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Mapping of Land Surface Deformation Using Ps-Insar for Disaster Risk Management in the Future

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ABSTRACT

DKI Jakarta is experiencing land subsidence due to overexploitation of its use and the increasing population. It is feared that this decline or deformation will occur in the location of the new national capital. The research objective is "Mapping of Land Surface Deformation using PS-InSAR for Disaster Risk Management in the Future." Quantitative and qualitative research and data collection methods use secondary and primary data. Secondary data in the form of Permanent Scatterers Interferometry Synthetic Aperture Radar (PS-InSAR) Sentinel-1A images to determine soil deformation. Primary data uses a questionnaire to assess disaster risk management. Data analysis uses spatial and statistical analysis. Spatial analysis for land deformation mapping and statistical analysis for risk management. The results showed that the pattern of land deformation before the determination of the location of the capital city of Indonesia was random. On the other hand, after decision-making, it appears to be more systematic and homogeneous in adjacent areas with a decreasing range of about 5 cm per year. Other findings show that disaster risk management carried out by several agencies, especially the problem of land deformation in East Kalimantan, is still far from expectations and very minimal. The findings can be used for future disaster risk management to minimize negative impacts and reduce disaster risk.

INTRODUCTION

Indonesia has many islands (Mutaqin, B. W et al., 2021). Disasters can suddenly hit every region in every country, so people often do not have time to anticipate preventing disasters. Indonesia's territory is geographically located on the Indo-Australian, Eurasian, and Pacific plates, so it has the potential for various types of disasters (Edyanto, 2011; Kusmiati, 2005). Apart from its geographical location, which causes Indonesia to have the potential for various types of disasters, it is also due to the influence of extreme weather changes (Buchori et al., 2018) and the increasing population, which puts pressure on the physical environment (Amaratunga et al., 2018; Smets & van Lindert, 2016). Indonesia is a developing country (Rustamaji et al., 2020) that is prone to various types of disasters (Rosalina et al., 2019). The capital city of Indonesia is planned to be moved from DKI Jakarta to an area that is currently within the administrative area of East Kalimantan Province (Salsabila & Nurwati, 2020). The government chose East Kalimantan as the location for the new capital city of Indonesia because of its strategic location in the middle of the country's islands. This location is relatively safer against earthquakes than other large islands in Indonesia. The island of Borneo is relatively safe from earthquakes because it is located on the Eurasian plate and has no tectonic activity (Tjitradi, 2019).

One of the reasons for relocating to the New Capital City is because DKI Jakarta is prone to various types of disasters, such as earthquakes, floods, and slowly sinking plains (Manik & Marasabessy, 2010). DKI Jakarta is also experiencing land subsidence due to overexploitation in its utilization and increasing population, so the need for clean water also increases. Groundwater extraction in DKI Jakarta can impact the environment, one of which is the phenomenon of land subsidence or soil deformation (Prasetyo & Firdaus, 2019). Deformation is a change in the position or movement of points in absolute or relative terms, both on a regional and local scale or only in a small area (Haqqi et al., 2015). Deformation is one type of disaster that is feared to arise when a location rapidly develops into a capital city. The location is rapidly growing into a capital city, which will be followed by an increase in population growth, urbanization and industrialization so that it will have a profound impact on environmental conditions (Abd Wahid et al., 2016; Kumalawati et al., 2021). Deformation can also occur due to the rapid development of infrastructure in an increasingly massive area in line with the development of the public sector (Mohd-Rahim et al., 2022).

Deformation can be detected using the Synthetic Aperture Radar (SAR) satellite remote sensing technique. Satellite InSAR (Interferometry SAR) is currently one of the most exploited techniques for assessing land subsidence (soil deformation) and landslide risk management (H. Xu et al., 2021). Interferometry SAR (InSAR) can monitor ground deformation with millimetre accuracy from hundreds of kilometres away (Ferretti et al., 2007; Raspini et al., 2017; Raucoules et al., 2009). InSAR is also used to monitor and measure landslides (Hu et al., 2020; Wasowski & Bovenga, 2014), urban land subsidence, infrastructure deformation (bridges and buildings) (Erten & Rossi, 2019; Huang et al., 2017; Qin et al., 2018; Selvakumaran et al., 2020), and land deformation associated with earthquakes and land subsidence affected by groundwater extraction (Strozzi et al., 2017; Wang et al., 2019) with high accuracy (Crosetto et al., 2015; Milillo et al., 2016; van der Horst et al., 2018). InSAR satellites can measure ground deformation at local scales (Dumka et al., 2020) and national scales (Raspini et al., 2018) and identify potential disaster risks (Costantini et al., 2017).

Research on deformation has been very important since the beginning because of the negative impact of deformation. Deformation can damage infrastructure and other facilities (Ulma, 2021) and cause socio-economic burdens (Dasanayaka & Matsuda, 2022). Land subsidence worldwide is a significant concern for the authorities responsible for dealing with geohazard risks (Boukhemacha et al., 2021). Many factors influence land subsidence, including several natural and anthropogenic phenomena (Tosi et al., 2013). Factors contributing to the decline include over-extraction of groundwater (Castellazzi et al., 2016), underground construction, and mining (Xu et al., 2016). Uncontrolled and unplanned growth in an area often leads to uncontrolled urbanization, affecting natural resources. The daily increase in water demand results in excessive groundwater extraction, which causes land subsidence (Al-Musawi & Al-Hinkawi, 2020; Shahzad et al., 2020). The National Disaster Management Agency (BNPB) has assessed various disaster risks, such as forest and land fires, droughts, floods, landslides, and earthquakes. Information about disaster risk is publicly available, but information about deformation is hardly available. Seeing this, doing more in-depth research on deformation is very important.

This study will analyze land deformation that occurs in the location of the State Capital in order to contribute to disaster risk reduction (mitigation) due to deformation in the future so that disaster risk management can be carried out early on. This research on deformation is also a form of disaster risk management to minimize larger negative impacts, such as reducing or avoiding physical, economic, and mental losses, as well as accelerating recovery and providing protection to disaster-affected communities. Disaster risk management is an applied science that seeks, by systematically observing and analyzing disasters, to increase measures (measures) related to prevention (preventive), reduction (mitigation), preparation, and emergency response. and recovery (Kodoatie, 2006).

Management of disasters with the aim of reducing disaster risks and victims is an important and urgent matter (Rozita & Setiadi, 2020), spatial planning is one of the instruments that play an important role (Abi Suroso & Firman, 2018; Burby et al., 2000; Glavovic, 2010; Lazarević, 2011). One of the roles of spatial planning in reducing disaster risk can be to set spatial patterns and structures to increase an area's capacity and reduce its people's vulnerability (Zakina & Pamungkas, 2019). The formulation of land use plans or spatial plans can be formulated by incorporating or integrating various strategies from the disaster risk management (MRB) concept, especially disaster risk reduction (Burby et al., 1999; Sutanta, 2012) in disaster management.

Disaster management is also all activities that include planning and disaster management aspects, namely before, during, and after a disaster occurs, which is known as the disaster risk management cycle with the main objective of reducing disaster risk (Baas et al., 2008). Management in disaster relief is important for top management, including planning, organizing, directing, coordinating, and controlling (Kodoatie, 2006). The main problem of disaster management for disaster risk management is that the communication system in disaster areas does not yet have an optimal way to produce information that can be used in a disaster event (Tunggali et al., 2019). Communication itself arises because of the need to reduce uncertainty (Littlejohn & Foss, 2014; Umam, 2019). Communication during a disaster is necessary not only in a disaster emergency but also in a pre-disaster situation. Community preparation in disaster-prone areas must always be done. In this study, disaster risk management for disaster management and disaster risk reduction was carried out to minimize the larger negative impact. Disaster risk management must be done pre-disaster, during emergency response, and post-disaster to obtain optimal results. Based on the above background, it is necessary to research Mapping Land Surface Deformation using PS-InSAR for Disaster Risk Management in the Future. Soil deformation research has never been carried out at the capital city construction site in East Kalimantan. The findings can be used for disaster risk management in the future to minimize negative impacts and reduce the risk of disaster due to land subsidence.

Research Materials

Globally, big cities are experiencing rapid housing growth that threatens the social balance of ecosystems (Nurdin, 2015), such as the current capital city of Indonesia, DKI Jakarta. DKI Jakarta is undergoing rapid urbanization and experiencing an increase in daily water use and population growth. Over-pumping, high demand for groundwater, and poor water quality (Khan et al., 2021) for local communities will affect sustainability below ground level. It is important to monitor the ground surface below using remote sensing techniques, namely the Synthetic Aperture Radar (SAR) satellite, which can be applied to obtain large-scale ground information. This technology is non-destructive and efficient for data acquisition (Chen et al., 2017; Pantjawati et al., 2020).

Using satellite remote sensing techniques for geohazard prevention, mapping, and monitoring has grown significantly, contributing to landslide risk reduction, impact assessment, and disaster response in urban areas (Xiao et al., 2018).

Space SAR sensors have contributed to investigating slope instability and ground deformation (Bianchini et al., 2021; Wasowski & Bovenga, 2014). As an active remote sensing technology, spaceborne SAR provides ground surface information occasionally and in weather using microwaves (Solari et al., 2020). InSAR (Interferometry SAR) satellite is a technique for assessing land subsidence (land deformation) (H. Xu et al., 2021).

Persistent Scatterer Interferometric SAR (PS-InSAR) is a developed InSAR method (Azeriansyah et al., 2019; Singhroy et al., 2018). The journal SAR Interferometry was the first to publish the PS-InSAR technique in Permanent Scatterers (Ferretti et al., 2001). Compared to other methods, such as the InSAR method, the advantages of this method are that it can eliminate the effect of decorrelation and increase the accuracy of the results. The disadvantage of the PS-InSAR method is that it requires a lot of radar imagery and hardware with high specifications. PSInSAR (Ferretti et al., 2001) provides valuable information for various research areas, such as landslide analysis (Crosetto et al., 2016), monitoring of ground movement (Carla et al., 2016; Cigna et al., 2019), natural hazards, and risk mitigation (Cavur et al., 2021), deformation and time series analysis (Lu et al., 2014), monitoring of volcanic activity (Massonnet & Rabaute, 1993), and monitoring of surface impacts from groundwater pumping (Jónsson et al., 1999).

PS InSAR can monitor the movement of the ground surface, allowing the user to make regular measurements and monitor fixed objects on the earth's surface (Brandt et al., 2020). PS-InSAR technology is applied in deformation monitoring and can provide decision support for development (Luo et al., 2020). PS-InSAR and high-resolution radar imagery can detect building subsidence in urban areas (Jiang et al., 2021). PS-InSAR is a state-of-the-art geodetic technique that can generate detailed spatial datasets over a coverage area (~100 x 100 km) (Tran et al., 2021). The main principle of the PS-InSAR technique is to utilize multitemporal SAR imagery observation data over a long period of time to detect potential coherence points.

PS-InSAR is one of the InSAR methods developed, and the DInSAR method is currently being developed. Persistent InSAR (PSInSAR) gives better results than differential InSAR (DInSAR) (Prasetyo et al., 2017). The PS-InSAR method can detect small movements from an area with an accuracy of up to millimetres. PS-InSAR, in this study, used Sentinel-1 Imagery. Sentinel 1 is the latest radar imagery from the ESA (Europe Space Agency), which is fully operational daily using the C band sensor. Sentinel 1 has the shortest visit time compared to other radar images and is useful for marine monitoring, land monitoring, and disaster response (Azeriansyah et al., 2019).

The PS-InSAR method in the research area will observe the average speed of land subsidence and uplift at the location of the New Indonesian Capital City and urban areas, built-up, peri-urban, landslides, and geophysics (Besoya et al., 2021). The calculation and analysis of the significant level of land subsidence determine the amount of land subsidence (Azeriansyah et al., 2019). Based on these facts, it is necessary to conduct systematic research to observe the soil movement at the IKN location. Monitoring deformation is crucial to avoid catastrophic environmental damage from resource extraction (Devanthéry et al., 2016). It is necessary to map the existing ground movement in the location of the new IKN to plan mitigation and prevent future damage so that it can be used as an approach to disaster risk management.

One strategy to avoid the impact of the disaster getting worse due to land subsidence in the future is to move the location of the national capital to the province of East Kalimantan. Regular monitoring of soil deformation is necessary to prevent similar incidents from happening again in the location of the new capital city of Indonesia. Land deformation research is carried out for future disaster mitigation so that constructing a new capital city does not encourage environmental damage. The disaster mitigation process requires the involvement of all parties. As a policymaker, the government is the most crucial element in carrying out the disaster risk mitigation and reduction process. Effective disaster risk mitigation and reduction requires an effective communication process (Shahzad et al., 2020). The right communication approach involves individuals influencing behaviour change (Shahzad et al., 2020). Disaster management is the task of the Government and the community to reduce disaster risk, both pre-, during, and post-disaster, to create a disaster-resistant society. Many problems arise due to natural, social, and other environmental disasters. Seeing this, it is very important to know disaster risk management in each region.

Communication problems often arise in disaster risk management. Disaster communication focuses on understanding disaster science from the point of view of communication science (Ockwell et al., 2009). Frank Dance (Lestari, 2018) states that reducing uncertainty is an important aspect of communication. Disaster communication for disaster risk management is communication for disaster prevention Adila et al., 2019; Dewi et al., 2019) and disaster risk reduction. Communication about disaster risk management is very important because it can reduce tension in the community to act effectively and appropriately. Community and private institutions need accurate information from stakeholders, namely the government, to prevent disasters and minimize casualties or material losses (Littlejohn & Foss, 2009a, 2009b). can be used in future disaster risk management to minimize the negative impact, which is much greater. Information related to soil deformation that occurred in East Kalimantan Province is a preventive measure to prevent future disasters. Early information about land deformation can serve as an early warning for the community and policymakers in building and developing the location of the new capital city of Indonesia.

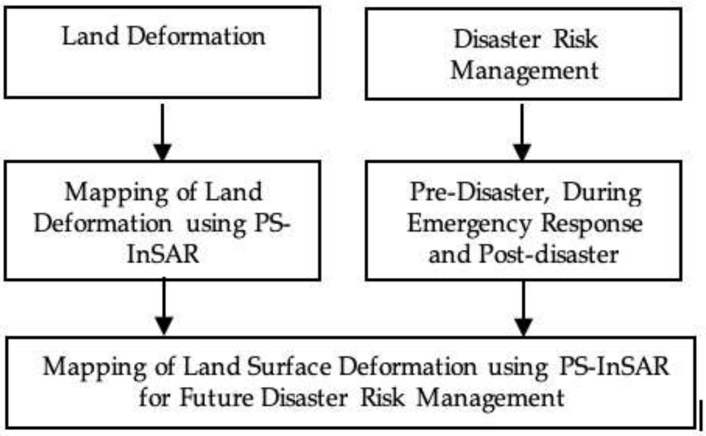


Figure 1. Mapping of Land Deformation using PS-InSAR for Future Disaster Risk Management

RESEARCH METHODS

The study was conducted in the location of the new capital city of Indonesia, namely East Kalimantan Province (see Figure 2). The data collection method used secondary data and primary data. Secondary data in the form of images of Permanent Scatterers Interferometry Synthetic Aperture Radar (PS-InSAR) Sentinel-1A to determine soil deformation (Fadhlurrohman et al., 2020). Primary data uses a questionnaire to determine pre-disasters, during, and post-disasters disaster risk management. The data processing technique uses primary data processing to determine disaster risk management (pre-disaster, during-disaster, and post-disaster) (see Figure 3) and Sentinel-1A image processing to determine soil deformation. Sentinel-1A imagery has a return time of every 12 days. So, in the predecision and post-decision periods, 32 Sentinel-1A plots were used for each. The total Sentinel-1A used in this study was 64 interferometric-wide (IW) plots. The TOPSAR Sentinel-1A image is only split into three subplots, and from the 6th to the 8th burst, the PSInSAR analysis involves three shots. PSInSAR processing involves three superior software, namely ESA Sentinel Application Platform (SNAP), Stanford Method for Persistent Scatterers (StaMPS) (Fadhlurrohman et al., 2020), and MATLAB. Sentinel-1A image preparation was performed in SNAP software. The PSInSAR computation process is carried out using StaMPS on MATLAB software. The results of the PSInSAR computational process directly produce the rate of soil deformation in millimetres per year.

The research variables can be seen in Table 1. Data analysis used a quantitative and qualitative approach (mixed method). The analytical technique used is the analysis of the results of field observations, primary data processing (statistical analysis), and spatial analysis. Statistical analysis for risk management and spatial analysis for land deformation mapping. The spatial analysis technique uses Arc GIS, SNAP, StaMPS, and MATLAB to determine deformation in the research area. This study uses a two-phase land deformation analysis before and after IKN. The "phase before" is from January 2 to 9, 2019, while the "phase after" is from May 8, 2020, to September 12, 2021. The findings in this study map the deformation of land before and after determining the location of the IKN. The mapping results can be used for future disaster risk management to minimize the negative impacts that may arise due to soil deformation at the IKN location.

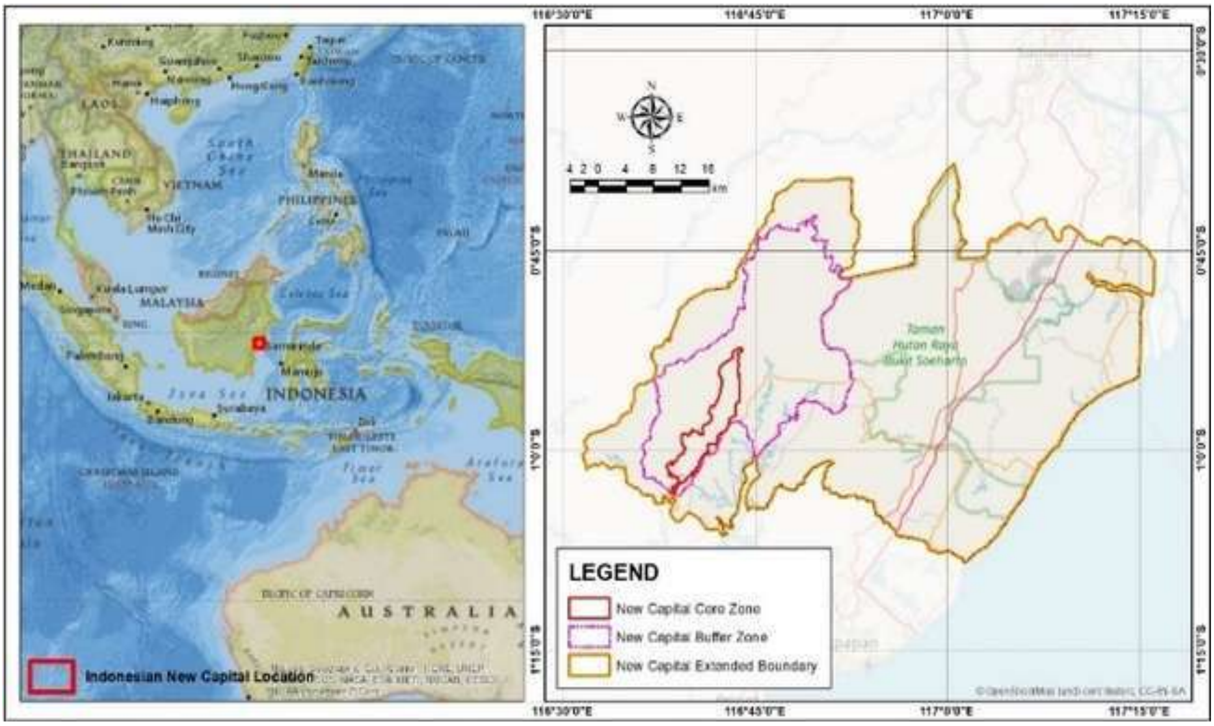


Figure 2. Research Location

Table 1. Research Variables

No	Variable	Indicator	Data collection
1.	Land Deformation Mapping before and after IKN. location determination	a. PS-InSAR, b. Citra Sentinel-1	Secondary Data, Mapping, and Image Processing
2.	Disaster Risk Management	a. Pre-disaster b. During Emergency Response c. Post-disaster	Primary Data, Questionnaire

Source: BIG., 2021; Data Processing., 2023

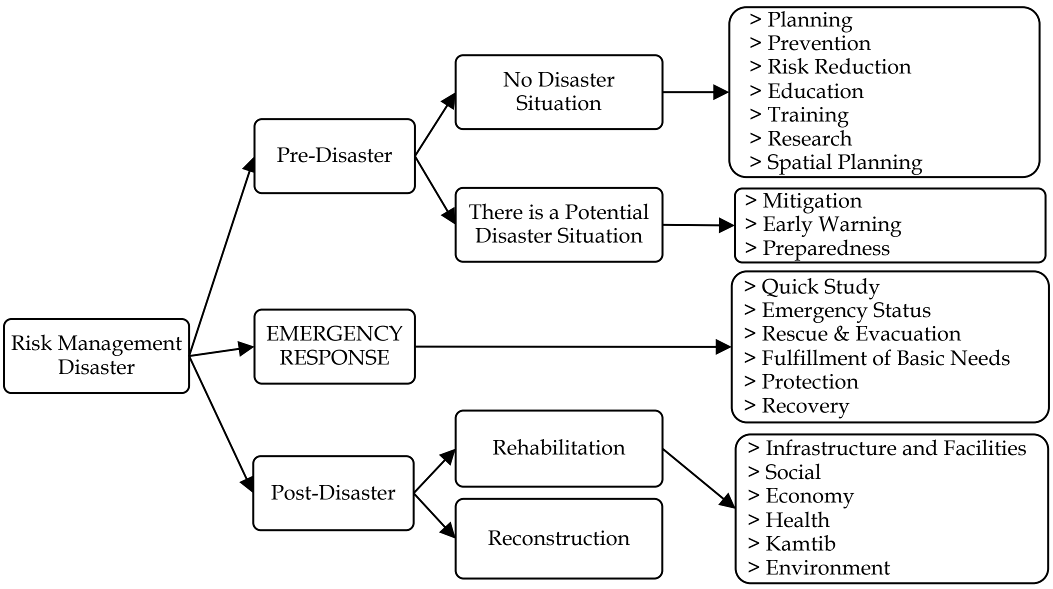


Figure 3. Disaster Risk Management (Source: BNPB Perka No. 4 of 2008)

RESULTS AND DISCUSSION

1. Deformation

Analysis to monitor the rate of soil deformation at the location of new national capital cities using the Digital Elevation Model (DEM) (Dumka et al., 2020; Foroughnia et al., 2019; Zhou et al., 2018). Land deformation is the dominant type of subsidence in terms of overall terrain conditions (Gong et al., 2018). Measurement of deformation at the location of new nation's capital cities to optimize resource allocation, using Sentinel 1 via multi-scale InSAR processing (Dong et al., 2021). The InSAR technique, known as PS-InSAR, overcomes the limitations of temporal and geometric decorrelation (Ferretti et al., 2007). PS-InSAR has the potential to map regional ground movement and subsidence to the millimetre level (Dong et al., 2021; Ferretti et al., 2007). Persistent Scatterer means backscatters that are persistent or constant over time. Over time, the PS-InSAR approach uses threshold points and can only retrieve coherent soil feature structures, such as buildings and bridges. PSInSAR achieves submillimeter accuracy when carefully processing data (Ferretti et al., 2007; Raucoules et al., 2009). So, theoretically, the PS-InSAR process can only be effective and accurate if it is implemented on objects that do not change their backscattering characteristics to SAR waves over time. The objects whose backscatter does not change are solid objects such as buildings, concrete fields, paved roads, etc. PS-InSAR has limitations in vegetated areas where the landscape changes rapidly over time (H. Xu et al., 2021). Other objects, such as vegetation areas and water levels, will change even in days, hours, minutes, and even seconds. Wind-blown vegetation, for example, the orientation of the canopy or leaves, will affect the backscatter of waves emitted by the SAR sensor, as will the surging water surface. As a result, land surface deformation measurements made on vegetation or water surfaces will have a large enough error, so the results cannot be justified.

This study uses Sentinel-1 imagery, a C-band SAR (Potin et al., 2017), which generally has a 3.75 to 7.5 cm wavelength. Theoretically, C-band SAR can only penetrate the vegetation canopy layer by a few centimetres (Meyer, 2019). As a result, dense vegetation such as Sentinel-1 Forest can still not penetrate the leaves and twigs or small branches of trees, which generally will move actively when blown by the wind. This differs from ALOS/PALSAR, an L-band SAR with a wavelength of up to 23 cm (Meyer, 2019). L-band SARs such as ALOS/PALSAR can penetrate deeper into the forest canopy and hit hard parts of trees that are relatively immobile when blown by the wind, such as large branches and tree trunks. So basically, ALOS/PALSAR will be more effective if it is used to measure deformation in vegetated areas. However, the drawback of ALOS-PALSAR is its commercial image, so it is not freely available to the public.

This study aims to determine the deformation of the land surface using Sentinel-1 imagery both before and after the determination of the new state capital. The research focuses on deformations that occur over settlements or infrastructure, such as the paved road network. While the deformations occur in the forest or above the water surface, the information cannot be used further. The results of the mapping of ground surface deformation in the research area are:

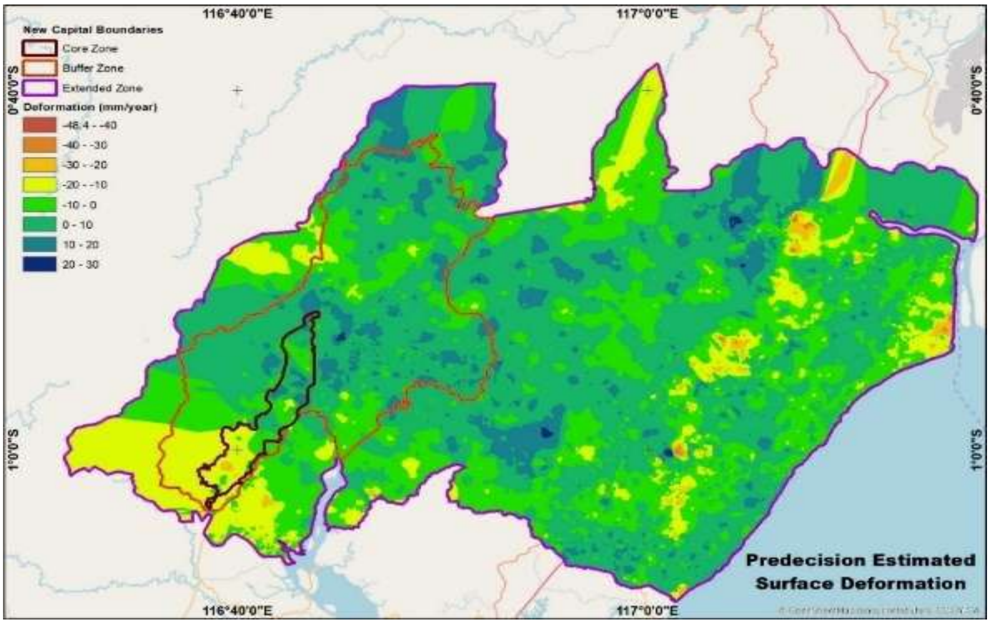
a. Deformation Before set as IKN Location

Land deformation analysis "before establishing the New Indonesian Capital City" resulted in random soil deformation patterns (see Figure 4 and Table 2). Surface deformation can be seen from the Velocity Classes. A negative Velocity Class means there is land subsidence, whereas if it is positive, it means there is a land surface increase. Negative soil deformation indicates land subsidence, while positive deformation indicates a land surface increase (see Figure 4). The analysis of land deformation "after IKN determination" has a more systematic and homogeneous pattern. Adjacent infrastructure areas have higher land deformation rates. Soil deformation analysis also shows that the overall rate of soil deformation "before the New Indonesia Capital City" and "after the New Indonesia State Capital" has different results.

b. Deformation After Set as IKN Location

The new Indonesian capital's core and buffer zones have changed in pace and pattern. However, the government has not yet officially started the construction of IKN's physical infrastructure. Changes in land subsidence are seen outside the core zone and buffer zone of the IKN, especially in coastal areas with a main road traffic lane at the IKN location. This shows a fairly massive development after the establishment of the new capital city of Indonesia. Field observations are still needed to prove this hypothesis. The new capital city of the northern part of Indonesia has experienced land subsidence. Still, with the development of new roads, the land surface has increased, especially on the road body due to asphalt (Figure 5 and Table 3).

One of the areas experiencing rapid land subsidence is Sungai Seluang Village (see Figure 6). This village experienced land subsidence of more than 4 cm/year. This city is located on the outskirts of the capital city of Indonesia. This is quite worrying because, before the construction of the building, the rate of land subsidence was more than 4 cm/year. PS-InSAR accurately estimates ground movement information in areas with high coherence values. The area in question is a built-up area. Meanwhile, in vegetated areas or water features, the coherence value is low enough, so information on land deformation is not accurate enough or cannot be estimated.



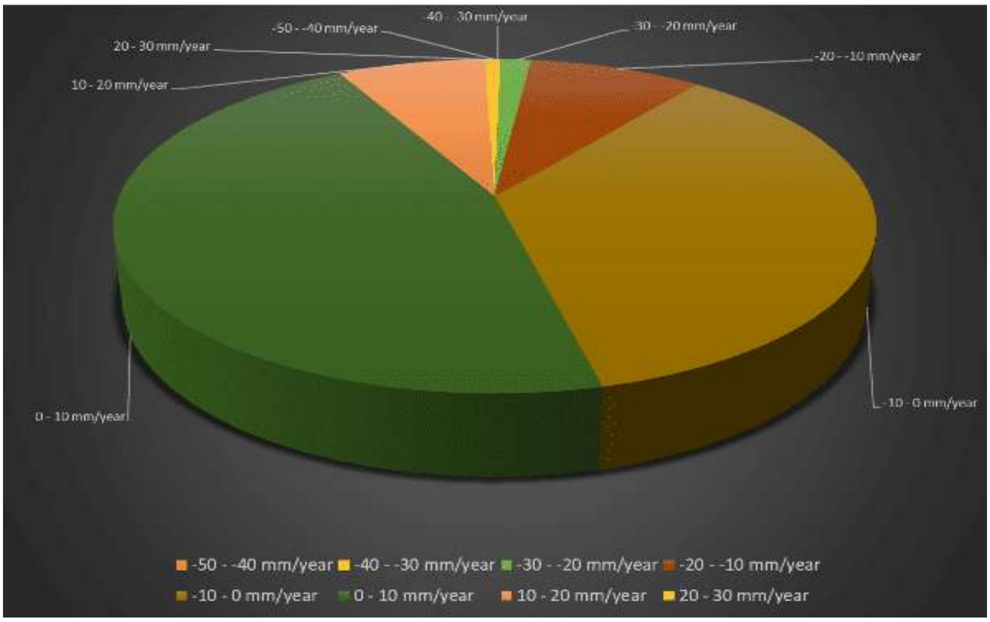


Figure 4. Map of Prediction Surface Deformation Before set as IKN Location (Source: Results of satellite image processing, 2021; Field Observations 2022; Analysis, 2022-2023)

Table 2. Prediction Surface Deformation Before set as IKN Location

No.	Velocity Classes	Number of Points	Average of Velocity (mm/year)	Standard Deviation of Velocity (mm/year)
1	-50 - -40 mm/year	20	-42.41	2.40
2	-40 - -30 mm/year	242	-33.63	2.54
3	-30 - -20 mm/year	1356	-23.74	2.66
4	-20 - -10 mm/year	7785	-13.66	2.70
5	-10 - 0 mm/year	31699	-3.87	2.80
6	0 - 10 mm/year	40836	4.16	2.75
7	10 - 20 mm/year	6642	12.84	2.39
8	20 - 30 mm/year	426	22.65	1.89

Source: Results of satellite image processing, 2021; Field Observations 2022; Analysis, 2022-2023

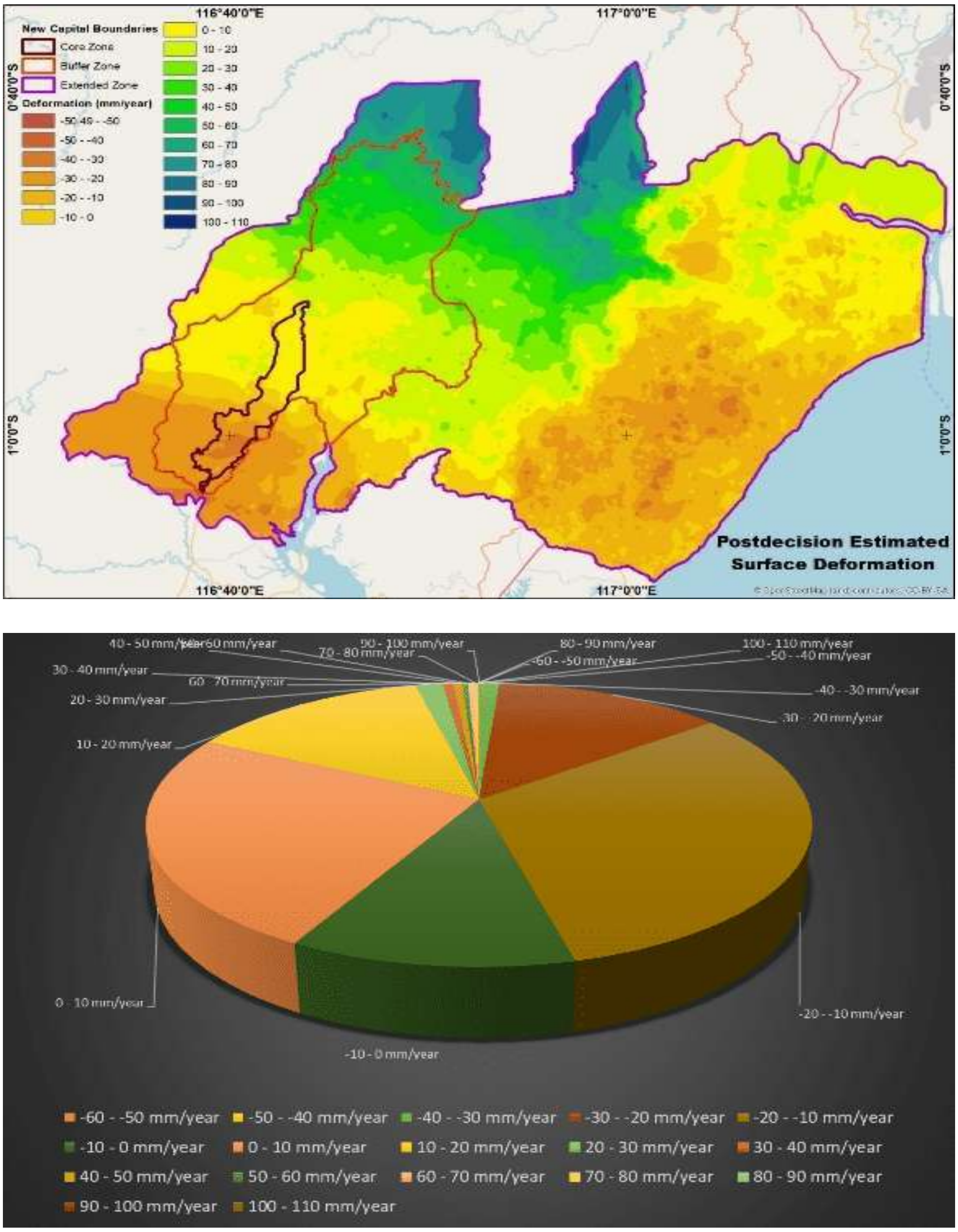


Figure. 5. Map of Prediction Surface Deformation After Set as IKN Location (Source: Results of satellite image processing, 2021; Field Observations 2022; Analysis, 2022-2023)

Table 3. Prediction Surface Deformation After Setting as IKN Location

No.	Velocity Classes	Number of Points	Average of Velocity (mm/year)	Standard Deviation of Velocity (mm/year)
1	-60 - -50 mm/year	1	-50.93	0.00
2	-50 - -40 mm/year	52	-43.37	2.79
3	-40 - -30 mm/year	850	-33.11	2.41
4	-30 - -20 mm/year	10164	-23.34	2.48
5	-20 - -10 mm/year	24278	-14.85	2.80
6	-10 - 0 mm/year	9010	-5.54	3.18
7	0 - 10 mm/year	18884	5.55	2.72
8	10 - 20 mm/year	10624	13.62	2.55

9	20 - 30 mm/year	1216	23.49	2.69
10	30 - 40 mm/year	450	34.68	2.80
11	40 - 50 mm/year	424	44.37	2.88
12	50 - 60 mm/year	237	55.26	2.98
13	60 - 70 mm/year	258	64.19	2.69
14	70 - 80 mm/year	153	74.29	2.85
15	80 - 90 mm/year	66	83.28	2.15
16	90 - 100 mm/year	12	95.18	2.34
17	100 - 110 mm/year	1	100.30	0.00

Source: Results of satellite image processing, 2021; Field Observations 2022; Analysis, 2022-2023

c. Deformation Before and After Set as IKN Lokasi Location

The results of the appearance of geospatial information on land surface deformation before and after the determination of the new state capital can be seen in contrast to the differences in the distribution of land surface movements (see Table 4). Based on the deformation value, the average deformation, and the standard deviation of the land surface, it can be seen that the land surface movement was relatively slower and more homogeneous before determining the new state capital. Meanwhile, post-determination, the movement of the land surface becomes faster and more heterogeneous. The heterogeneous and drastically increasing deformation indicates a fairly massive development if the PS-InSAR calculation process is accurate. The calculation results of deformation can be inaccurate due to weather factors, baseline factors, or the satellite's relative position between recording times that are too close. Theoretically, weather, such as very thick rainstorms, can refract radar waves, which can cause errors in the process of estimating land surface movements. Likewise, the baseline or perpendicular distance of the Sentinel-1 satellite, which is too short for recording times, can also cause the estimation of land. The next action that can be taken is to reduce groundwater extraction to maintain a stable pressure below the land surface. If the city is sufficiently developed, it would be better if later thought to provide sources of water supply from other places. For example, flowing from the mountains through water channels or even using seawater distillation technology, considering the location of the country's capital area on the seafront. Another conservative action that can be taken is to protect and not construct large buildings in areas with the most unstable land surface, such as swamps or mangroves. This includes maintaining catchment areas in higher areas, or from the outset, further planning has been planned to allocate urban spatial plans with infiltration areas spread evenly throughout the city. This aims to maintain a continuous groundwater supply, and the pressure below the land surface remains stable. Surface movements are less accurate. Ideally, if the perpendicular baseline is too short, it is better to estimate the land surface movement using the Short Baseline Subset (SBAS) method (Berardino et al., 2002) instead of using PS-InSAR.

Figure 6. Deformation of the ground surface after the decision in Sungai Seluang Village

Table 4. Deformation before and after IKN. Location Determination

Time Measurement	Minimum Velocity (mm/year)	Maximum Velocity (mm/year)	Average Velocity (mm/year)	Standard Deviation Velocity (mm/year)
Predecision	-48.55	29.83	-0.06	7.99
Post decision	-50.93	100.30	-4.15	15.85

Source: Results of satellite image processing, 2021; Field Observations 2022; Analysis, 2022-2023

The weakness of this research is that there is no accurate field validation process for land surface deformation, such as measuring changes in land surface elevation using geodetic GPS, which has millimetre accuracy. Measures should be taken before and after determining the new nation's capital, which will be quite difficult. However, despite validation, several research results have proven that PS-InSAR is generally quite reliable in estimating land surface movements. The research results of (Cigna et al., 2021) showed that both PS-InSAR and SBAS had a relative error of below 20% for land subsidence 15 mm/year or faster. Assuming an error of 20%, it can be calculated that if the average land subsidence before a determination is -0.06 mm/year, and after a determination is -4.15 mm/year, then the range of land subsidence is -0.048 to - 0.072 mm/year at the time before the determination and -3.32 to -4.98 mm/year after the determination of the new national capital.

The next action that can be taken is to reduce groundwater extraction, which will maintain a stable pressure below the land surface. If the city is sufficiently developed, it would be better if later thought to provide sources of water supply from other places. For example, flowing from the mountains through water channels or even using seawater distillation technology, considering the location of the country's capital area on the seafront. Another conservative action that can be taken is to protect and not construct large buildings in areas with the most unstable land surface, such as swamps or mangroves. This includes maintaining catchment areas in higher areas, or from the outset, further planning has been planned to allocate urban spatial plans with infiltration areas spread evenly throughout the city. This aims to maintain a continuous groundwater supply, and the pressure below the land surface remains stable.

After knowing the results of mapping areas that have the potential to experience soil deformation and its prevention, the mapping results can be used as an early warning system for both the community and policymakers, especially in constructing the new Indonesian capital city. It is very important to monitor land subsidence in the new location of the Indonesian Capital City because it can provide an overview of soil movement so that mitigation can be carried out to prevent the recurrence of land subsidence in DKI Jakarta. Deformation mapping and prevention are two forms of risk management that can reduce the impact of a greater disaster in the future due to the decline that occurs. It is very important to do risk management early on, especially before a disaster occurs, so the community and government will be better prepared to deal with various possible disasters that can occur along with the construction of IKN locations.

2. Disaster Risk Management

Disaster risk management can occur at the pre-disaster, during a disaster, and post-disaster stages. There are two types of risk management carried out at the pre-disaster stage or before the disaster occurs: situations where there is no disaster and situations where there is a potential disaster. In a non-disaster situation, the activities consist of disaster management planning, prevention, disaster risk reduction, education, training, research, and spatial planning (Sari & Yuniningsih, 2019), while the situation where there is a potential disaster, the activities are mitigation, early warning, and preparedness. Conditions during a disaster event or during an emergency response include a quick study, emergency status, rescue and evacuation, fulfilment of basic needs, protection, evacuation, and recovery. Meanwhile, post-disaster includes rehabilitation and reconstruction. The results of disaster risk management in the research area can be seen in Table 5.

There are two types of disaster risk management carried out at the pre-disaster stage or before the disaster occurs, namely situations where there is no disaster and situations where there is a potential for disaster (>80%) (see Table 5). Disaster risk management in conditions during a disaster event or during an emergency response includes rapid assessment of the status of an emergency, rescue and evacuation, fulfilment of basic needs, protection, evacuation, and recovery (>89%). Meanwhile, post-disaster risk management includes rehabilitation and reconstruction (>80%). Based on these results, it can be seen that disaster risk management, in general, has been carried out well at IKN locations. However, deformation, in particular, is still very limited and far from expectations. Many people still do not know the potential for disasters related to land subsidence (deformation). Seeing this, it is still very necessary to carry out special and intensive socialization regarding the potential for catastrophic deformation at the IKN location so that the community can take precautions to minimize the larger negative impact

Table 5. Disaster Risk Management at IKN. Locations

Disaster Risk Management		Answer	Responden	Percentage (%)
Pre-Disaster	Disaster management planning	Yes	97	97
		No	3	3
	Disaster prevention	Yes	86	86
		No	14	14
	Disaster Risk Reduction	Yes	88	88
		No	12	12
	Education and training for the community regarding potential disasters and disaster mitigation	Yes	95	95
		No	5	5
	Disaster research	Yes	80	80
		No	20	20
	Spatial planning in disaster areas	Yes	89	89

		No	11	11
	Mitigation includes the installation of evacuation route signs	Yes	88	88
		No	12	12
	Early Warning	Yes	89	89
		No	11	11
	Dissemination and dissemination of disaster information in order to improve community preparedness to face disasters	Yes	97	97
		No	3	3
When a Disaster	Quick study	Yes	89	89
		No	11	11
	State of emergency	Yes	100	100
		No	0	0
	Rescue and evacuation of victims, property	Yes	100	100
		No	0	0
	Fulfillment of Basic Needs	Yes	95	95
		No	5	5
	Protection	Yes	100	100
		No	0	0
	Refugee Management	Yes	97	97
		No	3	3
	Restoration of Infrastructure and Facilities	Yes	90	90
		No	10	10
Post Disaster	Repair and restoration of all aspects of public or community services to an adequate level (rehabilitation)	Yes	80	80
		No	20	20
	Reconstruction of all infrastructure and institutional facilities in post-disaster areas, both at the government and community levels with the main objectives of growing and developing economic, social, and cultural activities, upholding law and order, and increasing community participation in all aspects of community life in post-disaster areas. reconstruction)	Yes	85	85
		No	15	15

Source: BNPB Perka No. 4 of 2008; Primary Data., 2021; Primary Data Processing and Analysis., 2022-2023.

CONCLUSION

Land deformation analysis shows that the pattern of land deformation has changed before and after IKN. Before the new capital city of the Republic of Indonesia, the land deformation had a random pattern. In contrast, the land deformation had a systematic and homogeneous pattern after the new Indonesian capital.

The maximum speed of land subsidence, both before and after the determination of the new state capital, reaches up to -5 cm/year. This is worrying because land subsidence was fast before massive infrastructure development, especially if various urban infrastructures had been constructed.

One of the areas experiencing rapid land subsidence is the Sungai Seluang Village area, which is more than 4 cm/year. This is worrying because, before building construction, the rate of land subsidence was more than 4 cm/year,

In general, disaster risk management has been carried out well at IKN locations; however, deformation, in particular, is still very limited and far from expectations. Many people still do not know the potential for land subsidence (deformation) disasters, so it is necessary to carry out special and intensive socialization regarding the potential for deformation disasters at the IKN location so that the community can take precautions to minimize the larger negative impact.

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