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REVIEW ARTICLE

Analysis of Land subsidencein coastal and urban areas by using various techniques– Literature Review

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Abstract Over the past several decades, subsidence has emerged as a significant issue affecting urban, coastal, and mining areas worldwide. This phenomenon has been exacerbated by a decrease in groundwater resources, which has become a major problem on a global scale. Insufficient availability of surface water has led to excessive exploitation of the earth's groundwater system through unplanned processes. As a result, serious problems have arisen, including economic challenges, hazardous activities, and damage to the Earth's surface. One of the most significant and impactful consequences of excessive groundwater extraction is land subsidence. During a comprehensive literature review focusing on land displacement, 40 research papers were analyzed and discussed. These studies explored various techniques employed to monitor subsidence, such as synthetic aperture radar (SAR), interferometry synthetic aperture radar (InSAR), persistent scatterer interferometry synthetic aperture radar (PS-InSAR), and differential synthetic aperture radar (D-InSAR). Researchers have consistently found a strong correlation between the over extraction of underground fluids, such as water, oil, and gas, and land subsidence. One prominent cause of land subsidence identified by researchers is the over extraction of underground fluids. When excessive amounts of water, oil, or gas are extracted from underground reservoirs, the resulting voids and reduced pressure cause the overlying land to sink and compact. This process can have severe consequences for human settlements, infrastructure, and ecosystems in affected areas. The depletion of groundwater reserves, in particular, has become a pressing concern because of its vital role in supporting agricultural, industrial, and domestic water needs.

Furthermore, the underground construction of tunnels has also been identified as a significant contributor to land subsidence. The excavation of tunnels creates voids and alters the natural balance of underground structures, leading to ground settlement and subsidence. This issue is particularly relevant in urban areas where extensive tunneling projects are undertaken to facilitate transportation, utilities, and infrastructure development. To monitor and assess land subsidence, various methods and processes are employed. SAR, InSAR, PS-InSAR, and D-InSAR techniques are valuable tools in this regard. SAR uses satellite-based radar systems to capture high-resolution images of the Earth's surface, enabling the detection of subtle changes over time. In contrast, InSAR employs two or more radar images to measure ground deformation by analyzing interference patterns. PS-InSAR focuses on persistent scatterers, which are specific targets that exhibit stable radar reflections over time, providing precise measurements of subsidence. D-InSAR combines two radar images acquired at different times to accurately calculate differential ground movements. By using advanced monitoring methods, scientists can assess the extent of subsidence and develop strategies to mitigate its negative impacts. It is crucial to adopt sustainable practices and ensure careful management of groundwater resources to effectively address this pressing issue.

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1. Introduction

Land subsidence refers to the gradual sinking or settling of the Earth's surface, leading to a decrease in land elevation. It is a geophysical phenomenon caused by various natural and human-induced factors. This process has significant implications for urban areas, agricultural regions, and infrastructure development. Understanding the causes, monitoring techniques and implications of land subsidence is crucial for mitigating its effects and ensuring sustainable land management practices. Land subsidence can occur due to both natural and anthropogenic factors. Natural causes include geological processes such as tectonic activity, underground water extraction, and the consolidation of sediment layers. Anthropogenic activities, on the other hand, are predominantly related to human interventions in the environment. These activities include groundwater pumping, mining operations, oil and gas extraction, construction of large infrastructures like dams and buildings, and the extraction of natural resources from underground.

Techniques used to study and monitor land subsidence are diverse and employ a combination of remote sensing, geodetic surveys, geological investigations, and geotechnical measurements. One of the most commonly used methods is satellite-based remote sensing, which enables large-scale and continuous monitoring of land subsidence. Satellite images from instruments such as InSAR provide valuable data on land surface deformations over time. By comparing multiple satellite images, scientists can detect changes in land elevation and identify areas prone to subsidence.

In addition to remote sensing, geodetic surveys play a crucial role in monitoring land subsidence. Techniques like Global Navigation Satellite Systems (GNSS) and precise leveling allow for accurate measurements of land elevation changes. GNSS receivers, which use signals from satellites like GPS, can determine the precise locations of points on the Earth's surface and detect millimeter-level changes in elevation over time. Precise leveling involves measuring the height differences between benchmark locations to identify areas experiencing subsidence. Geological investigations are also essential for understanding the causes of land subsidence. Geologists study the composition and structure of subsurface rock layers to determine their susceptibility to compaction and settling. By examining geological formations, researchers can assess the potential for subsidence and identify areas at risk. Geotechnical measurements, such as soil compaction tests and pore pressure monitoring, provide further insights into the behavior of subsurface materials and their contribution to subsidence.

Importance of studying and mitigating land subsidence cannot be overstated. One of the primary concerns is the impact on infrastructure and buildings. As the land sinks, structures built on the surface are subjected to uneven settling, leading to structural damage and reduced stability. This can result in increased maintenance costs, decreased property values, and even the collapse of critical infrastructure. By monitoring land subsidence and implementing appropriate engineering measures, the potential risks to infrastructure can be minimized. Agricultural regions also face significant consequences from land subsidence. Subsidence can disrupt irrigation systems by altering the slope and drainage patterns of fields. It can cause waterlogging and salinization, making the land unsuitable for cultivation. In coastal areas, subsidence combined with sea-level rise exacerbates the risk of flooding and saltwater intrusion into groundwater, further compromising agricultural productivity. By understanding the causes and patterns of land subsidence, farmers and land managers can implement sustainable practices to mitigate its effects and ensure long-term agricultural viability.

Another critical concern associated with land subsidence is the depletion of groundwater resources. Excessive pumping of groundwater for agricultural, industrial, and domestic use can lead to subsidence due to the compaction of aquifer systems. As the water is removed from underground reservoirs, the void spaces are filled with air, causing the overlying land to settle. This poses a serious threat to water availability, especially in regions heavily dependent on groundwater. Managing groundwater resources sustainably, implementing water conservation measures, and finding alternative water sources are essential for mitigating land subsidence and ensuring water security. Land subsidence can have adverse environmental impacts. It can disrupt natural ecosystems and alter hydrological regimes. Wetlands, rivers, and lakes may experience changes in water levels and flows, affecting biodiversity and habitat availability for various species. Subsidence-induced changes in land elevation can also affect the drainage patterns, leading to altered sediment transport, erosion, and deposition. Understanding these ecological consequences is crucial for the preservation of ecosystems and the development of appropriate mitigation strategies.

In this literature review subsidence over various country like; India, Mexico, China, USA, Pakistan, Nepal and Thailand; etc are discussed. Land subsidence is a complex geophysical phenomenon influenced by both natural and anthropogenic factors. Monitoring techniques such as remote sensing, geodetic surveys, geological investigations, and geotechnical measurements play a crucial role in understanding and managing subsidence. The importance of studying land subsidence lies in its implications for infrastructure, agriculture, water resources, and the environment. By identifying vulnerable areas, implementing mitigation measures, and promoting sustainable land management practices, the adverse effects of land subsidence can be minimized, ensuring the long-term viability and resilience of affected regions.

2. Importance of literature survey for subsidence study

A literature survey regarding subsidence is crucial for several reasons. First, subsidence, the gradual sinking or settling of the Earth's surface, is a complex geological phenomenon influenced by various factors such as natural processes, human activities, and climate change. Conducting a literature survey helps researchers gain a comprehensive understanding of the existing knowledge, theories, and findings related to subsidence. By reviewing previous studies, researchers can identify gaps in knowledge and areas that require further investigation. This helps in developing research questions and objectives, ensuring that new studies build upon and contribute to the existing body of knowledge. A literature survey also enables researchers to assess the methodologies, techniques, and models employed in previous studies. This evaluation helps determine the most appropriate approaches for data collection, analysis, and interpretation in future research. In addition, it aids in identifying any limitations or challenges faced by previous researchers, allowing for improvements and innovations in subsequent studies. Moreover, a literature survey provides researchers with an opportunity to analyze trends and patterns in subsidence research over time. This analysis helps in identify emerging research areas, technological advancements, and areas where new collaborations and interdisciplinary approaches can be fostered.

A literature survey regarding subsidence is essential for gaining insights, identifying research gaps, improving methodologies, and ensuring that new research contributes to the existing knowledge base. It facilitates scientific progress, enhances the quality of research outcomes, and supports evidence-based decision-making in addressing subsidence-related issues.

3. Review of Literature

Cause of Subsidence

Intui et al. (2022) conducted research on the analysis of land subsidence during the recovery of groundwater in the central part of Thailand. According to this study, in in the Chao Phraya river basin in Thailand, severe land subsidence is monitored, which is caused by excess withdrawal of groundwater. During 1960–1997, groundwater level decreased in the study area, which was recorded as 27 m27m from the ground surface. In 1997, the Department of Groundwater Resources introduced a law for controlling the groundwater level changes. After this law, the groundwater level was increased. In this study, the main focus is to monitor the land displacement during the recovery of groundwater level. The land subsidence ratio was recorded as 0.21–0.53 cm/year at the time of groundwater recovery.

Putri et al. (2021) reviewed the land subsidence area of Jakarta to reduce the disaster. The level of land subsidence in Jakarta is very high. In this area, different factors accelerate land subsidence. These factors are; excess usage of groundwater and soil conditions. On the basis of the results, it was recorded that excess use of groundwater caused severe land subsidence in the urban region of Jakarta.

Banerjee et al. (2020) monitored land subsidence in an under constructed tunnel of a railway project in Kolkata. From this study, it was monitored that the reason of land subsidence in this region is due to the drain of aquifer pore water. From this research, it was recorded that cracks are found in more than 10 buildings because of subsidence, from which some have collapsed. In this research, we studied the hydrological conditions of the area.

Wang et al. (2018) reviewed the land subsidence caused by underground water exploitation in Xi'an, China. In this review, they monitored that land subsidence in this area formed by over withdrawal of groundwater since 1960. On the basis of past records from 1959 to the present, they divide the land subsidence of Xi'an into three stages: from the year 1959 to 1971, named as the Preliminary stage; from the year 1972 to 1990, named as the rapid development stage; and from the year 1991 to the present, known as the slow development stage.

Kakar et al. (2016) studied land subsidence because of the withdrawal of underground water in Quetta Valley, Pakistan, by using ground water data from 2010 to-2015 and the land subsidence measured using GPS units. From this study, they monitored that the surface of the Quetta valley is sinking at the rate of 30 mm/y to 120 mm/y in the center part. Where the rate of subsidence is high, those are recorded 1.5 to 5.0 m/year drops of groundwater level are recorded.

Xu et al. (2016) estimated the land subsidence factors of Shanghai. In the urban center of Shanghai, the net water withdrawal limit has not change since 1980, but the groundwater level has decreased which caused land subsidence. According to this study from 1980, many underground constructions are done in Shanghai. Now these constructions are the main focus of land subsidence. In this paper, they discussed the different factors that are used to control and manage land subsidence.

Faunt et al. (2015) analyzed land subsidence and water availability in the central valley of California, USA. Agriculture in this area totally depends on groundwater pumping to fulfil the demand of water for irrigation purposes. In the drought period of 2007–2009 and 2012–present, withdrawal of the groundwater rises in this area, which caused subsidence. Central valley hydrologic model used to control and manage the impact of subsidence.

Zhu et al. (2015) studied land displacement in the northern Beijing plain of China caused by extraction of underground water. In this study, they monitored land subsidence over the period 2003-2010. During this study period, 92.5mm of less average elevation was recorded with subsidence up to 52 mm/year. In this study they did not observe any clear correlation between land subsidence rate and urban development.

Zhang et al. (2014) studied land subsidence in the Beijing city plain of China due to the withdrawal of groundwater. According to this study, Beijing city faces major land subsidence because of over withdrawn groundwater. During 2000 the highest land subsidence rate hits 6cm/year. In this study, some programs such as level survey, borehole extensometers, and layer monitoring of groundwater levels are designed to study the hydrologic behavior for land subsidence analysis.

Erban et al. (2014) studied the land subsidence formed because of the extraction of underground water and its impact on sea-level rise in the Mekong Delta of Vietnam. Land subsidence formed by underground water in the coastal areas caused flood hazards that mixed with sea-level rise. The Lower Mekong Delta lies above the mean sea level of <2m. In this area over extraction of groundwater caused a decrease in the groundwater level with an average rate of 0.3 m/y based on 79 wells from 18 locations. In these locations the mean rate of land subsidence was recorded as 1.6 cm/year. According to the analysis of this research, if pumping continues at the present rate, then in 2050 the average land subsidence is expected to be 0.88 m (0.35-1.4m).

Aobpaet et al. (2013) conducted research on the estimation of land subsidence in Bangkok city of Thailand using InSAR time-series data. According to this research, excess pumping of groundwater in the past made the subsidence rate up to 120 mm/year, which is now reduced to 20 mm/year by controlling the over extraction of groundwater. In this study, they identified more than 300,000 pixels with a mean density of 120 observations/ sq.km.

Erban et al. (2013) studied land subsidence caused by pumping in the Mekong Delta of Vietnam. In this area, arsenic is monitored in the deep Pliocene-Miocene age aquifer, where 900 wells are observed with depth of 200-500 m. Using the radar image of 2007-2010 they monitored that groundwater extraction in this area caused land subsidence of 3 cm/year. Since 1988, the total subsidence has been recorded up to 27 cm.

Xu et al. (2012) conducted research for monitoring land subsidence produced by urbanization. According to this study, the level of water in the ground has decreased and land subsidence has increased in central Shanghai since 1980. The theoretical analysis in this study defined that groundwater level decrease is the origin of land displacement. In this research, different factors are used to determine the progress of land subsidence during urbanization. These factors are the; additional load of building, underground structure construction, and long-period groundwater level reduction.

Xu et al. (2012) estimated land subsidence on the basis of underground structures in Shanghai, China. According to this research, infiltration of underground structures into aquifers can decrease groundwater levels and cause land displacement. In this study, they monitored two ultimate layout: distributed underground structure and a concentrated underground structure.

Sahu et al. (2011) studied the risk of land subsidence in Kolkata city and the wetlands of east Kolkata. According to this study geology of the subsurface in this city comprises series of sand, clay, and silty clay of quaternary sediments. During this study, the piezometric head shows lowering movement of land, which may be caused by land subsidence for excess withdrawal of groundwater. The mean rate of land displacement was 13.53 mm/year. When the piezometric head falls 1 m, then the average subsidence is recorded as 3.28 cm.

Lixin et al. (2010) monitored land subsidence in Tianjn, China. Tianjin affected by land subsidence for more than 50 years. Excess pumping of underground water is the major cause of land subsidence in this area. According to this study, in

2008, a total of 8000 sq.km area was affected by the subsidence of a maximum cumulative rate of 3.22 m. Severe subsidence was monitored in 1980 when the subsidence rate was recorded as more than 110 mm/year. During this subsidence period, a total of 1200 million m^3 of groundwater was extracted. By restricting the extraction of groundwater, after 1986, the subsidence rate in the build-up areas decreases to 10-15 mm/year. According to the results of this study subsidence area increased slowly, but the rate of subsidence is now controlled.

Galloway et al. (2008) defined land subsidence as a hazard to pipelines. According to this article, anthropogenic land subsidence is due to over withdrawal of fluids in the United State. According to this article, 45 states of the United States with a total of 44,000 sq.km of area are affected by subsidence.

Giao et al. (2006) studied the land subsidence in Bangkok, Thailand. According to this study, Bangkok has been hit by land subsidence due to deep well pumping over the last 35 years. In 1980 the rate of subsidence was greater than 120 mm/year. The rate of subsidence in Bangkok has decreased from time to time, but the area of subsidence has increased due to increased urbanization. In this study, monitored data showed a connection between subsidence and piezometric drawdown. According to the monitored data. groundwater pumping of 1 m^3 in Bangkok resulted in 0.10 m^3 of soil loss at the surface.

Thomas et al. (2005) studied the effect of land subsidence formed by over withdrawal of underground fluids. According to this study, a total of 26000 sq.km areas of the United States were lowered permanently. In this research review regarding the mechanism, occurrences, and impact are reviewed to control the land subsidence caused by the extraction of underground solutions.

Galloway et al. (2005) conducted research on land subsidence formed by extraction of underground solutions and its impact on the United States. The main reason behind lowering the land surface of a larger area is the excess withdrawal of groundwater and petroleum. According to this study in the United States, 26,000 sq.km land has lowered permanently. He defined that land faces many hazardous activities due to land subsidence, such as overflow of land, increasing chances of flooding, and breaking the land surfaces; etc.

Sun et al. (1999) studied the land subsidence in New Jersey, United States. According to this study from the past 20 years, the subsidence rate in New Jersey was recorded as 2-3 cm. if the level of groundwater decreased continuously, then in the future after 20 years, the subsidence rate will be 3cm. The average sea level rise was recorded as 2 mm/year. The combination of both subsidence and global sea level rise increases the flooding frequency in the shore part of New Jersey.

Subsidence monitoring techniques

Reshi et al. (2023) conducted research to understand land subsidence in the Chandigarh tri-city region by using surface displacement data from PSInSAR of the Sentinel-1 satellite and groundwater storage change data from the Gravity Recovery and Climate Experiment (GRACE) satellite mission. In addition to the satellite datasets, groundwater level data obtained from wells in the study area are also incorporated. GRACE data, available at a coarse spatial resolution of 1°, pose challenges in correlating them with the higher-resolution PSInSAR displacement data, which has been multi-looked at 14 m resolution. To address this, a deep learning multi-layer perceptron (DLMLP) model is employed, which integrates multiple sources of data. These include the monthly average of GRACE data, groundwater storage change, monthly average PSInSAR displacement per pixel, and interpolated groundwater level data from wells from 2017 to 2022. The DLMLP model serves as an indirect downscaling method, successfully estimating groundwater storage changes at the urban level. This approach is distinctive compared with direct downscaling methods applied to GRACE data. The DLMLP model exhibits promising results, yielding an R2-statistics value of 0.91 in the training phase and 0.89 in the testing phase. The model's performance was further evaluated using a mean absolute error (MAE) of 1.23 and a root mean square error (RMSE) of 0.87.

Tripathi et al. (2022) described the use of satellite data from Sentinel-1 and the Gravity Recovery and Climate Experiment (GRACE) for studying urban surface subsidence and groundwater fluctuations. Sentinel-1 is an active synthetic aperture radar (SAR) satellite equipped with a C-band SAR sensor operating at a center frequency of 5.405 GHz and a wavelength of 5.55 cm. It provides freely available SAR datasets that have made urban surface subsidence mapping easier through persistent scatterer SAR interferometry (PSInSAR) techniques. Urban surface subsidence is primarily caused by the overexploitation of groundwater, which leads to a loss of piezometric pressure in aquifers, resulting in net subsidence. To study groundwater level fluctuations, the GRACE satellite sensor is used. It enables the temporal analysis of groundwater variations. However, the coarse spatial resolution of GRACE data poses challenges for studying smaller watersheds. This study aims to establish a correlation between the average surface line of sight (LOS) displacement obtained from the PSInSAR technique of Sentinel-1 and the average groundwater fluctuations derived from the GRACE sensor. The analysis covers the period from May 2017 to February 2022. Additionally, the study examines the correlation between PSInSAR displacements in both VV and VH polarizations, revealing R2 values of 0.63 and 0.65, respectively, when compared with GRACE data.

Martin et al. (2022) studied the impact of land subsidence on the Pekalongan coast on hydrodynamic conditions. Due to land subsidence, the coastal part of Pekalongan sinks at a rate of 10 cm/year. In this study, they monitored land subsidence using a numerical model through Delft3D. In this study, they took two scenarios, 2016 and 2021, for using the numerical model. The numerical model was used after a land subsidence rate of 10 cm/year. On the basis of the sensitivity test result, the wave height is recorded as the most sensitive parameter. After the formation of land subsidence, they differentiated both scenarios for the sensitivity test, and during this test, it was recorded that the current velocity decreased by 0.05-0.1 m/s and the height of the wave rose by 0.05-0.15 m.

Khan et al. (2022) estimated the surface displacement in Rawalpindi and Islamabad, Pakistan. They used PS-InSAR methods to monitor surface displacement. Excess withdrawn ground water is the key point of land subsidence in these areas. In this research, they used SARPROZ software to process the sentinel-1 images from January 2019 to June 2021. According to the result, the rate of subsidence increased from -25 to -30 mm/year from -69 mm/year and -98 mm/year in 2019 and 2020, respectively.

Xue et al. (2022) calculated land subsidence using a model of the coupling effect of groundwater and coal mining. In this study, they used numerical and theoretical models to monitor land subsidence through the coupling effect. In this study, they chose a coal mine area in Jining city from 2000 to 2020. On the basis of this study, they monitored that in 2010, the maximum land subsidence was recorded as 128mm. in 2016, the land subsidence increased and reached 305 mm due to coal extraction in 2015.

Kirui et al. (2022) conducted research for the identification and monitoring surface displacement using InSAR images in Nairobi city of Kenya. According to this study, the main reason for surface displacement in this region is excess withdrawal of underground water. Surface displacement monitored at different locations in the region. From the analysis of this study, it was recorded that the highest land subsidence is 62 mm/year in the western part of the study area. This research will help in future for controlling and managing land subsidence.

Kumar et al. (2021) predicted land subsidence using the recurrent neural networks (RNNs). According to this study, for monitoring and predicting land subsidence, all techniques have limitations. In this study, they predicted the land subsidence in intervals of every 12 days for a period of 1 year. Data were collected for this study through modified PSInSAR. Data collected from 14 locations. By using Vanila and stacked long short-term memories (LSTMs), the forecast of land subsidence is done.

Darwish et al. (2021) performed an accuracy assessment of different images such as ALOS/ PALSAR-2 and Sentinel-1 in the land subsidence monitoring of the shore region in Alexandria city of Egypt. In this research, they used 9 sentinel-1 images and 11 ALOS/ PALSAR-2 images. Increase in vertical displacement of the region recorded as -60 mm with a mean rate of -12.5 mm during 2017 and 2020. The mean displacement rate of the area was recorded as -1.73 mm/year. According to this study, the highest land subsidence rates are found at the border of Maniout lakes and Abu Qir Lagoon, which is -20 mm/year.

Ahmed et al. (2020) studied the modelling of land subsidence due to withdrawal of underground water in the Konya Closed Basin, Turkey. In this research, they used GPS, InSAR, and ENVISAT SAR images to verify the model parameters. In this research, a novel numerical solution was prepared in MATLAB for forecasting the land subsidence of the area. This solution was developed on the basis of consolidation theory. By using this subsidence model developed for the forecast of surface movement in the basin.

Shi et al. (2020) studied land subsidence forecasts produced by different factors using a machine learning method. To collect data on land subsidence, they used Sentinel-1 radar images and persistent scatters interferometry (PSI). Using linear regression and principal component analysis (PCA) methods, they monitored that the correlation between land subsidence and effective components was non-linear. They introduced XGBoost to predict the amount of land subsidence.

Kang et al. (2019) investigated soil richness losses due to underground coal mining areas. In this research, they monitored that because of underground coal mining in West China, major land subsidence occurs, which directly affects the soil richness. From the soil sample of the subsidence area, it was recorded that the soil quality is very low. They used redundancy analysis (RDA) for allotment of the particle size of soil.

Yuan et al. (2017) conducted research on monitoring the land subsidence of a coal mine located in the Yuanbaoshan district. In this study, they used DInSAR techniques to monitor subsidence. According to the results, DInSAR techniques were found to be more effective than optical images of the location for monitoring underground mining subsidence.

Shrestha et al. (2017) worked on monitoring land subsidence through a model in the Kathmandu Valley in Nepal. In this research, land subsidence analysis was done using groundwater flow model acquired from a surface-subsurface modelling system. It was recorded that the average subsidence of the area was 1.6 mm/year. In two places of the northern area subsidence was recorded at 28 mm/year.

Andreas et al. (2017) studied land subsidence and its mitigation in Semarang. According to some reports in Semarang, subsidence has occured for more than 100 years. Centre of environmental geology done a leveling survey for monitoring subsidence during 1999-2003. From the analysis, it was recorded that the rate of subsidence in some parts of Semarang ranges from 1 to 17 cm/year. The average subsidence was recorded as 6-7 cm/year, and the highest rate of subsidence was recorded as 14-19 cm/year.

Mondal et al. (2016) conducted research for the analysis and management of land subsidence in the Raniganj mining area of Barddhaman district. In this research, they used cadastral techniques for the analysis of land subsidence. The two methods used in this study are Drawbacks Bord& Pillar and Pillar Stability analysis.

Chen et al. (2016) monitored land subsidence in Beijing, China caused by withdrawal of groundwater. For the analysis of land subsidence, they used satellite radar interferometry. According to this study, Beijing has experienced major land subsidence since 1935 because of excess extraction of groundwater. Envisat ASAR images and TerraSAR-X strip map images were collected between 2003-2010 and 2010-2011 respectively, and an InSAR technique processed these images for monitoring land subsidence. The major land subsidence rate is monitored as more than 100 mm/year. Land subsidence monitored using InSAR and GPS techniques displays the RMS difference of subsidence rate as 2.94 mm/year.

Noguez et al. (2015) studied the numerical model of land subsidence due to the single extraction of groundwater and faster infiltration of water. 2 models are used for numerical duplication of infiltration the two-phase flow model for porous media and the Mohr-Coulomb model for deformation.

Chatterjee et al. (2015) conducted research on detecting and monitoring the subsidence in the Jharia Coalfield of Jharkhand. In this research, they used space-borne DInSAR and GPS techniques. Two multi-frequency bands, the C-band and L-bands are used to detect subsidence areas. According to this research, the C-band is useful for detecting slow subsiding areas and the L-band is useful for detecting rapidly subsiding areas. The methodology used in this research successfully detects, maps, and monitors the subsidizing area.

Bhattacharya et al. (2012) represented two approaches to calculate subsidence; linear theory and logarithmic theory. According to this study, the linear theory coefficient of volume compressibility (M_v) and in logarithmic theory compression index (C_c) indicates the character of soil toward contraction. In this study area, from the top 30m of subsurface soil, 0-15m indicates softer clayey and 15-30m indicates stiffer clayey, which has high and low M values, respectively. From this study, the approximate subsidence rate was recorded as 11.56mm/year.

Hu et al. (2009) estimated the threat of land subsidence in the Tianjin shore parts of China. In this study, they collected and analyzed data on the increased subsidence volume, land subsidence velocity, and groundwater extraction strength. By using these data, a subsidence hazard evaluation map was prepared. For the preparation of the vulnerability map, they used data such as population mass, gross domestic product per square km, and building land portion. By merging the hazard map, vulnerability map, and land subsidence reduction and prevention map, a land subsidence risk map was prepared.

Tosi et al. (2001) reviewed the estimation of land subsidence performed using differential SAR interferometry. For monitoring land subsidence, they mention techniques such as SAR interferometry, differential SAR interferometry, interferogram stacking techniques, and error estimation for successful application of the techniques. From the subsidence map of different study areas it was observed that differential SAR interferometry is useful for the analysis of several velocities from m/year to mm/year.

4. Discussion

The literature survey provides various studies on land subsidence caused by different factors such as groundwater extraction, soil conditions, underground water exploitation, and urbanization. These studies focus on different regions around the world, including Thailand, Jakarta, Kolkata, Xi'an, Quetta Valley, Shanghai, California, Beijing, Mekong Delta, Bangkok, and New Jersey.

One common factor observed in many of these studies is the excessive withdrawal of groundwater, leads to severe land subsidence. The case of central Thailand, as studied by Intui et al. (2022), highlights the significant impact of excess groundwater withdrawal on land subsidence in the Chao Phraya river basin. Similarly, Jakarta, as studied by Putri et al. (2021), and Beijing, as studied by Zhu et al. (2015) and Zhang et al. (2014), also experienced severe land subsidence due to excessive groundwater usage. Research conducted in Kolkata by Banerjee et al. (2020) focused on land subsidence caused by the drain of aquifer pore water during the construction of a railway tunnel. This study emphasizes the importance of understanding hydrological conditions and their impact on land subsidence in specific areas. The case of Xi'an in China, as reviewed by Wang et al. (2018), demonstrates the different stages of land subsidence development over time due to over-withdrawal of groundwater. This finding highlights the long-term consequences of unsustainable groundwater practices. Monitoring techniques and tools have also been used in several studies to track and analyze land subsidence. For instance, Reshi et al. (2023) used satellite data from PSInSAR and GRACE missions, along with groundwater level data, to understand land subsidence in the Chandigarh tri-city region. Tripathi et al. (2022) explored the correlation between surface displacement data obtained from Sentinel-1 and groundwater fluctuations measured by the GRACE satellite.

The studies presented here showcase the wide-ranging impact of land subsidence on various regions and the importance of understanding the underlying causes and implementing appropriate management strategies. The research findings contribute to the knowledge base of policymakers, urban planners, and hydrologists, aiding in the development of effective measures to mitigate and manage land subsidence issues.

5. Research Gap

Inadequate Data Collection and Monitoring:

One primary scientific gap lies in the collection and monitoring of accurate and comprehensive subsidence data. Limited access to precise and timely data hampers the understanding of subsidence mechanisms and patterns. Existing monitoring systems often suffer from insufficient spatial coverage and temporal resolution, limiting their ability to detect subtle subsidence signals and assess their long-term impacts. Moreover, data from different sources are often not integrated, hindering holistic analyses.

Uncertainty in Subsidence Modeling:

Subsidence modeling is another area that requires attention. Current models often struggle to capture the complexity and interactions of multiple driving factors and their spatial and temporal variations. These models typically rely on simplified assumptions and overlook critical feedback mechanisms, resulting in significant uncertainties in the predicted subsidence patterns. Bridging this gap requires the development of advanced models that incorporate interdisciplinary knowledge and detailed geological, hydrological, and geotechnical information.

Incomplete Understanding of Coupled Processes:

Subsidence is influenced by a range of coupled processes, including groundwater flow, soil compaction, and geomechanical behavior. However, our understanding of these processes and their interactions remains incomplete. For instance, the dynamics of aquifer-system compaction due to groundwater extraction are not yet fully understood, thereby impeding accurate prediction of subsidence rates. Exploring the coupling mechanisms between various driving factors and their complex interactions is essential for bridging this scientific gap.

Insufficient Socioeconomic Considerations:

While subsidence research predominantly focuses on technical aspects, insufficient emphasis on socioeconomic considerations is evident. The impact of subsidence on communities, infrastructure, and ecosystems requires a multidisciplinary approach that incorporates social and economic factors. Evaluating the costs and benefits of mitigation strategies, assessing the vulnerability of communities, and developing effective communication strategies are essential components of comprehensive subsidence research.

6. Conclusion

From the above study, it was concluded that the major aspects that formed displacement are excess withdrawal of groundwater, excess and slow mining, and underground construction. Researchers conducted several studies for mapping, monitoring, predicting, and controlling subsidence using different types of methods. Applications such as GNSS and InSAR techniques have been most useful over the past two decades for detecting and monitoring land subsidence.

Surface displacement formed by both natural and man-made activities. The major causes of land subsidence are increased population and urbanization. When population increased, the need for water also increased. So everywhere groundwater is extracted from ground without any planning. Same as in the mining area after the extraction of coal, they did not fill the void spaces that accelerate land subsidence. Every aspect of planning is neglected. Therefore, many areas faced land subsidence because of the huge amount of groundwater withdrawn. Deep well pumping of groundwater also caused land subsidence. Other causes of land subsidence are building and construction load, nature of soil, and tectonic movement of the earth's surface. Land subsidence has many impacts such as constant flood risk, problems in urbanization settlement, and changes in earth topography, and reduced the aquifer storage. Some studies have identified that unplanned underground mining and underground water withdrawal are the major reasons behind land subsidence.

Therefore for the mitigation of land subsidence, we should follow some guidelines. We need to control the unplanned over extraction of groundwater and fill the void spaces after extraction in mines. Groundwater development is necessary to address the threat of land subsidence. Development of groundwater needs to be executed according to the groundwater potential and understanding the risk of land subsidence in the area. Geological structures can control the development and distribution of land subsidence in the study area. One of the effective methods to control land subsidence is changing the withdrawal of groundwater recharge. Land subsidence can also be controlled by reducing withdrawn volume and increasing recharge volume. For avoiding the damages caused by land subsidence in the future, some researchers recommended multi-scale analysis for recognizing the land subsidence.

This literature review helps in further land subsidence studies. The control management and development of hazardous activities caused by the subsidence of surface government of the affected area faces many challenges. It will be crucial for water agencies to plan for the ongoing subsidence of the area.

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