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A Comprehensive Review on Mining Subsidence and its Geo-environmental Impact

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Abstract

Over the course of several decades, subsidence has exerted a notable impact on the mining sector. The preponderance of subsidence occurrences is evident within coal mines. Remote sensing and Geographic Information Systems (GIS) have emerged as principal instruments for the evaluation and characterization of subsidence phenomena. The manifestation of mining-induced subsidence engenders concerns encompassing roof collapse, infrastructural damage, and the formidable challenge of preserving human lives. The repercussions of mining-related subsidence extend to indigenous flora and subterranean water reservoirs. This phenomenon critically impedes the sustainable advancement of mining zones, precipitates the depletion of natural reservoirs, and engenders a host of ecological and environmental predicaments that cast an adverse influence on socio-economic dynamics. Within mining contexts, subsidence manifests as both vertical and horizontal ground displacement, presenting as fissures, depressions, troughs, and sinkholes. The present article furnishes a comparative discourse on diverse methodologies harnessed for the assessment of mining-induced subsidence. The scholarly community has employed a repertoire of eight predominant techniques, as delineated in the conclusive remarks of this study. Over the bygone two decades, considerable strides have been taken, enabling the deployment of sophisticated paradigms, such as remote sensing and GIS, Light Detection and Ranging (LiDAR), and Differential Interferometric Synthetic Aperture Radar (DiNSAR), for the identification and quantification of land subsidence phenomena.

Keywords: *DiNSAR, Geo-Environmental, Mining Subsidence, Remote Sensing and GIS*

1.0 Introduction

Subsidence is when the ground sinks or changes shape. This can cause serious problems like disasters and environmental issues. After subsidence happens, the way the soil and other things in the ground behave can change. This can be good for things like soil moisture and carbon content. Subsidence from mining is a big problem for the economy, environment, and engineering. Digging underground leaves empty spaces, lowers water levels, and changes the surface. People use tools like total stations and satellite systems to measure subsidence, but it takes a lot of time and money. Mining can cause things like ground movement and changes to water sources, which lead to subsidence. This also hurts the environment by causing erosion, pollution, and flooding. Mining changes the way land looks and works. Surface subsidence is important because of underground mining. It's a big topic for studying the environment. Using images from space and technology can help measure subsidence with good accuracy. When miners dig underground, they make holes. These holes get bigger over time and weaken the ground above them. This can make mining dangerous. Subsidence from mining also changes how water behaves in the ground. Plants and the environment are affected by subsidence too.

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1.1 Survey Technique

Using tools to measure land changes caused by mining has been done for a long time. This involves checking how the ground's height changes at certain points before, during, or after mining. When we compare these measurements, we can tell if the land is sinking. One way to do this is by using a special tool that measures the height difference between two spots. This tool is put at a known height, and then measurements are taken on a stick held straight up at the reference point. This is done at different points to get accurate height information. Another common way to measure mining-related sinking is by using satellite technology called GNSS. This method is very accurate and can tell even tiny changes in height. It's great for checking large areas over a long time. Inclinometers are also used to detect sinking. These tools measure how much the ground tilts. They're put in holes dug into the ground, and they can find changes in slope caused by sinking. Using these methods is a good and precise way to find out if the land is sinking due to mining. Precise leveling, GNSS, and inclinometers are some of the most common tools used to watch for sinking in mining areas. They're really important for making sure the environment isn't harmed by sinking and that buildings and communities stay safe.

1.2 Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is a special way to find out if the ground is sinking because of mining. With GPR, we send special waves into the ground and measure how they bounce back. These bounces show us what's under the ground and if it's changed because of the sinking. GPR is a method that doesn't hurt the ground and isn't expensive. It can find sinking at different levels under the ground, depending on how fast the waves are. GPR can also give us information right away about what's under the ground. When we use GPR to find mining-related sinking, we put a special tool on the ground and move it around where we're interested. We record and look at how the waves bounce back to make a picture of what's under the ground. Changes in how the waves bounce can tell us where there might be sinking, and we can guess how deep it is. A really good thing about GPR is that it can also find breaks and cracks in buildings and things near the sinking ground. This helps us keep those things safe and fix them if needed. GPR is a great way to find out if the ground is sinking from mining. It's a method that doesn't hurt the ground and can find sinking at different levels. It also quickly tells us what's under the ground. The bonus is that it can also find damage to buildings. This helps us reduce the problems caused by sinking and keeps buildings and communities safe.

1.3 Seismic Method

Seismic monitoring is a way to find out if the ground is sinking because of mining. With this method, we use special devices called seismometers to measure the shaking of the ground caused by movements deep inside. These devices are put on the ground or in holes in the ground. When the ground shakes, the devices feel it and give us information. This information helps us figure out where and how much the ground is moving down. Seismic monitoring is very good at finding even small changes in the ground caused by sinking. It can find sinking at different levels under the ground, depending on how fast the shaking is. It also tells us right away what's going on below the ground. This helps us find sinking early and any problems that might come with it. The nice thing about using seismic monitoring is that it can watch over a big area for a long time. It also tells us how fast and which way the ground is moving down, which is important for knowing how much the sinking might affect things around it. This method can also find other problems like cracks in the ground or earthquakes. To use seismic monitoring, we put seismometers on the ground or in holes near where we want to check. The shaking can happen naturally or we can make it happen on purpose, and the seismometers feel it. The information they give us helps make a picture of what's happening under the ground. seismic monitoring is a great way to find out if the ground is sinking because of mining. It's good at finding sinking at different levels and tells us what's happening under the ground quickly. It also watches a big area for a long time. This method is valuable because it can find other problems besides just sinking.

1.4 Geodetic Monitoring

Geodetic monitoring is a way to check if the ground is sinking because of mining. We do this by looking at how certain points on the ground move. We use tools like GPS, GNSS, and special surveying methods to do this. These tools help us measure how the points move, both sideways and up-and-down. By using geodetic monitoring, we can get very exact information about where, how much, and how fast the ground is sinking over a big area and a long time. This helps us know which places are most affected and how it might impact buildings and communities nearby. One good thing about geodetic monitoring is that it can check sinking at different levels below the ground, depending on the tool we use. GPS and GNSS can tell us very accurately how high or low the points are, even to the millimeter. Other surveying tools help us know how far the points move side-to-side. To use geodetic monitoring, we set up points on the ground around the area we want to watch. We use GPS, GNSS, or other tools to regularly measure these points. The information we get is used to make a map that shows where the ground is sinking. Geodetic monitoring is a trustworthy and exact way to find out if the ground is sinking from mining. It can quickly give us data about what's happening below the ground, watch over a big area for a long time, and help us understand how sinking might affect buildings and communities nearby. Because it can check sinking at different levels and tell us where and how much it's happening, it's an important tool to keep the problems of sinking from mining under control.

1.5 InSAR (Interferometric Synthetic Aperture Radar)

The InSAR technique is like taking special pictures from far away to see if the ground is sinking because of mining. Instead of using normal pictures, it uses radar waves. It takes pictures of the same place at different times and then compares them. By looking at how the radar waves bounce back, we can figure out if the ground is moving down. This is useful because it can find even really tiny changes in how the ground looks over a big area. InSAR is good for finding mining-related sinking because it can show how the ground is changing, like if it's going down a little bit. It can even make maps that show where the sinking is happening and find small changes that other methods can't see. Besides just finding sinking, InSAR can also see how it affects things like buildings and roads. It can even see if plants are disappearing because of the sinking. There are some things InSAR can't do, like it needs clear weather and nothing in the way of the radar waves. The data it gives needs careful looking at to make sure it's right. But even with these things, InSAR is really useful for finding mining-related sinking and seeing how it affects the environment and communities. In short, InSAR is a great way to find out if the ground is sinking because of mining. It uses radar waves to take special pictures and can find even small changes over a big area. It can show how the ground is changing and what's happening to buildings and plants. While it has some limits, it's very helpful for knowing about sinking and how it affects the environment and communities. It helps us make decisions, plan for mining, and keep the environment and communities safe from the effects of sinking.

1.6 LiDAR (Light Detection and Ranging)

LiDAR, which stands for Light Detection and Ranging, is a way to find out if the ground is sinking because of mining. It uses special laser beams to measure changes in how high or low the ground is. This works by sending out quick bursts of laser light and seeing how long it takes for the light to bounce back. By looking at the time it takes and how strong the light comes back, LiDAR can make a 3D picture of what the ground looks like. It is really good at finding mining-related sinking. It can tell us how much the ground is moving down with very good accuracy, even down to just a few centimeters. It's like seeing very tiny changes on the ground. By looking at how the ground changes over time, LiDAR can show us where and when the sinking is happening and make maps that show these areas. It can also help us know how the sinking affects things like roads and plants. It is especially useful because it can make pictures of areas with lots of trees and can be used together with other ways of looking at things from far away, like photos from planes or satellites. But LiDAR is affected by the weather and needs to see the ground directly. Also, the information it gives needs careful looking at to be sure it's right. LiDAR is a helpful way to find out if the ground is sinking because of mining. It uses lasers to make pictures and can find even small changes over a big area. It can show how the ground is changing and what's happening to roads and plants. Even though it has some limits, it's great to know about sinking and how it affects the environment. This helps us make decisions, plan for mining, and keep the environment safe from the effects of sinking.

1.7 Microgravity Survey

The Microgravity Survey is a way to find out if the ground is sinking because of mining. It works by noticing changes in how strong gravity is in different places under the ground. This method is good for checking if mining is making the ground sink because it can see changes in how heavy the stuff under the ground. To do this, we use very sensitive tools that measure how strong gravity is in one spot. If things below the ground are getting less dense because of mining, the gravity in that spot will change a little. We can use this change to figure out if the ground is sinking because of mining. Microgravity Survey is really helpful for finding empty spaces and holes underground that are made by mining. These holes can make the ground sink. We can use Microgravity Survey to know where these holes are, how big they are, and what shape they have. This helps us make maps that show where the sinking is happening and how risky it might be. Also, we can use a Microgravity Survey to see how sinking might affect things like buildings and roads. But this method needs special tools that can feel very tiny changes in gravity and a place where the measurements won't change a lot. Even though it's not always possible to use this method, it's good at finding holes that other ways like LiDAR and InSAR might miss. The microgravity Survey is a useful way to find out if the ground is sinking because of mining. It uses special tools to measure how strong gravity is in different spots. This helps us know if the ground is getting lighter underneath. It's great for finding holes in the ground made by mining, and it can also show how sinking affects buildings and roads. While it's not always easy to use, it's really good at finding holes that other methods might not see. This helps us make good decisions about mining and keeps the environment and communities safe from the effects of sinking.

1.8 Aerial Photography and Satellite Imagery

Aerial Photography and Satellite Imagery are like taking faraway pictures to see if the ground is sinking because of mining. Aerial photography takes pictures from airplanes or drones, while satellite imagery takes pictures from special machines in space. Both methods give us useful information about how much the ground is sinking and how it's affecting the environment. With aerial photography and satellite imagery, we can make maps and models that show changes in how high or low the ground is over time. By looking at pictures taken at different times, we can see if the ground is sinking and how it's affecting buildings, plants, and other things on the ground. For example, if buildings are getting lower or if plants are disappearing, we can see that with these pictures. Aerial photography and satellite imagery can work together with other methods like LiDAR and Microgravity Survey to get a really good understanding of sinking and how it's affecting the environment. This helps us make better decisions and plans for mining and also helps us keep the environment and communities safe. One good thing about aerial photography and satellite imagery is that they can take pictures of big areas quickly and not cost too much. They are also easy to use and can show us where things are on a map. But sometimes, clouds and bad weather can make the pictures not very clear, and the pictures might not be detailed enough to show very small changes on the ground. Aerial photography and satellite imagery are great ways to find out if the ground is sinking because of mining. They help us make maps and models that show changes over time. These methods are important for making good decisions and plans for mining and for keeping the environment and communities safe from the effects of sinking.

2.0 Review of Literature

2.1 Hu *et al*

In this paper a study has been conducted in the Alto Guadalentín Basin in Spain, the ground has been sinking because people are using too much water from the underground reservoir called an aquifer. This has been happening for many years. In this study, we introduce a new way to find out about the sinking by looking at pictures of the land from above. We used a special method that looks at how the pictures change over time, called the multiscale Model-to-model Cloud Comparison (M3C2) algorithm. This way, we can see how much the ground is sinking over a big area. We used two sets of pictures taken from planes with lasers in 2009 and 2016. At first, we made the pictures smoother by using a special method. These pictures show things on the ground and things above the ground. We used another method to remove the things above the ground so we can focus on the land. Then we compared the pictures from both times using a special math method. The results showed that the ground went down by about 14 centimeters each year from 2009 to 2016, which matches what other studies found. We also looked at how the ground moved using other methods like GPS and radar pictures. The results were similar, which means our method works well. We also compared the results to how thick the soil is, and they matched too. This study shows that we can use this method with pictures taken by planes to see how the ground is sinking when too much water is taken from underground[1].

2.2 Diaz *et al*

Changes in the climate can make the ground sink, especially in cities near the coast where the water level on the surface and underground changes. This research paper talks about using two methods to find out if the ground is sinking or forming sinkholes before it becomes a big problem. They looked at an area in a place called Galicia in Spain, where it's often rainy. This area showed signs that the ground was sinking and buildings were settling lower in the last two years. The researchers used two methods, InSAR and GPR, to see if the ground was sinking. InSAR uses radar pictures taken from far away, and GPR sends special waves into the ground to see what's below. They compared these methods to know if they were getting the same results. The radar pictures showed that the ground went down by about 3.0 to 4.1 millimeters each year from June 2021 to March 2022. Then they used GPR in January 2022 to check if the radar results were right. The GPR also showed that the ground was sinking in the same way the radar pictures said. This information is really important because it helps us know if the ground is sinking before it causes bigger problems. It helps us plan to fix things before they get worse[2].

2.3 Bedini *et al*

In this study we used special pictures taken by a satellite to find out if the ground is moving in a city called Durrës in Albania. These pictures were taken by a radar on the satellite and we looked at them many times over two years, from January 2017 to December 2018. The results showed that parts of the ground are sinking by as much as 30 millimeters each year. This is happening in an area near the Durrës marsh that was turned into land for building. This area has seen a lot of new buildings being made quickly over the last twenty years. In a place called the Port of Durrës, a new wall built to protect against waves is also sinking by up to 30 millimeters each year. This study is the first time we used pictures from a satellite to see if the ground is moving in Durrës, Albania. But we need to keep looking at the ground to understand more about why it's sinking and what's causing it[3].

2.4 Solla *et al*

This research paper talks about making better pictures using GPR to see if the ground is sinking or structures are moving in a special concrete floor and the dirt underneath it. GPR is a way to take pictures underground without digging or damaging things. It shows us a clear picture of the ground under a big area in a short time (which saves time and money). In this study, the goal is to find any problems in the ground that could affect the concrete floor. They used GPR with a special antenna that works at a frequency of 500 million times a second. They also did other tests that involve drilling and poking the ground, which are not so gentle. This method they developed helps them see if the concrete floor is moving or if there are any issues under the ground. They also checked their GPR results by doing other tests. This way, they can know if their method is good for finding problems in the ground and under the floor[4].

2.5 Jianliang *et al*

Scientists did surveys in a place where salt is mined in China. They used special tools like Ground Penetrating Radar (GPR), seismic waves, and electrical imaging to understand how the ground is sinking. This is important because some parts of the ground are dissolving, and this can cause problems. They wanted to know which tool is best to use. They found that the GPR, seismic waves, and electrical imaging can work to find the sinking areas. But sometimes they don't work well because the salt in the ground affects the tools. They talked about how the seismic waves were good at showing the different layers underground, and this helped them see where the ground was sinking because of the dissolving salt. Overall, the study showed that using seismic waves is a good way to see where the ground is sinking because of the dissolving salt in the mine. This helps people understand the ground better and know where there could be problems[5].

2.6 Tonggui *et al*

This paper talks about a way to check how well a special kind of foundation is built. This foundation is called Vibro-sinking gravel pile foundation. They want to use a tool called Ground Penetrating Radar (GPR) to help them see how deep this foundation goes into the ground. This helps them make sure the foundation is built well and saves time and money. They use information about the ground and measurements from a smart machine that makes these foundations to understand how to use GPR[6].

2.7 Sapota *et al*

This article talks about how shaking in the ground can be a danger to buildings, structures, and other things we build. There are two main kinds of shaking, one caused by Earth's movements and another caused by people. This article looks at how a place's surface changed because of a series of small shakes in 2017. These shakes were caused by a quick movement in the ground called void clamping, which happened because of human activities. The shakes were possible because the area has rocks that are often shaken by mining activities. The authors focused on how the surface of a place in Poland changed after these shakes. They used a special technology to see these changes and also looked at data from different programs and systems to understand what happened[7].

2.8 Nicoll *et al*

The Telfer Gold Mine in Australia has an underground area called Telfer Underground Sub-Level Cave (SLC). This area is deep below the surface, about 600 to 1000 meters down from the west side of the Main Dome open pit. This SLC started forming in 2006 and reached the surface in 2009, making a big area that's sinking. This sinking continues at a rate of 500 to 2000 millimeters every month, and it's connected to how much mining is done underground. They also continue to mine both underground and in the open pit. A part of the open pit, called stage 4, can only be reached by a way called the West Ramp, which is close to the sinking area. This Ramp is also moving a bit because of the sinking. They use special tools to watch how the ground is changing and they have plans to respond if something goes wrong. In this research paper, they talk about how they use different tools to watch the sinking area and the ground around it. These tools include radar, special markers, and other instruments. By watching these changes, they can see how the sinking area is growing and where it's going. They also use plans to keep people safe if something bad is about to happen[8].

2.9 Metois *et al*

The Patos-Marinza oil field is a big area in Albania where they've been getting oil from the ground since 1939. It's one of the biggest onshore oil fields in Europe. Every year, they take out more than 7 million barrels of oil from the ground there. They do this in a place with a specific kind of rock called Messinian sandstone. A company called Bankers Petroleum Ltd. has been working there since 2004. In this study, they used special radar images taken from a satellite called Sentinel-1 to see how the ground is moving in a place called Myzeqeja plain especially in the Patos-Marinza oil field. They looked at images taken from different directions and over a few years to see how things are changing. They found that the ground is slowly sinking in a wide area because of natural and human activities. This sinking is even stronger in the oil field area, where they use techniques to get more oil. The sinking matches with where they have the most wells for getting oil. The way the ground is sinking is likely because of how they're getting oil from the ground. They used models to understand this better. They also talked about how this sinking might affect the earthquakes in the area, but they need more time and information to know for sure[9].

2.10 Mahmud *et al*

In this People in Nigeria have been using a lot of groundwater, oil, and gas from the ground near the coast. This has caused the water level underground to go down and they need to dig even deeper holes to get more water. From looking at special radar images, it seems like the land in Lagos state, Nigeria is sinking a bit. In some areas, like Lekki, Badagry, Ikorodu, and Epe, the land is sinking even faster than in Lagos city. This is happening because the ground is not as strong in these places, and buildings are sinking more in areas where there's a lot of sand. This could be because the sand gets pressed down easily by the weight of the buildings[10].

2.11 Ghaechaee *et al*

Many studies have shown that taking too much water from the ground can make the land sink. But there are other things besides taking water that can also make land sink. This study used radar and computer models to predict and understand why land is sinking in the Bakhtegan basin. They looked at how fast the land was sinking using radar. They used computers to pick out the most important things that cause land to sink. They used three different computer models to predict where land is likely to sink. All three models worked well, but the random forest model was the best. They found that land is sinking near places where people are farming with a lot of water and where there are certain land formations. This shows that taking water from the ground isn't the only reason land is sinking. This study's methods can be used in other similar places to understand why land is sinking[11].

2.12 Hu *et al*

In recent times, people have become more concerned about the big problems caused by the ground moving in cities. The usual ways of measuring the ground's movement are limited and don't work well in places with natural disasters. So, we decided to use a technology called InSAR to study how the ground is moving in cities. In our study, we used InSAR and a system called GNSS to find out about land sinking. We used two types of InSAR methods on a set of images taken by radar. These methods helped us see how the surface of Shenzhen in China and Hong Kong was changing over time. We also looked at data from a station in Hong Kong to compare different methods. Our main focus was on the changes along the coastline. By using InSAR and GNSS, we found out that the ground is sinking in certain areas, especially where new land has been added and where buildings with shallow foundations are located[12].

2.13 Bock *et al*

In coastal areas are facing more severe storms and higher sea levels due to global warming, which is making problems worse for the city of Venice. The city already deals with flooding from tides and sinking of the land caused by nature and human activities. Because of increased efforts to protect Venice from rising sea levels, we looked at how the land in the Venice Lagoon has sunk over the past ten years. We used GPS and radar images to study this. Our findings show that the northern part of the lagoon is sinking by 2 to 3 millimeters each year, and the southern part is sinking by 3 to 4 millimeters each year. Venice itself is still sinking too, about 1 to 2 millimeters each year, even though studies from the 1990s suggested that the sinking had stopped. Our research also shows that the land is tilting slightly towards the east, and the natural sinking caused by the movement of the earth's crust beneath the Apennine Mountains is around 0.4 to 0.6 millimeters each year. We used GPS and radar to measure this sinking very accurately, with a precision of 0.1 to 0.2 millimeters each year. When planning to protect Venice from floods, it's important to consider both the sinking of the land and the expected rise in sea level[13].

2.14 Yao *et al*

Detecting how the surface of the ground sinks due to coal mining is crucial to understand how much damage the mining is causing and to prevent accidents and property loss. This is especially important in hilly areas and when mining shallow coal seams that can cause fast and strong sinking of the ground. Many methods exist to detect these changes, but they may not be accurate in hilly areas. To address this, we developed a Digital Subsidence Model (DSuM) using airborne LiDAR, a technology that uses lasers to measure the ground. First, we collected a lot of data about the study area using LiDAR. Then, we used filters to remove unnecessary information and focused on the ground data. From this, we created a Digital Elevation Model (DEM) to understand how the ground's height changes over time. This helped us measure the sinking of the land. Using this data, we found out important information like the maximum sinking, the areas that are sinking, and the angles of the sinking. We checked the accuracy of our method by comparing it with actual measurements on the ground. Our method turned out to be very accurate, even down to the centimeter. This accurate information can be used to make sure mining is safe and to restore the environment after mining is done[14].

2.15 Rosid *et al*

A study was conducted to investigate the occurrence of subsidence and its rate in Jakarta between 2014 and 2018 using time-lapse or 4D microgravity techniques. Jakarta is predominantly situated on a quaternary alluvium fan.

The subsidence phenomenon resulted from multiple factors, including excessive water extraction, reduction in recharge area, surface loading, and the inherent settling characteristics of loose alluvial deposits. By employing a combination of the Complete Bouguer Anomaly (CBA) equation and gravity gradiometry methods, it became possible to determine the Bouguer density as 2.33 g/cm^3. As the subsidence primarily manifested near the surface, the regional gravity anomaly was separated from the CBA. This separation was achieved through a merged spectrum analysis and moving average techniques following the application of Fourier Transform. The outcomes of the study revealed widespread subsidence throughout Jakarta's coastal area. The average rate of subsidence exceeded 10 cm/year in northern Jakarta, with the most significant rate recorded in the Tambora district at 15.9 cm/year. Additionally, a negative 4D microgravity anomaly was identified in the southern part of Jakarta, which appeared to be linked to both ground-level uplift and declining groundwater levels[15].

2.16 Pringle *et al*

The region surrounding the town of Northwich in Cheshire, United Kingdom, has a lengthy historical background of significant ground subsidence. This subsidence is brought about by a combination of natural dissolution and the collapsing of abandoned mine workings within the underlying Triassic halite bedrock geology. In the village of Marston, the Trent and Mersey Canal intersects numerous deserted salt mine workings and areas that had previously experienced subsidence. In 1953, a catastrophic subsidence incident resulted in the canal being breached. A study spanning over two decades has been focusing on a specific section of this canal through traditional geotechnical topographic and microgravity surveys. The outcomes of 20 years of topographic time-lapse surveys have unveiled localized subsidence in specific zones, which were not foreseeable based on the available site information and mine abandonment plans. As a consequence of this subsidence, the canal banks have needed remediation in four separate phases. Over a decade of microgravity, time-lapse data has documented significant negative anomalies in specific areas, corresponding to the information from topographic surveys. Utilizing the existing site data, 2D gravity modeling has identified voids propagating upward and the accompanying collapse material, which closely aligns with the observed microgravity data. In-depth investigations have confirmed the existence of a void in the notable anomaly area. The benefits of conducting extended research of this kind are explored, particularly in relation to geophysicists, geotechnical engineers, and researchers in various application domains that involve near-surface studies[16].

2.17 Thompson *et al*

This article presents the planning and execution of a program designed to oversee the impacts of longwall mining-induced subsidence on wine grape production within the vineyards of the Hunter Valley in Australia. Commenced in 2003, this five-year initiative adopted a multi-scale and multi-temporal approach, using a sliding window monitoring strategy synchronized with the advancement of longwall mining panels. At the level of individual vineyard blocks, samples of grape yields were collected to assess the effects. On a broader regional scale, measurements of vine photosynthetically active biomass were extracted from satellite imagery captured by the Quickbird satellite. All gathered data were analyzed in conjunction with three distinct subsidence "zones": the least subsidence linked to chain pillars, the maximum subsidence tied to the longwall mining, and a zone that marked the transition between these two extremes. Throughout the duration of the project, visual inspections were carried out to validate the occurrence of sporadic localized surface cracking, particularly in regions experiencing significant soil tension. However, data obtained from both the vineyards and the individual blocks failed to demonstrate any conspicuous or systematic viticultural impacts caused by mining activities in the studied location over the project's duration. Instead, observed patterns in grape yields were better accounted for by the vine's biological responses to climatic conditions[17].

2.18 Joyce *et al*

Geological hazards and their resultant impacts often extend across large geographical areas. As a result, the optimal strategy for effectively mapping and monitoring these hazards involves utilizing satellite and airborne imaging platforms that can provide comprehensive and wide-ranging coverage. Given the diversity of hazards, potential data types, and processing methods available, determining the most suitable approach for mapping and monitoring can be quite complex. Hence, it becomes crucial to gain a comprehensive understanding of the spatial and temporal consequences of a specific hazard on the environment before selecting the most suitable data types and processing techniques to employ. This review is crafted to facilitate the decision-making process and aid in the selection of methods when initiating a hazard mapping or monitoring project. Its primary focus is on the application of optical, LiDAR, and synthetic aperture RADAR technologies for evaluating risks before an event and assessing damages after an event occurs. The geological hazards of global significance that are summarized herein encompass landslides and erosion, seismic and tectonic threats, ground subsidence, as well as flooding and tsunamis[18].

2.19 Riley *et al*

The introduction of Laser Scanning technology to the mapping sector took place in 1998. This technological innovation allows for the collection of point data using a laser scanning device, which can be installed on either a stationary or rotating aircraft (Airborne LiDAR, ALS) or set up on ground stations (Terrestrial LiDAR, TLS). Laser scanning offers a substantial augmentation in data points, for instance, up to 18 million data points can be obtained per hour. This stands in stark contrast to conventional data collection methods. Additionally, this technology brings about cost savings due to the reduced time needed for data acquisition and processing, especially when compared to methods like aerial photogrammetry or ground surveying. This advantage is particularly pronounced in areas with dense vegetation or challenging accessibility. Thanks to its relatively swift data acquisition and processing, the capacity to filter out vegetation from datasets, and a straightforward and adaptable data format, Airborne Laser Scanning (ALS) has become an integral and extended part of the mapping toolkit available to Illawarra Coal[19].

2.20 Marfai *et al*

The coastal region of Semarang experiences intricate geomorphological phenomena such as erosion-sedimentation, land subsidence, and the risk of tidal inundation. The undertaking of multi-year shoreline mapping holds significant value for the monitoring and evaluation of this coastal area. This study presents detailed maps that depict the dynamic changes in the shoreline within Semarang, Indonesia, using a variety of spatial data sources. The data for various time segments has been collected through the manual delineation of topographic maps from 1908, 1937, 1992, an Ikonos satellite image from 2003, as well as Digital Number (DN) value analysis and masking operations applied to Landsat MSS images from 1972 and Landsat ETM images from 2001. Over the span of nearly a century, the primary driver of shoreline dynamics in the Semarang coastal area has been the process of sedimentation. This has led to the shoreline extending seaward due to a combination of human-made structures and natural forces. The outcomes of the research have been deemed satisfactory, and the methodology has proven effective, particularly given the absence of a consistent dataset. Nevertheless, there is room for further enhancement in terms of geoprocessing techniques, and the accuracy of the results can be validated in future iterations of this study[20].

2.21 Lamb *et al*

In the past century, human activities have significantly contributed to the degradation of coastal wetlands, causing extensive losses of wetland vegetation and a shift towards open water areas. Although modern high-resolution satellite imagery is readily accessible for tracking current wetland changes, assessing the historical rates of wetland vegetation loss relies on the utilization of older panchromatic aerial photographs. This study involved a comparison between manual image thresholding and an automated Machine Learning (ML) technique to identify wetland vegetation and open water from historical panchromatic photographs taken in the Florida Everglades, a subtropical wetland ecosystem. To gauge the accuracy of detecting vegetation loss over a 72-year period (1940 to 2012) across different Minimum Mapping Units (MMUs), we compared the same categories delineated in the historical photos with multispectral satellite imagery from 2012. In general, regardless of the classification approach or MMUs used, classification accuracies exceeded 95% for both historical photographs and satellite imagery. An increase of 2.3–2.7 hectares in open water pixels was observed across all change maps, with overall accuracies surpassing 95%. Our analysis highlighted the applicability of ML classification methods in distinguishing between wetland vegetation and open water in low-quality, panchromatic aerial photographs. Additionally, it emphasized the compatibility of utilizing images with various resolutions for change detection purposes. The study underscored the significance of evaluating different MMUs, as it revealed the influence of scale on detection accuracy and the estimation of change classes. This assessment also aids in determining the most appropriate scale of analysis for the specific processes under consideration[21].

3.0 Conclusion

The paper review has supplied a wealth of insights concerning subsidence occurrences in mines. Various methodologies are employed to detect and observe land formation changes due to subsidence. The advancements in technology have introduced more adaptable means to monitor subsidence in mining regions. Numerous techniques are utilized for subsidence detection, some of which are cost-effective while maintaining high accuracy. Distinct resolution images, including optical, microwave, hyper-spectral, and microwave images, are harnessed to identify subsidence. Upon evaluation of the research, it becomes evident that the DInSAR method, renowned for its precision and accuracy, stands out as the most effective means for subsidence detection. Combining DInSAR with the ANFIS method has yielded notably accurate subsidence susceptibility maps. The phenomenon of subsidence is also observable in Riyadh, the capital of Saudi Arabia, specifically in the Sahara Arabian desert section. The underlying cause is the haphazard urban expansion. Another finding points to excessive groundwater extraction leading to subsidence. Remarkably, coal mines appear to experience the greatest degree of mining subsidence, a consequence of inadequate soil refilling post-coal extraction. DInSAR emerges as the standout technique, capable of detecting minute changes in land formation, sometimes coupled with machine learning like the RF method for predictive purposes. Remote sensing and GIS techniques prove highly efficient in identifying land formation changes, particularly in mining areas. This efficiency aids in anticipating potential hazards, thereby averting infrastructure damage and potential loss of life. The study unveils the multifaceted environmental impact of mining-related subsidence. Consequences include reduced soil fertility, shifts in groundwater quality, alterations in Landuse Landcover (LULC), changes in bulk density, and compromised soil water retention capacity. Additionally, morphological modifications stemming from mining-related subsidence are highlighted. It's crucial for governments to enact effective monitoring mechanisms for mining operations, and mining companies must adhere to regulations post-mineral extraction. Subsidence, particularly in underground mines, often arises from improper backfilling practices in void areas.

4.0 References

1. Hu L, Hernandez MI, Liu X, Tomas R, Tang X, Bru G, Ezquerro P, Zhang Q. Analysis of regional large-gradient land subsidence in the Alto Guadalentín Basin (Spain) using open-access aerial LiDAR datasets. 2022; 280:113218. https://doi.org/10.1016/j.rse.2022.113218.
2. Diaz AA, Casado J, Solla M, Laguela S. Using InSAR and GPR Techniques to Detect Subsidence: Application to the Coastal Area of "A Xunqueira" (NW Spain). 2023; 15:4233. https://doi.org/10.3390/rs15153729.
3. Bedini E. Detection of Ground Subsidence in the City of Durrës, Albania, by Persistent Scatterer Interferometry of Sentinel-1 Radar Imagery. 2019; 2:297-306. https://doi.org/10.15157/IJITIS.2019.2.4.297-306.
4. Solla M, Fernandez N, Lopez. Amplitude-based GPR imaging to detect subsidence under a reinforced concrete floor slab. 2021. 978-1-6654-2253-6/21/$31.00
5. Jianliang W, Iqbal I, Sanxi P, Yang Y, Jie L, Tianyu Z. Integrated Geophysical Survey in Defining Subsidence Features of Glauber's Salt Mine, Gansu Province in China. 2021; 40:325–334. ttps://doi.org/10.1007/s10706-021-01877-x.
6. Yuan T, Tonggui J, Xiaochao Z. Application of Ground Penetrating Radar in Deep Detection of Crushed Stone Pile Foundation, ICMMCT. 2019; 378-382. 10.23977/icmmct.2019.62074
7. Li Y, Wang J, Chen Y, Wang Z, Wang J. Overlying strata movement with ground penetrating radar detection in close-multiple coal seams mining. 2019, 15. https://doi.org/10.1177/1550147719869852.
8. Sopata P, Stoch T, Wojcik A, Mrochen D. Land Surface Subsidence Due to Mining-Induced Tremors in the Upper Silesian Coal Basin (Poland) - Case Study. Remote Sens. 2020; 12:3923. https://doi.org/10.3390/rs12233923.
9. Nicoll S, Bar N, Plessis P. Managing risks on an active haul road adjacent to a propagating subsidence zone

at telfer gold mine. 2017; 191:172-178. https://doi.org/10.1016/j.proeng.2017.05.169.

10. Metois M, Benjelloun M, Lasserre C, Grandin R, Barrier L, Dushi E, Koci R. Subsidence associated with oil extraction, measured from time series analysis of Sentinel-1 data: a case study of the Patos-Marinza oil field, Albania. 2020; 11:363–378. https://doi.org/10.5194/se-11-363-2020.
11. Mahmud M, Yakubu T, Adewuyi T, Sousa J, Armenteros AM, Bakon M, Lazecky M, Perssin D. Subsidence monitoring in the coastal region of Nigeria using multi temporal interferometric synthetic aperture radar (Mt -Insar). 2016; 178:36-50. 10.1016/j.isprsjprs.2021.05.019
12. Gharechaee H, Samani AN, Sigaroodi SK, Baloochiyan A, Moosavi MS, Hubbart JA, Sadeghi SMM. Land subsidence susceptibility mapping using interferometric synthetic aperture radar (InSAR) and machine learning models in a semiarid region of Iran. 2023; 12:843. https://doi.org/10.3390/land12040843.
13. Hu B, Chen J, Zhang X. Monitoring the land subsidence area in a coastal urban area with InSAR and GNSS. Sensors. 2019; 19:3181. https://doi.org/10.3390/s19143181.
14. Bock Y, Wdowinski S, Ferrati A, Novali F, Fumagalli A. Recent subsidence of the Venice Lagoon from continuous GPS and interferometric synthetic aperture radar. Q03023, 2012; 13(3). https://doi.org/10.1029/2011GC003976.
15. Zheng J, Yao W, Lin X, Ma B, Bai L. An accurate digital subsidence model for deformation detection of coal mining areas using a UAV-based LiDAR. 2022; 14:421. https://doi.org/10.3390/rs14020421.
16. Rosid MS, Prastama RA, Yusuf M, Daud M, Riyanto A. Monitoring Of Jakarta Subsidence Applying 4d Microgravity Survey Between 2014 And 2018. 2020; 20(79):132-138. https://doi.org/10.21660/2021.79.j2031.
17. Thompson JA, Lamb DW, Frazier PS, Ellem B. Monitoring the effects of longwall mine-induced subsidence on vineyards. 2010; 62:973–984. https://doi.org/10.1007/s12665-010-0582-7.
18. Joyce KE, Samsonov SV, Levick SR, Engelbrecht J, Bellis S. Mapping and monitoring geological hazards using optical, LiDAR, and synthetic aperture RADAR image data. Nat Hazards. 2013; 73:137–163. https://doi.org/10.1007/s11069-014-1122-7.
19. Riley P, Crowe P. Airborne and terrestrial laser scanning: applications for Illawarra coal. 2006; 266-275. https://ro.uow.edu.au/coal/54
20. Marfai MA, Al Mohammad H, Dey S, Susanto B, King L. 2007. Coastal dynamic and shoreline mapping: multi-sources spatial data analysis in Semarang Indonesia. Environ Monit Assess. 2008; 142:297-308. https://doi.org/10.1007/s10661-007-9929-2.
21. Lamb LM, Gann D, Velaquez JT, Troxler TG. Detecting vegetation to open water transitions in a subtropical wetland landscape from historical panchromatic aerial photography and multispectral satellite imagery. Remote Sens. 2022; 14:3976. https://doi.org/10.3390/rs14163976.