008). In other words, Considering the great importance of social capital and its impact on economic development, the existence of social capital, especially cohesion, participation and social trust, has an impact on the economic indicators of rural areas (Sonboli et al. 2021; Shayan et al. 2017). Sociologists and political scientists also define social capital as, a network of social relationships created by norms and mutual trust (Xue 2008; Woodhouse 2006). Unlike other capital, social capital does not exist physically, but it results from group and social interactions and norms, and on the other hand, its increase can lead to a serious drop in the level of the

expenses of public administration as well as the operating costs of the organizations (World Bank 1999). Patnam defines social capital as trust, norms, and communication networks, which facilitate the cooperation of actors to achieve mutual benefit.

In discussions of social capital, such issues as local participation and cooperation among individuals and groups, local trust, network development, and the extent to which institutional decision-making in local communities is important, can increase the ability of local communities to manage disasters and reduce the adverse effects of natural disasters (Roth 2022; Payanifar et al. 2022).

Thus, social capital appears as a common sense and civil responsibility and transforms society into something more than a set of individuals, which in this case it can be regarded as complementary to natural and human capital in the process of rural development and in enabling rural communities to manage and respond to the economic, social and environmental challenges, especially in relation to natural disasters as an effort to ensure sustainable development (Chou 2006).

2.2 Disaster management

Disaster management is a term used to control and reduce financial and health risks such as not construction of housing in high risk areas, taking preventive measures like consulting local engineers and building resilient housing, using durable materials, monitoring, insurance (Sutanta et al. 2010). The operational purpose of disaster management is the preparation and implementation of a comprehensive plan that can increase the ability of human settlements to reduce the impacts of disasters and deal with them without external assistance. The main purpose of disaster management is to save lives, reduce the number of injuries and decrease damage to property and assets of communities. In order to realize these goals, it is necessary to identify, within the framework of a program, the potential risks and methods of prevention and develop executive plans to reduce them. In some countries same as, Japan, Russia, Canada, and Australia have adopted a management approach for disaster management that includes prevention, preparedness, response and improvement based on a community-based approach (participation-oriented, people-oriented, attention to the situation of communities and risk assessment, attention to general progress, increasing community capacity to respond to events, people's participation in all stages of decision making for disaster management and emphasis on social capital, capacities, abilities and existing knowledge of local communities). Therefore, disaster management includes programs to decrease impacts and increase preparedness against disasters in order to reduce the vulnerability of rural communities. Disaster management can be considered an appropriate method of management when areas are identified and classified according to the degree of vulnerability so that authorities can prioritize resources adequately and effectively and reduce the effects of disasters (Sharafi and Zarafshani 2011). In case the disasters occur, they try to reduce the effects, provide the required preparation, provide immediate relief and improve the situation until returning to the normal state and reconstruction (Aysan 2003).

2.3 Research methodology

The present research is applied type with a descriptive-analytical method. To collect data and information, two methods including librarian and fieldwork (completion of questionnaires) have been employed.

The statistical population of the study consists of 30 villages in Khararood rural district of which 14 villages have been selected using Cochran sampling and considering geographic zoning.

According to the census of 2011, these villages have a total of 6,090 households and 22,412 inhabitants of whom 150 households have been randomly selected as samples based on the modified Cochran formula. In order to achieve the desired results, a questionnaire for examining and assessing earthquake disaster management in rural areas has been prepared.

It consists of five components (trust, cooperation and participation, attitude, social networking and cohesion) and emphasizes on social capital from the perspective of the household heads and local authorities. For data analysis, descriptive statistics (mean and standard deviation) and inferential statistics (single sample t-test, Friedman test and analysis of variance) have been used. The one-sample t-test is a very simple statistical test. It is used when we have a sample of numeric variable, and we want to compare its population mean to a particular value. The one-sample t-test evaluates whether the population mean is likely to be different from this value.

The Friedman test test is similar to a oneway repeated measures ANOVA, however, the null hypothesis states that the K repeated measures or matched groups come from the same population or from populations with the same median (Siegel and Castellan 1988), the data on the dependent variable is measured on an ordinal scale. The test assumes the study involves one independent variable, and that the same participants are repeatedly observed under three or more conditions. Also, the present test bears some resemblance to the Wilcoxon matched pairs signed rank test.

The components and indicators related to social capital are:

1) Component of trust: includes such indicators as the acceptance of the opinions of local architects and experts, trust in other villagers in the event of a crisis, in the dehyar for the pursuit of affairs, among the people, and in the functions of the Islamic

Council of the village, the temporary welcoming of family members or neighbors in case of destruction or damage to housing, the acceptance of the views of local architects, of the role of guidance, leadership and supervision of the Islamic Council and the dehyari, of the members of the Council and the dehyar as reliable local managers, the adoption of housing plans provided by local authorities, of the use of force and coercion for the supervision of construction, attention to the housing reinforcement regulations, and to the principles of Hadi projects.

2) Component of participation: includes indicators of cooperation with all rural inhabitants, with voluntary groups in providing first aid, with other villagers in deportation, search, transfer and treatment of the injured, participation in the reconstruction of public infrastructure of the village, cooperation with local institutions in rural affairs, consultation with local architects and engineers in building resilient housing, the tendency for temporary residence in camps provided by local institutions during the earthquake, cooperation with local architects and civil engineers in choosing the method of construction, collaboration for relief and rescue in case of accidents.
3) Component of attitude: includes indicators of belief in cooperation in rural affairs, the role of group collaboration in changing common values over time and improving the relations between neighbors and villagers, the level of villagers' awareness about the construction of resistant buildings, access to the technical knowledge of villagers, the level of awareness about rural vulnerability, the effectiveness of participation in training workshops, the usefulness of participating in the trainings provided by the cooperation of governmental and local organizations, the extent of obeying building codes, engineering regulations, benefiting from the local architects and trained workforce in construction.
4) Component of network: includes indicators of participation in training courses for coping with earthquake-induced injuries, attention to information and personal experience, to the use of experience of damaged villages, the role of relief and rescue training in reducing injuries, of the Islamic Council in increasing cooperation, of dehyari in establishing the relationship between the neighboring villages, of the Council and the village in establishing relationship between villagers and related institutions, of existing services in the village, the ability of local rural institutions to provide services, the role of the council and the executive in facilitating laws and financial services, the ability of the Islamic Council and dehyari in making a link among the village, other villages and city, availability and access of local institutions to appropriate equipment and financial resources.
5) Component of social cohesion: includes indicators of participation in meetings and public hearings in the village, attention to social tasks of the villagers, discrimination in the supervision of local engineers and representatives, in referring someone to receive credit, in the council's and dehyar's decision-making based on interests, the role of group collaboration in reducing vulnerability and better recovery power, willingness to consult with local architects and expert, willingness to participate in plenary sessions and workshops about enhancements in the village, group decision-making, attention to common and public interests in local management discussion, the existence of common economic and financial incentives among villagers to increase cooperation.

Khararood village is located in the eastern parts of Khodabandeh district, near the Avaj district of Qazvin province. Topographically a large part of the region is the continuation of rough edges of western Kharqan (located in Qazvin province). Most of the rural settlements of the region are located in the Qeidar-Noorabad Miankoohi plain, the northern skirts of Kharqan Mountains and the margin of Khararood River. In zoning the relative risk of earthquakes in Iran, this region is identified to be a part of the Southern Alborz area.

3. Results

The descriptive findings of this research indicate that based on the percentage of age, from the total sample size for the household heads 14.6% are (20–30 years), 62.1% (31–40), 16% (41–50) and 7.3% (51 years and above). The age group of 31–40 with 62.1% and the age group of 51 and older with 7.3% constitute the highest and the lowest number of respondents, respectively. From the total sample of authorities, the age group of 31–40 with 51.5% and the age group of 51 years and older with 3% make up the highest and the lowest number of respondents. Moreover, among the households, 89.3% of respondents were male and 10.7% were female while among the authorities, 96.96% were male and 3.04% were female. Regarding the view of household heads and based on single sample t test, the analysis of numerical mean of the components of social capital of the villages under study indicates the high percentage of these components for earthquake disaster management in the studied villages. Calculating the range of spectrum of existing social capital components which fluctuate from 1 to 5 based on the Likert spectrum, this rate is evaluated to be more than numerical desirability (3) for all dimensions, trust with 3.37% has the highest and network with 3.03% has the lowest mean. Also, the difference of all components of social capital from the numerical desirability 3 has been positively evaluated.

Tab. 1 The significance of social capital components of household heads and rural authorities based on difference from the optimum and the t-test.

Components	Numerical Desirability Test 3									
	Household Heads					Rural authorities				
	Mean	T-test statistics	Degree of freedom	Significance	Difference from the optimum	Mean	T-test statistics	Degree of freedom	Significance	Difference from the optimum
Trust	3.37	7.35	149	0.00	0.37	3.38	4.05	32	0.00	0.38
Participation	3.31	6.60	149	0.00	0.31	3.37	3.95	32	0.00	0.37
Attitude	3.21	4.37	149	0.00	0.21	3.37	3.37	32	0.00	0.37
Network	3.03	1.03	149	0.302	0.03	3.40	3.40	32	0.00	0.40
Cohesion	3.33	7.30	149	0.00	0.33	3.48	4.11	32	0.00	0.48

Source: Research findings

According to Friedman test (Tab. 2), there is a significant difference between the mean social capital components of household heads and rural authorities at alpha 0.01 level; among household heads, the highest average is devoted to cohesion and the lowest to network and among the authorities the highest is dedicated to trust while the lowest is for participation.

Regarding the role of social capital in decreasing vulnerability, in other words, managing earthquake disaster, after theoretical examination and defining vulnerability indicators, firstly, the vulnerability of each village was ranked according to the Topsis model, and then it was used as a dependent variable in illustrating the path analysis model. Therefore, fit regression model of factors affecting disaster management among household heads has 0.643 positive effect and among rural authorities 0.623 on earthquake disaster management (Tab. 3).

According to Tab. 4, using the fit regression model, the factors and indicators affecting disaster management in the study area were determined from the viewpoint of the household heads and the authorities of the sample villages. The results indicate that the relationship between disaster management and social capital components is quite significant.

As illustrated in Tab. 5, looking at the ß values, it is obvious that a unit of variation in the standard deviation of social capital components (trust, participation, attitude, network and cohesion) will cause

Tab. 2 Comparing the mean rank of social capital components of household heads and rural authorities based on Friedman test.

Components	Household Heads		Rural authorities	
	Number	Friedman average	Number	Friedman average
Trust	150	3.27	33	3.17
Participation	150	3.23	33	2.76
Network	150	2.35	33	2.98
Attitude	150	2.85	33	2.94
Cohesion	150	3.31	33	3.15
K^2	50.922		1.511	
Degree of freedom	4		4	
Significance level	0.000		0.825	

Source: Research findings

Tab. 3 Factors affecting disaster management among household heads and rural authorities using fit regression model.

Household Heads				Rural authorities			
Criterion error	The adjusted coefficient of determination	The coefficient of determination	Multiple correlation coefficient	Criterion error	The adjusted coefficient of determination	The coefficient of determination	Multiple correlation coefficient
0.741	0.631	0.643	0.802	0.789	0.623	0.553	0.778

Source: Research findings

Tab. 4 The factors and indicators affecting disaster management of the area from the viewpoint of the household heads and authorities based on the fit regression model.

Components	Household heads					Rural authorities				
	Sum of squares	Degree of freedom	Square mean	F test statistic	Significance level	Sum of squares	Degree of freedom	Square mean	F test statistic	Significance level
Regression effect	1.426	5	0.285	51.91	0.000	0.270	5	0.054	8.915	0/000
Remaining	0.791	144	0.005			0.164	27	0.006		
Total	2.217	149				0.434	32			

Source: Research findings

Tab. 5 Social capital and the impact of earthquake disaster vulnerability based on the ß values.

Variable name	Household heads					Rural Authorities				
	Non-standard coefficients		Standard coefficients	T	Significance level B	Non-standard coefficients		Standard coefficients	T	Significance level B
	B	B error	B error			B	B error	B error		
y-intercept	1.366	0.54	–	25.509	0.000	1.282	0.107	–	11.968	0.000
Trust	−0.061	0.012	−0.306	−5.201	0.000	−0.045	0.037	−0.209	−1.203	0.240
Participation	−0.030	0.013	−0.144	−2.338	0.021	−0.017	0.043	−0.077	−0.384	0.704
Network	0.026	0.016	−0.091	−1.641	0.103	−0.062	0.032	−0.309	−1.954	0.061
Attitude	−0.068	0.012	−0.335	−5.539	0.000	−0.009	0.035	−0.040	−0.264	0.794
Cohesion	−0.051	0.013	−0.234	−3.980	0.000	−0.060	0.026	−0.348	−2.340	0.027

Source: Research findings

−0.306, −0.144, −0.335, −0.091 and −0.234 Units of variation among households and −0.209, −0.077, −0.309, −0.040 and −0.348 Units of variation among rural authorities in reducing the impact of earthquake disaster vulnerability in the villages of the study area.

The research path analysis model (local authorities) with regard to the relationship between variables can express the direct and indirect effects of independent variables on the dependent variable through correlation coefficient Based on the results of Tab. 6 regarding the total effects, trust with −0.623 at the level of household heads and −0.407 at the level of rural authorities has the highest impact and network with −0.091 at the level of the household heads and −0.040 at the level of the authorities has the least effect. Concerning the direct effect of social capital on reducing vulnerability, the components of attitude in the household heads and cohesion in rural authorities have the highest direct effect. Regarding the indirect effects, the trust component has the highest effect in both households and authorities. Moreover, network component has no indirect impact on reducing vulnerability neither at households nor rural authorities.

4. Conclusion

Empowerment is a key concept in social development and it is considered as an important strategy for regional and rural development. One of the most important challenges of rural development is not paying sufficient attention to the social capital of residents of these areas for disaster management. The purpose of this study was to investigate the role of empowerment of villagers in dealing for reducing environmental Hazards for reducing environmental hazards in

Tab. 6 Total direct and indirect impacts of social capital components at households and rural authorities.

Variable	Household Heads			Rural Authorities		
	Direct effects	Indirect effects	total	Direct effects	Indirect effects	total
Trust	−0.306	−0.317	−0.623	−0.209	−0.198	−0.407
Participation	−0.144	−0.099	−0.243	−0.077	−0.164	−0.241
Attitude	−0.335	−0.088	−0.423	−0.309	−0.039	−0.348
Network	−0.091	0	−0.091	−0.040	0	−0.040
Cohesion	−0.234	−0.014	−0.248	−0.348	−0. 003	−0.351

Source: Research findings

rural areas of Khararood village in in Khodabandeh city, in Northwest of Iran. While attention to social capital can play a key role in improving the planning process for rural development for relevant specialists and facilitating the participation of villagers in better implementation of the program.

Moreover, it can be of great importance in disaster management through interacting with other aspects of capitals leading to building trust, mutual relations, exchange of experiences and collective cooperation. In social capital discussions, issues such as local participation and cooperation between individuals and groups, local trust, network development, and the extent to which institutional decision-making in local communities is accepted, can increase the ability of local communities to manage natural disasters.

The local community structure with decentralized decision-making through social networks using normative behavior along with trust and mutual cooperation reduces the effects of accidents. Social capital as an important asset will increase the ability of individuals, groups and associations to confront and cope with crises caused by disasters. Therefore, contrary to the past, which focused more on reducing physical vulnerability, in recent years, social capacity has been strengthened by planners to reduce human losses. In other words, taking into account the restricted capacity of governmental and non-governmental organizations at the local level to provide assistance to all people, neighbors and locals are the first who help the victims, so some measures should be taken towards strengthening social capital in rural areas.

The findings of the present research indicate that the numerical mean of the value of social capital components of the villages surveyed from the viewpoint of the heads of households and the authorities of the villages based on the single sample T-test demonstrate the high percentage of social capital components for the management of earthquake disaster in the studied villages. Calculating the range of spectrum, the existing social capital components are evaluated to be more than numerical desirability (3) for all dimensions and trust with 3.37% has the highest and network with 3.03% has the lowest mean among the households while cohesion with 3.48% has the highest and network and participation with 3.37% the lowest mean among the authorities. Also, the difference of all components of social capital from the numerical desirability 3 has been positively evaluated. According to Friedman test, there is a significant difference between the mean social capital components of household heads and rural authorities at alpha 0.01 level. The results of path analysis indicate that regarding the total effects, trust with −0.623 at the level of household heads and −0.407 at the level of rural authorities has the highest impact and network with −0.091 at the level of the household heads and −0.040 at the level of the authorities has the least effect. Concerning the direct effect of social capital on reducing vulnerability, the components of attitude in the household heads and cohesion in rural authorities have the highest direct effect. Regarding the indirect effects, the trust component has the highest effect in both households and authorities. Moreover, network component has no indirect impact on reducing vulnerability neither at households nor rural authorities.

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Factors in the differentiation of regional mortality in developed countries

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ABSTRACT
The aim of this article is to discuss factors that influence the distribution and differences in mortality between both regions and subpopulations in developed countries. The article provides an outline of basic theories that attempt to explain socioeconomic differences in mortality. A range of socioeconomic factors is analysed from both the micro-level and macro-level perspectives. Based on the study of the relevant literature, it was determined that more privileged groups enjoy better health and longer lives. A strong association between socioeconomic factors and total mortality and mortality by the cause of death was revealed at both the individual and aggregated levels. The relationship between socioeconomic variables and health status and mortality is explained via various mechanisms through which this association arises. Socioeconomic variables that act to influence health status and mortality have been shown to be strongly interrelated. These factors, in turn, impact the lifestyle and psychological state of individuals. Existing socioeconomic health and mortality determinants represent one of the main problems and challenges for the public health sectors in both more and less developed countries.

KEYWORDS
mortality; regional differentiation; economic factors; social factors; cultural factors

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1. Introduction

Significant changes occur in terms of the intensity and structure of mortality in developed countries as a result of political, economic, social and cultural changes, which leads to the question of how regional differences in mortality (or, in general, differences in mortality between subpopulations) are influenced by external economic, social, political or cultural factors. The basic premise of this approach concerns the consideration that differences in mortality between different subpopulations rather than being biologically determined are due to external factors.

The relationship between mortality, health status and external factors has been studied with respect to a number of populations and, in general, it can be stated that higher socioeconomic status (most often higher education and income levels) correlates with better health and a longevity (e.g. House 2002; Mackenbach et al. 2008; Smith et al. 1998b). These inequalities represent one of the main problems for the public health sector. Indeed, the World Health Organisation considers health equality to be a basic human right (WHO 2020: 1):

> The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition.

Issues surrounding the socioeconomic determinants of health and mortality have also been addressed in various European Commission-initiated programmes (European Commission 2023), the aim of these programmes is to ensure the continuity of the relevant policies and the development of specific strategies aimed at positively influencing people's health. However, according to Marmot (2005), European countries address the various external health status and mortality factors only indirectly (sickness benefits, labour market policies, etc.). Moreover, it is the extent of the difference between the death rates of the most and least privileged groups in the population that offers potential sources of improvement concerning a nation's health status and life expectancy. However, differences in terms of mortality and health status cannot be explained only by the composition of the population and the various characteristics of its members, but also by the environment in which these individuals live.

The aim of this article, therefore, is to discuss the factors that influence the distribution of, and differences in, mortality between both regions and subpopulations in various developed countries.

The first part of the article focuses on the development of approaches to the study of the socioeconomic differentiation of mortality followed by a description of the basic theories that attempt to explain such differences. A range of socioeconomic factors are analysed from the micro-level (i.e. at the individual level) and the macro-level (i.e. aggregated individual variables or variables that do not have an individual equivalent) perspectives. The final chapter addresses the ecological fallacy and other potential issues connected to regional mortality factor studies. Although behavioural factors exert a significant influence on socioeconomic differences in mortality, determining an explanation of the mechanism by which these factors affect human health does not form the subject of this article.

2. The development of approaches to the study of the socioeconomic differentiation of mortality

Interest in the issue of differences in terms of the health and mortality of the population according to socioeconomic status has a long tradition. Even before the beginning of the 20th century, it was known that people from lower social class in society have a higher degree of intensity of mortality from most diseases (Bengtsson and Poppel 2011). The industrial revolution comprised the first stimulus for the investigation of the material aspects of living conditions and their impact on mortality. Social status was founded on income, position in the household and occupation indicators (Bengtsson and Poppel 2011). According to Hummer et al. (1998), the approach to the investigation of the differentiation of mortality in the second half of the 19th century and the first half of the 20th century was strictly demographic. The main objective of these studies was to document as accurately as possible the differences in the level of mortality within and between subpopulations, usually according to age, gender and race (or ethnicity). A smaller number of studies also included factors such as income, occupation and marital status. After World War II, life expectancy increased in many countries, and many scientists believed that social disparities in terms of mortality would converge (Bengtsson and Poppel 2011). However, global economic problems at the beginning of the 1970s severely diminished such optimism, and socioeconomic determinants of mortality once more became the subject of studies by demographers and epidemiologists. The key work in this respect comprised a study by Kitagawa and Hauser (1973), which examined the relationship between mortality, income and education in a sample of the US population. The approach to the study of mortality differentiation became significantly more comprehensive and was subsequently termed broader sociodemographic by Hummer et al. (1998). Mortality was no longer understood as a static phenomenon but, rather, as a long-term process influenced by many factors that exert positive or negative effects on the risk of death. Differences in mortality

are formed over the long term based on the entire life cycle of individuals and the development of society as a whole (Bengtsson and Poppel 2011). At the end of the 20th century, a transition to the individual longitudinal analysis approach occurred, which allowed for the deeper understanding of the formation of socioeconomic differences in mortality. Sociodemographic factors concerning mortality became understood as a reflection of so-called immediate determinants – i.e. behavioural, psychosocial, health and biological factors (Hummer et al. 1998; Dow and Rehkopf 2010).

3. The theory explaining socioeconomic differences in mortality

Throughout the development of the consideration of the relationship between socioeconomic factors and health alternatively mortality, the debate continued on the direction of the gradient between socioeconomic status and health (Smith 1999). The social causality hypothesis views higher morbidity rates as a consequence of poorer socioeconomic conditions (e.g. House 2002; Preston and Taubman 1994: 295–304). The simplest explanation for this causality is that healthcare is more easily available for people with higher socioeconomic status; moreover, higher socioeconomic status is associated with a more responsible approach to one's own health. For example, Cutler and Meara (2001) argue that more educated (and thus wealthier) people smoke less because they are well aware of the risks involved. Education has a stronger correlation to lower levels of smoking than does income. The opposing hypothesis assumes so-called selection, i.e. that poorer health is caused by lower socioeconomic status. A traditional example concerns the relationship between poor health and lower employment, as demonstrated by Bartley and Owen (1996) using the example of the United Kingdom. The selection hypothesis also considers the influence of socioeconomic conditions in childhood. Children from low-income households have a poorer health status, which subsequently impacts their income in adulthood (Case et al. 2002).

The relationship between socioeconomic variables and health status and mortality is explained by the various mechanisms via which this association arises. Skalická et al. (2009) divided health inequality theories into 5 closely related groups: the materialist, behavioural, psychosocial, biomedical and life course theories.

3.1 Materialist theories

Materialist theories view the main cause of socioeconomic differentiation in mortality as income and what that income allows. Higher incomes do not only mean that goods and services are more affordable, but they also offer the potential to avoid exposure to risk factors (polluted environment, inadequate housing, risky professions, etc.). At the macro level, materialist theories focus on the relationship between the public services available and the health of the population (Skalická et al. 2009).

Perhaps the most systematic model based on economics was described by Preston and Taubman (1994: 295–304). The model is based on the supposition that individuals make choices that help them to influence their health status. Death occurs when this state of health declines below a certain critical level. Although individuals are unable to directly decide the time of death, they can make decisions on investments (e.g. a healthy diet) and consumption (e.g. tobacco) that affect their health status. The authors also included education and occupation in the model. In general, those with higher education levels enjoy higher levels of income and are, therefore, able to invest more in their health (i.e. purchase healthier food, enjoy more free time and live in areas with better public services). Moreover, a person's occupation often influences their consumer goods taste preferences.

The neo-materialist theory is one of the other possible interpretations of health inequalities. This theory combines a lack of resources and exposure to risk factors with the unequal distribution of investments in a wide range of public and social infrastructure components. Unequal distribution is the result of historical, cultural and political-economic processes that both influenced the private resources of individuals and shaped the character of the public infrastructure, e.g. education, healthcare and transport services, environmental protection measures, the availability of high quality food, occupational health regulations, etc. (Lynch et al. 2000).

3.2 Behavioural theories

According to behavioural theories, socioeconomic differentiation concerning health and mortality is the result of the unequal distribution of unfavourable behaviour and lifestyles between socioeconomic groups. The influence of behavioural factors can only be examined in detail via the longitudinal analysis approach since such factors exhibit a long latent period before they begin to influence the onset of degenerative diseases and mortality; moreover, they may well change over time (Hummer et al. 1998).

The main principle behind so-called cultural-behavioural theories comprises the hypothesis that differences in lifestyle and unhealthy behaviour are the result of socioeconomic disadvantages and the higher degree of cultural acceptability of unfavourable behaviour by lower socioeconomic groups (Skalická et al. 2009). In addition, the social networks of persons with a higher status are characterised by the lower risk of exposure to passive smoking, enhanced support for behaviour that is associated with a healthy

lifestyle and better opportunities to be informed of the results of the latest health-related research. This is also one of the reasons for the persistence of socioeconomic inequalities despite ever-improving medical knowledge and opportunities, which are first taken advantage of by persons with higher socioeconomic status (Link and Phelan 1995).

3.3 Psychosocial theories

Psychosocial theories are based on the assumption that socioeconomic status affects the psyche of individuals, which subsequently exerts biological effects on the human organism. The socioeconomic gradient of morbidity and mortality can, thus, be explained by the uneven distribution of psychosocial risk factors, which may comprise the levels of social support and self-control and work-related demands, as well as susceptibility to hostility, anger and depression (Schneiderman 2004; Skalická et al. 2009). Preston and Taubman (2004: 295–304) consider the ability to avoid stressful situations to be one possible explanation for health-related socioeconomic differentiation. They opine that persons with a low level of education and/or low income are less able to avoid stressful and deprivation situations. Moreover, they emphasise the importance of multi-layered social relationships in terms of coping with psychologically-demanding situations. Furthermore, some studies (e.g. Tillmann et al. 2017) suggest that psychosocial factors are independent of each other, unlike many socioeconomic factors.

3.4 Biomedical theories

It is clear that biological mechanisms are involved in the association between socioeconomic status and mortality. The basic idea of the biomedical interpretation of socioeconomic inequalities in health and mortality concerns the unequal occurrence of biological risk factors between social groups (Skalická et al. 2009). According to House (2002), the biomedical paradigm gained popularity up until the 1960s and, currently, persists only in terms of the explanation of certain mortality risk factors, e.g. blood pressure, cholesterol and the functioning of the lungs. However, since one of the topics covered by biomedical theories comprises the relationship between genes and the environment, an approach that explains the socioeconomic differentiation of mortality as the unequal distribution of exposure to environmental risk factors in society could also be considered to be a biomedical factor.

Individuals with a lower socioeconomic status are more likely to be exposed to substances that exert adverse impacts on the human organism both at work and at home. Steenland et al. (2003) selected a range of harmful substances (dust, gases, fumes, smoke, arsenic, asbestos, cadmium, silicates, radiation, etc.) that are often detected in the work environments of manual workers, described their influence on various diseases and empirically proved their connection with the higher intensity of mortality experienced by lower social classes. Moreover, such persons are often also exposed to many of these substances in their place of residence.

Biomedical theories might also include theories that explain the difference in terms of mortality between races. At the turn of the 20th century, it was assumed that all the observed racial disparities relating to mortality were due to genetic differences between races (Williams et al. 2010). However, many studies (conducted mainly in the USA) have since proven that the main reason for such differences concerns primarily the persistent high degree of differentiation of socioeconomic status between races (e.g. Keil et al. 1992; Potter 1991).

3.5 Life course theory

The explanation of the socioeconomic gradient concerning health and mortality as a result of the accumulation of social, psychological and biological disadvantages during the lifespan is referred to as the life course theory (Skalická et al. 2009). This approach combines all the above theories, as well as social causality and selection. According to Osler et al. (2009), causal and selection mechanisms are interconnected throughout the life course and may apply in childhood as well as in adulthood.

Socioeconomic disparities relating to health apply at all ages. Children are influenced by the socioeconomic position of their parents as soon as they are born. Children born to women from lower social classes are more likely to be born with lower birth weights and birth defects as a result of the greater exposure of the foetus to risk factors such as smoking, physical inactivity and poor maternal diet (Osler et al. 2003).

The question remains, therefore, whether and how socioeconomic conditions and health in childhood influence a person's social position, health status and mortality in adulthood. Although many studies (e.g. Frankel et al. 1998; Pensola and Martikainen 2004; Smith et al. 1998a) have demonstrated the association between childhood socioeconomic status and adult mortality, this association is likely to be largely the result of the transfer of a person's social position from childhood to adulthood.

4. Socioeconomic factors that influence mortality

In terms of research into the differentiation of health status and mortality, the measurement of socioeconomic status is performed at both the individual and aggregate levels, the choice of which depends largely

on the sources and quality of the data available on the relevant socioeconomic variables. An individual's socioeconomic status can be understood as the internal characteristics and abilities of the individual. These micro-level factors are influenced by external processes that operate at the macro level. Both levels are equally important in terms of the study of regional mortality differentiation. Individual socioeconomic factors may be distributed differently between regions, and regional differences in mortality are determined, *inter alia*, by the composition of the population (Kibele et al. 2008). The individual socioeconomic variables that impact health status and mortality are strongly interconnected. The level of education attained logically affects one's future profession, income and economic activity. Together with family status, these factors affect the lifestyle (smoking, alcohol consumption, diet, BMI, etc.) and the psychological state of the individual (Fig. 1). For example, mortality rates for men over the age of 80 in Austria show a strong socioeconomic gradient. This gradient is already established during life, as it is linked first to education and then to income and social status in adulthood (Klotz et al. 2019).

4.1 Education

Education is considered to be a major socioeconomic factor in terms of the differentiation of health and mortality. A higher level of education is associated with the potential to attain a higher income and to be employed in a healthy environment, as well as enhanced accessibility to information and cognitive skills. According to van Oort et al. (2005), inequalities in mortality according to education are the result of both material and psychosocial factors that affect mortality through behavioural factors. The study of a sample of the Norwegian population (Skalická et al., 2009) suggested that psychosocial and behavioural factors are more important than material factors in terms of explaining differences in mortality according to education. However, the latter are of fundamental importance with respect to explaining income inequalities and mortality. Smoking comprises one of the key behavioural factors that are strongly associated with education. A higher prevalence of smoking among those with lower education levels was demonstrated by Smith et al. (1998a) and Winkleby et al. (1992). However, this association does not apply

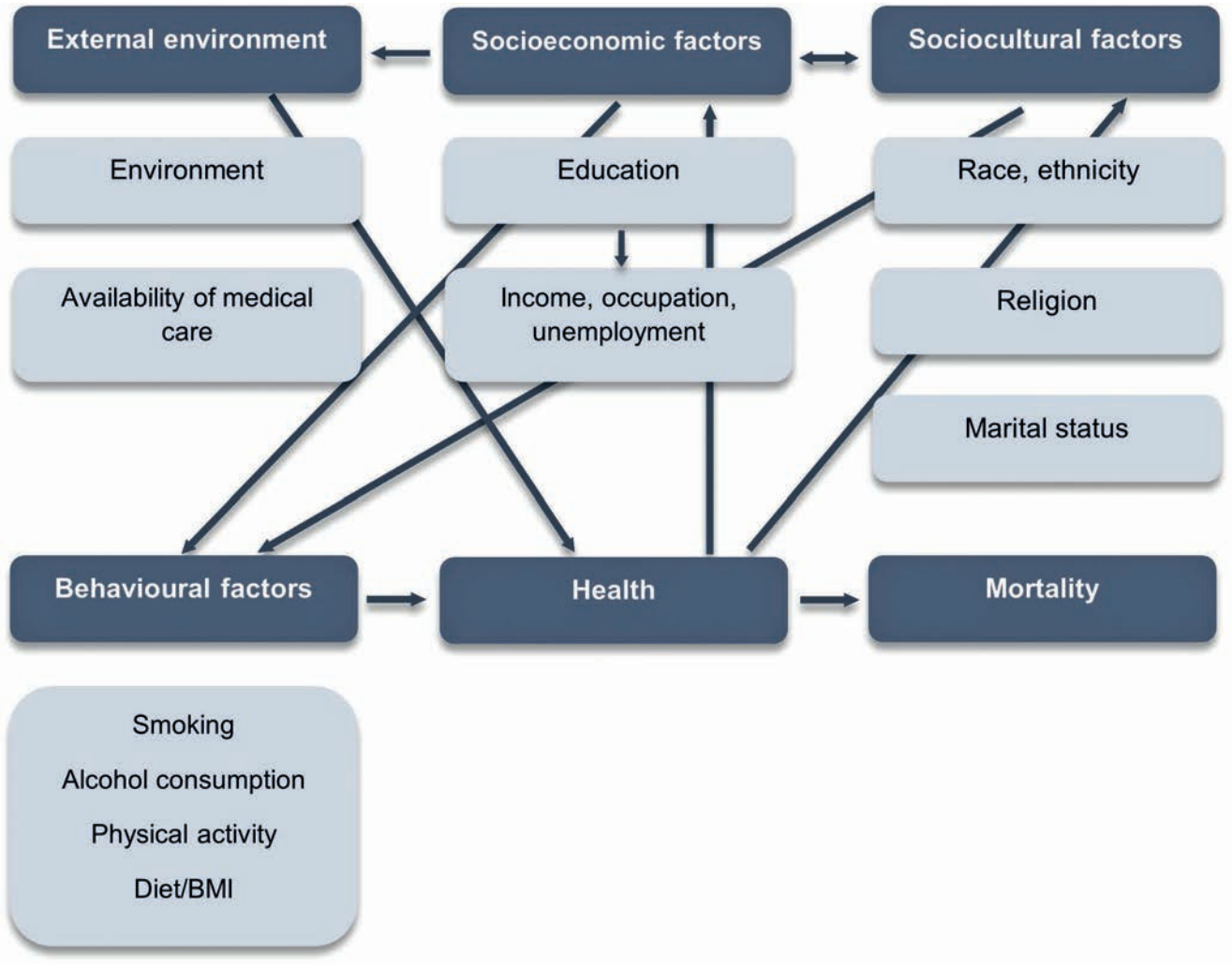

Fig. 1 Schematic representation of possible relationships between mortality factors.

universally. Mackenbach et al. (2008) observed a higher prevalence of smoking for groups of persons with higher education levels in southern European countries, whereas concerning other European regions, a higher proportion of smokers was associated with groups with lower education levels. The importance of behavioural factors was also confirmed by Mackenbach et al. (2015), who reported that differences in mortality by education are particularly evident in amenable mortality. At the same time, their study also found this trend is more significant in Central and Eastern Europe compared to other European countries.

The level of education also exerts an impact on the take-up of preventive medical care and, thus, on the early recognition of the onset of diseases. More highly educated persons are more likely to undergo regular medical examinations (Sabates and Feinstein 2006). The association of education and access to healthcare is mediated by the higher levels of health awareness, responsibility, motivation, patience, communication access, social inclusion and self-esteem of more highly educated groups.

The individual-level differentiation of mortality by education has been documented in a large number of longitudinal studies. A US study (Rogot et al. 1992) revealed substantial differences in life expectancy at the age 25 between persons with the highest and lowest levels of education, whereas concerning a population of Finnish men (Pensola and Martikainen 2004), the risk of death decreased considerably from the lowest to the highest education levels with concern to all the observed causes of mortality. According to the results of a study by Mackenbach et al. (2008), who investigated socioeconomic inequalities and mortality intensity in 22 European countries, the most significant differences in mortality by education are evident in Czechia and Lithuania, and the smallest, yet significant, differences apply to Sweden and England. These differences were observed for all the monitored causes of death with the exception of breast neoplasms. The high differentiation of mortality according to education in Eastern European and the Baltic countries is the result of significantly higher inequality in terms of the rate of death from cardiovascular disease. Indeed, mortality from cardiovascular disease exhibits the strongest association with education (McFadden et al. 2008; Smith et al. 1998b). The relationship between education and mortality concerning neoplasms is, however, ambiguous. In France (Menvielle et al. 2005), inequalities in cancer mortality according to education were observed only for men (concerning primarily mortality from lung and oesophageal neoplasms). Mackenbach et al. (1999) even determined a higher intensity of mortality from neoplasms for women with higher education levels in Czechia and Hungary; the only exception concerned lung neoplasm mortality, which was higher for women with lower education levels. In addition, more highly educated women also exhibited a higher rate of mortality from breast neoplasms in some of the other countries studied. The results of this study also revealed that inequalities in the level of mortality according to education are greater for men than for women in terms of both total mortality and mortality from all the investigated causes of death. Other authors have arrived at the same conclusions (McFadden et al. 2008; Vescio et al. 2003).

The unequal distribution of the population according to education also plays an important role in terms of explaining regional differences in mortality. Kravdal (2010) offers several explanations for the impact of higher education levels on lower mortality at the regional scale, including the observation that higher levels of education are associated with higher incomes, which serve to increase regional tax revenues, which, in turn, can be used to construct and manage a denser network of health facilities or to create infrastructure that encourages physical activity. Further aspects related to higher proportions of more educated groups comprise the greater attractiveness of the respective region for qualified healthcare personnel and, primarily, the existence of social interaction networks via which knowledge, attitudes and behaviour associated with a positive attitude to one's health are transmitted within the region. The relationship between higher levels of education and a lower levels of mortality has been confirmed for men and women with respect to Japanese cities (Fukuda et al. 2004), US states (Muller 2002) and Hungarian districts (Kopp et al. 2006). A study of mortality differentiation concerning districts in Slovakia (Rosicova et al. 2009) revealed that the effect of education was statistically significant only for men.

4.2 Income

The income level reflects the financial opportunity to secure adequate housing, nutrition and medical care. However, it is less stable than education in terms of providing a measure of socioeconomic status since it changes considerably over the life cycle. Therefore, household income distribution (e.g. Nakaya and Dorling 2005), in some cases personal income (e.g. Kopp et al. 2006), is used in the literature to express the level of income. Many authors (Phelan et al. 2004; Preston and Taubman 1994: 295–304) have emphasised the primary importance of higher incomes with regard to averting premature death, which can be prevented via the use of quality medical care, more expensive health treatment options and the consumption of selected foods. One of the aspects concerning the influence of income on mortality, which is discussed primarily in the USA, comprises the lack of the availability of health insurance for persons with lower incomes (Cutler et al. 2006).

In most populations, those with higher incomes enjoy better health and longer lives. At the individual

level, this fact has been observed, for example, in studies conducted in the USA (Chetty et al. 2016), Norway (Skalická et al. 2009) and Japan (Liang et al. 2003). Krueger et al. (2003) attempted to describe the dependence of mortality on income sources and determined that a higher risk of death was associated with both lower income levels and fewer income sources. This relationship intensifies with age.

Studies that examine the regional differentiation of mortality usually consider the measure of income in terms of the average income of persons or households in the region. An average income has been negatively associated with mortality intensity for US counties (Blanchard et al. 2008) and microregions in Ontario, Canada (Finkelstein et al. 2003). Moreover, a study of districts in Hungary (Kopp et al. 2006) revealed a strong relationship between the average income and the level of mortality from cardiovascular disease. A study by Nakaya and Dorling (2005) further determined that the average income in both the UK and Japan correlated significantly with differences in mortality between NUTS2 regions in the UK and prefectures in Japan. This association was found to be weaker in Japan and was even reversed at age 75 and over (i.e. a higher average income was associated with higher mortality rates). Conversely, Kravdal (2007), who analysed differences in mortality between regions in Norway, concluded that there is no relationship between the average income and mortality.

As mentioned previously, both differences in absolute incomes and their relative distribution (income inequality) are important in terms of explaining mortality differentiation. A positive linear relationship between income inequality and the mortality intensity has been described for example by Muller (2002) and Kawachi et al. (1997) for US states. However, no statistically significant relationship between these variables was identified for US districts (Blanchard et al. 2008). Nevertheless, a strong correlation between income inequality and mortality intensity was determined for NUTS2 level regions in the United Kingdom (Nakaya and Dorling 2005).

4.3 Unemployment

The link between unemployment and mortality can be explained via several mechanisms (Bartley 1994; Iversen 1989). Unemployment can be understood as a psychosocial stress factor that threatens the identity, self-esteem and social networks of individuals. These factors then exert a negative impact on susceptibility to the development of somatic and mental diseases. The loss of an employment position also exerts direct negative effects on blood pressure and the secretion of stress hormones that affect the efficiency of bodily functions. A further negative impact of the loss of an employment position concerns lifestyle changes and the increased consumption of tobacco and/or alcohol. Long-term unemployment undoubtedly also affects an individual's financial situation and material security. However, the higher mortality rate of the unemployed can also be explained via a selective mechanism, i.e. that many people who become unemployed lost their jobs due to poor health. Stewart (2001) described and empirically proved that those with poorer health have both a greater risk of losing their jobs and a higher chance of remaining long-term unemployed. Manual workers are more at risk of job loss due to poor health than other groups in the workforce (Bartley and Owen 1996).

Empirical studies of the relationship between unemployment and mortality have usually been conducted with respect to persons of working age (approx. 20–64 years). Nylen et al. (2001) identified a strong positive association between the unemployment rate and the mortality rate in Sweden. After excluding those with long-term illnesses, the association between unemployment and the mortality level remained unchanged for men but increased for women. Based on a sample of the Finnish population, Martikainen (1990) reported that the effect of unemployment on the higher intensity of mortality increases with the duration of the period of unemployment. Moreover, he demonstrated the selection of the unemployed based on their age, education and marital status; however, selection was not found to be significant with respect to health status.

One of the aspects of the relationship between employment and mortality intensity comprises the effect of part-time work. According to Nylen et al. (2001) most women who work part-time do so in order to be able to take care of children and the home, while if a man works part-time it is often due to health problems. This assumption was confirmed in the above cited paper using a sample of the Swedish population. For women, no relationship was determined between part-time work and mortality intensity, while for men, part-time work was related to a higher mortality risk.

Van Lenthe et al. (2005) compared the importance of unemployment in terms of the regional differentiation of mortality for several micro-regions in Europe and the USA. For men, those who live in regions with the highest quartile of unemployment higher mortality risk than those who live in regions with the lowest quartile of unemployment. The most significant differences were observed in the Netherlands and Finland and the least in England. A weaker relationship between the level of unemployment and regional mortality differentiation was observed for women. The mortality risk of women living in the highest unemployment quartile was highest in the USA. A stronger positive correlation between the unemployment rate and the male mortality level was also observed for cities in Japan (Fukuda et al. 2004) and districts in Slovakia (Rosicova et al. 2009), as well as for the intensity of mortality from cardiovascular disease for districts in Hungary (Kopp et al. 2006). The impact of

unemployment on mortality from cardiovascular disease was also confirmed by Brenner (2016) among European Union countries.

4.4 Occupation

Occupation has also been studied as one of the principle factors in the differentiation of mortality. For example, based on data from the 19th century, Stocks (1938) observed both the higher mortality intensity of butchers compared to pub landlords in London and a higher mortality level in those English regions with higher proportions of persons working in industry than those with higher proportions of the population working in agriculture. Employment is associated with various workplace-related physical and psychosocial factors. Human health is negatively affected in the workplace by harmful substances, the risk of injury, psychological stress and shared risk behaviour (Johnson et al. 1999). A person's occupation is mainly associated with the education level attained and, according to Sundquist and Johansson (1997), the higher mortality intensity of manual workers can be largely explained by their lower education levels and the various related risk factors.

Most of the evidence for a relationship between mortality intensity and occupation originated in the United Kingdom. An increasing level of mortality from non-manual professionals to unskilled manual workers was observed by McFadden et al. (2008) and Smith et al. (1998b). According to Smith et al. (1998b) the same gradient also exists for men in terms of the intensity of mortality from diseases of the circulatory system, neoplasms and other causes of death. A study by McFadden et al. (2008) concluded that differences in the intensity of mortality by occupation are lower for women and statistically significant only with respect to mortality from cardiovascular causes, which can be partly attributed to smaller differences in the proportion of female smokers between occupational groups. Moreover, the smaller differences in terms of alcohol consumption between women of different social classes according to occupation was determined by Harrison and Gardiner (1999) as being one of the most important factors in the differentiation of mortality by occupation in the UK. In addition, in Finland, the significant impact was determined of higher alcohol consumption among manual workers on the higher mortality level thereof, even for women (in contrast to the United Kingdom) (Mäkelä et al. 1997). A Japanese study Hirokawa et al. (2006) revealed that agricultural and forestry workers of both sexes have a lower total mortality intensity and, particularly, mortality from cardiovascular causes, than other manual and non-manual workers. Such workers were shown to have, on average, a lower consumption of alcohol and unhealthy food, higher physical activity levels and a lower propensity to smoke. Although the relatively low level of mortality among persons working in agriculture has also been observed in the USA, it was no lower than for highly qualified professionals (Johnson et al. 1999). Similar conclusions were also drawn by Menvielle et al. (2005) in France with concern to mortality from neoplasms. This study determined that the most significant inequalities according to occupation concerned the occurrence of lung and oesophageal neoplasms in men, which is most likely due to the unequal distribution of alcohol and tobacco consumption between occupational groups.

At the regional level, the influence of occupation on mortality has been studied only rarely. The proportion of manual workers has been found to be the most significant factor in terms of the differences in mortality rates between microregions in the Helsinki metropolitan area (Martikainen et al. 2003). Higher proportions of manual workers in certain regions was reflected primarily in higher levels of mortality from cardiovascular disease and external causes of death. Moreover, living in regions with higher proportions of manual workers has been significantly associated with a higher mortality intensity in Australia (Turrell et al. 2007), England (Sloggett and Joshi 1994) and the Turin metropolitan area (Marinacci et al. 2004). A correlation between employment type and mortality rates has also been confirmed in Central Europe, specifically between regions in Poland (Rój and Jankowiak 2021).

4.5 Marital status

The available literature reports that marital status and the formation and dissolution of marriage exert a significant impact on both health status and mortality. This phenomenon can be explained by a combination of a range of selection and causal mechanisms (Kravdal 2007; Rogers 1995). According to the selection hypothesis, healthy people are more likely to marry, and unhealthy individuals are more likely to divorce. The criteria for choosing a marriage partner include not only income, physical appearance, psychological stability, etc. but also the avoidance of risk factors such as smoking or excessive alcohol consumption. The protective function of marriage hypothesis assumes that the lower level of mortality of married persons is the result of enhanced accessibility to social relationships, integration and social support. Marriage also leads to the creation of a clear social role and levels of responsibility that result in the avoidance of risks and the leading of a healthier lifestyle. According to the stress hypothesis, the higher mortality rate of divorced and widowed persons can be attributed to their higher exposure to mortality risk factors (smoking, higher alcohol consumption rates, higher blood pressure, higher BMI, etc.) following the end of the marriage. The relationship between marital status and mortality may also be related to income. A serious decrease in financial resources

following the dissolution of a marriage may lead to a deterioration in living conditions, overall lifestyle and the potential for access to quality health care.

A comparison of differences in mortality according to marital status in 16 developed countries between 1940 and 1985 revealed that the mortality risk for unmarried persons was greater than for their married counterparts, with divorced persons affected by the highest mortality intensity rate in most cases. The differences were more significant for men than for women in all the countries studied (Hu and Goldman 1990). The same results were determined by a large number of longitudinal studies, e.g. in Sweden (Sundquist and Johansson 1997). In the USA, Rogers (1995) observed the highest mortality rate for unmarried persons; moreover, divorced and widowed persons were also observed to have a higher mortality rate than married persons. According to Murphy et al. (2007), who studied differences in the mortality level according to marital status in seven European countries, unmarried persons evince the highest intensity of mortality aged 40–59 years, whereas at older ages the mortality level is highest for divorced persons. Metsä-Simola and Martikainen (2013) found, based on a Finnish population sample, that the excess mortality of divorced men is highest immediately following divorce and decreases over time. This excess death rate was found to be lower for women than for men and to be evenly distributed over longer periods of time following divorce. Rogers et al. (2005) and Martikainen et al. (2005) emphasised the importance of the higher mortality intensity of unmarried persons from social pathology-related causes.

The usual measure of marital status and the formation and dissolution of marriage in terms of the study of the regional differentiation of mortality comprises the proportions of divorced, unmarried and widowed persons compared to those who are married (e.g. Kravdal 2007) or the intensity of the divorce rate (e.g. Popov 2009). In Norwegian municipalities, Kravdal (2007) determined that a higher proportion of divorced persons results in a higher mortality rate, while a higher proportion of single persons leads to a lower mortality rate for both men and women. Blomgren et al. (2004) identified the strong regional association of the proportion of divorced and single persons with alcohol-related mortality for a sample of the male population in Finland. According to a study of 89 Russian regions (Popov 2009), the change in the intensity of divorce in the period 1990–2003 was found to be one of the main determinants of mortality differentiation. The relationship between marital status (specifically divorce rate) and mortality has also been confirmed by Spijker (2014: 35–78). The negative effect of divorce is stronger for men than for women; and has also a larger effect in Eastern European countries compared to Western European countries. However, it is not significant for all causes of death.

4.6 Religion

Scientists agree on the positive effect of active religious participation on human health. The relationship between religion and mortality is reflected primarily via behavioural and psychosocial factors (Ellison and Levin 1998; Hummer et al. 1999; Musick et al. 2004). Part of the relationship between religious participation and mortality can be accounted for by health selection, i.e. many of those who do not attend religious meetings are unable to attend because of poor health (Hummer et al. 1999). Religious activity, particularly in the form of involvement in a religious community, may promote physical health via the regulation of health-related behaviour, particularly the lower consumption of alcohol, tobacco and addictive substances. However, less risky sexual behaviour and support for certain eating habits also comprise important factors. According to the empirical findings of Musick et al. (2004), behavioural factors are likely to explain 20% to 30% of the impact of the regular attendance of religious meetings on the lower intensity of mortality.

The enhanced social support network of religious communities also undoubtedly exerts a beneficial impact on health both formally and informally via an extensive network of social relationships with persons who share the same values, interests and activities. Other aspects concerning active religious participation comprise the enhancement of self-esteem and positive self-perception. The clearer and more complete value system that faith in God offers may also exert a beneficial effect on one's psychological resilience and health. Less evidence exists on the potential negative health effects of the social pressure within religious groups in terms of adhering to certain norms and behaviour. Breaking the rules may lead to the creation of strong feelings of guilt and shame. Moreover, many individuals may be negatively affected by remaining in unsatisfactory marriages due to the fear of societal condemnation should they decide to divorce (Ellison and Levin 1998; Oman et al. 2002).

Most studies that have addressed the relationship between religious participation and mortality in developed countries have focused only on those who follow the Christian and Jewish faiths (Powell et al. 2003). In addition, the lack of a unified definition of religious and spiritual activities presents a problem in terms of comparing different studies. In general, religious participation is most often measured as the frequency of attending church or praying.

Most of the evidence for a relationship between active religious participation and mortality originates in the USA, where religious activity is considered to be one of the main determinants of individual-level differences in mortality. According to Powell et al. (2003), this fact is based on the large proportion of the US population that believes in God and, primarily, the fact that the majority of the US population considers

religion to form a very important part of their lives. Dupre et al. (2006) observed a strong negative association between religious participation and mortality intensity for persons aged 65 years and older in North Carolina, USA. Their study revealed that those who did not attend religious gatherings had roughly twice the risk of mortality than those who attended services regularly. This risk was found to be slightly higher for women. Hummer et al. (1999) determined a considerable difference in the life expectancy at age 20 between men and women who do not participate in religious activities at all and those who participate more than once per week in the USA. According to Oman et al. (2002), who studied data from California, USA, the causes of death that have the strongest relationships to active religious participation comprise diseases of the circulatory system, diseases of the digestive tract and respiratory diseases. In Europe, a significant negative association between religious participation and mortality was demonstrated by la Cour et al. (2006) based on a sample of the elderly Danish population. However, this effect was found to be significant only for women. Moreover, they discovered no relationship between mortality and watching/listening to religious services on television or radio.

Räsänen et al. (1996) compared differences in mortality between Lutherans and Orthodox believers in Eastern Finland in the form of a longitudinal study. Even after adjusting for other socioeconomic variables, the total mortality intensity of Orthodox believers was strongly higher than that of Lutherans. A lower mortality rate for Protestants than for Catholics was determined by O'Reilly and Rosato (2008) in Northern Ireland. With respect to Christian churches, the avoidance of risk-taking behaviour is considered to be more characteristic of Protestants than Catholics, a factor that has been proven in several studies on regional differences. Holt et al. (2006) found that US states with a high proportion of Catholics have higher rates of alcohol consumption than predominantly Protestant states. Blanchard et al. (2008) studied the association of mortality differentiation for US states and the proportion of Catholics and Protestants. A higher proportion of Catholics correlated to a higher intensity of mortality from social pathology-related causes. Mackenbach et al. (1991) revealed that the excess mortality in the southern part of the Netherlands is strongly associated with a higher proportion of Roman Catholics. The higher proportion of Catholics was linked to both the higher intensity of total mortality and, significantly, a markedly higher level of mortality from lung cancer and other diseases directly related to smoking.

4.7 Race

Race in relation to differences in mortality has been studied to date primarily in the USA. Sometimes race is even used as an indicator of socioeconomic status due to its high correlation with education, income, occupation and unemployment. The higher mortality rate of African Americans compared to white Americans has been reported by many authors (Dupre et al. 2006; Keil et al. 1992; Potter 1991; Rogers et al. 1996). This difference decreases with age; however, according to the results of a study in North Carolina by Dupre et al. (2006), at around the age of 80, i.e. the highest age group, this trend is reversed and African Americans have a lower risk of mortality than white Americans. The authors offer two possible explanations for this phenomenon – the underestimation of the real intensity of mortality among African Americans in the highest age groups and the selective survival of the hardiest individuals in the African American subpopulation, which exhibits a higher mortality intensity for younger age groups. According to all the most recent studies on this theme, the higher mortality intensity of African Americans is attributed primarily to their lower socioeconomic status. Keil et al. (1992) showed via a longitudinal study that when education and occupation are considered, differences in mortality between African Americans and white Americans are no longer significant. A further observed trend in the USA concerns the lower mortality rate of Asians. According to Rogers et al. (1996), this is the consequence of their lower alcohol and tobacco consumption, healthier diet and higher socioeconomic status. Dwyer-Lindgren et al. (2017) concluded at the US county level that race is one of the causes of large and growing disparities in mortality rates. Consistent with studies at the individual level, the factor of race was confirmed to be closely associated with other socioeconomic and behavioural factors.

4.8 Migration, nationality and ethnicity

Mortality among immigrants and ethnic groups is influenced by a wide range of interacting social and cultural factors, as well as genetic differences and selective migration (Kibele et al. 2008). The health status of individual ethnic and immigrant groups differs from the population of the destination country due to differing behavioural, psychosocial and material characteristics, which may change with the length of stay in the destination country and with differing experiences of migration. In Europe, there is the evidence of immigrants being healthier and having lower mortality rates than the population of the destination country (e.g. Razum et al. 1998; Uitenbroek and Verhoeff 2002). This phenomenon can be explained by selective migration, i.e. most migrants decide to emigrate only if they enjoy good health. In addition, migrants often have to undergo mandatory medical examinations prior to migration. According to Uitenbroek and Verhoeff (2002), the selection of migrants is based on health status, as well as psychological resistance, ambition and motivation, which are thought to exert a positive impact on health at later ages. Razum et al. (1998) cites the return of immigrants to their

country of origin in case of serious illness as one of the potential reasons for the lower mortality rate of immigrants in Germany.

Studies of regional differences between districts in the Netherlands (Mackenbach et al. 1989) and between regions in Russia (Popov 2009) revealed only a weak relationship between the level of mortality and the proportion of immigrants.

4.9 Urbanisation

The relationship between urbanisation and mortality is reflected via a range of socioeconomic, behavioural, psychosocial and other factors. Urban environments offer more opportunities for employment, education and social contact, as well as enhanced access to health and social services. Conversely, living in cities in the developed world is also associated with higher psychological stress levels, an unhealthy lifestyle, air pollution, noise and higher crime rates. One of the most important aspects of the connection between urbanisation and the intensity of mortality concerns the differing composition of the population in cities and in the countryside. Concerning European countries, it has been shown that the populations of the most urbanised regions are younger and have higher education and income levels, higher proportions of atheists and single persons and higher divorce rates. Declining industrial regions, however, may be affected by the accumulation of economic and social unrest in urban areas (Mackenbach et al. 1991; van Hooijdonk et al. 2008).

The problem with comparing empirical studies concerns the various definitions of urban and rural regions. Some authors define urban regions based on land use (e.g. O'Reilly et al. 2007) and others via the population density (e.g. van Hooijdonk et al. 2008). The most frequently employed criterion for determining the degree of urbanisation consists of the proportion of the population that lives in cities above a certain population size. According to most studies concerning Western Europe, overall mortality increases with the degree of urbanisation; however, this gradient differs according to both the causes of death and age. Van Hooijdonk et al. (2008) in the Netherlands and O'Reilly et al. (2007) in Northern Ireland discovered slightly lower levels of total mortality in urban regions; however, the mortality of children and young people and those in the oldest age categories was found to be lower in rural regions. Both studies determined that the strongest relationship relates to living in urban regions and mortality from respiratory diseases and lung neoplasms. In addition to these two causes of death, Law and Morris (1998) also observed the higher intensity of mortality from diseases of the circulatory system in urban areas of England and Wales. These findings thus support the assumption that urban environments are associated with poorer air quality and the higher prevalence of smoking.

4.10 Availability of medical care

The development of medical care has undoubtedly contributed significantly to improving the health of the population and extending life expectancy. It is reasonable, therefore, to expect the significant influence of the availability of, and resources provided by, healthcare systems in terms of decreasing mortality intensity, especially with respect to conditions that can usually be treated by rapid medical intervention (e.g. heart attacks). However, studies on regional differences conducted in Western European countries in the second half of the 20th century failed to agree on a uniform and clear association between differences in healthcare provision and mortality levels (Mackenbach et al. 1990). According to several studies, the explanation for this inconsistent and unexpected relationship can be explained by the conscious and unconscious satisfaction of the demand for doctors according to the respective health problem in various countries. The hypothesis that the system responds to demand was proposed, for example, by Fukuda et al. (2004) based on the positive relationship between mortality intensity and the density of primary medical care facilities determined for cities in Japan. Mackenbach et al. (1990) believe that the absence of a clear association between medical care and mortality may be due to the fact that the indicators applied (i.e. most frequently the number of doctors or hospital beds per inhabitant) do not accurately reflect the quality and efficiency of the medical care provided. The availability of health services as an independent influence on the reduction of mortality has, however, been confirmed in the USA, unlike in several European countries. The negative association between the number of primary health care physicians per capita and the mortality rate was determined with respect to US states and to differences between US counties in the eastern and northern states of the country (Ricketts and Holmes 2007).

At the level of larger regional units, access to health care can also be measured by healthcare expenditures. This perspective was used, for example by Gavurova et al. (2020), in a study focusing on socioeconomic differences in mortality rates in the European Union. However, healthcare expenditures did not have a significant effect on explaining differences in mortality.

4.11 The environment

The environment influences all individuals regardless of their personal characteristics. A wide variety of harmful substances are able to enter the human body both with oxygen from the air and through the digestive system through contaminated water or food. Exposure routes and the health risks of the most frequently occurring pollutants are listed in the WHO air quality guidelines (Sivertsen 2006: 31–60). The occurrence of oxides of nitrogen and sulphur is

mainly associated with the burning of fossil fuels in the industrial sector, heating systems and motor vehicle emissions. These chemical compounds exert primarily an effect on the respiratory system. However, they may also have an impact on cardiovascular diseases or neoplasms via biological processes. The main substances that pollute the air in cities and industrial areas are oxides of sulphur and particulate matter, which contain a complex mixture of organic and inorganic substances of different sizes. Heavy metals also make up a dangerous component of such particles. Of the oxides of nitrogen, nitrogen dioxide, anthropogenically produced via transport-related combustion processes, exerts the greatest effect on the human body. However, since nitrogen dioxide is associated with the emissions of other substances, it is difficult to detect its independent effect (Sivertsen 2006: 31–60).

However, according to the results of several longitudinal studies conducted in Europe (e.g. Hoek et al. 2002) and the USA (e.g. Dockery et al. 1993), it is possible to conclude that pollutants that are concentrated in the external environment have a weaker effect on mortality than do the harmful substances inhaled through smoking. According to these studies, following adjustment for individual characteristics, air pollution exerts an impact on mortality from cardiopulmonary causes and lung neoplasms only. The short-term effect of particulate matter (PM_{10}) emissions on mortality has been studied in detail in 90 US cities (Samet et al. 2000) and 29 European cities (Katsouyanni et al. 2001). In the USA, a 10 $\mu g/m^3$ increase in PM_{10} concentrations was associated with a higher next-day mortality. A stronger relationship was observed for cardiopulmonary causes of death. The results varied widely concerning European cities. The greater impact of an increase in PM_{10} concentrations by 10 $\mu g/m^3$ was observed in the cities studied in southern Europe, on the other hand, for example in Germany, the relationship between daily PM_{10} emissions and mortality was observed to be negative. A similar analysis was also performed by Peters et al. (2000) in North Bohemian districts of Czechia and districts in Bavaria that border Czechia based on data from 1982–1994. While in Czechia the dependence of next-day mortality on the emission of pollutants was determined, the relationship between these variables was not found to be significant in Bavaria. The concentration of particulate matter exerted the greatest impact on next-day mortality, whereas the concentration of oxides of sulphur had the greatest effect on two-day mortality.

5. Ecological fallacy

Since no individual data is usually available for studies of regional mortality differences in defined territorial units, the unit of analysis adopted comprises data on groups of individuals. The danger associated with interpreting the results of such analysis concerns the so-called ecological fallacy, which results from the aggregated nature of the data. The ecological fallacy arises if the connections observed at the regional population level are applied to its constituent members (Diez 2002).

The distinction between individual and aggregate (ecological) level relationships was first described in the early 1950s by the American sociologist Robinson (1950), who investigated the relationship between race and illiteracy. Although the correlation coefficient of the proportion of African Americans and illiteracy in US states was found to be positive, this association was observed to be the opposite at the individual level. A further example of the ecological fallacy is provided by Diez (2002). In several countries worldwide, an increasing level of mortality from traffic accidents has been determined with increasing income per capita. However, this relationship is misleading since, according to studies conducted in various countries based on individual data, the death rate from traffic accidents is higher for persons on lower incomes.

However, the differences in the relationships found at the individual and ecological levels do not necessarily result from aggregation, but also from methodological errors and the poor selection of variables. Other variables and the interactions between them may exert a substantial impact on the explanation of the respective associations. Moreover, the relationships determined at the aggregate level should not be interpreted as causal, but as the connection between two variables. According to Lancaster and Green (2002), in general, in order to minimise bias in the results, it is sufficient to standardise the data and include other factors in the model that are potentially responsible for the variability of the explained variable. According to their study on the influence of socioeconomic conditions on differences in health status, the risk of ecological error is reduced when a different population structure is taken into account at the aggregate level. Schwartz (1994) emphasises the validity of ecological studies in terms of assessing the impacts of the differentiation of the external environment (economic, cultural and social) on human behaviour and health. Moreover, it is not necessarily the case that individual-level models are better defined than aggregate-level models. Indeed, the grouping process itself may serve to cleanse the data of errors that arise from biased responses provided in individual studies. Thus, ecological studies cannot be considered to be mere substitutes for individual studies due simply to the absence of data.

6. Conclusion

The existence of significant socioeconomic and sociodemographic differences in mortality observed and described in detail for many countries worldwide

demonstrates how extremely dependent health status and subsequent mortality are on external factors. Based on the study of the literature, it was determined that more privileged groups enjoy better health and longer lives. A strong association was revealed between socioeconomic factors and mortality at both the individual and the aggregate levels. However, the question remains as to which mechanisms such external factors are linked directly to human health. Most often, the existence of a relationship between socioeconomic or sociodemographic factors and mortality can be explained with the help of materialist theories (the main cause of the socioeconomic differentiation of mortality lies in income and what the income allows), psychosocial theories (socioeconomic status affects the psyche of individuals which, in turn, exerts biological impacts on the human organism), biomedical theories (the uneven occurrence of biological risk factors between social groups), the life course theory (the accumulation of social, psychological and biological advantages and disadvantages during the lifespan) and, above all, behavioural theories (the unequal distribution of unfavourable behaviour and lifestyles between socioeconomic groups).

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Sanitation strategies for reducing open defecation in rural areas of India and Ethiopia

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ABSTRACT
Sanitation change continues to be on the forefront of the global development agenda, even as it is becoming clear that the targets established in the Sustainable Development Goals will not be met. But since improving access to safely managed sanitation facilities remains a cost-effective and impactful measure to improve people's lives, it is still important to assess currently implemented policies to be able to learn from best practices and to understand how different approaches work under different contexts. This paper provides comparative analysis of country-level policies in India and Ethiopia, two countries that achieved notable progress in eliminating open defecation through distinct sanitation strategies, with the aim of confronting the advantages and disadvantages of both approaches. While in India the primary emphasis has been on the supply-side, i.e., provision of subsidized sanitation infrastructure, Ethiopian strategy prioritized the demand-side by addressing change in sanitation behavior through Community Total Led Sanitation. The analysis shows that neither of the strategies can fully achieve the sanitation change and a combination of both seems to be the most impactful approach in combating open defecation. It also argues that policymakers must consider not only local socioeconomic and budgetary constraints but also historical, institutional, sociocultural, and geographical specifics in deciding what type of subsidies would be the most fitting. At the same time, they also need to address the appropriate social norms to achieve the desirable change in sanitation behavior.

KEYWORDS
sanitation change; environmental health; India; Ethiopia; Sustainable Development Goals

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1. Introduction

The sixth Sustainable Development Goal (SDG) includes a target to end open defecation (OD) and secure access to adequate and equitable sanitation for all by 2030, which has been recognized as one of the most challenging features among all SDGs' targets (Moyer and Hedden 2020). The progress has been uneven so far (e.g. WHO/UNICEF 2019; Desphande et al. 2020) and it is unlikely that the global sanitation target will be met (UN 2018; Sadoff et al. 2020). The aim of this study is to provide a comparative analysis of sanitation policies used to address household-level sanitation in India and Ethiopia; two large countries that are major influencers of recent trends in the global sanitation indicators. Despite their dissimilar levels of socioeconomic development, until recently the majority of both Indian and Ethiopian households practiced OD (Tab. 1). However, between 2000 and 2017, Ethiopia and India achieved the largest and third largest decrease in OD rate worldwide, respectively, accounting for 4% and 60% global reduction of people practicing OD (WHO/UNICEF 2019). The more recent data (WHO/UNICEF 2021) shows further reduction of OD in both countries with India being ahead.

The strategies adopted by India and Ethiopia led to distinct outcomes (Tab. 2) with distinct remaining issues. In Ethiopia, the dominant sanitation infrastructure is low-quality facilities that do not ensure safe separation of fecal material from human contact (see Novotný and Mamo 2022). This makes presumed health impacts of the widened availability of latrines uncertain (Freeman et al. 2022; Aragie et al. 2022) and presents a risk of OD slippage (Abebe and Tucho 2020). Unimproved sanitation facilities are much less prevalent in India, but the key challenge is to ensure consistent use of available toilets (Coffey et al. 2014; Jain et al. 2020; Gupta et al. 2020), which seems to less an issue in Ethiopia (e.g., Novotný et al. 2018a).

2. Objectives and methods

The aim of the article and its main contribution to the knowledge on sanitation practice is a comparison of the two diametrically different sanitation policies and strategies to tackle OD. Both national strategies are on the opposite side of the current sanitation practice spectrum; India with fully subsidized toilet constructions and Ethiopia focusing on behavior change. This juxtaposition clearly shows each one's advantages or disadvantages and yields important lessons learned for further upgrades to or implementation of any revised sanitation directions either of the two countries or countries with similar trajectories might employ.

We used comparative analysis to explore both strategies across four domains: Political framing and support, Main narratives and legal ground, Financing, and Sanitation approach, which is further divided into sub-domains: behavior-change components and technology promoted. These domains were selected as the most contested ones based on our literature review.

In the remainder of this article we will firstly outline the development of sanitation policies in India and Ethiopia, especially the most recent sanitation schemes. The next section will compare in detail both countries' strategies along two main dimensions: political support and sanitation change approaches, each of which covers several domains. The concluding

Tab. 1 Basic development indicators and open defecation rates in rural and urban areas in India and Ethiopia.

	Population (millions)	GDP per capita (PPP, international dollars)			Human Development Index			Population practicing open defecation (%)		
	2020	2000	2019	Change (%)	2000	2018	Change (%)	2000	2017	2020
India	1380	1920	6980	363	0.497	0.647	130	74	24	15
Ethiopia	115	507	2720	537	0.283	0.470	166	77	26	17

Sources: Data on GDP are from the IMF World Economic Outlook (October 2020), Human Development Index is based on UNDP data for Human Development Report, 2019 (Conceição 2019); Sanitation data are from WHO/UNICEF (2019, 2021).

Tab. 2 "Ladder" of sanitation services available in rural and urban areas in % (2020).

Type of sanitation service	India			Ethiopia		
	Total	Rural	Urban	Total	Rural	Urban
Improved safely managed (private toilet, handwashing facility with soap and water)	**46**	51	37	**7**	4	16
Improved basic service (private toilet)	**25**	17	42	**2**	1	6
Improved limited service (facility but shared with other households)	**12**	8	19	**9**	3	31
Unimproved (sanitation facility which does not ensure separation of excreta from human contact)	**2**	2	0	**65**	71	45
No service (open defecation)	**15**	22	1	**17**	21	3

Source: WHO/UNICEF (2021).

section discusses lessons learned and possible examples for the rest of the world to follow in the run up to 2030.

3. Overview of sanitation policies

3.1 India

Inadequate sanitation received some attention during colonialism as a cause of poor health. After independence it received little attention until the 1980s (Duggal 1991; Khan 2006; Mushtaq 2009), when India introduced the Central Rural Sanitation Program. This first national sanitation scheme was ultimately unsuccessful, purely supply driven, and focused on the provision of uniform pour-flush toilets, which mostly remained unused (WSP 2010; Mohapatra 2019).

The scheme was restarted in 1999 as the Total Sanitation Campaign, aiming to make India open defecation free (ODF) by 2012. Although it called for a bottom-up community-led approach and for more emphasis on information, education, and communication activities, it retained fixation on toilet construction (Hueso and Bell 2013; Barnard et al. 2013; Mohapatra 2019). And while toilet coverage increased rapidly, the subsidized toilets were of poor quality, and again remained unused (Patil et al. 2014; Coffey et al. 2014; O'Reilly et al. 2017; Sinha et al. 2017). The Total Sanitation Campaign was remodeled into Nirmal Bharat Abhiyan in 2013, with the goal of universal access to sanitation set for 2022. This scheme was supposed to extend the focus on community-led approaches, but the issues remained. The implementation was inconsistent, poorly received, exclusionary, riddled with political interference, and toilet coverage increased only modestly (Routray et al. 2017; Mohapatra 2019).

On 2 October 2014, Narendra Modi launched Swachh Bharat Mission (SBM). Latrine construction was supposed to be again supplemented by various behavior change activities and information campaigns. It was implemented on an unprecedented scale and gained strong political support but faced criticism that it was again dominated by construction of subsidized toilets (Kumar 2017; Mohapatra 2019; Novotný et al. 2018b; Andres et al. 2020; Exum et al. 2020). But there is also evidence that the SBM performs better than the previous schemes and could support wider sanitation change (Curtis 2019; Hutton et al. 2020). While the toilet provision across rural India was the main focus of the SBM until 2019, the following second phase addresses the sustainability and behavioral aspects of sanitation change (e.g. Sarkar and Bharat 2021). It is also related to the ongoing government scheme called Jal Jeevan Mission that focuses on the provision of water at the household level to overcome a major barrier for toilet use in India (https://jaljeevanmission.gov.in).

3.2 Ethiopia

Measures addressing hygienic sanitation in Ethiopia have been incorporated into government health programs since the mid of the 20th century. More specifically, introduction of health services dates back to 1946 when the international community sponsored training of health assistants and sanitary inspectors. This can also be characterized as the rise of Ethiopian endeavors towards sanitation change. Since then, the sanitation agenda has come indirectly under the Federal Ministry of Health (FMoH) competences and stayed exclusively there until recently (Kloos 1998; Feleke 2019).

A milestone in addressing sanitation issues was the introduction of the Health Extension Program (HEP) in 2003 which serves among other things as the implementation channel for national sanitation strategy and confirms the direction of sanitation being closely linked to public health policies. The newest program, called One WASH National Program (OWNP) reflects problems of the current sanitation situation, including strategies, financing and implementation. It has officially recognized the close linkages between water, sanitation and hygiene (OpenWASH 2016), aiming to achieve universal access in all three domains. The OWNP and its related documents were signed by four different ministries (Water, Irrigation and Energy; Health; Finances; Education) proving an inclination towards the multi-institutional approach (National WASH coordination office 2018). The OWNP stresses good governance; efficient use of human and financial resources; and capacity development at all levels as the key components of improving sanitation.

4. Confronting current sanitation policies in India and Ethiopia

4.1 Political framing and support

4.1.1 India

In an unprecedented shift from previous schemes, through the SBM sanitation received one of the highest priorities among domestic policies, together with massive political support and attention. Public officials led by the Prime Minister Modi spearheaded the drive for sanitation change which was delegated to the Ministry of Drinking Water and Sanitation. SBM actually became one of the most important policies of Modi's administration, which also realized there are votes and publicity in toilets. Political representatives on the highest level committed themselves to sanitation and this commitment trickled down to the lower levels (Kumar 2017; Curtis 2019). But this political support goes hand in hand with overall politicization of social policies by the ruling party. This includes reproduction of caste and gender hierarchies which are now supported as drives for social mobility.

Occupational caste hierarchies are reimagined to provide a sense of inclusion and empowerment through pride and unity without tackling traditional purity-pollution hierarchical distinction (Gudavarthy and Vijay 2020). These issues coupled with former failed sanitation programs could be initiating distrust towards the government in states that are not ruled by Modi's BJP (Curtis 2019). However, there does not seem to be any difference in SBM outcomes in states governed by BJP and those governed by opposition parties so far (Bhattacharya et al. 2018).

4.1.2 Ethiopia

In a show of a strong political will to improve sanitation, the Ethiopian government very proactively integrated SDGs in governmental strategies and documents, with the promise to achieve access to adequate and equitable sanitation and hygiene for all and end open defecation by 2030 (Baye 2021). In cooperation with foreign actors the government defined the need to tackle sanitation through an integrated and multi-sectoral approach (Wateraid 2016; OneWASH 2019). Following this shift a wide WASH platform was established and several new strategic documents and programs were launched, including One Wash National Program (OneWASH 2019; WHO 2015).

In spite of this proactive approach, sanitation remains a low political priority in Ethiopia. It is somewhat buried within a wide development portfolio, surmounted by water, hygiene and other issues that are perceived as more directly linked to health (WaterAid 2016). It is important to note that this article was written during the so-called Tigray War, which made sanitation even less of a priority than usual. Sanitation programs have been implemented through the Health Extension Program as one out of its 16 types of provided health-related services (Alemu et al. 2019; Banteyerga 2011). The coordination of activities beyond the federal level has been questioned as well as a lack of clear ownership of implementation and budget, lack of reliable or consistent data, along with a lack of clarity on roles and responsibilities are causing drawbacks in sanitation change (Freeman 2013; Abraham et al. 2019). The state, labelled as authoritarian (Aalen and Tronvoll 2009), works more in command and control manner. The Ethiopian government puts pressure on achieving successful results in health services, including construction of latrines and declaration of ODF status. Households are forced through the HEP to own latrines but their quality and impacts on health are not relevant. It is more about positive numbers than the real health and dignity impacts (Melberg et al. 2019).

4.2 Main narratives and legal ground

4.2.1 India

SBM represents a paradigm shift in framing of sanitation in India. It became part of a broader strive for modernization, which also created better conditions for adopting modern toilets. Narendra Modi replaced the Nirmal Bharat Abhiyan with SBM soon after his election, creating his own signature cleanliness program, which spilled over into the political landscape, clearly demarking a line between "old dirty corrupted" India, and a "modern clean country" under his leadership. There is also no longer an aim to address caste and gender hierarchies, in a departure from previous rights-based social equality programs, which however did not enable social mobility and current approach is perceived as more honest (Curtis 2019; Gudavarthy and Vijay 2020). This also required changing traditional Hindu discourse surrounding purity and pollution (e.g. Coffey et al. 2014) which Modi's BJP successfully challenged (Curtis 2019). Public officials led by the Prime Minister broke taboos surrounding cleanliness and participating in SBM was seen as an enhancement of one's social status (Kumar 2017).

But India still lacks union or state law regulating rural sanitation, which thus has to be regulated by administrative directions. In this regard, SBM is focused mostly on individual needs without framing them in terms of individual rights. Making people responsible for sanitation and unable to hold the government accountable for the promises made (Cullet 2019), especially since the supreme court tends to decide environmental cases in a selective manner (Iyengar et al. 2019). But even if the right to sanitation was further cemented in law, there is no guarantee that it would be enforced. As is the case with manual scavenging, which is illegal in India but still practiced (e.g. Coffey et al. 2014).

4.2.2 Ethiopia

Ethiopia's constitution from 1994 contains an article about ensuring a clean and healthy environment for all Ethiopians as a constitutional right, encoding access to improved sanitation. Nonetheless, also here we can find similarities with India, as no national law regarding access to improved sanitation currently exists (Côrtes et al. 2016). Meaning there is no enforceability and no legal recognition of the right to sanitation.

Policies and policy areas which directly underpin the sanitation sector and create a regulatory framework in Ethiopia are three: water, health and environment (MoH 2005; OpenWASH 2016). However, health is the main driver for sanitation change and efforts to achieve sanitation for all are rooted in maximization of public and private health benefits. That is why the primary policy in terms of sanitation action is a health policy, titled the Health Policy of the Transitional Government and implemented through the Health Extension Program. The introduction of the Health Extension Program represented an important paradigm shift from a long-standing curative focus to one of prevention (MoH 2005).

4.3 Financing

4.3.1 India

On a macro level, SBM has been financed by the Indian government, which, in order to engage in such a massive task, negotiated a loan with the World Bank. Institutions like UNICEF, WaterAid, Bill and Melinda Gates Foundation, or the Tata Trust, provided technical support to and financial assistance for hiring sanitation consultants (Curtis 2019).

On a micro level, toilet construction is subsidized by up to 12 000 INR, of which usually 60% comes from the central government and 40% comes from the state governments. Information, education and communication activities received a maximum of 8% of the project expenditures (Ministry of Drinking Water and Sanitation 2018). In alignment with previous schemes, money spent on toilet construction were ex-post reimbursed to the household, which was criticized as ignorant to structural inequalities, and reinforced tendencies to not adopt toilets. It left no space for beneficiaries' inputs, and since higher castes often constructed toilets according to notions of purity and pollution, subsidized toilets become a symbol of caste and class discrimination (O'Reilly et al. 2017; Jain et al. 2020).

4.3.2 Ethiopia

The sanitation sector in Ethiopia has been financed by a wide range of funding mechanisms. The financial resources were mobilized through the federal government and regional budget allocation, bilateral aid, donor support in the form of grants and loans, NGOs resources allocation, or Woreda and Community contributions (OneWASH 2016; Haile 2009). Nonetheless, the sector stays heavily aid-dependent (WSP 2010). To create a transparent cash flow a new financing system was set up and there is a division of transparent accounts (FIN 2019).

In terms of microfinancing, there is an agreement at the governmental level that the hardware subsidies are not supported in any kind (Alemu et al. 2017; WSP 2010; WHO 2015). However, there appeared to be recent recommendations from foreign NGOs (IRC) to subsidize the poorest households via the Ministry of Agriculture's Productive Safety Net Program (Achenbach 2022) but it is still not implemented in official policies or in practice. The micro-financing mechanism is based on the idea of a sanitation ladder. People buy the cheapest solution with no subsidy and immediately as it is possible they try to improve it.

4.4 Sanitation approach: behavior-change components

4.4.1 India

Lack of behavior change is presumably the most criticized aspect of Indian programs and the government failed to reorient from latrine construction in past schemes (Kurup 1991; Barnard et al. 2013; Hueso and Bell 2013; Routray et al. 2017). SBM guidelines designate information, education and communication activities as a core aspect of the program and declare toilet construction as only supplemental to behavior change, though only a fraction of the budget was allocated to it (Ministry of Drinking Water and Sanitation 2018). There is also a discrepancy between the official narrative and a covert narrative believed by implementing officials who perceive information, education, and communication activities as secondary (Hueso et al. 2018), even as OD is still practiced in states officially declared as ODF (Exum et al. 2020). Strikingly, notable behavior change occurred not in villages but in government offices where previously uninterested and disgusted officials started to be deeply involved in sanitation (Curtis 2019).

Diverse motivational components, both those aiming at positive motivation and coercive measures, were part of SBM. The Nirmal Gram Pushkar, a clean village award connected to a financial incentive, was not reinstated for SBM due to tenuous results and difficult verification process (Bernard et al. 2013; Mohapatra 2019). But model early-win districts were selected to motivate skeptical district officials and village leaders were encouraged with dashboards where they could update and compare their progress, with the best ones receiving prices and praise on social media (Curtis 2019). The dashboards predominantly show the number of toilets constructed (Department of Drinking Water and Sanitation 2020). Coercive measures were heavily utilized during SBM, as officials pressured villagers to construct a toilet under a threat of government's benefits and rations withdrawal, or directly with fines and arrests by the police. Members of lower castes and BPL households were more often affected by the coercive measures and were further associated with filth because they are forced to use toilets that are not made according to notions of purity and pollution, and subsidies meant for them are captured by higher castes (O'Reilly et al. 2017; Cullet 2018; Gupta et al. 2020).

4.4.2 Ethiopia

Unlike India, behavior change approaches have been central to Ethiopian sanitation programs. After some NGOs successfully implemented Community-Led Total Sanitation (CLTS) in rural areas of Ethiopia, CLTS got wider acceptance and was formally adopted by the Ethiopian government as a key national sanitation approach. The Ministry of Health developed the National CLTS Implementation Guideline to support the uptake of CLTS throughout the country (more specifically, Ethiopian variants of CLTS have been referred to as CLTSH – Community-Led Sanitation and Hygiene). The implementation is rolled out across the country through the Health Extension Program (UNICEF 2017) and via woreda-level trained professionals (One Wash 2016). The main stress is to

address social determinants of health and affect the behavior of targeted groups (Asseffa et al. 2019).

The CLTS approach is community based, assuming that community behavior changes gradually. It involves early adopters (model families), then moving to the next group ready to change. Those resistant to change are gradually conditioned to change because of changes in their environment (Chawica et al. 2012). After some criticisms of the HEWs only visiting households and using household-centered approach, rather than CLTS community methods, the Ethiopian government in its One WASH program II (2018) officially addresses the need for designing a "community-centered approach". This new approach officially activates members of communities and other actors at the community level, such as community leaders, health sector actors, development agents, teachers and students etc. Community based approach is meant to be complementary to CLTS approach and to enhance other efforts and follow ups to change sanitation practice (National WASH coordination office 2018). Nonetheless it is a new initiative which has not yet been evaluated and monitored, thus there is no evidence of real results.

The official motivation strategies used to implement sanitation programs are mainly ODF certification, which rewards the community's achievement and encourages them to further improve sanitation behavior and increases the ownership of the entire process. However, the competition between villages encourages some officials to declare ODF status before it is reached. It creates strong pressure on constructing latrines but not on behavior change itself (Behailu 2015). It was reported that the pressure may take a form of sanctions (mostly financial, exceptionally jail or threatening by it) of households without latrines (Novotný et al. 2018a). Moreover, 15% of households fall back to open defecation after declaration of ODF status within one or two years after village ODF declaration. The reasons vary but one of them is incorrect implementation of CLTS activities (Abebe and Tucho 2020).

4.5 Sanitation approach: technology promoted

4.5.1 India

Twin pit pour flush toilets have been most widely recommended under SBM, although states can choose different options. Row toilets or complexes are also recommended, but their design should keep them affordable, e.g. the pits should not be unnecessarily large, while also making the superstructure acceptable for the beneficiaries. Community Sanitary Complexes should be constructed in places where individual latrines are not suitable, usually due to lack of space, or at public places (Ministry of Drinking Water and Sanitation 2018). The concept of sanitation ladder is therefore not utilized in India and twin pit pour flush toilets are the basic sanitation facilities provided. But there is a broader "WASH ladder" which starts with the provision of a toilet and continues with a household tap water connection or a concrete house (Ministry of Jal Sakthi 2019).

Twin pit pour flush toilets were chosen for their relatively easy fecal sludge management, but they are often not accepted and misunderstood by the communities. To prevent pit emptying people tend to merge the two pits or disconnect the toilet altogether. Containment pits are preferred but they are often built in poor quality and without proper management knowledge (Gupta et al. 2020; Chandana and Rao 2021). Water scarcity also represents a major barrier in community acceptance, as people in water-scarce regions prefer to use water for washing rather than sanitation (Bhattacharya et al. 2018).

4.5.2 Ethiopia

The National sanitation strategy recognizes the need for different variations of latrines depending on regional context, geographical conditions, desires of local population etc. (Ministry of Health 2005). Unlike in India, there is an agreement at the governmental level that the hardware subsidies are not supported in any kind. The complete responsibility for building latrines lies in households themselves (Alemu et al. 2017; WSP 2010; Ministry of Health 2005). At the same time the Ethiopian sanitation strategies work with the idea of a sanitation ladder. It assumes that people start with a basic latrine construction and when they have an opportunity they improve their latrines. For those reasons people are encouraged to build traditional pit latrines with basic structures from various local materials in order to reduce the costs and quickly adopt improved sanitation behavior.

Nonetheless the cheapest solution does not always lead to behavioral change. As the evaluations showed the change is not as sustainable as it is officially proclaimed (Assefa et al. 2017; Crocker et al. 2017). The current numbers (One WASH 2018) shows that 20% still has no access to latrines and most of the rest only to unimproved traditional pit latrines (Fig. 1).

5. Discussion

Throughout the past decades India and Ethiopia have developed their own specific approaches, both on paper and on the ground. And while much was achieved and many mistakes were made, their shared experience offers a great lesson to the rest of the world, that is running out of time to successfully fulfill SDG 6.2. by 2030. The following section and a summarization in Tab. 3 aims at distilling lessons learned from sanitation change drives in India and Ethiopia and offers best practices for other countries to follow.

Sanitation change habitually lacked strong political support, but the trend is rather improving (WaterAid

Fig. 1 Examples of household toilets common in rural Ethiopia (right side) and rural India (left side). Source: The authors.

Tab. 3 Confronting sanitation policies in India and Ethiopia.

	India	Ethiopia
Political support and prioritization of sanitation *Is there political will and support to improve sanitation? and political motivation?*	– Sanitation received **top priority** among domestic policies. – Retained political commitment. – Intertwining with ideological goals of right wing Hindu nationalism.	– Sanitation has **not been among top development priorities**, and not even among WASH policies. – There is political will for sanitation change.
Implementation fidelity	– Implementation **did not follow the policy guidelines**, especially in prioritizing behavior change measures.	– Policies are only **poorly reflected in practice,** and there is a high return rate to OD.
Main narrative(s) / framing/ Legal ground *What is the development paradigm, how is the sanitation approach legally grounded?*	– Main political narrative for sanitation change is **modernization**. – Sanitation recognized as a right but **not enforceable** due to lacking laws.	– Main political narrative for sanitation change is **preventative health**. – Sanitation recognized as a right but **not enforceable** due to lacking laws.
Financing (incl. Hardware subsidies)	– Interventions **fully funded by the government**. – At individual level standardized households hardware subsidies are a core aspect of SBM.	– **External funding** – Policy of **no hardware subsidies** for individuals
Technology promoted/used **Sanitation ladder** *What types of toilets etc. are used?*	– Twin pit pour flush toilets were built in a majority of cases, disregarding local context. – Sanitation ladder not utilized.	– Widespread usage of **dry pit latrines.** – Concept of s**anitation ladder relied upon** for upgrading but assumed progression along sanitation ladder has not occurred.
Behavior-change **Community based** *Is behavior change included in sanitation approaches? And are they community based?*	– **SBM did not prioritize behavior change approaches.** – Community-based approaches not utilized and subsidies reproduced caste hierarchies.	– The Ethiopian government applied the **CLTS** approach complemented by sanitation marketing. – CLTS is a community based sanitation approach which stresses **behavior change.** – The core of sanitation approaches is **behavior change**

2016), as exemplified by both Ethiopia and India, even as the overall narratives differ. India frames SBM as a part of an overall modernization effort and an issue of cleanliness – both in a physical and spiritual way, while Ethiopia constructs sanitation primarily as a health issue preventing the spread of diseases. This is not to say that sanitation in India is in no way seen as a tool for improving health, but the narrative communicated to the population revolves around shifting the country into the 21st century. These divergent narratives offer some deeper view into different motivations and subsequent results of sanitation policies. Health benefits of sanitation change are intangible and difficult to recognize in the short term. Linking the adoption of toilets to modernization as well as physical and spiritual cleanliness means a stronger leverage and directly measurable goal which is achievable by delivering sanitation facilities to every household. At the same time, it can be argued that the modernization narrative subverts behavioral aspects of sanitation change, as it is linked with toilet ownership, rather than use, thus disconnecting behavior change from the program's objective.

Political support is undoubtedly crucial for successful sanitation change. And we have seen politicians using the sanitation theme to win elections, as they did in India (Curtis 2019). And while this is generally a positive trend, inclusion of politicization of sanitation is also concerning, as again demonstrated by the Indian experience. SBM is now too important to fail and officially reported achievements are often exaggerated (Curtis 2019; Exum et al. 2020). Further, it created a political narrative around social policies that labels critics as outsiders disintegrating the nation, while encountered issues are blamed on previous governments' right-based programs, which in turn makes Modi's regime programs reproducing caste and gender hierarchies seen as more efficient (Gudavarthy and Vijay 2020). Although it is clear that gaining political support enables massive change in a short time, policy makers must be cautious when entangling sanitation policies with politics. A possible safeguard, that neither Ethiopia or India deployed, would be a legal framework that would codify the right to sanitation into the national legislature, which could provide the public with means to keep politicians accountable by making them entitled to sanitation, rather than responsible for it (Cullet 2018).

The actual implementation and realization of sanitation policies is also dissimilar. Modi's government singled out sanitation by granting it top priority among domestic policies and establishing a dedicated ministry of Jal Sakthi. While in Ethiopia sanitation became part of a broader One WASH program, an integrated, multi-sectoral, and multi-level approach created in response to uncoordinated projects and programs. This should minimize duplication of activities and spending, but requires a complex coordination and clarity of stakeholders' roles. In contrast, the Indian single institution approach allows for a more streamlined process. This reflects local contexts, as water supply is a far greater issue in Ethiopia, where the emphasis is more on water resources management and sanitation is just an accessory. With limited resources, it is seen as unfeasible to prioritize sanitation (Siraj and Rao 2016). India meanwhile struggled with often culturally grounded dislike of toilets and a preference for OD (Coffey et al. 2014; Sinha et al. 2017), and thus needed to mobilize attention into this single category. Integration of water-related sectors under one management is a popular trend in the current development discourse but in this case it can be argued that it was the preferential treatment of sanitation in India that led to the massive improvement in coverage under SBM, and thus might be advantageous for countries that are seriously falling behind in achieving sanitation change.

Both countries used different strategies for achieving sanitation change. Ethiopia has followed a global trend in using CLTS, which primarily targets behavior change through construction of new social norms with no external financial support. Indian programs meanwhile heavily relied on subsidized toilet construction and behavior change activities were only marginally implemented. Similarly, Ethiopia successfully utilized community-driven aspects of CLTS, where communities pressure individuals to alter their behavior due to changes in their environment. In the Indian context, community focused interventions are troublesome due to the omnipresent structural disadvantages and caste hierarchies, which often put an overwhelming blame for failing to adopt safe sanitation on individual households, thus creating social stigma towards usually disadvantaged groups (Jain et al. 2020). And while this could have been overcome by proper planning and context-sensitive policies, we would argue that SBM had neither of those.

Ethiopia and India also applied diverse motivational components for changing people's behavior. Both use some form of awards or recognition for ODF villages. India shifted its awards into the digital sphere, while Ethiopia kept its standardized certification protocol. Coercive measures are more complex and there have been documented cases of abuses and hard pressure in both countries. When withdrawal of government's benefits and rations, or direct fines and arrests by the police, are used as a tool to pressure villagers into constructing a toilet, lack of sanitation is used as a basis for denial of fundamental rights rather than an entitlement flowing from fundamental rights, which is again associated with the fact that both countries lack a sanitation-related legal framework. This is a frequent issue with development policies and goals, to which countries sign up but ultimately do not prescribe these policies into laws (Cullet 2019). In India these aspects of command and control are inherently bound to caste relationships and graded inequality, as they unevenly affect lower castes and

poor households (O'Reilly et al. 2017; Cullet 2018; Gupta et al. 2019).

The financing mechanisms for toilet construction in both countries are on the opposite ends of the spectrum. While the Ethiopian policy strictly forbids any individual household subsidies for latrine construction, in line with basic principles of CLTS, toilet construction in India is fully subsidized. The household subsidies definitely bear much of the responsibility for India's rapid rise in sanitation access but it is too early to fully judge what their long term effect will be. Traditionally, individual subsidies are blamed for hindering behavior change, but in this case they could have had an important role in creating a critical momentum to kick start a sustainable sanitation change. Meanwhile the Ethiopian approach, with complete responsibility for latrine construction left on individual households, pushes the families to the cheapest solutions, which are often low quality and non-durable latrines, not accepted by the owners. It is followed by the idea of sanitation ladder where the individuals climb up to reach the better sanitation solutions immediately as they can.

Paradoxically, although toilets available to households in India are generally of much higher quality than in Ethiopia (Fig. 1), inconsistent use seems to be comparatively more of an issue there. Water demands for toilet use for both flushing and post-defecation cleansing, sanitation rituals and culturally shaped perceptions of purity and pollution, or attitudes towards toilets specific technology and safe fecal sludge management (Coffey et al. 2004; Routray et al. 2015; O'Reilly et al. 2017; Yogananth and Bhatnagar 2018; Satyavada 2019). Low acceptance and prevailing misconceptions about the rate in which the pits fill up point towards lack of beneficiaries' participation in the design process (Jain et al. 2020). But Ethiopia struggles with a similar issue as high rates of observed slippage from previously ODF declared communities is linked to low technical quality and non-durability of constructed latrines (Crocker et al. 2017; Delea et al. 2019; Abebe and Tucho 2020). Although according to estimates, people in rural Ethiopia tend to use toilets relatively consistently, if they satisfy at least simple hygienic conditions. Although there has been considerably less research on behavioral aspects of toilet use in Ethiopia than in India, possible explanations may lead to the chosen sanitation strategy that created social pressures on toilet use but also the mechanisms of surveillance by local authorities generally related to the command-and-control nature of Ethiopian governance (Novotný et al. 2018a).

The analysis shows that relying solely on behavioral approaches and sanitation ladder are not very efficient strategies, if implemented without any external financial support. Similarly, it is ineffective to simply provide every household with a subsidized toilet without further activities that would ensure sustainable use. The former "Ethiopian model" achieved some behavioral change of inhabitants but pushed them to build latrines which do not fulfill their hygienic norms, with households not stepping up the sanitation ladder, but rather slipping back to OD. The latter "Indian model" led to a massive construction of hygienic toilets, but it in no way guaranteed sustainable sanitation change. Frail sense of ownership, poor targeting of subsidies that amplified preexisting structural inequalities, or lack of local participation and context insensitivity, might also be sources of slippage to OD in the long run.

Thus providing at least some financial assistance, especially to disadvantaged groups, which would allow them to construct safe, durable, acceptable, and appropriate toilets, should be used in tandem with behavior change approaches. And while the massive amounts of both political and financial resources available in India remain inaccessible for most countries, including aid-dependent Ethiopia, smart targeting of subsidies in combination with context sensitive community interventions could also lead to a critical momentum and multiplication effect (e.g. Pakhtigian et al. 2022) necessary for a wide-scale change. At the same time communities should be involved in selecting the final design and other decision-making processes to retain ownership. It is questionable whether the financial support should cover the whole cost of the facility, as in the case of the "Indian model". It will be important to closely monitor slippage rates back to OD in both countries to further evaluate both strategies. Nonetheless, the combination of changes to social norms and at least partial financial support to individuals seems to distill as the way towards widespread improved sanitation. With local context remaining crucial, continuous research into the micro-level conditions affecting sanitation change is still necessary to design sanitation policies. Though as shown by Chakraborty et al. (2021), an exaggerated focus on micro-level is also problematic since sanitation determinants tend to be geographically clustered and population-level studies are also necessary to fully understand how sustainable sanitation change can be achieved.

6. Conclusion

This article provided a comparative analysis of sanitation policies adopted in India and Ethiopia. Countries that recognized sanitation among their development priorities, implemented large-scale national programs, but chose contrasting approaches. Although both achieved remarkable progress in increasing toilet coverage, they faced specific challenges concerning sustainability of sanitation change and full realization of health and social benefits associated with hygienic and equitable sanitation.

As 2030, the ultimate deadline for the global community to achieve extraordinary advances in the

human condition, is less than a decade away, we must turn our attention to what was achieved in the past years and collectively learn from all the successes and failures alike. The strive of India and Ethiopia for universal safe sanitation offers a fair share of both. And with drastically different strategies can serve as examples and cautionary tales for other countries on the same journey. Each point where the Indian and Ethiopian policies clash can serve as a starting point for further research into suitability of national policies in countries such as Cambodia, where CLTS was also heavily deployed but calls for targeted household subsidies appear in recent literature (e.g., Kohlitz et al. 2021). And while it would be foolish to say that such effort would ensure that the World would fulfill the target 6.2 of the SDGs, it could nonetheless contribute to it.

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Spatiotemporal analysis of the changes of the main habitats of the Kozachelaherska arena (Nyzhniodniprovsky sands, Kherson region, Ukraine) in the period of 1990–2020

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ABSTRACT

Landsat satellite images (Landsat-5 for the period of 1990–2010 and Landsat-8 for the year of 2020) were used for the spatio-temporal analysis of the dynamics of the main habitats of the Kozachelaherska arena (Nyzhniodniprovsky sands, Kherson region, Ukraine). The algorithm of minimum distance of automatic k-mean clustering was used for the classification of the satellite images. Habitats were classified according to EUNIS classification principles. The analysis revealed a considerable decrease in a summary area of coniferous plantations in the period of 2000–2010. During the last two decades, the area of losses significantly exceeded the renewal area of coniferous plantations. The area of large permanent aquatic habitats in the north-east part of the arena decreased by 2.5 times in the last thirty years. The water supply of the territory is constantly decreasing, probably due to the reduction in precipitation and in the ground water level. At the same time, the area of territories under open sand doubled, the process of sand overgrowth with vegetation has slowed down, and its losses have increased. All these changes are most likely caused by the increasingly arid climate in southern Ukraine, which may, over time, lead to the replacement of habitats characteristic of sandy steppes with habitats of open sands.

KEYWORDS

GIS; remote sensing; land cover changes; habitats; Kozachelaherska arena

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1. Introduction

Nyzhniodniprovsky (Low-Dnipro) sands is an unique ecosystem which has been under a significant anthropogenic load for a long time. Excessive intervention of human into this ecosystem caused serious damage to the ecological balance. There appeared the necessity to do research on some ecological peculiarities of these territories and to work out the trends of the preservation of sand arenas, which are unique for Ukraine (Hranovska 2019). In 2010 a national natural park (NNP) "Oleshky sands" was created in the territory of two historically significant nyzhniodniprovsky arenas (Kozachelaherska and Chalbaska). However, in October of 2015, after the war in the East of Ukraine had broken out, a military training ground resumed its functioning in the territory of Kozachelaherska arena, which limited the access of the researchers to this place to a great extent. In February, 2022 the territory of NNP Oleshky sands was occupied by russian troops. Under these conditions, it became possible to monitor the condition of these valuable ecosystems only with the remote sensing techniques.

During the last decades, the Earth remote sensing techniques (ERS) have been widely used to monitor the changes of the land cover, including the areas under natural reserves (Alves et al. 2022; Zou et al. 2022; Melnyk and Yachniuk 2022; Myroniuk 2020; Sorokina and Petrov 2020). This can be explained by several advantages of the remote sensing techniques as compared with the traditional expedition methods: they cover large territories, they are informative, operative and objective, their use is quite frequently cheaper than the arrangement of research expeditions and chamber processing, they provide a precise topographic base to make the maps of the transformation of the territory structure, a digital format of the ERS materials and the use of special programs (software) for their processing and analysis guarantee fast results (García-Alvarez et al. 2022).

As far as the use of the data of ERS to monitor the condition of the ecosystem of Oleshky sands is concerned, a proper attention was not paid to it. We are aware of one research aimed at the identification of the dynamics of the land cover of the Kozachelaherska arena with the use of a 30-year (the years of 1987–2017) temporal series of Landsat images (Bogdanets 2017). It is to be stated that the method of visual decryption of satellite images, which allowed to identify only the largest noticeable changes of the land cover, was used in this research. Other than that, the author does not mention any numerical characteristics of the discovered changes of the land cover which makes an objective evaluation more complicated.

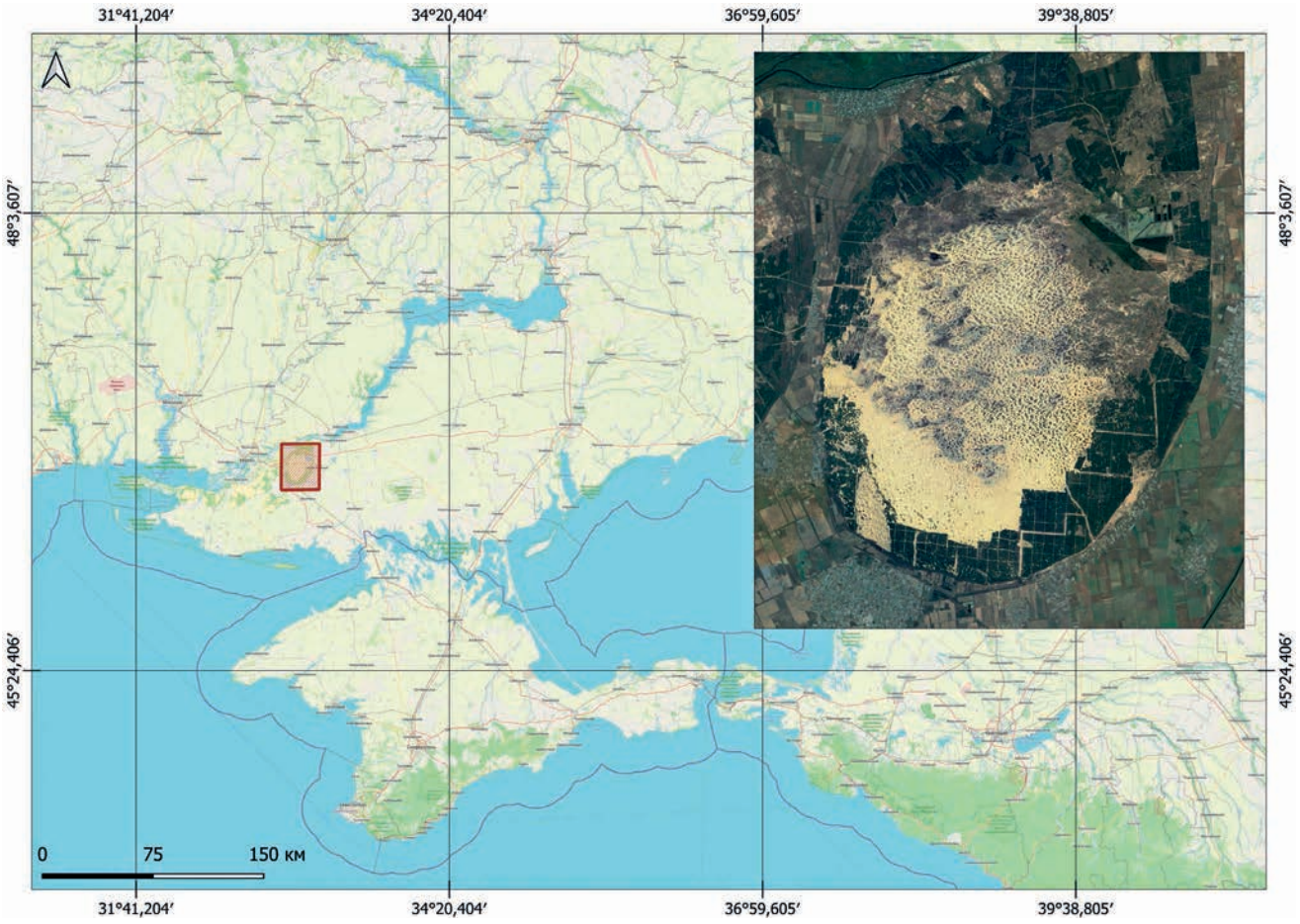

Fig. 1 Geographical location of Kozachelaherna arena of Low-Dnipro sands (Open Street Map, Google Satellite).

The purpose of this work is, based on the analysis of a temporal series of satellite images, to single out the main habitats of Kozachelaherska arena of Nyzhniodniprovsky sands, to establish the peculiar features of their spatial-temporal dynamics for the last thirty years. It may be useful for the management of the area and for conservation of endangered species. Also, it is important that this territory is currently in the area of military operations and is likely to be significantly affected. Therefore, this study provides valuable information on the initial state and habitat areas of this territory at the beginning of the full-scale invasion of Ukraine by the russian federation.

2. Characteristics of the territory under study

Nyzhniodniprovsky sands stretch for 150 km from Nova Kakhovka to Kinburnska foreland in the form of seven sand arenas. Five arenas are adjacent to Dnipro flood: Kakhovska, Kozachelaherska (Fig. 1), Oleshkivska, Zburiivska and Ivanivska (Oleshkivsky massif). Chalbaska arena is situated to the south-east of this massif and the last massif is located on Kinburnskyi peninsula. The total area of these arenas is 161 thousand hectares. Lowlands are situated among some massifs, salty lakes occur there (Hordiienko 1969).

Although the territory belongs to the basin of Dnipro, there are no permanent natural watercourses in it (National Atlas of Ukraine 2008). Only the lakes of anthropogenic and natural origin are available. Such water reservoirs have atmosphere and underground nutrition; in addition, adsorption and condensation of water vapor from the atmosphere due to the daily temperature gradient are available (Marynych 1989–1993).

According to botanical-geographical zoning, the territory of Nyzhniodniprovsky sands is part of Chornomorska (Black Sea, Pontic) steppe province, European-Asian steppe region and it belongs to the sub-zone of feather-fescue-grass steppes (Moisiienko 2012).

3. Materials and methodology

The data of spacecrafts (SC) of Landsat (Landsat-5 for the period of 1990–2010 and Landsat-8 for the year of 2020) was used for the spatiotemporal analysis of the land cover dynamics of the region under study. Free products of satellite images, used in this research, were received from geo-site of the geological survey of the USA (United States Geological Survey) (Earth Explorer 2022) with the module for downloading satellite images of Semi-Automatic Classification Plugin for QGIS (Congedo 2021). The images downloading was carried out in the mode of automatic prior processing.

The images taken on 06.06.1990, 26.06.2000, 06.06.2010 and on 08.06.2020 were used as they were characterized with the lack of cloudiness of the region under study.

The algorithm of minimum distance of automatic k-mean clustering, implemented in Semi-Automatic Classification Plugin for QGIS, was used for the classification of the satellite images (Congedo 2021). The optimal differentiation of the earth cover was reached when its 15 classes were singled out.

As a redundant quantity of the land cover classes is formed as a result of such classification, then at the next stage the reclassification of the results with the singling out of six main habitats was done: aquatic habitats, grassland habitats, psammophyte habitats, coniferous plantations, deciduous forests and open sands. Habitats were classified according to EUNIS classification principles. For terrestrial, the 2021 version of the classification was used (EUNIS habitat type hierarchical view … 2023). Since there is no classification of water and swamp habitats is not available in this version, we used an earlier version. Today, we are able to analyse with the help of satellite images mainly the habitats of the second level of the EUNIS classification (Willner et al. 2017). In some cases, we combine several units of this level together. Otherwise, we have to divide them into several smaller units.

To interpret and to make more accurate the results of the classification, satellite images of high resolution Google maps (Fig. 1) and photo materials Google Earth Pro were used.

The evaluation of the classification accuracy was carried out based on the matrix of mistakes. To calculate the latter, 5–6 training grounds were built for each habitat on the basis of visualization of a corresponding space picture in a natural color. Cross-validation of the classification results was done by pixel samples from these training grounds (García-Alvarez et al. 2022). The received Kappa-coefficient shows the correspondence/identity between the classification image and the standard (Foody 1992). It can take the values from 0 to 1. If the Kappa-coefficient is equal to zero, then there is no correspondence/identity between the classification image and the standard. If the Kappa-coefficient is equal to 1, then the classification image and the standard are totally identical. To interpret the values of the Kappa-coefficient, they are classified into 3 groups: over 0.80 (80%) – high classification accuracy, from 0.40 to 0.80 (40–80%) – average classification accuracy, lower than 0.40 (40%) – low classification accuracy (Congalton 1991).

To discover the temporal changes of the land cover, the algorithm “Land cover change”, implemented in the plagin menu of post-processing of the classification results for QGIS, was used (Congedo 2021). The received maps of spatial-temporal changes were reclassified to single out the changes of coniferous plantations, water habitats and sands. The graphs were created with the table processor Microsoft Excel

based on the digital characteristics of the land cover changes, received in QGIS.

4. Results

4.1 Main habitats in the territory under study and the peculiarities of their identification on satellite images

Aquatic habitats, grassland habitats, psamophyte habitats, deciduous forests, coniferous plantations, and open sands are important for identification on satellite images and for nature conservation practice.

Aquatic habitats are small bodies of water that mostly dry up in the summer. According to the EUNIS classification, these habitats belong to RLC – Freshwater habitat and RLD – Mires and bogs. Some of them were formed by the craters from powerful aerial bombs, formed when the national park was a military training ground (Moysiyenko et al. 2019). Only a few reservoirs remain permanently irrigated due to constant groundwater recharge. The reservoirs have a small open floodplain covered with sparse macrophytes. Coastal aquatic habitats are most often located in a narrow strip around such reservoirs. Halophilic vegetation develops on the banks of salty lakes. Since these habitats cover small areas, their correct identification on the used space images is somewhat difficult, and they are not always distinguished separately. This aspect also applies to coastal aquatic habitats, which are found sporadically in the studied area. In addition, coastal aquatic habitats are located in narrow strips around water bodies, which makes it difficult to identify and estimate areas.

Psammophyte habitats occupy the largest areas of the studied territory. These are mainly R1 – Dry grasslands, which are several types of sandy steppes (Shapoval and Kuzemko 2021). Among them, R1Q – Inland sanddrift and dune with siliceous grassland

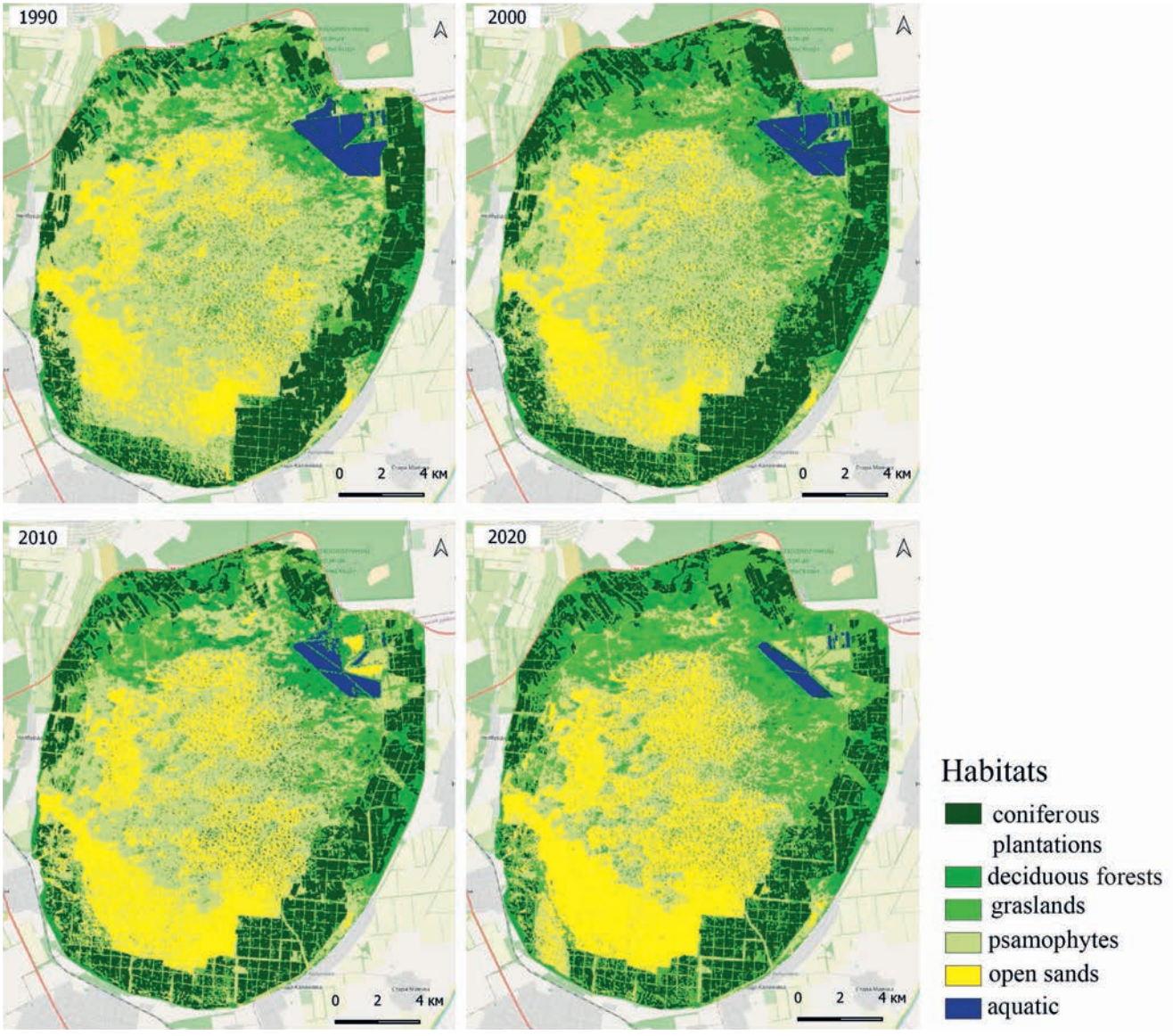

Fig. 2 Distribution of the main habitats in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990, 2000, 2010 and 2020.

and R11 – Pannonian and Pontic sandy steppe are most common. Other types of grassland are also found here. Small areas of wet meadows (R3 – Seasonally wet and wet grasslands according to the EUNIS classification) and mesophytic meadows (R2 – Mesic grasslands according to the EUNIS classification) occur around freshwater bodies.

Natural habitats formed by phanerophytes occur mainly in narrow strips around water bodies. By EUNIS classification, they belong to T4: Lines of trees, small anthropogenic forests, recently felled forest, early-stage forest, and coppice.

Artificial plantations are another type of phanerophyte habitats. Here, Pinus pallasiana, Pinus sylvestris and Robinia pseudoacacia were used for artificial plantations. The last species often penetrates into small deciduous natural forests. The coniferous plantation is somewhat different from the rest of the forest habitats. They have ecotonic areas with psammophytic vegetation of sandy steppes. Therefore, in this study we divided phanerophyte habitats into deciduous forests and coniferous plantation.

A large part of the studied area is represented by sand dunes practically devoid of vegetation. This habitat corresponds to U5 – Miscellaneous inland habitats usually with very sparse or no vegetation according to the EUNIS classification. After rains, temporary algae crusts (Hantzschia amphioxys, Klebsormidium flaccidum, K. mucosum Pinnularia borealis) form on the surface. The formation of vegetation is hindered by the constant movement of sand.

Under a visual analysis of the satellite images one can pay attention to the fact that during the period of 30 years, the arena area has not changed at all. This made it possible, based on a polygonal mask, to single out identical fragments from the satellite images, the ones which correspond to the arena territory with a stable number of image pixels. In turn, it became possible to monitor the transformation of each pixel during the period of the research, as well as to make the evaluation of the dynamics of the main habitats. Thus, as a result of the classification of the satellite images of the studied territory, six main habitats were classified (Fig. 2). The satellite images were analyzed over an interval of ten years, beginning from the year of 1990.

4.2 Evaluation of the classification accuracy.

The evaluation of the accuracy is an important step in the process of the classification of a satellite image. For instance, the classification accuracy defines the quality of a thematic map, prepared on the basis of a satellite image. We made the evaluation of the classification accuracy of four Landsat images used for the research (Tab. 1).

According to the results of the research it has been found out that the total classification accuracy ranges from 87.02% to 91.15%. The Kappa-coefficient varies from 0.83 to 0.89. It is a known fact that its value over 0.8 confirms high classification accuracy.

If to consider the classification accuracy of some habitats, it is to be stated that aquatic habitats and open sands are classified most reliably (Kappa coefficient = 1.0), which is natural as these classes are characterized with definite spectral peculiarities. The lowest classification accuracy is typical for the habitats of grasslands and psammophytes, but even in their cases the classification accuracy is sufficient. This makes it possible to use the received thematic maps for the analysis of spatiotemporal changes of the singled out habitats in the territory under study.

Tab. 1 Evaluation of the classification accuracy of the habitats in the territory of Oleshky sands.

Image	Parameters	Habitats						Overall accuracy (%)	Kappa (overall)
		Aquatic	Grasslands	Psamophytes	Coniferous plantations	Deciduous forests	Open sands		
1990	PA (%)	94.77	62.60	96.97	98.88	96.73	95.49	90.00	0.87
	UA (%)	100.00	91.81	80.33	96.55	99.01	99.84		
	Kappa	1.00	0.90	0.70	0.96	0.99	1.00		
2000	PA (%)	94.70	98.00	90.39	97.88	98.96	75.26	91.15	0.89
	UA (%)	100.00	82.37	85.45	98.38	99.08	99.94		
	Kappa	1.00	0.79	0.79	0.98	0.99	1.00		
2010	PA (%)	92.20	78.34	99.62	85.37	92.38	79.19	87.02	0.83
	UA (%)	100.00	80.47	72.54	99.53	98.15	99.89		
	Kappa	1.00	0.77	0.63	0.99	0.98	1.00		
2020	PA (%)	64.09	97.47	94.12	79.41	94.28	89.60	90.24	0.88
	UA (%)	100.00	78.53	85.32	96.49	98.53	99.84		
	Kappa	1.00	0.73	0.81	0.96	0.98	1.00		

5. Discussion

Three classes of the habitats were chosen for a further analysis: coniferous plantations (which are most clearly identified in the vegetation cover, and accordingly, their changes are clearly observed in the satellite images), open sands (as an indicator of aridization) and aquatic habitats (as an indicator of the water supply for the territory) (Didukh et al. 2020). As a result of the use of the identification procedure of the land cover change to the classified images, implemented in a Semi-automatic classification plagin for QGIS (SCP), a series of maps of the changes of the coniferous plantations with a ten-year interval (1990–2000, 2000–2010, 2010–2020) was created. Besides, the map of the changes of the coniferous plantations during the whole period under study was developed (1990–2020) (Fig. 3). Similar maps concerning the changes of the aquatic habitats (Fig. 4) and open sands (Fig. 5) were made.

The maps confirm that on the one hand, some plots of the coniferous plantations are lost, on the other hand, the renewal of this habitats take place. The nature of the location of the new plots of this habitats proves that the natural reproduction plays a very important role in this process. It concerns specifically the northern part of the arena.

The total area of the coniferous plantations decreased considerably in the years of 2000–2010 (Fig. 6), and in the following periods it remained relatively stable.

Accordingly, in the period of 2000–2010, the maximal losses of the coniferous plantations (21.07 km^2) were observed. In the last decade (2010–2020) this indicator decreased significantly (9.09 km^2), but the increase of the coniferous plantation losses doubled as compared with the period of 1990–2000. Along with this, in the first decade the losses were well compensated due to the renewal, however in

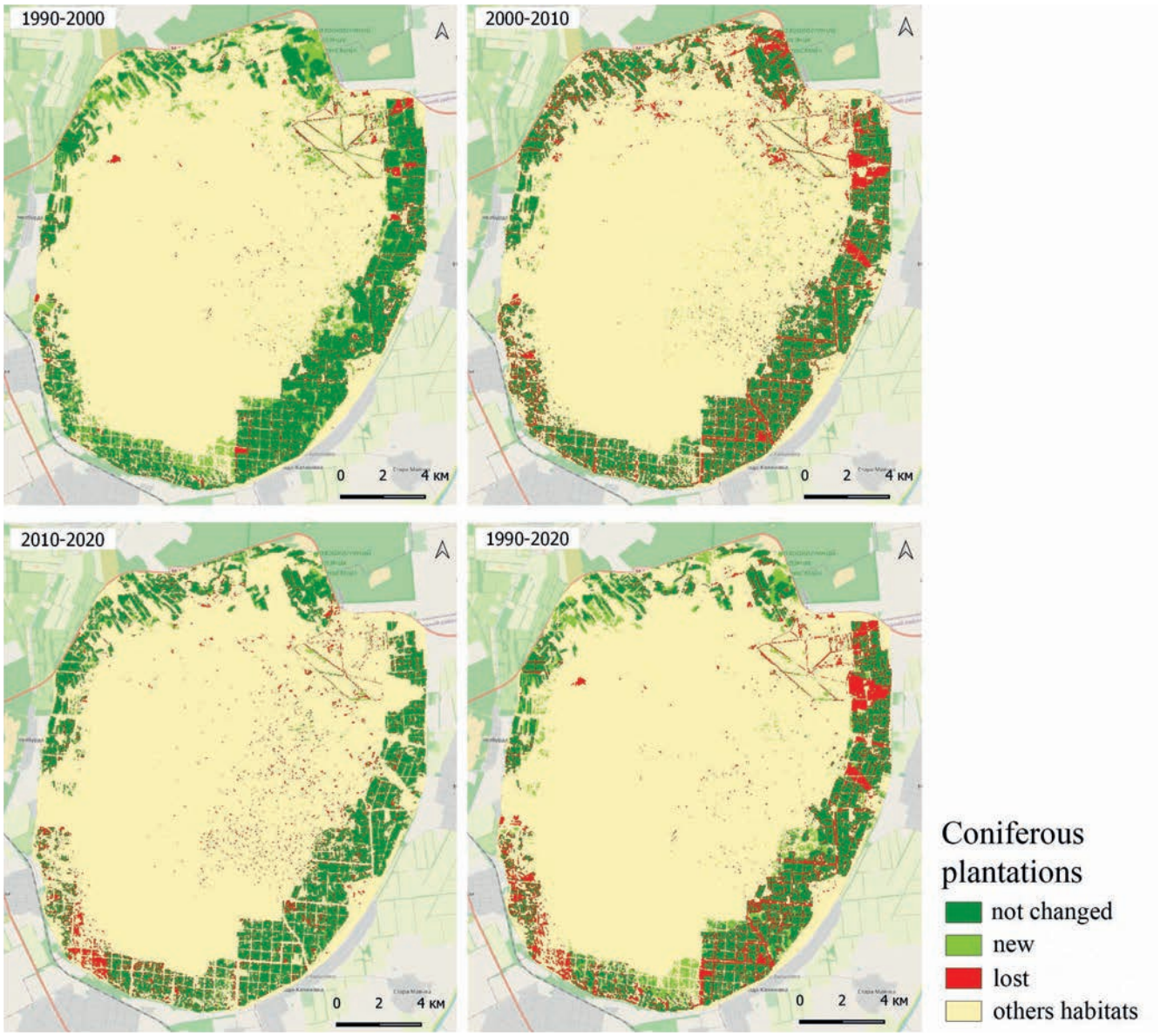

Fig. 3 Changes of the area under the coniferous plantations in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990–2020.

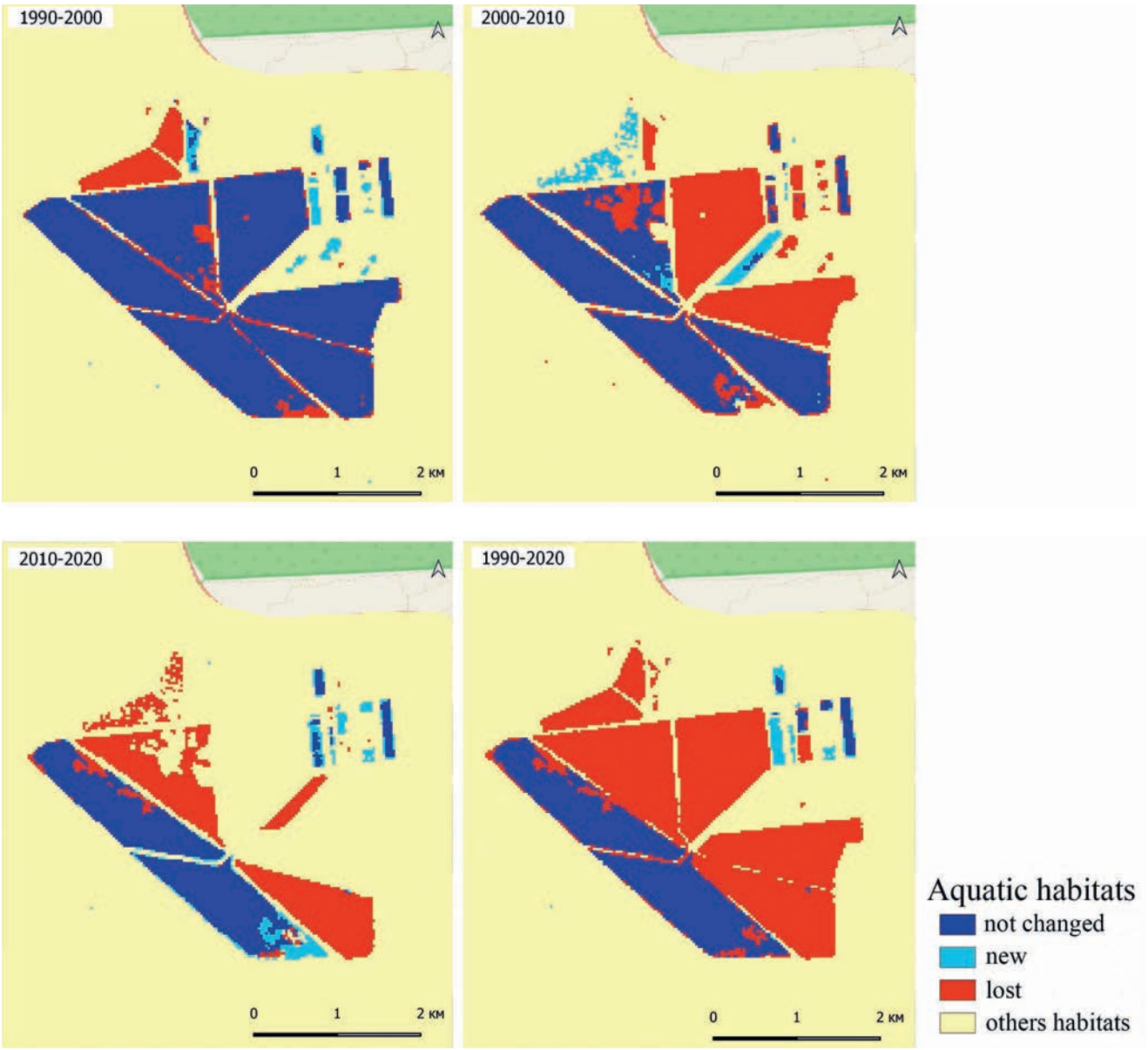

Fig. 4 Area changes of the aquatic habitats in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990–2020.

the latest decades the loss area exceeded, to a great extent, the area of the renewal of the coniferous plantations.

In fact, all permanent large aquatic habitats are concentrated in the north-east part of the arena. The results of the analysis made prove the progressive losses of the water surface. Within the period of thirty years, its area decreased by 2.5 times (from 7.1 km^2 to 2.57 km^2) (Fig. 4, Fig. 7). At the same time, the renewal of the aquatic habitats almost does not take place. Similar to the situation with the coniferous plantations, the maximal losses of the aquatic habitats were recorded in 2000–2010, which told about the unfavorable climatic conditions in this period. In general, it can be stated that the water supply of the territory decreases constantly, most likely it occurs due to the reduction of the precipitation amount and the level of the ground waters.

The results of the analysis of the open sand area changes (Fig. 4) show the progressive increase of the territories occupied by these habitats. Within the period of 30 years of the research, the area of the open sands increased from 46.86 km^2 to 84.21 km^2 (Fig. 8).

However, in case of the territory of Kozachelaherska arena, a clear pattern is recorded: the process of sand overgrowing with vegetation slows down gradually, and the losses of vegetation increases constantly (Fig. 8). This means that vegetation in these territories degrades gradually, and the territories with open sands increase. It is most likely connected with the general tendency towards the aridization of the climate of the south of Ukraine resulted from the global climate changes (Vozhehova et al. 2021). Over time, this may lead to the replacement of habitats characteristic of sandy steppes with habitats of open sands.

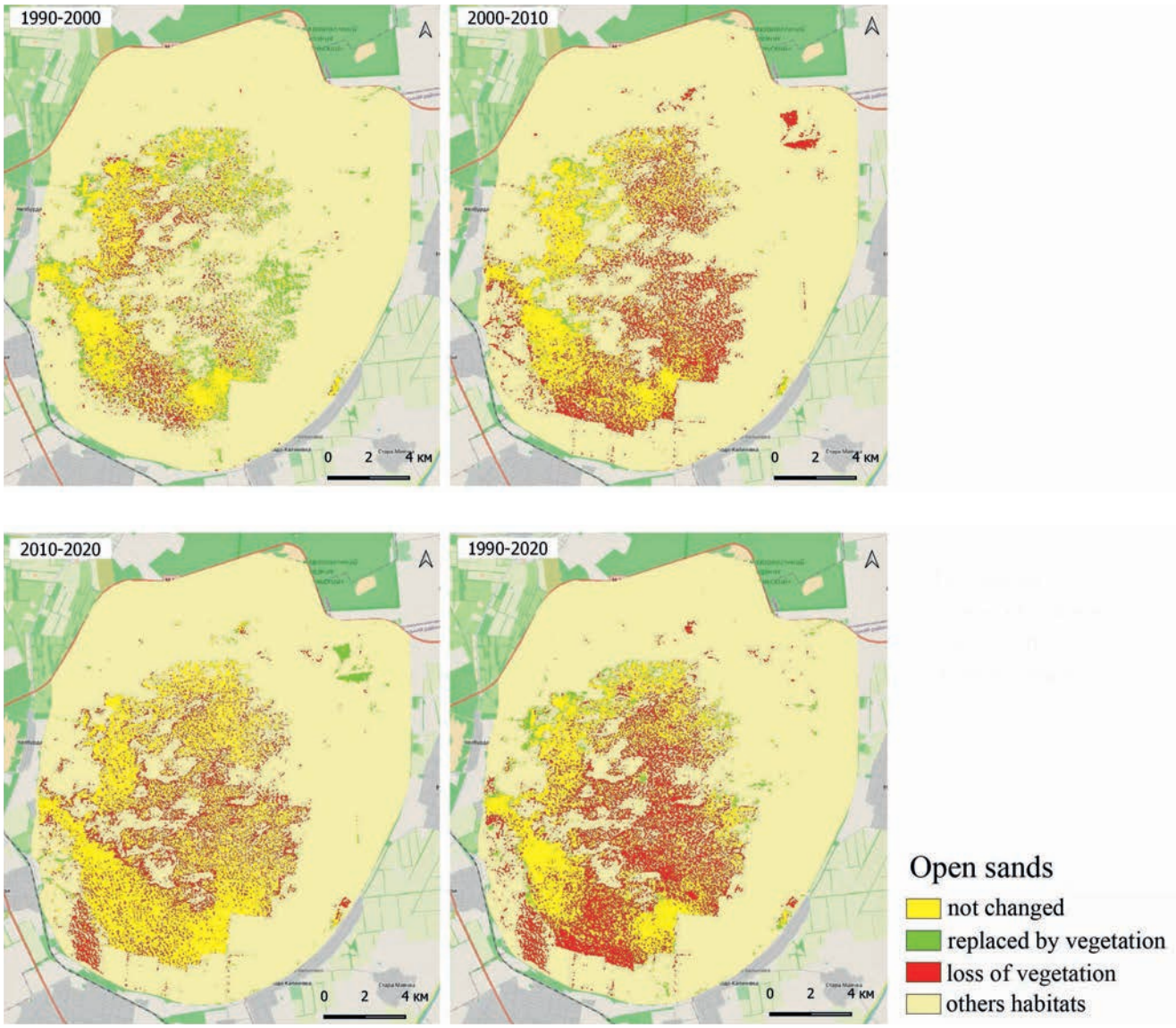

Fig. 5 Area changes of the open sands in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990–2020.

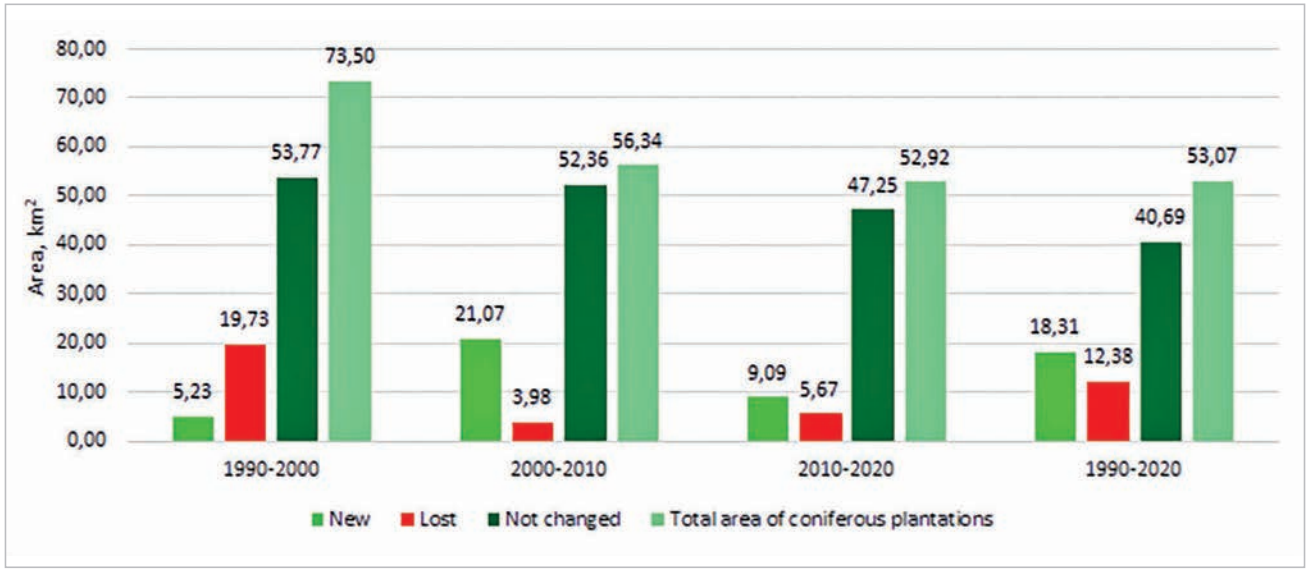

Fig. 6 Area dynamics of the coniferous plantations in the territory of Kozachelaherna arena of Low-Dnipro sands.

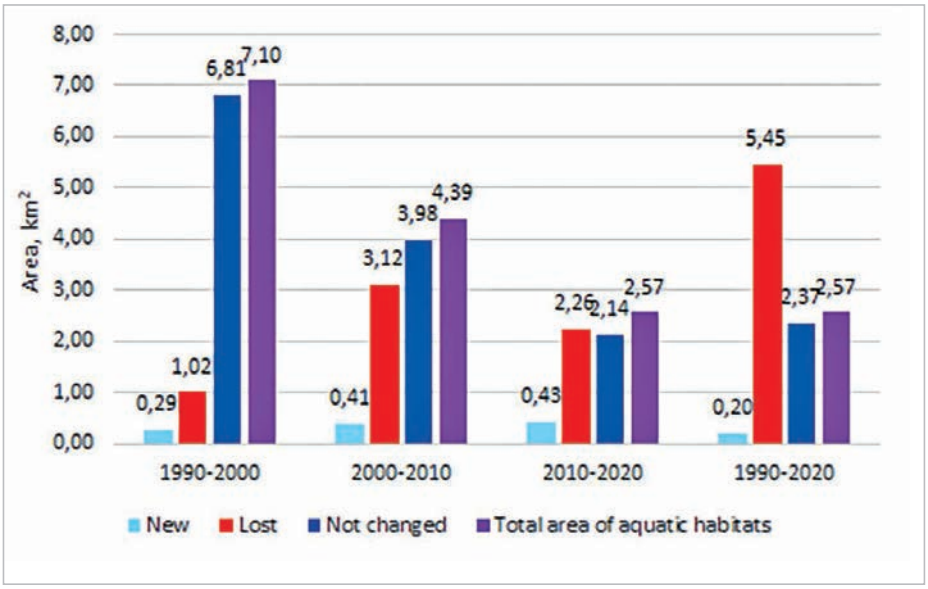

Fig. 7 Area dynamics of the aquatic habitats in the territory of Kozachelaherna arena of Low-Dnipro sands.

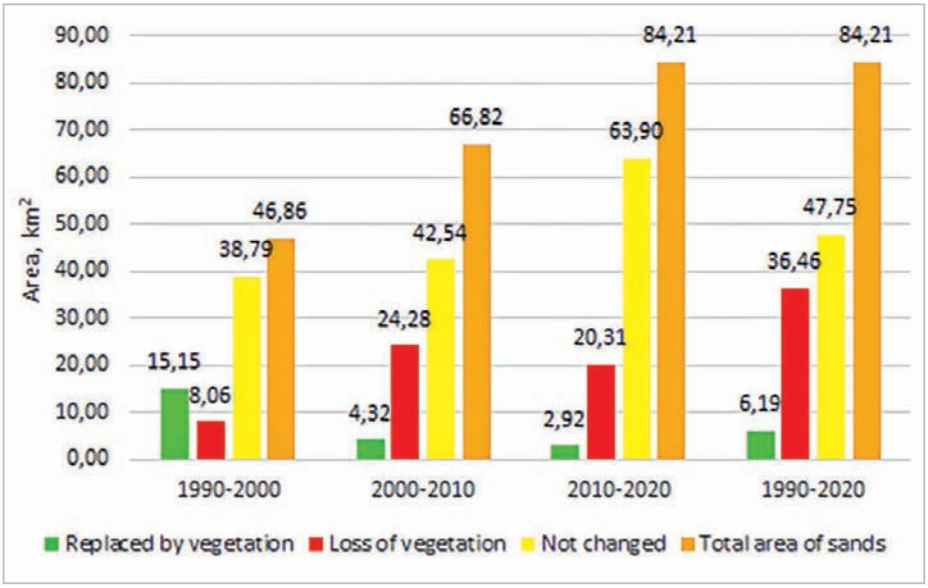

Fig. 8 Area dynamics of the open sands in the territory of Kozachelaherna arena of Low-Dnipro sands.

6. Conclusions

It was established that during thirty years of the research the total area of the coniferous plantations decreased considerably in the period of 2000–2010, and in the following period it remained relatively stable. Along with this, in the first decade the losses were well compensated due to the renewal, however in the latest decades the loss area exceeded significantly the area of the renewal of the coniferous plantations.

During thirty years the area of the large permanent aquatic habitats, located in the north-east part of the arena, decreased by 2.5 times (from 7.1 km^2 to 2.57 km^2). And in fact, their renewal does not take place. One can state that the water supply of these territories decreases constantly, probably because of the reduction of the precipitation amount and the level of the ground water.

There was a progress in the increase of the territories under open sands. During thirty years of the research the area of the open sands increased from 46.86 km^2 to 84.21 km^2. At the same time, the process of the overgrowing of the sands with vegetation slows down gradually, and the vegetation losses increase constantly. Most likely it is connected with the tendency towards aridization of the climate in the south of Ukraine. Over time, this may lead to the replacement of habitats characteristic of sandy steppes with habitats of open sands.

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The chronological account of the impact of tropical cyclones in Nicaragua between 1971 and 2020

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ABSTRACT

This article provides a chronological account of the occurrence and impact of tropical cyclones in Nicaragua between 1971 and 2020. While previous research has indicated potential associations between climate change and the higher frequency of intense hurricanes, no known empirical research has focused on systematizing the chronology of the significant tropical cyclones to identify patterns of change in Nicaragua. Therefore, the principal objective of this project was to develop a general overview of the major tropical storms and hurricanes that occurred between 1971 and 2020, triggering disasters in Nicaragua. The empirical data was collected from various documents via qualitative and interpretative methodology. It included reviewing research articles, books, academic websites, databases, documents, credible reports of international organizations, and newspaper sources. This study identified that from 1971 to 2020, Nicaragua was affected by 22 tropical cyclones, which caused catastrophic damage to the territory. There are records of 17 Category 1–5 hurricanes, predominating Category 4, one with no class associated, and four tropical storms. Mitch, Felix, and Joan were the most damaging hurricanes that affected the country in the last five decades. They occurred in 1998, 2007, and 1988, respectively. Of the 22 tropical cyclones, 15 occurred during Cold ENSO, whereas only three in Warm ENSO, and four were neutral. Empirical results presented can be of value to future research on disaster risk reduction.

KEYWORDS

tropical cyclones; hurricanes; tropical storms; Nicaragua; disaster risk; disasters; integrated disaster risk management

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1. Introduction

Central America and the Caribbean (CAC) is one of the regions most threatened and affected by various natural and socio-natural hazards (earthquakes, volcanic eruptions, landslides, floods, etc.). Tropical Cyclones (TCs) are one of the most significant hazards that occur every year. Nicaragua is no exception; disasters caused by hazards, primarily floods, and landslides associated with hurricanes and TSs, are frequent. Nicaragua's climatic exposure derives from its geographical position, given its location between latitudes 11° and 15° North, where several complex meteorological systems converge that cause rain and atmospheric phenomena common to all the tropical countries of the Caribbean Basin. The amount of precipitation depends on the different atmospheric systems; its distribution is mainly due to local factors such as the relief and the orientation of the coasts that mark the differences in precipitation between the Pacific and Atlantic coasts (Incer et al. 2000).

The rapidly increasing and unplanned urban population growth, along with the establishment of informal settlements in lower basins and valleys in Nicaragua, often mirroring the vulnerability of its inhabitants produced mainly by poverty and inequality, have amplified people's exposure to flooding and the consequent impact of associated disasters (GFDRR 2010).

Estimations provided by the World Bank suggest that between 1994 and 2013, in Nicaragua, hydrometeorological triggered disasters involved annual losses of US$301.75 million, much the same as ana yearly loss of 1.71% of its gross domestic product (GDP). These numbers indicate the potential significance of major disaster events in the government's effort to end extreme poverty and face the threat of overturning development (World Bank 2021).

Moreover, the country continues to face significant economic vulnerabilities, for example, high public debt levels, the external deficit of its current account, and the large dollarization of its economy (ALADI 2009). In addition, the territory is suffering alterations, such as environmental degradation, that have consequences in the present and are projected to future generations. Disasters and the effects of human activity on the environment affect the quality of life and the population's options since they impact physical, human, and social assets through mortality, loss of housing and infrastructure, or temporary or permanent migration (CEPAL 2002).

According to the Inform Annual Report 2021, considering a rating between 0 and 10, Nicaragua has a risk profile of 4.6, in other words, a medium risk index. While its index of vulnerability and exposure and lack of coping capacity is 5.3, the index for vulnerability is 3.5, and for disasters related to natural hazards is 6.6. (Tab. 1) (Inter-Agency Standing Committee and the European Commission 2021).

Although the risk index of Nicaragua for floods is medium (5.1), the continuous debilitating effects of disasters caused by TCs in the territory have undermined the country's ability to recover, as mirrored by hurricane Mitch in 1998 and, most recently, Eta and Iota in 2020.

Future flood scenarios are of great concern and have been recognized in the last few decades. It has been suggested that the current 'warming of the

Tab 1. Nicaragua risk profile.

INFORM RISK	4.6	Inequality	5.7
3-year trend	Stable	Economic dependency	2.4
Rank	60	Vulnerable groups	1.6
Reliability Index*	3.6	Uprooted people	0.9
HAZARD & EXPOSURE	5.3	Health conditions	1.0
Natural	6.6	Children U5	1.2
Earthquake	9.5	Recent shocks	1.9
Flood	5.1	Food security	4.5
Tsunami	8.1	Other vulnerable groups	2.3
Tropical cyclone	3.6	**LACK OF COPING CAPACITY**	5.3
Drought	4.1	Institutional	6.0
Epidemic	5.9	Disaster Risk Reduction	4.7
Human	3.6	Governance	7.2
Projected conflict risk	5.1	Infrastructure	4.5
Current highly violent conflict intensity	0.0	Communication	4.1
VULNERABILITY	3.5	Physical infrastructure	5.0
Socio-Economic Vulnerability	5.0	Access to healthcare	4.4
Development & Deprivation	6.0	* Reliability Index: more reliable 0-10 less reliable	

Source: Inter-Agency Standing Committee and the European Commission 2021).

climate system is unequivocal' (IPCC 2007); and that the frequency of intense hurricanes will likely increase with future climate change (IPCC 2012). Similarly, data from several studies have identified that such an increase could result in more intense storms over the next 50 years (Bender et al. 2010; Done et al. 2012; IPCC 2012). Indeed, the presence of hurricanes categories 4 and 5 considerably impacts countries with high vulnerability and exposure, such as Nicaragua.

Matinez et al. (2023) recently suggested an increase in significant hurricane occurrence and intensity in the North Atlantic and Northeast Pacific basins from 1970 to 2021. They argued that most interannual variability could be attributed to physical variables in the North Atlantic basin, comprising Vertical Wind Shear (VWS), Atlantic Multidecadal Oscillation (AMO), and El Niño-Southern Oscillation (ENSO), particularly with La Niña phases. In contrast, the critical variables in the Northeast Pacific basin are sea surface temperatures, relative humidity, and Trans-Niño Index.

It has also been shown that CAC faces significant challenges associated with climate change. Projections of the number of people at risk of future displacement by climate change and sea level rise in this region range from tens of millions to hundreds of millions by the end of this century, depending on the level of warming and conditions of exposure. As such, the influence of climate change on temporary, seasonal, or permanent migration leads to compounding people's exposure and vulnerability. This is highly associated with the impact of disasters triggered by precipitation from hurricanes and TSs. Consequently, population groups in the most vulnerable areas exposed to cascading risks, including Nicaragua, urgently need improved adaptive capacity (IPCC 2022).

Additionally, significant concerns on water security, severe health effects due to increasing epidemics, in particular vector-borne diseases, coral reef ecosystems degradation due to coral bleaching, food security due to frequent and extreme droughts, along with damages to lite and infrastructure due to floods, landslides, sea level rise, storm surges, and coastal erosion are also derived from climate change (IPCC 2023).

In the COVID-19 pandemic, the severe impact of hurricanes Eta and Iota in 2020 called for a detailed examination of these phenomena through time. This goes hand in hand with the fact that disaster risk knowledge is an essential component of integrated disaster risk reduction and the first step to understanding disaster risk. Likewise, this effort also concerns one of the Sendai Framework for Disaster Risk Reduction guiding principles, emphasizing that attention should be given to multi-hazard approaches and inclusive risk-informed decision-making (UNISDR 2015).

What is clear is that human-caused climate change is already having a considerable impact on weather and climate extremes in every region of the world, and Nicaragua, as all the other vulnerable communities that have in the past contributed to a lesser extent to current patterns of climate change, are excessively affected (IPCC 2023).

Studying the occurrence and impact of disasters triggered by hurricanes and TSs has grown in importance and has contributed genuinely and significantly to understanding disaster risk worldwide. Likewise, hazard knowledge has been acknowledged as a critical element in such an endeavor. However, until now, at the national level, little importance has been given to systematizing information about the historical occurrence of TSs and hurricanes in Nicaragua.

It is contended that in countries such as Nicaragua, lack of information is one of the first reasons for a weak interface between science and the policy domain to improve the decision-making ability of disaster risk management. Therefore, as a first step to such a challenge, the main objective of this work is to present a general overview of the significant TSs and hurricanes between 1971 and 2020, triggering disasters in Nicaragua and widening the gap towards the sustainable development of the country and the region.

2. Study area

Nicaragua is in the northern hemisphere, between 11°–15° north latitude and 83°–88° west longitude. It is in the middle of the Central American isthmus. It comprises 15 departments and two autonomous regions,

Fig. 1 Location map of Nicaragua.

the North and South Atlantic Autonomous Regions. The Nicaraguan territory has an approximate area of 130,370 km^2, which makes it the largest country in Central America (CA). Its climate is mainly influenced by the two oceans surrounding it, from which air masses loaded with moisture produce little precipitation until the formation of TCs (Incer et al. 2000) (Fig. 1).

It has a tropical climate with slight seasonal variation in temperature, ranging between 21–27 °C. It is characterized by two rainfall seasons: the 'wet' season occurs between May and October, whereas the 'dry' season is from November to April. The 'Canícula' is a dry period that regularly interrupts the wet season during late July and early August. Owing to its geographic location in the path of Pacific cyclones and Atlantic hurricanes, the territory is subject to increased rainfall intensity and strong winds from July–October. El Niño Southern Oscillation (ENSO) fluctuations during June and August bring relatively warmer, drier, colder, and wetter conditions, respectively (CCKP-World Bank n.d.).

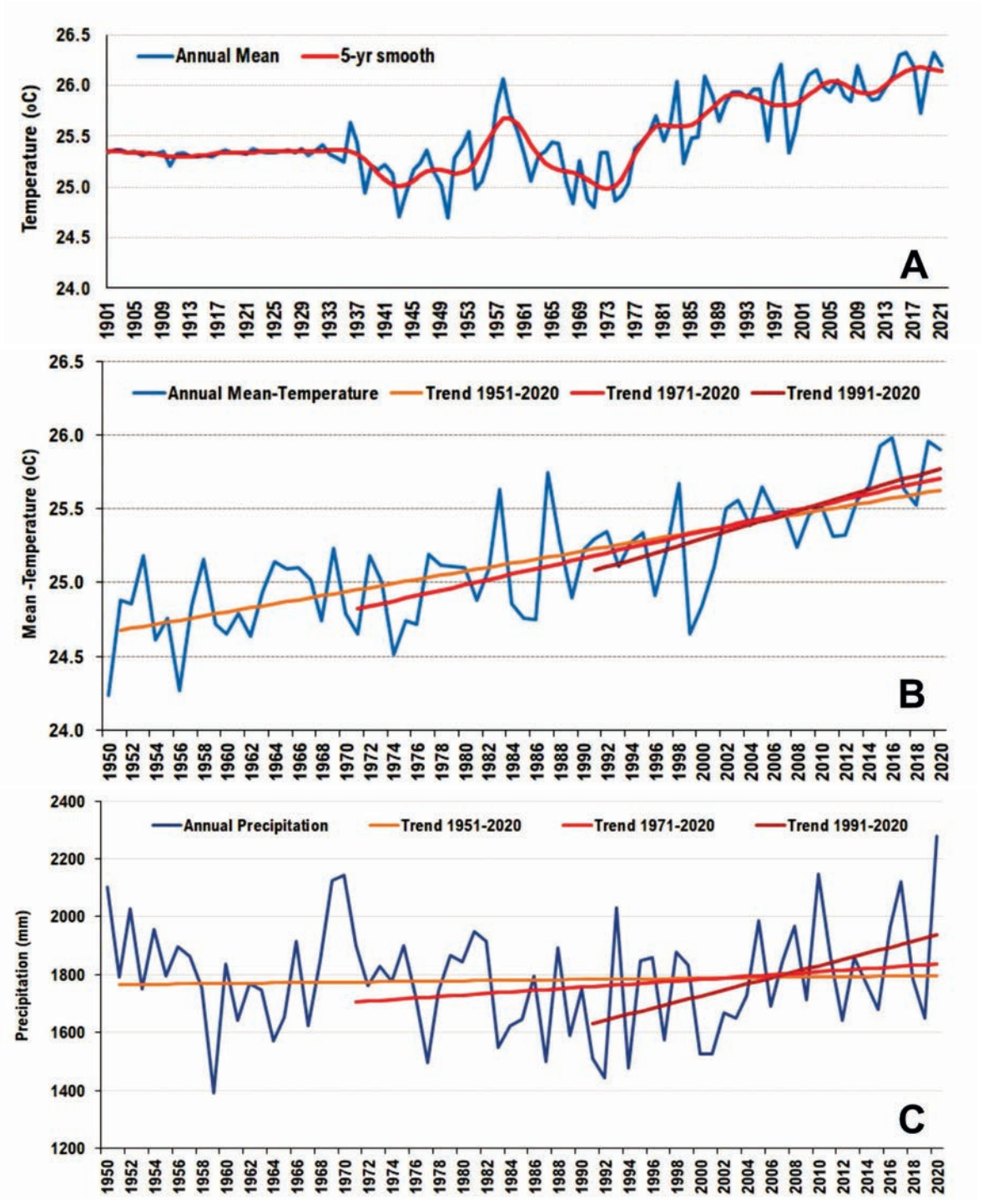

Fig. 2 Observed average annual mean-temperature for 1901–2021 (upper graph), mean-temperature annual trends (middle chart), and mean-precipitation annual trends (lower graph) with the significance of trend per decade and in Nicaragua.
Source: CCKP-World Bank n.d.

The population of Nicaragua is more than six million inhabitants (three million men and three million women), and its economically active population is 3,017,985 (World Bank 2021). Most economic activities occur in the Pacific coast's lowlands; the Atlantic coast is less developed, lacks infrastructure, and has forestry, fishing, and mining resources. The country has a long agricultural tradition on which it has based its economy, generating the main export crops (coffee, sugar cane, cotton, bananas, sesame, and peanuts) and domestic consumption (rice, beans, corn, and sorghum) (ALADI 2009).

As for any part of the world, in Nicaragua, the emergence of the climate change signal over the historical period increases towards the present. The annual mean temperature from 1901 to 2020 shows a clear increasing tendency (Fig. 2A). The minimum annual mean temperature was recorded in 1943 and 1950 (24.7 °C), whereas the maximum of 26.3 occurred in 2015, 2016, and 2020. The intensification of the forced change over the natural variability can be identified by comparing an entire period with trends over more recent intervals. Accordingly, the three trend lines, 1951–2020, 1971–2020, and 1991–2020 (Fig. 2B), represent progressive trends toward present-day temperature variables in Nicaragua. Precipitation records in the last decade show trends ranging from 1631.3 mm in 1991 to 1936.3 in 2020 (Fig. 2C) (CCKP-World Bank n.d.).

Monthly anomalies of mean temperatures over longer-term time horizons using a 10-year averaging for Nicaragua are illustrated in Tab. 2. The difference in magnitude across the seasons shows higher anomalies in 2011–2022, particularly in July, August, and September.

Mean monthly precipitation trends by decades are also a good indicator of change; downward trends associated with predominant natural variability contrast those of anthropogenic nature. In the case of Nicaragua, these trends are illustrated in Tab. 3. Increasing trends were found mainly in 2011–2020, with October being the month with the highest increase and January, August, November, and December through several decades.

3. Methods

This paper employs a qualitative and interpretative design of a documentary type, which is empirical in nature. The analysis domain for this investigation is spatially restricted to Nicaragua during 1971–2020. Best historical storm and hurricane tracks were obtained from the Hurricane Research Division of the National Oceanic and Atmospheric Administration database HURDAT2 (1971–2020). Essential core data on the occurrence and effects of disasters in Nicaragua was retrieved from the Emergency Events

Tab. 2 Mean monthly temperature trends by decades in Nicaragua. Source: CCKP-World Bank n.d.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011–2020	0.50	0.52	0.23	0.48	0.40	0.54	0.70	0.64	0.61	0.52	0.54	0.60
2001–2010	0.30	0.34	0.30	0.27	0.14	0.28	0.30	0.33	0.35	0.38	0.10	0.33
1991–2000	0.10	0.09	−0.03	0.13	−0.03	−0.01	0.03	−0.07	−0.05	−0.04	0.03	0.01
1981–1990	−0.12	−0.02	0.00	−0.03	0.11	0.00	−0.19	−0.12	−0.17	−0.11	0.11	0.03
1971–1980	−0.21	−0.31	−0.18	−0.37	−0.09	−0.24	−0.13	−0.29	−0.26	−0.17	−0.07	−0.32
1961–1970	−0.15	−0.16	−0.05	−0.27	−0.14	−0.22	−0.19	−0.17	−0.26	−0.22	−0.38	−0.23
1951–1960	−0.43	−0.47	−0.28	−0.21	−0.39	−0.37	−0.52	−0.33	−0.21	−0.36	−0.34	−0.41

−0.4 **−0.2** **0** 0.2 0.4 0.6 0.8

Tab. 3 Mean monthly precipitation trends by decades in Nicaragua. Source: CCKP-World Bank n.d.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011–2020	0.47	4.67	4.98	2.77	30.88	0.00	−32.21	−10.76	2.87	44.14	22.60	9.30
2001–2010	−1.49	−0.28	−1.20	−1.61	29.46	−11.66	6.31	14.63	−9.37	−10.63	4.01	−6.49
1991–2000	−5.81	−3.75	−5.85	−7.98	−17.27	−4.68	−13.95	0.38	1.02	−10.93	−4.61	−9.57
1981–1990	−4.49	1.46	−1.05	−10.60	−19.50	−8.96	19.11	12.08	−1.44	−30.20	−18.79	2.34
1971–1980	3.66	−1.65	1.92	8.40	−18.23	−9.00	−1.94	5.14	24.65	−7.17	8.86	−11.05
1961–1970	6.38	−1.72	5.31	11.94	−14.90	10.88	−14.71	−17.78	7.30	15.71	6.13	7.84
1951–1960	1.27	1.27	−4.10	−2.92	9.55	23.42	37.40	−3.70	−25.03	−0.92	−18.19	7.62

−40 **−30** **−20** −10 0 10 20 30 40 50

Database (EM-DAT) database launched by the Centre for Research on the Epidemiology of Disasters (CRED) EM-DAT (1971–2020).

To establish the chronology of TCs that affected Nicaragua, the trajectory segments of the hurricanes in the base of Hurdat2 (1971–2020) were imported into a Geographic Information System (GIS). The Hurdat2 data on which the description was based include the post-tropical phases of storms that started as TCs. Data imported to the GIS included recording the specific dates on which they affected the territory considering its intensity, record of maximum speed reported (m/s), and pressure (Pa).

To conduct this empirical study, research articles, books, academic websites, databases, documents, credible reports of international organizations, and newspaper sources were reviewed and searched based on the aim of the investigation. The information corresponding to those TCs classified as hurricanes and some TSs that have caused disasters in the Nicaraguan territory throughout its five decades of history was extracted from the NOAA HURDAT database. Information on the impact of disasters associated with hurricanes was recollected from EM-DAT. Additionally, due to the limited information available on TCs from a historical perspective, a review of technical reports from SINAPRED (National System for Disaster Prevention, Mitigation, and Attention) and newspaper archives was conducted.

4. Results

Nicaragua has historically been affected by hydrometeorological phenomena; 170 events were recorded in the 20th century. Data after 1900 is only found in references in colonial reports and chronicles. It is known that, since the discovery of America, 216 hurricanes have directly and indirectly affected the Nicaraguan territory. Of all, 90 are from this century, and half arrived directly on the coast. In the last thirty years, climatic phenomena have been the most frequent threat in Nicaragua (Incer et al. 2000). From 1971 to 2020, Nicaragua was affected by 22 TCs, which caused catastrophic damage to the territory. Of these TCs, there are records of 17, with a predominance of Category four and one with no class associated, along with four TSs (Alleta, Bret, Alma, and Matthew) (Tab. 4).

Tab. 4 Hurricanes and TSs that triggered disasters in Nicaragua from 1971 to 2020. Source: compiled from HURDAT database.

Name	Typology	Date	Maximum winds (m/s)	Pressure (Pa)	Category
Period 1971–1980					
Edith	H	September 5–17, 1971	72	94,300	5
Irene	H	September 16–20, 1971	34	98,900	1
Fifí	H	September 14–22, 1974	49	97,100	2
Period 1981–1990					
Alleta	TS	May 22–28, 1982	26	–	–
Joan	H	October 10–23, 1988	64	93,200	4
Period 1991–2000					
Bret	TS	August 4–11, 1993	20	100,200	–
Gert	H	September 14–21, 1993	44	97,000	2
Cesar-Douglas	H	July 24–29, 1996	38	98,500	4
Mitch	H	October 22–November 5 1998	80	90,500	5
Keith	H	September 28–October 6, 2000	59	93,900	4
Period 2001–2010					
Michelle	H	October 29–November 5 2001	62	93,300	4
Isidore	H	September 14–27, 2002	56	93,400	3
Stan	H	October 1–5, 2005	36	97,700	1
Beta	H	October 26–31, 2005.	51	96,200	2
Félix	H	August 31–September 5, 2007	72	93,400	5
Alma	TS	May 30, 2008	28	99,980	–
Ida	H	November 4–10, 2009	36	98,500	1
Matthew	TS	September 23, 2010	26	99,800	–
Period 2011–2020					
Otto	H	November 20–26, 2016	51	97,500	3
Nate	H	October 4–8, 2017	41	98,100	1
Eta	H	October 3–November 13, 2020	67	92,200	4
Iota	H	November 13–18, 2020	46–69	91,700	5

H: Hurricane, TS: Tropical Storms

4.1 Decadal impact of hurricanes

4.1.1 Period 1971–1980

4.1.1.1 Hurricane Edith

Hurricane Edith was the strongest hurricane (Category 5) that formed during the 1971 Atlantic hurricane season. It was first observed on September 2, near 12° N and 35° W. On September 8, Edith reached hurricane strength with sustained winds of 33 m/s and a central pressure of 99300 Pa. Edith's trajectory was controlled by a narrow, high-pressure ridge that extended from the southern Atlantic to the south of the Gulf of Mexico and protected it from southern currents that would have turned it north. It is worth mentioning that the behavior of Hurricane Edith was like that of Hurricane Camille (1969) and Celia (1979). Riehl (1979) considered that this phenomenon is because the transformation in the upper troposphere may be the source of the baroclinic release of energies that cause explosive deepening in some hurricanes (Fig. 3A) (National Hurricane Center 1997a).

This hurricane entered Nicaraguan territory with winds of 80 m/s and pressure of 94,300 Pa, affecting the North Atlantic Autonomous Region (RAAN). The highest accumulations of precipitation during this event were in Corinto (178 mm), Rivas (170 mm), and Chinandega (111 mm) (INETER 1998). In addition, 80 deaths were reported, 600 houses were destroyed, and approximately 4,000 people were without food. Two fishing boats sank, large banana plantations were destroyed, and Cabo Gracias a Dios was held incommunicado for several days. In Chinandega, several communities were flooded (El Nuevo Diario 2005).

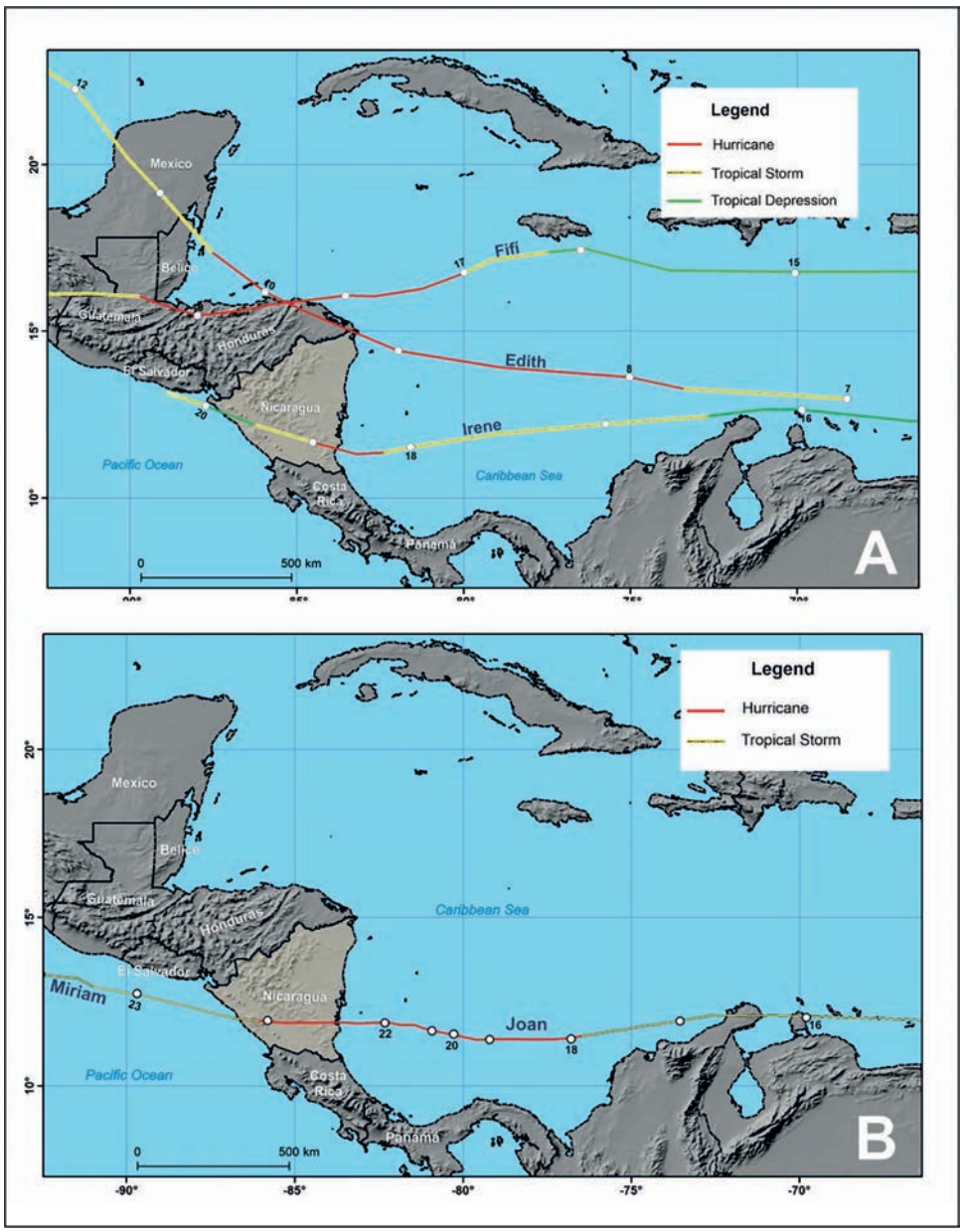

Fig. 3 The trajectory of hurricanes in Nicaragua in 1971–1980 (A) and 1981–1990 (B). Source: *HURDAT database*.

4.1.1.2 Hurricane Irene

A week after Hurricane Edith affected Nicaraguan territory, between September 16 and 20, 1971, the country was again impacted by another hurricane called Irene. This hurricane affected the South Atlantic Autonomous Region (RAAS), specifically in Punta Gorda, Bluefields (Fig. 3A). The highest accumulations of precipitation during the five days of affectation of this event were recorded in Rivas (212 mm), Corinto (200 mm), and Bluefields (192 mm). Its winds were 27.7 m/s, destroying 27 houses in Bluefields and San Juan del Norte (Consorcio ERN America Latina n.d.). In the department of Rivas, two people died due to the floods; 1,500 affected people were reported (INETER 1998).

4.1.1.3 Hurricane Fifi

Fifi was the third hurricane to form in the 1974 Atlantic hurricane season. Between September 14 and 22, Hurricane Fifi penetrated the southern part of Honduras, reaching hurricane strength with sustained winds of 49 m/s and a central pressure of 97,100 Pa. Hurricane Fifi is among the most devastating hurricanes that have hit the Western Hemisphere, with Honduras being the country where it caused the most significant disaster (National Hurricane Center 1997b) (Fig. 3A). In Nicaragua, heavy rainfall was generated, causing floods throughout the country. Some communities were isolated, and some houses were destroyed, mainly near the Honduras border. The highest daily precipitation values during this event were recorded on day 18. The highest accumulated precipitation corresponded to the Corinto (635 mm), León (530 mm), and Chinandega (368 mm) stations (INETER 1998).

4.1.2 Period 1981–1990

4.1.2.1 Tropical Storm Alleta

Even though TS Alleta did not cross Nicaraguan territory, it indirectly affected the Pacific and Central regions of the country from May 22 to 28, 1982. The most intense precipitation occurred on days 23, 24, and 25. The highest totals accumulated during the event were recorded in the departments of Chinandega (1,457 mm), León (1,002 mm), and Corinto (896 mm) (INETER 1998).

This TS caused the death of 108 people, and at least 20,000 people were left homeless. It caused flooding in some cities such as Managua, León, and Masaya in the Pacific sector. In western Nicaragua, 90% of the banana and 60% of the corn crop were destroyed. In the North region, it affected the departments of Boaco, Matagalpa, and Chontales (La Prensa 1982). USD$465 million in losses were estimated (The Leader-Post 1982).

4.1.2.2 Hurricane Joan

In 1988, the path of Hurricane Joan across the southern tip of the Caribbean was unusual. It is infrequent for a TS to transit the northern coast of South America, passing directly over Curacao in the Netherlands Antilles and the Guajira peninsula of Colombia. Earlier this century, only a 1933 TS did so, although the tracks of Edith and Irene in 1971 were only slightly north of that area (National Hurricane Center 1988).

Hurricane Joan reached the strength of a Category 4 hurricane on the Saffir-Simpson Scale on October 17 as it moved away from Colombia. On the 20th, Joan weakened, made a turn, and then resumed its westward motion and strengthened. It is estimated that the central pressure reached a minimum of 93,200 Pa at landfall on the Nicaraguan coast on October 22. Based on satellite imagery, Joan is calculated to have weakened to a TS before emerging over the Pacific Ocean on October 23. Joan was renamed Miriam upon entering the eastern Pacific Ocean basin and El Salvador and Guatemala coast. On October 28, it began to dissipate south of Acapulco, Mexico, to become a tropical depression and finally dissipated on November 2, 1988 (National Hurricane Center 1988) (Fig. 3B). The highest accumulated precipitation was recorded at the Managua (227 mm), Nandaime (215 mm), León (210 mm), Rivas (186 mm), and Juigalpa (182 mm) stations (INETER 1998).

According to press articles and reports from the Nicaraguan Embassy in Washington, D.C., Joan passed through Bluefields, causing many of the city's 6,000 houses to blow up or lose their roofs, and most of the main buildings were destroyed. There were 148 dead, 184 seriously injured, 100 missing, and 1missingshomeless throughout Nicaragua and the coastal island. Some 23,000 homes were destroyed, and another 9,000 were damaged. Approximately 15,700 cattle, 20,000 pigs, and 456,000 chickens died (El Nuevo Diario 1988a).

The rising waters destroyed 30 bridges and left another 36 seriously damaged. Some 404 miles of road sections were destroyed. In Nicaragua, approximately 120,000 people were evacuated. In addition, the most affected places in the rural sector were San Francisco Libre, Tipitapa, Ticuantepe, and El Crucero. In Bluefields, 100% of the power lines and telephone services were destroyed (El Nuevo Diario 1988b; 1988c). The Nicaraguan Embassy in Washington D.C. estimated the damage in Nicaragua at 840 million dollars (National Hurricane Center 1988).

A total of US$165.6 million in damages was estimated for transportation and communication. In the productive sector (agriculture, livestock, industry, and commerce), US$134.11 million in losses was estimated, US$161.75 million in natural resources, and US$347.21 million in the social sector (CEPAL 1988).

4.1.3 Period 1991–2000

4.1.3.1 Tropical storm Bret

TS Bret was the second to receive a name in the 1993 Atlantic hurricane season. On August 1, a tropical wave moved off the west coast of Africa, the system

that gave rise to Bret. On August 10, Bret strengthened into a TS. According to satellite estimates, Bret's maximum winds were close to 20 m/s and a pressure of 100,200 Pa when it crossed the coast of southern Nicaragua, near Punta Gorda Bay. After moving inland, Bret turned west-northwestward after moving inland, dissipating as a TS approached the Pacific coast on August 11. The system eventually regenerated into Tropical Depression 8, which later became Hurricane Greg (National Hurricane Center 1993b) (Fig. 4A).

The heavy rains associated with Bret caused ten deaths in Nicaragua; nine occurred on the high seas near the island of Maíz when a Spanish ship sank. Forty thousand people were also reportedly affected, and 25 isolated communities and seven bridges were destroyed in Nicaragua due to Bret. Almost all crops were lost on the North Atlantic coast and San Juan del Rio Coco. It is worth mentioning that the TS warning was only 8 hours in advance for the Nicaraguan coast (El Nuevo Diario 1993a; 1993b). TS Bret generated a maximum accumulated rainfall in Managua of 117 mm (INETER 1998).

4.1.3.2 Hurricane Gert

Gert was the seventh named storm and the third Category 2 hurricane on the Saffir-Simpson Hurricane Scale of the 1993 Atlantic hurricane season, one month after TS Bret. Gert originated as a tropical depression over the southwestern Caribbean Sea. On September 14, it reached the strength of a TS before reaching the coast of Nicaragua (Puerto Cabezas) and passing through Honduras (Fig. 4A). The rains generated by Gert caused flooding (mainly near Bluefields, Tasbapauní, Rama, Rivas, Chontales,

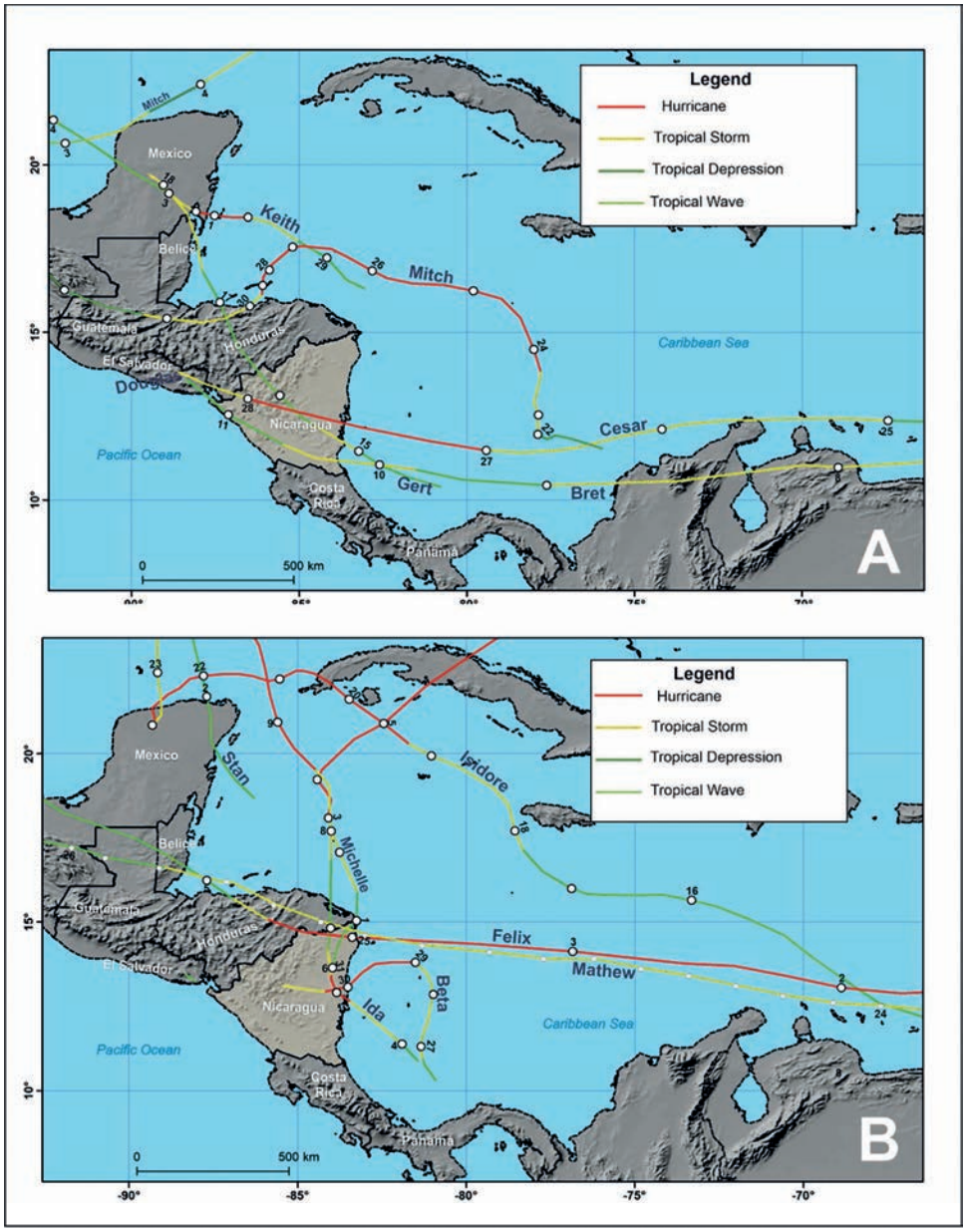

Fig. 4 The trajectory of storms and hurricanes in Nicaragua in 1991–2000 (A) and 2001–2010 (B). Source: *HURDAT database*.

and Boaco), causing the evacuation of approximately 24,000 inhabitants. In addition, the floods caused slope instability (mudslides) and damage to roads, houses, and crops (National Hurricane Center 1993a).

4.1.3.3 Hurricane Cesar-Douglas

Hurricane Cesar was the third storm of the 1996 Atlantic hurricane season. It developed into a tropical depression on July 24 as its path moved along the north coast of Venezuela. On July 27, Cesar reached the Category of Hurricane. Cesar began to strengthen more rapidly before landfall just north of Bluefields, Nicaragua, reaching its maximum intensity (38 m/s and a minimum pressure of 98,500 Pa) on July 28. Cesar crossed Nicaragua and entered the eastern North Pacific, where it re-intensified and became Hurricane Douglas (National Hurricane Center 1996) (Fig. 4A).

Hurricane Cesar generated intense rainfall, especially in the Central Pacific sectors, registering the accumulated values in Masatepe (237 mm), Nandaime (203 mm), Managua (179 mm) (INETER 1998), Bluefields (271 mm) and Corinto (208 mm) (National Hurricane Center 1996).

In Nicaragua, six people were reported dead after the passage of Hurricane Cesar, in addition to leaving 100,000 affected, 10,000 refugees, and the destruction of hundreds of homes, roads, and significant extensions of hectares of crops affected by floods in different departments of the country (El Nuevo Diario 1996a; 1996b).

4.1.3.4 Hurricane Mitch

H urricane Mitch is known for being one of the three most destructive hurricanes in the Atlantic Ocean. On October 22, a tropical depression formed south of Kingston, Jamaica. On the 24th of the same month, it became a TS, and two days later, it was classified as a Category 5 hurricane on the Saffir-Simpson scale (Consorcio ERN America Latina n.d.) (Fig. 4A).

Hurricane Mitch was the third hurricane of the century, with wind speeds greater than 79 m/s. Its cloudy spirals covered 400 km^2, encompassing CA (Incer et al. 2000) and concentrating mainly on Costa Rica, El Salvador, Guatemala, and Honduras. The affected population was approximately 3.5 million, of which 20,000 died and disappeared (ECLAC 1999, cited in Alcántara-Ayala 2009). In Nicaragua, no meteorological phenomenon caused as much damage as Hurricane Mitch. The rainfall associated with Mitch exceeded the historical rainfall produced by other hurricanes that have affected the territory (INETER 1999).

Once Hurricane Mitch made landfall in Honduras, its movement was slow for a week, causing estimated rainfall of 889 mm, mainly in Honduras and Nicaragua (National Hurricane Center 1999). Floods, landslides (Fig. 5) and a high number of deaths, damage to infrastructure (roads, health, housing, education), agricultural production, and the environment occurred (ECLAC 1999). The most affected area was the country's west (León and Chinandega). Lake Xolotlán rose 3 m (from 36.41 m above sea level on October 22, 1998, to 40.12 m on October 30), receiving approximately 3,300 million m^3 of water (Source: ECLAC 1999; Incer et al. 2000).

Fig. 5 The Casita volcano in western Nicaragua after a mudslide triggered by rainfall produced by Hurricane Mitch in October 1998. Source: USGS.

The damage generated by Hurricane Mitch on the Nicaraguan population was estimated at US$84 million in damage to facilities in the health sector, US$605.3 million in road infrastructure, US$471.1 million in housing, US$18 million in energy and electricity, US$12 million in communications, US$19.8 million in potable water and sewerage, US$51.3 million in education and US$1.1 million in the private sector. In addition, 867,752 people were affected (153,833 families); 254 were injured, 2,515 were dead, and 885 were missing (Álvarez et al. 1999).

4.1.3.5 Hurricane Keith

Hurricane Keith was the fifteenth tropical cyclone in the Atlantic. It formed on September 28, 2000, as a tropical depression, strengthening and becoming a TS the next day. Keith rapidly intensified over the northwestern Caribbean Sea and reached Category 4. In addition, the slow movement of Keith caused torrential rains in CA, mainly in Belize (National Hurricane Center, 2000) (Fig. 4A).

According to reports from the Meteorological Service and the media, the death toll was 12 in Nicaragua; in addition to hundreds of isolated communities, hundreds of families evacuated, and thousands of blocks of crops (corn, bananas, pastures) flooded (National Hurricane Center 2000; El Nuevo Diario 2000).

4.1.4 Period 2001–2010

4.1.4.1 Hurricane Michelle

The origin of Michelle was a tropical wave that moved west along the coast of Africa on October 16, 2001.

Squall activity increased on October 26 when it reached the Western Caribbean and a large area of low pressure near the coast of Nicaragua. On October 29, it became a tropical depression off the coast of Nicaragua, between Puerto Cabezas and Bluefields. On November 4, it became a Category 4 hurricane on the Saffir-Simpson scale, passing over Cuba (Fig. 4B). Michelle's slow initial movement caused widespread heavy rains in eastern Nicaragua. Press reports indicate that Nicaragua's deaths were 6, 12 missing people, more than a thousand affected, and almost 6,000 evacuees (National Hurricane Center 2001; El Nuevo Diario 2001).

4.1.4.2 Hurricane Isidore

Hurricane Isidore was the second hurricane in the 2002 Atlantic hurricane season. Isidore peaked as a Category 3 hurricane causing damage in Jamaica, Cuba, Mexico, and the United States. Hurricane Isidore had a slow movement (National Hurricane Center 2002) (Fig. 4B). In Nicaragua, Hurricane Isidore generated floods, causing damage to the road network, incalculable losses in the agricultural sector, undermining bridges, and evacuating numerous families. The most affected departments were Rivas (municipality of Tola and Belén), Managua, León, and Chinandega, and the municipalities of Masatepe and Nandaime (El Nuevo Diario 2002a; 2002b; 2002c).

4.1.4.3 Hurricane Stan

Category 1 Hurricane Stan generated flooding, landslides, and strong winds along its path in CA and Mexico. Stan quickly intensified into a hurricane on October 4, 2005, dissipating on October 5 over the terrain of the Mexican state of Oaxaca. It was the tenth hurricane of the Atlantic Ocean hurricane season (National Hurricane Center 2005) (Fig. 4B).

In Nicaragua, Hurricane Stan affected 2,470 people (467 families), of which 1,508 were evacuated. Homes affected included 14 destroyed, 50 semi-destroyed, and 359 flooded, in addition to 3 deaths. The departments most affected by Stan's rains were León, Chinandega, Managua, Granada, Matagalpa, and the municipality of Rosita in the North Atlantic Autonomous Region (RAAN) (SINAPRED 2005).

4.1.4.4 Hurricane Beta

From October 27 to 31, 2005, Nicaragua was directly affected by Hurricane Beta. The Executive Secretariat of the National System for Disaster Prevention, Mitigation, and Response (SINAPRED) informed the Nicaraguan population that Tropical Depression No. 26 evolved into a TS. According to Law 337, a Yellow Alert is declared for the Autonomous Region of the North Atlantic (RAAN), the Autonomous Region of the South Atlantic (RAAS), and the Center-North of the Country.

On October 30, the hurricane's center made landfall near La Barra del Río Grande, north of Laguna de Perla, on the central coast of Nicaragua, and moving in a north-westerly direction, which is why it reached Hurricane Category 2 on the Saffir-Simpson hurricane scale. This is the seventh and last hurricane of the Atlantic season. Beta turned west and dissipated over western-central Nicaragua on October 31 (SINAPRED 2005) (National Hurricane Center 2006) (Fig. 4B).

SINAPRED, in coordination with the Civil Defense General Staff, reported that on October 27 from 4:00 p.m. and until November 1 at 4:00 p.m., a state of yellow alert was declared in the areas of the Autonomous Region of the North Atlantic, Autonomous Region of the South Atlantic, Center and North of the Country. In Puerto Cabezas, there was total precipitation of 162.306 mm, with 131.064 mm falling in 6 hours on October 29 (National Hurricane Center 2006).

In the South Atlantic region, 2,580 people (430 families) were evacuated, while 4,780 (637 families) were evacuated in the North Atlantic Autonomous Region. In addition, the total forestry potential area affected was estimated at 33,816 hectares and 250 hectares of lost crops (cassava, corn, beans, and plantains). Also reported were 76 destroyed homes and 430 semi-destroyed (roof, window, and door repairs), and three destroyed docks. International aid was received from countries such as Germany, Denmark, Japan, the United States, France, and organizations including WFP, UNDP, UNICEF, and FAO (SINAPRED 2005).

4.1.4.5 Hurricane Felix

Category 5 Hurricane Felix caused significant damage in the Northeast of Nicaragua. On September 4, 2007, at 04:45 local time, it impacted the Nicaraguan Caribbean Coast 51 km north of Bilwi, North Atlantic Autonomous Region (RAAN). Felix is estimated to have recovered to Category 5 just before landfall near Punta Gorda, Nicaragua (1200 UTC, 4 September). After landfall, Félix rapidly weakened to a TS over northern Nicaragua (Fig. 4B and Fig. 6) (National Hurricane Center 2007).

The total precipitation between August 31 and September 5 was 180.594 mm in Puerto Cabezas (National Hurricane Center 2007). The data on the impact of Hurricane Felix in Nicaragua were as follows: 198,069 people were affected, corresponding to 33,687 families; 300 dead, of which 102 were official, 67 were identified, and 35 were unidentified; 133 disappeared and 106 notarized; 20,344 homes affected; 102 schools, 84 public buildings, and 57 churches; the total affectation was 1,394,218 hectares destroyed; of these, 86,538 ha are for agricultural use. The affectation of the wetlands and the forest area was approximately 1,394,218 ha in the RAAN (Miranda 2010). The Government of Nicaragua decreed a state of disaster for the territory of the RAAN (Region Autónoma del Atlántico Norte), as several towns were destroyed (El Nuevo Diario 2007).

Fig. 6 Citizens of Puerto Cabezas rush to get supplies and meals after Hurricane Felix. Source: U.S. Navy photo by Mass Communication Specialist 2nd Class Zachary Borden.

4.1.4.6 Tropical Storm Alma

On May 30, 2008, originated in the Pacific Ocean, Tropical Depression 1 evolved into TS Alma, entering Nicaraguan territory near León. At this point, Alma's maximum winds were close to 27.5 m/s, and a pressure of 99,400 Pa. Alma mainly affected the departments of León, Chinandega, Managua, Masaya, Carazo, Granada, and Rivas (ReliefWeb 2008). After crossing the coast of Nicaragua, Alma began to weaken, but it maintained TS strength as it moved toward southern Honduras (National Hurricane Center 2008). Alma caused damage to the housing infrastructure, as well as damage to bridges and the suspension of essential water and energy services (Fig. 4B) (El Nuevo Diario 2008a; 2008b).

4.1.4.7 Hurricane Ida

Ida was a late-season 2009 hurricane that significantly impacted the eastern coast of Nicaragua. It is estimated that the depression became a TS on November 4 while moving slowly toward the Northwest, toward the coast of Nicaragua. On November 5, additional intensification occurred, and Ida became a Category 2 hurricane on the Saffir-Simpson scale six hours after Ida made landfall on the eastern coast of Nicaraguan territory. Ida weakened as it moved north over the mountains between the Nicaraguan and Honduran border. Then it moved over the water to the north-eastern part of Honduras and strengthened again (Fig. 4B) (National Hurricane Center 2009).

More than 21,000 people were affected, and between 6,000 and 8,000 people evacuated reported. In addition to 530 homes destroyed, 80% of the power lines collapsed, lack of drinking water service, partial problems in telephone service, 1,408.8 hectares of crops were damaged, and 140 wells were contaminated due to Hurricane Ida passing through the Nicaraguan Caribbean coast (National Hurricane Center 2009; El Nuevo Diario 2009).

Between November 4 and 10 in the municipalities of Puerto Cabezas, there was a rainfall of 231 mm, Bluefields 63.5 mm, Corn Island 187.96 mm, Bonanza 215.9 mm, and San Juan del Sur 76 mm (National Hurricane Center 2009).

4.1.4.8 Tropical Storm Matthew

Matthew was a TS that formed on September 20, 2010. It began while it was approaching the Atlantic coast of CA and made landfall on September 24 in the extreme north of Nicaragua (east of Cape Gracias a Dios, the border between Nicaragua and Honduras). Mathew's maximum winds were close to 25 m/s and a pressure of 99,800 Pa when it crossed the North of Nicaragua on the border with Honduras. After landfall, Matthew moved west-northwestward across Honduras but did not weaken in the first 6 hours. Matthew weakened to a tropical depression as it moved across

Belize and into northern Guatemala. Its main impact was the rainfall (Fig. 4B). In Nicaragua, 65 fatalities and more than 70,000 people were affected, including the corn and bean crops (National Hurricane Center 2010).

4.1.5 Period 2011–2020

4.1.5.1 Hurricane Otto

Otto was the sixteenth tropical cyclone and seventh hurricane of the 2016 Atlantic hurricane season. Otto formed in the southwestern Caribbean Sea, best defined between November 17 and 18. However, in the early morning of November 20, a tropical depression began north of Colón Panama. The tropical depression became a TS on the 21st, and Otto moved slowly to the west-northwest. On the 23rd, it became a hurricane and, after intensifying, a Category 3 hurricane before landfall in southern Nicaragua.

Hurricane Otto weakened to a TS on November 25, just before leaving the Pacific coast of North-western Costa Rica, weakening on the 26th of the same month and becoming a tropical depression (Fig. 7). Otto caused winds that affected the Indio Maíz Biological Reserve (Southeast of the country), where extensive defoliation of the low forest canopy was reported. In addition, 76.2 to 152.4 mm of rainfall was recorded in the South and Southwest, the highest rainfall total being 161.29 mm in El Castillo, Nicaragua, causing flooding (National Hurricane Center 2017). Otto is one of the few TCs from the Atlantic to the eastern North Pacific basin to maintain tropical cyclone status. The last tropical cyclone to do so was Cesar, which landed in Nicaragua as a hurricane in July 1996 (National Hurricane Center 2017). The passage of this phenomenon left material damage. However, no deaths were reported due to this event (Baltodano 2016).

4.1.5.2 Hurricane Nate

Nate was the fourteenth named storm and ninth hurricane of the 2017 Atlantic hurricane season. This depression generally moved north-westward following its genesis, led by a weak subtropical ridge to the northeast, gradually strengthening. It is estimated to have become a TS shortly before landfall in north-eastern Nicaragua on October 5. Nate's strength changed little as it moved north-northwest through north-eastern Nicaragua (Puerto Cabezas) and eastern Honduras. On October 7, the TS reached hurricane intensity (Category 1) over the southeastern Gulf of Mexico (National Hurricane Center 2018) (Fig. 7).

Rains generated by Nate in Nicaragua caused flooding, and 16 deaths were reported (National Hurricane Center 2018). Likewise, SINAPRED estimated that 10,000 people were affected by the floods, seven were reported missing, 729 people evacuated, and damage to roads and houses in 31 municipalities in Nicaragua (CCRIF 2017).

4.1.5.3 Hurricane Eta

Eta constituted the 28th storm and the twelfth hurricane of the 2020 season (SINAPRED 2020). Eta's origin was a tropical wave estimated to have moved off the west coast of Africa on October 22. This system moved westward across the Atlantic for about a week, strengthening from a tropical depression into a TS on November 1. On November 2, Eta became a Category 4 hurricane on the Saffir-Simpson scale and, on November 3, made landfall in Nicaragua, about 27.78 km south-southwest of Puerto Cabezas. After crossing the coast, the hurricane moved slowly to the

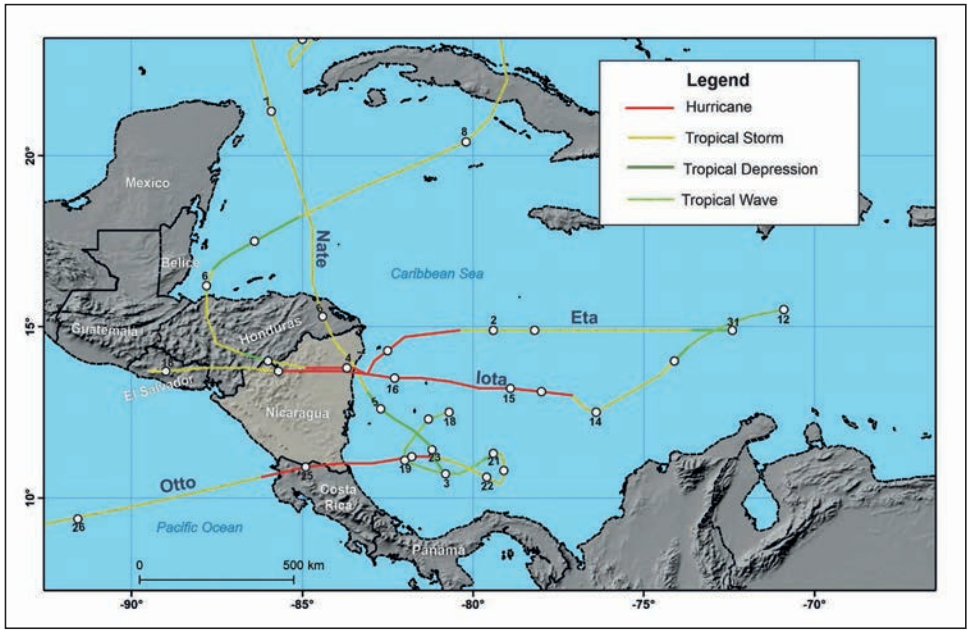

Fig. 7 The trajectory of hurricanes in Nicaragua in 2011-2020. Source: *HURDAT database*).

west over northern Nicaragua, steadily weakening until it became a TS on November 4 (Fig. 7) (National Hurricane Center 2021a).

The intensity of Eta when touching Nicaragua was 67 m/s (maximum intensity). The Nicaraguan weather service reported a storm surge 8 to 10 m above normal near Eta's landfall. Hurricane Eta's impact was compared to Hurricane Joan in 1988 in Bluefields. The highest precipitation reported by Eta was 733 mm in Puerto Corinto and Chinandega (National Hurricane Center 2021a).

After its landfall, it headed towards the city of Rosita in the mining triangle, arriving at dawn as a Category 1 hurricane heading towards San José de Bocay in the North of Jinotega, where it reached as a TS Category, passing through the North of Wiwilí from Jinotega and left the country between the night of November 4 and the early hours of November 5 (SINAPRED 2020).

Hurricane Eta caused flooding. Three million people were affected, 30,000 were sheltered, and infrastructure was damaged in 56 municipalities. Approximately 43,000 damaged/destroyed homes were reported. In addition, there were uprooted trees, power cuts, affected bridges, and road blockades. In addition, two people died from a landslide in the Bonanza mining area (National Hurricane Center 2021a) (Fig. 8).

Fig. 8 Effects of Hurricane Eta in Nicaragua: Children in Puerto Cabezas after Hurricane Eta (upper photo). Source: UNICEF); Debris of destroyed houses after the passage of Eta (lower image). Source: ONU News.

4.1.5.4 Hurricane Iota

Iota was the 30th storm of the 2020 Atlantic hurricane season (National Hurricane Center 2021b). It was a low-latitude tropical wave that moved off the coast of Africa on October 30. It was classified as a tropical depression formed over the Central-South Caribbean Sea on November 13; the depression continued to strengthen, becoming a TS 6 hours later. From November 14 to November 16, Iota strengthened into a Category 5 hurricane on the Saffir-Simpson Hurricane Scale, with winds of 68 m/s (National Hurricane Center 2021b) (Fig. 7 and Fig. 9).

On November 17, Hurricane Iota landed on the easternmost of Nicaragua near However Lagoon and the mouth of the Wawa, becoming a TS that same day while over western Nicaragua. It left the territory through Nueva Segovia (on the border between Nicaragua and Honduras) (SINAPRED 2020). There was little information on land wind associated with Hurricane Iota due to the passage of Hurricane Eta through the same area almost two weeks before Iota's arrival, causing damage or destruction of meteorological observation systems in the West of the Caribbean Sea and parts of CA (National Hurricane Center 2021b). The maximum precipitation reported was 250 mm in Puerto Cabezas and 200 mm in San Marcos. The Nicaraguan Institute of Territorial Studies (INETER) estimated a storm surge of about 8 m, north and south from the town of Haulover and further north on the coast near Wawa Bar of the Nicaraguan coast where Iota impacted (National Hurricane Center 2021b).

Fig. 9 Hurricane Iota and its passage through Nicaragua: Hurricane Iota's winds affected the infrastructure (upper photo) and housing (lower image) in Puerto Cabezas. Source: BBC News.

In Nicaragua, the damage was US$564–741 million dollars (EM-DAT n.d.; National Hurricane Center 2021b), almost more than half the estimated total damages for the Central American territory

(1.4 billion USD dollars). This damage estimate is less than expected for a Category 4 hurricane because Iota made landfall where Hurricane Eta caused extensive damage two weeks earlier. Additionally, 900,000 people were affected (EM-DAT n.d.), 39 died, and 29 were missing; 160,233 homes were left without electricity, 47,638 families lacked water service, and 35 communities had no telephone service (Fig. 9). Rains triggered by Iota caused flooding and landslides. The independent evaluation of the damage caused by the two hurricanes was quite difficult for local emergency managers (National Hurricane Center 2021b).

4.2 Most damaging hurricanes that have affected Nicaragua

The most significant losses of human life in Nicaragua are related to disasters triggered by seismic activity. However, the effects of TSs between 1971 and 2020 are in second place. The areas most affected in the territory are the Atlantic and Pacific Coasts (Incer et al. 2000) (Tab. 7). The meteorological phenomenon that had the most significant impact on the region was Hurricane Mitch in October 1998. Estimates indicate that 3,332 people died during this disaster (EM-DAT n.d.). Most deaths were associated with the lahar on the Casita volcano, which destroyed two villages and killed more than 2,500 people see Fig. 5 (Kerle and van Wyk de Vries 2003).

Total losses in production and capital goods were estimated at US$987.7 million, equivalent to 48.8% of GDP, 114% of exports of goods and services, 154.8% of gross fixed investment, and 16.5% of external debt. Furthermore, the impact of Hurricane Mitch had transcendental macroeconomic repercussions for the Central American region. The damaged infrastructure was to be reconstructed, opening a new opportunity to strengthen the Central American economic integration process (ECLAC 1999).

In the second place, there is Hurricane Felix in 2007, Category 5, which impacted the Nicaraguan Caribbean Coast, leaving 198,069 people affected, corresponding to 33,687 families; more than 300 dead, of which 102 were official (67 identified and 35 unidentified; 133 disappeared and 106 notarized) (Miranda 2010). The areas most affected by this hurricane were those with extreme poverty and marginalization. These were converted into one of the country's poorest areas with the lowest human development index. The passage of Hurricane Felix over the RAAN caused losses of approximately $716.31 million, equivalent to more than 14.4% of the 2006 GDP (PNUD 2008).

The third most damaging event was Category 4, Hurricane Joan, which in 1988 hit the city of Bluefields (Ruiz et al. 2013), causing 300,000 affected people and 130 deaths (EM-DAT n.d.). Approximately 300,000 to 500,000 hectares of rainforest were also affected between Bluefields and Rama, extending some 50 km from the coast (Vandermeer et al. 1990).

The hurricane occurred when the country was in a precarious economic situation, and the effects of the hurricane on gross domestic product showed its full impact in 1989. At that time, it was estimated that the agricultural sector would experience a contraction of 17% more pronounced than expected (initially more than 8%). The only economic sector where a more considerable expansion was estimated was the construction sector due to the anticipated effect of rehabilitation programs. In the medium term, the central government's financial situation was expected to worsen due to rehabilitation and reconstruction, which will pressure domestic financing unless foreign resources become available. The population settled in the regions directly affected by the hurricane were those food insecure and had limited access to nutrition, health, education, social security, and services such as water and sewage (CEPAL 1988).

The 2020 Atlantic hurricane season has been the most intense ever recorded and the only one in which two hurricanes have affected the territory. Eta and Iota occurred in November and had practically the same trajectory, contributing 37% of the total precipitation of the rainy season (May- November) in just 18 days (ONU-SINAPRED 2021).

Both hurricanes impacted the RAAN and part of the RAAS, Jinotega, Chinandega, Matagalpa, Madriz, Esteli, and Nueva Segovia. About 100,000 hectares of annual crops were exposed, including basic grains, roots, tubers, musaceaes, and vegetables. In the fishing sector, total losses were estimated at $19.6 million. The hurricanes affected 3,152,356 hectares of forests (palm, pine, broadleaf, and gallery forests) (ONU-SINAPRED 2021).

Additionally, 44 natural areas were affected, and total economic losses in environmental resources were estimated at $41 million. At the national level, the damage was reported in 16 of the 19 Local Integral Health Care Systems (SILAIS). The evolution of the COVID pandemic in Nicaragua was in a community transition stage, which increased the risk in the populations that had been evacuated and sheltered from the areas affected by hurricanes and vector diseases such as malaria and dengue. Concerning school infrastructure, 261 schools and six delegations reported destruction to their infrastructure. Damage to water, sanitation, and hygiene infrastructure was also reported, including wells and rainwater collection systems. According to data provided by the government of Nicaragua, more than 98,000 families at the urban level and more than 15,000 families at the rural level were affected (ONU-SINAPRED 2021).

Within the strategic responses in the early recovery and livelihoods sector, actions were proposed that would contribute to overcoming the diverse needs of the rural and indigenous populations directly affected. This included food assistance but was accompanied by comprehensive solutions aimed at

guaranteeing the reintegration of the people into their productive activities (seed and tool supply programs, small livestock, the establishment of various crops, etc.). Government institutions coordinated these programs, maintaining coordination with the indigenous and Afro-descendant peoples of the Caribbean Coast through the Regional, Municipal, and Territorial Indigenous Governments. Other sectors were also strengthened, including food security, water and sanitation, and health (ONU-SINAPRED 2021; FAO 2021).

Historically, only a similar example to what happened in 2020, when two hurricanes were spinning toward Nicaragua, has been reported. It occurred in 1971, with Category 5 Hurricane Edith and Category 1 Hurricane Irene impacting the Caribbean Coast (RAAN and RAAS) one week apart.

4.3 Some insights derived from the historical account of Tropical Cyclones that have affected Nicaragua

The affectation of hurricanes and TSs in Nicaragua has historically occurred in the months included in the cyclonic season, from June to November. This chronology establishes that between 1971 and 2020, 18 hurricanes (Fig. 10A) and four TSs (Fig. 10B) affected Nicaragua. Fifty percent of the hurricanes were Category 4 or 5, while three were Category 1 and 2.

Only two hurricanes were Category 3, and the remaining one had no associated Category due to a lack of information (Tab. 5). Mitch (1998), Felix (2007), and Joan (1988) were the most damaging hurricanes that affected the country in the last five decades.

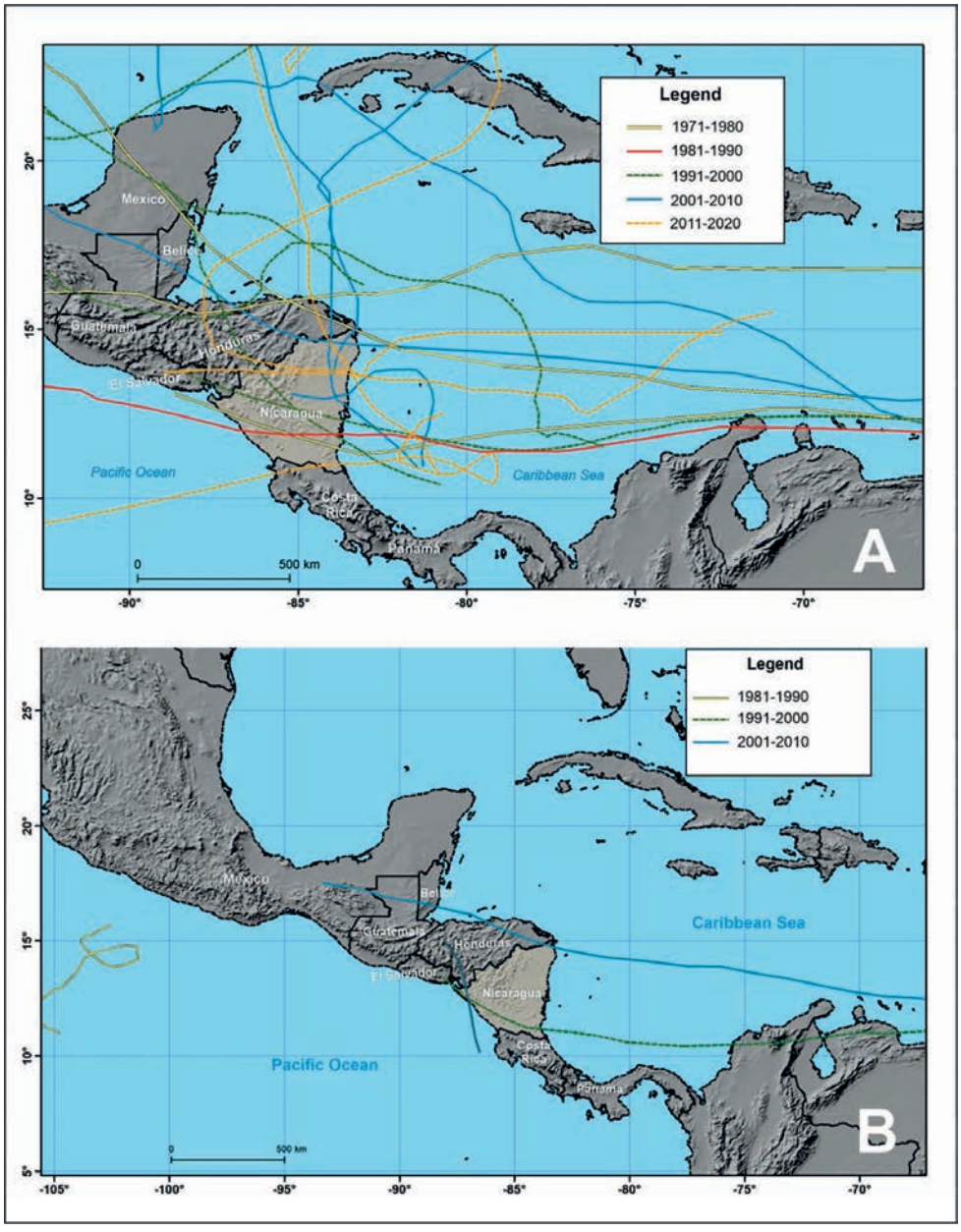

Fig. 10 The trajectory of hurricanes (A) and tropical storms (B) in 1971–2020. Source: HURDAT database.

Tab. 5 The frequency of Nicaragua's hurricanes ranked according to the Saffir-Simpson Scale (1971-2020).

Category	Maximum wind speeds (m/s)	Pressure (Pa)	Number	%
1	36–41	97,700–98,500	4	22.2
2	44–51	96,200–97,100	3	16.6
3	51–56	93,400–97,500	2	11.1
4	38–67	93,200–98,500	5	27.7
5	69–80	90,500–93,400	4	22.2
		Total	**18**	**100**

These events, which originated mainly in the Atlantic Ocean, are correlated with oceanographic oscillations and physical variables such as AMO, VWS, and ENSO, particularly with the La Niña phase (Martinez et al. 2023).

Of the 22 TCs, 15 occurred during Cold ENSO, whereas only 3 in Warm ENSO and four TCs between the ENSO-neutral periods (Fig. 11 and Tab. 6).

TSs Alleta and Alma occurred in May and July, and Hurricane Cesar-Douglas. In August, one TS (Bret) and a major hurricane (Felix). In September, TS Matthew and six hurricanes were recorded (Edith, Irene,

Tab. 6 Distribution of storms in Nicaragua in ENSO Warm, Cold, and Neutral Phases in 1971–2020.

Event	Total number of years associated with the event	Number of Atlantic-originated storms during the event	Number of Pacific-originated storms during the event	Total number of storms that occurred during the event	Rate of Nicaragua storms occurrence per event
Warm ENSO	23	2	1	3	0.13
Cold ENSO	22	14	1	15	0.68
Neutral	5	4	0	4	0.8

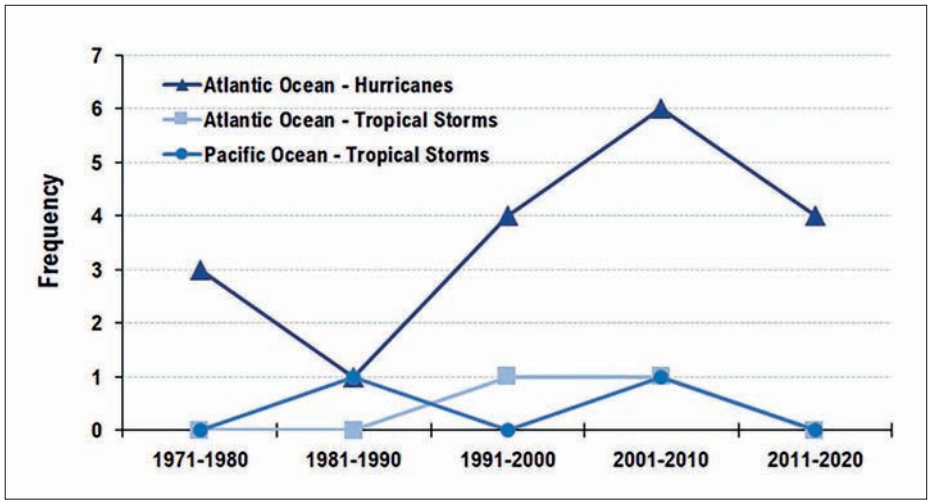

Fig. 11 Frequency of hurricanes and tropical storms in 10-year periods in Nicaragua in 1971–2020.

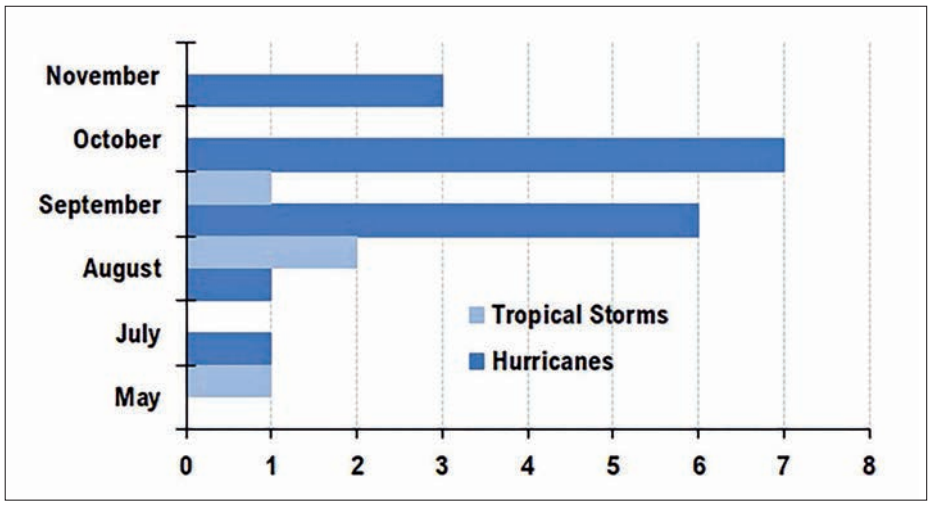

Fig. 12. Monthly distribution of hurricanes and tropical storms in Nicaragua in 1971–2020.

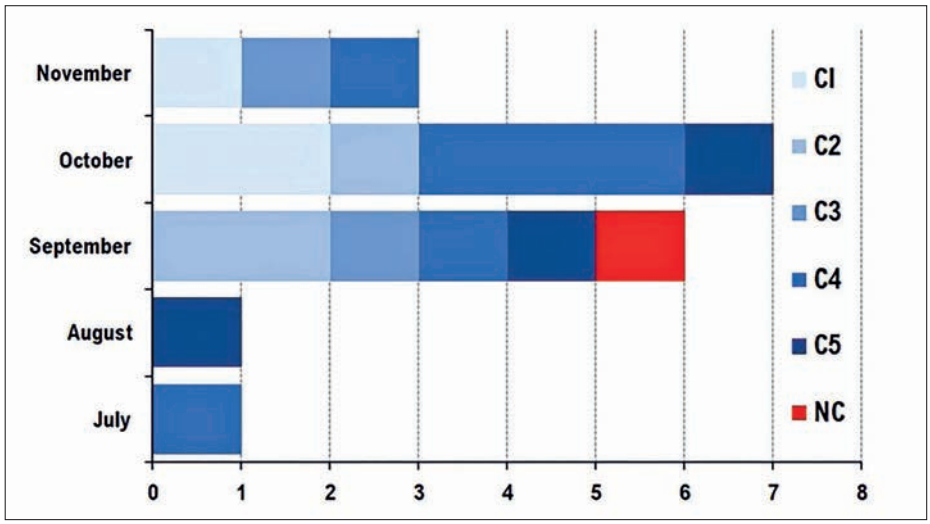

Fig. 13 Monthly distribution of significant hurricanes in Nicaragua according to the Saffir-Simpson Category scale in 1971–2020 (NC: no Category included due to lack of information).

Fifi, Gert, Keith, and Isidore), while in October, there were seven (Joan, Mitch, Mitchelle, Beta, Stan, Nate, and Eta), and in November, three (Ida, Otto, and Iota). The period was established as the Atlantic cyclone season except for May. The affected month is October and September. July is the month with the minor impacts (Fig. 12 and Fig. 13).

5. Discussion

The analysis of TSs and hurricanes through the bibliographic review of various sources allowed the elaboration of the chronology of TCs in Nicaragua, with specific information on the date, the intensity of landfall, and the main affectations (Tab. 4 and Tab. 7). This was

No.	Year	Month	Event	Maximum intensity (Saffir-Simpson scale)	Intensity at landfall	Deaths	Affected population	Total damage (millions of dollars)
1	1971	September	Edith	5	5	28–35	4,650	380
2	1971	September	Irene	1	1	2	1,500	n.dat.
3	1974	September	Fifí	2	2	0	n.dat.	n.dat.
4	1982	May	Alleta	TS	TS	71*–80	52,000*–70,000	356*–599
5	1988	October	Joan	4	4	130*–148	550,000	1,160
6	1993	August	Bret	TS	TS	37*	123,000*	5.1
7	1993	September	Gert	2	TS	8	>24,000	5.6
8	1996	July	Cesar–Douglas	4	4	9–42*	10,724*–29,500	10*–53
9	1998	October	Mitch	5	NLF	3,045–3,332*	368,261–868,228*	987.7*–988
10	2000	September	Keith	4	NLF	1*	2,300*	1*
11	2001	October	Michelle	4	n.dat.	16*	24,866*	1*
12	2002	September	Isidore	3	NLF	2*	300*	1*
13	2005	October	Stan	1	NLF	3	7,780	n.dat.
14	2005	October	Beta	2	2	4*	5,763*	n.dat.
15	2007	August	Félix	5	5	188*	188,726*	293.3
16	2008	May	Alma	TS	TS	13*	25,000*	n.dat.
17	2009	November	Ida	1	1	n.dat.	19,897*	n.dat.
18	2010	September	Matthew	TS	TS	65	70,000	10.2
19	2016	November	Otto	3	3	0	10,570*	360
20	2017	October	Nate	1	TS	16	10,000	n.dat.
21	2020	November	Eta	4	4	2*	30,000*	178*
22	2020	November	Iota	5	5	18*	900,000*	741*

Tab. 7 Chronological list of all hurricanes and tropical storms and associated economic losses and human impact in Nicaragua in 1970–2020. Sources: * EM-DAT (n.d.); Consorcio ERN America Latina (n.d.); Incer et al. (2000); HURDAT2 (1971–2020); Defensa Civil (2010); SINAPRED (2008, 2016); Abate et al. (2014); UNOCHA (2010; 2017). NLF means no landfall, and n.dat. means no data is available.

quantified as an insight to analyze the lessons learned from past events and contribute to future effective mitigation strategies.

The historical account of TCs in Nicaragua presented here does not refer to any meteorological analysis or specific links to the dynamics of long-term climate change. Nonetheless, as far as it is known, previous research has yet to provide a detailed account of the occurrence and impact of tropical cyclones in Nicaragua, which can be of value to future research on disaster risk reduction.

The knowledge provided by the IPCC (2007; 2012; 2022; 2023) and other studies for CA (see Martínez et al. 2023), together with the effects of TS and hurricanes described here, suggest that knowledge of these historical records could increase sensitivity to the need to develop systematized information not only at the regional level but at the national level. This is critical for the population in the most vulnerable and exposed regions to compound and cascading risks, as they urgently need to strengthen adaptive capacity (IPCC 2022). Lacking information and knowledge is a significant obstacle to implementing integrated disaster risk management and capacity for climate change adaptation.

Moreover, the goal concerning the compromise that "Early warning systems must protect all people on Earth within five years," recently committed by the UN Secretary-General Antonio Guterres, cannot be achieved without fundamental information of past events, especially in countries where communities are highly vulnerable and exposed to hydrometeorological events such as TSs and the development of science is not as optimal as needed.

Nonetheless, it must be recognized that a few questions regarding the dynamics of TSs in CA and the Caribbean remain to be addressed. A closer look at the literature on the interlinkages between climate change and hydrometeorological hazards, especially floods and landslides, reflect significant progress on this matter at the global and regional level. However, it also reveals several gaps and shortcomings at national and subnational scales, easily reflected in the weak interface between science and policymaking.

6. Conclusion

In the 50 years compiled in this research, seven hurricanes of Category 4 to 5 affected the territory of Nicaragua, which caused direct and indirect harmful effects on the population and the economy, often not visible such as the social disruption that is not counted.

The information collected has made it possible to identify the sectors and services historically vulnerable to hydrometeorological phenomena, such as housing, agriculture, electrical networks, telephone service, drinking water service, roads, bridges, forestry systems, and coastal ecosystems.

Despite the effects of disasters such as those caused by hurricanes Eta and Iota, the environmental consciousness of the state and citizens remain underdeveloped, and the government not often engages in climate change adaptation measures, even though the nation depends mainly on its agricultural exportations (Bertelsmann Stiftung 2022).

This research provides a timely and necessary chronological account of the occurrence and impact of TCs in Nicaragua, which can be of value to future research on disaster risk reduction. Therefore, given the potential effect of TCs on the population, systematic efforts should be developed to ensure preparedness and integrated disaster risk management.

As reflected in the Mid-term review of the Sendai Framework for Disaster Risk Reduction 2015–2030, developing better multi-hazard early warning systems (MHEWS) is essential to reduce disaster risk and future disasters. Among other aspects, MHEWS must address how hazards interact temporally and spatially and include reliable and updated disaster risk information, including vulnerability and exposure conditions of at-risk populations (International Science Council 2023). This should be, without doubt, one of the priorities of Nicaragua and other countries in Central America and the Caribbean, particularly regarding hydrometeorological hazards.

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The impact of human activities on the mangrove forests of the Qeshm Island, Iran

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ABSTRACT

This article investigates the human impact on the mangrove forest in the Qeshm Geopark on the Qeshm Island in the south of Iran from 1986 to 2020. The area of mangrove forests increased by 14% from 5,131 hectares in 1986 to 5,472 hectares in 2000, and to 5,967 hectares in 2020. The mangrove forest is threatened by oil and gas facilities and a zinc smelter located on the island. The average concentration of nickel in sediment (97.2 µg/g) and in leaves (3.1 µg/g) was higher than the average concentration of vanadium in sediment (38.7 µg/g) and in leaves (0.5 µg/g). The results showed that the transfer coefficient of nickel and vanadium from root to leaf on the dry side of the Qeshm habitat (r = 0.597 and r = 0.516, respectively) was positively correlated with pH. Therefore, increasing the pH leads to an increased metal transfer from the root to the leaf, which endangers the mangrove habitat on the island. The mangrove forest in the vicinity of the zinc factory is threatened by high concentrations of lead (244.2 ppm), zinc (3172.8 ppm), arsenic, and cadmium found in the soil sample.

KEYWORDS

geopark; mangrove change; Google Earth Engine; bio pollution; Qeshm; Iran

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1. Introduction

Geosite and geomorphosite are two new concepts in tourism studies that have entered the geographical and tourism literature with an emphasis on determining special and valuable places of tourism (Ielenicz 2009). Today, geotourism has a special place among the disciplines and types of tourism that emphasize the responsibility of tourism activities. Geotourism, which has been less studied in comparison with living nature, emphasizes that the use of geological and geomorphological forms and capabilities should be centered on the protection of these forms and features and their sustainable use (Sabokkhiz et al. 2012).

Geomorphosites are systems that are the result of external and internal active factors in an area and are of great importance in understanding the geological history and geological evolution of an area. The value of a geomorphosite is very high because of its focus on conservation for the future and the accumulation of tourism capital (Comănescu 2011). In this situation, the first step in geotourism should be to recognize and introduce the scientific and intrinsic values of a geomorphosite in order to be known to tourists and, while considering the issue of protection, to provide infrastructure and tourism services for geomorphosites. In fact, it should be said that geotourism attaches great importance to recognizing the scientific and conservation value of a landform and considers the values of tourism to be conditional on the improvement of scientific and conservation values. Geotourism can provide a desirable experience for the tourist and at the same time maintain the unique quality of tourism destinations in an integrated way, so it can be considered useful for both groups of tourists and indigenous people (Boley et al. 2011). In addition to emphasizing the forms, features and geological and geomorphological capabilities, geotourism emphasizes the issue of indigenous society as well as cultural and ecological values, which in a way as value-added, reinforces and complements geotourism. Qeshm Island can be considered a gateway for Iranian geotourism. Qeshm Geopark as one of the most important natural attractions, despite the existence of many potentials in the supply of nature tourism, due to the lack of facilities and infrastructure services is not growing much. Based on this, the capacity of Qeshm Geopark has not been evaluated so far. Therefore, to solve these problems, it is possible to plan to select the best geosites for Qeshm Geopark by applying the desired criteria. Qeshm Island, along with some shortcomings, has very significant opportunities, facilities and potentials. Qeshm Island, due to its privileged nature tourism areas such as mangrove forests and unique tourism and beautiful coastal shores and ancient history and unique cultural heritage, as well as the special culture of indigenous peoples, has many capabilities to attract tourists. Overall, it can have a significant impact on the region's conomy. However, due to negligence and lack of proper management of tourism in the lowest levels of tourist attraction with the aim of nature tourism and consequently economic stagnation in the region is facing. Lack of public awareness and lack of facilities to introduce the island's attractions can each be a factor in the lack of tourism in Qeshm Island. Next to Qeshm Geopark are mangrove forests, which are a unique example in southwestern Asia. This forest is a unique example on Qeshm Island. Therefore, due to the establishment of oil and gas facilities and zinc factory, it is necessary to take the necessary measures to protect it. Many mangrove forests have been destroyed by human activities or natural causes. Today, the world's mangrove forests with an area of about 137.760 square kilometers (Giri et al. 2011), are the source of more than 21 ecological services and 45 natural products and play an important role in providing human welfare (Eggert and Olsson 2009; Duke et al. 2007). Despite the great importance of these ecosystem services in meeting human needs, the destruction and extinction of these unique coastal habitats has intensified over the past three decades around the world. So far, more than 50% of the world's mangrove forests have been destroyed (FAO 2016). Different coastal ecosystems, especially mangroves, are exposed to multiple environmental stresses and disturbances (geological, physical, chemical and biological) almost constantly and simultaneously, and vary in their characteristics over time and space (Venter et al. 2006; Halpern et al. 2007). The direct result of these disturbances will be a reduction in the size and health of mangroves, an intensification of global warming and other climate change, a decline in coastal water quality, a reduction in biodiversity, the destruction of coastal habitats and the destruction of much of society's resources (Walters et al. 2008). Given that mangrove ecosystems are always exposed to threats from natural and human hazards, planning and providing appropriate tools to mitigate their effects is inevitable (Allen et al. 2001). Achieving the above goal and helping to prioritize management actions and provide the desired infrastructure to reduce risks or their consequences, depends on sufficient and accurate knowledge and information about the process of change in these ecosystems over time (Allen et al. 2001). Examining changes in the mangrove area over time will enable responsible organizations and managers to select appropriate adaptive options and solutions that play an important role in the efficiency and success of mangrove forest conservation and development programs and as part of Integrated coastal zone management ensures a balance between economic exploitation and cultural values and prioritizes existing threats and helps meet managerial, organizational and legal needs (Eslami-Andargoli et al. 2009; Alongi et al. 2015). Therefore, in this study, changes in the level of Qeshm mangrove forest in a period of 30 years from 1986 to 2016 were examined and plotted

through NDVI images. Deforestation can be identified and investigated with data obtained from various sensors and GIS. Meanwhile, the assessment of forest changes by satellites provides a comprehensive and clear view to quantify how and how quickly they are destroyed (Myers 1988). In addition to studying the changes in mangrove forests, changes in various climatic elements in the study period can be studied and evaluated. This data can be stored in a database and provide basic information and visual maps to decision makers. Reconstruction of the area damaged, destroyed or abandoned by human actions should also be among the management priorities of these forests. In addition, improving the living conditions of indigenous communities can also play an effective role in this regard, thus the need for these communities to harvest timber, demolition to increase land under cultivation of agricultural products, shrimp farming, use of branches as Forage should be provided. It is necessary to carry out all these measures, to know the level of these forests and their quantitative and qualitative changes, and to pay attention to climatic elements and human activities simultaneously. In this regard, the use of remote sensing data and the use of valuable tools of GIS is very important and effective. Extensive studies have been conducted on mangrove forests. Kjerfve and Donald (1997) in their study examined factors such as temperature, hydrology, water level, tides, carbon dioxide and tropical storms. Alongi (2002) stated that despite the tremendous value of mangrove ecosystems for coastal communities and their associated species, these forests have been extinct at an alarming rate. About a third of the world's mangrove forests have been lost in the last 50 years. Manson et al. (2003) evaluated changes in the distribution and spread of mangroves in Moreton Bay and southeastern Queensland, Australia, using two methods: spatial and temporal analysis model and change detection analysis. The findings show that over the past 25 years, about 3,800 hectares have been lost as a result of natural losses and mangrove clearing for urban development, aquaculture, industrial and agricultural development, and currently only about 15,000 hectares of mangroves remain in the bay remained. Mahdavi et al. (2003) in a study examined the trend of quantitative and qualitative changes in mangrove forests in the mangrove protected area between Qeshm and Bandar Khamir. In this research, aerial photographs of 1967 and 1994 were used. Based on the results, the area of mangrove forests in the Qeshm habitat area in 1967 was estimated at 8026 hectares and in 1994, 8016 hectares, which shows a decreasing trend in the area of mangroves in this habitat over a period of 27 years. In a study by Karen (2004), the effects of climate change on mangrove ecosystems were investigated and the role of increasing water levels and atmospheric carbon dioxide was investigated. In another study, the effects of climate change and rising sea levels on mangroves in the oceanic islands were investigated (Gilman et al. 2006). Virk and King (2006) examined changes in mangrove forests in the Indian state of Kartaka using Landsat images from 1986 and 2003 and two change determination techniques. Finally, by analyzing the results of their work, they concluded that deforestation is mainly the result of the development of hydropower, while reforestation is mainly due to afforestation projects. Armenteros et al. (2006) studied temporal and spatial changes in mangrove systems communities in the Cuban Bay of Cuba and concluded that seasonal changes in tropical mangroves occur due to changes in factors such as temperature, dissolved oxygen, and water pH. Hajjarian (2006) investigated quantitative changes in mangrove forests in Qeshm region using aerial photographs and satellite data over a period of 40 years. The results of this study show the rate of different changes in the level of mangrove forests in this period. In the years 1957 to 1966 had a decreasing trend, in the period 1966 to 1998 had an increasing trend, in the period 1998 to 2001 had a decreasing trend and finally from 2001 to 2005 had an increasing trend. In this study, the existence of regional and global changes caused by artificial stimuli has been expressed as a factor in changes in the area values of mangroves in different time periods. Another study in which the relationship between environmental factors and their effects on mangroves was discussed in more detail is related to the study of Catherine et al. (2007) in which the effects of factors such as atmospheric carbon dioxide, sea level, precipitation and Temperatures were studied and the effect of each of them was predicted to predict the possible situation affected by the impact of these factors on the forests of Australia in 2030 and 2100. Giri et al (2007) measured the rate of change of Bangladeshi mangroves over a 23-year period (1977–2000) using Landsat satellite imagery. In this study, images of three time periods related to 1977, 1989 and 2000 were processed and changes in the size of mangroves in these three time periods were identified. As in other parts of the world, in Iran, studies have been conducted on changes in the size of mangroves in different habitats. Giri et al. (2008) examined the degradation of mangrove forests in Madagascar. In their studies, they used satellite data from the years 1975–1990 and 2005 and considered both supervised and unsupervised classification methods for evaluation. The results of their research showed that the main reason for the destruction and reduction of the mentioned forests is their conversion into agricultural lands and aquaculture lands and urban development. Liu et al. (2010) in a study examined the changes in the spatial distribution of mangroves in the southern Chinese province of Guangdong from 1977 to 2010. In this study, a set of land use and land cover data was monitored through classification and produced using Landsat satellite images over a period of time. Thus, changes in mangrove cover and its

relationship with changes in the size of shrimp farms were investigated. Taghizadeh et al. (2009) in a study examined the distribution of mangrove forest communities in the Sirik habitat of Hormozgan province. The results of studying the distribution of mangrove communities in this habitat showed that from the east to the west of the habitat, the establishment of Rhizophora mucronate masses increases and with approaching large Rhizophora mucronate, Rhizophora mucronate masses become more dominant. Pure mangrove, pure Rhizophora mucronate and mixed masses have an area of 272.6, 43.9 and 326.7 hectares, respectively, and the total area of Sirik habitat in this study is 643.2 hectares. Yáñez-Espinosa and Flores (2011) discuss the effects of rising water levels on the morphological and anatomical properties of mangrove species and believe that mangroves can adapt to these changes if the water level changes slowly. Sirajuddin et al. (2012) in a study investigated the effect of climatic element fluctuations on the area of Iranian mangrove forests in Gwadar Bay. The results showed that the quantitative status of Gwadar Bay mangrove forests during the statistical period (1987–2008) has an upward trend and the area of forests has increased from 384 hectares in 1987 to 607 hectares in 2008. In a study conducted by Nguyen et al. (2013), spatial and temporal changes in mangrove area as well as land use changes around mangroves over a 20-year period (1989–2009) were evaluated. In this study, using the supervised classification method, a map of mangrove cover changes was prepared and its relationship with other surrounding uses was investigated. Khorani et al. (2016) investigated the changes in the level of mangrove forests due to climatic fluctuations in the habitat zones of Khamir and Qeshm. The results of this study showed that the level of mangrove forest cover between 1984 to 1998 has an increasing trend (with an average area increase of 33.92 hectares per year) and in the period between 2001 to 2009 has an increasing trend (with increasing amount Equal to 450 hectares per year). Salehipour and Lak (2014) examined changes in the size of Iranian mangroves over a 35-year period from 1973 to 2008. The results of this study showed that all mangrove habitats in the country had an increasing trend during the period. According to the results of this study, all mangrove habitats in Iran in the period 1975 to 1989 have an increasing trend and only the size of Jask habitat zone has been reduced in the same period. Qeshm mangroves also had the highest increase among all habitat zones in the country in the same period. Finally, the size of all mangrove habitats in the country until 2008 has been increasing. The size of the country's mangroves has increased by 37.8% from 1975 to 2008. In a study conducted by Bazrafshan et al. (2016), the effect of runoff and sediment upstream watershed on changes in the size of mangrove Gabrik forests in Hormozgan province was investigated. In this study, Landsat satellite images over a period of 7 years (1993 to 2010) were used to study the area of mangroves. According to the results of this study, the amount of increase in the area of Gabrik mangroves in a period of 7 years was equal to 0.22 hectares per year. In addition to this research, the dangers facing mangrove forests should also be considered. Mangrove forests are in increasing danger. One of the problems that threatens the life of mangrove ecosystems today is the accumulation of heavy metals in their habitats (Alongi 2002). Due to the fact that plants show different sensitivities to chemicals and especially to increasing the concentration of heavy metals in the reaction environment, some of them disappear from the environment and some increase their tolerance to metals, so their study is essential (Smical et al. 2008). Due to their physical and chemical properties, mangroves are able to accumulate large amounts of metals in the effluent of their environment (Defew et al. 2005). In the bed of mangrove habitats, contaminants are transferred to adjacent waters, including groundwater, through runoff and urban, agricultural and industrial effluents, and as a result are easily available to mangrove trees. On the other hand, pollution from fossil fuels, factories and surrounding industries helps to increase the transfer and absorption of pollutants through mangrove forests. Extensive studies have been performed on the concentration and distribution of metals including nickel and vanadium in mangrove habitats. In this research, the capabilities of Qeshm Island such as geopark and mangrove forest are introduced and changes in the size of these forests over a period of 30 years from 1986 to 2016 are investigated and finally the threatening factors of these forests in terms of heavy metals are introduced and the status of 7 toxic elements was expressed. In this regard, the information of Qeshm Geopark site (qeshmgeopark.ir) and the research of Mafi Gholami et al. (2017), Moradi et al. (2014) and Moore et al. (2013) have been used. The results of their findings were used to understand the current situation of Qeshm Island.

2. Study area

Qeshm Island is located between 55 degrees and 15 minutes and 38 seconds to 56 degrees and 16 minutes and 52 seconds east longitude and 26 degrees and 32 minutes and 20 seconds to 27 degrees north latitude. The height of the island is about 10 meters above sea level. The island leads from the north to Bandar Abbas and part of Bandar Lengeh, from the northeast to Hormuz Island, from the east to Larak Island, from the south to Hengam Island and from the southwest to Greater and Lesser Tunbs and Abu Musa (Figs. 1–3). The length of the island is about 115 km and the width from the ridge of Bandar e Laft in the northern part to the ridge of Shib Deraz in the southern part of the island is about 35 km and in the narrowest place

Basaidu is about 10 km and the total area of the island is 1628 km^2. Qeshm is one of the hot and dry lands and the relative humidity in Qeshm is high. The first and most important plant community of the island in the mangrove forests is a species of mangrove called Avicennia marina and they occupy a large area of the island. Qeshm plants are drought tolerant and need high humidity in summer and are mostly visible in the form of short semi-desert shrubs. Rainfall is rare on Qeshm Island, so the southern coastal climate should be considered hot and dry. The climatic situation and the calcareous lands of the island have deprived the soil of Qeshm from having proper vegetation. The island's lands have little vegetation. The vegetation of the North, Northeast and Tourian lands is more impressive than the lands of other parts of the island. The most important vegetation of the island is the trees and shrubs of tropical areas such as dates.

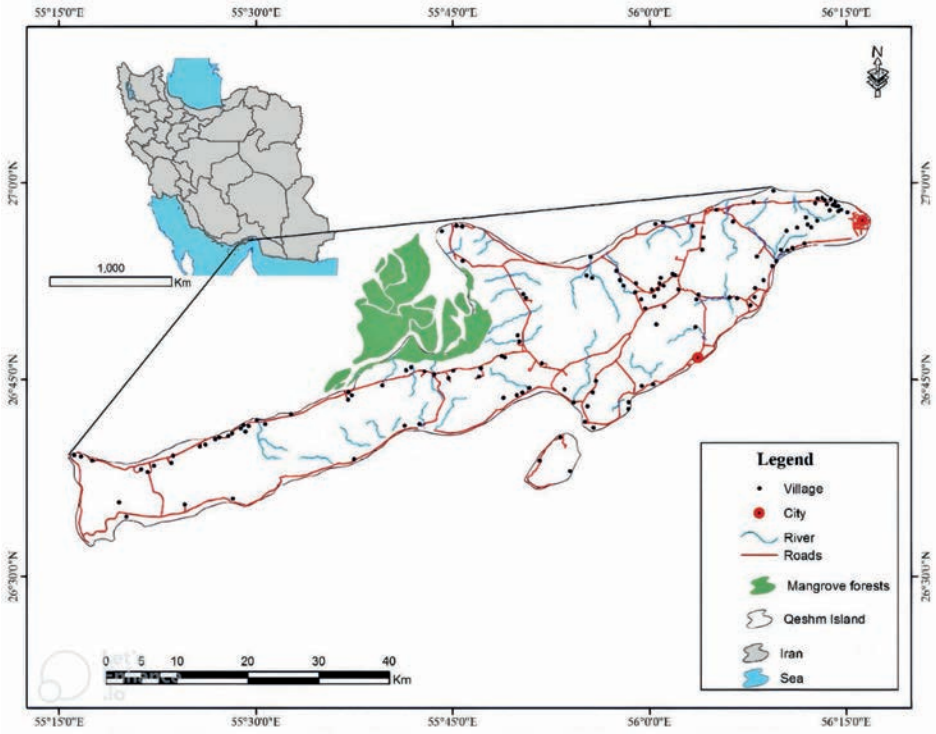

Fig. 1 Location of Qeshm Island.

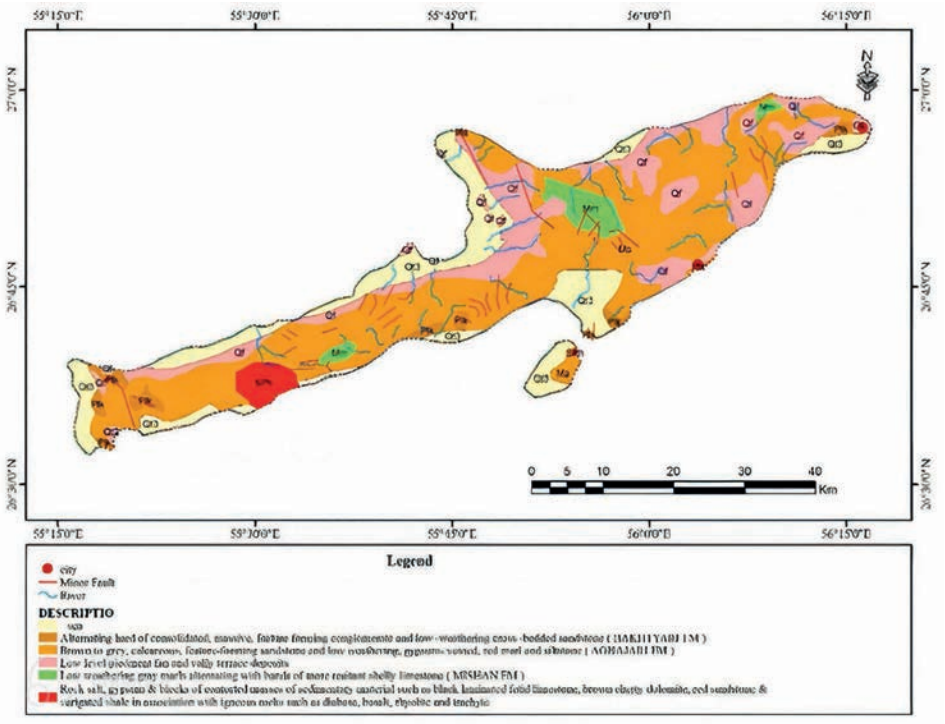

Fig. 2 Geological map of Qeshm Island.

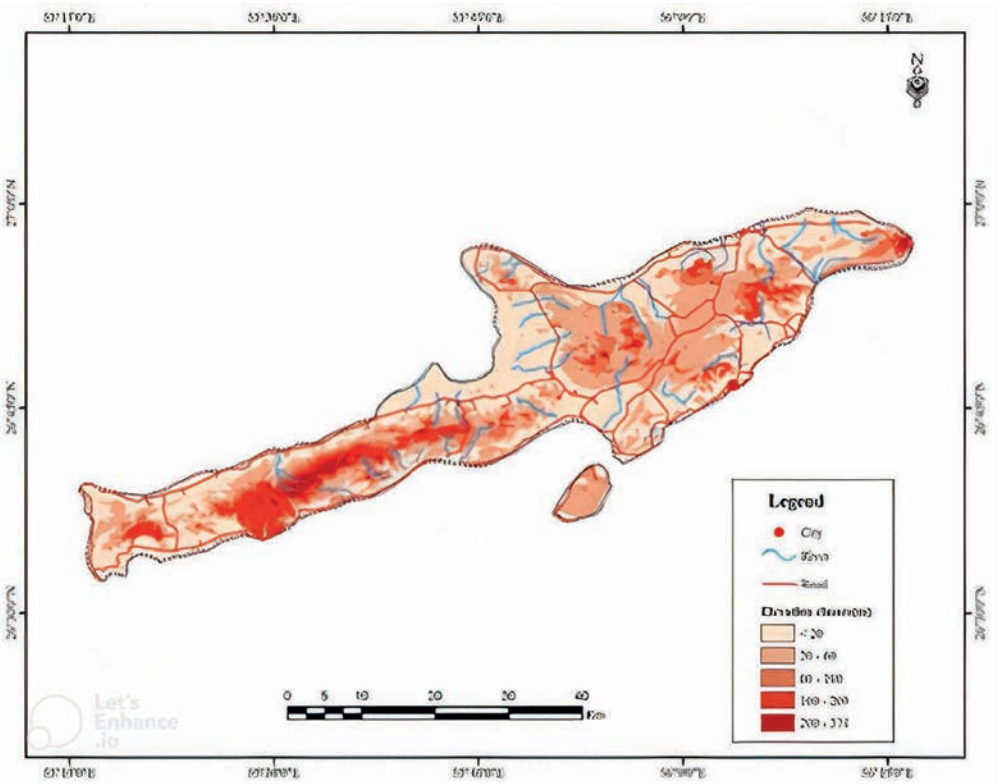

Fig. 3 Topographic map of Qeshm Island.

3. Material and method

In this study, the geotourism and ecotourism status of Qeshm Island was investigated and then the threats to Qeshm nature were investigated. For this purpose, Qeshm Geopark was first introduced through the information mentioned in Qeshm Geopark website (qeshmgeopark.ir). In the meantime, special emphasis was placed on the geosites of Chakavir Gorge, Awli Gorge, Namakdan salt complex, Chahkuh Gorge, Shur Valley, Tandisha Valley, Setarehgan Valley, Star's valley, Roof of Qeshm and Korkora kooh Gorge and their location was drawn on the map. Then the mangrove forest on Qeshm Island was studied. This forest is one of the unique examples of Avicennia marina mangrove forest in southwest Asia. In this study, to identify changes in the 34-year period and to estimate the area of mangrove forests, the Landsat Surface Reflectance images of 1986, 2000 and 2020 were used in the Google Earth Engine software. Annual climate change in the study area leads to the submergence of forests and other lands in the area. Therefore, in order to cover such a problem and create a cloudless image for each year, the average seasonal images (spring, summer, autumn and winter) were calculated and selected separately. The NDVI index was also used to identify changes and better differentiate mangrove cover from other lands. Then, in order to study the hazards threatening the nature of Qeshm, the role of pollutants caused by oil and gas facilities along with the zinc plant was investigated. For this purpose, the findings Moradi et al. (2014) in the field of nickel and vanadium accumulation in the sediment, mangrove roots and leaves were used. The findings of Moore et al. (2013) were used to analyze the role of zinc Factory in soil pollution of Qeshm Island. Then the amount of 7 toxic elements, arsenic, cadmium, lead, zinc, cobalt, selenium and antimony in the soil was determined. Finally, the status of pollutants on Qeshm Island as well as changes in mangrove forest area were investigated.

4. Result and discussion

There are unique geotourism and ecotourism attractions on Qeshm Island, including Qeshm Geopark and Mangrove Forest. In this section, first Qeshm Geopark is introduced and then the factors that threaten Qeshm Geopark and mangrove forest are introduced and the extent of their effects is introduced.

4.1 Analysis of geotourism attractions of Qeshm Island

The Persian Gulf region has about 130 small and large islands that are scattered in different parts of it. Qeshm Island is the largest island in the country and the Persian Gulf in the province of Hormozgan and is located at the mouth of the Strait of Hormuz (Mostofi Almamaleki and Rostam Gourani 2009). Qeshm Island with its natural attractions is one of the tourism hubs of Iran. Beautiful nature, heights and mountains, antiquities, beaches and mangrove islands can make this island one of the most lucrative places in terms

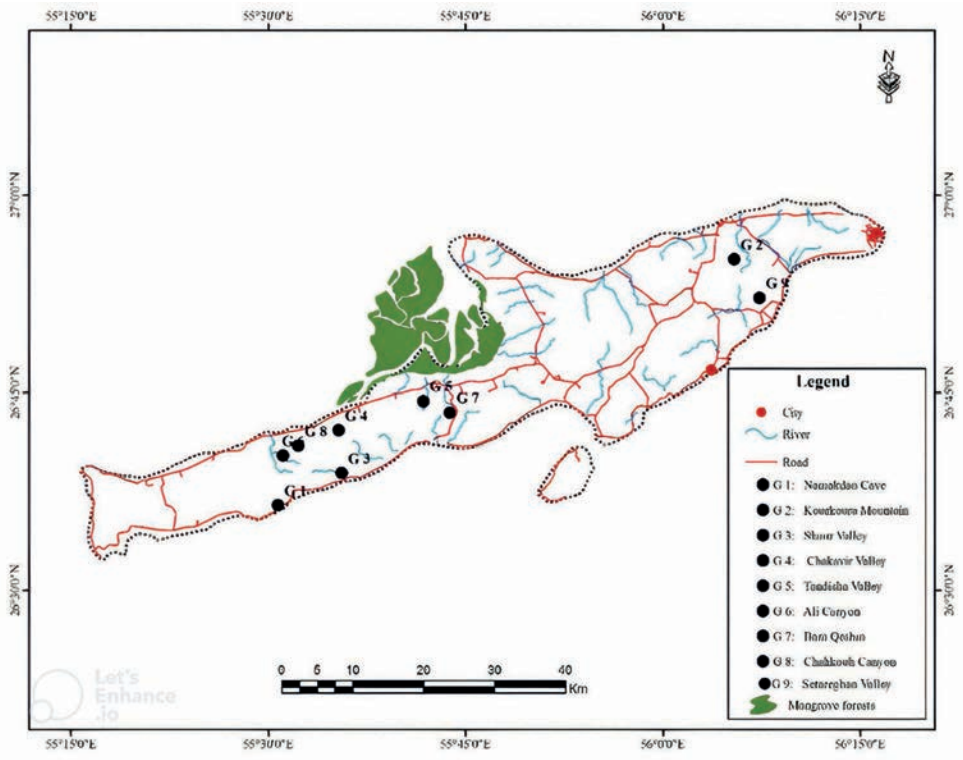

Fig. 4 Map of Qeshm Island Geopark.

of tourist attraction (Akbarpour and Nourbakhsh 2011). Qeshm Geopark with an area of 30,000 hectares is located in the west of the island. The geopark has a museum that displays the region's wildlife and photographs of the geopark's geological phenomena (Fig. 4).

Qeshm Island, as the largest island in the Persian Gulf, has a collection of tourist attractions and landscapes. But what has made the island more attractive in recent years is the island's geopark, which was inscribed on the UNESCO World Heritage List in 2006. This geopark has a set of geotourist and cultural attractions. Tandisha Valley, ChahKuh Gorge, Stars Valley, Korkorakooh, Roof of Qeshm, Shur Valley are among the important geomorphological features in Qeshm Island (Figs. 5–13).

Stars Valley geosite located near Borka Khalaf village is one of the most popular geosites in Qeshm World Geopark.This geosite is a unique example of geosites. The formation of this valley is due to the action of erosion factors such as water and wind and weight pressures on various parts of the earth. In the sections that had more resistant material, the erosion factors were less affected and as a result, these sections remained. But in the weaker parts, the erosion performance is more severe and has destroyed these parts. In the walls of this valley, two completely different genders can be seen from a thick and relatively soft layer of yellow to light gray below and a thin, hard layer of white to dark gray above. The substrate is loose and wears out and degrades rapidly against erosion agents. However, the top layer is resistant due to the presence of a natural cement made of lime and protects the bottom layer against erosion like a shield. Wherever the top layer is lost or has seams and cracks, erosion has acted more intensely and rapidly, causing small valleys and various cracks to open in the area. In some parts of this valley, columns can be seen, some of which are needle-shaped and narrow. One of the reasons for the formation of these shapes is the rotational movement and flooding of seasonal rainwater around the column or the remnants of old walls. Also, a strong part of the upper layer on a small part of the lower layer, has preserved this part as a column. The layers of this valley are very sensitive and fragile due to the mentioned features, and even the weight of a human being on its floors can cause their sudden collapse.

Fig. 5 Stars Valley Geosite.

Fig. 6 Korkorakooh geosite.

Fig. 7 Roof of Qeshm.

Fig. 8 Tandisha Valley.

Fig. 9 Namakdan Salt complex.

Fig. 10 Chahkuh Gorge.

Fig. 11 Namakdan Cave.

Fig. 12 Awli gorge Geosite.

Fig. 13 Chakavir Gorge.

To the east of Giahdan village is Korkorakooh geosite. Due to the beauty of the area, it has been introduced as another main site of the geopark. The construction of the area was mostly made of marl. Due to erosion by running water, the limestone layer placed on the marl has eroded and valleys have formed in the marl layer. In the central part of Qeshm Island, there is a beautiful plain, from which a wonderful view is located on the north and south coast of the island and is known as the roof of Qeshm. This roughness is a wide plateau with a height of more than 120 meters, which is located in the central part of Qeshm Island. Alternating layers of marl and sandstone can be seen on its wall. roof of Qeshm is a beautiful attraction. From the roof of Qeshm, you can see the mangrove forest, the Tandisha valley and the Persian Gulf from the north and south of Qeshm Island, which has a very beautiful and unique view. Tandisha Valley is another geopark site whose surface is often covered with cracks. It is structurally relatively similar to the Valley of the Stars, except that it is larger. It is located on the south coast of the island and near of Namakdan salt complex, the Shur valley geosite. The oldest sedimentary layers of the island can be seen in this valley. Also, the highest peak of the island with a height of nearly 400 meters overlooks this valley. On the other hand, due to the location of this area in the center of the anticline, rich gas resources are located in this site. Chahkuh Gorge is located in the southwest of Qeshm Island. Chahkuh Gorge is a special and unique example of erosive performance of running water. The rapid and powerful movement of water in heavy rains has been the main factor in the formation of this Gorge. However, water erosion is a secondary factor in the formation of this Gorge. The floors surrounding this gorge are part of the north-west ridge of the anticline where Namakdan Mountain is exposed. Due to lateral pressures and stretching of the anticline layers, seams, cracks and fractures appear in the anticline wall. These joints and fractures are the weak points of the wall and various erosive factors have stronger and more effective performance in those points. Chahkuh gorge is one of these primary fractures caused by erosive factors. One of the features of the geological formation of Chahkuh Strait is its impermeability to water. This causes water to flow into it and erode its cracks. The Namakdan salt complex is located in the southwest of Qeshm Island. The 6 km long Namkadan salt complex is the longest salt cave in the world, which is formed inside the Namakdan salt dome. One of the sights around the salt domes and salt caves is the presence of colorful layers of minerals and various stones. Great care is needed when visiting different parts of the salt dome. On the surface of salt domes, there are many dissolution holes that the risk of falling into them is very serious. Some of these holes are hidden and may be covered by a thin layer that may not be obvious at first glance. The Awli Gorge geosite is located in the western part of the island in the south of Chahu Sharghi village. This geological phenomenon is composed of thin layers of marl at the bottom of the gorge. The entrance to the gorge is wide at first, but after 50 meters it becomes very narrow. This gorge is very similar to Chahkuh gorge. Adjacent to Guran village, the Chakavir Strait geosite is located 92 km from Qeshm city. This strait is caused by water erosion. The concave cavities of the walls of this gorge have created an amazing view. This strait is one of the most beautiful geopark geosites.

4.2 Analysis of mangrove forest in Qeshm Island

Another attraction of Qeshm Island is the mangrove forest. Mangrove forests are tropical ecosystems that grow on the margins of two different environments, sea and land (Saleh 2007). The growing environment of mangroves is very dynamic and the water level in these habitats has daily and seasonal flows (Iftekhar et al. 2008). The main goal of sustainable management in mangrove forests is to create the necessary conditions for the protection, improvement and proper use of mangrove forests. Access to mangrove forests is in some cases impossible. For this reason, ground studies are not sufficient to determine the location of phenomena, and the use of telemetry information can provide users with the necessary information. One of the suitable methods to achieve this goal is to use satellite images during different periods and compare the trend of changes during this period. Detection of change is a process that shows changes in the state of different phenomena at different times (Singh, 1989). Correct detection of changes in surface features can be a good model for a better understanding of the relationship between humans and natural phenomena. The three main stages of change detection include initial image processing including geometric correction, radiometric and atmospheric corrections and topographic corrections, selection of appropriate techniques for change detection analysis and evaluation of the results. Qeshm Island mangrove forests are located in the geographical range of 26 degrees and 45 minutes to 27 degrees north latitude and 55 degrees and 20 minutes to 55 degrees and 51 minutes east longitude in the northern part of Qeshm Island (Fig. 14).

Most of the forest communities of Qeshm Island are spread in Laft and Tabl and cover a large area. Mangrove forests in Iran are among the conservation tree communities and the exploitation of these communities is in the form of harvesting branches for livestock, beekeeping, aquaculture and recreational use. Iran's mangrove forests are exposed to degradation due to various natural and human hazards such as over-harvesting of branches, illegal hunting, unplanned tourism, development of some industries, entry of urban and industrial wastewater and oil pollution. In addition to these factors, the presence of some environmental stresses such as drought, high summer heat, lack of annual rainfall and even

Fig. 14 View of mangrove forests on Qeshm Island.

the impact of tropical storms, has made mangroves a sensitive ecosystem. Therefore, these areas are in dire need of protection (Danehkar et al. 2007). Therefore, in this section, the condition of Qeshm mangrove forests has been studied. To identify changes over the 34-year period and to estimate the area of mangrove forests, the Landsat Surface Multi-spectrum images of 1986, 2000 and 2020 were used in the Google Earth Engine software. Annual climate change in the study area is such that it leads to the submergence of forests and other lands in the area. Therefore, in order to cover such a problem and create a cloudless image for each year, the average seasonal images (spring, summer, autumn and winter) were calculated and selected separately. The NDVI index on all images (12 Landsat images) was also used to help accurately identify changes and better distinguish mangrove cover from other areas (Viana et al. 2019; Vo et al. 2013; Seto and Fragkias 2007). Previous studies have used the NDVI index to identify changes in mangrove forests (Adi et al. 2016; Bihamta et al. 2019; Bihamta et al. 2020). Then, the supervised classification method was used. In these methods, it is first necessary for the user to enter values into the algorithm. For this purpose, 155 mangrove samples, 121 mud samples from tidal areas and 110 water samples were collected for each study year. Finally, these samples were placed at the input of the SVM (Support vector machine) algorithm to classify annual NDVI images. It can also be used to classify mangroves using pixel reflectance (Mahendra et al. 2019). A total of 50 samples were taken from Google Earth images to validate the vegetation maps of 1986, 2000 and 2020. Then, the maps were evaluated using the Confusion matrix, which includes the statistical parameters of overall accuracy, kappa coefficient. Overall accuracy and kappa coefficient are calculated from the following equations (Jensen 2015). Finally, to estimate the percentage of decrease and increase of vegetation, especially mangrove, the classification maps of 1985, 2000 and 2020 were reviewed.

$$\frac{N\sum_{i=1}^{r} xii - \sum_{i=1}^{r}(x_{i+}\times x_{+1})}{N^2 - \sum_{i=1}^{r}(x_{i+}\times x_{+1})} \quad (1)$$

Where k is the number of rows (e.g., land-cover classes) in the error matrix, xii is the number of observations in row i and column i, and x_{i+} and x_{+j} are the marginal totals for row i and column j, respectively, and N is the total number of samples.

$$\frac{1}{N}\sum Pii \quad (2)$$

Where OA defines the total accuracy of the model, test pixels are described by *N*, and *P pii* represents the total number of correctly classified pixels.

Tab. 1 shows the results of the Confusion matrix of land cover maps of 1986, 2000 and 2020. As can be seen in Tab. 1, the accuracy of User Accuracy in every 3 years of study is more than 93.33%, which indicates the high accuracy of extracting mangrove cover class from other lands. The overall accuracy of the maps in the studied years is 97.77, 91.11 and 93.33%, respectively. Also, the kappa coefficient of the maps is equal to 0.96, 0.86 and 0.90, respectively. In general, the results of overall accuracy and kappa coefficient indicate the high accuracy of the prepared maps, which can be used to identify mangrove changes.

Tab. 2 shows the area of vegetation in 1986, 2000 and 2020, as well as the rate of change over the 34-year period of mangrove cover. According to this table, mangrove forests in 1986 increased from 5130.78 hectares to 5471.87 hectares in 2000, which indicates a 6.23% increase in mangrove area. In 2020, the area of mangrove has reached about 5967.13 hectares, which is an increase of about 8.30% compared to the area of mangrove cover in 2000. Overall, mangrove levels have increased by about 14.02 percent over the 34-year period from 1986 to 2020. Fig. 15 and Fig. 16 show the vegetation map by years and the time series map of changes in the mangrove forests of Qeshm Island over a period of 34 years, respectively.

4.3 Threatening factors of mangrove forests in Qeshm Island

All residents and experts of the Hormozgan Province Natural Resources Department who participated in the interview blamed the excessive exploitation of mangrove forests for the destruction of these habitats because the natives of the areas cut down trees to provide livestock feed. One of the problems that threatens the life of mangrove ecosystems today is the accumulation of heavy metals in their habitats (Alongi 2002). Due to their physical and chemical properties, mangroves are able to accumulate large amounts of metals in the surrounding effluent (Defew et al. 2005). One of

Tab. 1 Results of Confusion matrix parameters of mangrove forest maps in 1986, 2000, 2020.

Land Cover 1986					
Classes	Mangrove	Mud and Tidal	Sea	User Accuracy	Producer Accuracy
Mangrove	100	0	0	100	100
Mud and Tidal	0	100	6.67	100	93.75
Sea	0	0	93.33	93.33	100
Overall Accuracy: 97.77					
Kappa Coefficient: 0.96					
Land Cover 2000					
Classes	Mangrove	Mud and Tidal	Sea	User Accuracy	Producer Accuracy
Mangrove	93.33	0	6.67	93.33	93.33
Mud and Tidal	6.67	86.67	0	92.86	86.67
Sea	0	13.33	93.33	87.50	93.33
Overall Accuracy: 91.11					
Kappa Coefficient: 0.86					
Land Cover 2020					
Classes	Mangrove	Mud and Tidal	Sea	User Accuracy	Producer Accuracy
Mangrove	93.33	6.67	0	93.33	93.33
Mud and Tidal	6.67	86.67	0	92.86	86.67
Sea	0	6.67	100	93.75	100
Overall Accuracy: 93.33					
Kappa Coefficient: 0.90					

Tab. 2 Area and extent of mangrove changes from 1986 to 2020.

Categories	**Extent (ha)**			**Change (%)**		
Classes	1986	2000	2020	1986-2000	2000-2020	1986-2020
Mangrove	5130.78	5471.87	5967.13	6.23	8.30	14.02
Mud and Tidal	17019.0	16971.7	16334.5	−0.28	−3.90	−4.19
sea	14079.6	13785.6	13927.3	−2.13	1.02	−1.09

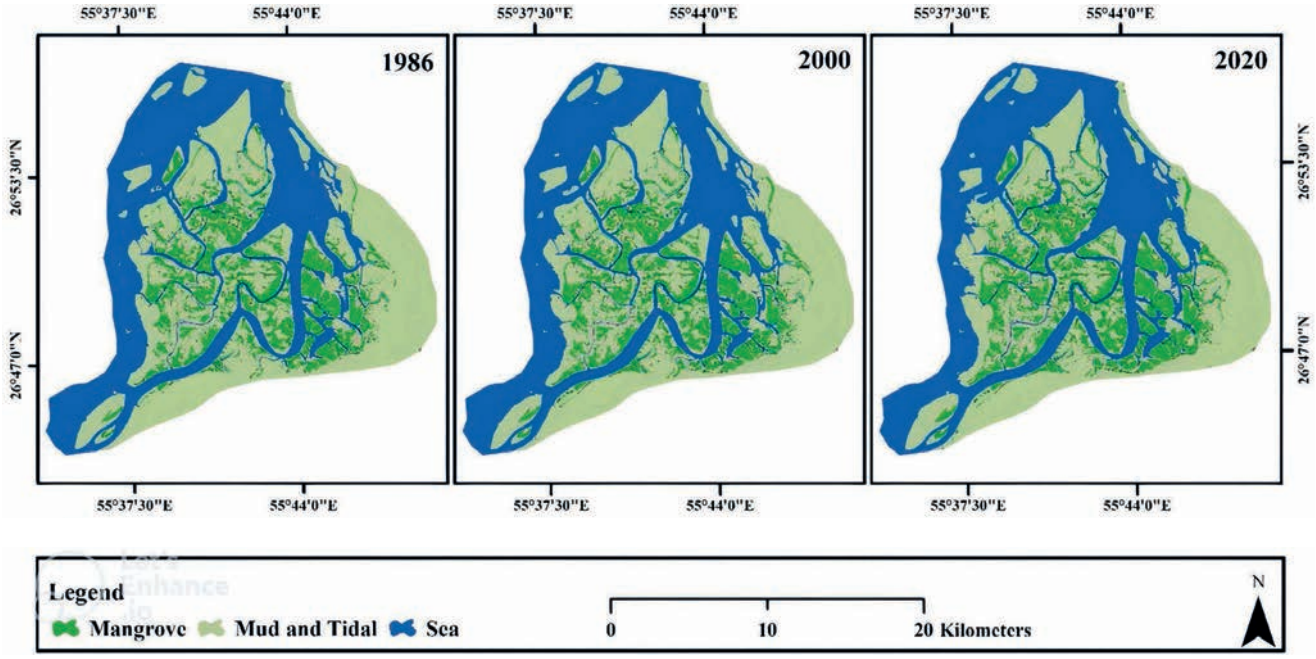

Fig. 15 Land cover map using SVM classification algorithm.

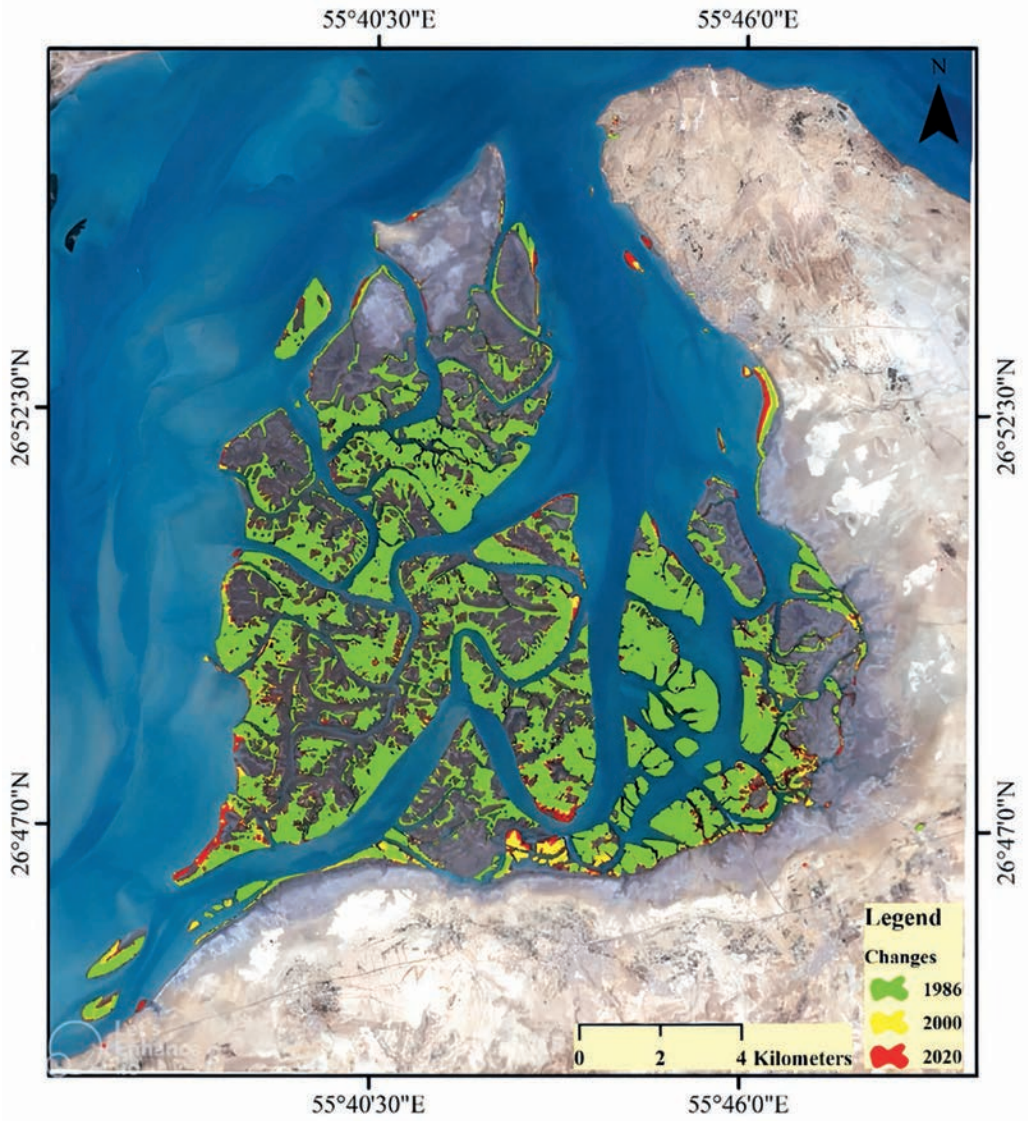

Fig. 16 Changes in mangrove levels over a 34-year period.

Tab. 3 Correlation of metal transfer from sediment to root with bed characteristics on land and sea in mangrove habitat in Qeshm. Source: Moradi et al. 2014.

Parameter	Statistical analysis	Qeshm			
		sea		land	
		nickel	vanadium	nickel	vanadium
PH	Correlation Coefficient	0.216	−0.302	−0.650	−0.451
	p-value	0.500	0.340	0.030	0.164
Organic Compound	Correlation Coefficient	0.389	−0.259	0.528	0.031
	p-value	0.106	0.416	0.095	0.928
EC	Correlation Coefficient	0.324	−0.252	−0.665	−0.715
	p value	0.152	0.429	0.013	0.013
Clay	Correlation Coefficient	−0.216	0.060	−0.216	0.302
	p-value	0.500	0.854	0.500	0.340
Silt	Correlation Coefficient	−0.518	0.475	0.183	0.763
	p-value	0.084	0.119	0.591	0.006
Gravel	Correlation Coefficient	0.216	−0.302	−0.442	−0.745
	p-value	0.500	0.340	0.087	0.008

the main sources of heavy metals entering mangrove trees occurs in oil-contaminated areas. The most important heavy metals in petroleum compounds are nickel and vanadium. The concentration of nickel in oil is in the range of more than 300–300 mg/l (Barceloux et al. 1999; Danzon 2000). Although very low concentrations of vanadium and nickel are beneficial for plant growth, high concentrations are toxic (Barceloux et al. 1999; Campel et al. 2006). The Persian Gulf is one of the most valuable aquatic ecosystems in the world, which has valuable resources from the huge mangrove forests. But in recent years, these ecosystems have become one of the most vulnerable areas of the Persian Gulf to a variety of environmental stresses, especially oil pollution and heavy metal emissions. In this part of the research, the findings of Moradi et al. (2014) on the accumulation and transfer rate of heavy metals in mangrove trees are presented. The texture of sediments in Qeshm habitats is mainly sandy. In Qeshm habitat, the average concentration of nickel in sediment (97.2 µg/g) and leaves (3.1 µg/g) was higher than the average concentration of vanadium in sediments (38.7 µg/g) and leaves (0.5 µg/g). In Qeshm habitat, the concentration of vanadium (19.8 µg/g) in the roots was higher than the concentration of nickel (14.7 µg/g). The results of the correlation of transfer coefficients from sediment to root are presented in Tab 3.

Most significant correlations were observed in the land section. The correlation of nickel and vanadium transfer coefficient from root to leaf with substrate characteristics is shown in Tab. 4.

Tab. 4 Correlation of metal transfer from root to leaf with bed characteristics on land and sea in mangrove habitat in Qeshm (Moradi et al. 2014).

Parameter	Statistical analysis	Qeshm			
		sea		land	
		nickel	vanadium	nickel	vanadium
PH	Correlation Coefficient	−0.301	−0.400	0.597	0.516
	p-value	0.341	0.198	0.40	0.086
Organic Compound	Correlation Coefficient	−0.173	0.365	−0.668	−0.535
	p-value	0.591	0.243	0.018	0.073
EC	Correlation Coefficient	−0.326	0.203	−0.175	−0.097
	p-value	0.301	0.526	0.587	0.765
Clay	Correlation Coefficient	0.376	0.248	−0.389	−0.087
	p-value	0.228	0.438	0.212	−0.789
Silt	Correlation Coefficient	0.648	−0.110	0.302	0.178
	p-value	0.011	0.367	0.340	0.580
Gravel	Correlation Coefficient	−0.418	−0.130	−0.251	−0.150
	p value	0.176	0.686	0.432	0.643

The results showed that the transfer coefficient of nickel and vanadium from root to leaf on the dry side of Qeshm habitat (with r = 0.597 and r = 0.516, respectively) was positively correlated with pH. Therefore, increasing the pH leads to increased metal transfer

from root to leaf. In addition, nickel and vanadium transfer coefficients in Qeshm habitat (r = −0.668 and r = −0.535, respectively) showed a negative correlation with substrate organic matter. Therefore, with the increase of organic matter, the transfer of nickel and vanadium metals from root to leaf decreases. In Qeshm habitat, nickel transfer coefficient on the sea side has a positive correlation with silty texture (r = 0.648). The above study showed that the proximity of this habitat to oil and gas extraction facilities has caused the vulnerability of these trees. Another source of pollution on Qeshm Island that threatens the island's habitats is the zinc factory. The zinc factory on Qeshm is located on the Dargahan-Laft road in NFCQ. The altitude of this area is 8.84 meters above sea level and the distance of this factory to Laft village is 10 km. This factory was established in 1998 by NFC China. The output of this company is zinc ingots. The results of research by Farid Moore et al. (2013) were used to investigate zinc pollution in Qeshm Island. The material presented in this section is the result of the research of these researchers. The results for the seven toxic metals arsenic, cadmium, lead, zinc, cobalt, selenium and antimony are given in the table below. According to the results, it is clear that the concentration of metals such as arsenic, cadmium, lead and zinc in soil samples around the factory is very high and zinc metal has the highest average and medium. The mobility of elements in the soil largely depends on the physical and chemical properties of the soil. Meanwhile, pH and soil organic matter can change the mobility of metals (Denaix et al. 2001). PH and relatively high levels of organic matter limit the mobility of metals (Kapusta et al. 2011). According to Tab. 5, soil pH is in the range of neutral to alkaline and therefore metal mobility is expected to be limited. The percentage of organic matter in the soil is relatively low and therefore can be expected to play a lesser role in the mobility or immobility of metals. According to studies, arsenic is in the range of moderate to very high pollution, Cd, Pb, Sb and Zn are in the range of moderate to extremely high pollution, Se is in the range of no pollution to moderate pollution and Co is in the range of no pollution.

The distribution and dispersion of heavy metals in soil samples around the zinc factory shows that the amount of heavy metals in the soils adjacent to the factory increases in the direction of the prevailing wind (S-SW) and near the factory. By moving away from the plant, the concentration of these metals in the soil is significantly reduced. According to research conducted by Moore et al. (2013), the soil is contaminated with metals such as cadmium, lead, arsenic, zinc and antimony and the risk of cadmium and lead contamination in the study area is very high. Soil contamination with lead, cadmium and antimony metals is also high in samples contrary to wind direction. The reason for this is pollution caused by washing metals by rainwater runoff in the factory or passing vehicles on the road from Laft to Qeshm (about 100 meters north of the factory). According to the SDM index, the amount of metals in the area of 500 meters around the factory is very high and decreases with increasing distance from the amount of metals in the soil. The results of factor analysis test also confirm the origin of the studied metals. Although soils with neutral to alkaline pH limit the mobility of elements in the soil, sandy texture limits soil capacity and severe soil contamination with heavy metals as a result of metal leaching causes groundwater contamination. Given that surface runoff carries heavy metals and eventually enters the coastal environment, the possibility of coastal pollution in the long run will not be unexpected (Fig. 17).

5. Conclusion

The purpose of this study was to evaluate the capabilities of Qeshm Island with emphasis on Qeshm Geopark and mangrove forests as well as the threats to the island's ecosystem. Therefore, in the first stage, Qeshm Geopark was introduced using Qeshm Geopark website (qeshmgeopark.ir) and the location of Chakavir Gorge, Awli Gorge, Namakdan Salt Complex, Chahkuh Gorge, Shur Valley, Tandisha Valley, Roof of Qeshm and Korkora kooh Gorge on Qeshm Island it was shown. In the second phase, the mangrove forest on the island is introduced and using Landsat series Surface Reflectance images in 1986, 2000 and 2020 in Google Earth Engine software, land coverage area of 1986, 2000 and 2020 and the rate of change in the 34-year period of mangrove cover has also been estimated. Mangrove forests increased from 5130.78 hectares in 1986 to 5471.87 hectares in 2000, which indicates an increase in the mangrove area of about 6.23 percent. Also in 2020, the area of mangrove has reached about 5967.13 hectares, which is an increase of about 8.30% compared to the area of mangrove cover in 2000. Overall, the rate of change in mangrove land has increased by about 14.02% over the 34-year period from 1986 to 2020. In the next

Tab. 5 Descriptive statistics of heavy metal concentrations in soil samples (Moore et al. 2013).

Descriptive Statistics	As (ppm)	Cd (ppm)	Co (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Zn (ppm)
Mean	48.3	19.6	19.6	244.2	6.7	0.34	3172.8
Median	21.5	14.7	14.7	88.7	2.5	0.29	725
Minimum	6.20	11.6	11.6	6.3	0.3	0.05	62.8
Maximum	204	53.1	53.1	1620	37.8	0.88	34600

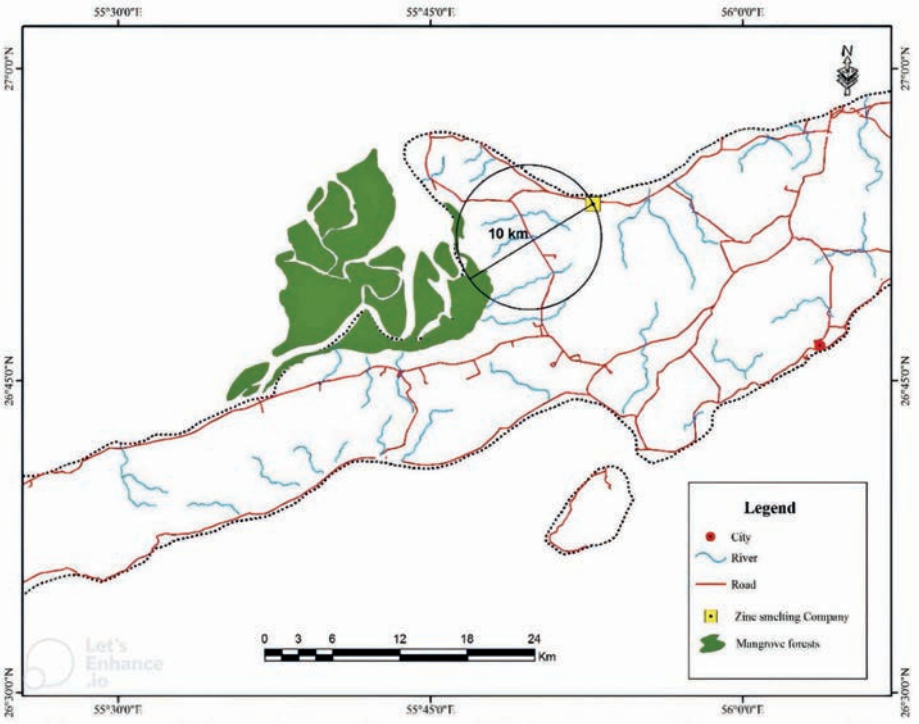

Fig. 17 Location of the zinc factory relative to the mangrove forest.

stage of the research, the threats to the ecosystem of Qeshm Island were investigated. For this purpose, using the research of Moradi et al. (2014), the accumulation status and transfer rate of heavy metals in mangrove trees of Qeshm Island were investigated. Accordingly, the average concentration of nickel in sediment (97.2 µg/g) and leaves of mangrove trees (3.1 µg/g) was higher than the average concentration of vanadium in sediments (38.7 µg/g) and leaves (0.5 µg/g). The results showed that the transfer coefficient of nickel and vanadium from root to leaf on the dry side of Qeshm habitat (with r = 0.597 and r = 0.516, respectively) was positively correlated with pH. Therefore, increasing the pH leads to increased metal transfer from root to leaf. The above study showed that the proximity of this habitat to oil and gas extraction facilities has caused the vulnerability of these trees. The polluting factor of Qeshm Island is not only allocated to oil and gas facilities, but also the zinc factory near the mangrove forest can be another threatening factor. Moore et al. (2013) investigated the status of seven toxic metals arsenic, cadmium, lead, zinc, cobalt, selenium and antimony in Qeshm Island. The results of their research are listed in this section. Studies have shown that the concentrations of metals such as arsenic, cadmium, lead and zinc in soil samples around the factory are very high and zinc metal has the highest average and medium. According to studies, arsenic is in the range of moderate to very high pollution, Cd, Pb, Sb and Zn are in the range of moderate to extremely high pollution, Se is in the range of no pollution to moderate pollution and Co is in the range of no pollution. Therefore, it can be argued that the zinc factory can damage the soil and ecosystem of Qeshm Island due to the significant volume of toxins. Considering the capabilities of Qeshm Island and the dangers threatening the island, it can be argued that mismanagement and neglect of the attractions of Qeshm Island has made this region face irreparable dangers.

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Different forms of innovation leadership in the strategic planning of municipalities in the structurally affected regions of Czechia

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ABSTRACT
This paper examines different forms of leadership in strategic planning in structurally affected regions of Czechia. Based on the leadership concepts and strategic planning in municipalities, evaluates different leadership approaches according to the population size of municipalities and the stability/continuity of municipal representatives. Four types of leaders were identified, with entrepreneurial leadership being the most important in all examined regions. The dependence of the types of leadership on the stability/continuity of government in strategic planning was revealed, while, the dependence on the population size of municipalities was no. The importance of entrepreneurial leadership increases with the increasing number of electoral cycles elected leaders remain in office.

KEYWORDS
leadership; strategic planning; municipalities; structurally affected regions; Czechia

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1. Introduction

Strategic planning at the municipal, regional, and national levels is becoming increasingly important, as it significantly influences the future development of the territory and contributes to more efficient use of funds from public budgets (Gustafsson, Päivärinne and Hjelm 2019). In Central and Eastern Europe (CEE), an elaborated strategy is a prerequisite for drawing external financial resources, for example in the case of some national and EU subsidies for specific projects or activities that include cross-border and international cooperation (Vozáb 2007). Actors entering the strategic-planning process are influenced by various assumptions or factors (internal and external), which of course influence the final form of the strategic document. The involvement of these actors in the strategic document creation process is often through varying methods (e.g., questionnaires or discussion meetings). Leadership in planning is an important prerequisite for quality strategic planning (Sotarauta, Horlings and Liddle 2014). Leadership is primarily applied in the form of a relationship between the leader of the strategic document process and the other stakeholders. The characteristics of the leaders have a strong influence on the development of the territory they manage (Swianiewicz, Lackowska and Hanssen 2018) – in this case on the strategic development document creation process and its quality, but also its successful implementation (Gustafsson, Päivärinne and Hjelm 2019). In strategic planning, we can distinguish at least five main types of innovative leadership: transactional, transformational, interpersonal, entrepreneurial and network governance leadership (Lewis, Ricard and Klijn 2018).

Strategic planning and leadership differ in various types of municipalities and regions in most developed countries. So far, little attention has been paid to structurally affected regions in the CEE former command economies that had to undergo a dynamic social and economic transformation and that often have to cope with selective population migration, lower attractiveness to foreign investors, higher unemployment and other below-average socio-economic indicators.

The aim of the research is therefore to understand and clarify different types of leadership in strategic planning in structurally affected and transforming regions, and to compare their approaches in terms of settlement differentiation (i.e. municipality population size) and the continuity/stability of community representatives. Furthermore, three research questions were defined:

1. What are the main differences between the three structurally affected regions in terms of the application of individual types of leadership in strategic planning?
2. To what extent are these differences conditioned by the population size of the municipalities in which the strategic leadership is implemented?
3. To what extent are these differences affected by the stability/continuity of municipal representatives and the continuity of their work and activities in the municipality?

The paper is conceived as follows. First, attention is paid to the strategic planning process and the specific characteristics of Czechia. Subsequently, the different types of leadership are characterized based on current knowledge, and this part ends with their own leadership typologies and their potential application in different types of regions. The next section presents methodological approaches to analysis, data collection and related analysis limits. The empirical part is structured according to the three main research questions.

2. Conceptual departures

2.1 Strategic planning

Strategic planning is highly important for achieving regional and local development over the long term and contributes to regional or local stability and sustainability. It was first applied in the corporate sector, where it mainly dealt with the development and building of companies or the planning and implementation of various projects. In the 1980s, Taylor identified five main corporate strategic planning styles: central control, a framework for innovation, strategic management, political planning and futures research (Kaufman and Jacobs 2007). Over time, companies began considering the area around them in the strategic planning of their plants, and thus strategic planning gradually became part of the public sector (Kaufman and Jacobs 2007).

Strategic planning is therefore a process to form a certain idea or vision of the future. In the public sector environment, strategic planning is always related to a specific geographical location, for example, a country, region, or municipality. European regional and local governments began implementing strategic planning about 60 years ago (Johnsen 2016).

The most important aspect of strategic planning is a future vision for the relevant location. This vision must be favorably balanced between economic growth and environmental protection. In addition to the economic and environmental aspects, it is also important to consider the social aspect in strategic planning. Before creating a vision, it is necessary to collect and evaluate data about the territory and create a SWOT analysis. The vision is achieved through a broad spectrum of received goals and activities (Poister and Streib 2005). The implementation of the planned activities and goals is addressed through

the implementation part of the strategy, which determines the financial demands, schedule, responsibilities, and monitoring and evaluation activities (Kaufman and Jacobs 2007).

The involvement of all the stakeholders is a very important feature in the strategic planning process. These stakeholders, from the business and non-profit sectors, as well as active citizens, can influence the form of the strategic document and, through their efforts, contribute to its better implementation and feasibility. There are many ways to involve them, including discussion meetings, questionnaires, and individual interviews (Tietjen and Jørgensen 2016).

Strategic planning cooperates closely with spatial planning (Gustafsson, Päivärinne and Hjelm 2019) and takes place at multiple levels of public government. The capacity and capabilities of these levels or other units can vary widely (Pablo et al. 2007). What is important is the interest and the significance attached to it by political leaders and government officials. This ensures efficiency and subsequent strategy implementation (Caceres et al. 2019).

Strategic planning in regional and local development was widespread in Western Europe in the 1950s and 1960s, mainly as part of efforts to solve the problems associated with growing territorial differences and economic growth. The expansion of strategic planning in a form similar to that of today was supported in post-socialist states only from the second half of the 1990s (Wokoun et al. 2008).

2.2 Strategic planning in Czechia

Strategic planning at local, regional and national levels in Czechia was a new discipline in the early 1990s, and not in the forefront of interest. During this period, political activities, including regional policy, were focused on transformational socio-economic changes (Blažek and Vozáb 2004). In the late 1990s, interregional disparities began to grow, motivating governments to take an interest in addressing them. This was an important breakthrough in strategic planning and regional policy development. The second factor was the gradual preparations for EU membership. There were many strategic planning deficiencies around 2000, including conceptual and in terms of personnel (Blažek and Vozáb 2006).

The biggest problems were the unfinished public administration reform and insufficient legal and methodological support for strategic planning activities (Blažek and Vozáb 2006). The first significant strategic development document at the national level in Czechia was the Regional Development Strategy of the Czech Republic in 2000. Moreover, 14 regional governments (NUTS III) were established in that year and started their own strategic planning. Although some municipalities started strategic planning activities in the 1990s, the role of municipalities in strategic planning was only anchored in the 2000 Act on Municipalities (Wokoun et al. 2008).

Strategic planning at the municipal level in Czechia first appeared in the 1990s in larger municipalities and towns. Smaller municipalities faced a worse situation because they did not have the personnel capacity or finances for such activities. The quality of the strategic planning process and the quality of the resulting strategy were often quite different. There were also several cases where municipalities developed a strategy simply because it was a condition for obtaining subsidies. The situation is getting better and the quality of strategies has been improving since 2000 (Lněnička 2016).

In the 1990s, like today, municipalities are not legally obliged to develop a strategy and the decision is therefore up to them. If municipalities decide to make a strategic development document, they can use several manuals or methodologies that can help them with this. Methodological support at the national level is protected by the Ministry for Regional Development of the Czech Republic, which has also prepared a methodology for creating municipal development strategies and other supporting materials. The law only gives representatives the authority to approve the municipality's strategy. However, some of today's grant titles require a strategy as an annex to the grant application (Wokoun et al. 2008).

2.3 Strategic planning and regional development in structurally affected regions in Czechia

There are three structurally affected regions in Czechia: Ústí nad Labem Region, Karlovy Vary Region and Moravian-Silesian Region. All these regions are situated as geographically marginal parts of Czechia and there are referred to as coal regions. The regions have passed gradually large structural changes in their regional economies from the Velvet Revolution to the present day. These changes are also connected with processes of globalization, economic integration, internationalization of trade and services and liberalization of conditions for foreign direct investment. Further these changes not only have an impact on the structure of regional economies but also, for example, on the quality of life, the social sphere, or the formation of better relations with the environment. In recent years, more emphasis has been placed, for example, on soft factors, leadership, use of innovations, application of SMART concepts, or regional identity, which significantly shape the future of these regions (Rumpel et al. 2008).

Blažek and Květoň (2022) are interested in the implementation of different approaches and theories in the development of structurally affected regions, including the evaluation of differences and causes in their development. Regional path development Ústí nad Labem Region and Moravian-Silesian Region are different by many factors. Among the most important

factors are the structure of regional stakeholders, the level of public administration activity and its success, the structure of the transforming economy and the role of universities. For example, fields with a higher added value developed in the Moravian-Silesian Region than in Ústí nad Labem Region, which was also caused by the proximity of Germany, which is adjacent to Ústí nad Labem region (focused on assembly plants and export of incomplete product to Germany). In the case of universities, it was found that the universities in Moravian-Silesian Region were able to respond more to regional needs in the offer of education and the implementation of research activities than in the Ústí nad Labem Region. As a last example, I will give greater support for research and development actives or innovative activities in the Moravian-Silesian Region compared to the Ústí nad Labem Region, which was caused by the earlier implementation of these support activities and the stability of the support institutions (Blažek and Květoň 2022).

2.4 Leadership

It is sometimes difficult to explain leadership theories. The views of theoreticians and practitioners can differ (Van Wart 2013). There are two basic contrasting views on leadership. The first focuses on explaining through analysis of leaders' behaviour and linking it to the results. The second is based on an analysis of the interaction between leaders and their subordinates (Tummers and Knies 2013). There are many types of leadership. For example, Lewis, Ricard and Klijn (2018) identify 11 different types, i.e. Classical leadership, Administrative leadership, Transactional leadership, Transformational leadership, Horizontal leadership, Collaborative leadership, Interpersonal leadership, Ethical leadership, Critical leadership, Network governance leadership, Entrepreneurial leadership. Five of these are close to an innovation environment that supports regional development (Lewis, Ricard and Klijn 2018). These five innovation leadership types are also used by authors Ricard, L. et al. (2017) and they compare the use of these types in innovation in Copenhagen, Rotterdam and Barcelona. The development of regions and municipalities is linked to strategic planning and the implementation of development activities. The success of such implementation depends on leadership and its types (Sotarauta, Horlings and Liddle 2014). A brief definition of these five "innovation" or "strategic" types of leadership follows.

Transactional leadership is based on a series of communication exchanges between leaders and followers. One highly important attribute of this leadership type is that the leader and followers come together in a specific relationship. This relationship shifts the interests of both towards themselves, but there is no deeper or longer cooperation between them (Denhardt and Campbell 2009). The leader is considered a supervisor who should lead people, yet their view of the organizational structure and their legitimacy in it is more important (Ricard et al. 2017). The leader monitors deviations from rules and standards and takes corrective measures. These measures are only taken if the rules and standards are not complied with. The leader can also provide rewards where there is good performance (Bass 1990).

Transformational leadership consists of a combination of four parts, namely inspirational motivation, intellectual stimulation, individualized thinking and idealized charisma (Leong and Fischer 2011). The most important feature of transformational leaders is that they lead and inspire subordinates using correct information about the vision of the organization, processes and outcomes. The goal is to better adapt the subordinates to these processes and outcomes to enhance efficiency. The ideal situation is that the organization has a vision agreed upon and trusted by all the stakeholders. This type of leadership works with a lot of communication and suppresses formal bureaucracy (Moynihan, Wright and Pandey 2012). Transformational leaders must also encourage and lead their subordinates to achieve the organization's vision because the agreement of all the stakeholders is not enough. This leadership role is based on confidence and is very important. Transformational leadership is applied in public and non-profit organizations because they often provide community-oriented services (Pandey and Wright 2010).

Interpersonal leadership emphasizes how leaders communicate and cooperate with their employees, the goal of such communication and cooperation being to maximize results. Other key characteristics of interpersonal leadership are empowerment and personal development, humility, authenticity, interpersonal acceptance, and providing direction and stewardship (Van Dierendonck 2011). These characteristics distinguish interpersonal leadership from most transactional and transformational approaches to leadership. The leader is a facilitator who creates relationships between people in an organization and provides moral examples of behaviour. The leader is willing to take responsibility for the entire organization and its members. One of their important roles is to strengthen trust among people, but also in the organization itself (Ricard et al. 2017).

The basis of network governance leadership is an active network of stakeholders. We can observe that these networks play a big role in public administration because public administration is increasingly important in people's lives, for example in the provision of services. This means that networks are associated with new systems for public policy, decision-making and implementation. Networks are based on the relationship between the public sector, private sector, non-profit organizations and civil society (Klijn, Steijn

and Edelenbos 2010). One leadership role in this concept is to facilitate contact among stakeholders and strengthen their cooperation. Another is to balance the power among stakeholders and to activate new necessary stakeholders (Ansell and Gash 2008). Trust among stakeholders and a high degree of interdependence form the basis for a network's success (Klijn, Edelenbos and Steijn 2010).

Entrepreneurial leadership is primarily connected with the business environment but is also applied in the public and non-profit sectors (Kuratko 2007). An entrepreneurial leader must respond to unpredictable and rapid changes in the environment and adapt the processes in the organization to them. The leader mostly responds by adapting the organization through reorganizing or mobilizing resources (Gupta and MacMillan 2002). These reactions must be strategically examined and integrated into the organization's structure. Past routines and organizational behaviour are also important in shaping these reactions. Other important characteristics of a leader include the ability to initiate and defend change and to adapt to the political environment (Ricard et al. 2017).

Place-based leadership is a new term. It can be interpreted as the interaction between leaders, government officials, the community and other institutions (Beer et al. 2018). Sotarauta and Suvinen (2019) state that interconnections across geographical, governmental, professional and sectoral boundaries are also important.

Place-based leadership is a tool for transformation or change but can be suppressed by those with formal power. The concept of place-based leadership can be applied at the level of regions, subregions, cities, municipalities or settlements. Place-based leadership is very important for kick-starting the successful development of regions and municipalities (Beer et al. 2018).

Leaders who apply place-based leadership aim to strengthen the resilience and competitiveness of the managed territories (mostly rural) to transformational economic changes and globalizing tendencies and to increase their dependence on the central authority. In particular, they use endogenous approaches based on a thorough knowledge of the environment and its institutional basis. Based on these elements, they design measures tailored to the specific needs and problems of the given areas, through which they seek to use the locally available resources (Horlings, Roep and Wellbrock, 2018).

2.5 Leadership & stability in different types of regions

In strategic planning, leader stability and continuity is a crucial precondition in the implementation of their agendas, i.e., in strategy creation but especially in their subsequent implementation. Where there is significant fluctuation in a municipality's management, there is an obvious lack of information about previously implemented or ongoing activities, evident especially in the post-election period or after the exchange of key positions in the management of the municipality or region (Marks-Bielska et al. 2020). In the case of strategic planning, it should be kept in mind that the development strategy of a municipality is a medium-term document and its implementation, respectively the implementation of the activities in the strategy, can also take place over three election periods. Partly for this reason, it is necessary to discuss the content of the strategic document and to be in line with all stakeholders (Johnsen 2016). The individual leadership types are applied mainly in communication and consensus in planning and implementation, but some may play a greater role than others. Therefore, it can be assumed that Network governance leadership has much greater application potential than Transactional leadership, assuming the stability and continuity of functions in local government. If there is insufficient stability and continuity, there is a real risk that the implementation of the strategy may not be successful (Klijn, Steijn and Edelenbos 2010).

Municipality population size also plays an important role in the process of creating a strategy and its subsequent implementation. Different leadership types apply in all types of territory to varying degrees but are likely to have varying intensities (Johnsen 2016). However, there are also types that, by their attributes, are more useful in rural, suburban, or urban environments. These characteristics of individual leadership types include, for example, the way a leader communicates with others, the position of the leader in the territory, the leader's ability to be empathetic, or whether they have a talent for bringing members of different social groups together. Not only must the leader be able to evaluate this, but they must also pay attention to the individual topics addressed through strategic planning, because their adoption differs in each region type, e.g. a solution successfully adopted in an urban environment can cause significant concern or misunderstandings elsewhere (Ricard et al. 2017).

Therefore, the table below shows the relationships among the different leadership types surveyed and their characteristics and the aspects contained in the research questions, i.e. the stability and continuity of leaders and the type of territory in which those leaders operate. Based on a study of the literature, the table thus links the individual theoretical anchors of the surveyed leadership types with the subject of the research, based on, inter alia, the characteristics of the individual leadership types, showing the relationship to leader stability or the type of territory.

Tab. 1 Comparison of leadership types in different region types.

Type of leadership	Nature of leadership	Innovation is viewed as:	Importance of leader stability and continuity	The region type most suitable for its use
Transactional leadership	Strong directive leader image	Initiated by leaders and their ability to steer subordinates	Low	Rural
Transformational leadership	Leaders are charismatic people that drive change and performance	Achieved by charismatic leaders who initiate needed changes	Medium	Urban
Interpersonal leadership	Leaders secure outcomes through people in organizations	Achieved by authentic leaders whose strength lies in stewardship and altruistic behaviour	Low	Suburban
Entrepreneurial leadership	Entrepreneurs embedded in organizational routines	Driven by the need to adapt to the environment and the leader's ability to adjust routines	High	Not specified
Network governance leadership	The leader is 'primus inter pares' and more a facilitator bringing actors together	Achieved by collaborative leaders able to explore new ideas and connect various actors to these ideas	High	All categories

Source: Own modification based on Ricard et al. (2017).

3. Methodology and data analysis

Following the established goal and research questions, a methodological approach was chosen in which quantitative methods were used. Applications of the different leadership types according to Ricard et al. (2017) were tested and empirically verified on a set of municipalities with up to 10,000 inhabitants in three structurally affected NUTS III regions (Moravian-Silesian Region, Ústí nad Labem Region and Karlovy Vary Region).

The research was carried out in July and August 2019, with 749 municipalities in these regions being contacted by email. All 749 municipalities had less than 9,999 inhabitants. The research method was an online questionnaire, shown in Appendix 1. The opportunity to answer research questions was Yes, Rather Yes, Rather No, No. The structure of municipalities by size category and the structure of respondents (i.e. municipalities with a completed questionnaire) is shown in Tab. 2.

237 questionnaires were completed (a return rate of 31.6%), with 199 respondents stating they have a community development strategy and filling in the questionnaires to comment on the leadership types applied. A total of 38 respondents stated they do not have a community development strategy. The most common reasons for the absence of municipality development strategies include the financial complexity of creating a community development strategy and the fact that municipal representatives have a strategy 'only in their heads' and do not need to have it written down.

The respondent structure by municipality size category can be considered highly representative, as it roughly corresponds to the representation of the municipalities in the individual size categories. The share of municipal representatives in the Ústí nad Labem Region is 44.2%, in the Moravian-Silesian Region 42.2% and in the Karlovy Vary Region 13.6%. Ústí nad Labem Region had 38% of all municipalities, Karlovy Vary Region 17%, and Moravian-Silesian

Tab. 2 Structure of municipalities in regions and participating municipalities by size category.

	Number of municipalities by size category						
	to 199	from 200 to 499	from 500 to 999	from 1,000 to 1,999	from 2,000 to 4,999	from 5,000 to 9,999	total
Total number of municipalities in the Ústí nad Labem Region	13	57	75	76	45	19	285
Total number of municipalities in the Karlovy Vary Region	17	43	32	15	16	4	127
Total number of municipalities in the Moravian-Silesian Region	48	126	85	42	28	8	337
Total number of municipalities in all regions surveyed	78	226	192	133	89	31	749
Percentage representation of municipalities in individual size categories	10.4	30.2	25.6	17.8	11.9	4.1	x
Number of municipalities involved in the questionnaire	9	54	50	42	33	11	199
Percentage of municipalities involved in the questionnaire	4.5	27.1	25.1	21.1	16.6	5.5	x

Source: CZSO, own elaboration.

Region 45%. When comparing the distribution of municipalities among regions and respondent distribution, we find that this is also very representative.

The characteristics of the respondents who have a community development strategy and answered the questionnaire are as follows. Among the respondents, the most frequent were mayors with 161 deputies (81.7%), deputy mayors with 19 deputies (19.6%) and 17 representatives (8.6%). The number of full-time jobs was 155 (78.3%) and 43 (21.7%) were part-time jobs. There were 111 men (55.8%) and 88 women (44.2%).

31 respondents are in their first term as members of the municipal assembly, 52 are in their second term, and 53 in their third term. Four respondents have been members of the municipal assembly for four or more terms.

The leadership characteristics were determined in the questionnaire, and are listed in Tab. 3 below. The individual leadership characteristics are also associated with the five main leadership types.

Three research questions were defined and relevant methods were used to evaluate leadership in other countries (e.g., Ricard et al. 2017). For all the questions, the variability was first evaluated and the ANOVA method (research question No 2 and 3) and factor analysis (research question No 1) were applied.

4. Empirical results

4.1 Leadership in various old industrial regions

The research plan indirectly follows a similar analysis to the one published in a paper by Ricard et al. (2017). However, that paper dealt with large cities in Western Europe, in particular Copenhagen, Rotterdam and Barcelona. In the case of this paper, therefore, it is a matter of transferring research from large cities to the rural environment, but also from Western Europe to Eastern Europe, and even to problematic regions. These aspects testify to the uniqueness of the analyses performed, as none of them had yet been implemented in the examined regions.

The first research question deals with the differences in the approach of local government representatives to the management of municipalities and comparisons among the individual regions studied.

Tab. 4 shows a comparison of the application of the five types of leadership examined in strategic planning among the regions. Entrepreneurial

Tab. 3 Overview of leadership types in relation to individual characteristics.

Leadership characteristic	Transactional leadership	Transformational leadership	Interpersonal leadership	Network governance leadership	Entrepreneurial leadership
A – Good communication skills			x	x	
B – Visionary		x			x
C – Takes initiative	x	x			x
D – Authoritative	x				
E – Visible leadership		x			
F – Displays a long-term perspective				x	x
G – Displays a short-term perspective	x				
H – Good at gathering information				x	x
I – Problem-oriented	x			x	x
J – Result-oriented		x			x
K – Inspirational		x			
L – Provides intellectual stimulation			x		
M – Committed to colleagues and the organization		x	x	x	
N – Willing to sacrifice self-interest			x		
O – Good at mobilizing the resources needed		x		x	x
P – Works collaboratively				x	
Q – Knowledgeable			x		x
R – Good at learning from mistakes			x		
S – Willing to risk mistakes by employees			x		
T – Open to new ideas		x		x	x
U – Takes all decisions alone	x	x			
V – Involves others in key decisions				x	
W – Always follows procedures	x				

Source: Ricard et al. (2017): Assessing public leadership styles for innovation: a comparison of Copenhagen, Rotterdam and Barcelona. Public Management Review. 19(2), 134–156.

Tab. 4 Descriptive statistics – mean (S.D.).

Region	n	Transactional leadership	Transformational leadership	Interpersonal leadership	Network governance leadership	Entrepreneurial leadership
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Ústí nad Labem Region	88	2.43 (0.92)	2.10 (0.87)	2.54 (0.96)	2.14 (0.90)	1.98 (0.82)
Karlovy Vary Region	27	2.40 (0.77)	2.06 (0.85)	2.49 (0.95)	2.12 (0.83)	1.91 (0.75)
Moravian-Silesian Region	84	2.44 (0.87)	2.02 (0.87)	2.50 (0.91)	1.91 (0.83)	1.85 (0.79)
All three regions	199	2.43 (0.88)	2.06 (0.88)	2.51 (0.94)	2.04 (0.87)	1.92 (0.80)

Note: Leadership scores for the five types are based on 23 items.
Source: Questionnaire-based own elaboration.

leadership dominates in all the regions and is the only leadership type to have a value under 2, except for Network governance leadership in the Moravian-Silesian Region (the lower the value, the greater the application of the elements of the given leadership type). From this, it can be concluded that local government representatives use elements from the business environment in their operation. Crisis and unexpected sudden situations often arise in municipalities and need to be addressed with a flexible and appropriate approach, as is the case in companies. Local governments in the Moravian-Silesian Region are shown to be much more interconnected with other actors (business and the non-profit sector) than in the Ústí nad Labem Region and Karlovy Vary Region (Blažek and Květoň 2022). This interconnection of actors in the Ústí nad Labem Region and Karlovy Vary Region is hindered by a greater concentration of socio-economic barriers and less determination to do something about them compared to the Moravian-Silesian Region (Hlaváček 2012).

Among the other most common leadership types in the Ústí nad Labem Region and Karlovy Vary Region are ones based on attributes such as inspiration, motivation, stimulation and application of visions (Transformational leadership). This type is only in third place in the Moravian-Silesian Region, behind Network governance leadership. Network governance leadership is in third place in the Ústí nad Labem Region and the Karlovy Vary Region. The greater use of Transformational leadership in the Ústí nad Labem Region and Karlovy Vary Region also highlights the greater importance of local government representatives in these regions in planning, promoting and explaining new things and changes to the public (Pileček, Chromý and Jančák 2013).

Transactional leadership is of rather limited importance in all regions, as is leadership based on cooperation where the emphasis is put on communication and maximizing results (Interpersonal leadership). Both leadership types were identified by the representatives as less preferred. The overall differences among the regions in the use of individual leadership types in strategic planning are not very large, but other aspects are examined in the following sections of the paper, namely the differences between municipality population size and the stability of local government representatives, where significantly higher differences can be expected.

When researching the characteristics of individual leaders, attention was also focused on comparing the application of individual leadership characteristics. Factor analysis was applied for this purpose and the results are presented in Tab. 5.

Tab. 5 Rotated factor matrix.

Factors	1	2	3	4
E – Visible leadership	0.850			
C – Takes initiative	0.778			
A – Good communication skills	0.656			
U – Takes all decisions alone	0.416			
O – Good at mobilizing the resources needed	0.385		0.388	
Q – Knowledgeable	0.381	0.477		
B – Visionary		0.906		
F – Displays a long-term perspective		0.716		
I – Problem-oriented		0.472		
J – Result-oriented		0.418		
S – Willing to risk mistakes by employees			0.763	0.362
T – Open towards new ideas			0.724	
R – Good at learning from mistakes			0.573	
W – Always follows procedures			0.364	0.311
H – Good at gathering information				0.962
P – Works collaboratively				0.714
L – Provides intellectual stimulation				0.327

Source: Questionnaire-based own elaboration.

Tab. 5 shows the results of the factor analysis performed. During testing, it proved most suitable to use four factors that explain 39.44% of information about leadership characteristics. Six leadership characteristics were not significant. Based on the results of the

factor analysis, a classification of four types of leaders was created. The first leader type is referred to as a 'manager'. They are persons with great coordination skills, who are proactive, communicative and not afraid to make decisions on their own. The second most frequently used leader type is a long-term-oriented and informed visionary who addresses the real problems and needs of the community with an emphasis on real results. This type can be summarized as a 'practitioner'. The third leader type can be described as a person who has learned from past mistakes and who, within the rules, tries to enable the implementation of new thoughts and ideas, while having the risks properly analyzed. Such a person can be defined as an 'innovator'. The last type is an inspired, short-term-minded person who takes advice from members of their team or experts and takes care to follow well-established procedures. This type of leader can be termed a 'bureaucrat', but this is not the predominant type in the set of monitored municipalities. Tab. 6 shows the percentage of leaders according to the four types in all the regions.

Tab. 6 Leaderships factors.

Factor	Percentage representation of that leadership type
1 (manager)	12.74 %
2 (visionary)	10.85 %
3 (innovator)	9.24 %
4 (bureaucrat)	6.61 %

Source: Questionnaire-based own elaboration.

4.2 Leadership and municipality population size

Research question 2 aims to evaluate the differences in the sets of characteristics of leaders in different municipality size categories during strategic planning. Three size categories were set, taking into account the structure of rural municipalities in Czechia.

Tab. 7 compares the results, while the most commonly applied leadership in strategic planning is again Entrepreneurial leadership, which occupies the first position in all size categories. It is therefore clear that municipality population size is not an important determinant for the more intensive involvement of business characteristics or representatives of companies in the strategic planning process. One reason for the application of Entrepreneurial leadership in smaller municipalities is their greater flexibility in decision-making and organization of activities, as these municipalities do not have large numbers of employees, unlike cities.

In 2017, Ricard et al. carried out similarly focused research in Copenhagen, Rotterdam and Barcelona and they found Transactional leadership was most commonly used. This leadership type is among the least common in Czech rural areas, whereas it is used the most in European cities. This difference is mainly because large municipal authorities have dozens of officials and complex bureaucratic management, but in small municipalities, most agendas are the direct responsibility of the mayor. As a result, there is a greater potential for the application of Entrepreneurial leadership elements in smaller municipalities.

Entrepreneurial leadership came in second position in metropolitan areas compared to Network governance leadership, and Network governance leadership in third position in metropolitan areas compared to Transformational leadership. The change in the ranking of Network governance leadership highlights the slightly greater use of its elements in the structurally affected regions, i.e. in particular the use of various formal and informal networks between leaders and stakeholders.

On the other hand, there is an evident difference in Transformational leadership, which ranks second in the category of up to 499 inhabitants but third in the categories from 500 to 1,999 and from 2,000 to 9,999 inhabitants. This can be explained by the differing position of the mayor in smaller and larger municipalities. In particular, in municipalities with up to 499 inhabitants, some mayors do not perform their function as a full-time job (i.e., the mayor also has another job), but also, apart from the mayor, there is often very little staff capacity for the administration of the municipality, and this is precisely the reason for the more significant use of Transformational leadership in strategic planning. The importance of a single person and their characteristics are much greater here than in the other size categories.

On the other hand, in larger municipalities, the interconnections of all actors, including the private

Tab.7 Descriptive statistics – mean (S.D.).

Municipality size categories by population	n	Transactional leadership	Transformational leadership	Interpersonal leadership	Network governance leadership	Entrepreneurial leadership
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
up to 499	63	2.32 (0.86)	2.01 (0.86)	2.51 (0.93)	2.08 (0.84)	1.94 (0.79)
from 500 to 1,999	92	2.46 (0.88)	2.05 (0.87)	2.49 (0.95)	1.99 (0.88)	1.88 (0.80)
from 2,000 to 9,999	44	2.52 (0.86)	2.16 (0.87)	2.56 (0.88)	2.08 (0.83)	1.96 (0.80)
all categories	199	2.43 (0.88)	2.06 (0.88)	2.51 (0.94)	2.04 (0.87)	1.92 (0.80)

Note: Leadership scores for the five types are based on 23 items.
Source: Questionnaire-based own elaboration.

and non-profit sectors, are important for successful development, and this also explains Network governance leadership being ranked second in size categories from 500 to 1,999 and from 2,000 to 9,999 inhabitants. Another reason for the greater application of Network governance leadership in these two categories is that in municipalities with less than 500 inhabitants, there are not enough actors interested in participating in the development of the municipality.

The leadership type is based on intensive communication exchange and connections between the leader and others, but that also emphasizes informal relationships (Transactional leadership) is relatively little used in strategic planning. This indicates that many mayors are dominant leaders who, however, want to discuss their decisions with others, while being able to assert their views and rationally justify them. Interpersonal leadership is similarly weaker for analogous reasons.

4.3 Leadership and policy stability

Research question 3 evaluates the differences between the leader characteristics concerning the duration of their work in the municipal council. In Czechia, one standard election period is four years and the main purpose in this part of the analysis is to point out the possible association of experiences of local politicians and to find regularity while applying different leadership types.

Tab. 8 compares the application of individual leadership types in strategic planning according to the number of election periods the leader has had in the municipal council. The first position was taken by Entrepreneurial leadership, which is more significant as the number of election periods rises. From this, it can be concluded that with growing experience in local politics, leaders begin to apply more elements from the business environment and to cooperate more effectively with business representatives.

One important aspect in the use of Entrepreneurial leadership is the level of experience in local government. If a newly elected local government representative has experience in this field, it can be assumed that they will work more flexibly and that the use of Entrepreneurial leadership elements will be higher compared to local government representatives from outside the field or similar fields, as they must first become acquainted with the agendas and their start will be more complicated. Their use of business leadership elements will be greater in the following election periods if they remain in local government. Another reason for applying Entrepreneurial leadership elements is to establish and build contacts and relationships with representatives of other municipalities, something very often associated with the transfer of experience in the field of local government.

Network governance leadership, i.e., leadership based on the interconnection of entities from all sectors and their cooperation, is in second place among local government representatives in their first, fourth and subsequent election periods. The application of Network governance leadership in strategic planning in the first period can be justified by initial enthusiasm and energy from working in a new position. For the fourth and subsequent election periods, the reason will be experience, a well-established office and a high degree of coexistence with other actors. On the other hand, Transformational leadership ranks second among representatives in their second and third periods.

The role of Transformational leadership in the second and third periods is quite crucial for many leaders as its important feature is to change/transform established processes or activities, and this is what leaders do well in their second and third terms. During their first period, they initially have to get acquainted with most of their agendas and only then have room to make changes. The order in the third position is exactly the opposite. The degree of application of Network governance leadership and Transformational leadership in strategic planning is more pronounced with a growing number of election periods.

Transactional leadership and Interpersonal leadership are the least applied in all size categories, which is predictable given the characteristics of these leaders. The application of the characteristics of both leadership types is more pronounced with a growing number of election periods.

Tab. 8 Descriptive statistics – mean (S.D.).

Number of periods in the council	n	Transactional leadership	Transformational leadership	Interpersonal leadership	Network governance leadership	Entrepreneurial leadership
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1st period	31	2.65 (0.97)	2.40 (1.00)	2.66 (0.97)	2.22 (0.96)	2.18 (0.92)
2nd period	52	2.49 (0.87)	2.13 (0.86)	2.62 (1.00)	2.15 (0.87)	1.98 (0.81)
3rd period	53	2.34 (0.85)	1.95 (0.81)	2.46 (0.84)	1.97 (0.83)	1.86 (0.74)
4th and subsequent period	63	2.39 (0.80)	1.95 (0.76)	2.40 (0.90)	1.92 (0.81)	1.80 (0.71)
all categories	199	2.43 (0.88)	2.06 (0.88)	2.51 (0.94)	2.04 (0.87)	1.92 (0.80)

Note: Leadership scores for the five types are based on 23 items.
Source: Questionnaire-based own elaboration.

Tab. 9 ANOVA – use of leadership types by number of election periods

	Sum of squares	df	Mean square	F	Sig.
Between groups	2.169	3	.723	5.775	.001
Within groups	23.035	184	.125		
Total	25.204	187			

Note: Data distribution can be considered normal at 95% confidence level (Shapiro-Wilk test).
Source: Questionnaire-based own elaboration.

Tab. 9 and the multiple comparisons in Appendix 2 show that it was possible to demonstrate differences between the application of individual leadership types in strategic planning in different election periods, unlike in different municipality population size categories. In the case of Transactional leadership, its application differs between local government representatives in their 1st and 3rd periods and between local government representatives in their 1st and 4th and subsequent periods. This is primarily due to the gathering of experience in the performance of their functions because one of the important features of Transactional leadership is highly developed competencies associated with friendly management and excellent communication with citizens. It is also important that municipal representatives receive messages from citizens and work with them.

The same evaluation applies to Transformational leadership, but here it is based on other reasons also related to experience in the field or function. The point here is that the local government representatives need to get acquainted with most agendas or activities in their first period, and then can try to implement changes and adjust/transform processes in the following periods. We must also emphasize that municipal representatives become more confident in their decisions the longer they are in their functions.

The application of Interpersonal leadership in strategic planning is different for local government representatives in their 2nd and 4th and subsequent election periods. One reason may be that some local government representatives in their 4th and subsequent election periods routinely do part of their agenda and do not fully perceive the problems and needs of their territory and citizens.

In the case of Network governance leadership, there are differences in its application in strategic planning between municipality representatives in their 1st and 4th and subsequent election periods and also between them in their 2nd and 4th and subsequent election periods. In this leadership type, the differences are due to the connections between the local government representatives and other actors from the public and private sectors. An important role is also played here by their professions or the activities they performed before they became local government representatives, as this shows the degree of connection with such actors before becoming part of local government.

Differences in the application of Entrepreneurial leadership in strategic planning are evident between the 1st and 3rd election periods and between the 1st and 4th and subsequent election periods. Here again, the local government representatives' experience and previous professions or cooperation with companies related to the implementation of various public-benefit development activities play a role. Graph 1 also shows that the answers relating to the number of election periods are often quite different.

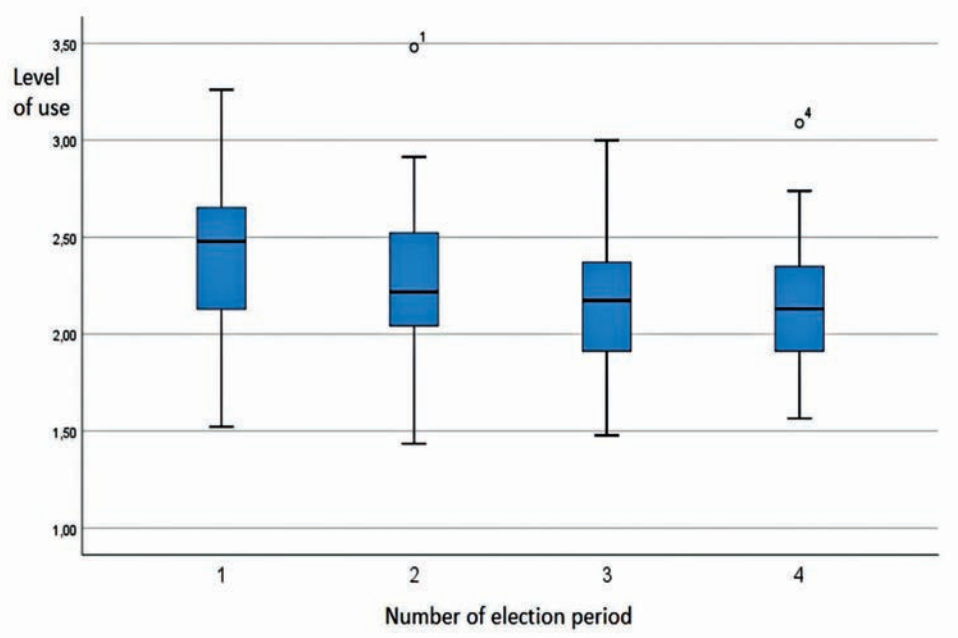

Fig. 1 Comparison of respondents' answers by number of election periods.
Source: questionnaire-based own elaboration

5. Conclusion

This paper aimed to understand and clarify different types of innovation leadership in strategic planning in structurally affected and transforming regions, and to compare their approaches in terms of settlement differentiation (i.e., municipality population size) and the continuity/stability of municipal representatives in their functions using the example of Czechia. The paper works with five types of innovative leadership, which have already been used or somewhat used in other studies (Lewis, Ricard and Klijn 2018). Although the definitions of the individual leadership types and their properties have limits, they are still sufficient for use in this research.

Differences were identified as part of a general comparison of the application of the characteristics of leaders in strategic planning between the Ústí nad Labem Region, Karlovy Vary Region and Moravian-Silesian Region. However, Entrepreneurial leadership is most used in all these regions because the elements of this leadership type are often very important for the functioning of municipalities. The main difference is that the second place is occupied by Network governance leadership in the Moravian-Silesian Region, while Transformational leadership took the same place in the Ústí nad Labem Region and Karlovy Vary Region. In other words, it was found that local government representatives in the Moravian-Silesian Region communicate and cooperate with public and private sector actors more than the representatives in the Ústí nad Labem Region and Karlovy Vary Region (Blažek and Květoň 2022). Intensified communication and cooperation are likely to be reflected in the economic field, as this region has been growing dynamically in recent years, and communication among the major regional actors is perceived as a driver of the region's current evolutionary trajectory (Blažek et al. 2019). Representatives of local governments in the Ústí nad Labem Region and Karlovy Vary Region exhibit a greater determination to change established processes and ways of implementing various activities compared to their counterparts in the Moravian-Silesian Region, yet they lack sufficient personnel and financial capacities, and this is reflected in the slow changes in the region's economic structure and overall quality of life.

Furthermore, dependence between the leadership types and the stability/continuity of local government representatives in strategic planning was proved, but dependence between the leadership types and the municipality size categories was not. First of all, it is important to emphasize that Entrepreneurial leadership becomes increasingly important as the number of election periods enjoyed by a representative grows. In other words, leaders begin applying elements from the business environment more and cooperate more effectively with company representatives as they gain more experience in local politics. In the first period (but also in the fourth and subsequent periods) Network governance leadership is also applied, i.e., leadership based on the interconnection of entities from all sectors and their cooperation. In the first year, the situation is more initial enthusiasm, while after four or more periods, it is more the experience and knowledge of the local environment that favours this type of leadership. On the other hand, Transformational leadership is more typical for the second and third periods, as these usually feature efforts to change/transform established processes or activities in the municipality/region.

The topic of applying different leadership types has potential research opportunities in the field of local governments, but also public administration. Either surveys on a similar principle on the same topic can be carried out in other regions of Czechia or Central Europe, or it is possible to monitor the application of leadership in other public administration activities. There is considerable potential for comparison within CEE, as these are post-socialist countries that have had to undergo a social transformation, while there were no elites at any levels of state administration and local government, meaning they had to gradually develop. Therefore, it can be assumed that leadership supported by an increase in the quality of the institutional environment can significantly influence development in these regions.

Making comparisons using research carried out in the Western European metropolises of Copenhagen, Rotterdam and Barcelona (for more see Ricard et al. 2017), we can state that the application of individual leadership types in structurally affected regions seems different, as Transformational leadership was more often applied than Entrepreneurial leadership. This means that leaders in structurally affected regions use more elements of the business environment in their work, unlike leaders in metropolitan areas, who make their decisions after communication with stakeholders and using other elements of interaction with the environment. The main reasons for the above differences include the different ways of development of public administration, i.e., the differences between the democratic and socialist establishment of individual states in the past (Grabher and Stark 1997), but above all the fact that the metropolitan areas and structurally affected regions function very differently. Other causes include for example, differences in the use of social capital, the degree of institutional density and the style and implementation of regional policy (Sotarauta, Horlings and Liddle 2014). Given the comparable characteristics of structurally affected regions in Central and Eastern Europe, the situation in these regions can be expected to be similar.

Furthermore, a recommendation for future research is to evaluate data obtained through a questionnaire survey based on other attributes. This paper deals with regional comparisons, comparisons between municipality size groups, and the number of periods of office of local representatives. However, we

can suggest making comparisons between full-time and part-time, male and female, and different age categories of local government representatives, another possibility for future research.

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Appendix 1 The questionnaire

Leadership characteristic	Question in the questionnaire
A – Good communication skills	Were you the moderator of most public meetings on the community development program?
B – Visionary	Do you have a clear vision of the future of the municipality?
C – Takes initiative	Were you the initiator of the creation of the community development program?
D – Authoritative	Did you personally refuse to include a project in the community development program?
E – Visible leadership	Were you the predominant coordinator of the process of creating a community development strategy?
F – Displays a long-term perspective	Do you have a clear vision of the future of the village in 10 years?
G – Displays a short-term perspective	Do you plan the development of the municipality for one election period, i.e. do you not start activities that could exceed it?
H – Good at gathering information	Were citizens involved in the creation of the community development program?
I – Problem – oriented	Do you think that all the real problems and needs in the municipality were sufficiently taken into account when creating the development strategy of the municipality?
J – Result – oriented	Are the specific results of the projects planned in the community development program already visible?
K – Inspirational	Did you look for inspiration in other municipalities/regions when formulating goals, activities and specific projects for the community development strategy?
L – Provides intellectual stimulation	Did you use the help of a professional external entity in the creation of the community development strategy?

M – Committed to colleagues and organization	Were the representatives active in creating the community development program?
N – Willing to sacrifice self-interest	Did you have any private personal interest in creating the community development program that you were able to suppress? (promoting this interest would gain an economic or another advantage for you or your family)
O – Good at mobilizing the resources needed	When planning projects for the community development strategy, did you address their future financing?
P – Works collaboratively	Were local non-profit organizations (associations), entrepreneurs, or other entities involved in the creation of the community development program?
Q – Knowledgeable	Do you think that you have sufficient knowledge of official methodologies and procedures related to the creation of a community development program?
R – Good at learning from mistakes	Did you take into account the shortcomings in the creation and implementation of previous strategic documents of the municipality?
S – Willing to risk mistakes by employees	Do you have the risks of possible project implementation mentioned in the community development strategy?
T – Open to new ideas	Do you have a project in the community development strategy that can be described as a SMART project?
U – Takes all decisions alone	Did you make most of the key decisions about future projects listed in the community development program yourself?
V – Involves others in key decisions	Were the municipal representatives involve in most of the key decisions concerning future projects listed in the municipal development program?
W – Always follows procedures	Did the process of creating the community development program respect these official methodologies and procedures?

Appendix 2 Multiple Comparisons – use of leadership types according to the number of election periods

Tukey HSD

Dependent Variable	(I) Number of election periods	(J) Number of election periods	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Transactional leadership	1	2	.16276	.10011	.367	–.0968	.4223
		3	.34224*	.09975	.004	.0836	.6009
		4	.26807*	.09727	.032	.0159	.5202
	2	1	.16276	.10011	.367	–.4223	.0968
		3	.17948	.08536	.156	–.0418	.4008
		4	.10531	.08245	.579	–.1084	.3191
	3	1	–.34224*	.09975	.004	–.6009	–.0836
		2	–.17948	.08536	.156	–.4008	.0418
		4	–.07417	.08201	.803	–.2868	.1384
	4	1	–.26807*	.09727	.032	–.5202	–.0159
		2	–.10531	.08245	.579	–.3191	.1084
		3	.07417	.08201	.803	–.1384	.2868
Transformational leadership	1	2	.26906	.10413	.051	–.0009	.5390
		3	.44580*	.10337	.000	.1778	.7138
		4	.46042*	.10079	.000	.1991	.7217
	2	1	–.26906	.10413	.051	–.5390	.0009
		3	.17674	.08891	.196	–.0538	.4072
		4	.19136	.08590	.120	–.0314	.4141
	3	1	–.44580*	.10337	.000	–.7138	–.1778
		2	–.17674	.08891	.196	–.4072	.0538
		4	.01462	.08498	.998	–.2057	.2349
	4	1	–.46042*	.10079	.000	–.7217	–.1991
		2	–.19136	.08590	.120	–.4141	.0314
		3	–.01462	.08498	.998	–.2349	.2057

Dependent Variable	(I) Number of election periods	(J) Number of election periods	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Interpersonal leadership	1	2	–.00217	.10035	1.000	–.2623	.2580
		3	.17531	.09999	.299	–.0839	.4345
		4	.23328	.09750	.082	–.0195	.4861
	2	1	.00217	.10035	1.000	–.2580	.2623
		3	.17748	.08556	.165	–.0443	.3993
		4	.23545*	.08264	.025	.0212	.4497
	3	1	–.17531	.09999	.299	–.4345	.0839
		2	–.17748	.08556	.165	–.3993	.0443
		4	.05797	.08220	.895	–.1551	.2711
	4	1	–.23328	.09750	.082	–.4861	.0195
		2	–.23545*	.08264	.025	–.4497	–.0212
		3	–.05797	.08220	.895	–.2711	.1551
Network governance leadership	1	2	.07456	.10509	.893	–.1979	.3470
		3	.26249	.10471	.062	–.0090	.5340
		4	.31437*	.10210	.013	.0497	.5791
	2	1	–.07456	.10509	.893	–.3470	.1979
		3	.18793	.08960	.158	–.0444	.4202
		4	.23981*	.08654	.031	.0155	.4642
	3	1	–.26249	.10471	.062	–.5340	.0090
		2	–.18793	.08960	.158	–.4202	.0444
		4	.05188	.08608	.931	–.1713	.2750
	4	1	–.31437*	.10210	.013	–.5791	–.0497
		2	–.23981*	.08654	.031	–.4642	–.0155
		3	–.05188	.08608	.931	–.2750	.1713
Entrepreneurial leadership	1	2	.19353	.09937	.212	–.0641	.4512
		3	.31891*	.09864	.008	.0632	.5747
		4	.38327*	.09619	.001	.1339	.6327
	2	1	–.19353	.09937	.212	–.4512	.0641
		3	.12538	.08484	.453	–.0946	.3454
		4	.18975	.08198	.098	–.0228	.4023
	3	1	–.31891*	.09864	.008	–.5747	–.0632
		2	–.12538	.08484	.453	–.3454	.0946
		4	.06436	.08110	.857	–.1459	.2746
	4	1	–.38327*	.09619	.001	–.6327	–.1339
		2	–.18975	.08198	.098	–.4023	.0228
		3	–.06436	.08110	.857	–.2746	.1459

* The mean difference is significant at the 0.05 level.
Note: 1 – first election period, 2 – second election period, 3 – third election period, 4 – fourth and more election periods.
Source: Questionnaire-based own elaboration.

How to integrate cultural and geological heritage? The case of the Comuniterrae project (Sesia Val Grande UNESCO Global Geopark, northern Italy)

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ABSTRACT

Geoheritage is recognized as a component of the cultural heritage, especially in areas like UNESCO Global Geoparks. In the Sesia Val Grande UNESCO Global Geopark (northern Italy), the "Comuniterrae project" is a participated project focusing on the elaboration of Community Maps of the Middle Lands and including 10 municipalities located in a "mid" territory between the valley bottom and the highlands. Local communities have inventoried 270 elements, both immaterial and material, as components of their cultural heritage. These sites show a strong link with the geological and geomorphological background. We aimed at enlightening this link by selecting the most iconic geo-cultural sites. An original procedure of classification based on 3 main criteria was set on 70 selected sites: i) the kind of geofeatures; ii) the spatial relation between geofeatures and cultural sites, and the reciprocal conditioning; iii) the relation between humans and geofeatures. The results highlight that heritage stones and natural landforms, especially if conditioning the cultural site location, are the most recurrent categories. The use of geofeatures by humans is the most common kind of relation. These results invite to organize meetings with local populations to discuss these outcomes, and to enrich the touristic offer with multidisciplinary approaches.

KEYWORDS

geocultural sites; geoheritage; landscape; UNESCO Global Geoparks; Comuniterrae project

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1. Introduction

Since the beginning of the XXI century the concept of geological heritage as component of cultural heritage has been boosted by many geoscientists (e.g., Gordon et al. 2021). Anyway, as remarked by Pijet-Migoń and Migoń (2022), many UNESCO World Heritage Sites, the most emblematic examples of cultural heritage, despite being characterized by mixed geological and cultural features, are not recognized for their intrinsic geological value. In 2018 Brilha (2018), reviewing a large amount of literature, codified clearly what geoheritage means. In particular, if we consider the diversity of geological elements of a region (i.e., *geodiversity*, sensu Gray 2004), some sites could be selected to depict this diversity: these are the *geodiversity sites* (Table 1). When these sites are recognized as having a relevant scientific value, they become, according to Brilha (2018), *geoheritage sites*. Within this term is inherent the concept of heritage, something to be protected and transmitted to future generations.

In order to select sites that can be considered elements of the geoheritage deserving conservation, several methodologies have been applied, again reviewed by Brilha (2018). These methodologies were mainly tested to evaluate sites of geomorphological interest (i.e., *geomorphosites*; Panizza 2001; Table 1), but may be applied to all the geoheritage sites. In general, at this scope, according to Panizza and Piacente (2003) two classes of values can be distinguished: the scientific value (proper and intrinsic of the geoheritage sites s.s.) and additional values (cultural, socio-economic, aesthetic and ecological). The cultural, aesthetic and socio-economic values, in particular, represent the starting point to raise awareness in the society, and even more in local populations, of this kind of heritage (Lahmidi et al. 2022). The single sites, indeed, are part of a complex cultural landscape that should be valued. According to the European Landscape Convention, signed in 2000, local population living in a territory, then, should be aware of this heritage and of its resources.

In this research the focus has been put in particular onto the cultural value: this is also one of the geosystem services provided by geodiversity to society, as described by Gray et al. (2013). The cultural value of a geodiversity or geoheritage site could, indeed, be related to both material and immaterial cultural features connected with it. The cultural features could depend strictly on the geo-features (e.g., the influence of the geomorphological setting on human settlements), making the site acquire an even higher cultural value, or could be not related at all (e.g., a geo-feature of interest located nearby a cultural asset) (e.g., Forno et al. 2022). Moreover, the reciprocal importance could be variable: the cultural aspect may prevail on the geological one, as for cultural sites having an additional geological value, or vice versa (Pijet-Migoń and Migoń 2022). When one feature prevails over the other, the challenge consists in giving value to both the components of the heritage. Indeed, as mentioned before, one of the main obstacles to the recognition of the geoheritage value associated with sites representing cultural heritage s.s. is the scarce awareness of society about the role of geofeatures and their importance in underpinning the cultural heritage. Local populations in particular, as underlined by Reynard and Giusti (2018), are more open to protect their cultural heritage than the natural abiotic heritage, thus negatively affecting the implementation of protection policies at the local level. This is a relevant aspect if we consider the potential change that natural resources experience in relation to ongoing climate change, undermining the integrity of sites and provoking a loss of their value (Prosser et al. 2010; Pelfini and Bollati 2014). For this reason, it could be really important to investigate the potential interconnections to boost conservation of both features (Lahmidi et al. 2022).

In literature the potential connection between cultural and geological values has been only recently investigated, and mainly in relation to archaeological heritage, one of the categories of cultural heritage (Moroni et al. 2015; Melelli et al. 2016; Melis and Mariani 2022). Considering the definition of archeological site as that by Watkinson and Corfield (2008; Table 1), in this specific case, new terms were recently introduced in the literature to indicate sites where both interests are found (Tab. 1): *cultural geomorphosites* (Niculiță and Mărgărint 2018), *geoarcheoheritage sites* (Taha and El-Asmar 2018), *geoarcheosite* and *archeogeomorphosite* (Fouache and Rasse 2009; Fouache et al. 2012), *archeo-geosites* (Melelli et al. 2016); *geoarcheomorphosite* (Brandolini et al. 2019).

In particular, *archeo-geosites* are "archeological sites where the geological substratum and/or the geomorphological evolutionary conditions are determinant for the knowledge and correct interpretation of the site itself" (Melelli et al. 2016). Instead, in the case of *geoarcheomorphosite* (Brandolini et al. 2019) the emphasis is strongly put on the impact and changes produced by human activities on sites of archeological and geomorphological interest. These last definitions open the great issue of human impact on cultural sites, leading in some cases to the geomorphosites being totally dismantled or, at least, hidden and not visible anymore (Prosser et al. 2010; Pelfini and Bollati 2014; Niculiță and Mărgărint 2018; Clivaz and Reynard 2018). Moreover, for Brandolini et al. (2019), archeological information at *geoarcheomorphosites* is very important to understand the evolution of the geomorphosite, and not only additional as stressed by previous authors (Fouache and Rasse 2009; Fouache 2012). Another interesting term proposed for complex situations at the landscape scale is *archaeo-cityscape* which considers the geological and

Tab. 1 List of definitions applied to sites of interest from an archaeological and geological point of view, and for sites where the combination of interests is clear. In bold the term selected for the present study.

Category	Name	Reference	Definition
Archeological	Archeological site	Watkinson and Corfield (2008)	Archaeological sites are locations where former human activity is manifested. Any concentration of artifacts, ecofacts, features, and structures manufactured or modified by humans.
Geological	Geodiversity site	Brilha (2018)	Geodiversity elements that do not have a particular scientific value but which are still important resources for education, tourism, or cultural identity of communities (in situ and ex situ).
	Geological site heritage, or geoheritage		(i) in situ occurrences of geodiversity elements with high scientific value – geosites (ii) ex situ geodiversity elements that, in spite of being displaced from their natural location of occurrence, maintain a high scientific value (for instance, minerals, fossils, and rocks available for research in museum collections) – geoheritage elements.
	Geomorphosite	Panizza (2001)	A landform to which a value can be attributed
Combined	Archeo-geosite	Melelli et al. (2016) and reference therein	An archaeological site where the geological substratum and/or the geomorphological evolutionary conditions are determinant for the knowledge and correct interpretation of the site itself.
	Archaeo-cityscape	Mariani and Melis 2022) and reference therein	An existing or past urban-related landscape (a cityscape) where the geological (e.g., structural and lithological setting, potential hazards and catastrophic events, mineral resources, ores, and quarry materials) and geomorphological (e.g., morphodynamics in time, response to climate change) history play a part in its heritage value from before its inception to its decline, abandonment, or transformation.
	Geoarcheosite	Fouache and Rasse (2009)	An archaeological site located on a geomorphosite.
	Archeo-geomorphosite	Fouache et al. (2012)	A geomorphosite with archaeological interest and in which the geomorphological study has been prompted by historical and archeological questions.
	Geoarcheoheritage site	Taha and El-Asmar (2018)	Not provided.
	Cultural geomorphosite	Niculiță and Mărgărint (2018) and reference therein	Landforms which have an intrinsic cultural value or which favored human activities (archaeological sites, historical monuments or construction of settlements) and gain a cultural value.
	Geoarchaeomorphosites	Brandolini et al. (2019)	Any geomorphosite derived by the dynamic interaction between natural (mainly fluvial) and human events (es. Protohistoric TC settlements, Roman regular field system, Medieval canals and artificial river diversions) and for which the archaeo-historical data are crucial to assess its genesis and development during different historical times, and to enhance the geomorphosites' scientific and cultural/historical values.
	Geocultural site	Reynard and Giusti (2018)	Sites where "the geological features interact with cultural elements (historical or archaeological vestiges, cultural or religious monuments, etc.), and the geoheritage value joins the cultural value".

geomorphological variables in the assessment of the evolution of urban landscapes, underlining how the connection between cultural and geological features may empower dissemination of knowledge since general public is more familiar to cultural heritage (Mariani and Melis 2022).

Recently, Reynard and Giusti (2018) introduced a further definition, that of *geocultural sites* (Table 1), to indicate more broadly all the sites where "the geological features interact with cultural elements (historical or archaeological vestiges, cultural or religious monuments, etc.), and the geoheritage value joins the cultural value".

All these proposals and related investigations contribute to the discipline named *cultural geomorphology* (Panizza and Piacente 2003), reflecting the important role of geomorphological features in the cultural heritage assessment.

As depicted in a recent review (Pijet-Migoń and Migoń 2022), there are several kinds of interrelations (spatial, conceptual, causal, and thematic) between geoheritage and cultural heritage, that could be translated into topics of research. In figure 1 some practical examples of these interconnections are depicted, referring to the cases listed as follows, modified from (Pijet-Migoń and Migoń 2022). Please, consider that sites may belong to more than 1 category.

a) The use of rocks in buildings (De Wever et al. 2017) and the urban geoheritage in general, including landforms in urban environments (Bizzarri et al.

2018; Thornbush and Allen 2018; Pelfini et al. 2021) (Fig. 1a);

b) Cultural landscape i.e., landscapes deeply influenced by human action (e.g., mining and quarrying sites, terraces) (e.g., Gordon 2018a) (Fig. 1b, c);
c) History of Sciences as cultural, but mainly scientific, value of the site (e.g., Gordon 2018b) (Fig. 1d).
d) How natural processes, especially catastrophic ones, affect cultural heritage and human settlements (e.g., Canuti et al. 2009; Bollati et al. 2012; 2018; Taha and El-Asmar 2018; Migoń and Pijet-Migoń 2019; Forno et al. 2022; Mariani and Melis 2022) (Fig. 1e);
e) Intangible values like art (among which rock art sites), literature, religion and traditions (e.g., Nesci and Borchia 2017; Gordon 2018b; *Geomithology*, Vitaliano 2017; Variale et al. 2022) (Fig. 1f).

Again concerning the potential threat to cultural heritage from natural and anthropic processes (point d), the importance of considering geoheritage

Fig. 1 Some examples of interconnections between geological and cultural features in potential geocultural sites. a) Montorfano church of the Romanesque period built mainly with the local granites and gneiss of the Ossola Valley (Northern Italy); b) the Cava Madre of Candoglia where the beautiful marble for the Milan Cathedral has been quarried since the XIV century (Ossola Valley, Northern Italy); c) Wine terraces of Lavaux, UNESCO World Heritage sites along the shore of Lake Léman (Vaud Canton, Switzerland); d) Erratic boulder used by Guglielmo Marconi for the first attempt of phone communication (Valais Canton, Switzerland); e) Example of Alpine rural heritage completely isolated by a landslide of geological interest; the yellow dotted line represents, according to an oral communication by local people, the previous path to reach the Alpine hut and the red cross indicates the interruption of the path due to the landslide on the right, blocking the access to the valley and obstructing the stream; f) the iconic landscape drawn by Piero della Francesca in the Italian Renaissance in the Italian Apennines. Source https://www.marinadeicesari.it/montefeltro-paesaggi-invisibili.

as a cultural element deserving attention has been recently analyzed. Indeed, not only cultural assets of anthropic origin may be damaged by geomorphic processes like the climate-related ones, but also geoheritage sites themselves (Prosser et al. 2010; Bollati et al. 2012; Pelfini and Bollati 2014; Gordon et al. 2021; Migoń and Pijet-Migoń 2019). If this kind of processes modifies features of geoheritage and geodiversity sites, and, where applicable, of geocultural sites, modifications could be irreversible, potentially causing a relevant loss of value (Pelfini and Bollati 2014; Migoń and Pijet-Migoń 2019).

In this research the main objects of interest are potential geocultural sites (Reynard and Giusti 2018), where several diversified cultural and geofeatures could be found, offering visitors a broader experience. Even if for Reynard and Giusti (2018) geocultural sites are more connected to the concept of geoheritage sites, rather than geodiversity sites (*sensu* Brilha 2018), in this research the concept includes both geoheritage and geodiversity sites, having scientific value but indeed featured by a relevant cultural value.

The aim of the research is, hence, to investigate the possibility of integrating cultural and geological heritage at specific geocultural sites, selecting an area where this link is particularly strong.

1.1 The case study: the Comuniterrae project

Specific areas where cultural and geological heritage may be intimately related are the UNESCO Global Geoparks (UGGPs). They are officially defined as "single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development" (source: https://www.unesco.org/en/iggp/geoparks/about). A bottom-up approach, combining conservation with sustainable development and aimed at actively involving local communities, characterizes these regions. UNESCO ratified the interest towards the Global Geoparks Network in 2015 with the birth of the UNESCO program named "International Geoscience and Geoparks Programme". At present (2022), there are 177 UGGPs in 46 countries. Hence, in such areas, the mixture between social and scientific values is often very strong and the possibility of investigating their potential integration is relevant.

For this reason, we selected a case study in the territory of a UGGP, the Sesia Val Grande (SVGP, Piedmont Region, Northern Italy) (Fig. 2) which in 2013 officially became a member of the UGGP Network (http://www.sesiavalgrandegeopark.it/index.php/en/). It is a wide territory spanning from the Eastern Ossola Valley, bonding the Val Grande National Park, to the Sesia Valley, and occupying about 2202 km sq, including 106 municipalities. Its geological heritage is rich and diversified (Perotti et al. 2020): 68 geosites, 18 geotrails and 13 thematic museums, these latter representing offsite geoheritage sites (Brilha 2018), were inventoried. This broad offer to tourists and school students, founded on *place-based learning* (Gordon et al. 2021), can promote the value of potential geocultural sites, underlining the need to preserve them for both their scientific value and importance for the society.

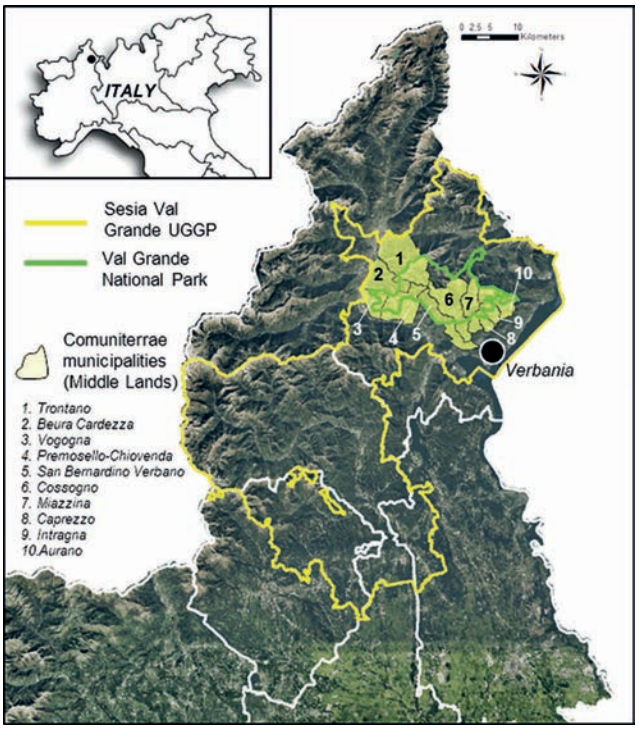

Fig. 2 Location of the Sesia Val Grande UGGP (yellow line) in northern Piedmont, in the Italian Alps, with the areas of the 10 municipalities of the Comuniterrae project (in light brown), represented in relation to the borders of the Val Grande National Park (green line).

Then, the choice fell specifically on the easternmost portion of the SVGP, where an interesting project has recently started: the *Comuniterrae Project* (http://www.comuniterrae.it/) (Cerutti 2019; Bagnati and Perlo 2020; Cerutti 2020), started in November 2016 and launched in January 2017. The project was awarded with the European Heritage Award / Europa Nostra Award 2019 for the actions in the frame of "Education, training and awareness raising". It is a cultural participated project involving 10 municipalities, spread in 2 valleys, in a "mid" territory (i.e., Middle Lands; Fig. 2) located between 300 and 900 m (a.s.l.), the valley bottom and the high lands (Bagnati and Perlo 2020), across the borders of the Val Grande National Park, featured by unique and identity-making features (Cerutti 2019). The area can be considered a marginal or peripheral region where, despite the abandonment and depopulation (Bagnati and Perlo 2020), a rich cultural heritage, representing a socio-economic and touristic asset, is preserved (Cerutti 2019). The municipalities, in which about 9.6 thousand people still live (Cerutti 2019), are: Aurano, Beura-Cardezza, Caprezzo, Cossogno, Intragna, Miazzina, Premosello-Chiovenda,

San Bernardino, Trontano and Vogogna. The 10 communities are involved in the production of Community Maps of the Middle Lands through the institution of "focus groups" (Fig. 3a, b). One of the main results of the project is the weakening of the borders among municipalities, strengthening the idea of a unique "Middle lands" territory (Cerutti 2019; Bagnati and Perlo 2020). The next planned step will be the foundation of an Ecomuseum that will be managed by local populations with the support of the Val Grande National Park (Cerutti 2019).

In particular, the community or participatory maps derive from the evolution of the concept of the Parish maps born in the XX century from an idea of Clifford and King (1996). The maps are aimed at drawing cultural landscapes tying together the interconnections between physical places, with hidden or forgotten stories and with the capacity of representing and narrating them. As demonstrated in the framework of several analogous national and international projects (Summa 2009), they are a strong communicative tool in collecting and sharing the knowledge with different spheres of inhabitants, landscape users and tourists, practicing a process of heritage valorization. In the Comuniterrae case local inhabitants are involved as both "shareholders", since sharing the territory and its heritage, and "stakeholders", since they use the territory and are interested, as a person or community, in a good management of its heritage (Cerutti 2019). Community maps favor the identification of a community through a cartographic representation, and increase the perception and consequent representation of the territory and its cultural heritage, being it material or immaterial. Moreover, they represent an opportunity for local development and heritage conservation, actively involving local communities in the management of territories (Cerutti 2019). Within the Comuniterrae project, 250 have been the participants (e.g., entities, associations, municipalities administrators, inhabitants), 270 sites and common goods have been selected by local communities, according to specific criteria (see details on the procedure in Cerutti 2019), and marked on site with plates with a QR Code (Fig. 3c). Many other sites are still under evaluation. Among the activities of the participants are: organization of meetings in each municipality involving the inhabitants in selecting the heritage sites (Fig. 3d), inventory of the heritage sites, preparation of the Community maps of

Fig. 3 The identifying traits of the Comuniterrae Project. (a) The Community map of the entire Middle Lands; (b) Example of a Community map of a municipality (Premosello- Chiovenda); (c) Plate with the QR Code placed at one of the Comuniterrae site; (d) One of the meetings involving local communities to work on the inventory of sites; (e) Leaflet of a Comunitour organized in one of the municipalities. Source of images a, b, d, e: www.comuniterrae.it).

the Middle Lands (1 global map, Fig. 3a, and 1 for each municipality, Fig. 3b) and organization of Comunitours (Fig. 3e), tours guided by the local population to accompany visitors to discover and become aware of the local cultural heritage. Indeed, people living in the territory are "insiders", reading their own identity in the cultural landscape, offering it to people visiting the territory, that are instead "outsiders" (Cerutti 2019). The final Community Maps were released in November 2018, and several were the realized Comunitours (4 editions from 2019 till 2022), considering also the Covid-19 forced pause.

Our research was stimulated by the fact that some of the 270 Comuniterrae sites preserve and show a strong link with the geological and geomorphological background. Being the Comuniterrae territory part of the SVGP, geoheritage has been already inventoried. There are 3 sites included in the national Geosites Inventory (http://sgi.isprambiente.it/GeositiWeb/ricerca_geositi.aspx), 5 sites listed in the Piedmont Regional Inventory of sites of interest (https://www.geoportale.piemonte.it/cms/), and 6 included in the SVGP geosite list (Perotti et al. 2020). Moreover 5 geotrails connecting some of these localities are also present (Perotti et al. 2020).

Finally, this research is aimed at enlightening those tight links proposing a classification of potential geocultural sites among those inventoried within the Comuniterrae project.

2. Material and methods

The method consists in a preliminary selection of the most suitable sites that can be considered geocultural sites among those inventoried in the Comuniterrae project. After that, a method for classification and categorization of such sites has been applied and proposed as original and never tested before.

First of all, a preliminary survey using the Google © platforms was distributed to one representative selected by the Comuniterrae project managers for each one of the 10 municipalities. The aim was investigating the effective interest towards geofeatures, and collecting more inputs about them in their own territory. The survey (in Italian language), is closed but it can be viewed at this link: https://docs.google.com/forms/d/e/1FAIpQLSdPs3w7NMArGXeZKyLYHZKla4tUq4-jFzVaIA5dfcslxmA5OA/viewform?usp=sharing.

Then, according to the workflow in figure 4, a preliminary analysis of the existing data about the sites was followed by direct observations in the field, that allowed one to collect and confirm in situ geological and geomorphological data, pictures and information. Rocks cropping out at or related to the geocultural sites were sampled and identified through petrographic study in thin section, forming a database which may be used in the future for further themes of divulgation. The geological and geomorphological results were integrated and compared with the available maps and literature concerning the study area.

Then, we removed from the preliminary list those sites that, according to our judgment, do not show evident geofeatures (e.g., Middle-Land festivities, bakery ovens, dairies, schools). The classification of the remaining geocultural sites was performed according to 3 main steps or criteria (Fig. 5). The method of classification is completely original, but it considers the main outcome of the researches available in literature (see Section 1). The steps or criteria are listed as follows:

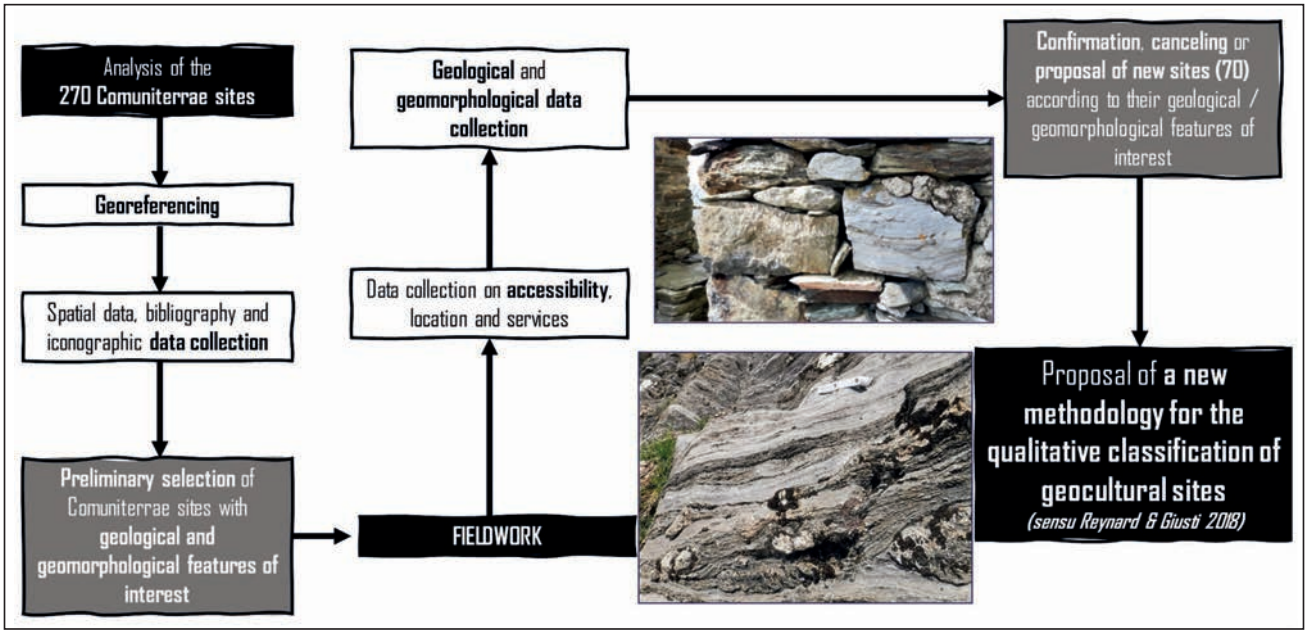

Fig. 4 Workflow of the research from the preliminary data collection, to fieldwork activities as far as the final selection of the potential geocultural sites among the 270 sites inventoried by the Comuniterrae Project participants.

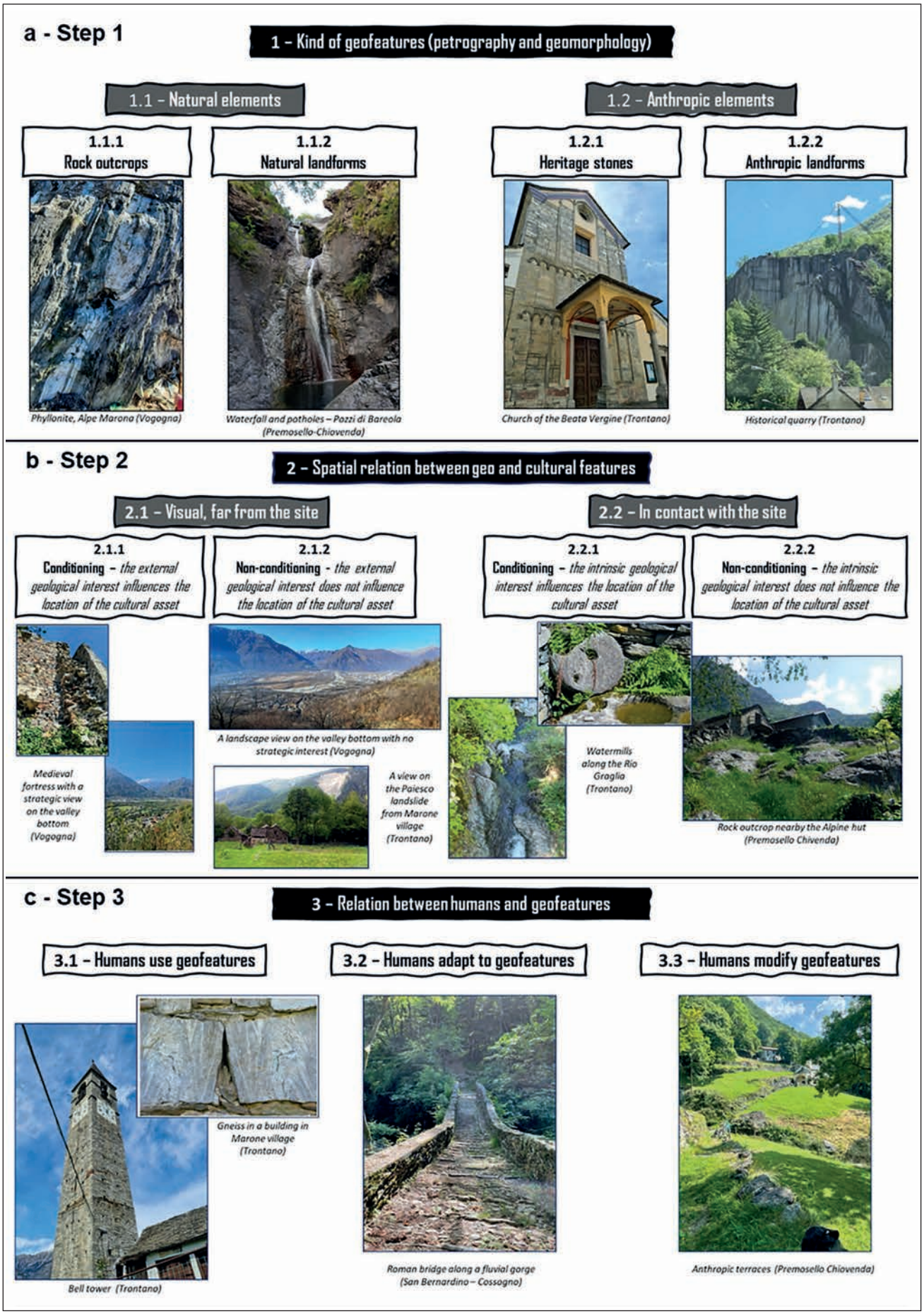

Fig. 5 Classification of the geocultural sites according to 3 main steps or criteria.

1) *Kind of geofeatures* and distinction between *natural* and *anthropic geofeatures*: the question is if the geological and geomorphological features of interest are of natural (rock outcrops, natural landforms) or anthropic origin (heritage stones, anthropic landforms);
2) *Spatial relation between geo- and cultural features* that is the relation of *distance* (i.e., visual) or *proximity* (i.e., in contact), *and degree of conditioning of the interesting geofeatures on the site's location* (i.e., conditioning or non-conditioning). In the case of visual geofeatures, the concept of *viewpoint geosite* proposed by Migoń and Pijet-Migoń (2017) was considered. They are "locations which allow for unobstructed observation of the surrounding landscape and comprehension of Earth history recorded in rocks, structures and landforms visible from this locality";
3) *Relation between humans and geofeatures* (i.e., usage, adaptation, modification). The question is if humans were able to use local georesources or needed to adapt to the local conditions, in some cases modifying the georesources.

According to the results, finally, a discussion on the potential outcomes of the methodology will be proposed.

3. Results and discussion

The preliminary survey was completed by 9 over 10 representatives (90%). They all demonstrated to be aware of the meaning of geological elements, and almost always indicated appropriate examples of geofeatures in their own municipalities (e.g., rock outcrops, tectonic lines, rocks shaped by glaciers, and "fertility rocks", rocks traditionally believed to be talismans for female fertility). Also concerning landforms, they brought both natural and anthropic examples (e.g., alluvial fans, landslides, terraces, mountains, hills and plains). Finally, they proved to understand the importance of such elements as resources for the territory and as cultural elements, useful for building the collective memory. They believe that such elements are worth to be included and promoted within the Comuniterrae Project. These results stimulated the continuation of our research.

Hence, the preliminary phase and the fieldwork led to the selection of 70 sites from the 270 Comuniterrae sites (Fig. 6). These sites are featured by 151 geocultural characteristics, as a single site may show more than one kind of interest. All the data on the 70 sites and the related classification according to the 3 criteria are included in the Supplementary File A.

Among the categories used in the Comuniterrae project, recently slightly modified, there was one named Nature/Landscape (Cerutti 2019): among its sub-categories (i.e., trails and mule tracks, water, woods, panoramic viewpoints, fauna) only indirect indications to Geosciences can be retrieved (i.e., water, panoramic viewpoints). It is then interesting that only 3 sites were evidently included in the Comuniterrae list for their prominent geological or geomorphological interest (Fig. 7): the Vogogna-Premosello geological trail (Vogogna) (Fig. 7a); the Brigalun landslide (Aurano) (Fig. 7b); the Bareola waterfalls and potholes (Premosello-Chiovenda) (Fig. 7c). We assume that these sites were indicated since they are well known by the local population. The last two show very evident geomorphological characteristics, that are easily perceived by the public (Fig. 7b and c), and in particular one of them was considered for the inherent local legend (see more information in Section 3.1.2). The geological trail, instead, even if the topic is more difficult, is close to the Vogogna village, with some illustrative panels within the town itself.

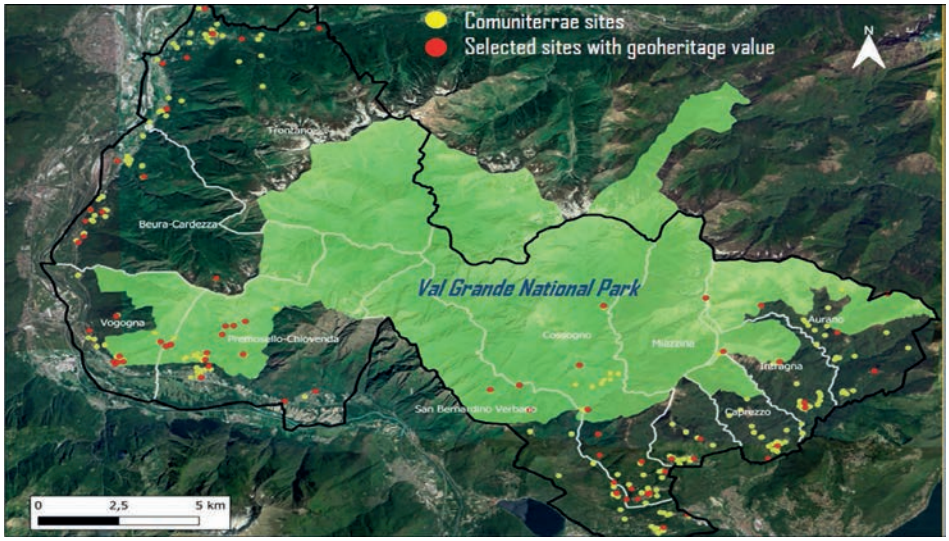

Fig. 6 Spatial distribution of the 270 Comuniterrae sites (yellow dots) and of the 70 sites selected for the analysis (red dots). The sites are depicted with respect to the borders of each municipality (in white) and of the Val Grande National Park (in black) (Background: Google Earth ©).

It is also very publicized and used by local schools, so the inhabitants are really aware of its importance.

The graphs in Fig. 8 summarize the final results of the classification (Fig. 8a), as well as the results of the 3 steps of the procedure (Fig. 8b, c, d and e). The classification demonstrated to be very hard to perform, due to the possible occurrence of geofeatures in different categories of the same step, especially in step 3 (*Kind of relation between humans and geofeatures*). In doubtful cases, we selected the prevalent one according to our judgment.

In general, the great majority of sites (40%) shows 1 geofeature of interest, while the maximum value is 7 geofeatures characterizing only 1% of the sites (Fig. 8a) (see an example in Section 3.1.1). The subdivision of the sites among the categories for each of the 3 steps revealed no great difference between anthropic (85; 56%) and natural (66; 44%,) elements, a prevalence of sites in contact with the geofeatures of interest (126 over 151; 83%), and finally, a dominance of the use of geofeatures (70; 66%) by humans over adaptation (22; 21%) or modification (14; 13%) (Fig. 8b).

More in detail, concerning the *kind of geofeatures and distinction between natural and anthropic geofeatures* (Fig. 8c), natural landforms and heritage stones (anthropic elements) reached respectively 36% (55 elements) and 33% (49 elements) of abundance, while rock outcrops and anthropic landforms of interest are less common (20%; 30 elements and 11%; 17 elements respectively). Whereas rock outcrops have been deeply studied in the region, heritage stones of monuments still need to be specifically investigated in the municipalities using the great amount of material collected during the fieldwork for the present project. Natural landforms, the dominating category, represent the first elements to be enhanced and promoted and also need to be investigated in detail. Concerning the *spatial relation between site and geofeatures*, the elements in contact with the sites represent the majority of cases (84%; 126 elements), and non-conditioning are the most abundant (52%; 78 elements). Again, the geofeatures in contact with the sites also represent a future object of attention.

Concerning *the kind of relation between humans and geofeatures*, the results show a majority of sites characterized by the use by humans (66%; 70 elements). Some examples are reported in figure 9: the

Fig. 7 The 3 sites of geological or geomorphological interest included in the Comuniterrae list. (a) The Vogogna-Premosello geological trail (Vogogna; source: www.parcovalgrande.it); (b) The Brigalun landslide (Aurano); (c) The Bareola waterfalls and potholes (Premosello-Chiovenda).

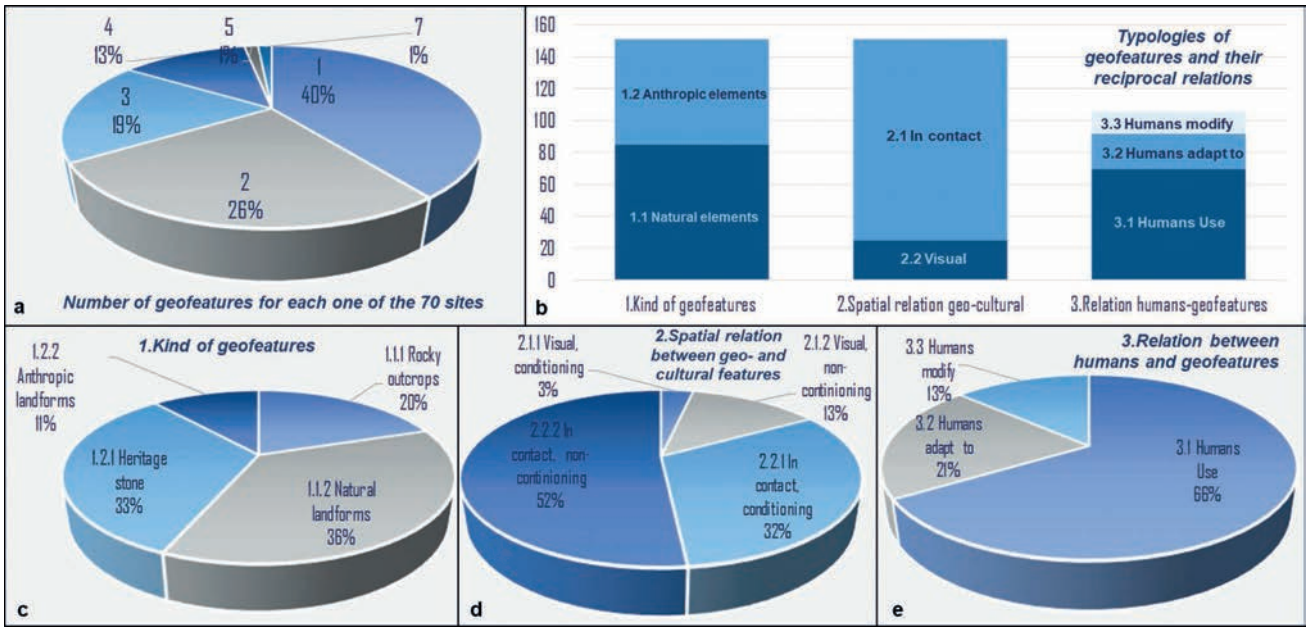

Fig. 8 Graph summarizing the result of the classification of the 70 sites according to the criteria in figure 5. (a) Number of geofeatures for each site; (b) Distribution of geofeatures among the 3 steps of the classification; (c) Kind of geofeatures (petrography or geomorphology; natural or anthropic); (d) Spatial relation between geo- and cultural features; (e) Relation between humans and geofeatures.

Fig. 9 Examples of sites where the relationship between humans and geofeatures is evident – (a) Rocks from local outcrops used in building of mountain huts; (b) The use of water at the Rio Graglia watermill in the Trontano municipality; (c) The quarries in front of Alpe Marona in the Vogogna municipality; d) The Dragone bridge in the Aurano municipality; (e) Anthropic terraces at Colloro village in the Premosello Chiovenda municipality.

use of rocks as heritage stones for buildings (Fig. 9a), the use of water at water mills (Fig. 9b), and again the use of rocks in local quarries (Fig. 9c). They are hence georesources. The sites characterized by adaptation (e.g., bridges over a river Fig. 9d) and modification (e.g., terraces) are less abundant (21%; 22 elements; 13%; 14 elements respectively), but also significant.

Summarizing, the results obtained in this research suggest to plan, in the future, activities more specifically addressed to some categories of sites: heritage stones, natural landforms and sites in contact, as well as sites where people use geofeatures. These initiatives still regard the scientific research, but other suggestions emerge for an effective use of these data in the framework of the Comuniterrae project. What is really important is to calibrate the proposal to the end-user (Gordon et al. 2021).

Concerning local populations, the first step could be the organization of dedicated meetings to share the outcome of this research, discussing the

parameters considered for the classification and the possible integration of the geofeatures characterizing the assets inventoried within the community maps of each municipality. Maybe, after these meetings new ideas could also arise from the local population indicating other potential geocultural sites. Moreover, local people could also contribute to the monitoring of geocultural sites for detecting potential threats by natural and anthropic processes inducing damages (point c; Section 1), in the view of participatory approaches. These latter could be intended not only for allowing more punctual data collection about the site conditions (e.g., as for glaciers Pelfini and Leonelli 2014), but also for suggesting proper management strategies in the view of conservation (Kaur 2022). An interesting example is represented by the projects sponsored by Vegas et al. (2018): "Watch over a rock" or "Adopt a geosite". The project invites volunteers to take care of a geosite that could be a special place for them, in order to inform about any threat to the site. This kind of dialogue could be intended as a form of 'heritage revelation', namely the identification by geologists of the heritage value of geosites and sharing of information with an audience outside the geo-heritage specialists (Reynard and Giusti 2018): Comuniterrae participants, as in this case, or external visitors of the area (i.e., tourists). Also for this category, proposals could be done. The most immediate and potentially successful one could be the promotion within the Comunitours of the topic of geofeatures linked to the visited sites, as suggested for cultural tours at archaeo-cityscapes by Mariani and Melis (2022). This could increase the attractiveness of the area offering multidisciplinary thematic trails (Moroni et al. 2015; Melelli et al. 2016; Pijet-Migoń and Migoń 2022), as highlighted in the specific case of archeo-geosites (Moroni et al. 2015; Melelli et al. 2016; Taha and El-Asmar 2018). In addition to mutual enrichment, there could be an impulse towards the conservation and protection of both elements, overcoming the problem reported in the literature (Reynard and Giusti 2018; Taha and El-Asmar 2018), of comparatively minor interest of local populations towards the protection of natural heritage with respect to cultural heritage. The idea that a loss of cultural sites is a loss of the related geological site too, and vice versa, could be really strengthened in this way. Finally, since the survey also revealed that people are not really aware of the role of a UGGP for a territory, we think that the promotion of projects of this kind can help to clarify what the institution of a UGGP can do for the development of a territory like that of the Middle Lands.

3.1 Examples of application to selected geocultural sites

In the next sections two practical and different examples will be illustrated: the first one (3.1.1) aims at integrating geological and geomorphological features within a Comunitour offered by the Premosello-Chiovenda municipality; the second one (3.1.2) is a single site in the Aurano municipality, particularly meaningful for the link between natural hazards and immaterial goods (i.e., legends).

3.1.1 The "Alpeggi di Premosello" trail (Premosello-Chiovenda)

One of the sites selected to study the potential for mixing cultural, geological and geomorphological aspects is a path connecting some mountain pastures (Alpeggi "I Curt", "Curpic", "La Colla") scattered on the slope behind the Premosello-Chiovenda village (Fig. 3b). This trail was proposed as a Comunitour within the Comuniterrae Project in 2019. The Comunitour was essentially focused on presenting local traditions and ancient activities, since the pastures were used until the 1950s by local inhabitants. The "*Premosellese Mountain Consortium*" still takes care to clean the path as well as other agro-silvo-pastoral trails.

From our fieldwork during 2019 and 2021, accompanied by the study of rock samples and by geomorphological observations, we concluded that this trail offers numerous examples of interaction between geological and cultural elements. The main themes suitable for promotion are:

i) *The scientific value of the area to show the effects of geological and geomorphological processes (point e; Section 1)* – The selected path runs along the Insubric Line, a major fault which constitutes the contact between the Austroalpine Domain (to the NW), involved in the Alpine metamorphism, and the South Alpine Domain (to the SE), which preserves much older structures (Steck 2008, Steck et al. 2013) (Fig. 10a, b).
The first outcrops encountered along the path are granulites (metapelites and metabasites, Fig. 10c, d) and mantle peridotites (ultramafic rocks; Fig. 10e), belonging to the lower crustal Southalpine Ivrea Verbano Zone. They are followed by outcrops of phyllonites (Fig. 10f) mainly derived from Austroalpine gneisses, and metacarbonates (Fig. 10f), among which calcschists (Fig. 10g), derived from Permo-Triassic cover rocks interposed between the two main domains. This 'geodiversity' also gives the opportunity to show in more detail how the different lithotypes were differently affected by low temperature deformation related to the Line, according to their structural characters.
Furthermore, the proposed trail offers good examples of lithological and structural control on landscape evolution. Two litho-structurally-controlled saddles, one along the trail ("La Colla", the endpoint of this trail; Fig. 10a), and one visible from the trail itself ("La Colma di Premosello"), may be easily recognized in correspondence with the band of rocks more affected by the movements of the

Insubric Line. Moreover, they are both aligned with the glacio-structural saddle of the "Scaredi Hut", visible at some distance and linked too with the Insubric Line, and which is the arrival point of the *Loana Geotouristic Trail* (see below). Finally, the presence of carbonate rocks, more sensitive to erosion, allowed for the development of small, deeply incised valleys and karst features (i.e., local sinkholes; Fig. 10i). Similar bedrock and geomorphic features are visible along the *Loana Geotouristic Trail* located at the opposite side of the Val Grande National Park, in the Malesco municipality, outside the Comuniterrae area (https://ecomuseomalesco.it/anello-geoturistico-della-valle-loana/). The trail was equipped with panels in 2019 (Bollati et al. 2018; 2019; 2020). This similarity may offer insights on the spatial scale of geological processes and the potential common traits existing also among distant municipalities.

ii) *The influence of geomorphology on human settlements (point b; Section 1)* – The mountain pastures of "I Curt" and "Curpic" are located on morphological terraces (Fig. 10h), probably the remnants of ancient glacial terraces of Pleistocene glacier stages (Sacco, 1930), whereas the hut of "La Colla" lies within the above-mentioned litho-structural saddle. The panoramic viewpoints along the path (Fig.10a, b) are also suitable for discussing the evolution of local relief in relation to the general context of the Toce valley landscape.

iii) *The use of local geofeatures as georesources (point a, b; Section 1)* – The mountain huts are mostly built with rocks cropping out 'in situ' or in the immediate vicinity (Fig. 10j, k). These rocks were mainly used according to their characteristics: the phyllonites, which are schistose rocks easily splitting along flat surfaces, for roofing and other planar elements (e.g., seats or shelves protruding from the walls; Fig. 10k), and the very compact granulites and ultramafic rocks, in natural or just roughly squared blocks, for wall building (Fig. 10j). In addition, we also recognized blocks of orthogneiss, a lithology cropping out some tens of km upstream in the Ossola valley and exploited for centuries in numerous quarries. The blocks may represent quarry waste brought here specifically for construction purposes by the stonecutters residing in this area, or alternatively materials of the upper Ossola Valley, transported to this area by the Toce glacier. Following the indications of local inhabitants, we also discovered a possible lime kiln, probably located in correspondence of a natural sinkhole (Fig. 10i) developed in limestone cropping out near one of the pastures. A similar kiln, more developed and better preserved, recently refurbished and used for demonstration of lime production for schools and tourists, is located along the above-mentioned *Loana Geotouristic Trail* (Bollati et al. 2018; 2020).

As already discussed, the width of a geocultural site (in this case an area clustering several mountain pastures) determines the variety of geological and geomorphological features (i.e., local geodiversity). In this specific case the guideline is represented by the Insubric Line, the consequent geomorphological modelling and the cultural use of georesources, be they rocks or landforms, for specific uses. These types of topics are listed by Pijet-Migoń and Migoń (2022) among the potential link between geoheritage and cultural heritage (see Section 1).

3.1.2 The Brigalun landslide (Aurano)

This is one of the only 3 sites of geological type selected by the Comuniterrae participants (Fig. 7b), probably because this natural landform is linked to a legend told from generation to generation (point c, d; Section 1). It is a landslide located in the Aurano municipality (http://www.comuniterrae.it/luogo/frana-brigalun/) and classified in the Italian Landslide Inventory (IFFI) as quiescent, with a last reactivation in 2014 (ID 1035003300; https://idrogeo.isprambiente.it/app/iffi/f/1035003300), but with no data about its first occurrence. The date of 19 October 1863 indicated in the Comuniterrae website, is recorded in a memorial preserved in the Parish Archives of Aurano. The movement is of rockfall / toppling type and the crown is located along a ridge where micaschists and paragneisses are in contact with amphibolites, near a N-S oriented fault (Boriani et al., 1975). The detachment area is indicated with the names of Monte Brugherato (from 'brughiera', a kind of low and stunted vegetation like moor or heath) and Monte Nudo (naked), both recalling the idea of a surface not occupied by vegetation due to instability (source Catasto Teresiano, 1722; Sommarione, ACA, Catasto b.95). The name of the landslide (Brigalun) derives from *brigaà*, a local term meaning "big landslide" (Gagliardi 2016). A watermill was active at the foot of the slope, but it was damaged by the landslide and then abandoned (Gagliardi 2016). This site can be considered an active geomorphosite (Prosser et al. 2010; Pelfini and Bollati 2014), where geomorphic processes responsible for the site genesis are ongoing, potentially affecting cultural heritage (point c; Section 1).

The legend linked to this site is well rooted in the community culture (point d; Section 1). It attributes the landslide to the ghost of a priest that haunted the Scareno village. During the second half of the 16th century, padre Bartolomeo Caneva, a Jesuit, was asked to drive away the spirit. During its escape, the ghost hit the mountain slope provoking the landslide. The legend also says that the evil is still hidden inside the landslide body, and for this reason the movement is still active. Other similar legends are still alive in the area, to the point that even in recent times priests

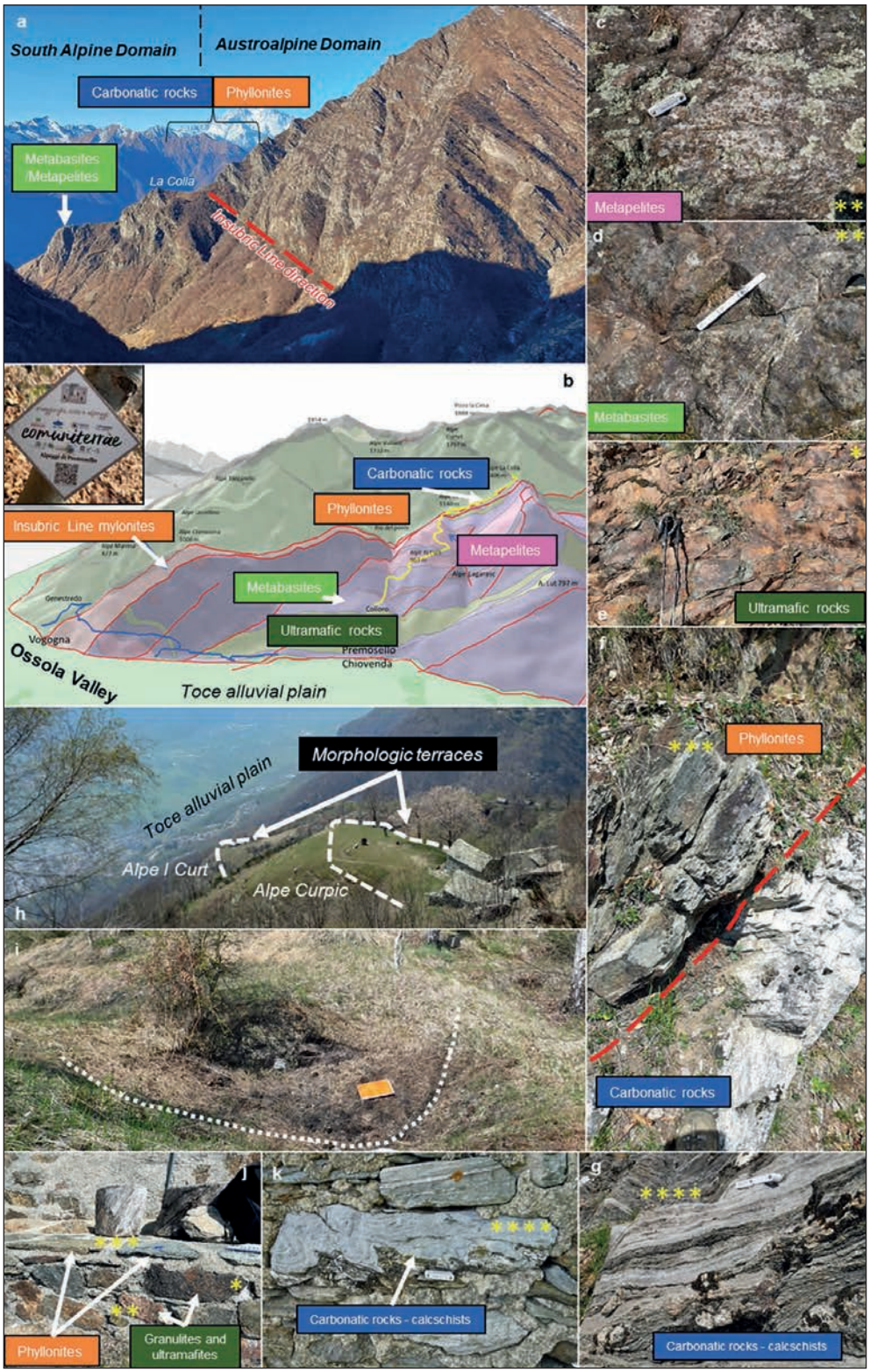

Fig. 10 The Comuniterrae geocultural site "Alpeggi di Premosello"– a) Panoramic view on the structural saddle where the mountain hut "La Colla" is located, viewed from "La Colma di Premosello"; b) The 3D model with the geological map of the Val Grande National Park (source: shapefile courtesy of the Val Grande National Park) depicted on the Digital Elevation Model (5 m resolution, source: Geoportale Regione Piemonte) using the ArcScene software and the QR Code of the Comunitour; c, d) Metapelites and metabasites of the Ivrea-Verbano Zone near "I Curt" and "Curpic"; e) Ultramafic rocks cropping out in the Colloro village; f) Tectonic contact between phyllonites, testifying for deformation along the Insubric Line, and carbonatic rocks at "Curpic"; g) Calcschists near "La Colla"; h) Morphological terraces where the pastures of "I Curt" and "Curpic" are settled; i) Sinkholes used as lime kilns by mountain inhabitants; j, k) The use of local rocks (phyllonites and ultramafic rocks, j; calcschists, k) as architectural elements in Alpine huts at "I Curt". The yellow stars and the respective numbers link the rocks used in the buildings to their outcrops in the surrounding area.

have blessed the mountain to avoid further disasters (Chiaberta 2000; Gagliardi 2016).

The connection between the physical conditions predisposing the slope to landsliding and the legend passed down, could be an interesting starting point for the institution of a geocultural site. As demonstrated in many other situations (Coratza and De Waele 2012; Migoń and Pijet-Migoń 2019; Forno et al. 2022), a geocultural site like this could be a useful tool for raising awareness of local inhabitants in the hazardous dynamics deriving from natural processes, taking care of preserving the traditional believing.

4. Concluding remarks

Geoheritage, as other types of natural heritage, can be considered as part of the cultural heritage, in a broad sense, of a society, a nation or humankind (Panizza and Piacente 2003). According to Pijet-Migoń and Migoń (2022), geoheritage sites may "show an additional value associated with cultural heritage. However, the relationship can be also in reverse, in that cultural values are considered as superior, but this should not lead to the neglect of geodiversity and geoheritage aspects at these sites." This concluding message is strongly sustained by the results of the present research, depicting very relevant geocultural sites where the geological and geomorphological features deeply influenced the settlements of cultural sites. The Comuniterrae project, initially born to highlight the cultural heritage of a territory, the Middle Lands, and its change through time (Bagnati and Perlo 2020), could hence widen the view to the concept of geocultural site, thus increasing awareness in both local populations or external visitors towards geocultural heritage and natural and human dynamics mining its preservation. As highlighted by Gordon et al. (2021), if people understand different values that geodiversity and geoheritage may have, they could feel a deeper connection with them, more likely viewing them as assets to be managed sustainably (see also Reynard and Giusti 2018). Moreover, sustainable promotion and conservation of geocultural sites may be favored through participatory approaches, involving local populations in data collection and proposing management strategies, allowing a constant monitoring of the cultural heritage in a territory by local inhabitants, aware of its value and of the threats potentially damaging it (Pelfini and Bollati 2014). The link between geodiversity and cultural landscape, especially people's cultural roots and sense of place (Variale et al. 2022), can help in boosting a holistic approach to Nature, including geoheritage among the cultural assets s.s. (Gordon et al. 2021). Concluding, the *place-base aesthetic* and *emotional experiences*, as those offered in the case studies described in this text, are key elements, prerogative of geocultural sites.

Appendix

See Supplementary Material A (available online) including the list of the 70 sites selected for this research with the classification according to the 3 criteria.

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