DOI 10.4430/bgta0327

Oil and gas activities in Emilia-Romagna Region (Italy): land deformation and territory protection

P. Severi[1], R. Mazzoni[2] and L. Martelli[1]

[1] *Geological, Seismic and Soil Survey, Emilia-Romagna Region, Bologna, Italy*
[2] *Environmental Impact Assessment Department, Emilia-Romagna Region, Bologna, Italy*

(Received: 17 December 2019; accepted: 14 April 2020)

ABSTRACT Emilia-Romagna currently ranks third in Italy for the production of methane, hosts five gas storage reservoirs, and over ten exploration permits have been requested. Land deformation, and particularly subsidence, is one of the issues in oil and gas activities concerning hydrocarbon production that most worries both stakeholders and the local population alike. Subsidence can induce negative impacts on the efficiency of a hydrographic network (natural and artificial), coastal erosion, and building stability. In order to counteract subsidence and ensure the maximum protection for the territory, the Emilia-Romagna Authority follows a precise set of rules in the Environmental Impact Assessment (EIA) procedure, which require that companies implement a mathematical forecasting model for subsidence to verify any damage caused by subsidence and define an integrated land deformation monitoring with the precision of one millimetre a year. Once hydrocarbon production has begun, if the measured subsidence exceeds the calculated subsidence, the competent authority (Ministry and Regions) together with the oil and gas companies involved, will consider the possibility to modify or stop the production.

Key words: hydrocarbon activities, subsidence, land deformation monitoring, EIA procedures, Emilia-Romagna Region.

1. Introduction

In Emilia-Romagna, oil and gas activities started in the early years of the last century, in the Parma and Piacenza Apenninic areas. Subsequently, starting from the 1950s, thanks to the development of the seismic reflection technique, hydrocarbons exploration, production, and storage, expanded more significantly, particularly in the Emilia-Romagna plain (Assomineraria, 2015). Today, these activities are less widespread than in the past, but still remain significant. Emilia-Romagna ranks third in Italy for production of methane, with about thirty permits for oil and gas production, five gas storage reservoirs, and over ten new requests for exploration permits [data from Ministero Sviluppo Economico (2020a)]. Almost all the activities related to hydrocarbons are currently located in the plain (Fig. 1).

The northern side of Emilia-Romagna is part of the Po Plain, an active foredeep basin interposed between two chains still in formation: the Apennines to the south and the Alps to the north (Fig. 2). The upper part of the stratigraphic succession is made up of recent alluvial

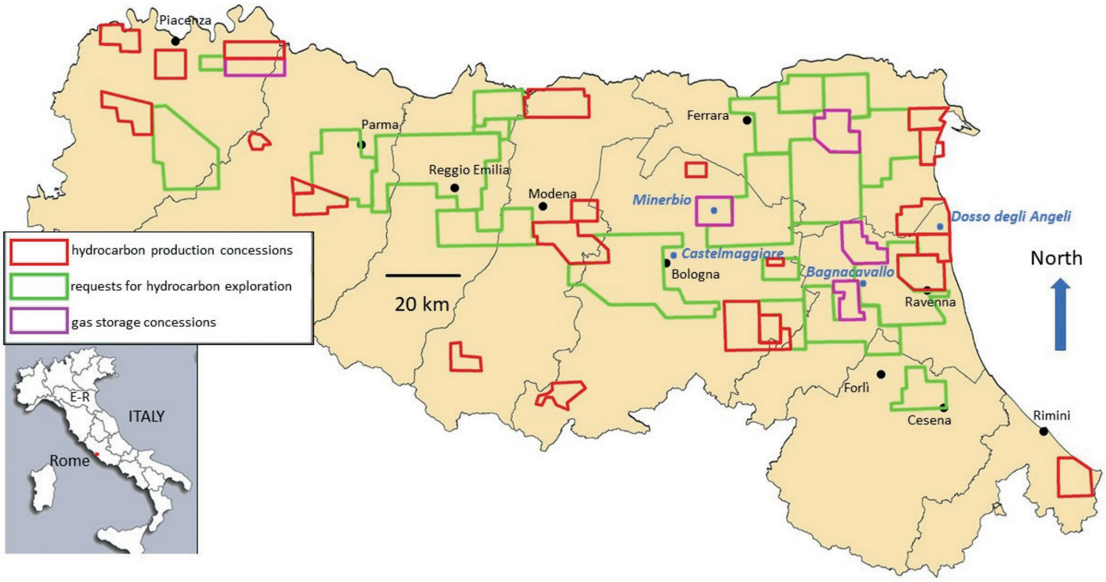

Fig. 1 - Hydrocarbon activities in Emilia-Romagna (from Ministero Sviluppo Economico, 2020a, modified). Blue dots and toponyms indicate the sites mentioned in the text. Black boundaries, dots, and toponyms indicate Provinces and County seats. In the box at the bottom left, E-R stands for Emilia-Romagna Region.

sediments (Middle Pleistocene-Holocene), which locally exceed 500 m in thickness (Fig. 3). In particular, the Emilia-Romagna alluvial deposits are the result of the depositional activity of the Po River and its Apennine tributaries and are mainly made up of fine and unconsolidated

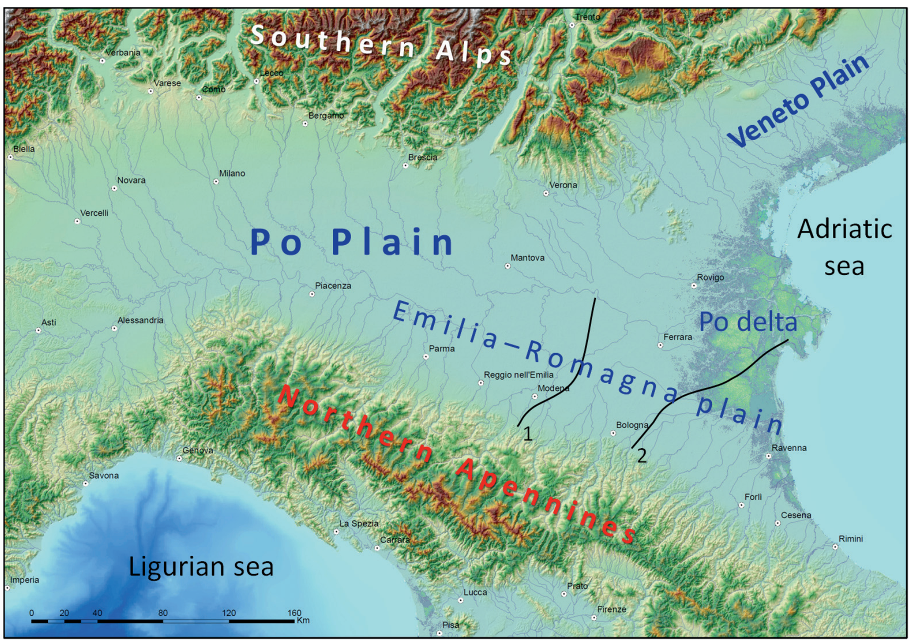

Fig. 2 - Geographical framework of the Emilia-Romagna plain; black lines indicate the traces of the geological cross-sections represented in Fig. 3.

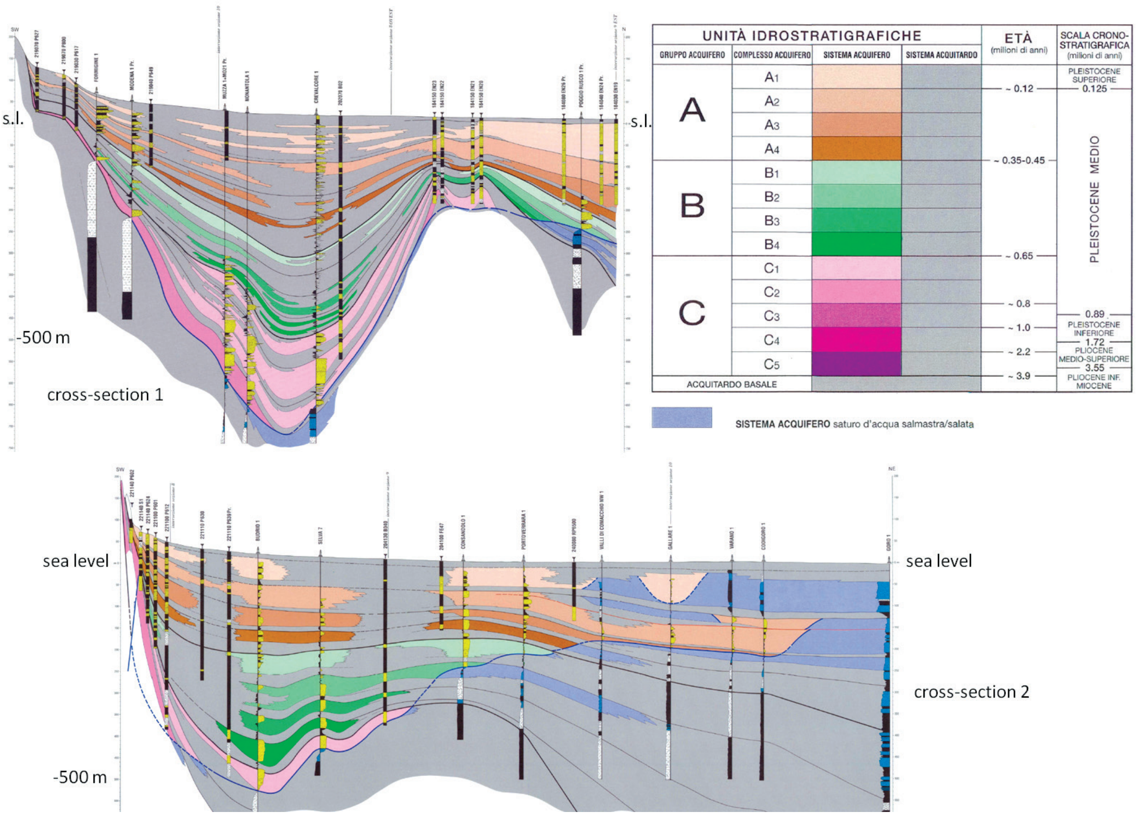

Fig. 3 - Hydrogeological cross-sections across the Emilia-Romagna plain (from Regione Emilia-Romagna and ENI-AGIP, 1998); traces in Fig. 2. A: deposits of the upper alluvial sedimentary cycle (0.45 My-Present), B: deposits of the lower alluvial sedimentary cycle (0.65-0.45 My), C: marine substratum (Pliocene-Middle Pleistocene).

sediments (alternation of sands, silts and clays); gravels are present only in the southern part of the plain, along the Apennine-Po Plain morphological margin. Therefore, since the upper part of the Emilia-Romagna plain is made up of hundreds of metres of unconsolidated sediments, this sector of the region is subject to subsidence. This natural subsidence can be amplified by the extraction of fluids from the subsoil.

The subsidence can be a very significant problem in Emilia-Romagna alluvial and coastal plains, where the very low topographic gradient could induce negative impacts on the efficiency of the hydrographic network (natural and artificial) and on coastal erosion. This aspect is particularly pertinent in the large area (over 1,000 km^2) of the Po River delta, where the topographic surface is frequently below sea level and the topographic gradient is around 1/1000. For these reasons, the Emilia-Romagna Authority has monitored the subsidence since the last century and implemented many measures in order to reduce ground lowering (Regione Emilia-Romagna, 2004).

In accordance with European Directives 85/337/CEE and 97/11/CE (Consiglio della Comunità Europea, 1985, 1997) and with Italian and Regional legislation (Presidente della Repubblica Italiana, 1999; Regione Emilia-Romagna, 1999), all oil and gas activities, starting from 1999, are subject to an Environmental Impact Assessment (EIA). The impacts potentially induced by subsidence due to hydrocarbon extraction are, thus, one of the most relevant aspects to be considered in the EIA.

2. Land deformation monitoring in the Emilia-Romagna plain

Land deformation is one of the issues in oil and gas activities that most worries both stakeholders and the local population. Ground movements related to oil and gas activities have been observed during storage and extraction, though it is worth noting that research and exploration do not induce ground movement. The storage activities, i.e. injection and withdrawal, usually produce a sinusoidal deformation because ground lowering and raising generally have the same amplitude. The most notable subsidence values have been observed in extraction fields. A clear example of the sinusoidal ground motion trend induced by gas storage activities is shown by Interferometric Synthetic-Aperture Radar (InSAR) data on the Minerbio reservoir, located in the Bologna alluvial plain (Fig. 4).

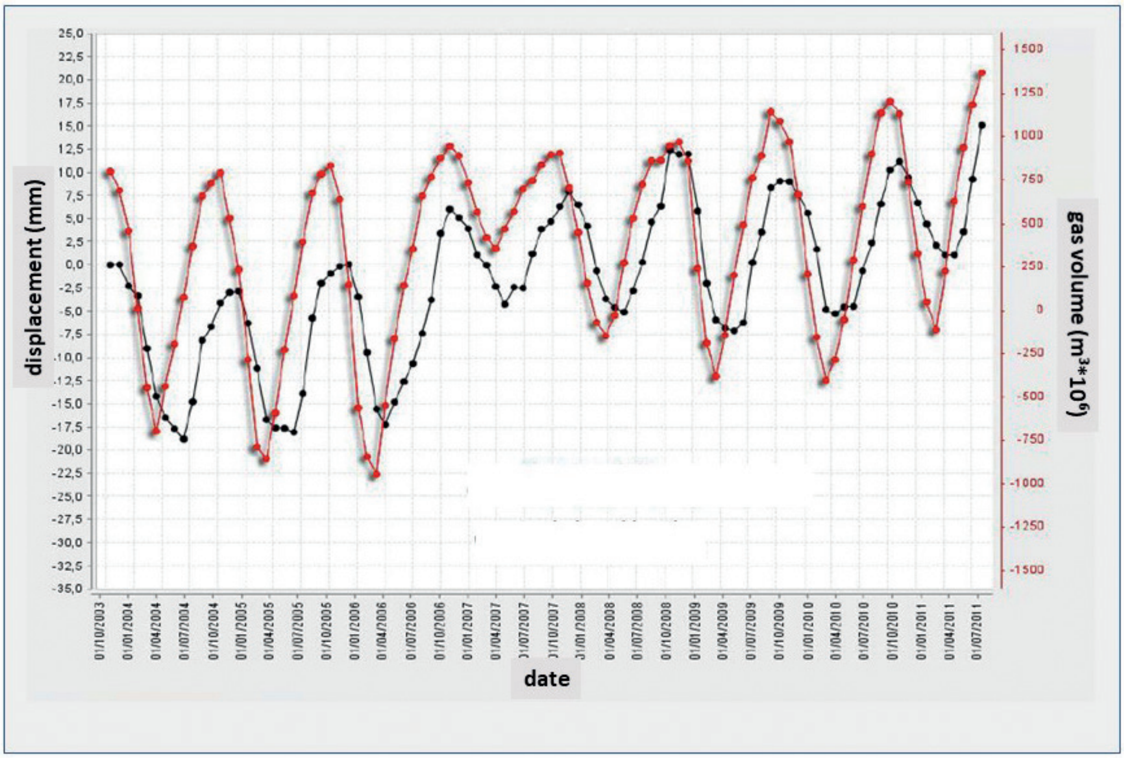

Fig. 4 - Example of sinusoidal ground motion trend (black line) induced by gas storage and depletion activities (red line) at Minerbio (Bologna Province) (STOGIT S.p.A., 2013).

As mentioned above, the subsidence in the Emilia-Romagna plain has natural origins, because of the compaction of sediments and tectonics, but in some cases human activities, like extraction of water and hydrocarbons from subsoil, can significantly increase the lowering of the soil (Carminati and Martinelli, 2002; Teatini *et al.*, 2006; Cenni *et al.*, 2013; Antoncecchi *et al.*, 2021; Calabrese *et al.*, 2021; Severi, 2021).

In this context, it is very important to distinguish between subsidence due to natural causes and subsidence induced by human activities (gas and groundwater withdrawal). The estimated rate of natural subsidence is about a few millimetres per year, while the anthropogenic subsidence can exceed natural subsidence by one order of magnitude (Carminati and Martinelli, 2002). In the

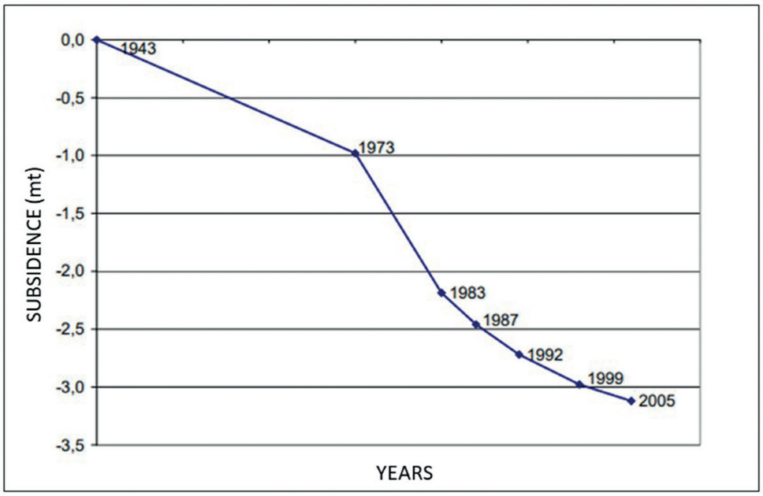

Fig. 5 - Lowering of benchmark n. 051140 (ARPAE, 2006), Castelmaggiore (Bologna Province, see location in Fig. 1).

Bologna alluvial plain, the groundwater extraction carried out in the 1970s and 1980s induced a ground lowering down to -1.2 m in ten years (ARPAE, 2006; Fig. 5).

Subsidence in this area today has strongly decreased, as shown by the last monitoring data (ARPAE, 2018).

In November 2014, the Italian Ministry of Economic Development published specific guidelines for the monitoring of subsurface industrial activities (Ministero Sviluppo Economico, 2014). In this document different kinds of methodology for ground movement measurements are indicated: InSAR networks of permanent Global Navigation Satellite Systems (GNSS), possibly topographic levelling, extensometers, and piezometers.

To ensure maximum protection of the territory, the Emilia-Romagna Authority has always paid great attention to the monitoring of subsidence. In EIA procedures the same kind of monitoring indicated in the ministerial guidelines (Ministero Sviluppo Economico, 2014) has been prescribed, even before 2014.

Five ground deformation maps in the Emilia-Romagna plain have been published by the Emilia-Romagna Authority in collaboration with the Emilia-Romagna Regional Agency for Prevention, Environment, and Energy (ARPAE). These maps illustrate the ground movements from 1970 to 2016 and show that the subsidence has generally diminished over time (ARPAE, 2020). The latest available map shows the average subsidence velocity during the period 2011-2016. The map indicates that only in a few areas, located in the central part of the plain, does the velocity of subsidence exceed 10 millimetres per year (Fig. 6). The comparison between the 2011-2016 map and the map related to the preceding period (2006-2011) shows a reduction of subsidence in almost all plain areas (Fig. 7).

3. Current oil and gas activities in Emilia-Romagna

The Italian law n. 12/2019 (Repubblica Italiana, 2019) suspended all exploration permits for hydrocarbons, both on- and off-shore, though gas storage is not affected by this suspension.

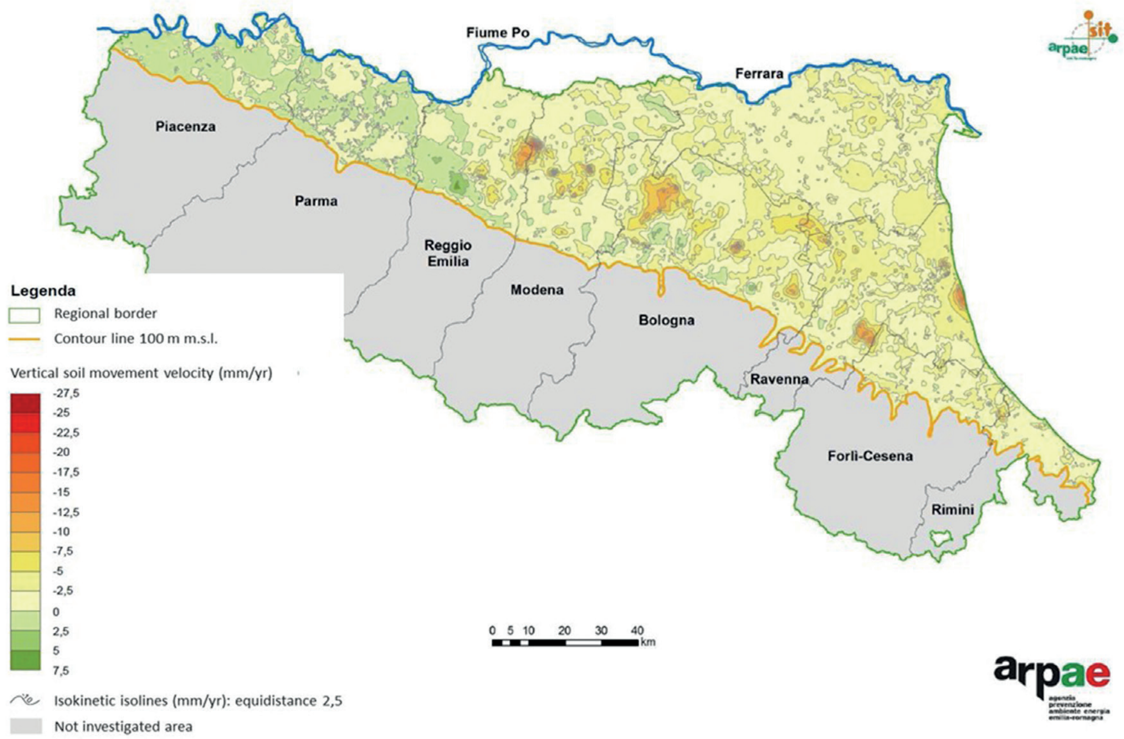

Fig. 6 - Average subsidence velocity during the period 2011-2016 in Emilia-Romagna plain (ARPAE, 2018).

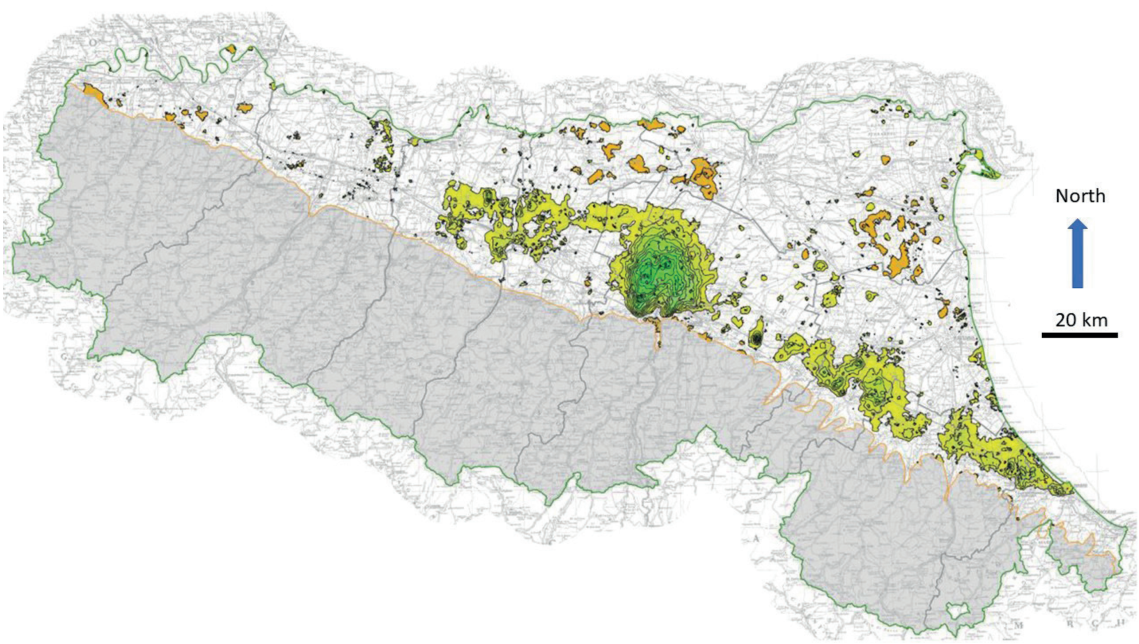

Fig. 7 - Comparison between vertical ground movement in 2006-2011 and 2011-2016. In the yellow and green areas subsidence has decreased, in white areas subsidence has remained roughly the same, in orange areas subsidence has increased (ARPAE, 2018).

Research activities will restart after the implementation of a National Plan, which will identify the areas where hydrocarbon researches are permitted. This Plan should be approved 18 months after the law enactment. Because of this law, 11 EIA procedures for hydrocarbon exploration and production have been suspended.

Only two gas production procedures, granted before the law enactment, are actually underway. In Emilia-Romagna there are currently 27 concessions in which the production or storage of hydrocarbons (mainly gas) is permitted (Ministero dello Sviluppo Economico, 2020b).

In 2019, 19 gas wells were in operation and the annual gas production was about 166 MSm^3 (million of standard cubic metres); in 2018 the gas production was 200 MSm^3. During the previous years, the production was much higher, with peaks in the last decades of the last century [example Dosso degli Angeli Gas Field, location in Fig. 1, 1,600 MSm^3 in 1987 (Ministero dello Sviluppo Economico, 2020b)].

4. A case history: land deformation analysis in the EIA procedure of the Longanesi gas field

In December 2016, the EIA procedure for the gas production from Longanesi reservoir (Bagnacavallo Municipality, Ravenna Province, Italy) was concluded. Longanesi reservoir is expected to produce over 1,000 MSm^3 of methane gas, over a period of about 10 years (Padana Energia S.p.A., 2010).

During the EIA procedure, land subsidence was carefully analysed, with the implementation of a mathematical forecasting model, able to calculate different values of land lowering due to gas production, according to different values of geotechnical parameters. The model produced a series of maps showing the expected subsidence for the different geotechnical parameters used. The gas exploitation causes a cone-shaped deformation of the ground, with a maximum lowering in the area above the reservoir. The maximum subsidence (5-7 cm) is expected after 30 years from the beginning of gas production in a small area above the reservoir, while the overall expected extension of the cone lowering is in the order of 100 km^2 (Fig. 8).

As above-mentioned, one of the main environmental issues due to the subsidence induced by the gas extraction is the loss of efficiency in the hydrographic network: the ground lowering could change or reverse the slope of the canals and in case of intense rains it could induce flooding.

During the EIA procedure, a specific hydraulic model was requested, in order to evaluate the real possibility of flooding, also considering exceptional precipitation events possibly induced by climate change. The model allowed verifying the overall sustainability of the subsidence induced by the exploitation of the Longanesi reservoir, so EIA was positively evaluated and the project was approved (Regione Emilia-Romagna, 2016).

There were no other possible critical impacts of subsidence, such as damage to buildings or coastal erosion. This is due to the fact that the subsidence cone is too large to produce differential deformation under individual buildings, and the coastal line is more than 30 km away from the subsidence area.

In order to verify the congruence between subsidence predicted by the mathematical models and the real one, an accurate and integrated monitoring of subsidence has been prescribed, able to measure a ground lowering rate of 1 mm/yr. The monitoring system was devised by Regional

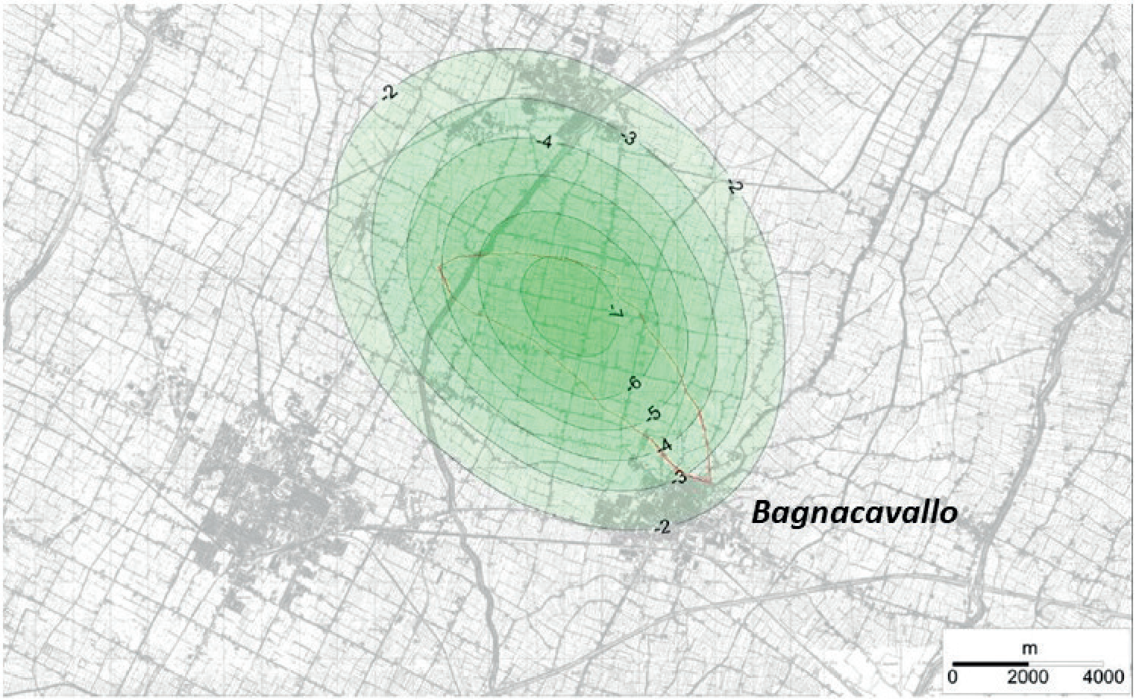

Fig. 8 - Evaluation of land subsidence induced by gas extraction in Longanesi field (Bagnacavallo, see location in Fig. 1) by numerical modelling, 30 years after the start of production. Black lines indicate the expected subsidence in cm. The red polygon represents the surface projection of the gas field (Padana Energia S.p.A., 2010).

and ARPAE technicians, in accordance with the ministerial guidelines (Ministero Sviluppo Economico, 2014).

The monitoring system to be implemented before the start of the gas extraction consists of InSAR measurements, the implementation of a new network of nine Continuous Global Positioning System (CGPS) permanent stations, the installation of two extensometers and two piezometers, and the carrying out of topographic levelling.

In a context such as the Emilia-Romagna plain, where the extraction of hydrocarbons is frequently coupled with groundwater withdrawal, it is very important to consider the possibility of distinguishing between subsidence due to gas extraction compared to that due to groundwater withdrawal. In this perspective, particular attention is paid to the extensometers, which are anchored below the stratigraphic level of the aquifers and, therefore, allow measuring subsidence due to water withdrawal.

In order to measure subsidence induced by gas extraction, it will be necessary to subtract the value of the subsidence measured by the extensometers from the overall subsidence measured by satellite data. If the subsidence observed during the production period exceeds the one provided in the mathematical models, the Emilia-Romagna Authority and the National Authority will consider the possibility of decreasing or stopping gas exploitation.

5. Concluding remarks

Land deformation, particularly subsidence, is one of the environmental impacts that most worry both stakeholders and the local population when oil and gas activities are performed.

In accordance with the European, Italian, and Regional legislation, since 1999 oil and gas activities (exploration, production, and storage) are subject to the EIA procedure. Today, two EIA procedures are underway, another eleven have been suspended by the Italian law n. 12/2019.

With the aim of obtaining the best results for territorial protection, in EIA procedures regarding oil and gas activities, Emilia-Romagna Authority requires the companies to implement a mathematical forecasting model, aimed at estimating the land lowering due to gas production. The companies must, then, investigate if subsidence could induce negative impacts on the efficiency of the hydrographic network (natural and artificial) and/or on coastal erosion and buildings stability. If the impact is not sustainable, the EIA procedure can be closed negatively; if the impact is sustainable the EIA procedure can be closed positively with specific prescriptions.

The subsidence requirements indicated in the EIA procedure include an integrated monitoring system that considers different types of monitoring. Analyses of satellite data (InSAR and CGPS network), extensometers and piezometric data, topographic surveys, allow measuring land subsidence with an accuracy of a few millimeters per year. Thanks to this monitoring plan, it is possible to verify the forecast of the subsidence model. If the measured subsidence exceeds the threshold considered sustainable in the EIA, competent authorities and companies will examine the possibility of decreasing or stopping the production.

We believe that the illustrated procedures are examples of good practice in managing the impacts on subsidence produced by the oil and gas activity.

Currently, the monitoring is supported by the oil companies. A positive aspect is that generally the oil companies are aware that monitoring is necessary. Oil companies have collaborated in carrying out the required monitoring, and sometimes they themselves proposed some additional monitoring. Thanks to ongoing monitoring, it is possible to verify the effects on the territory of these industrial activities.

Up to now, the illustrated procedures have already been adopted, after the EIA, in a gas production field and a gas storage field currently in production, for almost a decade. To date, no differences have been observed between the expected and measured soil movements.

For a complete assessment, the monitoring must continue after the end of the duration of the mining activity. Therefore, it will always be possible to evaluate any deviations between the forecasts and the measured soil movement values and to take the relative measures. However, in order to have a better awareness of the real benefits and potential problems related to the recommended monitoring, it will be necessary to implement the proposed monitoring system also in all the other EIA procedures in progress.

Acknowledgements. The paper was presented at the 37th GNGTS meeting in Bologna (Italy), on 19-21 November 2018; the authors thank the Organizing Committee of the GNGTS meeting for offering the opportunity to publish this paper in this BGTA special volume.

REFERENCES

Antoncecchi I., Ciccone F., Rossi G., Agate G., Colucci F., Moia F., Manzo M., Lanari R., Bonano M., De Luca C., Calabrese L., Perini L., Severi P., Pezzo G., Macini P., Benetatos C., Rocca V., Carminati E., Billi A. and Petracchini L.; 2021: *Soil deformation analysis through fluid-dynamic modelling and DInSAR measurements: a focus on groundwater withdrawal in the Ravenna area (Italy)*. Boll. Geof. Teor. Appl., 62, 301-318, doi: 10.4430/bgta0350.

ARPAE; 2006: *Rilievo della subsidenza nella pianura emiliano-romagnola*. Regione Emilia-Romagna, Arpa Emilia-Romagna, Bologna, Italy, Relazione finale, 72 pp., <www.arpae.it/cms3/documenti/subsidenza/Relfin_05_001.pdf>.

ARPAE; 2018: *Rilievo della subsidenza nella pianura Emiliano-Romagnola*. Regione Emilia-Romagna, Arpa Emilia-Romagna, Bologna, Italy, Seconda fase, 105 pp., <www.arpae.it› documenti › subsidenza › Subsidenza2017_fase2>.

ARPAE; 2020: *Subsidenza*. Regione Emilia-Romagna, Arpa Emilia-Romagna, Bologna, Italy, <www.arpae.it/index.asp?idlivello=1414>.

Assomineraria; 2015: *Territorio e idrocarburi in Emilia-Romagna, Quaderno di approfondimento*. Ricerche Industriali ed Energetiche, Roma, Italy, 53 pp.

Calabrese L., Luciani P. and Perini L.; 2021: *A review of impact of subsidence induced by gas exploitation on costal erosion in Emilia-Romagna, Italy*. Boll. Geof. Teor. Appl., 62, 279-300, doi: 10.4430/bgta0356.

Carminati E. and Martinelli G.; 2002: *Subsidence rates in the Po Plain, northern Italy: the relative impact of natural and anthropogenic causation*. Eng. Geol., **66**, 241-255.

Cenni N., Viti M., Baldi P., Mantovani E., Bacchetti M. and Vannucchi A.; 2013: *Present vertical movements in central and northern Italy from GPS data: possible role of natural and anthropogenic causes*. J. Geodyn., **71**, 74-85.

Consiglio della Comunità Europea; 1985: *Valutazione dell'impatto ambientale di determinati progetti pubblici e privati*. Direttiva 85/337/CEE del Consiglio del 27 giugno 1985, G.U.C.E. 5 luglio 1985, n. L175, Bruxelles, Belgium.

Consiglio della Comunità Europea; 1997: *Valutazione dell'impatto ambientale di determinati progetti pubblici e privati*. Direttiva 97/11/G.U.C.E. n. L073, Bruxelles, Belgium, pp. L5-L15.

Ministero Sviluppo Economico; 2014: *Guidelines for monitoring seismicity, ground deformation and pore pressure in subsurface industrial activities*. Roma, Italy, 34 pp., <unmig.mise.gov.it/index.php/it/sicurezza/geomonitoraggi/linee-guida>.

Ministero Sviluppo Economico; 2020a: *Elenco titoli minerari*. Roma, Italy, 24 pp., <unmig.mise.gov.it/index.php/it/dati/ricerca-e-coltivazione-di-idrocarburi>.

Ministero Sviluppo Economico; 2020b: *Dati*. Roma, Italy, <unmig.mise.gov.it/index.php/it/dati>.

Padana Energia S.p.A.; 2010: *Studio di impatto ambientale sviluppo campo gas Longanesi*. Milano, Italy, <serviziambiente.regione.emilia-romagna.it/viavas/servlet/AdapterHTTP?ACTION_NAME=LOGIN_ACTION> (then type "longanesi" on "titolo procedura").

Presidente della Repubblica Italiana; 1999: *Disposizioni sulla tutela delle acque dall'inquinamento e recepimento della direttiva 91/271/CEE concernente il trattamento delle acque reflue urbane e della direttiva 91/676/CEE relativa alla protezione delle acque dall'inquinamento provocato dai nitrati provenienti da fonti agricole*. Decreto legislativo 11 maggio 1999 n. 152, GU Serie Generale n. 124 del 29 maggio 1999, Supplemento ordinario n. 101/L, Roma, Italy.

Regione Emilia-Romagna; 1999: *Disciplina della procedura di valutazione dell'impatto ambientale*. L.R. Emilia-Romagna 18/05/1999 n. 9, B.U.R. Emilia-Romagna 21/05/1999 n. 66, Bologna, Italy.

Regione Emilia-Romagna; 2004: *Piano di Tutela delle Acque*. Deliberazione di Assemblea Legislativa n. 40 del 21 dicembre 2005, B.U.R. Emilia-Romagna 01.02.2006 n. 14 (Parte Seconda), Bologna, Italy, <www.arpae.it/cms3/documenti/subsidenza/Relfin_05_001.pdf>.

Regione Emilia-Romagna; 2016: *Esito della procedura di VIA relativa al progetto di sviluppo unitario del giacimento Longanesi presentato da Società Padana Energia S.p.A. e Aleanna Italia s.r.l.* Deliberazione di Giunta della Regione Emilia-Romagna n. 2266/2016, B.U.R. Emilia-Romagna 08.02.2017 n. 30 (Parte Seconda), Bologna, Italy.

Regione Emilia-Romagna and ENI-AGIP; 1998: *Riserve idriche sotterranee della Regione Emilia-Romagna*. S.EL.CA., Firenze, Italy, 119 pp.

Repubblica Italiana; 2019: *Legge 11 febbraio 2019 n. 12: Conversione in legge, con modificazioni, del decreto-legge 14 dicembre 2018, n. 135, recante disposizioni urgenti in materia di sostegno e semplificazione per le imprese e per la pubblica amministrazione (19G00017)*. G.U. Serie Generale n. 36 del 12-02-2019, Roma, Italy.

Severi P.; 2021: *Soil uplift in the Emilia-Romagna plain (Italy) by satellite radar interferometry*. Boll. Geof. Teor. Appl., in print, doi: 10.4430/bgta0349.

STOGIT S.p.A.; 2013: *Studio di impatto ambientale stoccaggio gas - Concessione Minerbio stoccaggio/ampliamento*. Milano, Italy, <serviziambiente.regione.emilia-romagna.it/viavas/servlet/AdapterHTTP?ACTION_NAME=LOGIN_ACTION> (then type "minerbio stoccaggio ampliamento" on "titolo procedura").

Teatini P., Ferronato M., Gambolati G. and Gonella M.; 2006: *Groundwater pumping and land subsidence in the Emilia-Romagna coastland, Italy: modeling the past occurrence and the future trend*. Water Resour. Res., **42**, W01406, doi: 10.1029/2005WR004242.

Corresponding author: Paolo Severi
Servizio Geologico, Sismico e dei Suoli, Regione Emilia-Romagna
Viale della Fiera 8, 40127 Bologna, Italy
Phone: +39 051 527 4335; e-mail: paolo.severi@regione.emilia-romagna.it