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Comprehensive database of land subsidence in 143 major coastal cities around the world: overview of issues, causes, and future challenges

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Subsidence refers to the gradual lowering or sudden sinking of the ground surface and is known to impact human lives in terms of damages to the infrastructures, utility lines, and buildings as well as changes in the surficial drainage systems and groundwater conditions. The impacts of land subsidence will be greater in the future, considering the sea level rise, population growth, intensification of coastal erosion and extreme events, as well as increase in flood risk or freshwater salinization, mostly in coastal cities. The main aim of this work is to provide an open-source, peer-reviewed, and comprehensive database identifying the main and secondary causes of land subsidence in 143 coastal cities. We highlight the potential impacts of subsidence that are still unknown in some at-risk cities and non-existence of mitigation measures. The database additionally shows that mitigation measures, specifically those addressing subsidence due to groundwater extraction, have proven successful in the past. The proposed database aims to increase the knowledge on the subsidence phenomenon and also global awareness of land subsidence issues among researchers, the scientific community, stakeholders, and policymakers in terms of urban planning and development.

KEYWORDS

subsidence, database, coastal, groundwater, cities

1 Introduction

Land subsidence refers to the gradual lowering or sudden sinking of the ground as a result of natural and human-induced factors (Poland, 1984; Galloway and Burbey, 2011). Over the long-term duration, land subsidence could have severe impacts in terms of damages to infrastructures, utility lines, and buildings as well as changes in the natural surficial drainage systems (Barlow and Eric, 2010; Eggleston and Pope, 2013; Margat and Van der Gun, 2013; Schmidt, 2015), while the populations in the areas that may potentially be flooded are rising globally (Zhong et al., 2023). The natural and anthropic drivers of subsidence include sediment consolidation, peat oxidation, earthquakes, tectonics, karst phenomena, groundwater exploitation, hydrocarbon extraction, geothermal activities, mining of ore materials or tunneling, and building and infrastructure loads

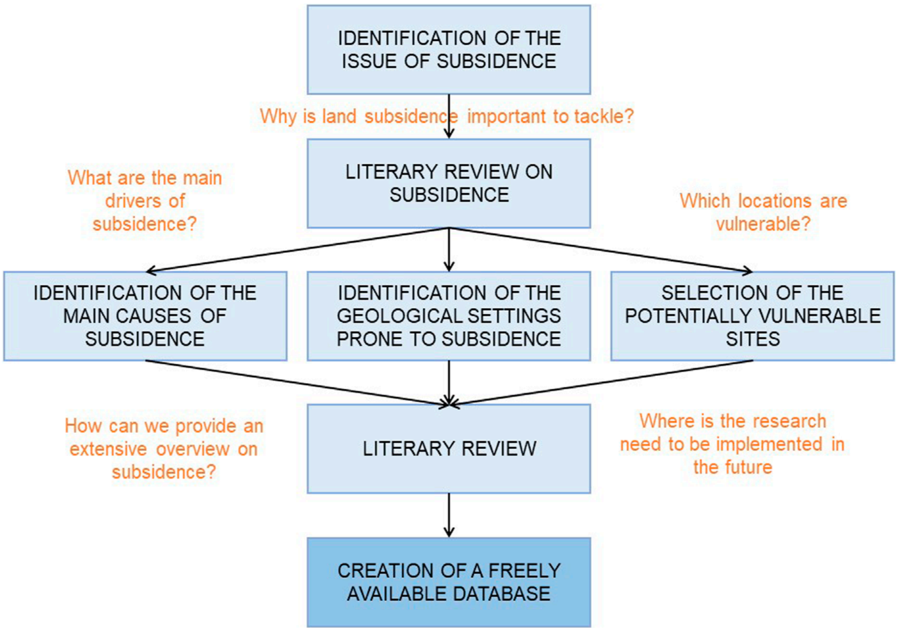

FIGURE 1
Flowchart of the methodology used in this work.

(Poland and Hamilton, 1984; Huang and Jiang, 2010; Margat and Van der Gun, 2013; Higgins et al., 2014; Minderhoud et al., 2015; Omoko et al., 2018; de Glopper and Ritzema, 2023).

The geological settings as well as anthropic activities in an area play important roles in land subsidence (Momotake, 1996; Galloway et al., 1999; Allis, 2000; Hu et al., 2004; Caramanna et al., 2008; Tularam and Krishna, 2009; Lorphensri et al., 2011; Tomás et al., 2014; Mastin et al., 2018; Solari et al., 2018; Loupasakis, 2020; Calabrese et al., 2021; Hamdani et al., 2021; Sarah et al., 2021; Satriyo, 2021; Budiyono et al., 2022; Kurniawan and Deviantari, 2022; Sadjadi, 2022). For instance, given its geological context, Italy is prone to slow natural subsidence phenomena that may be accelerated, especially along the coasts and in urbanized areas, by anthropogenic factors, i.e., groundwater overexploitation, urban expansion, and geothermal activities (Solari et al., 2018). Land subsidence is also attributable to multiple factors that may make it difficult to disentangle the contribution of one cause over another, since these vary highly over space and time (Poland and Hamilton, 1969). Methods to mitigate subsidence include regulation, reduction, or abandonment of groundwater extraction, artificial recharge of aquifers, repressuring of aquifers through wells, or geotechnical measures to reduce ground lowering (Omoko et al., 2018).

Reliable and accurate techniques to measure the magnitude and distribution of land subsidence over time are available; for instance, ground-based monitoring techniques (leveling, global position systems, extensometers, and geodetic surveys) can be combined with remote sensing (interferometric synthetic aperture radar or InSAR) (Jensen, 2009; Grgić et al., 2020; Fabris et al., 2021; Cenni et al., 2021; Raspini et al., 2022). Indeed, InSAR can detect ground movements over wide areas and has often been helpful in discovering unknown subsidence features (Strozzi et al., 2001; Omoko et al., 2018; Solari et al., 2018; Radutu and Vlad-Sandru, 2023). The impacts of land subsidence are expected to become greater issues in the future considering the increasing sea level, population growth, intensification of coastal erosion and extreme events, and increases in flood risk and freshwater salinization (Klein et al., 2003; Nicholls et al., 2007; Eggleston and Pope, 2013; Hallegatte et al., 2013; Erkens et al., 2015). Owing to their positions and low elevations, cities in coastal or deltaic environments are more vulnerable to these phenomena (Nicholls et al., 2007), which are further worsened by proneness to subsidence of their sedimentary deposits induced by natural or anthropic causes or both (Poland, 1984; Galloway et al., 1999).

In the future, increasing numbers of people living in coastal areas will be exposed to higher risks of flooding due to sea level rise and climate change than those living in non-coastal areas (Hanson et al., 2011; Higgins, 2016). In 2005, about 13 of the 20 most populated cities of vital economic importance globally were port cities (Nicholls, 2008). A total of 136 possibly at-risk cities were identified by Nicholls (2008) based on their marine flood vulnerability, and this number is expected to increase with demography and socioeconomic future evolutions of the cities, their vulnerability to sea level rise due to climate changes, and human-induced subsidence effects (Nicholls, 2008; Hallegatte et al., 2013); with population growth, socioeconomic growth and urbanization would be the most important drivers of the exposure rate (Nicholls, 2008). Hallegatte et al. (2013) additionally quantified the economic losses expected by 2050 from increased flood risks in these 136 coastal cities by considering the growing populations, changing climates, and rough estimates of land subsidence. The demand for drinking water is also expected to increase over the next few decades due to population and economic growths, which will result in groundwater depletion (Famiglietti, 2014; Water, 2022)

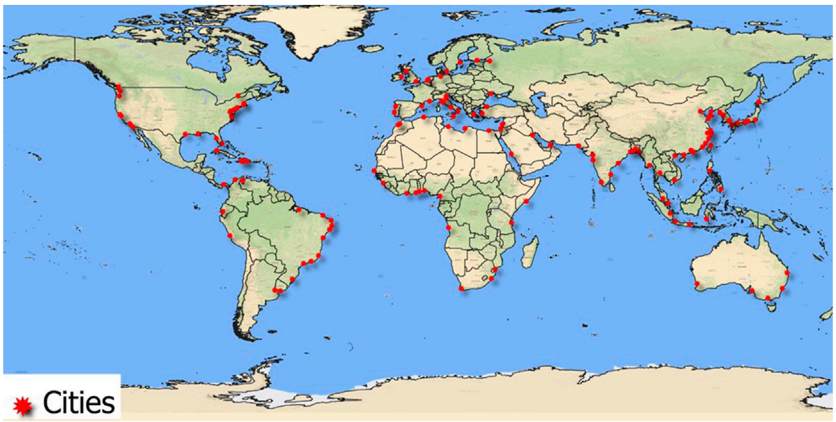

FIGURE 2
Locations of the coastal cities considered in this work.

TABLE 1 Brief overview of the collected bibliographies for each continent.

Continent	No. of cities	No. of articles	Year range
Africa	19	42	1953–2022
Asia	54	346	1969–2022
Europe	23	178	1909–2022
Oceania	6	21	1993–2022
North America	25	104	1948–2022
South America	16	22	1988–2022

and consequently lead to potential subsidence that threatens almost 12 million km^2 (8%) of the global land surface with a probability exceeding 50%, according to Herrera-García et al. (2021).

Other authors have previously investigated existing literature on land subsidence; for instance, Buffardi and Ruberti (2023) conducted a bibliometric analysis of the abstracts, keywords, and titles of published works; although their work highlights the most commonly investigated research topics, it does not provide site-specific information on the drivers of subsidence. The database proposed by Bagheri-Gavkosh et al. (2021) analyzes subsidence around the world, including metropolitan areas; however, many of the cities that were identified by Nicholls (2008) as expected to grow in relation to the demography and socioeconomic future were not included in their research. Additionally, since the authors investigated subsidence in both coastal and non-coastal areas, their bibliographic review of each site is not comprehensive, whereas the aim of the present work is to provide a thorough overview of land subsidence in each selected city.

Given this framework, the present study aims to provide an open-source, peer-reviewed, and comprehensive database of the land subsidence phenomenon in 143 major coastal cities. Moreover, we aim to facilitate future research on land subsidence in both previously identified cities and cities where further research is still needed.

The main novelties of the present work are as follows:

- To respond to the need for an exhaustive database of land subsidence in 143 major coastal cities, which can be shared with the scientific community, stakeholders, and policymakers;
- To identify the most common lithological classes and groundwater resource classes (aquifer types and productivity) among the chosen coastal cities;
- To identify the main and secondary causes of land subsidence in each of these coastal cities;
- To pinpoint selected cities that lack adequate research on land subsidence, especially cities where subsidence has been detected and whose causes are yet to be identified.

The proposed database is expected to expand the knowledge on land subsidence and its causes while increasing global awareness of this phenomenon among researchers, the scientific community, stakeholders, and policymakers by providing land subsidence information at the city scale as well as proneness to land subsidence that can also be useful in urban planning and development. Furthermore, the free availability of the database aims to promote cooperation among researchers globally, so that the database can be updated and missing information on land subsidence in major coastal cities can be supplemented.

2 Data and methods

The flowchart in Figure 1 explains the overall methodology of this study. The first step involved identifying the importance of tackling land subsidence through a literary review on land subsidence; this process allowed us to identify the main causes of land subsidence and the geological settings in which subsidence occurs. It was also possible to identify sites that were potentially vulnerable to both subsidence and sea level rise (Nicholls, 2008; Hallegatte et al., 2013; Solari et al., 2018), which resulted in the

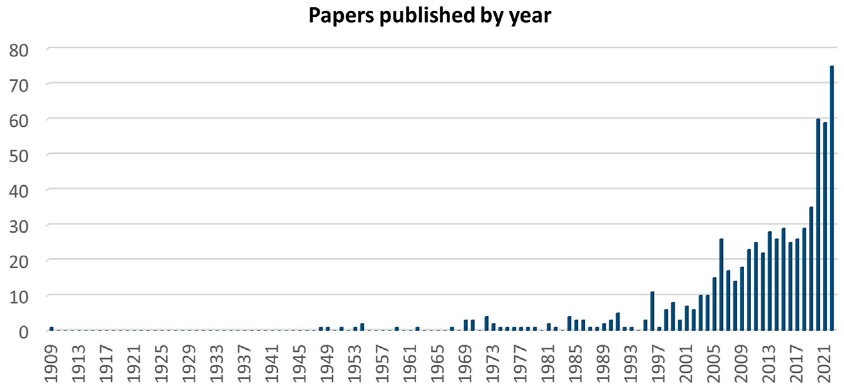

FIGURE 3
Graph representing the number of articles published per year.

selection of 143 cities around the world (Supplementary Table S1), including the 136 cities reported by Hallegate et al. (2013). An exclusive literary review of scientific papers was conducted to ensure high reliability of the information on the selected 143 coastal cities (Figure 2; Supplementary Table S1), and these data were collected in a database. For each city, the following information was extracted: main and secondary causes of land subsidence, lithological class, and groundwater recharge class.

The research papers were collected from researchgate.net, scopus.com, and scholar.google.com using keywords such as "satellite name (for example: ERS-1/2, Radarsat-1/2, Sentinel-1)+city name," "land subsidence+city name," "land subsidence+country name," "GPS+city name," "ground deformation+city name," and "insar+city name." The proposed database collected papers published until the end of 2022. Articles and books published in English, Italian, French, Dutch, and Spanish were also considered. The geological settings for each city were derived from the Global Lithological Map Database (Hartmann and Moosdorf, 2012) and Groundwater Resources of the World (Richts et al., 2011). The Global Lithological Map Database is composed of 16 classes: unconsolidated sediments, basic volcanic rocks, siliciclastic sedimentary rocks, basic plutonic rocks, mixed sedimentary rocks, carbonate sedimentary rocks, acid volcanic rocks, metamorphic rocks, acid plutonic rocks, intermediate volcanic rocks, water bodies, pyroclastic rocks, intermediate plutonic rocks, evaporates, no data, and ice and glaciers. The Groundwater Resources of the World map was organized under three main groups: major basins, complex structures, and local/shallow aquifers. Each group was classified on the basis of groundwater recharge (mm/year). For the major basins group, the classes include very low (<2), low (2–20), medium (20–100), high (100–300), and very high (>300) recharge. The complex structures group included classes like low to very low (<20), medium (20–100), high (100–300), and very high (>300) recharge. The local/shallow aquifers comprise classes like medium to very low (<100) and very high to high (>100) recharge. Additionally, a more detailed analysis was carried out in cities where groundwater extraction is or has been the main driver of land subsidence.

3 Results

We collected 679 published articles on the 143 coastal cities around the world (Table 1) to compile the database, which is freely available at https://doi.org/10.5281/zenodo.8349293 (Pedretti et al., 2023). The oldest report on subsidence in one of the 143 cities was published in 1909 about land subsidence in the Netherlands (Molengraaff, 1909), and no further works were published until the late 1940s, when some reports were published on land subsidence in Los Angeles (Harris and Harlow, 1948; Gilluly and Grant, 1949; McCann and Wilts, 1951; Berbower, 1959). The first paper in the database on an African city was published in 1953 regarding subsidence in South Africa (King, 1953); the first paper on subsidence in Asia was published in 1969 (Poland and Davis, 1969), while the first report from Oceania was in 1993 (Belperio, 1993) and that from South America was in 1988 (Aubrey et al., 1988).

Reports on land subsidence published before the 2000s account for only 13% of all papers found, while those published between 2000 and 2009 amount to 19% and papers published between 2010 and 2022 constitute 69% of the total. As seen in Figure 3 (number of publications per year), there is an increasing number of articles published over the last few years, with nearly 200 articles being published between 2020 and 2022 alone. Table 2 summarizes the causes of land subsidence commonly found in literature, which were adopted in the database. The main causes of subsidence identified for each continent are shown in Figure 4. In Africa, 26% of subsidence is unexplained, while 20% of the subsidence in North America is due to groundwater extraction; in South America, 31% of incidents are unexplained, while 44% of the incidents in Asia are due to groundwater extraction; in Europe, 26% of incidents are due to artificial loading, and 50% of the incidents in Oceania are due to groundwater extraction.

The main causes of subsidence identified in the 143 coastal cities are shown in Figure 5. In about 28% of these cities, groundwater extraction is identified as the main cause of land subsidence at present or possibly in the future, and this factor is considered the most common cause (Table 3). The remaining cities experience land subsidence due to artificial loading (13%), consolidation of

TABLE 2 Summary and explanation of causes for land subsidence commonly found in the literature.

Cause	Description
Artificial loading	Settlement due to the weight of the infrastructures
Clay shrinking/swelling	Subsidence due to the shrinkage and swelling of clays
Consolidation	Subsidence due to the consolidation of sediments
Groundwater extraction	Subsidence due to the extraction of groundwater
Hydrocarbon extraction	Subsidence due to the extraction of hydrocarbons
Karst	Subsidence (sinkholes) due to karst phenomena
Mining	Subsidence due to extraction of ore materials
No data	No data available
Others	Subsidence due to other causes
Peat oxidation	Subsidence due to peat oxidation
Tectonics/earthquakes	Subsidence due to tectonics or earthquakes
Tunneling	Subsidence due to extraction of materials due to underground excavations
Undetected	No subsidence detected based on literature review
Unexplained	Cause of subsidence is unexplained

sediments (11%), or tectonics and earthquakes (6%). In 2% of the cities, land subsidence is due to hydrocarbon extraction, and mining of ores was responsible in 3% of the cases. The shrinkage and swelling of clay-rich soils are the main causes of land subsidence in 1% of the identified cities, while 1% of the cities were reported to have multiple causes of land subsidence.

The percentage of cities in which no data were available was 20% globally: 32% in Africa, 28% in North America, 31% in South America, 17% in Oceania, 11% in Asia, and 13% in Europe. In 10% of the cities, there is evidence of land subsidence without clear identification of the causes, while land subsidence was not detected for 1% of the cities based on our research. The secondary causes of land subsidence identified for each continent are shown in Figure 6. These secondary causes are artificial loading (11%) and consolidation (11%) in Africa, artificial loading (8%) in North America, multiple secondary causes in South America and Europe (6% and 22%, respectively), and consolidation in Oceania and Asia (both 17%). The secondary causes of land subsidence identified for the 143 cities are shown in Figure 7. In 34% of the cities, the secondary cause of land subsidence was not clear, and no information could be found for 22% of the cities; in 11% of the cities, there were multiple secondary causes of land subsidence. For instance, artificial loading was associated with mining in the city of Fuzhou-Fujian, shrinkage and swelling of clay were the causes in Barranquilla and Amsterdam, consolidation of sediments was the cause in Venice, peat oxidation was the cause in Venice and Amsterdam, and tectonics or earthquakes were responsible in Karachi and Sapporo. Furthermore, groundwater extraction was associated with the consolidation of sediments in Ravenna, Surabaya, and Xiamen, with mining in Athens, and tectonics or earthquakes in Surabaya. Artificial loading was the secondary cause in 7% of the cities, while consolidation of sediments and groundwater extraction were the secondary drivers of subsidence in 8% of the cities.

In the 143 cities identified herein, the most commonly found lithological classes are unconsolidated sediments (44%) and sedimentary rocks (30%) (Figure 8A; Hartmann and Moosdorf, 2012), of which 30% are carbonate sedimentary rocks. Figure 8B shows the lithology classification for each continent: unconsolidated sediments, basic volcanic rocks, siliciclastic sedimentary rocks, basic plutonic rocks, mixed sedimentary rocks, carbonate sedimentary rocks, acid volcanic rocks, metamorphic rocks, acid plutonic rocks, intermediate volcanic rocks, and pyroclastic rocks.

Major basins, including shallow unconfined aquifers and deep confined aquifers, are the most common type of Groundwater Resources of the World in the 143 cities (53%) (Figure 9A). The volumes of stored groundwater in the major basins are significant, since they include highly productive aquifers as well as artesian zones (Margat and Van, 2013). Aquifers with complex geological structures account for 25% of the total, and these include rather productive local aquifers (volcanic or karst aquifers) that are shallow or deep and have significant storage (Margat and Van, 2013). Lastly, 22% of all aquifers are local and shallow aquifers in weathered or fissured rock and alluvial aquifers, characterized by low volumes of stored groundwater (Margat and Van, 2013). Figure 9B shows how 74% of all African cities are located in correspondence with major basins, 21% in complex structures, and 5% in local or shallow aquifers. In Asia, the most common types are the major basins, which account for 54% of the total, while 22% of the cities are in complex structures and 24% are in local or shallow aquifers. In Europe, 48% of the cities are in major basins, 35% are in complex structures, and 17% are in local or shallow aquifers. In the North and South Americas, the most common types are major basins (36% and 56%, respectively), while 32% of the cities are located in complex structures in North America and 38% are located in local or shallow aquifers in South America. In Oceania, 50% of the cities are in major basins, while the remaining 50% are in complex structures.

We additionally compared the main causes of land subsidence, i.e., groundwater extraction (40 cities), with the lithology and groundwater resource classes (Figure 10). About 60% of these 40 cities are located in unconsolidated sediments, 47.5% are located in major groundwater basins with high (100–300 mm/year) recharge, 15% are situated in major groundwater basins with very high (>300 mm/year) recharge, 12.5% are located in complex hydrogeological structures with high (100–300 mm/year) recharge, and 5% are situated in local and shallow aquifers with very high

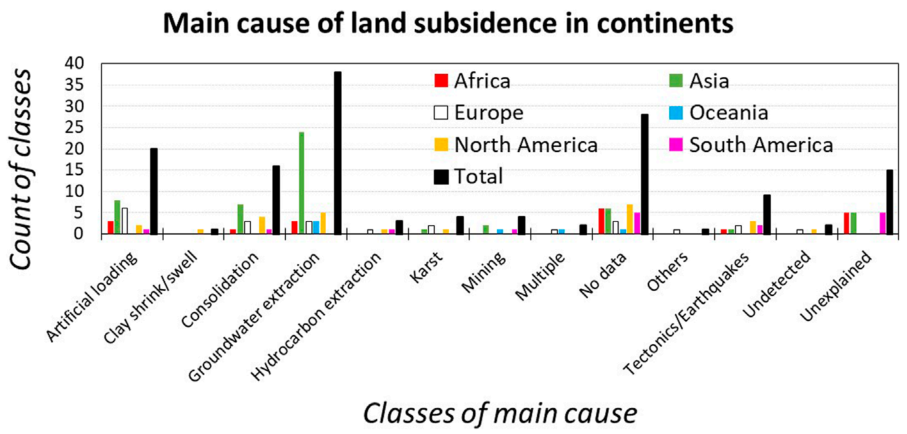

FIGURE 4
Main causes of land subsidence in each continent according to the literature.

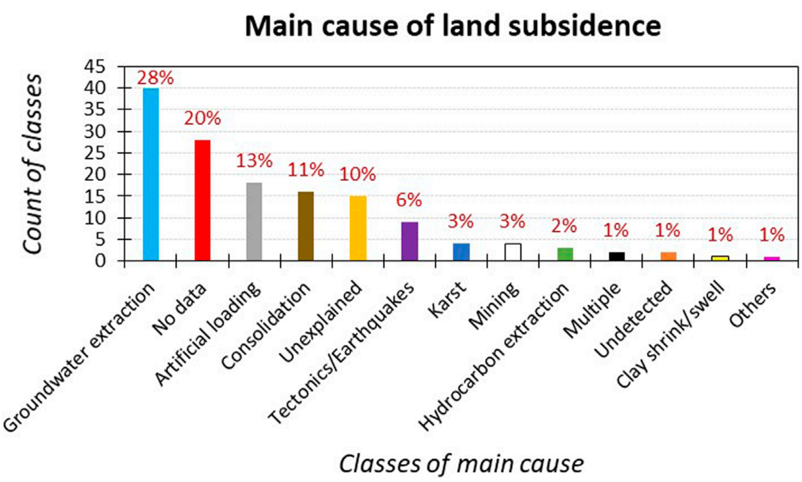

FIGURE 5
Main causes of land subsidence in each of the cities considered.

to high (>100 mm/year) recharge. A more detailed analysis of the 40 cities spread across all continents, in which groundwater extraction is or has been the main driver of subsidence, is provided in Table 4. Of these, 33 cities are still experiencing subsidence at present, whereas mitigation techniques adopted in three cities (e.g., regulation of the quantity of groundwater that can be pumped or artificial recharge of the aquifer system) (Tang et al., 2022; Sahuquillo et al., 2022; Wu et al., 2022) stopped land subsidence altogether. A total of 15 cities have adopted mitigation techniques to limit land subsidence, while 25 either do not have such measures in place or no information could be found. Subsidence has been recorded in these cities as early as the 19th century and has been monitored throughout the decades using satellite, GPS, and GNSS techniques. The maximum subsidence rate recorded was 280 mm/year; however, it was not possible to gather the maximum yearly subsidence rate for seven cities.

4 Discussion

The bibliographic review reported in this work identifies groundwater extraction as the most frequent cause of subsidence in the cities located in Africa, North and South Americas, Asia, and Oceania, whereas artificial loading was the most main subsidence cause in Europe. These findings are in line with the report of Nicholls et al. (2007), according to whom subsidence related to groundwater extraction is more prominent in cities that are growing; for instance, most cities in Asia have grown both economically (increasing gross domestic product (GDP)) and geographically, with increased population density, while cities in Africa and

TABLE 3 Main causes of land subsidence in the 143 coastal cities.

Main cause	Percentage over total (%)	Cities
Groundwater extraction	28	Abidjan, Adelaide, Auckland, Barcelona, Chittagong (Chattogram), Fuzhou-Fujian, Guangzhou (Guangdong), Haiphong, Hangzhou, Houston (TX), Jakarta, Karachi, Khulna, Kolkata (Calcutta), Krung Thep (Bangkok), Lagos, Lomé, London, Los Angeles (CA), Manila, Mumbai, Nagoya, Ningbo, Osaka-Kobe, Perth, Qingdao (Tsingtao), Saigon (Ho Chi Minh City), San Diego (CA), San Jose (CA), Shanghai, Taipei, Tianjin (Tientsin), Tokyo, Ujung Pandang (Makassar), Ulsan, Venezia (Venice), Virginia Beach (VA), Wenzhou, Recife, and Yangon
No data	20	Al Kuwait (Kuwait City), Baixada Santista (Santos), Bayrut (Beirut), Belem, Benghazi, Cape Town, Ciudad de Panama (Panama City), Dar al-Bayda (Casablanca), Dublin, Grande Vitoria, Izmir, La Habana (Havana), Marseille, Melbourne, Nampo (Namp'o), Natal, Odesa (Odessa), Philadelphia (PA), Portland (OR), Porto Alegre, Providence (RI), Rabat, Santo Domingo, Tarabulus (Tripoli), Tel Aviv–Yafo, Visakhapatnam (Vizag, Viśākha or Waltair), and Washington D.C.
Artificial loading	13	Alexandria, Athens, Dakar, Helsinki, Hong Kong, Incheon, Istanbul, Kobenhavn (Copenhagen), Kochi (Cochin), Lisboa (Lisbon), Livorno, Maputo, Miami (FL), Rotterdam, Seattle (WA), Singapore, Surabaya, and Xiamen (Amoy)
Unexplained	10	Buenos Aires, Conakry, Dar es Salaam, Davao, Durban, Guayaquil, Hiroshima, Jiddah (Jeddah), Lima, Luanda, Montevideo, Muqdisho (Mogadishu), Palembang, Rio de Janeiro, and Surat
Consolidation	11	Amsterdam, Barranquilla, Boston (MA), Busan (Pusan), Dalian, Dhaka, Douala, Dubayy (Dubai), New Orleans (LA), Saint Petersburg, San Francisco-Oakland (CA), Sapporo, Shenzhen, Siracusa (Syracuse), Vancouver, and Zhanjiang
Tectonics/earthquakes	6	Accra, Baltimore (MD), Chennai (Madras), Crotone, Fortaleza, Napoli (Naples), San Salvador, New York (NY), and San Juan
Karst	3	Grosseto, Hamburg, Kuala Lumpur, and Tampa - St. Petersburg (FL)
Mining	3	Fukuoka-Kitakyushu, Maceió, Sydney, and Yantai (Chefoo)
Hydrocarbon extraction	2	Long Beach (Los Angeles) (CA), Maracaibo, and Ravenna
Multiple	1	Brisbane and Glasgow
Undetected	1	Oporto (Porto) and Port-au-Prince
Clay shrinking/swelling	1	Montreal
Others	1	Stockholm

South America have undergone rapid urban expansion and have witnessed increases in population density (Pandey et al., 2013; Zhong et al., 2023). Additionally, among the top-10 countries for total groundwater usage, eight are located in Asia (Ritchie and Roser, 2023). Similarly, cities in Oceania (Australia) have been steadily growing in population (Krockenberger, 2015), and Australia is the third country in the world with the most amount of groundwater withdrawal for agricultural purposes (Ritchie and Roser, 2023). Although North American and European cities have experienced increases in their GDPs, the population densities are decreasing (Zhong et al., 2023). Nevertheless, two North American countries (United States and Mexico) are respectively 3rd and 7th based on total groundwater usage. Additionally, the United States has the highest water usage rate *per capita* worldwide, while Mexico has the 2nd highest groundwater withdrawal rate in the world for agricultural purposes as of 2015 (Ritchie and Roser, 2023).

Groundwater extraction was identified as the main cause of subsidence in 40 cities, which constitute 28% of the total and 35% of the 115 cities in which it was possible to identify a main cause of subsidence; this makes subsidence through groundwater extraction an especially pressing issue and the most commonly occurring factor according to the World Population Prospects created by the United Nations Organization (ONU). This finding is in line with the report by Bagheri-Gavkosh et al. (2021), where groundwater extraction was identified as the most common cause of land subsidence. Of the 40 cities identified, 15 have been implementing mitigation techniques to reduce the impacts of groundwater extraction on land subsidence; these entail regulation of the quantity of groundwater that can be pumped and artificial recharge of the aquifer system (Sahuquillo et al., 2022; Tang et al., 2022; Wu et al., 2022). Although it is not usually possible to restore an aquifer to its original thickness (Tang et al., 2022), mitigation techniques have proven to be successful in reducing or even stopping subsidence altogether. For

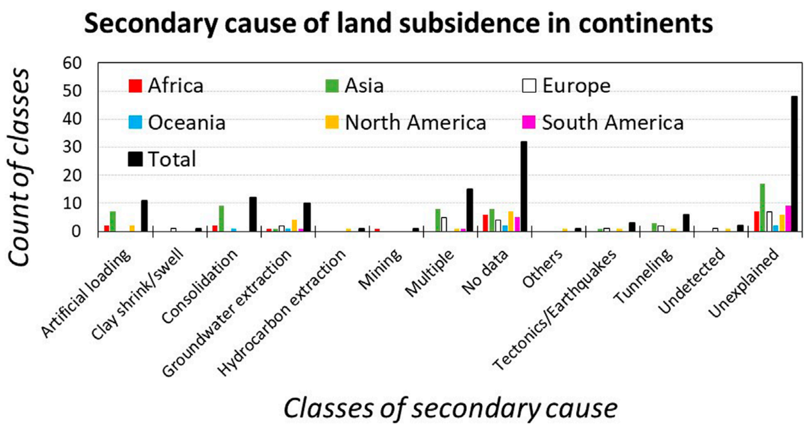

FIGURE 6
Secondary causes of land subsidence in each continent according to the literature.

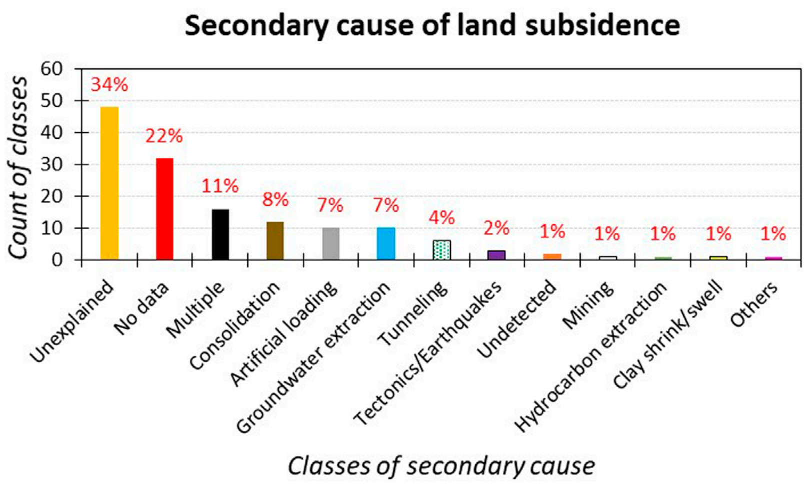

FIGURE 7
Secondary causes of land subsidence in each of the cities considered.

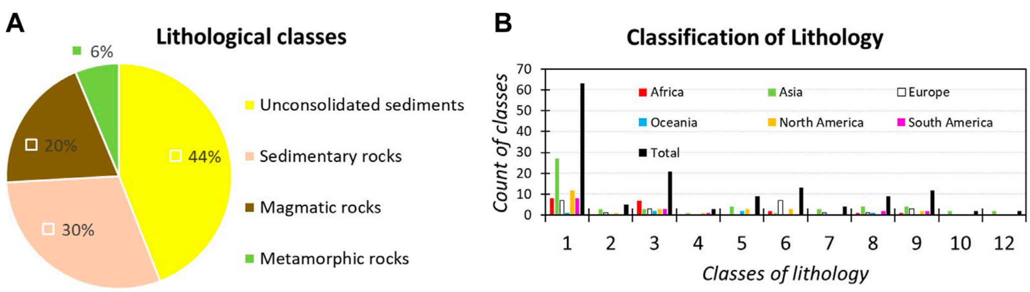

FIGURE 8
Lithological classes of the 143 cities. **(A)** shows a percentage breakdown and **(B)** shows a breakdown by continent of each class: (1) unconsolidated sediments, (2) basic volcanic rocks, (3) siliciclastic sedimentary rocks, (4) basic plutonic rocks, (5) mixed sedimentary rocks, (6) carbonate sedimentary rocks, (7) acid volcanic rocks, (8) metamorphic rocks, (9) acid plutonic rocks, (10) intermediate volcanic rocks and (12) pyroclastic rocks.

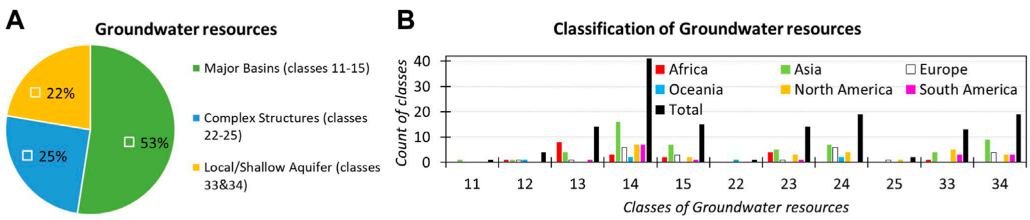

FIGURE 9
Classes of groundwater resources for each continent. **(A)** shows a percentage breakdown and **(B)** shows a breakdown by continent of each class: (11) major basins-very low (<2 mm/year) recharge, (12) major basins-low (2–20 mm/year) recharge, (13) major basins-medium (20-100 mm/year) recharge, (14) major basins-high (100–300 mm/year) recharge, (15) major basins-very high (>300 mm/year) recharge, (22) complex structures-low to very low (<20 mm/year) recharge, (23) complex structures-medium (20–100 mm/year) recharge, (24) complex structures-high (100-300 mm/year) recharge, (25) complex structures-very high (>300 mm/year) recharge, (33) local/shallow aquifers-medium to very low (<100 mm/year) recharge and (34) local/shallow aquifers-very high to high (>100 mm/year) recharge.

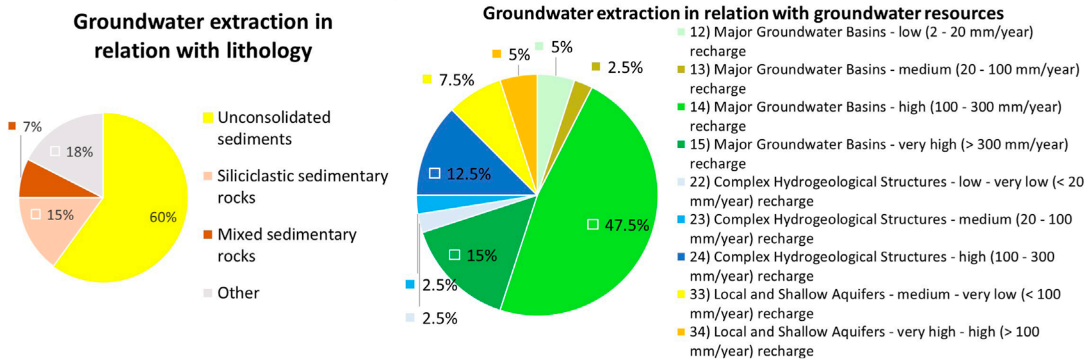

FIGURE 10
Main causes of land subsidence compared with the lithology and groundwater resource classes.

instance, in the cities of San Jose (CA), Tokyo, and Taipei, subsidence is no longer considered an issue (Hwang and Moh, 2020; Cao et al., 2021; Sahuquillo et al., 2022). In Jakarta, the subsidence rate has decreased from a maximum of 280 mm/year over 1982–2010 (Abidin et al., 2011) to a minimum of 50 mm/year (Wu et al., 2022) with the implementation of mitigation techniques in the suburbs. Similarly, in Shanghai where the maximum cumulative subsidence was 2.6 m, the yearly land subsidence rate decreased from 16 mm over 1990–2001 (Chai et al., 2004) to 10 mm close to many places near the water (Wu et al., 2022). Most of the area within the limits of Houston city show no substantial subsidence at present, while subsidence is still recorded in the suburban areas; however, a total subsidence of 3.0 m has been historically measured since 1917 (Galloway et al., 1999; Khan et al., 2022). In Krung Thep (Bangkok), land subsidence reached its most critical state in the early 1980s, when the rate was as high as 120 mm/year (Phien-wej et al., 2006); this regional-scale subsidence decreased to a maximum of 30 mm/year between 2018 and 2021 following mitigation efforts (Jeon and Yi, 2021). Among the analyzed cities, Guangzhou, Ho Chi Minh City, and Mumbai are already experiencing subsidence due to groundwater extraction and are among the cities that have experienced the majority of population increase worldwide, according to Zhong et al. (2023). Of these, only Ho Chi Minh City has been investing in mitigation measures since 1998 to reduce the impacts of floods (Ho, 2008). It is therefore clear from this analysis that historically, regulation of groundwater extraction is an effective tool for mitigating land subsidence in cities where groundwater extraction is the main cause.

It is not always possible to pinpoint a single cause of subsidence in cities where multiple influencing factors have been observed. This is the case for cities like Brisbane and Glasgow; in Brisbane, literature research identified multiple possible causes, such as mining of ore materials and excavation of tunnels, whereas in Glasgow, it was not possible to identify a single main cause among consolidation, artificial loading, and excavation of tunnels. In the case of Port-au-Prince and Porto, based on the literature review, the cities were deemed to be stable. However, while subsidence has not been recorded at present, it could still be occurring in areas that are yet to be investigated; therefore, it is advisable to continue investing resources for subsidence.

In the cities identified by Nicholls et al. (2007) and Hallegatte et al. (2013) on the basis of geopolitical and economic factors, it was oftentimes not possible to confirm or deny the occurrence of land subsidence. Of the 143 cities investigated, it was not possible to gather any data on 32% of African cities, 28% of North American cities, 31% of South American cities, 17% of Oceanian cities, 13% of European cities, and 11% of Asian cities. This can be due to absence of subsidence or lack of resources to investigate the issue or lack of

TABLE 4 Analysis of the cities in which groundwater extraction is the main driver of subsidence.

City	Maximum subsidence rate (mm/year)	Earliest subsidence observation	Monitoring technique	Subsidence still present	Mitigation
Abidjan	5.0	2014	Satellite	Yes	N/A
Adelaide	2.8	1943	N/A	Yes	N/A
Auckland	4	2003	Satellite	Yes	N/A
Barcelona	8	2016	Satellite	N/A	N/A
Chittagong (Chattogram)	20	2015	Satellite	Yes	N/A
Fuzhou-Fujian	22	1957	Satellite; ground benchmarks	Yes	N/A
Guangzhou (Guangdong)	23	2011	Satellite	Yes	N/A
Haiphong	N/A	N/A	N/A	N/A	N/A
Hangzhou	40	1993	Satellite	Yes	N/A
Houston (TX)	3,000 *	1917	Satellite; ground benchmarks	Yes	Yes
Jakarta	280	1982	Satellite; ground benchmarks	Yes	Yes
Karachi	10	2015	Satellite	Yes	N/A
Khulna	N/A	N/A	N/A	N/A	N/A
Kolkata (Calcutta)	16	1992	Satellite	Yes	N/A
Krung Thep (Bangkok)	120	1980	Satellite; ground benchmarks	Yes	Yes
Lagos	4	2018	Satellite	Yes	N/A
Lomé	N/A	N/A	N/A	Yes	No
London	25	1992	Satellite; ground benchmarks	Yes	Yes
Los Angeles (CA)	60	1998	Satellite; ground benchmarks	Yes	Yes
Manila	17	2017	Satellite; GPS	Yes	No
Mumbai	93	2014	Satellite	Yes	No
Nagoya	2	1925	Satellite; ground benchmarks	Yes	Yes
Ningbo	11.4	1960s	Satellite; ground benchmarks	Yes	Yes
Osaka-Kobe	20	1920s	Satellite	Yes	Yes
Perth	6	1970s	Satellite; GPS	Yes	Yes
Qingdao (Tsingtao)	34.48	2017	Satellite	Yes	No

(Continued on the following page)

TABLE 4 (*Continued*) Analysis of the cities in which groundwater extraction is the main driver of subsidence.

City	Maximum subsidence rate (mm/year)	Earliest subsidence observation	Monitoring technique	Subsidence still present	Mitigation
Recife	0.68	1970s	GNSS	Yes	Yes
Saigon (Ho Chi Minh City)	53	20th century	Satellite	Yes	Yes
San Diego (CA)	75 *	2016	Satellite; GNSS	Yes	No
San Jose (CA)	68	1898	Geodetic survey/ground network/benchmarks	No	Yes
Shanghai	2,630 *	1920	Satellite; ground benchmarks	Yes	Yes
Taipei	62	1940s	Ground benchmarks	No	No
Tianjin (Tientsin)	100	1950s	Ground benchmarks	Yes	No
Tokyo	64	1910s	Ground benchmarks	No	Yes
Ujung Pandang (Makassar)	150	N/A	Satellite	Yes	N/A
Ulsan	48	N/A	Satellite	Yes	N/A
Venezia (Venice)	30	20th century	Satellite	Yes	Yes
Virginia Beach (VA)	4.8	20th century	Satellite/GPS	Yes	No
Wenzhou	N/A	21st century	N/A	N/A	N/A
Yangon	90	21st century	Satellite	Yes	No

An asterisk (*) is used to identify cities in which only the cumulative subsidence for an unspecified time period was available.

available literature in languages accessible to the authors. It is clear that further investigations are necessary to fill this gap in research and that the problem of land subsidence is an urgent issue that must be investigated, measured, and monitored.

The main limitation of this research is that it aims to group past investigations regarding the subsidence phenomenon at the city level; however, this phenomenon can be very heterogeneous as both localized and widespread sinking can be classified as subsidence within a city. Large numbers of publications (e.g., in case of calamities) may also introduce biases when estimating the main causes of subsidence in such cities. Additionally, authors commonly analyze subsidence occurring within the same city at different locations, making it difficult to pinpoint a single driver of subsidence and study the spatial and temporal evolutions of the phenomena. Even within the same city, local variations in lithology or changes in land use can influence the subsidence dynamics considerably (Momotake, 1996; Galloway et al., 1999; Allis, 2000; Hu et al., 2004; Caramanna et al., 2008; Tularam and Krishna, 2009; Lorphensri et al., 2011; Tomás et al., 2014; Mastin et al., 2018; Solari et al., 2018; Loupasakis, 2020; Hamdani et al., 2021; Sarah et al., 2021; Satriyo, 2021; Calabrese et al., 2021; Budiyono et al., 2022; Sadjadi, 2022; Kurniawan and Deviantari, 2022). This also means that when multiple subsidence causes are identified for a city, it is possible that they may interact or could have occurred at different locations or occurred in specific moments in time, therefore being unrelated.

It may not be possible to provide a meaningful subsidence rate for each city because the rates derived from literature may not be comparable even within the same city. The subsidence rates are also obtained with different techniques in different years over different time spans using different remote sensing methods (ERS-1/2, Radarsat-1/2, Sentinel-1, etc.) at different spatial resolutions in different areas of the same cities and using unique classifications of the rates. Oftentimes, authors do not provide information regarding how the subsidence rate was acquired in the first place, or they only provide subsidence rates along the line of sight of the satellite or as vertical velocities. This means that once the cities are grouped into those with common characteristics, the number of comparable rates is very limited and therefore not significant to identify patterns of correlation between subsidence rates recorded by remote sensing sensors and from the ground. For local subsidence mitigation, the proposed database would therefore need to be integrated with more detailed analyses, including field observations and data collection.

Another limitation of this work is that the classifications proposed within the database are subjective and the research was limited to scientific papers while excluding local news sources for the sake of information quality: the search was limited to peer-reviewed articles from websites such as https://researchgate.net, https://scopus.com, and https://scholar.google.com. Additionally, only articles in languages accessible to the authors, such as English, Italian, French, Dutch, and Spanish, were considered.

However, this work provides a thorough investigation on the phenomenon of subsidence in 143 coastal cities and its relationships to the local hydrogeological settings. Hence, it could be a useful tool for the scientific community because it gives a preliminary overview of subsidence as well as the drivers in these areas, while highlighting the existing gaps in literature. The database is openly accessible, is peer-reviewed, and has global scope, promoting cooperation between academia and local communities as well as different countries, especially those where research on this topic is still lacking. It allows experts who aim to build local hydrogeological models to easily access information regarding both the hydrogeological settings and drivers of subsidence in each city.

The database also allows stakeholders and policymakers who may not be familiar with the issue of subsidence to easily access a comprehensive collection of peer-reviewed articles about their cities. This approach can provide an overview of the vulnerable areas within a city and allow access to information regarding how the issue of subsidence was tackled in similar hydrogeological settings or in areas where the drivers of subsidence were similar. It is expected to provide stakeholders with precedents on addressing the issue of subsidence in their own countries to limit economical losses while also protecting the population.

In literature, subsidence has been monitored through a very diverse array of techniques and methodologies: the database also provides an overview of the drivers of subsidence in a large sample of major coastal cities worldwide. This approach facilitates the creation of global subsidence models to address the issue at a global scale, benefitting countries that do not have the means to investigate the drivers of subsidence on their own at present. This database also contributes to fulfilling the goals of the Sustainable Development Agenda 2030 (UN, 2015) by aiding stakeholders in urban planning and management through reducing the impacts of subsidence on the more vulnerable and marginalized communities, while promoting and enabling future research along with increasing awareness to current and future risks caused by human activities and climate changes.

5 Conclusion

Subsidence is the gradual lowering or sudden sinking of the ground surface and is known to cause widespread impacts in terms of damages to infrastructures, utility lines, and buildings as well as changes in surficial drainage systems and groundwater conditions. This issue is expected to broaden in the future and impact the population more severely in major coastal cities, while also being concerned with the issues of sea level rise, population growth, intensification of coastal erosion and extreme events, increases in flood risk and salinization of freshwater, and increased extraction of groundwater due to population growth.

The aim of this work was to provide an open-source, accurate, peer-reviewed, and comprehensive database of subsidence in 143 coastal cities along with their main and secondary subsidence causes to help facilitate future research regarding subsidence in both priorly identified at-risk areas and areas where the potential impacts of subsidence are still unknown. In line with the findings of Bagheri-Gavkosh et al. (2021), the extraction of groundwater was identified as the most common driver of subsidence in the 143 cities, which is especially concerning given the World Population Prospects for population growth proposed by the ONU.

In African, Asian, Oceanian, and South American cities that are either growing economically or expanding, the increases in water demands reflect the increases in subsidence frequency, whereas this is not the case in European cities, where the GDP is growing on average even as the population density is decreasing. In North American cities, the extraction of groundwater is still the main driver of subsidence even as the population density is decreasing; however, as of 2020, the United States and Mexico are among the top-7 countries for total annual freshwater withdrawals, with the United States additionally having the highest water usage rate *per capita* and Mexico having the second highest groundwater withdrawal rate for agricultural purposes globally as of 2015 (Ritchie and Roser, 2023).

The analysis was conducted on 40 cities that are either experiencing or have experienced subsidence due to extraction of groundwater, and the findings highlight that implementation of mitigation techniques such as regulation of the pumping rates or artificial recharge of aquifer systems have either reduced or stopped subsidence altogether. It is therefore clear from this analysis that historical regulations of groundwater extraction have been effective tools for mitigating land subsidence in cities where groundwater extraction was the main cause. Owing to the method of selection of the cities, which was based on geopolitical and economic factors, and the severe lack of research regarding subsidence in some areas, it was not possible to gather data regarding land subsidence in a significant portion (20%) of the listed cities.

It must be noted that even within the same city, subsidence may have occurred at different locations due to different drivers and may have been measured using different techniques over different time spans; occasionally, the authors of these investigations do not provide insights into any of these variables, so it was not possible to analyze subsidence quantitatively based on literature alone in some cases. In other cases, the analysis of groundwater extraction rates (in place and time) as well as historical development of mining activities and underground engineering (such as tunneling) could be carried out on the city scale; however, this was beyond the scope of the present work.

The proposed database provides an in-depth investigation of land subsidence in a large sample of major cities around the world and was compiled with the aim of increasing the knowledge on the phenomenon to enhance global awareness of land subsidence among researchers, the scientific community, stakeholders, and policymakers for formulating prevention and urban planning strategies.

Author contributions

LP: conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing–original draft, and writing–review and editing. AG: conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing–original draft, and writing–review and editing. MK: methodology, supervision, validation, and writing–review and editing. JL: methodology, supervision, validation, and writing–review and editing. CM: conceptualization, funding acquisition, methodology, project administration, resources, supervision, validation, and writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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References

Abdelrahman, K., Al-Otaibi, N., and Ibrahim, E. (2021). Environmental hazard assessment for ground failure in Jeddah city, western Saudi Arabia, through cross-hole seismic testing. *J. King Saud University-Science* 33 (1), 101274. doi:10.1016/j.jksus.2020.101274

Abdullah, F. M., Andriyanto, H., Nababan, J. R., Abdillah, F., and Sulistyawan, R. I. H. (2021). Results of land subsidence measurement using GPS method in the Jakarta groundwater basin in 2015-2019. *IOP Conf. Ser. Earth Environ. Sci.* 873 (1), 012034). doi:10.1088/1755-1315/873/1/012034

Abidin, H. Z., Andreas, H., Djaja, R., Darmawan, D., and Gamal, M. (2008). Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys. *Gps Solutions* 12, 23–32. doi:10.1007/s10291-007-0061-0

Abidin, H. Z., Andreas, H., Gamal, M., Djaja, R., Subarya, C., Hirose, K., et al. (2005). "Monitoring land subsidence of Jakarta (Indonesia) using leveling, GPS survey and InSAR techniques," in *A window on the future of geodesy: proceedings of the international association of geodesy IAG general assembly sapporo, Japan june 30–july 11, 2003* (Springer Berlin Heidelberg), 561–566.

Abidin, H. Z., Andreas, H., Gumilar, I., Fukuda, Y., Pohan, Y. E., and Deguchi, T. (2011). Land subsidence of Jakarta (Indonesia) and its relation with urban development. *Nat. hazards* 59, 1753–1771. doi:10.1007/s11069-011-9866-9

Abidin, H. Z., Andreas, H., Gumilar, I., Gamal, M., Fukuda, Y., and Deguchi, T. (2009). "Land subsidence and urban development in jakarta (Indonesia)," in *Proceedings of the 7th FIG regional conference* (Hanoi).

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T., Azdan, M., Ali, F., et al. (2016). Disaster risk reduction of land subsidence in jakarta land subsidence in Indonesian cities land subsidence in java. doi:10.13140/RG.2.1.4448.9206

Abidin, H. Z., Djaja, R., Darmawan, D., Hadi, S., Akbar, A., Rajiyowiryono, H., et al. (2001). Land subsidence of Jakarta (Indonesia) and its geodetic monitoring system. *Nat. Hazards* 23, 365–387. doi:10.1023/a:1011144602064

Adhikari, D. K., Roy, M. K., Datta, D. K., Roy, P. J., Roy, D. K., Malik, A. R., et al. (2006). Urban geology: a case study of khulna city corporation, Bangladesh. *J. Life Earth Sci.* 1 (2), 17–29.

Aditiya, A., Takeuchi, W., and Aoki, Y. (2017). Land subsidence monitoring by InSAR time series technique derived from ALOS-2 PALSAR-2 over Surabaya city, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 98 (1), 012010, doi:10.1088/1755-1315/98/1/012010

Adkhi, I. I., Karuniasa, M., and Tambunan, R. P. (2021). Watershed flood vulnerability assessment based land subsidence analysed from a long time period of sentinel-1 radar data. *IOP Conf. Ser. Earth Environ. Sci.* 940 (1), 012035. doi:10.1088/1755-1315/940/1/012035

Agarwal, V., Kumar, A., Gee, D., Grebby, S., Gomes, R. L., and Marsh, S. (2021). Comparative study of groundwater-induced subsidence for London and Delhi using PSInSAR. *Remote Sens.* 13 (23), 4741. doi:10.3390/rs13234741

Agudelo, G., Wang, G., Liu, Y., Bao, Y., and Turco, M. J. (2020). GPS geodetic infrastructure for subsidence and fault monitoring in Houston, Texas, USA. *Proc. Int. Assoc. Hydrological Sci.* 382, 11–18. doi:10.5194/piahs-382-11-2020

Agustan, A., Kriswati, E., Ito, T., Abdullah, F. M., Anantasena, Y., and Nugroho, D. (2021). "Land subsidence rate of jakarta metropolitan area observed by stacking sentinel-1 data," in *2021 IEEE asia-pacific conference on geoscience, electronics and remote sensing technology (AGERS)* (IEEE), 69–72.

Ahmad, Z. (2006). *Study on groundwater depletion and land subsidence in Dhaka city*.

Akagi, T. (1979). Some land subsidence experiences in Japan and their relevance to subsidence in Bangkok, Thailand. *Geotech. Eng.* 10 (1).

Akther, H., Ahmed, M. S., and Rasheed, K. B. S. (2009). Spatial and temporal analysis of groundwater level fluctuation in Dhaka city, Bangladesh. *Asian J. Earth Sci.* 2 (2), 49–57. doi:10.3923/ajes.2009.49.57

Alademomi, A. S., Mayaki, A. O., Daramola, O. E., Salami, T. J., and Olaleye, J. B. (2020). Establishment of deformation and subsidence monitoring baseline in the coastal environment: a case study of University of Lagos. *South Afr. J. Geomatics* 9 (1), 13–30. doi:10.4314/sajg.v9i1.2

Alam, M. (1996). "Subsidence of the Ganges—brahmaputra Delta of Bangladesh and associated drainage, sedimentation and salinity problems," in *Sea-level rise and coastal subsidence* (Dordrecht: Springer), 169–192.

Aldiss, D., Burke, H., Chacksfield, B., Bingley, R., Teferle, N., Williams, S., et al. (2014). Geological interpretation of current subsidence and uplift in the London area, UK, as shown by high precision satellite-based surveying. *Proc. Geologists' Assoc.* 125 (1), 1–13. doi:10.1016/j.pgeola.2013.07.003

Aldrich, H. P., and Lambrechts, J. R. (1986). Back bay Boston, Part II: groundwater levels. *Civ. Eng. Pract.* 1 (2), 1–64.

Alimuddin, I., Luhur Bayuaji, Rohaya Langkoke, Josaphat Tetuko Sri Sumantyo, Hiroaki Kuze, (2013). Evaluating land surface changes of makassar city using DInSAR and landsat thematic mapper images. *David Publ. Co.* 7, 1287. doi:10.17265/1934-7359/2013.10.012

Allis, R. G. (2000). Review of subsidence at Wairakei field, New Zealand. *Geothermics* 29 (4-5), 455–478. doi:10.1016/s0375-6505(00)00016-x

Al Mukaimi, M. E., Dellapenna, T. M., and Williams, J. R. (2018). Enhanced land subsidence in Galveston Bay, Texas: interaction between sediment accumulation rates and relative sea level rise. *Coast. Shelf Sci.* 207, 183–193. doi:10.1016/j.ecss.2018.03.023

Amin, G., Shahzad, M. I., Jaweria, S., and Zia, I. (2022). Measuring land deformation in a mega city Karachi-Pakistan with Sentinel SAR Interferometry. *Geocarto Int.* 37 (17), 4974–4993. doi:10.1080/10106049.2021.1903572

Andreas, H., Abidin, H. Z., Pradipta, D., Sarsito, D. A., and Gumilar, I. (2018). Insight look the subsidence impact to infrastructures in Jakarta and Semarang area; Key for adaptation and mitigation. *MATEC Web Conf.* 147, 08001. doi:10.1051/matecconf/201814708001

Andreas, H., Abidin, H. Z., Sarsito, D. A., and Pradipta, D. (2019). The investigation on high-rise building tilting from the issue of land subsidence in Jakarta City. *MATEC Web Conf.* 270, 06002. doi:10.1051/matecconf/201927006002

Anjasmara, I. M., Yulyta, S. A., Cahyadi, M. N., Khomsin, K., Taufik, M., Jaelani, L. M., et al. (2018). "Land subsidence analysis in Surabaya urban area using time series InSAR method," in *AIP Conference Proceedings* (NY: AIP Publishing), 1987. No. 1.

Anping, C. H. E. N., Yuanmo, T. A. N., Cheng, Y. A. N. G., and Yongji, Q. I. N. (2021). Deformation monitoring along Fuzhou metro line based on radar technology. *Bull. Surv. Mapp.* (7), 86. doi:10.13474/j.cnki.11-2246.2021.0214

Antoncecchi, I., Ciccone, F., Rossi, G., Agate, G., Colucci, F., Moia, F., et al. (2021). Soil deformation analysis through fluid-dynamic modelling and DInSAR measurements: a focus on groundwater withdrawal in the Ravenna area (Italy). *BGTA-Bollettino Geofis. Teor. Appl.* doi:10.4430/bgta0350

Antonellini, M., Giambastiani, B. M. S., Greggio, N., Bonzi, L., Calabrese, L., Luciani, P., et al. (2019). Processes governing natural land subsidence in the shallow coastal aquifer of the Ravenna coast, Italy. *Catena* 172, 76–86. doi:10.1016/j.catena.2018.08.019

Antonellini, M., Giambastiani, B. M. S., Greggio, N., Bonzi, L., Calabrese, L., Luciani, P., et al. (2020). Hydrologic control on natural land subsidence in the shallow coastal aquifer of the Ravenna coast, Italy. *Proc. Int. Assoc. Hydrological Sci.* 382, 263–268. doi:10.5194/piahs-382-263-2020

Anzidei, M., Scicchitano, G., Scardino, G., Bignami, C., Tolomei, C., Vecchio, A., et al. (2021). Relative sea-level rise scenario for 2100 along the coast of south eastern sicily (Italy) by InSAR data, satellite images and high-resolution topography. *Remote Sens.* 13 (6), 1108. doi:10.3390/rs13061108

Ao, M., Wang, C., Xie, R., Zhang, X., Hu, J., Du, Y., et al. (2015). Monitoring the land subsidence with persistent scatterer interferometry in Nansha District, Guangdong, China. *Nat. Hazards* 75, 2947–2964. doi:10.1007/s11069-014-1471-2

Aobpaet, A., Caro Cuenca, M., Hooper, A., and Trisirisatayawong, I. (2010). Land subsidence evaluation using InSAR time series analysis in Bangkok metropolitan area. *In Fringe 2009, Proceedings of the workshop*, 677. Frascati, Italy: ESA Special Publication.

Aobpaet, A., Cuenca, M. C., Hooper, A., and Trisirisatayawong, I. (2013). InSAR time-series analysis of land subsidence in Bangkok, Thailand. *Int. J. Remote Sens.* 34 (8), 2969–2982. doi:10.1080/01431161.2012.756596

Aobpaet, A., Trisirisatayawong, I., Aung, H. H., and Maksin, P. (2015). *Yangon surface displacement as detected by insar time series analysis*.

Aoyama, S. (1996) "Japan's experience in urban environmental management," in *Metropolitan environment improvement program*. Bretton Woods, NH: the World Bank.

Appeaning Addo, K. (2014). Coastal vulnerability index to sea level rise in Ghana. Applied Earth Observation and Geoinformation, 23, 49–61. *Coast Mar. Res.* 2 (1), 1–7. doi:10.12966/cmr.01.01.2014

Applied Earth Observation and Geoinformation (2019). *Applied earth observation and geoinformation*, 49–61.

Arca, S., and Beretta, G. P. (1985). Prima sintesi geodetico-geologica sui movimenti verticali del suolo nell'Italia settentrionale (1897-1957). *Boll. Geod. Sci. affini* 44 (2), 125–156.

Ardha, M., Khomarudin, M. R., Pranowo, W. S., Chulafak, G. A., Yudhatama, D., Pravitasari, S., et al. (2022). Spatial information on the rate of subsidence in North Coastal Area of Java and the estimation of inundation in 2031. *IOP Conf. Ser. Earth Environ. Sci.* 1109 (1), 012022. doi:10.1088/1755-1315/1109/1/012022

ARPAE (Agenzia Prevenzione Ambientale Energia Emilia-Romagna) (2008). *Analisi preliminare degli effetti dei prelievi di acque sotterranee sulla evoluzione recente del fenomeno della subsidenza in Emilia-Romagna anno*. Available at: www.arpae.it/dettaglio_generale.asp?id=2045&idlivello=1425,www.arpae.it/cms3/documenti/subsidenza/Relfin_2008.pdf.

ARPAE (Agenzia Prevenzione Ambientale Energia Emilia-Romagna) (2012). *Rilievo della subsidenza nella pianura emiliano-romagnola - seconda fase anno*. Available at: www.arpae.it/cms3/documenti/subsidenza/Relfin_2012.pdf.

Artesea, G., Fiaschib, S., Di Martirec, D., Tessitorec, S., Fabrisd, M., Achillid, V., et al. (2016). Monitoring of land subsidence in Ravenna municipality using integrated SAR-GPS techniques: description and first results. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 7, 23–28. doi:10.5194/isprs-archives-xli-b7-23-2016

Asangwe, C. K. (2006). The Douala coastal lagoon complex, Cameroon: environmental issues. Administering marine spaces. *Int. Issues. Fig. Publ.* 36, 134–147.

Aslan, G., Cakır, Z., Ergintav, S., Lasserre, C., and Renard, F. (2018). Analysis of secular ground motions in istanbul from a long-term insar time-series (1992–2017). *Remote Sens.* 10 (3), 408. doi:10.3390/rs10030408

Aubrey, D. G., Emery, K. O., and Uchupi, E. (1988). Changing coastal levels of South America and the Caribbean region from tide-gauge records. *Tectonophysics* 154 (3-4), 269–284. doi:10.1016/0040-1951(88)90108-4

Babel, M. S., Gupta, A. D., Domingo, N. D. S., and Donna, N. (2006). Land subsidence: a consequence of groundwater over-exploitation in Bangkok, Thailand. *Int. Rev. Environ. Strategies* 6 (2), 307–327.

Baghdikian, S., Jepson, J. D., Henry, M. J., Holtz, K., Bock, L., Fayman, J., et al. (2010). "Enhancements to GPS-based subsidence monitoring at the wilmington oil field," in *SPE western regional meeting* (OnePetro).

Bagheri-Gavkosh, M., Hosseini, S. M., Ataie-Ashtiani, B., Sohani, Y., Ebrahimian, H., Morovat, F., et al. (2021). Land subsidence: a global challenge. *Sci. Total Environ.* 778, 146193. doi:10.1016/j.scitotenv.2021.146193

Bakr, M. (2015). Influence of groundwater management on land subsidence in deltas: a case study of Jakarta (Indonesia). *Water Resour. Manag.* 29 (5), 1541–1555. doi:10.1007/s11269-014-0893-7

Baldi, P., Casula, G., Cenni, N., Loddo, F., and Pesci, A. (2009). GPS-based monitoring of land subsidence in the Po Plain (Northern Italy). *Earth Planet. Sci. Lett.* 288 (1-2), 204–212. doi:10.1016/j.epsl.2009.09.023

Banerjee, S., and Sikdar, P. K. (2020). Land Subsidence due to leakage of aquitard-aquifer pore water in an under-construction tunnel of East-West Metro Railway Project, Kolkata. *J. Geol. Soc. India* 96, 467–474. doi:10.1007/s12594-020-1584-z

Banks, V. J., Arnhardt, C., Ramli, Z., Ahmad, F., and Pereira, J. (2020). "Sinkhole susceptibility mapping in the Kuala Lumpur and the need for a buried karst database," in *Nckri symposium 8*.

Bao, X., Zhang, R., Shama, A., Li, S., Xie, L., Lv, J., et al. (2022). Ground deformation pattern analysis and evolution prediction of Shanghai pudong international airport based on PSI long time series observations. *Remote Sens.* 14 (3), 610. doi:10.3390/rs14030610

Barlow, P. M., and Eric, G. R. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology J.* 18 (1), 247–260. doi:10.1007/s10040-009-0514-3

Bateson, L., and Novellino, A. (2019). *Glasgow geothermal energy research field site: ground motion survey report*.

Bau, D., Gambolati, G., and Teatini, P. (2000). Residual land subsidence near abandoned gas fields raises concern over northern Adriatic coastland. *EOS Transactions-American Geophys. Union* 81, 245–249. doi:10.1029/00eo00169

Bawden, G. W., Johnson, M. R., Kasmarek, M. C., Brandt, J. T., and Middleton, C. S. (2012). *Investigation of land subsidence in the Houston-Galveston region of Texas by using the global positioning system and interferometric synthetic aperture radar, 1993-2000 (No. 2012-5211)*. Reston, VA: US Geological Survey.

Bawden, G. W., Thatcher, W., Stein, R. S., Hudnut, K. W., and Peltzer, G. (2001). Tectonic contraction across Los Angeles after removal of groundwater pumping effects. *Nature* 412 (6849), 812–815. doi:10.1038/35090558

Bayuaji, L., Sumantyo, J. T. S., and Kuze, H. (2010). ALOS PALSAR D-InSAR for land subsidence mapping in Jakarta, Indonesia. *Can. J. Remote Sens.* 36 (1), 1–8. doi:10.5589/m10-023

Becker, M., Papa, F., Karpytchev, M., Delebecque, C., Krien, Y., Khan, J. U., et al. (2020). Water level changes, subsidence, and sea level rise in the Ganges–Brahmaputra–Meghna delta. *Proc. Natl. Acad. Sci.* 117 (4), 1867–1876. doi:10.1073/pnas.1912921117

Bekaert, D. P. S., Hamlington, B. D., Buzzanga, B., and Jones, C. E. (2017). Spaceborne synthetic aperture radar survey of subsidence in Hampton Roads, Virginia (USA). *Sci. Rep.* 7 (1), 14752. doi:10.1038/s41598-017-15309-5

Bello, A. (2022). *Recent updates on global warming and geologic hazards*. Available at SSRN 4108277.

Belperio, A. P. (1993). Land subsidence and sea level rise in the Port Adelaide estuary: implications for monitoring the greenhouse effect. *Aust. J. Earth Sci.* 40 (4), 359–368. doi:10.1080/08120099308728087

Berbower, R. F. (1959). Subsidence problem in the Long Beach harbor district. *J. Waterw. Harb. Div.* 85 (2), 43–80. doi:10.1061/jwheau.0000124

Bertoni, W., Elmi, C., and Marabini, F. (2005). The subsidence of Ravenna. *G. Geol. Appl.* 1 (2). doi:10.1474/GGA.2005-01.0-03.0003

Bhattacharya, A. K. (2008). Hydrogeology and land subsidence in Salt Lake City, Kolkata, India. *Electron. J. Geotechnical Eng.* 13, 1–14.

Bhattacharya, A. K. (2011). Land subsidence in Kolkata due to groundwater depletion. *Electron. J. Geotechnical Eng.* 16.

Bhattacharya, A. K. (2013). An analysis of land subsidence in Bangkok and Kolkata due to over-extraction of groundwater. *Electron. J. Geotechnical Eng.* 18, 1683–1694.

Bhattacharya, A. K., Basak, S., and Patra, M. N. (2004). Land subsidence in Calcutta under the effect of hydrogeological conditions and over-extraction of groundwater. *EJGE* 9, 1–16.

Bhattacharya, A. K., and Kumar, D. (2012). Land subsidence in east Calcutta. *IOSR J. Eng.* 2 (03), 408–413. doi:10.9790/3021-0203408413

Bhattacharya, N., and Lamond, J. (2011). *A review of urban flood risk situation in African growing economies*. na.

Bianchini, S., Raspini, F., Solari, L., Del Soldato, M., Ciampalini, A., Rosi, A., et al. (2018). From picture to movie: twenty years of ground deformation recording over Tuscany region (Italy) with satellite InSAR. *Front. Earth Sci.* 6, 177. doi:10.3389/feart.2018.00177

Bianchini, S., Solari, L., Del Soldato, M., Raspini, F., Montalti, R., Ciampalini, A., et al. (2019). Ground subsidence susceptibility (GSS) mapping in Grosseto Plain (Tuscany, Italy) based on satellite InSAR data using frequency ratio and fuzzy logic. *Remote Sens.* 11 (17), 2015. doi:10.3390/rs11172015

Bingley, R. M., Ashkenazi, V., Penna, N. T., Booth, S. J., Ellison, R. A., and Morigi, A. N. (1999). Monitoring changes in regional ground level, using high precision GPS. *Environ. Agency R&D Tech. Rep. W210*. Available at: http://www.freshwaterlife.org/projects/media/projects/images/0/6683_ca_object_representations_media_70_original.pdf.

Bissoli, R., Bitelli, G., Bonsignore, F., Rapino, A., and Vittuari, L. (2010) *Land subsidence in Emilia-Romagna Region, northern Italy: recent results*, 339. England: IAHS-AISH publication, 307–311.

Biswas, K., Chakravarty, D., Mitra, P., and Misra, A. (2019). "Estimation of ground deformation using psinsar with L-band alos palsar data: a case study of Kolkata, India," in *IGARSS 2019-2019 IEEE international geoscience and remote sensing symposium* (IEEE), 2119–2122.

Bitelli, G., Bonsignore, F., Carbognin, L., Ferretti, A., Strozzi, T., Teatini, P., et al. (2010). Radar interferometry-based mapping of the present land subsidence along the low-lying northern adriatic coast of Italy. Land subsidence, associated hazards and the role of natural resources development. *Proc. EISOLS* 339, 279–286.

Bitelli, G., Bonsignore, F., Del Conte, S., Franci, F., Lambertini, A., Novali, F., et al. (2020). Updating the subsidence map of Emilia-Romagna region (Italy) by integration of SAR interferometry and GNSS time series: the 2011–2016 period. *Proc. Int. Assoc. Hydrological Sci.* 382, 39–44. doi:10.5194/piahs-382-39-2020

Bitelli, G., Bonsignore, F., Del Conte, S., Novali, F., Pellegrino, I., and Vittuari, L. (2015a). "Integrated use of Advanced InSAR and GPS data for subsidence monitoring," in *Engineering geology for society and territory-volume 5: urban geology, sustainable planning and landscape exploitation* (Springer International Publishing), 147–150.

Bitelli, G., Bonsignore, F., Pellegrino, I., and Vittuari, L. (2015b). Evolution of the techniques for subsidence monitoring at regional scale: the case of Emilia-Romagna region (Italy). *Proc. Int. Assoc. hydrological Sci.* 372 (372), 315–321. doi:10.5194/piahs-372-315-2015

Bitelli, G., Bonsignore, F., and Unguendoli, M. (2000). Levelling and GPS networks to monitor ground subsidence in the Southern Po Valley. *J. Geodyn.* 30 (3), 355–369. doi:10.1016/s0264-3707(99)00071-x

Bock, Y., Wdowinski, S., Ferretti, A., Novali, F., and Fumagalli, A. (2012). Recent subsidence of the Venice Lagoon from continuous GPS and interferometric synthetic aperture radar. *Geochem. Geophys. Geosystems* 13 (3). doi:10.1029/2011gc003976

Bonì, R., Meisina, C., Cigna, F., Herrera, G., Notti, D., Bricker, S., et al. (2017). Exploitation of satellite A-DInSAR time series for detection, characterization and modelling of land subsidence. *Geosciences* 7 (2), 25. doi:10.3390/geosciences7020025

Boretti, A. (2020). Relative sea-level rise and land subsidence in Oceania from tide gauge and satellite GPS. *Nonlinear Eng.* 9 (1), 175–193. doi:10.1515/nleng-2020-0007

Boretti, A. (2022). An alternative procedure to compute the sea-level acceleration from long-term-trend tide gauge records. *Arabian J. Geosciences* 15 (7), 566–569. doi:10.1007/s12517-022-09864-z

Bott, L. M., Schöne, T., Illigner, J., Haghighi, M. H., Gisevius, K., and Braun, B. (2021). Land subsidence in Jakarta and Semarang Bay–The relationship between physical processes, risk perception, and household adaptation. *Ocean Coast. Manag.* 211, 105775. doi:10.1016/j.ocecoaman.2021.105775

Bouin, M. N., and Wöppelmann, G. (2010). Land motion estimates from GPS at tide gauges: a geophysical evaluation. *Geophys. J. Int.* 180 (1), 193–209. doi:10.1111/j.1365-246x.2009.04411.x

Brambati, A., Carbognin, L., Quaia, T., Teatini, P., and Tosi, L. (2003). The Lagoon of Venice: geological setting, evolution and land subsidence. *Episodes J. Int. Geoscience* 26 (3), 264–268. doi:10.18814/epiiugs/2003/v26i3/020

Brandt, J. T., Sneed, M., and Danskin, W. R. (2020). Detection and measurement of land subsidence and uplift using interferometric synthetic aperture radar, San Diego, California, USA, 2016–2018. *Proc. Int. Assoc. Hydrological Sci.* 382, 45–49. doi:10.5194/piahs-382-45-2020

Braun, C. L., and Ramage, J. K. (2022). *Status of water-level altitudes and long-term water-level changes in the Chicot and Evangeline (undifferentiated) and Jasper aquifers, greater Houston area, Texas, 2021*. Reston, Virginia: U.S. Geological Survey. No. 2022-5065.

Bremard (2020). *t. Sinking bangkok*.

Bremard, T. (2022). Monitoring land subsidence: the challenges of producing knowledge and groundwater management indicators in the Bangkok metropolitan region, Thailand. *Sustainability* 14 (17), 10593. doi:10.3390/su141710593

Brinkmann, R., and Parise, M. (2010). The timing of sinkhole formation in Tampa and Orlando, Florida. *Fla. Geogr.* 41.

Brown, S., and Nicholls, R. J. (2015). Subsidence and human influences in mega deltas: the case of the Ganges–Brahmaputra–Meghna. *Sci. Total Environ.* 527, 362–374. doi:10.1016/j.scitotenv.2015.04.124

Browne, M. A. E., Forsyth, I. H., and McMillan, A. A. (1986). Glasgow, a case study in urban geology. *J. Geol. Soc.* 143 (3), 509–520. doi:10.1144/gsjgs.143.3.0509

Bruni, S., Zerbini, S., Raicich, F., and Errico, M. (2019). Rescue of the 1873–1922 high and low waters of the Porto Corsini/Marina di Ravenna (northern Adriatic, Italy) tide gauge. *J. Geodesy* 93, 1227–1244. doi:10.1007/s00190-019-01238-w

Buckley, S. M., Rosen, P. A., Hensley, S., and Tapley, B. D. (2003). Land subsidence in Houston, Texas, measured by radar interferometry and constrained by extensometers. *J. Geophys. Res. solid earth* 108 (B11). doi:10.1029/2002jb001848

Budiyono, Y., Nuraini Melati, D., Khaerani, P., Krisna Yuliana, D., Riyandari, R., Fiqi Riyalda, B., et al. (2022). "Review on land subsidence and socio-hydrology of northern Java, Indonesia," in *EGU general assembly conference abstracts*, EGU22–8170.

Buffardi, C., and Ruberti, D. (2023). The issue of land subsidence in coastal and alluvial plains: a bibliometric review. *Remote Sens.* 15 (9), 2409. doi:10.3390/rs15092409

Bui, D., Kawamura, A., Tong, T., Amaguchi, H., and Nakagawa, N. (2012). Spatio-temporal analysis of recent groundwater-level trends in the red river delta, vietnam. *Hydrogeology J.* 20 (8), 1635–1650. doi:10.1007/s10040-012-0889-4

Bulhões, J. A. (2022). *Colapso Urbano? Narrativas de moradores do Pinheiro sobre a subsidência do solo em Maceió-AL*.

Burgmann, Roland, Hilley, G., Ferretti, A., and Novali, F. (2006). Resolving vertical tectonics in the San Francisco Bay Area from permanent scatterer InSAR and GPS analysis. *Geology* 34 (3), 221–224. doi:10.1130/g22064.1

Burland, J. B., Standing, J. R., and Jardine, F. M. (2001). "Building response to tunnelling," in *Case studies from construction of the jubilee line extension* (London), 134–145.

Buurman, N. (2010). *Zirkular-Strukturen in der Metropolregion Hamburg und ihre potenziellen Geogefahren*. PhD thesis.

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. Geofis. Teor. Appl.* 62 (2). doi:10.4430/bgta0356

Calò, F., Abdikan, S., Görüm, T., Pepe, A., Kiliç, H., and Balik Şanli, F. (2015). The space-borne SBAS-DInSAR technique as a supporting tool for sustainable urban policies: the case of Istanbul Megacity, Turkey. *Remote Sens.* 7 (12), 16519–16536. doi:10.3390/rs71215842

Camporese, M., Gambolati, G., Putti, M., and Teatini, P. (2006). Peatland subsidence in the Venice watershed. *Dev. Earth Surf. Process.* 9, 529–550. doi:10.1016/S0928-2025(06)09023-7

Canova, F., Tolomei, C., Salvi, S., Toscani, G., and Seno, S. (2012). Land subsidence along the Ionian coast of SE Sicily (Italy), detection and analysis via Small Baseline Subset (SBAS) multitemporal differential SAR interferometry. *Earth Surf. Process. Landforms* 37 (3), 273–286. doi:10.1002/esp.2238

Cao, A., Esteban, M., Valenzuela, V. P. B., Onuki, M., Takagi, H., Thao, N. D., et al. (2021). Future of asian deltaic megacities under sea level rise and land subsidence: current adaptation pathways for Tokyo, jakarta, manila, and Ho Chi Minh city. *Curr. Opin. Environ. Sustain.* 50, 87–97. doi:10.1016/j.cosust.2021.02.010

Cao, G., Han, D., and Moser, J. (2013). Groundwater exploitation management under land subsidence constraint: empirical evidence from the Hangzhou–Jiaxing–Huzhou Plain, China. *Environ. Manag.* 51 (6), 1109–1125. doi:10.1007/s00267-013-0037-5

Caputo, M., Pieri, L., and Tesi, F. R. (1972). Land subsidence in Venice and Porto corsini. *Ann. Geophys.* 25 (1), 56–61.

Caramanna, G., Ciotoli, G., and Nisio, S. (2008). A review of natural sinkhole phenomena in Italian plain areas. *Nat. hazards* 45 (2), 145–172. doi:10.1007/s11069-007-9165-7

Carbognin, L., Gatto, P., Mozzi, G., and Gambolati, G. (1978). "Land subsidence of Ravenna and its similarities with the Venice case," in *Evaluation and prediction of subsidence* (Reston, Virginia: ASCE), 254–266.

Carbognin, L., Rizzetto, F., Tosi, L., Strozzi, T., Teatini, P., and Vitturi, A. (2005a). "A new monitoring strategy to control land movements. The Veneto Region test area," in *Land subsidence* (Shanghai Scientific & Technical Publishers).

Carbognin, L., Teatini, P., Tomasin, A., and Tosi, L. (2010). Global change and relative sea level rise at Venice: what impact in term of flooding. *Clim. Dyn.* 35, 1039–1047. doi:10.1007/s00382-009-0617-5

Carbognin, L., Teatini, P., and Tosi, L. (2004). Eustacy and land subsidence in the Venice Lagoon at the beginning of the new millennium. *J. Mar. Syst.* 51 (1-4), 345–353. doi:10.1016/j.jmarsys.2004.05.021

Carbognin, L., and Tosi, L. (2002). Interaction between climate changes, eustacy and land subsidence in the North Adriatic Region, Italy. *Mar. Ecol.* 23, 38–50. doi:10.1111/j.1439-0485.2002.tb00006.x

Carisi, F., Domeneghetti, A., Gaeta, M. G., and Castellarin, A. (2017). Is anthropogenic land subsidence a possible driver of riverine flood-hazard dynamics? A case study in Ravenna, Italy. *Hydrological Sci. J.* 62 (15), 2440–2455. doi:10.1080/02626667.2017.1390315

Carminati, E., and Di Donato, G. (1999). Separating natural and anthropogenic vertical movements in fast subsiding areas: the Po plain (N. Italy) case. *Geophys. Res. Lett.* 26 (15), 2291–2294. doi:10.1029/1999gl900518

Carminati, E., Enzi, S., and Camuffo, D. (2007). A study on the effects of seismicity on subsidence in foreland basins: an application to the Venice area. *Glob. Planet. Change* 55 (4), 237–250. doi:10.1016/j.gloplacha.2006.03.003

Castellazzi, P., and Schmid, W. (2021). Interpreting C-band InSAR ground deformation data for large-scale groundwater management in Australia. *J. Hydrology Regional Stud.* 34, 100774. doi:10.1016/j.ejrh.2021.100774

Casu, F., Buckley, S. M., Manzo, M., Pepe, A., and Lanari, R. (2005). "Large scale InSAR deformation time series: Phoenix and Houston case studies," in *Proceedings. 2005 IEEE international geoscience and remote sensing symposium, 2005* (IEEE), 7, 5240–5243. doi:10.1109/igarss.2005.1526866

Catalao, J., Nico, G., and Conde, V. (2011a). "Detection of ground subsidence in the city of Lisbon: comparison of InSAR and topographic measurements," in *2011 joint urban remote sensing event* (IEEE), 417–420.

Catalao, J., Nico, G., Conde, V., and Miranda, J. (2011b). "Quantification of subsidence rates associated with groundwater flow using SAR interferometry," in *Proc.'Fringe 2011 workshop* (Frascati, Italy: '), 19–23.

Catalão, J., Nico, G., Lollino, P., Conde, V., Lorusso, G., and Silva, C. (2015). Integration of InSAR analysis and numerical modeling for the assessment of ground subsidence in the city of Lisbon, Portugal. *IEEE J. Sel. Top. Appl. Earth Observations Remote Sens.* 9 (4), 1663–1673. doi:10.1109/jstars.2015.2428615

Catalao, J., Raju, D., and Fernandes, R. M. S. (2013). Mapping vertical land movement in Singapore using InSAR GPS. *ESA Living Planet Symposium 2013*, 722. Edinburgh, UK: ESA Special Publication, 54.

Catalao, J., Raju, D., and Nico, G. (2020). InSAR maps of land subsidence and sea level scenarios to quantify the flood inundation risk in coastal cities: the case of Singapore. *Remote Sens.* 12 (2), 296. doi:10.3390/rs12020296

Cenni, N., Fiaschi, S., and Fabris, M. (2021). Monitoring of land subsidence in the po river delta (Northern Italy) using geodetic networks. *Remote Sens.* 13 (8), 1488. doi:10.3390/rs13081488

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. doi:10.1016/j.jog.2013.07.004

Cerenzia, I., Putero, D., Bonsignore, F., Galassi, G., Olivieri, M., and Spada, G. (2016). Historical and recent sea level rise and land subsidence in Marina di Ravenna, northern Italy. *Ann. Geophys.* 59 (5), 0546. doi:10.4401/ag-7022

Chai, J. C., Shen, S. L., Zhu, H. H., and Zhang, X. L. (2004). Land subsidence due to groundwater drawdown in Shanghai. *Geotechnique* 54 (2), 143–147. doi:10.1680/geot.2004.54.2.143

Chatterjee, R., Roy, P., Dadhwal, V., Lakhera, R., Quang, T., and Saha, R. (2007). Assessment of land subsidence phenomenon in Kolkata city, India using satellite-based D-InSAR technique. *Curr. Sci.* 93, 85–93.

Chatterjee, R. S., Fruneau, B., Rudant, J. P., Roy, P. S., Frison, P. L., Lakhera, R. C., et al. (2006). Subsidence of Kolkata (Calcutta) City, India during the 1990s as observed from space by differential synthetic aperture radar interferometry (D-InSAR) technique. *Remote Sens. Environ.* 102 (1-2), 176–185. doi:10.1016/j.rse.2006.02.006

Chaussard, E., Amelung, F., Abidin, H., and Hong, S. H. (2013). Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction. *Remote Sens. Environ.* 128, 150–161. doi:10.1016/j.rse.2012.10.015

Chavez, H., Alexander, J., Šebesta, J., and Bakoň, M. (2020a). Relation between surface dynamics and remote sensor InSAR results over the Metropolitan Area of San Salvador. *Nat. Hazards* 103 (3), 3661–3682. doi:10.1007/s11069-020-04150-1

Chávez, J. A., Bichara, Y., Miranda, K., Funes, B., Alfaro, I., Vasquez, M., et al. (2020b). Promoting resilience and sustainability in the metropolitan area of san salvador. *Urban Des.* 3 (1), 22–36. doi:10.31058/j.ud.2020.31002

Chebo, A. K. (2009). Monitoring wetlands deterioration in the Cameroon coastal lowlands: implications for management. *Procedia Earth Planet. Sci.* 1 (1), 1010–1015. doi:10.1016/j.proeps.2009.09.156

Chen, C. T., Hu, J. C., Lu, C. Y., Lee, J. C., and Chan, Y. C. (2007). Thirty-year land elevation change from subsidence to uplift following the termination of groundwater pumping and its geological implications in the Metropolitan Taipei Basin, Northern Taiwan. *Eng. Geol.* 95 (1-2), 30–47. doi:10.1016/j.enggeo.2007.09.001

Chen, F., Lin, H., Zhang, Y., and Lu, Z. (2012). Ground subsidence geo-hazards induced by rapid urbanization: implications from InSAR observation and geological analysis. *Nat. Hazards Earth Syst. Sci.* 12 (4), 935–942. doi:10.5194/nhess-12-935-2012

Chen, Q., Liu, G., Ding, X., Hu, J. C., Yuan, L., Zhong, P., et al. (2010). Tight integration of GPS observations and persistent scatterer InSAR for detecting vertical ground motion in Hong Kong. *Int. J. Appl. Earth Observation Geoinformation* 12 (6), 477–486. doi:10.1016/j.jag.2010.05.002

Chen, Y., Liao, M., Wu, J., Li, X., Xiong, F., Liu, S., et al. (2022). Elastic and inelastic ground deformation in Shanghai lingang area revealed by sentinel-1, leveling, and groundwater level data. *Remote Sens.* 14 (11), 2693. doi:10.3390/rs14112693

Chen, Z., Wang, J., and Huang, X. (2018). Land subsidence monitoring in greater Vancouver through synergy of InSAR and polarimetric analysis. *Can. J. Remote Sens.* 44 (3), 202–214. doi:10.1080/07038992.2018.1481736

Cheng, Y. M., Au, S. K., Pearson, A. M., and Li, N. (2013). An innovative geonail system for soft ground stabilization. *Soils Found.* 53 (2), 282–298. doi:10.1016/j.sandf.2013.02.009

Chi, Y. X. (2009). Analysis of influence factors for land subsidence in Fuzhou. *Hydrogeology Eng. Geol.* 36 (6), 131–133.

Chian, M. (1977). *Groundwater depletion and land subsidence in taipei basin*.

Cho, M., and Lee, C. W. (2014). Ground subsidence measurements of noksan national industrial complex using C-band multi-temporal SAR images. *Korean J. Remote Sens.* 30 (2), 161–172. doi:10.7780/kjrs.2014.30.2.1

Chunga, K., León, C., Quiñónez, M. F., Benítez, S., and Montenegro, G. (2005). "Seismic hazard assessment for guayaquil city (Ecuador): insights from quaternary geological data," in *Abstract final meeting, dark nature, rapid natural change and human responses*, 55–56.

Cian, F., Blasco, J. M. D., and Carrera, L. (2019). Sentinel-1 for monitoring land subsidence of coastal cities in africa using PSInSAR: a methodology based on the integration of snap and StaMPS. *Geosciences* 9 (3), 124. doi:10.3390/geosciences9030124

Cigna, F., Jordan, H., Bateson, L., McCormack, H., and Roberts, C. (2015). Natural and anthropogenic geohazards in greater London observed from geological and ERS-1/2 and ENVISAT persistent scatterers ground motion data: results from the EC FP7-SPACE PanGeo project. *Pure Appl. Geophys.* 172 (11), 2965–2995. doi:10.1007/s00024-014-0927-3

Cigna, F., and Tapete, D. (2020) "Mapping land subsidence in urban areas using Esa's G-POD and the P-SBAS Insar technique: examples in Asia, South America and North Africa," in *2020 mediterranean and middle-east geoscience and remote sensing symposium (M2GARSS)*. IEEE.

Coda, S., Tessitore, S., Di Martire, D., Calcaterra, D., De Vita, P., and Allocca, V. (2019). Coupled ground uplift and groundwater rebound in the metropolitan city of Naples (southern Italy). *J. Hydrology* 569, 470–482. doi:10.1016/j.jhydrol.2018.11.074

Colazas, X. C., and Strehle, R. W. (1995). "Chapter 6 subsidence in the wilmington oil field, long beach, California, USA," in *Developments in petroleum science* (Elsevier), 41, 285–335. doi:10.1016/s0376-7361(06)80053-1

Comerci, V., and Vittori, E. (2019). The need for a standardized methodology for quantitative assessment of natural and anthropogenic land subsidence: the Agosta (Italy) gas field case. *Remote Sens.* 11 (10), 1178. doi:10.3390/rs11101178

Confuorto, P., Medici, C., Bianchini, S., Del Soldato, M., Rosi, A., Segoni, S., et al. (2022). Machine learning for defining the probability of Sentinel-1 based deformation trend changes occurrence. *Remote Sens.* 14 (7), 1748. doi:10.3390/rs14071748

Coplin, L. S., and Galloway, D. (1999). *Houston-Galveston, Texas. Land subsidence in the United States*, 1182. US geological survey circular, 35–48.

Cormick, J. (2019). *Land subsidence detection and monitoring using InSAR in Australia*.

Costa, A. L., Kok, S., and Korff, M. (2020). Systematic assessment of damage to buildings due to groundwater lowering-induced subsidence: methodology for large scale application in The Netherlands. *Proc. Int. Assoc. Hydrological Sci.* 382, 577–582. doi:10.5194/piahs-382-577-2020

Cuenca, M. C., van Leijen, F. J., and Hanssen, R. F. (2010). "Shallow subsidence in th Dutch wetlands estimated by satellite radar interferometry," in *First international conference on Frontiers in shallow subsurface technology (pp. cp-150)* (European Association of Geoscientists & Engineers).

Cuervas-Mons, J., Zêzere, J. L., Domínguez-Cuesta, M. J., Barra, A., Reyes-Carmona, C., Monserrat, O., et al. (2022). Assessment of urban subsidence in the Lisbon metropolitan area (Central-West of Portugal) applying sentinel-1 SAR dataset and active deformation areas procedure. *Remote Sens.* 14 (16), 4084. doi:10.3390/rs14164084

Cuixia, L. I., and Wenbin, J. I. A. N. (2006). THE ENVIRONMENTAL AND GEOLOGICAL PROBLEM OF FUZHOU CITY DURING ITS CITY CONSTRUCTION. 工程地质学报 14 (S1), 223–227.

Dahm, T., Heimann, S., and Bialowons, W. (2011). A seismological study of shallow weak micro-earthquakes in the urban area of Hamburg city, Germany, and its possible relation to salt dissolution. *Nat. Hazards* 58, 1111–1134. doi:10.1007/s11069-011-9716-9

Dahm, T., Kühn, D., Ohrnberger, M., Kröger, J., Wiederhold, H., Reuther, C. D., et al. (2010). Combining geophysical data sets to study the dynamics of shallow evaporites in urban environments: application to Hamburg, Germany. *Geophys. J. Int.* 181 (1), 154–172. doi:10.1111/j.1365-246x.2010.04521.x

Da Lio, C., Teatini, P., Strozzi, T., and Tosi, L. (2018). Understanding land subsidence in salt marshes of the Venice Lagoon from SAR Interferometry and ground-based investigations. *Remote Sens. Environ.* 205, 56–70. doi:10.1016/j.rse.2017.11.016

Damoah-Afari, P., and Ding, X. L. (2005). "Measuring ground subsidence in Shanghai using permanent scatterer insar technique," in *The 26th asian conference on remote sensing (ACRS2005)*, 7–11.

Damoah-Afari, P., Ding, X. L., Li, Z., Lu, Z., and Omura, M. (2007). "Six years of land subsidence in Shanghai revealed by JERS-1 SAR data," in *2007 IEEE international geoscience and remote sensing symposium* (IEEE), 2093–2097.

Damoah-Afari, P., Ding, X. L., Lu, Z., Li, Z., and Omura, M. (2010). *Magnitude and extent of six years of land subsidence in Shanghai revealed by JERS-1 SAR China data*. InTech.

Darwish, N., Kaiser, M., Koch, M., and Gaber, A. (2021). Assessing the accuracy of ALOS/PALSAR-2 and sentinel-1 radar images in estimating the land subsidence of coastal areas: a case study in Alexandria city, Egypt. *Remote Sens.* 13 (9), 1838. doi:10.3390/rs13091838

Dassargues, A., and Zhang, J. (1992). Land subsidence in Shanghai: hydrogeological conditions and subsidence measurements. *Bull. Eng. Geol. Environ.* 46, 27–36. doi:10.1007/bf02595030

de Glopper, R. J., and Ritzema, H. P. (2023). *13 land subsidence*.

Del Greco, O., Garbarino, E., and Oggeri, C. (2004). *A multidisciplinary approach for the evaluation of the "Bottegone" subsidence (Grosseto, Italy)*. Berlin, Heidelberg: Engineering Geology for Infrastructure Planning in Europe: A European Perspective, 685–693.

Delinom, R. M., Assegaf, A., Aibidin, H. Z., Taniguchi, M., Suherman, D., Lubis, R. F., et al. (2009). The contribution of human activities to subsurface environment degradation in Greater Jakarta area, Indonesia. *Sci. total Environ.* 407 (2009), 3129–3141. doi:10.1016/j.scitotenv.2008.10.003

Del Soldato, M., Solari, L., Raspini, F., Bianchini, S., Ciampalini, A., Montalti, R., et al. (2019). Monitoring ground instabilities using SAR satellite data: a practical approach. *ISPRS Int. J. Geo-Information* 8 (7), 307. doi:10.3390/ijgi8070307

de Luna, R. M. R., dos Anjos Garnés, S. J., da Silva Pereira Cabral, J. J., and dos Santos, S. M. (2021). Suitability of GNSS for analysis of soil subsidence in Recife in a highly urbanized coastal area. *Nat. Hazards* 106, 1821–1837. doi:10.1007/s11069-021-04513-2

de Luna, R. M. R., Garnés, S. J. D. A., Cabral, J. J. D. S. P., and dos Santos, S. M. (2017). Groundwater overexploitation and soil subsidence monitoring on Recife plain (Brazil). *Nat. Hazards* 86, 1363–1376. doi:10.1007/s11069-017-2749-y

De Natale, G., Troise, C., and Somma, R. (2020). Invited perspectives: the volcanoes of Naples: how can the highest volcanic risk in the world be effectively mitigated? *Nat. Hazards Earth Syst. Sci.* 20, 2037–2053. doi:10.5194/nhess-20-2037-2020

Deros, S. N. M., Din, N. M., Norzeli, S. M., Omar, R. C., Usman, F., and Hamim, S. A. (2022). Land subsidence susceptibility projection for palembang slum area by complex MCDM-AHP technique. *J. Eng. Technol. Sci.* 54, 220104. doi:10.5614/j.eng.technol.sci.2022.54.1.4

Devanthéry, N., Crosetto, M., Monserrat, O., Cuevas-González, M., and Crippa, B. (2014). An approach to persistent scatterer interferometry. *Remote Sens.* 6 (7), 6662–6679. doi:10.3390/rs6076662

Dietrich, J. K., and Norman, M. R. (2003). Steam flooding intensifies subsidence at Wilmington field. *Oil gas J.* 101 (17), 41.

Di Lisa, M., Ali, H. E. A., Mazzanti, P., and Moretto, S. (2020). Inferring the creep settlement behavior of rockfill in reclaimed lands by advanced SAR interferometry and numerical modeling: an example from arabian gulf. *Remote Sens.* 12 (3), 527. doi:10.3390/rs12030527

Ding, X. L., Liu, G. X., Li, Z. W., Li, Z. L., and Chen, Y. Q. (2004). Ground subsidence monitoring in Hong Kong with satellite SAR interferometry. *Photogrammetric Eng. Remote Sens.* 70 (10), 1151–1156. doi:10.14358/pers.70.10.1151

Dixon, T. H., Amelung, F., Ferretti, A., Novali, F., Rocca, F., Dokka, R., et al. (2006). Space geodesy: subsidence and flooding in new orleans. *Nature* 441 (7093), 587–588. doi:10.1038/441587a

Djaja, R., Rais, J., Abidin, H. Z., and Wedyanto, K. (2004). "Land subsidence of Jakarta metropolitan area," in *Proceedings of the 3rd FIG regional conference for Asia and the pacific*, 3–7.

Dokka, R. K. (2011). The role of deep processes in late 20th century subsidence of New Orleans and coastal areas of southern Louisiana and Mississippi. *J. Geophys. Res. Solid Earth* 116, B06403. doi:10.1029/2010jb008008

Dong, S., Samsonov, S., Yin, H., Ye, S., and Cao, Y. (2014). Time-series analysis of subsidence associated with rapid urbanization in Shanghai, China measured with SBAS InSAR method. *Environ. earth Sci.* 72, 677–691. doi:10.1007/s12665-013-2990-y

Doornhof, D., Kristiansen, T. G., Nagel, N. B., Pattillo, P. D., and Sayers, C. (2006). Compaction and subsidence. *Oilfield Rev.* 18 (3), 50–68.

Du, J., Greiving, S., and Yap, D. L. T. (2022). Informal settlement resilience upgrading-approaches and applications from a cross-country perspective in three selected metropolitan regions of southeast Asia. *Sustainability* 14 (15), 8985. doi:10.3390/su14158985

Du, Y., Feng, G., Liu, L., Fu, H., Peng, X., and Wen, D. (2020). Understanding land subsidence along the coastal areas of Guangdong, China, by analyzing multi-track MTInSAR data. *Remote Sens.* 12 (2), 299. doi:10.3390/rs12020299

Duc, N. A. (1999). *Updating and analysis of Bangkok land subsidence caused by deep well pumping with emphasis on shallow soil settlement*. Asian Institute of Technology. Master Thesis.

Duffy, C. E., Braun, A., and Volker, H. (2020). Surface subsidence in urbanized coastal areas: PSI methods based on Sentinel-1 for Ho Chi Minh City. *Remote Sens.* 12 (24), 4130. doi:10.3390/rs12244130

DWASA, IWM (2008). *Final report, resource assessment study, part 2. Dhaka Water Supply and Sewerage Authority*. Dhaka.

Eggleston, J., and Pope, J. (2013). Land subsidence and relative sea-level rise in the southern Chesapeake Bay region. *U. S. Geol. Surv. Circ.* 1392, 30. doi:10.3133/cir1392

Elsaka, B., Radwan, A. M., and Rashwan, M. (2020). Evaluation of nile delta-mediterranean sea conjunction using GPS, satellite-based gravity and altimetry datasets. *J. Geoscience Environ. Prot.* 8 (2), 33–46. doi:10.4236/gep.2020.82003

Emery, K. O., and Aubrey, D. G. (2012). *Sea levels, land levels, and tide gauges*. Springer Science & Business Media.

Emilia-Romagna, A. R. (2007). "Rilievo della subsidenza nella pianura Emiliano-romagnola," in *Analisi interferometrica* (Regione Emilia-Romagna, ATO), 5.

Emmanuel, I. F., and Chidi, O. V. (2020). Characterisation and mapping of land subsidence based on geodetic techniques data in Lagos, Nigeria. *Geodesy Geodyn.* doi:10.1016/j.geog.2019.12.006

Emmanuel, I. F., Chidi, O. V., and Babatunde, O. O. (2020). Geostatistical evaluation of spatial variability of land subsidence rates in Lagos, Nigeria. *Geodesy Geodyn.* 11, 316–327. doi:10.1016/j.geog.2020.04.001

Endo, T. (2011). Sinking cities and governmental action: institutional responses to land subsidence in Osaka and Bangkok. Groundwater and Subsurface Environments. *Hum. Impacts Asian Coast. Cities*, 271–288. doi:10.1007/978-4-431-53904-9_14

Engelkemeir, R., Khan, S. D., and Burke, K. (2010). Surface deformation in Houston, Texas using GPS. *Tectonophysics* 490 (1-2), 47–54. doi:10.1016/j.tecto.2010.04.016

Erban, L. E., Gorelick, S. M., and Zebker, H. A. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environ. Res. Lett.* 9 (8), 084010. doi:10.1088/1748-9326/9/8/084010

Erban, L. E., Gorelick, S. M., Zebker, H. A., and Fendorf, S. (2013). Release of arsenic to deep groundwater in the Mekong Delta, Vietnam, linked to pumping-induced land subsidence. *Proc. Natl. Acad. Sci.* 110 (34), 13751–13756. doi:10.1073/pnas.1300503110

Erkens, G., Bucx, T., Dam, R., De Lange, G., and Lambert, J. (2015). Sinking coastal cities. *Proc. Int. Assoc. Hydrological Sci.* 372 (372), 189–198. doi:10.5194/piahs-372-189-2015

Erkens, G., and Stouthamer, E. (2020). The 6M approach to land subsidence. *Proc. Int. Assoc. Hydrological Sci.* 382, 733–740. doi:10.5194/piahs-382-733-2020

Esaki, T., Makino, R., Djamaruddin, I., and Ikemi, H. (2010). Environmental geotechnology to cope with subsidence and sinkhole problem -some experiences in old mining districts-. *J. Jpn. Soc. Eng. Geol.* 50 (6), 319e328. (in Japanese with English abstract).

Espiritu, K. W., Reyes, C. J., Benitez, T. M., Tokita, R. C., Galvez, L. J., and Ramirez, R. (2022). Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR) reveals continued ground deformation in and around Metro Manila, Philippines, associated with groundwater exploitation. *Nat. Hazards* 114, 3139–3161. doi:10.1007/s11069-022-05509-2

Esteban, M., Takagi, H., Jamero, L., Chadwick, C., Avelino, J. E., Mikami, T., et al. (2020). Adaptation to sea level rise: learning from present examples of land subsidence. *Ocean Coast. Manag.* 189, 104852. doi:10.1016/j.ocecoaman.2019.104852

Euillades, P. A., Euillades, L. E., Rosell, P, and Roa, Y. (2020). "Subsidence in maceio, Brazil, characterized by dinsar and inverse modeling," in *2020 IEEE Latin American GRSS & ISPRS remote sensing conference (LAGIRS)* (IEEE), 313–317.

Fabris, M., Achilli, V., Borgstrom, S., Floris, M., Fiaschi, S., and Siniscalchi, V. (2014). *Valutazione della subsidenza nell'area di Ravenna tramite un approccio integrato InSAR/livellazione classica*.

Fabris, M., Cenni, N., and Fiaschi, S. (2021). Editorial for special issue "monitoring land subsidence using remote sensing". *Remote Sens.* 13 (9), 1771. doi:10.3390/rs13091771

Fadhillah, M. F., Achmad, A. R., and Lee, C. W. (2020). Integration of InSAR time-series data and GIS to assess land subsidence along subway lines in the Seoul metropolitan area, South Korea. *Remote Sens.* 12 (21), 3505. doi:10.3390/rs12213505

Famiglietti, J. S. (2014). The global groundwater crisis. *Nat. Clim. Change* 4 (11), 945–948. doi:10.1038/nclimate2425

Fang, J., Nicholls, R. J., Brown, S., Lincke, D., Hinkel, J., Vafeidis, A. T., et al. (2022). Benefits of subsidence control for coastal flooding in China. *Nat. Commun.* 13 (1), 6946. doi:10.1038/s41467-022-34525-w

Farolfi, G., Del Soldato, M., Bianchini, S., and Casagli, N. (2019). A procedure to use GNSS data to calibrate satellite PSI data for the study of subsidence: an example from the north-western Adriatic coast (Italy). *Eur. J. Remote Sens.* 52 (Suppl. 4), 54–63. doi:10.1080/22797254.2019.1663710

Featherstone, W., Filmer, M., Penna, N., Morgan, L., and Schenk, A. (2012). Anthropogenic land subsidence in the Perth Basin: challenges for its retrospective geodetic detection. *J. R. Soc. West. Aust.* 95 (1), 53–62.

Featherstone, W. E., Penna, N. T., Filmer, M. S., and Williams, S. D. P. (2015). Nonlinear subsidence at Fremantle, a long-recording tide gauge in the Southern Hemisphere. *J. Geophys. Res. Oceans* 120 (10), 7004–7014. doi:10.1002/2015jc011295

Feldkamp, D. (2022). *The effects of foundation quality on residential housing value; a case study of the municipality of Rotterdam (Doctoral dissertation)*.

Fiaschi, S., and Wdowinski, S. (2015b). *The contribution of land subsidence to the increasing coastal flooding hazard in Miami Beach*. University of Padua.

Fiaschi, S., Di Martire, D., Tessitore, S., Achilli, V., Ahmed, A., Borgstrom, S., et al. (2015a). Monitoring of land subsidence in Ravenna Municipality using two different DInSAR techniques: comparison and discussion of the results. *Ecology* 23 (1), 38–50.

Fiaschi, S., Tessitore, S., Bonì, R., Di Martire, D., Achilli, V., Borgstrom, S., et al. (2017). From ERS-1/2 to Sentinel-1: two decades of subsidence monitored through A-DInSAR techniques in the Ravenna area (Italy). *GIScience Remote Sens.* 54 (3), 305–328. doi:10.1080/15481603.2016.1269404

Fiaschi, S., and Wdowinski, S. (2020). Local land subsidence in Miami Beach (FL) and Norfolk (VA) and its contribution to flooding hazard in coastal communities along the US Atlantic coast. *Ocean Coast. Manag.* 187, 105078. doi:10.1016/j.ocecoaman.2019.105078

Fonseca, J. F., Palano, M., Falcão, A. P., Hrysiewicz, A., and Fernandez, J. (2021). Interseismic strain accumulation near Lisbon (Portugal) from space geodesy. *Geophys. Res. Lett.* 48 (24), e2021GL096862. doi:10.1029/2021gl096862

Fornasiero, A. N. N. A., Putti, M. A. R. I. O., Teatini, P. I. E. T. R. O., Ferraris, S. T. E. F. A. N. O., Rizzetto, F., and Tosi, L. (2003). *Monitoring of hydrological parameters related to peat oxidation in a subsiding coastal basin south of Venice*, 278. Italy: International Association of Hydrological Sciences, Publication, 458–462.

Foster, S., Hirata, R., Eichholz, M., and Alam, M. F. (2022). Urban self-supply from groundwater—an analysis of management aspects and policy needs. *Water* 14, 575. doi:10.3390/w14040575

Frihy, O. E. (2003). The Nile delta-Alexandria coast: vulnerability to sea-level rise, consequences and adaptation. *Mitig. Adapt. Strategies Glob. Change* 8 (2), 115–138. doi:10.1023/a:1026015824714

Frihy, O. E. S., Deabes, E. A., Shereet, S. M., and Abdalla, F. A. (2010). Alexandria-Nile Delta coast, Egypt: update and future projection of relative sea-level rise. *Environ. Earth Sci.* 61 (2), 253–273. doi:10.1007/s12665-009-0340-x

Fuangswasdi, A., Worakijthamrong, S., and Shah, S. D. (2019). "Addressing subsidence in bangkok, Thailand and Houston, Texas: scientific comparisons and data-driven groundwater policies for coastal land-surface subsidence," in *IAEG/AEG annual meeting proceedings, San Francisco, California, 2018-volume 5: geologic hazards: earthquakes, land subsidence, coastal hazards, and emergency response* (Springer International Publishing), 51–60.

Gabrysch, R. K., and Bonnet, C. W. (1975). *Land-surface subsidence in the Houston-Galveston region, Texas*, 74. Austin, Texas: Texas Water Development Board.

Galloway, D. L., and Burbey, T. J. (2011). Revisão: Subsidência regional associada à extracção de água subterrânea. *Hydrogeol. J.* 19, 1459–1486. doi:10.1007/s10040-011-0775-5

Galloway, D. L., Coplin, L. S., and Ingebritsen, S. E. (2003). "Effects of land subsidence in the greater Houston area," in *Managing urban water supply*, 187–203.

Galloway, D. L., Jones, D. R., and Ingebritsen, S. E. (1999). *Land subsidence in the United States* (Reston, Virginia: US Geological Survey), 1182.

Gambolati, G., Giunta, G., Putti, M., Teatini, P., Tomasi, L., Betti, I., et al. (1998) "Coastal evolution of the Upper Adriatic Sea due to sea level rise and natural and anthropic land subsidence," in *CENAS: coastline evolution of the upper adriatic sea due to sea level rise and natural and anthropogenic land subsidence*, 1–34.

Gambolati, G., Putti, M., and Teatini, P. (1996). Land subsidence. *Hydrology Disasters*, 231–268. doi:10.1007/978-94-015-8680-1_9

Gambolati, G., Putti, M., Teatini, P., Camporese, M., Ferraris, S., Stori, G. G., et al. (2005). Peat land oxidation enhances subsidence in the Venice watershed. *Eos, Trans. Am. Geophys. Union* 86 (23), 217–220. doi:10.1029/2005eo230001

Gambolati, G., Putti, M., Teatini, P., and Gasparetto Stori, G. (2006a). Subsidence due to peat oxidation and impact on drainage infrastructures in a farmland catchment south of the Venice Lagoon. *Environ. Geol.* 49, 814–820. doi:10.1007/s00254-006-0176-6

Gambolati, G., Ricceri, G., Bertoni, W., Brighenti, G., and Vuillermin, E. (1991). Mathematical simulation of the subsidence of Ravenna. *Water Resour. Res.* 27, 2899–2918. doi:10.1029/91wr01567

Gambolati, G., Teatini, P., and Ferronato, M. (2006b). "Anthropogenic land subsidence," in *Encyclopedia of hydrological sciences*.

Gambolati, G., Teatini, P., Tomasi, L., and Gonella, M. (1999). Coastline regression of the Romagna region, Italy, due to natural and anthropogenic land subsidence and sea level rise. *Water Resour. Res.* 35 (1), 163–184. doi:10.1029/1998wr900031

Gambolati, G. I. U. S. E. P. P. E., Putti, M. A. R. I. O., Teatini, P., and Stori, G. G. (2003). Subsidence due to peat oxidation and its impact on drainage infrastructures in a farmland catchment south of the Venice Lagoon. *Mater. Geoenvironment* 50, 125–128.

Gao, Q., Crosetto, M., Monserrat, O., Palama, R., and Barra, A. (2022). Infrastructure monitoring using the interferometric synthetic aperture radar (InSAR) technique. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 43, 271–276. doi:10.5194/isprs-archives-xliii-b3-2022-271-2022

Ge, L., Chang, H. C., Rizos, C., and Omura, M. (2005). "Mine subsidence monitoring: a comparison among ENVISAT, ERS and JERS-1," in *Envisat & ERS symposium*, 572.

Ge, L., Cheng, E., Li, X., and Rizos, C. (2003). "Quantitative subsidence monitoring: the integrated InSAR, GPS and GIS approach," in *The 6th international symposium on satellite navigation technology including mobil positioning & location services*, 87.

Geertsma, J. (1973). Land subsidence above compacting oil and gas reservoirs. *J. petroleum Technol.* 25 (06), 734–744. doi:10.2118/3730-pa

Giang, N. N. H., Quang, C. N. X., Long, D. T., Ky, P. D., Vu, N. D., and Tran, D. D. (2022). Statistical and hydrological evaluations of water dynamics in the lower sai gon-dong nai river, vietnam. *Water* 14 (1), 130. doi:10.3390/w14010130

Giao, P. H. (1997). Artificial recharge of the Bangkok aquifer system for the mitigation of land subsidence. *D. Eng. Diss.*, 2–96.

Gilluly, J., and Grant, U. S. (1949). Subsidence in the long beach harbor area. California. *Geolo. Soc. Am. Bull.*60 (3), , 461–530.

Gómez, J. F., Kwoll, E., Walker, I. J., and Shirzaei, M. (2021). Vertical land motion as a driver of coastline changes on a deltaic system in the Colombian Caribbean. *Geosciences* 11 (7), 300. doi:10.3390/geosciences11070300

Gonella, M., Gambolati, G., Giunta, G., Putti, M., and Teatini, P. (1998). "Prediction of land subsidence due to groundwater withdrawal along the Emilia-Romagna coast," in *CENAS: coastline evolution of the upper adriatic sea due to sea level rise and natural and anthropogenic land subsidence*, 151–168.

Gong, H., Pan, Y., Zheng, L., Li, X., Zhu, L., Zhang, C., et al. (2018). Long-term groundwater storage changes and land subsidence development in the North China Plain (1971–2015). *Hydrogeology J.* 26 (5), 1417–1427. doi:10.1007/s10040-018-1768-4

Gornitz, V., Couch, S., and Hartig, E. K. (2001). Impacts of sea level rise in the New York City metropolitan area. *Glob. Planet. Change* 32 (1), 61–88. doi:10.1016/s0921-8181(01)00150-3

Grgić, M., Bender, J., and Bašić, T. (2020). Estimating vertical land motion from remote sensing and *in-situ* observations in the Dubrovnik area (Croatia): a multi-method case study. *Remote Sens.* 12 (21), 3543. doi:10.3390/rs12213543

Grube, F. (1973). "Ingenieurgeologische Erkundung der Erdfälle im Bereich des Salzstocks Othmarschen-Langenfelde (Hamburg)," in *Symposium, sink-holes and subsidence: engineeringgeological problems related to soluble rocks= effondrements et affaissements: problemes de geologie de l'ingenieur relatifs aux roches solubles: proceedings, Hannover*, 1–7.

Guerrera, F., Martín-Martín, M., Tramontana, M., Nimon, B., and Essotina Kpémoua, K. (2021). Shoreline changes and coastal erosion: the case study of the coast of Togo (bight of Benin, west africa margin). *Geosciences* 11 (2), 40. doi:10.3390/geosciences11020040

Hakim, W. L., Achmad, A. R., Eom, J., and Lee, C. W. (2020). Land subsidence measurement of Jakarta coastal area using time series interferometry with Sentinel-1 SAR data. *J. Coast. Res.* 102 (SI), 75–81. doi:10.2112/si102-010.1

Halicioglu, K., Erten, E., and Rossi, C. (2021). Monitoring deformations of Istanbul metro line stations through Sentinel-1 and levelling observations. *Environ. Earth Sci.* 80 (9), 1–10. doi:10.1007/s12665-021-09644-0

Hallegatte, S., Green, C., Nicholls, R. J., and Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. *Nat. Clim. change* 3 (9), 802–806. doi:10.1038/nclimate1979

Hamdani, R. S., Hadi, S. P., and Rudiarto, I. (2021). Progress or regress? A systematic review on two decades of monitoring and addressing land subsidence hazards in semarang city. *Sustainability* 13 (24), 13755. doi:10.3390/su132413755

Hamim, S. A., and Usman, F. (2019). "Determination of land subsidence caused by land-use changing in palembang city using remote sensing data," in *Third international conference on sustainable innovation 2019–technology and engineering (IcoSITE 2019)* (Atlantis Press), 101–106.

Hamling, I. J., Wright, T. J., Hreinsdóttir, S., and Wallace, L. M. (2022). A snapshot of New Zealand's dynamic deformation field from Envisat InSAR and GNSS observations between 2003 and 2011. *Geophys. Res. Lett.* 49 (2), e2021GL096465. doi:10.1029/2021gl096465

Haque, D. M. E., Hayat, T., and Tasnim, S. (2019). Time series analysis of subsidence in Dhaka City, Bangladesh using Insar. *Malays. J. Geosciences* 3 (1), 32–44. doi:10.26480/mjg.01.2019.32.44

Haque, S. J., Onodera, S. I., and Shimizu, Y. (2013). An overview of the effects of urbanization on the quantity and quality of groundwater in South Asian megacities. *Limnology* 14, 135–145. doi:10.1007/s10201-012-0392-6

Harris, F. R., and Harlow, E. H. (1948). "Subsidence of the terminal island-long beach area," in *Transactions of the American society of civil engineers*, 113, 375–396.

Hartmann, J., and Moosdorf, N. (2012). *Global Lithological Map Database v1.0 (gridded to 0.5° spatial resolution)*. PANGAEA. doi:10.1594/PANGAEA.788537

Hashimoto, R., Kazama, S., Hashimoto, T., Oguma, K., and Takizawa, S. (2022). Planning methods for conjunctive use of urban water resources based on quantitative water demand estimation models and groundwater regulation index in Yangon City, Myanmar. *J. Clean. Prod.* 367, 133123. doi:10.1016/j.jclepro.2022.133123

Hawkes, A. D., Horton, B. P., Nelson, A. R., Vane, C. H., and Sawai, Y. (2011). Coastal subsidence in Oregon, USA, during the giant Cascadia earthquake of AD 1700. *Quat. Sci. Rev.* 30 (3-4), 364–376. doi:10.1016/j.quascirev.2010.11.017

Hayati, N., Widodo, A., Kurniawan, A., Sanjiwani, I. D. M. A., Darminto, M. R., Yudha, I. S., et al. (2022). Small baselines techniques of time series InSAR to monitor and predict land subsidence causing flood vulnerability in Sidoarjo, Indonesia. *Geomatics, Nat. Hazards Risk* 13 (1), 2124–2150. doi:10.1080/19475705.2022.2109518

He, X. C., Yang, T. L., Shen, S. L., Xu, Y. S., and Arulrajah, A. (2019). Land subsidence control zone and policy for the environmental protection of Shanghai. *Int. J. Environ. Res. public health* 16 (15), 2729. doi:10.3390/ijerph16152729

Heleno, S., Henriques, M. J., Falcao, A. P., Lima, N., Fonseca, A. M., Mancuso, M., et al. (2010). "Measuring subsidence in the center of Lisbon with persistent scatters interferometry (PSI), CGPS and levelling surveys," in *ESA living planet symposium*, 686.

Heleno, S. I., Oliveira, L. G., Henriques, M. J., Falcão, A. P., Lima, J. N., Cooksley, G., et al. (2011). Persistent scatterers interferometry detects and measures ground subsidence in Lisbon. *Remote Sens. Environ.* 115 (8), 2152–2167. doi:10.1016/j.rse.2011.04.021

Hendarto, H., and Standing, J. (2019). "Influence of groundwater extraction on land subsidence in Jakarta," in *Proceedings of the XVII European conference on soil mechanics and geotechnical engineering, ECSMGE*, 1–8.

Hengxing, L. A. N., Yunshan, M. E. N. G., and Yixing, Z. H. A. N. G. (2019). Spatiotemporal evolution analysis of land subsidence in Fuzhou city under the influence of complex factors. 工程地质学报 27 (6), 1350–1361. doi:10.13544/j.cnki.jeg.2018-268

Henriques, M. J., Lima, J. N., Falcao, A. P., Mancuso, M., Heleno, S., and Falcao, A. P. (2011). "Land subsidence in Lisbon area: validation of PsinSAR results," in *Proc. Of FIG working week*.

Herrera-García, G., Ezquerro, P., Tomás, R., Béjar-Pizarro, M., López-Vinielles, J., Rossi, M., et al. (2021). Mapping the global threat of land subsidence. *Science* 371 (6524), 34–36. doi:10.1126/science.abb8549

Higa, T. L. (2001). *Subsidence in Long Beach, California: the decisionmaking process in determining mitigation policy and disbursement of oil revenues*. Fullerton: California State University.

Higgins, S. A. (2016). Review: advances in delta-subsidence research using satellite methods. *Hydrogeology J.* 24 (3), 587–600. doi:10.1007/s10040-015-1330-6

Higgins, S. A., Overeem, I., Steckler, M. S., Syvitski, J. P., Seeber, L., and Akhter, S. H. (2014). InSAR measurements of compaction and subsidence in the Ganges-Brahmaputra Delta, Bangladesh. *J. Geophys. Res. Earth Surf.* 119 (8), 1768–1781. doi:10.1002/2014jf003117

Hilmi, E., and Christianto, D. (2022). The potential of high tidal flooding disaster in North Jakarta using mapping and mangrove relationship approach. In *IOP Conf. Ser. Earth Environ. Sci.* 989 (1), 012001. doi:10.1088/1755-1315/989/1/012001

Hirose, K., Maruyama, Y., Murdohardono, D., Effendi, A., and Abidin, H. Z. (2001). Land subsidence detection using JERS-1 SAR Interferometry. *J. Surv. Geod.* XI (3), 9–14.

Hishammuddin, M. A. H., and Wang, J. X. (2021). Towards sustainable, resilient and adaptive urban underground space (uus) exploration, land subsidence and economic impact spatial model (USEM) in shanghai, PR China: systematic reviews, model framework, initial results and pre-determined challenges. *IOP Conf. Ser. Earth Environ. Sci.* 861 (7), 072033. doi:10.1088/1755-1315/861/7/072033

Ho, L. P. (2008). "Impacts of climate changes and urbanisation on urban inundation in Ho Chi Minh City," in *11th international conference on urban drainage* (Edinburgh, Scotland, UK).

Holzer, T. L. (1981). Preconsolidation stress of aquifer systems in areas of induced land subsidence. *Water Resour. Res.* 17 (3), 693–703. doi:10.1029/wr017i003p00693

Holzer, T. L. (1989). State and local response to damaging land subsidence in United States urban areas. *Eng. Geol.* 27 (1-4), 449–466. doi:10.1016/0013-7952(89)90041-0

Holzer, T. L. (1990). *Land subsidence caused by withdrawal of oil and gas in the Gulf Coastal Plain–the Houston, Texas, case history*.

Holzer, T. L., and Bluntzer, R. L. (1984). Land subsidence near oil and gas fields, Houston, Texas a. *Groundwater* 22 (4), 450–459. doi:10.1111/j.1745-6584.1984.tb01416.x

Holzer, T. L., and Galloway, D. L. (2005). *Impacts of land subsidence caused by withdrawal of underground fluids in the United States*.

Holzer, T. L., and Johnson, A. I. (1985). Land subsidence caused by ground water withdrawal in urban areas. *GeoJournal* 11, 245–255. doi:10.1007/bf00186338

Hong, S. H., Ju, J. H., Park, S. W., and Cigna, F. (2022). "Multi-frequency synthetic aperture radar observations to explore ground subsidence," in *IGARSS 2022-2022 IEEE international geoscience and remote sensing symposium* (IEEE), 4931–4934.

Hoogeveen, R., and Van Leeuwen, B. (1996). The large scale development of land subsidence in northwest Jakarta and north Tangerang, Indonesia. *Int. J. Rock Mech. Min. Sci. Geomechanics Abstr.* 7 (33), 298A.

Horman, J. (2020). Phenomenon of sinking jakarta from groundwater usage and other drivers that affect its implication geographically, social, economically, and its environment. *J. Jakarta Groundw. Issue*, 7810700.

Hou, A. Y., Qiao, X., and Li, D. (2016). Ground deformation monitoring in qingdao coastal areas by time-series terrasar-X images. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 7, 29–33. doi:10.5194/isprsarchives-xli-b7-29-2016

Hu, B., Chen, J., and Zhang, X. (2019a). Monitoring the land subsidence area in a coastal urban area with InSAR and GNSS. *Sensors* 19 (14), 3181. doi:10.3390/s19143181

Hu, B., Chen, X., and Zhang, X. (2019b). Using multisensor SAR datasets to monitor land subsidence in Los Angeles from 2003 to 2017. *J. Sensors* 2019, 1–15. doi:10.1155/2019/9389820

Hu, B., Yang, B., Zhang, X., Chen, X., and Wu, Y. (2019c). Time-series displacement of land subsidence in Fuzhou downtown, monitored by SBAS-InSAR technique. *J. Sensors* 2019, 1–12. doi:10.1155/2019/3162652

Hu, B., Zhang, J., Na, J., Liu, D., and Xie, G. (2022). Temporal principal component analysis and synthetic aperture radar interference analysis of the spatial and temporal evolution of ground subsidence in the Los Angeles area. *J. Appl. Remote Sens.* 16 (4), 044504. doi:10.1117/1.jrs.16.044504

Hu, B., Zhou, J., Wang, J., Chen, Z., Wang, D., and Xu, S. (2009). Risk assessment of land subsidence at Tianjin coastal area in China. *Environ. Earth Sci.* 59, 269–276. doi:10.1007/s12665-009-0024-6

Hu, R., Wang, S., Lee, C., and Li, M. (2002). Characteristics and trends of land subsidence in Tanggu, Tianjin, China. *Bull. Eng. Geol. Environ.* 61, 213–225. doi:10.1007/s100640100132

Hu, R. L., Yue, Z. Q., Wang, L. U., and Wang, S. J. (2004). Review on current status and challenging issues of land subsidence in China. *Eng. Geol.* 76 (1-2), 65–77. doi:10.1016/j.enggeo.2004.06.006

Huang, H., Xue, D., Zhuo, G., Yu, X., Qiao, J., and Yang, L. (2019). "Monitoring land subsidence in Fuzhou City (China) using the SBAS-InSAR method with Sentinel-1 imagery data," in *2019 6th asia-pacific conference on synthetic aperture radar (APSAR)* (IEEE), 1–5.

Huang, J. M., Guo, Y., Hu, R. Q., and Zhou, Z. Y. (2013). Analysis of land subsidence in jinshazhou area, Guangzhou city. *Chin. J. Geol. Hazard Control* 24 (2), 61–67.

Huang, Y., and Jiang, X. (2010). Field-observed phenomena of seismic liquefaction and subsidence during the 2008 Wenchuan earthquake in China. *Nat. Hazards* 54, 839–850. doi:10.1007/s11069-010-9509-6

Hussain, M. A., Chen, Z., Shoaib, M., Shah, S. U., Khan, J., and Ying, Z. (2022). Sentinel-1A for monitoring land subsidence of coastal city of Pakistan using Persistent Scatterers In-SAR technique. *Sci. Rep.* 12 (1), 5294. doi:10.1038/s41598-022-09359-7

Hutabarat, L. E., and Ilyas, T. (2017). Mapping of land subsidence induced by groundwater extraction in urban areas as basic data for sustainability countermeasures. *Int. J. Technol.* 8 (6), 1001–1011. doi:10.14716/ijtech.v8i6.754

Hutabarat, L. E., Sinaga, H. R. M., Ilyas, T., and Prakoso, W. A. (2019). Land subsidence induced by the rate of consolidation of marine clay in kamal muara northern jakarta. *IOP Conf. Ser. Earth Environ. Sci.* 258 (1), 012019. doi:10.1088/1755-1315/258/1/012019

Hwang, C., Yang, Y., Kao, R., Han, J., Shum, C. K., Galloway, D. L., et al. (2016). Time-varying land subsidence detected by radar altimetry: California, Taiwan and north China. *Sci. Rep.* 6, 28160. doi:10.1038/srep28160

Hwang, R. N., and Moh, Z. C. (2020). *Back analyses of historical ground subsidence induced by the lowering of groundwater table*.

Ikemi, H. (2017). Geologically constrained changes to landforms caused by human activities in the 20th century: a case study from Fukuoka Prefecture, Japan. *Appl. Geogr.* 87, 115–126. doi:10.1016/j.apgeog.2017.08.001

Ikuemonisan, F. E., and Ozebo, V. C. (2020). Characterisation and mapping of land subsidence based on geodetic observations in Lagos, Nigeria. *Geodesy Geodyn.* 11 (2), 151–162. doi:10.1016/j.geog.2019.12.006

Ikuemonisan, F. E., Ozebo, V. C., and Olatinsu, O. B. (2020). Geostatistical evaluation of spatial variability of land subsidence rates in Lagos, Nigeria. *Geodesy Geodyn.* 11 (5), 316–327. doi:10.1016/j.geog.2020.04.001

Ikuemonisan, F. E., Ozebo, V. C., and Olatinsu, O. B. (2021a). Investigating and modelling ground settlement response to groundwater dynamic variation in parts of Lagos using space-based retrievals. *Solid Earth Sci.* 6 (2), 95–110. doi:10.1016/j.sesci.2021.03.001

Ikuemonisan, F. E., Ozebo, V. C., and Olatinsu, O. B. (2021b). Investigation of Sentinel-1-derived land subsidence using wavelet tools and triple exponential smoothing algorithm in Lagos, Nigeria. *Environ. Earth Sci.* 80, 1–17. doi:10.1007/s12665-021-10020-1

Ingebritsen, S. E., and Galloway, D. L. (2014). Coastal subsidence and relative sea level rise. *Environ. Res. Lett.* 9 (9), 091002. doi:10.1088/1748-9326/9/9/091002

Ingebritsen, S. E., and Jones, D. R. (1999). Santa clara valley, California." land subsidence in the United States. *U. S. Geol. Surv. Circ.* 1182, 15–22.

Intui, S., Inazumi, S., and Soralump, S. (2022a). Evaluation of land subsidence during groundwater recovery. *Appl. Sci.* 12 (15), 7904. doi:10.3390/app12157904

Intui, S., Inazumi, S., and Soralump, S. (2022b). Sustainability of soil/ground environment under changes in groundwater level in bangkok plain, Thailand. *Sustainability* 14 (17), 10908. doi:10.3390/su141710908

Irawan, D. S., Nursetyowati, P., Nova, M. C., and Maulina, S. (2022). System dynamic simulation to determine the effect of water consumption on land subsidence during covid-19 pandemic in jakarta. *IOP Conf. Ser. Earth Environ. Sci.* 1065 (1), 012016. doi:10.1088/1755-1315/1065/1/012016

Ishii, M., Kuramochi, F., and Endo, T. (1970). "Recent tendencies of the land subsidence in Tokyo," in *Proceedings of the anaheim symposium*.

Ismail, S., Mansor, S., Rodsi, A., and Bujang, B. K. (2011). Geotechnical modeling of fractures and cavities that are associated with geotechnical engineering problems in Kuala Lumpur limestone, Malaysia. *Environ. Earth Sci.* 62, 61–68. doi:10.1007/s12665-010-0497-3

Jacobi, D., and Syme, B. (2005). Port Adelaide seawater stormwater flooding study. *City Port Adel. Enfield* 1.

Jago-on, K. A. B., Kaneko, S., Fujikura, R., Fujiwara, A., Imai, T., Matsumoto, T., et al. (2009). Urbanization and subsurface environmental issues: an attempt at DPSIR model application in Asian cities. *Sci. total Environ.* 407 (9), 3089–3104. doi:10.1016/j.scitotenv.2008.08.004

Jakobsen, P. R., Wegmuller, U., Capes, R., and Pedersen, S. A. S. (2013). Terrain subsidence detected by satellite radar scanning of the Copenhagen area, Denmark, and its relation to the tectonic framework. *Geol. Surv. Den. Greenl* 28, 25–28. doi:10.34194/geusb.v28.4713

Jensen, J. R. (2009). *Remote sensing of the environment: An earth resource perspective 2/e*. New Delhi: Pearson Education India.

Jeon, W., and Yi, J. (2021). Observation of ground subsidence in bangkok, Thailand using PSInSAR technique. *Korean J. Remote Sens.* 37 (6_1), 1625–1630. doi:10.7780/KJRS.2021.37.6.1.11

Jiacheng, X. I. O. N. G., Yunju, N. I. E., Yue, L. U. O., and Yongfei, L. I. (2019). Monitoring urban land subsidence by dual-polarization Sentinel-1 data: a case study of Shanghai. *Bull. Surv. Mapp.* 11, 98. doi:10.13474/j.cnki.11-2246.2019.0360

Jiang, Y., Liao, M., Wang, H., Zhang, L., and Balz, T. (2016). Deformation monitoring and analysis of the geological environment of Pudong international airport with persistent scatterer SAR interferometry. *Remote Sens.* 8 (12), 1021. doi:10.3390/rs8121021

Jian-Zhong, W. U., Han-Mei, W. A. N. G., and Tian-Liang, Y. A. N. G. (2009). Recharge to shallow aquifer to control land subsidence due to construction in Shanghai city. *Geoscience* 23 (6), 1194.

Jing, L. (2007). Environmental and geological problems caused by over-exploitation of groundwater and its prevention of Guangdong Province. *Chin. J. Geol. Hazard Control* 18 (1), 64–67.

Jo, M.-J., Won, J.-S., and Kim, S.-W. (2011). "A time-series observation of ground subsidence at Ulsan area using SAR interferometry," in *2011 3rd international asia-pacific conference on synthetic aperture radar (APSAR)* (IEEE).

John, B., and Das, S. (2020). Identification of risk zone area of declining piezometric level in the urbanized regions around the City of Kolkata based on ground investigation and GIS techniques. *Groundw. Sustain. Dev.* 11, 100354. doi:10.1016/j.gsd.2020.100354

Jones, C. E., An, K., Blom, R. G., Kent, J. D., Ivins, E. R., and Bekaert, D. (2016). Anthropogenic and geologic influences on subsidence in the vicinity of New Orleans, Louisiana. *J. Geophys. Res. Solid Earth* 121 (5), 3867–3887. doi:10.1002/2015jb012636

Jones, L. L., and Warren, J. P. (1976). Land subsidence costs in the Houston-Baytown area of Texas. *Journal-American Water Works Assoc.* 68 (11), 597–599. doi:10.1002/j.1551-8833.1976.tb02501.x

Junior, J. R. T., Candeias, A. L. B., and Jaime, J. da S. P. C. (2020). *DINSAR technical proposal for study of soil subsidence the neighborhood of Boa viagem, recife-PE, Brazil*.

Kaitantzian, A., Loupasakis, C., Tzampoglou, P., and Parcharidis, I. (2020). Ground subsidence triggered by the overexploitation of aquifers affecting urban sites: the case of Athens coastal zone along faliro bay (Greece). *Geofluids* 2020, 1–18. doi:10.1155/2020/8896907

Kanwal, S. (2022). *Study of ground displacements, erosion and sea level rise along Karachi coast*. Karachi.

Kanwal, S., Ding, X., Wu, S., and Sajjad, M. (2022). Vertical ground displacements and its impact on erosion along the Karachi coastline, Pakistan. *Remote Sens.* 14 (9), 2054. doi:10.3390/rs14092054

Kanwal, S., Ding, X., and Zhang, L. (2018). "Measurement of vertical deformation in Karachi using multi-temporal insar," in *IGARSS 2018-2018 IEEE international geoscience and remote sensing symposium* (IEEE), 1395–1398.

Karila, K., Karjalainen, M., and Hyyppä, J. (2005). Urban land subsidence studies in Finland using synthetic aperture radar images and coherent targets. *Photogramm. J. Finl.* 19, 43–53.

Kearns, T. J. (2018). *GPS monitoring and land subsidence in the Houston metropolitan area (doctoral dissertation)*.

Kearns, T. J., Wang, G., Bao, Y., Jiang, J., and Lee, D. (2015). Current land subsidence and groundwater level changes in the Houston Metropolitan Area (2005–2012). *J. Surv. Eng.* 141 (4), 05015002. doi:10.1061/(asce)su.1943-5428.0000147

Kearns, T. J., Wang, G., Turco, M., Welch, J., Tsibanos, V., and Liu, H. (2019). Houston16: a st4geodetic reference frame for subsidence and faulting study in the Houston metropolitan area, Texas, US. *Geodesy Geodyn.* 10 (5), 382–393. doi:10.1016/j.geog.2018.05.005

Kebede, A. S., and Nicholls, R. J. (2012). Exposure and vulnerability to climate extremes: population and asset exposure to coastal flooding in Dar es Salaam, Tanzania. *Reg. Environ. Change* 12, 81–94. doi:10.1007/s10113-011-0239-4

Kelsey, J., and Gray, D. A. (1972). Geodetic aspects concerning possible subsidence in southeastern England. *Philosophical Trans. R. Soc. Lond. Ser. A, Math. Phys. Sci.* 272 (1221), 141–149. doi:10.1098/rsta.1972.0040

Kenfack, J. A. A., Gwet, H., Wirngo, H. M., Tchawa, P., and Tagne Tiegam, R. F. (2024). *Detection of underground water cavities in urban areas by electrical resistivity tomography*. Available at SSRN 4081815.

Kersten, T., Kobe, M., Gabriel, G., Timmen, L., Schön, S., and Vogel, D. (2017). Geodetic monitoring of subrosion-induced subsidence processes in urban areas. *J. Appl. Geodesy* 11 (1), 21–29. doi:10.1515/jag-2016-0029

Khaing, K. K. (2016) "Groundwater environment in yangon, Myanmar," in *Groundwater environment in asian cities*. Butterworth-Heinemann, 317–335.

Khan, S. D., Gadea, O. C., Tello Alvarado, A., and Tirmizi, O. A. (2022). Surface deformation analysis of the Houston area using time series interferometry and emerging hot spot analysis. *Remote Sens.* 14 (15), 3831. doi:10.3390/rs14153831

Kim, D., Lee, H., Okeowo, M. A., Basnayake, S., and Jayasinghe, S. (2017). Cost-effective monitoring of land subsidence in developing countries using semipermanent GPS stations: a test study over Houston, Texas. *J. Appl. Remote Sens.* 11 (2), 026033. doi:10.1117/1.jrs.11.026033

Kim, J. S., Kim, D. J., Kim, S. W., Won, J. S., and Moon, W. M. (2007). Monitoring of urban land surface subsidence using PSInSAR. *Geosciences J.* 11, 59–73. doi:10.1007/bf02910381

Kim, J. S., Park, S. E., and Moon, W. I. M. (2006). Application of PSInSAR technique for monitoring surface deformation over coastal area of incheon. 한국지구물리탐사학회 학술대회논문집, 277–280.

King, C. L. (1953). Sea-level movement in the vicinity of Durban. *South Afr. J. Geol.* 56 (1), 121–126. doi:10.10520/AJA10120750_2182

Kirshen, P., Knee, K., and Ruth, M. (2008). Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies. *Clim. Change* 90 (4), 453–473. doi:10.1007/s10584-008-9398-9

Klein, R. J., Nicholls, R. J., and Thomalla, F. (2003). The resilience of coastal megacities to weather-related hazards. *Build. safer cities*, 101–120.

Ko, L. M. Ko, and Giao, P. H. (2021). "Land subsidence of yangon plain: an overview and preliminary results of consolidation analysis," in *4th Asia pacific meeting on near surface geoscience & engineering* (Netherlands: EAGE Publications BV), 2021. No. 1.

Konagai, K., Asakura, T., Suyama, S., Kyokawa, H., Kiyota, T., Eto, C., et al. (2011). "Soil subsidence map of the Tokyo bay area liquefied in the March 11th Great East Japan Earthquake," in *Proceeding of international symposium on engineering lessons learned from the giant earthquake (one year after 2011 great east Japan earthquake)*, 855–864.

Kontogianni, V., and Stiros, S. C. (2020). Ground loss and static soil–structure interaction during urban tunnel excavation: evidence from the excavation of the Athens Metro. *Infrastructures* 5 (8), 64. doi:10.3390/infrastructures5080064

Korff, M. (2013). *Response of piled buildings to the construction of deep excavations*, 13. Netherlands: IOS Press.

Koster, K., Stafleu, J., and Stouthamer, E. (2018). Differential subsidence in the urbanised coastal-deltaic plain of The Netherlands. *Neth. J. Geosciences* 97 (4), 215–227. doi:10.1017/njg.2018.11

Koudogbo, F. N., Duro, J., Arnaud, A., Bally, P., Abidin, H. Z., and Andreas, H. (2012). "Combined X-and L-band PSI analyses for assessment of land subsidence in Jakarta," in *Remote sensing for agriculture, ecosystems, and hydrology XIV* (Bellingham, WA, United States: SPIE), 8531, 46–58. doi:10.1117/12.974821

Kovach, R. L. (1974). Source mechanisms for Wilmington oil field, California, subsidence earthquakes. *Bull. Seismol. Soc. Am.* 64 (3-1), 699–711. doi:10.1785/bssa0643-10699

Krassakis, P., Kazana, S., Chen, F., Koukouzas, N., Parcharidis, I., and Lekkas, E. (2019). Detecting subsidence spatial risk distribution of ground deformation induced by urban hidden streams. *Geocarto Int.* 36, 622–639. just-accepted). doi:10.1080/10106049.2019.1622601

Krockenberger, M. (2015). *Population growth in Australia*. Manuka: Australia Institute.

Kruger, F., and Klinge, K. (2002). "The 1996 Teutschenthal Potash Mine Collapse: an unusual event with an unusual mechanism," in *Ten years of German regional seismic network (GRSN)*. Editor M. Korn (Senate commission for geoscience), 206–210.

Kühn, F., Margane, A., Tatong, T., and Wever, T. (2004). InSAR-based land subsidence map for Bangkok, Thailand. *Z. für Angew. Geol.* 50 (1), 74–81.

Kurniawan, A., and Deviantari, U. W. (2022). Literatur review: perbandingan berbagai teknik pemodelan land subsidence. *Geoid* 17 (2), 267–272. doi:10.12962/j24423998.v17i2.11340

Latief, H., Putri, M. R., Hanifah, F., Afifah, I. N., Fadli, M., and Ismoyo, D. O. (2018). Coastal hazard assessment in northern part of jakarta. *Procedia Eng.* 212, 1279–1286. doi:10.1016/j.proeng.2018.01.165

Laura, C., Pietro, T., and Luigi, T.(2005b). Land subsidence in the Venetian area: known and recent aspects. *Geol. Appl.* 1, 5–11. doi:10.1474/GGA.2005-01.0-01.0001

Lavoie, J., Dubeau, S., and Tremblay, M. (2015). *Affaissement d'une chaussée construite sur argile à Montréal*. QC.

Le Cozannet, G., Raucoules, D., Wöppelmann, G., de Michele, M., and Poupardin, A. (2014). "InSAR monitoring of ground motions impacts for in-situ sea level measurement: the example of Dakar (Senegal)," in *2014 IEEE geoscience and remote sensing symposium* (IEEE), 970–973.

Le Cozannet, G., Raucoules, D., Wöppelmann, G., Garcin, M., Da Sylva, S., Meyssignac, B., et al. (2015). Vertical ground motion and historical sea-level records in Dakar (Senegal). *Environ. Res. Lett.* 10 (8), 084016. doi:10.1088/1748-9326/10/8/084016

Lexa, J., Sebesta, J., Chavez, J. A., Hernández, W., and Pecskay, Z. (2011). Geology and volcanic evolution in the southern part of the san salvador metropolitan area. *J. Geosciences* 56 (1), 106–140. doi:10.3190/jgeosci.088

Li, C., Tang, X., and Ma, T. (2006). Land subsidence caused by groundwater exploitation in the Hangzhou-Jiaxing-Huzhou Plain, China. *Hydrogeology J.* 14 (8), 1652–1665. doi:10.1007/s10040-006-0092-6

Li, D., Li, B., Zhang, Y., Fan, C., Xu, H., and Hou, X. (2022a). Spatial and temporal characteristics analysis for land subsidence in Shanghai coastal reclamation area using PS-InSAR method. *Front. Mar. Sci.* 9. doi:10.3389/fmars.2022.1000523

Li, G., Zhao, C., Wang, B., Liu, X., and Chen, H. (2022). Land subsidence monitoring and dynamic prediction of reclaimed islands with multi-temporal InSAR techniques in Xiamen and Zhangzhou cities, China. *Remote Sens.* 14 (12), 2930. doi:10.3390/rs14122930

Li, J., Zhou, L., Ren, C., Liu, L., Zhang, D., Ma, J., et al. (2021a). Spatiotemporal inversion and mechanism analysis of surface subsidence in Shanghai area based on time-series InSAR. *Appl. Sci.* 11 (16), 7460. doi:10.3390/app11167460

Li, J., Zhou, L., Zhu, Z., Qin, J., Xian, L., Zhang, D., et al. (2022c). Surface deformation mechanism analysis in Shanghai areas based on TS-InSAR technology. *Remote Sens.* 14 (17), 4368. doi:10.3390/rs14174368

Li, M., Zhang, X., Bai, Z., Xie, H., and Chen, B. (2022). Land subsidence in Qingdao, China, from 2017 to 2020 based on PS-InSAR. *Int. J. Environ. Res. Public Health* 19 (8), 4913. doi:10.3390/ijerph19084913

Li, M. G., Chen, J. J., Xu, Y. S., Tong, D. G., Cao, W. W., and Shi, Y. J. (2021b). Effects of groundwater exploitation and recharge on land subsidence and infrastructure settlement patterns in Shanghai. *Eng. Geol.* 282, 105995. doi:10.1016/j.enggeo.2021.105995

Li, P., Li, M., Li, Z., and Wang, H. (2020). Coastal lowlands' inundation risk assessment with high-resolution TanDEM-X DEM in qingdao coastal plains, China. *Proc. Int. Assoc. Hydrological Sci.* 382, 621–627. doi:10.5194/piahs-382-621-2020

Liao, M., Pei, Y., Wang, H., Fang, Z., and Wei, L. (2012). Subsidence monitoring in Shanghai using the PSInSAR technique. *Shanghai Land Resour.* 33 (3), 5–10.

Liao, X., Zhang, B., and Wu, S. (2022). "Monitoring of ground deformation along shenzhen metro system with sentinel-1A SAR Imagery," in *IGARSS 2022-2022 IEEE international geoscience and remote sensing symposium* (IEEE), 2943–2946. doi:10.1016/j.jag.2022.103099

Lin, S. Y. (2022). Urban hazards caused by ground deformation and building subsidence over fossil lake beds: a study from Taipei City. *Geomatics, Nat. Hazards Risk* 13 (1), 2890–2910. doi:10.1080/19475705.2022.2141139

Liu, G., Luo, X., Chen, Q., Huang, D., and Ding, X. (2008). Detecting land subsidence in Shanghai by PS-networking SAR interferometry. *Sensors* 8 (8), 4725–4741. doi:10.3390/s8084725

Liu, Y., and Li, J. (2022). Land subsidence due to creep of the gulf coast aquifer system in the houston-galveston region. *Environ. Eng. Geoscience* 28 (3), 237–254. doi:10.2113/eeg-d-21-00076

Liu, Y., Li, J., and Fang, Z. N. (2019). Groundwater level change management on control of land subsidence supported by borehole extensometer compaction measurements in the Houston-Galveston Region, Texas. *Geosciences* 9 (5), 223. doi:10.3390/geosciences9050223

Liu, Y., Rashvand, M., and Li, J. (2020). "Preliminary investigation of land subsidence impacts on sea level change in Baltimore inner harbor, Maryland," in *World environmental and water resources congress 2020* (Reston, VA: American Society of Civil Engineers), 236–243.

Lixin, Y., Jie, W., Chuanqing, S., Guo, J. W., Yanxiang, J., and Liu, B. (2010). Land subsidence disaster survey and its economic loss assessment in Tianjin, China. *Nat. Hazards Rev.* 11 (1), 35–41. doi:10.1061/(asce)1527-6988(2010)11:1(35)

Lorphensri, O., Ladawadee, A., and Dhammasarn, S. (2011). "Review of groundwater management and land subsidence in Bangkok, Thailand. Groundwater and subsurface environments," in *Human impacts in Asian coastal cities*, 127–142.

Loupasakis, C. (2020). An overview of the land subsidence phenomena occurring in Greece, triggered by the overexploitation of the aquifers for irrigation and mining purposes. *Proc. Int. Assoc. Hydrological Sci.* 382, 321–326. doi:10.5194/piahs-382-321-2020

Lui, T. (1991). Land subsidence in Shanghai. in *Shanghai land subsidence volume (pp. 1-14)* (Bureau of Geology and Mineral Resources of Shanghai China).

Luo, H., Tan, G., and Lin, S. (2022). "Analysis of spatial and temporal characteristics of ground subsidence in xiamen based on PS-InSAR," in *2022 7th international conference on image, vision and computing (ICIVC)* (IEEE), 307–311.

Luo, Q., Perissin, D., Lin, H., Zhang, Y., and Wang, W. (2013). Subsidence monitoring of Tianjin suburbs by TerraSAR-X persistent scatterers interferometry. *IEEE J. Sel. Top. Appl. Earth Observations Remote Sens.* 7 (5), 1642–1650. doi:10.1109/jstars.2013.2271501

Luo, Q., Perissin, D., Zhang, Y., and Jia, Y. (2014). L-and X-band multi-temporal InSAR analysis of Tianjin subsidence. *Remote Sens.* 6 (9), 7933–7951. doi:10.3390/rs6097933

Luo, Y., Ye, S., Wu, J., Wang, H., and Jiao, X. (2016). A modified inverse procedure for calibrating parameters in a land subsidence model and its field application in Shanghai, China. *Hydrogeology J.* 24 (3), 711–725. doi:10.1007/s10040-016-1381-3

Luxiang, S., and Manfang, B. (1984). Case History No. 9.2; Shanghai, China. Guidebook to studies of land subsidence due to ground-water withdrawal. *UNESCO Stud. Rep. Hydrol.* 40, 155–160.

Ma, P., Wang, W., Zhang, B., Wang, J., Shi, G., Huang, G., et al. (2019). Remotely sensing large-and small-scale ground subsidence: a case study of the Guangdong–Hong Kong–Macao Greater Bay Area of China. *Remote Sens. Environ.* 232, 111282. doi:10.1016/j.rse.2019.111282

Ma, P., Zheng, Y., Zhang, Z., Wu, Z., and Yu, C. (2022). Building risk monitoring and prediction using integrated multi-temporal InSAR and numerical modeling techniques. *Int. J. Appl. Earth Observation Geoinformation* 114, 103076. doi:10.1016/j.jag.2022.103076

Magnan, A. K., Oppenheimer, M., Garschagen, M., Buchanan, M. K., Duvat, V. K., Forbes, D. L., et al. (2022). Sea level rise risks and societal adaptation benefits in low-lying coastal areas. *Sci. Rep.* 12 (1), 10677. doi:10.1038/s41598-022-14303-w

Mahmud, M. U., Yakubu, T. A., Adewuyi, T. O., Sousa, J. J., Ruiz Armenteros, A. M., Bakon, M., et al. (2016). *Subsidence monitoring in the coastal region of Nigeria using multi temporal interferometric synthetic aperture radar*. MT-InSAR.

Mallum, F. (2022). Stormwater management and the assessment of green infrastructure implementation in new orleans. *Shima Int. J. Res. Isl. Cult.* 16, 61–75. doi:10.21463/shima.146

Mangano, G., Zecchin, M., and Civile, D. (2020). Large-scale gravity-driven phenomena in the Crotone Basin, southern Italy. *Mar. Petroleum Geol.* 117, 104386. doi:10.1016/j.marpetgeo.2020.104386

Margat, J., and Van der Gun, J. (2013). *Groundwater around the world: a geographic synopsis*. Boca Raton, FL, United States: CRC Press.

Marsden, S. S., and Davis, S. N. (1967). Geological subsidence. *Sci. Am.* 216 (6), 93–100. doi:10.1038/scientificamerican0667-93

Marshall, C., Large, D. J., Athab, A., Evers, S. L., Sowter, A., Marsh, S., et al. (2018). Monitoring tropical peat related settlement using ISBAS InSAR, Kuala Lumpur International Airport (KLIA). *Eng. Geol.* 244, 57–65. doi:10.1016/j.enggeo.2018.07.015

Mason, P. J., Ghail, R. C., Bischoff, C., and Skipper, J. A. (2015). *Detecting and monitoring small-scale discrete ground movements across London, using Persistent Scatterer InSAR (PSI)*.

Mastin, T., Styles, S., and Feist, K. (2018). "A review of subsidence measurements near mendota, California," in *World environmental and water resources congress 2018: watershed management, irrigation and drainage, and water resources planning and management* (Reston, VA: American Society of Civil Engineers), 50–61.

Mayuga, M. N., and Allen, D. R. (1969). "Subsidence in the wilmington oil field, long beach, California, USA," in *Proceedings of the Tokyo symposium on land subsidence, international association of scientific hydrology, studies and reports in hydrology* (IASH-UNESCO), 1, 66–79.

Mazzotti, S., Lambert, A., Van der Kooij, M., and Mainville, A. (2009). Impact of anthropogenic subsidence on relative sea-level rise in the Fraser River delta. *Geology* 37 (9), 771–774. doi:10.1130/g25640a.1

McCall, G. (1996). *Urban geoscience* (CRC Press), 20.

McCann, G. D., and Wilts, C. H. (1951). *A mathematical analysis of the subsidence in the long beach-san pedro area*.

Miller, M. M., and Shirzaei, M. (2019). Land subsidence in Houston correlated with flooding from Hurricane Harvey. *Remote Sens. Environ.* 225, 368–378. doi:10.1016/j.rse.2019.03.022

Miller, R. D., Xia, J., Park, C. B., Anderson, J. M., Fiedler, M., and Overton, R. (1999). MASW to investigate subsidence in the Tampa, Florida area. *Kans. Geol. Surv. Open File Rep.*, 99–33.

Minderhoud, P. S. J., Erkens, G., Pham, V. H., Vuong, B. T., and Stouthamer, E. (2015). Assessing the potential of the multi-aquifer subsurface of the Mekong Delta (Vietnam) for land subsidence due to groundwater extraction. *Proc. Int. Assoc. Hydrological Sci.* 372 (372), 73–76. doi:10.5194/piahs-372-73-2015

Minh, D., Van Trung, Le, and Toan, T. (2015). Mapping ground subsidence phenomena in Ho Chi Minh City through the radar interferometry technique using ALOS PALSAR data. *Remote Sens.* 7 (7), 8543–8562. doi:10.3390/rs70708543

Minh, D. H. T., Ngo, Y. N., Lê, T. T., Le, T. C., Bui, H. S., Vuong, Q. V., et al. (2022). "Mapping ground motions by open-source persistent and distributed scatterers Sentinel-1 radar interferometry: Ho Chi Minh city case study," in *IGARSS 2022-2022 IEEE international geoscience and remote sensing symposium* (IEEE), 1632–1635.

Minh, D. H. T., Yen-Nhi, N. G. O., Lê, T. T., Le, T. C., Bui, H. S., Vuong, Q. V., et al. (2021). *Quantifying horizontal and vertical movements in Ho Chi Minh city by Sentinel-1 radar interferometry*.

Moe, I. R., Kure, S., Januriyadi, N. F., Farid, M., Udo, K., Kazama, S., et al. (2017). Future projection of flood inundation considering land-use changes and land subsidence in Jakarta, Indonesia. *Hydrological Res. Lett.* 11 (2), 99–105. doi:10.3178/hrl.11.99

Mohamadi, B., Balz, T., and Younes, A. (2019). A model for complex subsidence causality interpretation based on PS-InSAR cross-heading orbits analysis. *Remote Sens.* 11 (17), 2014. doi:10.3390/rs11172014

Mohamed, S. A. (2020). Coastal vulnerability assessment using GIS-Based multicriteria analysis of Alexandria-northwestern Nile Delta, Egypt. *J. Afr. Earth Sci.* 163, 103751. doi:10.1016/j.jafrearsci.2020.103751

Molengraaff, G. A. F. (1909). The subsidence of the soil of The Netherlands. *KNAW, Proc.* 12.

Momotake, M. (1996). Historical riview of land subsidence in niigata city and its vicinity. *Quat. Res. (Daiyonki-Kenkyu)* 35 (3), 253–258. doi:10.4116/jaqua.35.253

Montalti, R., Solari, L., Bianchini, S., Del Soldato, M., Raspini, F., and Casagli, N. (2019). A Sentinel-1-based clustering analysis for geo-hazards mitigation at regional scale: a case study in Central Italy. *Geomatics, Nat. Hazards Risk* 10 (1), 2257–2275. doi:10.1080/19475705.2019.1690058

Montuori, A., Pezzo, G., Anderlini, L., Palano, M., Chiarabba, C., Stramondo, S., et al. (2017). "Land subsidence from geo-resources exploitation: evidences from InSAR and GPS observations," in *11° Workshop Tematico di Telerilevamento*.

Morishita, Y. (2021). Nationwide urban ground deformation monitoring in Japan using Sentinel-1 LiCSAR products and LiCSBAS. *Prog. Earth Planet. Sci.* 8 (1), 6–23. doi:10.1186/s40645-020-00402-7

Muir Wood, R. (1990). London: not waving but drowning. *Terra nova.* 2, 284–291. doi:10.1111/j.1365-3121.1990.tb00077.x

Murayama, S. (1970). "Land subsidence in osaka," in *Proceedings of the Tokyo symposium on land subsidence*, 1.

Murria, J. (1991). "Subsidence due to oil production in Western Venezuela: engineering problems and solutions," in *Land subsidence* (Houston, Texas: IAHS), 129–139.

Murshed, S., Griffin, A. L., Islam, M. A., Wang, X. H., and Paull, D. (2022). Assessing multi-climate-hazard threat in the coastal region of Bangladesh by combining influential environmental and anthropogenic factors. *Prog. Disaster Sci.* 16, 100261. doi:10.1016/j.pdisas.2022.100261

Na, T., Kawamura, Y., Kang, S. S., and Utsuki, S. (2021). Hazard mapping of ground subsidence in east area of Sapporo using frequency ratio model and GIS. *Geomatics, Nat. Hazards Risk* 12 (1), 347–362. doi:10.1080/19475705.2021.1873198

Nalakurthi, N. V., Sudha, R. N., and Ranjan Behera, M. (2022). *Detection of land subsidence using sentinel-1 interferometer and its relationship with sea-level-rise, groundwater, and inundation: a case study along Mumbai coastal city*.

Nasrul, F. A., Schultz, B., Susantao, R. H., and Suryadi, F. X. (2011). "Impacts of changes on flood protection systems. Case study of Indonesia and The Netherlands in comparative perspective," in *Proceedings of 25th European Regional ICID Conference on Deltas in Europe. Integrated water management for multiple land use in flat coastal areas*, 15. Groningen, the Netherlands, 16-20 May, 2011.

Nelson, G. R., Rowton, M., Kershaw, S., Bust, R. A., Cooke, S., and Tipper, L. (2013). "A historical perspective on the subsidence effects of mine closure," in *Mine closure 2013: proceedings of the eighth international seminar on mine closure* (Australian Centre for Geomechanics), 537–546.

Nerem, R. S., Van Dam, T. M., and Schenewerk, M. S. (1998). Chesapeake Bay subsidence monitored as wetlands loss continues. *Eos, Trans. Am. Geophys. Union* 79 (12), 149–157. doi:10.1029/98eo00110

Newman, W. A., and Holton, W. E. (2006). *Boston's Back Bay: the story of America's greatest Nineteenth-Century landfill project*. Upne.

Ng, A., Wang, H., Dai, Y., Pagli, C., Chen, W., Ge, L., et al. (2018). InSAR reveals land deformation at Guangzhou and Foshan, China between 2011 and 2017 with COSMO-SkyMed data. *Remote Sens.* 10 (6), 813. doi:10.3390/rs10060813

Ng, A. H. M., Chang, H. C., Zhang, K., Ge, L., and Rizos, C. (2009). "Land subsidence monitoring in Australia and China using satellite interferometry," in *Observing our changing earth* (Berlin, Heidelberg: Springer), 743–750.

Ng, A. H. M., Ge, L., Li, X., Abidin, H. Z., Andreas, H., and Zhang, K. (2012). Mapping land subsidence in Jakarta, Indonesia using persistent scatterer interferometry (PSI) technique with ALOS PALSAR. *Int. J. Appl. Earth Observation Geoinformation* 18, 232–242. doi:10.1016/j.jag.2012.01.018

Ng, A. H. M., Ge, L., Zhang, K., and Li, X. (2011). "Application of persistent scatterer interferometry for land subsidence monitoring in Sydney, Australia using ENVISAT ASAR data," in *34th international symposium on remote sensing of environment*.

Nicholls, R. J. (2008). *The exposure of port cities to flooding: a comparative global analysis*.

Nicholls, R. J., Wong, P. P., Burkett, V., Codignotto, J., Hay, J., McLean, R., et al. (2007). *Coastal systems and low-lying areas*.

Niedermayer, J. (1962). Die geologischen Verhältnisse im Bereich des Salzstockes von Hamburg-Langenfelde. *Geol. Landesamt*.

Noi, H., Binh, N., Phong, H., Binh, T., Yen, H., Duong, H., et al. (2024). *The red river delta, vietnam: an overview of groundwater resources*.

Normand, J., and Heggy, E. (2015). InSAR assessment of surface deformations in urban coastal terrains associated with groundwater dynamics. *IEEE Trans. Geoscience Remote Sens.* 53, 6356–6371. doi:10.1109/TGRS.2015.2437368

Nur, A. S., Achmad, A. R., and Lee, C. W. (2020). Land subsidence measurement in reclaimed coastal land: noksan using C-band Sentinel-1 radar interferometry. *J. Coast. Res.* 102 (SI), 218–223. doi:10.2112/si102-027.1

Nutalaya, P. (1989). "Land subsidence in bangkok during 1978-1988," in *Workshop on bangkok land subsidence-what's next?* (Bangkok), 1–48.

Nutalaya, P., Chandra, S., and Balasubramaniam, A. S. (1986). "Subsidence of Bangkok clay due to deep well pumping and its control through artificial recharge," in *Proceedings of the 3rd international symposium on land subsidence* (Wallingford: International Association of Hydrological Sciences).

Nutalaya, P., and Rau, J. L. (1981). Bangkok: the sinking metropolis. *Episodes J. Int. Geoscience* 4 (4), 3–8. doi:10.18814/epiiugs/1981/v4i4/001

Nutalaya, P., Yong, R. N., Chumnankit, T., and Buapeng, S. (1996). "Land subsidence in bangkok during 1978–1988," in *Sea-level rise and coastal subsidence* (Dordrecht: Springer), 105–130.

Ohenhen, L. O., and Shirzaei, M. (2022). Land subsidence hazard and building collapse risk in the coastal city of lagos, west Africa. *Earth's Future* 10 (12), e2022EF003219. doi:10.1029/2022ef003219

Ohshima, T., Ueshita, K., and Daito, K. (1991). "Land subsidence and groundwater condition in Nagoya," in *Land subsidence*, 283–294.

Ojeda Arzuza, A. D. (2021). *Potencial de la Interferometría de Radar de Apertura Sintética (InSAR) para el análisis del desplazamiento del terreno: caso de estudio*. Colombia: Barranquilla.

Olson, K. R., and Kreznor, W. (2021). Managing the chao phraya river and delta in bangkok, Thailand: flood control, navigation and land subsidence mitigation. *Open J. Soil Sci.* 11 (4), 197–215. doi:10.4236/ojss.2021.114011

Omoko, E. N., Okeke, O. C., and Opara, K. D. (2018). A review of the mechanism and engineering/environmental problems of subsidence due to groundwater extraction. *Int. J. Geogr. Environ. Manag.* 4 (4), 1–12.

Onta, P. R., and Gupta, A. D. (1995). Regional management modeling of a complex groundwater system for land subsidence control. *Water Resour. Manag.* 9 (1), 1–25. doi:10.1007/bf00877386

Ostanciaux, E., Husson, L., Choblet, G., Robin, C., and Pedoja, K. (2012). Present-day trends of vertical ground motion along the coast lines. *Earth-Science Rev.* 110 (1-4), 74–92. doi:10.1016/j.earscirev.2011.10.004

Otokiti, K. V., Akinola, O., and Adeniji, K. N. (2019). Geospatial mapping of flood risk in the coastal megacity of Nigeria. *Am. J. Geophys. Geochem. Geosystems* 5 (4), 129–138.

Pace, S. (2021). Urban infrastructure inundation risk from permanent sea-level rise scenarios in London (UK), Bangkok (Thailand) and Mumbai (India): a comparative analysis. *Geogr. Inf. Sci.* Master Thesis.

Paluska, A. (2002). Geologische stellungnahme zum bebauungs-planentwurf Gross flottbek 10 (osdorfer marktplatz). Report Az, 33, 1–76.

Pamungkas, Y. A., and Chiang, S. H. (2021). Monitoring land subsidence induced by groundwater change using satellite gravimetry and radar interferometry measurements. Case study: Surabaya city, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 916, 012030. doi:10.1088/1755-1315/916/1/012030

Pandey, B., Joshi, P. K., and Seto, K. C. (2013). Monitoring urbanization dynamics in India

Parcharidis, I., Lagios, E., Sakkas, V., Raucoules, D., Feurer, D., Le Mouélic, S., et al. (2006). Subsidence monitoring within the Athens Basin (Greece) using space radar interferometric techniques. *Earth, planets space* 58 (5), 505–513. doi:10.1186/bf03351947

Park, S. W., and Hong, S. H. (2021). Nonlinear modeling of subsidence from a decade of InSAR time series. *Geophys. Res. Lett.* 48 (3), e2020GL090970. doi:10.1029/2020gl090970

Park, S. W., Jung, S. W., and Hong, S. H. (2019). "Monitoring a time-series of land subsidence in Busan, Korea using space-based multi-temporal SAR observations," in *IGARSS 2019-2019 IEEE international geoscience and remote sensing symposium* (IEEE), 1602–1605.

Parker, A. L., Castellazzi, P., Fuhrmann, T., Garthwaite, M. C., and Featherstone, W. E. (2021). Applications of satellite radar imagery for hazard monitoring: insights from Australia. *Remote Sens.* 13 (8), 1422. doi:10.3390/rs13081422

Parker, A. L., Filmer, M. S., and Featherstone, W. E. (2017). First results from sentinel-1A InSAR over Australia: application to the perth basin. *Remote Sens.* 9 (3), 299. doi:10.3390/rs9030299

Parker, A. L., Pigois, J. P., Filmer, M. S., Featherstone, W. E., Timms, N. E., and Penna, N. T. (2021b). Land uplift linked to managed aquifer recharge in the Perth Basin, Australia. *Int. J. Appl. Earth Observation Geoinformation* 105, 102637. doi:10.1016/j.jag.2021.102637

Pedretti, L., Giarola, A., Korff, M., Lambert, J., and Meisina, C. (2023). Database of subsidence in major coastal cities around the world. *Zenodo*. [Data set]. doi:10.5281/zenodo.8349293

Peng, M., Zhao, C., Zhang, Q., Lu, Z., Bai, L., and Bai, W. (2020). Multi-scale and multi-dimensional time series InSAR characterizing of surface deformation over Shandong Peninsula, China. *Appl. Sci.* 10 (7), 2294. doi:10.3390/app10072294

Peng, Y., Dong, D., Chen, W., and Zhang, C. (2022). Stable regional reference frame for reclaimed land subsidence study in East China. *Remote Sens.* 14 (16), 3984. doi:10.3390/rs14163984

Perissin, D., Wang, Z., and Lin, H. (2012). Shanghai subway tunnels and highways monitoring through Cosmo-SkyMed Persistent Scatterers. *ISPRS J. Photogrammetry Remote Sens.* 73, 58–67. doi:10.1016/j.isprsjprs.2012.07.002

Petersen, C., Turco, M. J., Vinson, A., Turco, J. A., Petrov, A., and Evans, M. (2020). Groundwater regulation and the development of alternative source waters to prevent subsidence, Houston region, Texas, USA. *Proc. Int. Assoc. Hydrological Sci.* 382, 797–801. doi:10.5194/piahs-382-797-2020

Pethick, J., and Orford, J. D. (2013). Rapid rise in effective sea-level in southwest Bangladesh: its causes and contemporary rates. *Glob. Planet. Change* 111, 237–245. doi:10.1016/j.gloplacha.2013.09.019

Phien-wej, N., Giao, P. H., and Nutalaya, P. (2006). Land subsidence in bangkok, Thailand. *Eng. Geol.* 82 (4), 187–201. doi:10.1016/j.enggeo.2005.10.004

Pierce, R. L. (1970). Reducing land subsidence in the wilmington oil field by use of saline waters. *Water Resour. Res.* 6 (5), 1505–1514. doi:10.1029/wr006i005p01505

Poland, J. F. (1969). *Land subsidence and aquifer-system compaction, santa clara valley, California, USA. United states, department of the interior*. Geological Survey.

Poland, J. F. (1972). *Subsidence and its control*.

Poland, J. F. (1984). *Guidebook to studies of land subsidence due to ground-water withdrawal*.

Poland, J. F., and Hamilton Davis, G. (1969). *Land subsidence due to withdrawal of fluids*.

Polcari, M., Albano, M., Montuori, A., Bignami, C., Tolomei, C., Pezzo, G., et al. (2018). InSAR monitoring of Italian coastline revealing natural and anthropogenic ground deformation phenomena and future perspectives. *Sustainability* 10 (9), 3152. doi:10.3390/su10093152

Polcari, M., Anderlini, L., Albano, M., Pezzo, G., Secreti, V., Serpelloni, E., et al. (2020). "Subsidence monitoring along Ravenna coastal area (northern Italy) by insar and GPS data," in *IGARSS 2020-2020 IEEE international geoscience and remote sensing symposium* (IEEE), 810–813.

Pooja, B., Oommen, T., Sajinkumar, K. S., Nair, A. G., Rajaneesh, A., Aswathi, J., et al. (2021). Correspondence of PSInSAR monitoring and Settle3 modelling at cochin international airport, SW India. *Appl. Geomatics* 13, 735–746. doi:10.1007/s12518-021-00387-y

Pousa, J., Tosi, L., Kruse, E., Guaraglia, D., Bonardi, M., Mazzoldi, A., et al. (2007). Coastal processes and environmental hazards: the Buenos Aires (Argentina) and Venetian (Italy) littorals. *Environ. Geol.* 51, 1307–1316. doi:10.1007/s00254-006-0424-9

Pranantya, P. A., Sukiyah, E., and Utomo, E. P. (2017). Modelling for groundwater extraction effect for Jakarta land subsidence. *Int. J. Sci. Res.* 6 (8), 184–190.

Priest, G., Baptista, A. M., Myers III, E., and Kamphaus, R. (2001). "Tsunami hazard assessment in Oregon," in *Proceedings of international tsunami symposium*, 55–65.

Qiao, X., Chu, T., Tissot, P., and Louis, J. (2022). "Mapping and evaluation of land deformation with InSAR and GNSS measurements near Houston, Texas, USA," in *IGARSS 2022-2022 IEEE international geoscience and remote sensing symposium* (IEEE), 2478–2481.

Qin, Y., and Perissin, D. (2015). Monitoring ground subsidence in Hong Kong via spaceborne Radar: experiments and validation. *Remote Sens.* 7 (8), 10715–10736. doi:10.3390/rs70810715

Qu, F., Lu, Z., Zhang, Q., Bawden, G. W., Kim, J. W., Zhao, C., et al. (2015). Mapping ground deformation over Houston–Galveston, Texas using multi-temporal InSAR. *Remote Sens. Environ.* 169, 290–306. doi:10.1016/j.rse.2015.08.027

Radhi, A. A. B. M. (2017). *Monitoring land subsidence of airport using InSAR timeseries techniques with atmospheric and orbital error corrections (doctoral dissertation, thesis, universiti teknologi Malaysia)*.

Radutu, A., and Gogu, R. C. (2019). Chronological reflection on monitoring urban areas subsidence due to groundwater extraction. *E3S Web Conf.* 85, 07015. doi:10.1051/e3sconf/20198507015

Radutu, A., and Vlad-Sandru, M. I. (2023). Review on the use of satellite-based radar interferometry for monitoring mining subsidence in urban areas and demographic indicators assessment. *Min. Rev.* 29 (1), 42–62. doi:10.2478/minrv-2023-0004

Ramasamy, S. M., Vijay, A., and Dhinesh, S. (2018). Geo-anthropogenic aberrations and Chennai floods: 2015, India. *Nat. Hazards* 92 (1), 443–477. doi:10.1007/s11069-018-3213-3

Ramirez, R. A., and Kwon, T. H. (2022). Sentinel-1 persistent scatterer interferometric synthetic aperture radar (PS-InSAR) for long-term remote monitoring of ground subsidence: a case study of a port in busan, South Korea. *KSCE J. Civ. Eng.* 26 (10), 4317–4329. doi:10.1007/s12205-022-1005-5

Ramnarong, V., Buapeng, S., Chootnatut, S., and Loupensri, A. (1998). "Groundwater and land subsidence crisis in Bangkok metropolitan and vicinity," in *Technical report* (Thailand: Department of Mineral Resources (DMR) Bangkok), 3.

Ramnarong, V., and Buapeng, S. (1991). *Mitigation of groundwater crisis and land subsidence in Bangkok*.

Raspini, F., Bianchini, S., Ciampalini, A., Del Soldato, M., Montalti, R., Solari, L., et al. (2019). Persistent Scatterers continuous streaming for landslide monitoring and mapping: the case of the Tuscany region (Italy). *Landslides* 16, 2033–2044. doi:10.1007/s10346-019-01249-w

Raspini, F., Bianchini, S., Ciampalini, A., Del Soldato, M., Solari, L., Novali, F., et al. (2018). Continuous, semi-automatic monitoring of ground deformation using Sentinel-1 satellites. *Sci. Rep.* 8 (1), 7253. doi:10.1038/s41598-018-25369-w

Raspini, F., Caleca, F., Del Soldato, M., Festa, D., Confuorto, P., and Bianchini, S. (2022). Review of satellite radar interferometry for subsidence analysis. *Earth-Science Rev.* 104239. doi:10.1016/j.earscirev.2022.104239

Rateb, A., and Abotalib, A. Z. (2020). Inferencing the land subsidence in the Nile Delta using Sentinel-1 satellites and GPS between 2015 and 2019. *Sci. Total Environ.* 729, 138868. doi:10.1016/j.scitotenv.2020.138868

Raucoules, D., Le Cozannet, G., Wöppelmann, G., De Michele, M., Gravelle, M., Daag, A., et al. (2013). High nonlinear urban ground motion in Manila (Philippines) from 1993 to 2010 observed by DInSAR: implications for sea-level measurement. *Remote Sens. Environ.* 139, 386–397. doi:10.1016/j.rse.2013.08.021

Ray, R. D., Beckley, B. D., and Lemoine, F. G. (2010). Vertical crustal motion derived from satellite altimetry and tide gauges, and comparisons with DORIS measurements. *Adv. Space Res.* 45 (12), 1510–1522. doi:10.1016/j.asr.2010.02.020

Reuther, C. D., Buurmann, N., Kühn, D., Ohrnberger, M., Dahm, T., and Scherbaum, F. (2007). Erkundung des unterirdischen Raums der Metropolregion Hamburg–Das Projekt HADU. *Geotech. Organ Dtsch. Ges. für Geotech.* 29 (1), 11–20.

Reyes, R., Bauzon, M., Angela, D., Pasaje, N. A., Alfante, R. M., De Lara, P. M., et al. (2022). Quantifying vertical land motion at tide gauge sites using permanent scatterer interferometric synthetic aperture radar and global navigation satellite system solutions. *Spatial Inf. Res.* 30 (2), 309–319. doi:10.1007/s41324-022-00431-y

Ricceri, G. (2007). *Il futuro di Venezia tra subsidenza ed eustatismo*, 3. Rivista Italiana di Geotecnica.

Richts, A., Struckmeier, W., and Zaepke, M. (2011). "WHYMAP and the groundwater resources of the world 1:25,000,000," in *Sustaining groundwater resources. International year of planet earth*. Editor J. Jones (Springer). doi:10.1007/978-90-481-3426-7_10

Riel, B., Simons, M., Ponti, D., Agram, P., and Jolivet, R. (2018). Quantifying ground deformation in the Los Angeles and Santa Ana Coastal Basins due to groundwater withdrawal. *Water Resour. Res.* 54 (5), 3557–3582. doi:10.1029/2017wr021978

Rigamonti, S., Bellotti, F., Dattola, G., Frattini, P., Guarino, P. M., and Battista Crosta, G. (2021). "Analysis of subsidence in the metropolitan area of Naples based on SAR data," in *EGU general assembly conference abstracts*, EGU21–15169.

Ritchie, H., and Roser, M. (2023). Water use and stress. *Our World Data*.

Rodolfo, K. S., and Siringan, F. P. (2006). Global sea-level rise is recognised, but flooding from anthropogenic land subsidence is ignored around northern Manila Bay, Philippines. *Disasters* 30 (1), 118–139. doi:10.1111/j.1467-9523.2006.00310.x

Romero, P. (2022). Asia's coastal cities 'sinking faster than sea level-rise. *SciDev. net-Environment*.

Roque, D., Fonseca, A. M., Henriques, M. J., and Falcão, A. P. (2014). A first approach for displacement analysis in Lisbon Downtown using PS-InSAR. *Procedia Technol.* 16, 288–293. doi:10.1016/j.protcy.2014.10.094

Rosi, A., Tofani, V., Agostini, A., Tanteri, L., Stefanelli, C. T., Catani, F., et al. (2016). Subsidence mapping at regional scale using persistent scatters interferometry (PSI): the case of Tuscany region (Italy). *Int. J. Appl. earth observation geoinformation* 52, 328–337. doi:10.1016/j.jag.2016.07.003

Rotchanameka, S., and Mairaing, W. (2023). *The characteristic of aquifer drawdown and settlement of bangkok and vicinity area*.

Rubinetti, S., Taricco, C., Zanchettin, D., Arnone, E., Bizzarri, I., and Rubino, A. (2022). Interannual-to-multidecadal sea-level changes in the Venice lagoon and their impact on flood frequency. *Clim. Change* 174 (3-4), 26. doi:10.1007/s10584-022-03448-2

Ruilin, H. (2009). "Urban land subsidence in China. Engineering geology for tomorrow's cities," in *Geological society* (London: Engineering Geology Special Publication). (on CD-ROM insert, Paper 786).

Sadjadi, S. (2022). Review on current status and challenging issues of land subsidence in Iran. *J. Future Sustain.* 2 (1), 33–38. doi:10.5267/j.jfs.2022.9.001

Safari Ghaleh, A., and Shahir, H. (2022). Effect of bedrock ridges on formation of earth fissures due to land subsidence. *Bull. Eng. Geol. Environ.* 81 (11), 455. doi:10.1007/s10064-022-02952-0

Sagoe-Addy, K., and Appeaning Addo, K. (2013). Effect of predicted sea level rise on tourism facilities along Ghana's Accra coast. *J. Coast. conservation* 17 (1), 155–166. doi:10.1007/s11852-012-0227-y

Sahu, P., and Sikdar, P. K. (2011). Threat of land subsidence in and around Kolkata city and east Kolkata wetlands, West Bengal, India. *J. earth Syst. Sci.* 120, 435–446. doi:10.1007/s12040-011-0077-2

Sahuquillo, A., Cassiraga, E., Gómez-Hernández, J. J., Andreu, J., Pulido-Velazquez, M., Pulido-Velazquez, D., et al. (2022). Management alternatives of aquifer storage, distribution, and simulation in conjunctive use. *Water* 14 (15), 2332. doi:10.3390/w14152332

Samsonov, S., Tiampo, K., González, P. J., Manville, V., and Jolly, G. (2010). Ground deformation occurring in the city of Auckland, New Zealand, and observed by Envisat interferometric synthetic aperture radar during 2003–2007. *J. Geophys. Res. Solid Earth* 115 (B8). doi:10.1029/2009jb006806

Samsonov, S. V., d'Oreye, N., González, P. J., Tiampo, K. F., Ertolahti, L., and Clague, J. J. (2014). Rapidly accelerating subsidence in the Greater Vancouver region from two decades of ERS-ENVISAT-RADARSAT-2 DInSAR measurements. *Remote Sens. Environ.* 143, 180–191. doi:10.1016/j.rse.2013.12.017

Samsonov, S. V., and Tiampo, K. F. (2016a). "Monitoring of urban subsidence in coastal cities: case studies Vancouver and Seattle," in *Third international conference on digital information processing, data mining, and wireless communications (DIPDMWC)* (IEEE).

Samsonov, S. V., Tiampo, K. F., and Feng, W. (2016b). Fast subsidence in downtown of Seattle observed with satellite radar. *Remote Sens. Appl. Soc. Environ.* 4, 179–187. doi:10.1016/j.rsase.2016.10.001

Sanli, F. B., Calò, F., Abdikan, S., Pepe, A., and Gorum, T. (2014). Analysis of deformation patterns through advanced DINSAR techniques in Istanbul megacity. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 40 (7), 19–21. doi:10.5194/isprsarchives-xl-7-19-2014

Santamaría-Gómez, A., Gravelle, M., Collilieux, X., Guichard, M., Míguez, B. M., Tiphaneau, P., et al. (2012). Mitigating the effects of vertical land motion in tide gauge records using a state-of-the-art GPS velocity field. *Glob. Planet. Change* 98, 6–17. doi:10.1016/j.gloplacha.2012.07.007

Saowiang, K., and Giao, P. H. (2021). Numerical analysis of subsurface deformation induced by groundwater level changes in the Bangkok aquifer system. *Acta Geotech.* 16 (4), 1265–1279. doi:10.1007/s11440-020-01075-8

Sarah, D., and Soebowo, E. (2018). Land subsidence threats and its management in the north coast of java. In *IOP Conf. Ser. Earth Environ. Sci.* 118, 012042. doi:10.1088/1755-1315/118/1/012042

Sarah, D., Soebowo, E., and Satriyo, N. A. (2021). Review of the land subsidence hazard in Pekalongan Delta, Central Java: insights from the subsurface. *Rudarsko-geološko-naftni Zb.* 36 (4), 163–176. doi:10.17794/rgn.2021.4.13

Sartoretto, F., Gambolati, G., and Rinaldo, A. (1990). Land subsidence due to gas/oil production in inhomogeneous transversally anisotropic half-space by a boundary element method. *Int. J. Numer. Anal. methods geomechanics* 14 (6), 379–399. doi:10.1002/nag.1610140602

Sarwar, G., and Alizai, A. (2013). Riding the mobile Karachi arc, Pakistan: understanding tectonic threats. *J. Himal. Earth Sci.* 46 (2).

Sato, C., Haga, M., and Nishino, J. (2006). Land subsidence and groundwater management in Tokyo. *Intern. Rev. Environ. Strat.* 6 (2), 403.

Sato, K., and Van Hoang, N. (1996). Recent countermeasures for land subsidence and groundwater resources in Japan. *Int. J. Rock Mech. Min. Sci. Geomechanics Abstr.* 8 (33).

Satriyo, N. A., and Soebowo, E. (2021). Review of the land subsidence hazard in Pekalongan Delta, Central Java: insights from the subsurface. *Rudarsko-Geolosko-Naftni Zb.* 36 (4), 163–176. doi:10.17794/rgn.2021.4.13

Scheiber, L., David, C. G., Hoballah Jalloul, M., Visscher, J., Nguyen, H. Q., Leitold, R., et al. (2022). Low-regret climate change adaptation in coastal megacities–evaluating large-scale flood protection and small-scale rainwater detention measures for Ho Chi Minh City, Vietnam. *Nat. Hazards Earth Syst. Sci. Discuss.* 2022, 1–22. doi:10.5194/nhess-23-2333-2023

Schmidt, C. W. (2015). *Delta subsidence: an imminent threat to coastal populations*.

Schokker, J., Bakker, M. A. J., Dubelaar, C. W., Dambrink, R. M., and Harting, R. (2015). 3D subsurface modelling reveals the shallow geology of Amsterdam. *Neth. J. Geosciences* 94 (4), 399–417. doi:10.1017/njg.2015.22

Scoular, J., Ghail, R., Mason, P., Lawrence, J., Bellhouse, M., Holley, R., et al. (2020). Retrospective InSAR analysis of east London during the construction of the lee tunnel. *Remote Sens.* 12 (5), 849. doi:10.3390/rs12050849

Secreti, V., Polcari, M., Anderlini, L., Albano, M., Palano, M., Serpelloni, E., et al. (2022). Cross-validated multi-technique geodetic dataset of the Upper Adriatic Sea coastal area of Italy. *Data brief* 43, 108342. doi:10.1016/j.dib.2022.108342

Secreti, V., Trasatti, E., Polcari, M., Albano, M., Anderlini, L., Serpelloni, E., et al. (2020). "Natural and anthropogenic origin of subsidence of the Northern Adriatic coast (Italy) from satellite data and modelling," in *EGU general assembly conference abstracts*, 9903.

Sengupta, D., Chen, R., Meadows, M. E., and Banerjee, A. (2020). Gaining or losing ground? Tracking Asia's hunger for 'new'coastal land in the era of sea level rise. *Sci. Total Environ.* 732, 139290. doi:10.1016/j.scitotenv.2020.139290

Sestini, G. (1996). "Land subsidence and sea-level rise: the case of the Po Delta region, Italy," in *Sea-level rise and coastal subsidence: causes, consequences, and strategies*, 235–248.

Severi, P. (2021). Soil uplift in the Emilia-Romagna plain (Italy) by satellite radar interferometry. *Boll. Geof. Teor. Appl.* 62, 527–542. doi:10.4430/bgo00349

Sew, G. S., and Seng, L. P. (1996). *Investigation into a ground subsidence in limestone formation in kuala lumpur*.

Shen, S., and Xu, Y. (2014). Investigation of the mechanism associated with recent land subsidence in Shanghai. *Shanghai Land Resour.* 35 (4), 12–16. doi:10.1680/geot.54.2.143.36332

Shen, S. L., Wu, H. N., Cui, Y. J., and Yin, Z. Y. (2014). Long-term settlement behaviour of metro tunnels in the soft deposits of Shanghai. *Tunn. Undergr. Space Technol.* 40, 309–323. doi:10.1016/j.tust.2013.10.013

Shen, S. L., and Xu, Y. S. (2011). Numerical evaluation of land subsidence induced by groundwater pumping in Shanghai. *Can. Geotechnical J.* 48 (9), 1378–1392. doi:10.1139/t11-049

Shi, X., Chen, C., Dai, K., Deng, J., Wen, N., Yin, Y., et al. (2022a). Monitoring and predicting the subsidence of dalian jinzhou bay international airport, China by integrating inSAR observation and Terzaghi consolidation theory. *Remote Sens.* 14 (10), 2332. doi:10.3390/rs14102332

Shi, X., Jiang, S., Xu, H., Jiang, F., He, Z., and Wu, J. (2016). The effects of artificial recharge of groundwater on controlling land subsidence and its influence on groundwater quality and aquifer energy storage in Shanghai, China. *Environ. Earth Sci.* 75, 1–18. doi:10.1007/s12665-015-5019-x

Shi, X., Wu, J., Ye, S., Zhang, Y., Xue, Y., Wei, Z., et al. (2008). Regional land subsidence simulation in Su-xi-Chang area and Shanghai City, China. *Eng. Geol.* 100 (1-2), 27–42. doi:10.1016/j.enggeo.2008.02.011

Shi, X., Zhu, T., Tang, W., Jiang, M., Jiang, H., Yang, C., et al. (2022b). Inferring decelerated land subsidence and groundwater storage dynamics in

Tianjin–Langfang using Sentinel-1 InSAR. *Int. J. Digital Earth* 15 (1), 1526–1546. doi:10.1080/17538947.2022.2122610

Shi, Y., Shi, D., and Cao, X. (2018). Impacting factors and temporal and spatial differentiation of land subsidence in Shanghai. *Sustainability* 10 (9), 3146. doi:10.3390/su10093146

Shiru, M. S., Shahid, S., Shiru, S., Chung, E. S., Alias, N., Ahmed, K., et al. (2020). Challenges in water resources of Lagos mega city of Nigeria in the context of climate change. *J. Water Clim. Change* 11 (4), 1067–1083. doi:10.2166/wcc.2019.047

Shirzaei, M., and Bürgmann, R. (2018). Global climate change and local land subsidence exacerbate inundation risk to the San Francisco Bay Area. *Sci. Adv.* 4 (3), eaap9234. doi:10.1126/sciadv.aap9234

Shoham, T. (2006). *Groundwater decline and the preservation of property in Boston*. Doctoral dissertation, Massachusetts Institute of Technology.

Sikdar, P. K., Biswas, A. B., and Saha, A. K. (1996). A study on the possible land subsidence in Calcutta and Howrah cities due to groundwater overdraft. *Indian J. Geol.* 68, 193–200.

Simeoni, U., Tessari, U., Corbau, C., Tosatto, O., Polo, P., and Teatini, P. (2017). Impact of land subsidence due to residual gas production on surficial infrastructures: the Dosso degli Angeli field study (Ravenna, Northern Italy). *Eng. Geol.* 229, 1–12. doi:10.1016/j.enggeo.2017.09.008

Sinclair, W. C. (1982). Sinkhole development resulting from ground-water withdrawal in the Tampa area, Florida. *U. S. Geol. Surv. Water Resour. Div*.

Single, M. (2008). Global change and integrated coastal management: the Asia-Pacific region. *N. Z. Geogr.* 64 (2), 171–172. doi:10.1111/j.1745-7939.2008.136_3.x

Siriwardane-de Zoysa, R. (2020). Beyond the wall: dyking as an object of everyday governance in the Bay of Manila, Philippines. *Mar. Policy* 112, 103661. doi:10.1016/j.marpol.2019.103661

Siriwardane-de Zoysa, R., Schöne, T., Herbeck, J., Illigner, J., Haghighi, M., Simarmata, H., et al. (2021). The 'wickedness' of governing land subsidence: policy perspectives from urban Southeast Asia. *PLoS One* 16 (6), e0250208. doi:10.1371/journal.pone.0250208

Situmorang, D., Arhatin, R. E., and Lumban-Gaol, J. (2021). Land subsidence detection in jakarta province using sentinel-1A satellite imagery. *IOP Conf. Ser. Earth Environ. Sci.* 944 (1), 012036. doi:10.1088/1755-1315/944/1/012036

Soares, P. F. C., Zuchello, F., Anjos, L. H. C. D., Pereira, M. G., and Oliveira, A. P. P. D. (2015). Soil attributes and c and n variation in histosols under different agricultural usages in the state of Rio de Janeiro, Brazil. *Biosci. j.(Online)* 31, 1349–1362. doi:10.14393/bj-v31n5a2015-26365

Soboyejo, L. A., Giambastiani, B. M., Molducci, M., and Antonellini, M. (2021). Different processes affecting long-term Ravenna coastal drainage basins (Italy): implications for water management. *Environ. Earth Sci.* 80 (15), 493. doi:10.1007/s12665-021-09774-5

Solari, L., Del Soldato, M., Bianchini, S., Ciampalini, A., Ezquerro, P., Montalti, R., et al. (2018). From ERS 1/2 to Sentinel-1: subsidence monitoring in Italy in the last two decades. *Front. Earth Sci.* 6, 149. doi:10.3389/feart.2018.00149

Somerville, S. H., and Shelton, J. C. (1972). Observed settlement of multi-storey buildings on laminated clays and silts in Glasgow. *Géotechnique* 22 (3), 513–520. doi:10.1680/geot.1972.22.3.513

Soudarin, L., Crétaux, J. F., and Cazenave, A. (1999). Vertical crustal motions from the DORIS space-geodesy system. *Geophys. Res. Lett.* 26 (9), 1207–1210. doi:10.1029/1999gl900215

Sousa, J. J., Bastos, L. C., Ruiz, A. M., Hooper, A. J., and Hanssen, R. (2012). Detection of ground deformation in the oporto metropolitan area with multi-temporal interferometry (MTI). *Fringe* 697, 92–9092.

Standing, J. R., and Burland, J. B. (2006). Unexpected tunnelling volume losses in the Westminster area, London. *Géotechnique* 56 (1), 11–26. doi:10.1680/geot.2006.56.1.11

Stanley, J. D., and Clemente, P. L. (2017). Increased land subsidence and sea-level rise are submerging Egypt's Nile Delta coastal margin. *GSA Today* 27 (5), 4–11. doi:10.1130/gsatg312a.1

Steckler, M. S., Akhter, S. H., Seeber, L., Bilham, R. G., Kogan, M. G., Masson, F., et al. (2012). GPS velocities and structure across the Burma accretionary prism and shillong anticline in Bangladesh. *AGU Fall Meet. Abstr.* 2012, T51F–T2667.

Steckler, M. S., Nooner, S. L., Akhter, S. H., Chowdhury, S. K., Bettadpur, S., Seeber, L., et al. (2010). Modeling Earth deformation from monsoonal flooding in Bangladesh using hydrographic, GPS, and Gravity Recovery and Climate Experiment (GRACE) data. *J. Geophys. Res. Solid Earth* 115 (B8). doi:10.1029/2009jb007018

Steckler, M. S., Oryan, B., Wilson, C. A., Grall, C., Nooner, S. L., Mondal, D. R., et al. (2022). Synthesis of the distribution of subsidence of the lower Ganges-Brahmaputra Delta, Bangladesh. *Earth-Science Rev.* 224, 103887. doi:10.1016/j.earscirev.2021.103887

Strehle, R. (1987). *Subsidence in long beach*.

Strozzi, T., Teatini, P., Tosi, L., Wegmüller, U., and Werner, C. (2013). Land subsidence of natural transitional environments by satellite radar interferometry on artificial reflectors. *J. Geophys. Res. Earth Surf.* 118 (2), 1177–1191. doi:10.1002/jgrf.20082

Strozzi, T., Tosi, L., Teatini, P., and Wegmüller, U. (2008). "Monitoring land subsidence in the Venice lagoon with TerraSAR-X," in *3rd TerraSAR-X science team meeting* (Germany: Oberpfaffenhofen), 25–26.

Strozzi, T., Tosi, L., Teatini, P., Werner, C., and Wegmüller, U. (2009). "Monitoring land subsidence within the Venice lagoon with SAR interferometry on trihedral corner reflectors," in *2009 IEEE international geoscience and remote sensing symposium* (IEEE), 4, IV–33. doi:10.1109/igarss.2009.5417602

Strozzi, T., Tosi, L., Wegmüller, U., Teatini, P., Carbognin, L., and Rosselli, R. (2002). "Thematic and land subsidence maps of the Lagoon of Venice from ERS SAR interferometry," in *Scientific Research and Safeguarding of Venice. CORILA Research program 2001-2003. Vol. I. 2001 results. CORILA, Venezia; Istituto Veneto di Scienze* (Lettere ed Arti, Venezia; La Garangola, Padova).

Strozzi, T., Tosi, L., Wegmuller, U., Werner, C., Teatini, P., and Carbognin, L. (2003a). "Land subsidence monitoring service in the Lagoon of Venice," in *Igarss 2003. 2003 IEEE international geoscience and remote sensing symposium. Proceedings* (IEEE: IEEE Cat. No. 03CH37477), 1, 212–214. doi:10.1109/igarss.2003.1293727

Strozzi, T., Wegmuller, U., Tosi, L., Bitelli, G., and Spreckels, V. (2001). Land subsidence monitoring with differential SAR interferometry. *Photogrammetric Eng. remote Sens.* 67 (11), 1261–1270.

Strozzi, T., Wegmüller, U., Werner, C., Wiesmann, A., Tosi, L., Teatini, P., et al. (2003b). Venezia subsidence monitoring service in the lagoon of venice for regional administrative and water authorities data user programme (dup), ii period executive summary.

Strozzi, T., WegmüllerWe, U., Werner, C., Teatini, P., and Tosi, L. (2005). "SAR Interferometric point target analysis and application to the monitoring of land subsidence in the Venice Lagoon," in *Land subsidence* (Shanghai Scientific & Technical Publishers).

Subraelu, P., Ebraheem, A. A., Sherif, M., Sefelnasr, A., Yagoub, M. M., and Rao, K. N. (2022). Land in water: the study of land reclamation and artificial islands formation in the uae coastal zone: a remote sensing and gis perspective. *Land* 11 (11), 2024. doi:10.3390/land11112024

Suganthi, S., and Elango, L. (2020). Estimation of groundwater abstraction induced land subsidence by SBAS technique. *J. Earth Syst. Sci.* 129 (1), 46. doi:10.1007/s12040-019-1298-z

Suganthi, S., Elango, L., and Subramanian, S. K. (2017). Microwave D-InSAR technique for assessment of land subsidence in Kolkata city, India. *Arabian J. Geosciences* 10, 1–10. doi:10.1007/s12517-017-3207-6

Sun, Q., Jiang, L., Jiang, M., Lin, H., Ma, P., and Wang, H. (2018). Monitoring coastal reclamation subsidence in Hong Kong with distributed scatterer interferometry. *Remote Sens.* 10 (11), 1738. doi:10.3390/rs10111738

Sundell, J., Haaf, E., Norberg, T., Alén, C., Karlsson, M., and Rosén, L. (2019). Risk mapping of groundwater-drawdown-induced land subsidence in heterogeneous soils on large areas. *Risk Anal.* 39 (1), 105–124. doi:10.1111/risa.12890

Sundell, J., and Rosén, L. (2016). *City-Link Stockholm; an integrated hydrogeological and geotechnical risk assessment. NGU REPORT*, 20.

Tabassum, F., Imtiaz, F., Alam, J., and Alam[4], T. (2024). *Risk assesment of sinkhole occurrence in Bangladesh by analyzing trigger factors of south asian sinkhole collapse incidents with suggestions for possible preventive measures*.

Taftazani, R., Kazama, S., and Takizawa, S. (2022). Spatial analysis of groundwater abstraction and land subsidence for planning the piped water supply in jakarta, Indonesia. *Water* 14 (20), 3197. doi:10.3390/w14203197

Takagi, H., Esteban, M., Mikami, T., Pratama, M. B., Valenzuela, V. P. B., and Avelino, J. E. (2021). People's perception of land subsidence, floods, and their connection: a note based on recent surveys in a sinking coastal community in Jakarta. *Ocean Coast. Manag.* 211, 105753. doi:10.1016/j.ocecoaman.2021.105753

Takagi, H., Fujii, D., Esteban, M., and Yi, X. (2017). Effectiveness and limitation of coastal dykes in Jakarta: the need for prioritizing actions against land subsidence. *Sustainability* 9 (4), 619. doi:10.3390/su9040619

Takami, J. (2021). "Monitoring artificial islands subsidence in North jakarta using persistent and distributed scatterers InSAR analysis," in *2021 IEEE international geoscience and remote sensing symposium IGARSS* (IEEE), 6956–6959.

Takekawa, J. Y., Thorne, K. M., Buffington, K. J., Spragens, K. A., Swanson, K. M., Drexler, J. Z., et al. (2013). *Final report for sea-level rise response modeling for San Francisco Bay estuary tidal marshes (No. 2013-1081)*. US Geological Survey.

Talib, O. C., Shimon, W., Sarah, K., and Tonian, R. (2022). Detection of sinkhole activity in West-Central Florida using InSAR time series observations. *Remote Sens. Environ.* 269, 112793. doi:10.1016/j.rse.2021.112793

Tang, M., Zhao, Q., Pepe, A., Devlin, A. T., Falabella, F., Yao, C., et al. (2022a). Changes of Chinese coastal regions induced by land reclamation as revealed through TanDEM-X DEM and InSAR analyses. *Remote Sens.* 14 (3), 637. doi:10.3390/rs14030637

Tang, W., Zhao, X., Motagh, M., Bi, G., Li, J., Chen, M., et al. (2022b). Land subsidence and rebound in the Taiyuan basin, northern China, in the context of inter-basin water transfer and groundwater management. *Remote Sens. Environ.* 269, 112792. doi:10.1016/j.rse.2021.112792

Tang, Y. Q., Cui, Z. D., Wang, J. X., Lu, C., and Yan, X. X. (2008). Model test study of land subsidence caused by high-rise building group in Shanghai. *Bull. Eng. Geol. Environ.* 67, 173–179. doi:10.1007/s10064-008-0121-x

Tao, Q., Guo, Z., Wang, F., An, Q., and Han, Y. (2021). SBAS-InSAR time series ground subsidence monitoring along Metro Line 13 in Qingdao, China. *Arabian J. geosciences* 14, 1–14. doi:10.1007/s12517-021-08616-9

Taqwa, F. M. L., Hutabarat, L. E., Ilyas, T., and Prakoso, W. A. (2019). Estimation of settlement induced land subsidence of marine clay on kamal muara area, northern jakarta, based on the change of pore water pressure. *J. Phys. Conf. Ser.* 1376 (1), 012007. doi:10.1088/1742-6596/1376/1/012007

Tay, C., Lindsey, E., Chin, S. T., McCaughey, J., Bekaert, D., Nguyen, M., et al. (2021). *Sinking land intensifies sea-level rise: a global InSAR analysis of coastal cities*.

Tay, C., Lindsey, E. O., Chin, S. T., McCaughey, J. W., Bekaert, D., Nguyen, M., et al. (2022). Sea-level rise from land subsidence in major coastal cities. *Nat. Sustain.* 5 (12), 1049–1057. doi:10.1038/s41893-022-00947-z

Teatini, P., Ferronato, M., Gambolati, G., Bertoni, W., and Gonella, M. (2005a). A century of land subsidence in Ravenna, Italy. *Environ. Geol.* 47, 831–846. doi:10.1007/s00254-004-1215-9

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 (1). doi:10.1029/2005wr004242

Teatini, P., Gambolati, G., Tomasi, L., and Putti, M. (1998). "Simulation of land subsidence due to gas production at Ravenna coastline," in *CENAS: coastline evolution of the upper adriatic sea due to sea level rise and natural and anthropogenic land subsidence*, 133–150.

Teatini, P., Strozzi, T., Tosi, L., Wegmüller, U., Werner, C., and Carbognin, L. (2007). Assessing short-and long-time displacements in the Venice coastland by synthetic aperture radar interferometric point target analysis. *J. Geophys. Res. Earth Surf.* 112 (F1). doi:10.1029/2006jf000656

Teatini, P., and Tosi, L. (2013). La subsidenza naturale e antropica di Venezia. Monitoraggio e analisi tramite satelliti con tecnologia "Synthetic Aperture Radar"(SAR). *Geocentro Mag.* 5 (29), 86–84.

Teatini, P., Tosi, L., and Strozzi, T. (2011). Quantitative evidence that compaction of Holocene sediments drives the present land subsidence of the Po Delta, Italy. *J. Geophys. Res. Solid Earth* 116 (B8), B08407. doi:10.1029/2010jb008122

Teatini, P., Tosi, L., and Strozzi, T. (2014). "Capability of X-band persistent scatterer interferometry to monitor land subsidence in the venice lagoon," in *Engineering geology for society and territory–volume 4: marine and coastal processes* (Springer International Publishing), 175–178.

Teatini, P., Tosi, L., Strozzi, T., Carbognin, L., Cecconi, G., Rosselli, R., et al. (2012). Resolving land subsidence within the Venice Lagoon by persistent scatterer SAR interferometry. *Phys. Chem. Earth, Parts A/B/C* 40, 72–79. doi:10.1016/j.pce.2010.01.002

Teatini, P., Tosi, L., Strozzi, T., Carbognin, L., Wegmüller, U., and Rizzetto, F. (2005b). Mapping regional land displacements in the Venice coastland by an integrated monitoring system. *Remote Sens. Environ.* 98 (4), 403–413. doi:10.1016/j.rse.2005.08.002

Teeuw, R. (2007). Applications of remote sensing for geohazard mapping in coastal and riverine environments. *Geol. Soc. Lond. Spec. Publ.* 283 (1), 93–106. doi:10.1144/sp283.8

Terranova, C., Ventura, G., and Vilardo, G. (2015). Multiple causes of ground deformation in the Napoli metropolitan area (Italy) from integrated Persistent Scatterers DinSAR, geological, hydrological, and urban infrastructure data. *Earth-science Rev.* 146, 105–119. doi:10.1016/j.earscirev.2015.04.001

Tesauro, M., Berardino, P., Lanari, R., Sansosti, E., Fornaro, G., and Franceschetti, G. (2000). Urban subsidence inside the city of Napoli (Italy) observed by satellite radar interferometry. *Geophys. Res. Lett.* 27 (13), 1961–1964. doi:10.1029/2000gl008481

Tessitore, S., Ramondini, M., and Calcaterra, D. (2011). "Applicazione di tecniche satellitari al monitoraggio delle deformazioni del suolo," in *Iarg 2011*, 1–6.

Thanvisitthpon, N., Shrestha, S., and Pal, I. (2018). Urban flooding and climate change: a case study of Bangkok, Thailand. *Environ. Urbanization ASIA* 9 (1), 86–100. doi:10.1177/0975425317748532

Thoang, T. T., and Giao, P. H. (2015). Subsurface characterization and prediction of land subsidence for HCM City, Vietnam. *Eng. Geol.* 199, 107–124. doi:10.1016/j.enggeo.2015.10.009

Timothy, J. (2015). *Current land subsidence and groundwater level changes in the Houston metropolitan area (2005–2012)*. American Society of Civil Engineers.

Tirmizi, O., and Khan, S. (2021). Hazard potential in southern Pakistan: a study on the subsidence and neotectonics of Karachi and surrounding areas. *AGU Fall Meet. Abstr.* 2021, EP55A–1056. doi:10.3390/rs15051290

Toivanen, T. L., and Leveinen, J. (2015). "Groundwater level variation and deformation in clays characteristic to the Helsinki metropolitan area," in *Engineering geology for society and territory-volume 6: applied geology for major engineering projects* (Springer International Publishing), 309–312.

Tomás, R., Romero, R., Mulas, J., Marturià, J. J., Mallorquí, J. J., López-Sánchez, J. M., et al. (2014). Radar interferometry techniques for the study of ground subsidence phenomena: a review of practical issues through cases in Spain. *Environ. earth Sci.* 71, 163–181. doi:10.1007/s12665-013-2422-z

Tosi, L., Da Lio, C., Strozzi, T., and Teatini, P. (2016). Combining L-and X-band SAR interferometry to assess ground displacements in heterogeneous coastal environments: the Po River Delta and Venice Lagoon, Italy. *Remote Sens.* 8 (4), 308. doi:10.3390/rs8040308

Tosi, L., Lio, C. D., Teatini, P., and Strozzi, T. (2018). Land subsidence in coastal environments: knowledge advance in the Venice coastland by TerraSAR-X PSI. *Remote Sens.* 10 (8), 1191. doi:10.3390/rs10081191

Tosi, L., Strozzi, T., Da Lio, C., and Teatini, P. (2015). Regional and local land subsidence at the Venice coastland by TerraSAR-X PSI. *Proc. Int. Assoc. Hydrological Sci.* 372 (372), 199–205. doi:10.5194/piahs-372-199-2015

Tosi, L., Teatini, P., Carbognin, L., and Brancolini, G. (2009). Using high resolution data to reveal depth-dependent mechanisms that drive land subsidence: the Venice coast, Italy. *Tectonophysics* 474 (1-2), 271–284. doi:10.1016/j.tecto.2009.02.026

Tosi, L., Teatini, P., Carbognin, L., and Frankenfield, J. (2007). A new project to monitor land subsidence in the northern Venice coastland (Italy). *Environ. Geol.* 52, 889–898. doi:10.1007/s00254-006-0530-8

Tosi, L., Teatini, P., and Strozzi, T. (2013). Natural versus anthropogenic subsidence of Venice. *Sci. Rep.* 3 (1), 2710–2719. doi:10.1038/srep02710

Tosi, L., Teatini, P., Strozzi, T., Carbognin, L., Brancolini, G., and Rizzetto, F. (2010). Ground surface dynamics in the northern Adriatic coastland over the last two decades. *Rendiconti Lincei* 21, 115–129. doi:10.1007/s12210-010-0084-2

Tosi, L., Teatini, P., Strozzi, T., and Da Lio, C. (2014). "Relative land subsidence of the Venice coastland, Italy," in *Engineering geology for society and territory–volume 4: marine and coastal processes* (Springer International Publishing), 171–173.

Tseng, H.-T., Yu, H.-L., and Chang, T.-J. (2020). Using data-based modeled groundwater model to developing groundwater optimal pumping strategy-A case of Taipei basin. *EGU General Assem. Conf. Abstr.*

Tularam, G. A., and Krishna, M. J. J. O. A. S. I. E. S. (2009). Long term consequences of groundwater pumping in Australia: a review of impacts around the globe. *J. Appl. Sci. Environ. Sanitation* 4 (2).

Turcott, E., and Maathuis, H. (1996). Groundwater abstraction-induced land subsidence prediction: bangkok and Jakarta case studies. *Int. J. Rock Mech. Min. Sci. Geomechanics Abstr.* 7 (33), 298A.

Ulma, T., Mutiara Anjasmara, I., and Hayati, N. (2021). Atmospheric phase delay correction of PS-InSAR to monitor land subsidence in Surabaya. *IOP Conf. Ser. Earth Environ. Sci.* 936 (1), 012033. doi:10.1088/1755-1315/936/1/012033

UN (2015). Transforming our world: the 2030 Agenda for sustainable development (UN, New York, 2015) using DMSP/OLS night time lights and SPOT-VGT data. *Int. J.*

Vadivel, S. K. P., Kim, D. J., Jung, J., and Cho, Y. K. (2022). "Vertical land motion monitoring at tide gauges in Korean peninsula using sequential sbas-insar," in *IGARSS 2022-2022 IEEE international geoscience and remote sensing symposium* (IEEE), 6951–6954.

Van Beers, M. (2017). *Floodwater governance as key urban challenge in beira, Barranquilla and Ho Chi Minh city (doctoral dissertation)*.

Van der Horst, T. (2017a). *Sinking Yangon: detection of subsidence caused by groundwater extraction using SAR interferometry and PSI time-series analysis for Sentinel-1 data*.

van der Horst, T. (2017b). *Land subsidence in Yangon: don't blame the messenger*. TU Delft DeltaLinks.

van der Horst, T., Rutten, M. M., van de Giesen, N. C., and Hanssen, R. F. (2018). Monitoring land subsidence in Yangon, Myanmar using Sentinel-1 persistent scatterer interferometry and assessment of driving mechanisms. *Remote Sens. Environ.* 217, 101–110. doi:10.1016/j.rse.2018.08.004

Van Veen, J. (1954). Tide-gauges, subsidence-gauges and flood-stones in The Netherlands. *Geol. Mijnb.* 16 (6), 214–219.

Vassileva, M., Al-Halbouni, D., Motagh, M., Walter, T. R., Dahm, T., and Wetzel, H. U. (2021a). A decade-long silent ground subsidence hazard culminating in a metropolitan disaster in Maceió, Brazil. *Sci. Rep.* 11, 7704. doi:10.1038/s41598-021-87033-0

Vassileva, M., Al-Halbouni, D., Motagh, M., Walter, T. R., Dahm, T., and Wetzel, H. U. (2021b). "Man-made disaster on urban area: subsidence and underground salt dissolution in Maceio (Brazil) revealed by remote sensing and numerical modelling," in *EGU general assembly conference abstracts*, EGU21–12371. doi:10.5194/egusphere-egu21-12371

Vassileva, M. S., Al-Halbouni, D., Dahm, T., Motagh, M., Walter, T., and Wetzel, H. U. (2020). Rapidly accelerating subsidence in Maceió (Brazil) analazyed by multi-temporal

DInSAR analysis and 2d geomechanical modeling (No. EGU2020-19905). *Copernic. Meet*.

Vicente, E. M., Amurane, D. P., and Leonardo, X. (2006). *Assessment of slope stability in maputo city, Mozambique*.

Vicente, E. M., Jermy, C. A., and Schreiner, H. D. (2009). "Urban geology of Maputo, Mocambique." Engineering geology of tomorrow's cities," in *Geological society* (London: Engineering Geology Special Publication), 22.

Vishwanath Harish, T., Sairam, N., Yang, L. E., Garschagen, M., and Kreibich, H. (2022). "Identifying the drivers of private flood precautionary measures," in *Ho Chi Minh city, vietnam* (EGUsphere), 2022, 1–25.

Vollrath, A., Bekaert, D., Bonforte, A., Guglielmino, F., Hooper, A., Stramondo, S., et al. (2014). "The advancement of intraplate tectonic motion detection by the use of atmospherically corrected InSAR time-series and its decomposition into a 3D-field vector in South-east sicily, Italy," in *AGU fall meeting abstracts*, 2014, G31A–G0405.

Vollrath, A., Zucca, F., Bekaert, D., Bonforte, A., Guglielmino, F., Hooper, A. J., et al. (2017). Decomposing DInSAR time-series into 3-D in combination with GPS in the case of low strain rates: an application to the Hyblean Plateau, Sicily, Italy. *Remote Sens.* 9 (1), 33. doi:10.3390/rs9010033

Wang, G., Greuter, A., Petersen, C. M., and Turco, M. J. (2022a). Houston GNSS network for subsidence and faulting monitoring: data analysis methods and products. *J. Surv. Eng.* 148 (4), 04022008. doi:10.1061/(asce)su.1943-5428.0000399

Wang, G., Welch, J., Kearns, T. J., Yang, L., and Serna, J., Jr (2015a). Introduction to GPS geodetic infrastructure for land subsidence monitoring in Houston, Texas, USA. *Proc. Int. Assoc. Hydrological Sci.* 372, 297–303. doi:10.5194/piahs-372-297-2015

Wang, G., Yu, J., Kearns, T. J., and Ortega, J. (2014a). Assessing the accuracy of long-term subsidence derived from borehole extensometer data using GPS observations: case study in Houston, Texas. *J. Surv. Eng.* 140 (3), 05014001. doi:10.1061/(asce)su.1943-5428.0000133

Wang, H., Feng, G., Xu, B., Yu, Y., Li, Z., Du, Y., et al. (2017). Deriving spatio-temporal development of ground subsidence due to subway construction and operation in delta regions with PS-InSAR data: a case study in Guangzhou, China. *Remote Sens.* 9 (10), 1004. doi:10.3390/rs9101004

Wang, H., Wright, T. J., Yu, Y., Lin, H., Jiang, L., Li, C., et al. (2012). InSAR reveals coastal subsidence in the Pearl River Delta, China. *Geophys. J. Int.* 191 (3), 1119–1128. doi:10.1111/j.1365-246x.2012.05687.x

Wang, H., Yu, Y. P., and Jiang, L. L. (2014c). Monitoring land subsidence in Guangzhou and Foshan using InSAR. *Sci. Surv. Mapp.* 39, 66–71.

Wang, H. M., Wang, Y., Jiao, X., and Qian, G. R. (2014b). Risk management of land subsidence in Shanghai. *Desalination Water Treat.* 52 (4-6), 1122–1129. doi:10.1080/19443994.2013.826337

Wang, J., Gu, X., Jiang, Y., Huang, T., and Feng, B. (2013). Point-line-area-volume index system of land subsidence and application in Ningbo, China. *Nat. hazards* 69, 2197–2214. doi:10.1007/s11069-013-0801-0

Wang, J., Yang, T., Wang, G., Liu, X., Xu, Na, Stoumather, E., et al. (2022). *Control and prevent land subsidence caused by foundation pit dewatering in a coastal lowland mega city: indicator definition, numerical simulation and regression analysis*. doi:10.21203/rs.3.rs-1221768/v1

Wang, J. X., Liu, X. T., and Yang, T. L. (2015b). Prevention partition for land subsidence induced by engineering dewatering in Shanghai. *Proc. Int. Assoc. Hydrological Sci.* 372 (372), 207–210. doi:10.5194/piahs-372-207-2015

Wang, M., Li, T., and Jiang, L. (2016). Monitoring reclaimed lands subsidence in Hong Kong with InSAR technique by persistent and distributed scatterers. *Nat. hazards* 82, 531–543. doi:10.1007/s11069-016-2196-1

Wang, Q., Zhao, Q., Ding, J., Fedotov, A. A., Badenko, V., Liu, M., et al. (2020). Investigation of the ground displacement in Saint Petersburg, Russia, using multiple-track differential synthetic aperture radar interferometry. *Int. J. Appl. Earth Observation Geoinformation* 87, 102050. doi:10.1016/j.jag.2020.102050

Wang, R., Yang, M., Dong, J., and Liao, M. (2022c). Investigating deformation along metro lines in coastal cities considering different structures with InSAR and SBM analyses. *Int. J. Appl. Earth Observation Geoinformation* 115, 103099. doi:10.1016/j.jag.2022.103099

Wang, R., Yang, M., Yang, T., Lin, J., and Liao, M. (2022d). Decomposing and mapping different scales of land subsidence over Shanghai with X-and C-Band SAR data stacks. *Int. J. Digital Earth* 15 (1), 478–502. doi:10.1080/17538947.2022.2036835

Wang, S. F., and Zheng, M. X. (2011). Application of biot consolidation theory to analyze land subsidence. *Adv. Mater. Res.* 168, 2615–2618. doi:10.4028/www.scientific.net/amr.168-170.2615

Wang, W. (2014). "Detection of land subsidence of Shanghai: a research based on differential SAR interferometry," in *Earth observing missions and sensors: development, implementation, and characterization* (SPIE), 9264, 277–285. doi:10.1117/12.2068383

Wang, Y. (1998). Sea-level changes, human impacts and coastal responses in China. *J. Coast. Res.*, 31–36.

Ward, P. J., Pauw, W. P., Van Buuren, M. W., and Marfai, M. A. (2013). Governance of flood risk management in a time of climate change: the cases of Jakarta and Rotterdam. *Environ. Polit.* 22 (3), 518–536. doi:10.1080/09644016.2012.683155

Wassie, Y., Gao, Q., Monserrat, O., Barra, A., Crippa, B., and Crosetto, M. (2022). Differential sar interferometry for the monitoring of land subsidence along railway infrastructures. International archives of the photogrammetry. *Remote Sens. Spatial Inf. Sci*. doi:10.5194/isprs-archives-XLIII-B3-2022-361-2022

Water, U. N. (2022). "Groundwater: making the invisible visible," in *The United Nations world water development report*.

Watson, K. M., Bock, Y., and Sandwell, D. T. (2002). Satellite interferometric observations of displacements associated with seasonal groundwater in the Los Angeles basin. *J. Geophys. Res. Solid Earth* 107 (B4). ETG-8. doi:10.1029/2001jb000470

Wdowinski, S., and Fiaschi, S. (2022). "Localized coastal subsidence in Miami beach and surfside, Florida," in *EGU general assembly conference abstracts*, EGU22–3199.

Wdowinski, S., Oliver-Cabrera, T., and Fiaschi, S. (2020). Land subsidence contribution to coastal flooding hazard in southeast Florida. *Proc. IAHS* 382, 207–211. doi:10.5194/piahs-382-207-2020

Widodo, J., Herlambang, A., Sulaiman, A., Razi, P., Perissin, D., Kuze, H., et al. (2019). Land subsidence rate analysis of Jakarta Metropolitan Region based on D-InSAR processing of Sentinel data C-Band frequency. *J. Phys. Conf. Ser.* 1185 (1), 012004. doi:10.1088/1742-6596/1185/1/012004

Willis, M. J., Tiampo, K. F., Heijkoop, E. R., and Nerem, R. S. (2021). "Monitoring of coastal subsidence by combining multiple sensors," in *2021 IEEE international geoscience and remote sensing symposium IGARSS* (IEEE), 1715–1718.

Winslow, A. G., and Doyel, W. W. (1954). Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas. *Econ. Geol.* 49 (4), 413–422. doi:10.2113/gsecongeo.49.4.413

Wnuk, K. C. (2021). *Post-processing of InSAR persistent scatterer time-series to investigate deformational processes induced by subsurface excavation*. 2021-Mines Theses & Dissertations.

Wöppelmann, G., Le Cozannet, G., De Michele, M., Raucoules, D., Cazenave, A., Garcin, M., et al. (2013). Is land subsidence increasing the exposure to sea level rise in Alexandria, Egypt? *Geophys. Res. Lett.* 40 (12), 2953–2957. doi:10.1002/grl.50568

Worawattanamateekul, J. (2006). *The application of advanced interferometric radar analysis for monitoring ground subsidence doctoral dissertation*. Technische Universität München.

Wu, H. A., Zhang, Y. H., Luo, G. F., Kang, Y. K., and Zhu, Y. M. (2016). Monitoring ground subsidence in areas covered by dense vegetation using terrasar-X images: a case study of hangzhou. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 41, 55–59. doi:10.5194/isprs-archives-xli-b7-55-2016

Wu, H. N., Shen, S. L., and Yang, J. (2017). Identification of tunnel settlement caused by land subsidence in soft deposit of Shanghai. *J. Perform. Constr. Facil.* 31 (6), 04017092. doi:10.1061/(asce)cf.1943-5509.0001082

Wu, J., Shi, X., Xue, Y., Zhang, Y., Wei, Z., and Yu, J. (2008). The development and control of the land subsidence in the Yangtze Delta, China. *Environ. Geol.* 55, 1725–1735. doi:10.1007/s00254-007-1123-x

Wu, P. C., Wei, M., and D'Hondt, S. (2022). Subsidence in coastal cities throughout the world observed by InSAR. *Geophys. Res. Lett.* 49 (7), e2022GL098477. doi:10.1029/2022gl098477

Wu, Z., Zhao, Z., Zheng, Y., and Ma, P. (2021). "Automatic detection of widely distributed local-scale subsidence bowls in rapidly urbanizing metropolitan region using time-series InSAR and deep learning methods," in *2021 IEEE international geoscience and remote sensing symposium IGARSS* (IEEE), 8464–8467.

Xiong, S., Wang, C., Qin, X., Zhang, B., and Li, Q. (2021). Time-series analysis on persistent scatter-interferometric synthetic aperture radar (PS-InSAR) derived displacements of the Hong Kong–Zhuhai–Macao bridge (HZMB) from Sentinel-1A observations. *Remote Sens.* 13 (4), 546. doi:10.3390/rs13040546

Xiong, Z., Deng, K., Feng, G., Miao, L., Li, K., He, C., et al. (2022). Settlement prediction of reclaimed coastal airports with InSAR observation: a case study of the Xiamen Xiang'an International Airport, China. *Remote Sens.* 14 (13), 3081. doi:10.3390/rs14133081

Xu, B., Feng, G., Li, Z., Wang, Q., Wang, C., and Xie, R. (2016a). Coastal subsidence monitoring associated with land reclamation using the point target based SBAS-InSAR method: a case study of Shenzhen, China. *Remote Sens.* 8 (8), 652. doi:10.3390/rs8080652

Xu, H., Tian, Z., Sun, L., Ye, Q., Ragno, E., Bricker, J., et al. (2022). Compound flood impact of water level and rainfall during tropical cyclone periods in a coastal city: the case of Shanghai. *Nat. Hazards Earth Syst. Sci.* 22 (7), 2347–2358. doi:10.5194/nhess-22-2347-2022

Xu, Y. S., Ma, L., Shen, S. L., and Sun, W. J. (2012). Evaluation of land subsidence by considering underground structures that penetrate the aquifers of Shanghai, China. *Hydrogeology J.* 20 (8), 1623–1634. doi:10.1007/s10040-012-0892-9

Xu, Y. S., Shen, S. L., Cai, Z. Y., and Zhou, G. Y. (2008). The state of land subsidence and prediction approaches due to groundwater withdrawal in China. *Nat. Hazards* 45, 123–135. doi:10.1007/s11069-007-9168-4

Xu, Y. S., Shen, S. L., Hayashi, S., and Cai, Z. Y. (2007). Analysis on groundwater withdrawal and land subsidence in Shanghai. *Lowl. Technol. Int.* 9 (2, Dec), 2–7.

Xu, Y. S., Shen, S. L., Ren, D. J., and Wu, H. N. (2016b). Analysis of factors in land subsidence in Shanghai: a view based on a strategic environmental assessment. *Sustainability* 8 (6), 573. doi:10.3390/su8060573

Yamamoto, S. (1984). "Case history No. 9.5. Osaka, Japan," in *Guidebook to studies of land subsidence due to groundwater withdrawal*. Editor J. E. Poland (Paris: UNESCO), 185–194.

Yamamoto, S. (1995). *Recent trend of land subsidence in Japan*, 234. IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences, 487.

Yamamoto, S., and Poland, J. F. (1984). "Case history No. 9.4. Tokyo, Japan," in *Guidebook to studies of land subsidence due to groundwater withdrawal* (Paris: United Nations Educational, Scientific and Cultural Organization), 175–184.

Yan, D., Ge, D., Yang, J., Zhang, L., Wang, Y., and Guo, X. (2010). "PSI analyses of land subsidence due to economic development near the city of Hangzhou, China," in *2010 IEEE international geoscience and remote sensing symposium* (IEEE), 2410–2413.

Yan, D., Zeng, Q., Guo, X., and Ge, D. (2012). "PSI analyses of land subsidence due to industrial structure near the city of Hangzhou, China," in *2012 IEEE international geoscience and remote sensing symposium* (IEEE), 6725–6728.

Yan, H., Dai, W., Xie, L., and Xu, W. (2022). Fusion of GNSS and InSAR time series using the improved STRE model: applications to the San Francisco Bay Area and Southern California. *J. Geodesy* 96 (7), 47. doi:10.1007/s00190-022-01636-7

Yan, X., Xu, Y., Yang, T., Tosi, L., Stouthamer, E., Minderhoud, P., et al. (2022c). Sustainable development of coastal cities through control of land subsidence: activities of IGCP Project 663 in Jakarta. *Episodes J. Int. Geoscience* 45 (1), 101–108. doi:10.18814/epiiugs/2021/021014

Yan, X., Yang, T., Xu, Y., Tosi, L., Stouthamer, E., Andreas, H., et al. (2020). Advances and practices on the research, prevention and control of land subsidence in coastal cities. *Acta Geol. Sinica-English Ed.* 94 (1), 162–175. doi:10.1111/1755-6724.14403

Yang, M., Wang, R., Li, M., and Liao, M. (2022). A PSI targets characterization approach to interpreting surface displacement signals: a case study of the Shanghai metro tunnels. *Remote Sens. Environ.* 280, 113150. doi:10.1016/j.rse.2022.113150

Yang, M., Yang, T., Zhang, L., Lin, J., Qin, X., and Liao, M. (2018). Spatio-temporal characterization of a reclamation settlement in the Shanghai coastal area with time series analyses of X-C-and L-band SAR datasets. *Remote Sens.* 10 (2), 329. doi:10.3390/rs10020329

Yang, T., Wang, H., and Jiao, X. (2014). Land subsidence zoning control in Shanghai. *Shanghai Land Resour.* 35 (4), 105–109.

Yang, T., Yan, X., Huang, X., and Wu, J. (2020). Integrated management of groundwater exploitation and recharge in Shanghai based on land subsidence control. *Proc. Int. Assoc. Hydrological Sci.* 382, 831–836. doi:10.5194/piahs-382-831-2020

Ye, S., Luo, Y., Wu, J., Yan, X., Wang, H., Jiao, X., et al. (2016). Three-dimensional numerical modeling of land subsidence in Shanghai, China. *Hydrogeology J.* 24 (3), 695–709. doi:10.1007/s10040-016-1382-2

Yi, L., Fang, Z., He, X., Shijie, C., Wei, W., and Qiang, Y. (2011). Land subsidence in tianjin, China. *Environ. Earth Sci.* 62 (6), 1151–1161. doi:10.1007/s12665-010-0604-5

Yin, J., Yu, D., and Wilby, R. (2016). Modelling the impact of land subsidence on urban pluvial flooding: a case study of downtown Shanghai, China. *Sci. Total Environ.* 544, 744–753. doi:10.1016/j.scitotenv.2015.11.159

Yin, Y., Zhang, K., and Li, X. (2006). Urbanization and land subsidence in China. China Geol. *Surv* 31 (15.11).

Yu, J., Wang, G., Kearns, T. J., and Yang, L. (2014). Is there deep-seated subsidence in the Houston-Galveston area? *Int. J. Geophys.* 2014, 1–11. doi:10.1155/2014/942834

Yu, L., Yang, T., Zhao, Q., Liu, M., and Pepe, A. (2017). The 2015–2016 ground displacements of the Shanghai coastal area inferred from a combined COSMO-SkyMed/Sentinel-1 DInSAR analysis. *Remote Sens.* 9 (11), 1194. doi:10.3390/rs9111194

Yu, Q., Yan, X., Wang, Q., Yang, T., Lu, W., Yao, M., et al. (2021a). A spatial-scale evaluation of soil consolidation concerning land subsidence and integrated mechanism analysis at macro-and micro-scale: a case study in Chongming East Shoal Reclamation Area, Shanghai, China. *Remote Sens.* 13 (12), 2418. doi:10.3390/rs131 22418

Yu, W., Gong, H., Chen, B., Zhou, C., and Zhang, Q. (2021b). Combined GRACE and MT-InSAR to assess the relationship between groundwater storage change and land subsidence in the Beijing-Tianjin-Hebei Region. *Remote Sens.* 13 (18), 3773. doi:10.3390/rs13183773

Yu, X. (2016). Assessing the land subsidence governance in ningbo city: by a close study of the building collapse at the strictly protected land subsidence area. *EGU General Assem. Conf. Abstr.* 18. doi:10.5194/egusphere-egu22-2114

Yu, X., and Hu, X. (2022). Multi-annual InSAR solution of vertical land motion in 2021 lethal building collapse site in Miami. *Copernic. Meet.* No. EGU22-2114.

Yuan, L., Cui, Z. D., Yang, J. Q., and Jia, Y. J. (2020). Land subsidence induced by the engineering-environmental effect in Shanghai, China. *Arabian J. Geosciences* 13 (6), 1–11. doi:10.1007/s12517-020-5224-0

Yujin, S. H. I., Xuexin, Y. A. N., and Nianqing, Z. H. O. U. (2007). Land Subsidence Induced By Recent Alluvia Deposits In Yangtze River Delta Areaa Case Study Of Shanghai Lingang New City. *J. Eng. Geol.* 15 (3), 391–394.

Yusuf, M. A., Takizawa, S., and Katayama, H. (2007). Ground water storage in aquifer of Dhaka City and land subsidence: a major concern in potable water supply in Dhaka Metropolis in 2030. *Southeast Asian water Environ.* 2, 205–212.

Zaid, S. M., Mamoun, M. M., and Al-Mobark, N. M. (2014). Vulnerability assessment of the impact of sea level rise and land subsidence on north Nile Delta region. *World Appl. Sci. J.* 32 (3), 325–342. doi:10.5829/idosi.wasj.2014.32.03.14505

Zanello, F., Teatini, P., Putti, M., and Gambolati, G. (2011). Long term peatland subsidence: experimental study and modeling scenarios in the Venice coastland. *J. Geophys. Res. Earth Surf.* 116 (F4), F04002. doi:10.1029/2011jf002010

Zeitoun, D. G., and Wakshal, E. (2013). *Land subsidence analysis in urban areas: the Bangkok metropolitan area case study*. Springer Science & Business Media.

Zerbini, S., Richter, B., Rocca, F., van Dam, T., and Matonti, F. (2007). A combination of space and terrestrial geodetic techniques to monitor land subsidence: case study, the Southeastern Po Plain, Italy. *J. Geophys. Res. Solid Earth* 112 (B5). doi:10.1029/2006jb004338

Zhang, X. S., Wang, J. X., Wong, H., Leo, C. J., Liu, Q., Tang, Y. Q., et al. (2013). Land subsidence caused by internal soil erosion owing to pumping confined aquifer groundwater during the deep foundation construction in Shanghai. *Nat. hazards* 69, 473–489. doi:10.1007/s11069-013-0718-7

Zhang, Y., Wu, J., Xue, Y., Wang, Z., Yao, Y., Yan, X., et al. (2015). Land subsidence and uplift due to long-term groundwater extraction and artificial recharge in Shanghai, China. *Hydrogeology J.* 23 (8), 1851–1866. doi:10.1007/s10040-015-1302-x

Zhang, Z., Ding, X. L., Wu, S., and Kang, Q. (2022). The settlement of Hong Kong international airport based on the interferometric point target analysis. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 43, 1267–1272. doi:10.5194/isprs-archives-xliii-b3-2022-1267-2022

Zhang, Z., Wang, X., Wu, Y., Zhao, Z., and E, Y. (2021) "Applied research on InSAR and GPS data fusion in deformation monitoring. *Sci. Program.* 2021, 1–9. doi:10.1155/2021/3888975

Zhao, Q., Lin, H., Jiang, L., Chen, F., and Cheng, S. (2009). A study of ground deformation in the Guangzhou urban area with persistent scatterer interferometry. *Sensors* 9 (1), 503–518. doi:10.3390/s90100503

Zhao, Q., Pan, J., Devlin, A., Xu, Q., Tang, M., Li, Z., et al. (2021). Integrated analysis of the combined risk of ground subsidence, sea level rise, and natural hazards in coastal and Delta River regions. *Remote Sens.* 13 (17), 3431. doi:10.3390/rs13173431

Zhong, C., Guo, H., Swan, I., Gao, P., Yao, Q., and Li, H. (2023). Evaluating trends, profits, and risks of global cities in recent urban expansion for advancing sustainable development. *Habitat Int.* 138, 102869. doi:10.1016/j.habitatint.2023.102869

Zhou, B., Urosevic, M., and Shen, B. (2015). Subsidence assessment using 3-D seismic data at Collingwood Park, Brisbane. *J. Environ. Eng. Geophys.* 20 (3), 257–272. doi:10.2113/jeeg20.3.257

Zhou, C., Gong, H., Chen, B., Gao, M., Cao, Q., Cao, J., et al. (2020). Land subsidence response to different land use types and water resource utilization in Beijing-Tianjin-Hebei, China. *Remote Sens.* 12 (3), 457. doi:10.3390/rs12030457

Zhou, L., Zhao, Y., Zhu, Z., Ren, C., Yang, F., Huang, L., et al. (2022). Spatial and temporal evolution of surface subsidence in Tianjin from 2015 to 2020 based on SBAS-InSAR technology. *J. Geodesy Geoinformation Sci.* 5 (1), 60–72.

Zhu, K., Zhang, X., Sun, Q., Wang, H., and Hu, J. (2022a). Characterizing spatiotemporal patterns of land deformation in the santa ana basin, Los Angeles, from InSAR time series and independent component analysis. *Remote Sens.* 14 (11), 2624. doi:10.3390/rs14112624

Zhu, Y. Y., He, Y., Li, H. Y., Lv, Z. P., and Xu, G. C. (2022b). Land subsidence monitoring and analysis in Fuzhou based on insar and multispectral remote sensing technology. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sciences-ISPRS Archives* 43, 373–379. doi:10.5194/isprs-archives-xliii-b3-2022-373-2022

Zhu, Z. L., Ren, C., Zhou, L., Shi, X. J., Li, X. G., and Zhang, D. (2020). Monitoring Tianjin land subsidence by SBAS-InSAR based on Sentinel-1A SAR images. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 42, 315–319. doi:10.5194/isprs-archives-xlii-3-w10-315-2020

Zhuo, G., Dai, K., Huang, H., Li, S., Shi, X., Feng, Y., et al. (2020). Evaluating potential ground subsidence geo-hazard of Xiamen Xiang'an new airport on reclaimed land by SAR interferometry. *Sustainability* 12 (17), 6991. doi:10.3390/su12176991

Zou, F., Tenzer, R., Fok, H. S., Meng, G., and Zhao, Q. (2021). The sea-level changes in Hong Kong from tide-gauge records and remote sensing observations over the last seven decades. *IEEE J. Sel. Top. Appl. Earth Observations Remote Sens.* 14, 6777–6791. doi:10.1109/jstars.2021.3087263