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Review / Pregledni znanstveni članak

# Pseudo-Dynamics Identification (1817–2022) on the North Coast of Java (Pantura) using Dynamics Topography

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*ABSTRACT. Pantura is one of the regions on the north coast of Java Island that is vulnerable to subsidence disasters. However, in reality, subsidence and uplift occur in the form of emergent land due to high sedimentation rates. Subsidence and uplift are part of the earth's dynamic equilibrium in maintaining a ratio of water area of 71% to land area of 29%. This process gives rise to pseudo-dynamics, which are often overlooked, resulting in errors that frequently occur in disaster mitigation, regional planning, and infrastructure development. This research aims to identify the pseudo-dynamics in Pantura using dynamics topography. Dynamics topography is a geomodelling and geoforensics approach by integrating the latest DTM, time-series topography, and time-series vertical deformation (modified D-InSAR method) so that it is known how to classify the dynamics topography changes in the areas being studied. The data used are topography maps made in England (1817), topography maps made in the US Army (1944), Indonesia topography map (2018), WorldView 2/3 from World Imagery (2022), and Sentinel-1 (2017–2022). The research area is located in 26 regions, divided into the West Pantura (10 areas), the Central Pantura (8 areas), and the East Pantura (8 areas). The research results obtained three criteria for areas experiencing pseudo-dynamics, namely subsidence, uplift, and alternating subsidence–uplift. Areas experiencing subsidence (13 areas) are Tangerang–Jakarta, Jakarta, South Tangerang–Depok–Bogor–Bekasi, Jakarta–Bekasi–Citarum estuary, Pemalang–Pekalongan, Pekalongan–Batang, Batang–Kendal, Kendal–Semarang, Semarang, Semarang–Demak–Jepara, Lamongan–Gresik–Surabaya, Surabaya–Sidoarjo, and Sidoarjo–Pasuruan. The areas experiencing uplift (7 areas) are Seribu Islands (North), Seribu Islands (South), Karawang–Subang, Subang–Indramayu, Indramayu–Cirebon, Indramayu–Cirebon, and Karimun Jawa Islands. The areas experiencing alternating subsidence and uplift (6 areas) are Banten–Tangerang, Citarum estuary–Karawang, Brebes–Tegal, Tegal–*

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*Pemalang, Jepara–Pati, and Pati–Rembang–Tuban–Lamongan. The results of this pseudo-dynamics research with dynamics topography can be used to consider disaster mitigation and regional planning in Pantura.*

*Keywords: pseudo-dynamics, dynamics topography, the north coast of Java (Pantura), subsidence, uplift.*

## 1. Introduction

Dynamics topography is one of the important parameters in geodynamics that influence the dynamics of land and seawater (Julzarika et al. 2022). Dynamics topography is a dynamic process that occurs due to the influence of the earth's movements (rotation and revolution) on the dynamics within the earth and their interactions (Turcotte and Schubert 2014). The problems related to topography have become the main thing in various thematic geospatial aspects (Pham et al. 2018). The topography that causes this condition is the basic geospatial data used in thematic geospatial. Thematic geospatial information cannot be created if there is no basic geospatial data. The quality of topography data also determines the quality of the resulting thematic geospatial information. Topography quality includes spatial resolution, type of input data, and level of accuracy used in topography extraction (Julzarika et al. 2022, Rau et al. 2024). Topography includes land topography and underwater topography (bathymetry) (Julzarika et al. 2021). Topography data has good quality if it is in the Digital Terrain Model (DTM) form.

DTM is a terrain model in a digital 3D form that displays bare land without buildings, vegetation, and other surfaces (Li et al. 2004). So far, most topography data is available in the Digital Surface Model (DSM) form (Julzarika and Harintaka 2019). Topography data can be extracted from terrestrial measurements, aerial photography, Unmanned Aerial Vehicle (UAV) imagery, and satellite imagery (Julzarika and Djurdjani 2018). Not all areas have detailed topography (microtopography) data, and most of them still have static topography. For example, Shuttle Radar Topographic Mission (SRTM) data is still in DSM form for 2000 (Adam et al. 2000, Sefercik and Jacobsen 2006), the Indonesian National Digital Elevation Model (DEMNAS) is mostly in DSM form for 2004–2010 (BIG 2019, Julzarika and Harintaka 2019), etc. There are also topography maps in several countries that were extracted before 2000. These conditions only reflect the topography conditions at the time of data acquisition. Now, it is 2024; this condition no longer represents the current condition. It is caused by dynamic conditions of earth movement due to geodynamics (vertical and horizontal deformation) (Nelson and Cottle 2017, Turcotte and Schubert 2014). To overcome the problem of static topography conditions, it is necessary to provide products and methods for extracting dynamics topography, which is influenced by dynamic earth movements (Julzarika 2024, Lazecký et al. 2018). Dynamics topography can be extracted by integrating DTM with vertical deformation (Julzarika et al. 2021). The quality of DTM influences the quality of topography detail, while the quality of vertical deformation influences the updated geospatial information (Julzarika et al. 2023). One example of this dynamics topography is the latest DTM, a large-scale time-series DTM of mining areas (Dalponte et al. 2019, Fukuda et al. 2016, Suhadha and Julzarika 2022).

The novelty of this research is pseudo-dynamics in the Pantura (the Western Pantura, the Central Pantura, and the Eastern Pantura) based on dynamics topography data (time-series vertical deformation). Then, the results of this pseudo-dynamics analysis can be used to classify the 26 areas in the Pantura and determine whether uplift, subsidence, or uplift–subsidence occurs alternately. The results of this research can be used for various thematic geospatial applications. This research aims to model pseudo-dynamics based on dynamics topography data in the Pantura so that the dynamic conditions of vertical deformation are known.

The study area is located on the North Coast of Java (Pantura), see Figure 1. Number 1 to 26 are the study areas on the North Coast of Java, Seribu Islands (7 and 8), and Karimun Jawa Islands (21). The Pantura stretches from Banten Province to East Java Province, which is located in the northern part of Java Island – the north coast of Java borders directly on the Java Sea. The Pantura is experiencing the phenomenon of abrasion and sedimentation (siltation); this is proven by changes in the coastline in several districts on the Pantura. Sedimentation is the process of deposition of material carried by seawater, while abrasion is the process of coastal erosion caused by sea currents. Old topography maps, dynamics topography, and vertical deformation dynamics can prove changes in coastlines. Dynamics topography on the Pantura is influenced by sedimentation, abrasion, human activity, vertical deformation, raised soil, soil softness, and rapid land use land cover (LULC) change upstream (Ardha et al. 2021, Julzarika et al. 2020, Suhadha et al. 2023). Sediment movement is influenced by current speed and sediment grain size (Hakiki et al. 2021, Mulyaningsih et al. 2020). The larger the size of the sediment grains, the greater the current speed required to transport the sediment particles. Currents are also the force that determines the direction and distribution of sediment (Horstmann et al. 2015). The formation of emergent soil is influenced by accretion, sedimentation from land, and the influence of wave characteristics or seasons in a place.

The Pantura have dynamic earth movement, which is influenced by pseudo-dynamics (Gumilar et al. 2013, Julzarika and Tejo 2022, Lubis et al. 2011, Ng et al. 2012). The dynamics of uplift and subsidence in this region are very high and dynamics. Apart from that, this region also has tens of millions of residents, lots of emergent land, high LULC conversion rates, and many buildings and industries that have an impact on society and the environment. Non-tectonic influences are more dominant in the pseudo-dynamics in Pantura than tectonic influences. Awareness of the understanding of the local community and government regarding the importance of pseudo-dynamics knowledge is also important in this research. This understanding can be used as the main parameter in mitigating and restoring understanding of neglected local wisdom regarding these conditions.


Figure 1. *The study area is located on the North Coast of Java (Pantura). Pantura is located on the north side of Java Island. There are three regions in Pantura: Western Pantura (1–10), Central Pantura (11–18), and Eastern Pantura (19–26).*

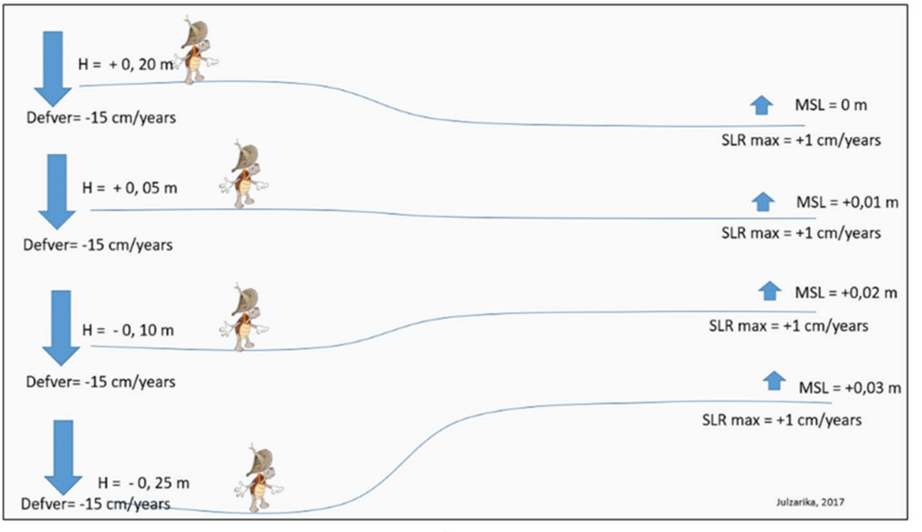
## 2. Materials and Methods

### 2.1. Data

The research data used in Pantura are old topography maps and satellite imagery. The old topography maps used are topography maps made in England (1817), topography maps made in the US Army (1944), and Indonesia topography maps (2018). The satellite imagery used is WorldView 3 from World Imagery (2022). Vertical deformation dynamics using Sentinel-1 imagery (2017–2022). Horizontal deformation dynamics include changes in the dynamics of the coastline of the north coast of Java based on old topography maps compared with satellite images in 2022.

### 2.2. Pseudo-Vertical Deformation Movement

Pseudo-dynamics uses the philosophical concept of geodesy & geology, which states that the Earth is dynamic and is influenced by various geodynamic factors and has a relatively fixed area and volume (Hofmann-Wellenhof and Moritz 2006, Simons and Rosen 2015, Turcotte and Schubert 2014, Vanicek and Krakiwsky 1986). The ratio of water to land is 71.111% (water) and 28.8889% (land), known as the earth's equilibrium ratio of 7:3 (Julzarika 2024, Turcotte and Schubert 2014, Vanicek and Krakiwsky 1986).

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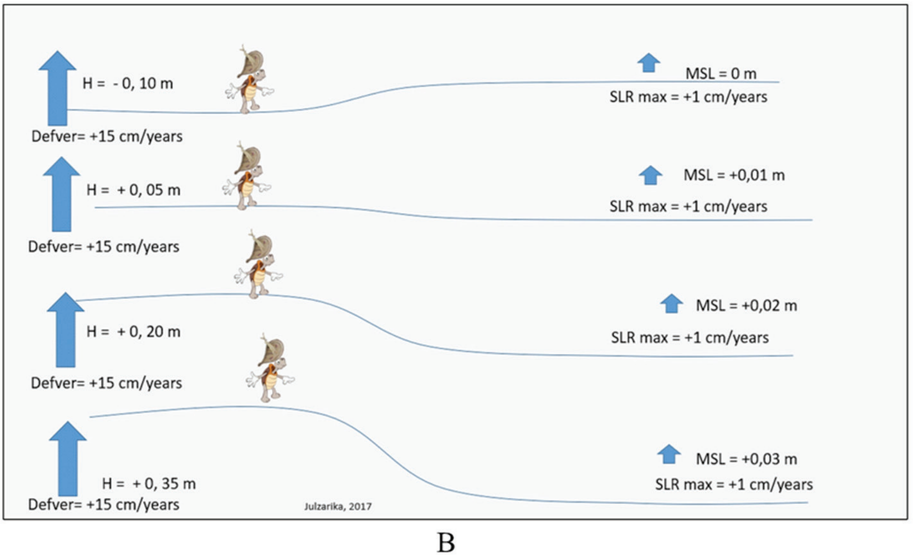


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Figure 2. *Pseudo-vertical deformation movement. A. Pseudo-movement of Subsidence; B. Pesudo-movement of uplift.*

Geodynamics is influenced by vertical deformation (subsidence and uplift) and horizontal deformation, where the percentage conditions are always the same even though they are dynamic (Turcotte and Schubert 2014). The pseudo-dynamics discussed in this research are caused by dynamics topography, which includes the Western Pantura being influenced by the Seribu Islands, the Central Pantura being influenced by Karimun Jawa Islands, and the Eastern Pantura being influenced by Bawean Island. The pseudo movement of vertical deformation is a false movement that causes some people to appear as if they see the sea rising, resulting in land subsidence, or some people in other areas as if they know the sea is going down, resulting in uplift (Julzarika 2024, Turcotte and Schubert 2014, Vanicek and Krakiwsky 1986). This condition occurs due to tectonic and non-tectonic dynamics which move up (uplift) or down (subsidence) due to the dynamic movement of the earth in maintaining its equilibrium (the ratio of land to water is always the same (71%:29% or 7:3). This equilibrium usually exists which are immediately visible on land (topography changes) and some which are often overlooked, generally there is a rise in the seabed (bathymetric changes) (Julzarika 2024). This rise in the seabed is more dominant compared to land changes. The pseudo motion of vertical deformation is divided into pseudo-movement of subsidence and pseudo-movement of uplift.

The pseudo-vertical deformation movement (subsidence) commonly occurs in land subsidence events (Julzarika 2024). The land subsidence referred to in this research is a downward movement caused by both tectonic and non-tectonic movements such as excessive groundwater extraction, high loads of infrastructure, and soft soil (Amighpey and Arabi 2016, Ardha et al. 2021, Caló et al. 2017, Pradhan et al. 2014, Setyawan et al. 2015). This apparent movement of vertical deformation is usually found on small islands surrounded by vast seas and coastal areas that have heavy populations, lots of ponds, and a minimum of mangroves.

As a result of this pseudo-vertical deformation movement, most people think that sea levels will rise, causing many lands to sink. Based on satellite altimetry data, the highest sea level rise is only +1 cm/year. Meanwhile, according to the *Intergovernmental Panel on Climate Change* (IPCC), sea level rise on the North Coast of Java is only 4–7 mm/year. In reality, what is dominant is extreme land subsidence due to tectonic and non-tectonic influences, not caused by sea level rise. In Figure 2, we can see a simple simulation using a max sea level rise (SLR) value of +1 cm/year and an average vertical deformation of –15 cm/year on the North Coast of Java. In the first year, the land position was still above sea level. Then, in the second year, the land began to be parallel to the sea. In the view of humans in the field, the seawater rises while the land remains in the same position. In the third year, the land began to be lower than the sea. This condition causes seawater to start flooding the land. From the perspective of humans on the field, there is a high rise in sea levels. Then, in the fourth year, the land became lower, and seawater began to submerge the land. This condition gives rise to misunderstandings in uncovering the phenomenon of pseudo-vertical deformation movement. Generally, people conclude that there has been an excessive rise in sea levels, causing the land to sink. In this research, the author wants to convey the mistakes that have occurred so far and emphasize the importance of understanding the pseudo-vertical deformation movement so that we can respond to the mitigation of this incident.

In contrast to the pseudo-movement of subsidence, there is also a pseudo-movement of uplift. This pseudo-movement generally occurs on small islands that have just been formed and are surrounded by narrower seas (i.e., Rote Islands, Maluku Islands, Seribu Islands, Karimun Jawa Islands, Alaska, etc.). Apart from that, it also occurs in areas with high sedimentation (i.e., Segara Anakan, Aral Sea, East Sumatra, etc.), areas near faults and sub-faults with active seismic-tectonics (Nias Islands, Mentawai Islands, Japan, northern Russia, southern Java, etc.) and areas with active volcanoes (Hunga Tonga, Krakatoa, Philippines, etc.). In regions experiencing this pseudo-movement of uplift, most people see the sea receding. Most land areas with hard rock, lots of coral and sand experience this pseudo-movement of uplift condition (Julzarika et al. 2022). In the first year, the land was still below sea level with a vertical deformation value of +15 cm/year and sea water rise of +1 cm/year. Then, in the second year, the land began to appear and was above sea level. In the third year, the land rose further and moved away from sea level. In this period, humans will see a decrease in seawater. Then, in the fourth year, the land elevation was far above sea level, and the seawater receded considerably. In areas like this, it is rarely published because it is an antithesis that sea level rise does not apply and is not proven.

## 2.3. Dynamics Topography

The dynamic earth movement is characterized by changes in land and sea (Castellazzi et al. 2016, Turcotte and Schubert 2014). The topography of dynamic earth movements is always characterized by upward movement (uplift), downward movement (subsidence), and horizontal movement (Julzarika 2023, Turcotte and Schubert 2014). For example, the shallowing and narrowing of the Aral Sea have now become land. Another example is the formation of new land or additional land after a large earthquake, high sedimentation, etc. In other areas, there is also land subsidence caused by excessive groundwater extraction, rapid LULC change, an excessive number of settlements and industries, etc (Hakiki et al. 2021, Hengl et al. 2004, Thomas et al. 2017). All of these events have influenced the balance of the earth, with a relatively equal percentage of water and land, since ancient times. Various geodynamic events with this equilibrium are caused by pseudo-dynamics (Turcotte and Schubert 2014). This condition is often overlooked by human observation. One example of this event is the dynamics of shoreline changes, dynamics of volcanic craters, dynamics of coral reefs, changes in the shape of rivers and their estuaries, dynamics of lake shapes, dynamics of lake water leveling, and dynamics of processes that occur inland waters, etc.

Dynamics topography is obtained after integrating the latest DTM (2022) with vertical deformation (according to year) (Julzarika et al. 2022). If annual monitoring of vertical deformation is carried out from 2017–2022, there will be as many as six topographies in the time series. This time-series topography is called dynamics topography. If the available data is an old topography map, the dynamics topography is calculated from the year the map was made against the latest DTM. If the old topographic map is from 1817, then the dynamics topography is 1817–2022. The latest DTM is the latest dynamic terrain or topography modeling data extracted from the integration results of the DTM master with the latest vertical deformation (Julzarika et al. 2021). This DTM master can be extracted from various types of geospatial data (satellite imagery, aerial photography, UAV, and terrestrial survey) with multiple types of 3D methods (stereo model, reverse stereo, interferometry synthetic aperture radar (InSAR), sonar, LiDAR, videogrammetry, etc.) (Julzarika and Djurdjani 2018, Rau et al. 2024). We use the DEM integration method to combine the DTM master with the latest vertical deformation:

$$\textit{The latest DTM} = \textit{DTM master} + \textit{the latest vertical deformation (true)} \quad (1)$$

$$\textit{Dynamics topography} = \textit{The latest DTM} + \textit{old topography map} \quad (2)$$

Vertical deformation (true) is extracted using the modified differential interferometry synthetic aperture radar (D-InSAR) method using Sentinel-1 time-series data (Julzarika 2023). The modified D-InSAR method is a modified method of traditional D-InSAR, parallel small baseline subset (P-SBAS), and persistent scatterer InSAR (PS-InSAR), which has taken into account error propagation in the model and data used and has changed the final result of vertical deformation (line of sight or LOS) to vertical deformation (true) (Julzarika 2023, Suhadha et al. 2021). Equation 4 is the vertical deformation (true) algorithm. LOS vertical deformation means the tilted vertical deformation value according to the direction of the satellite's viewpoint (incidence angle) of the ground surface (Julzarika 2023, Suhadha et al. 2021). Equation 3 is the vertical deformation (LOS). Vertical deformation (true) means that the resulting vertical deformation value has been corrected for the nadir or it is perpendicular to the nadir (Julzarika 2023). The vertical deformation (true) values are close to the actual values in the field. D-InSAR measurements focus on precise vertical deformation results. D-InSAR results still have high precision but low vertical accuracy, so they must be integrated with several field measurement points (Ferretti et al. 2007, Serrano-Juan et al. 2017). Field data brings vertical deformation values following the reference coordinate system on the earth's surface. This method can be complementary to field surveys. Integrating modified D-InSAR and field data will produce vertical deformation measurements with high precision and accuracy over a wide area. Monitoring vertical deformation is crucial to support defense and regional planning, especially in areas with dynamic land use changes, urban areas, and emergent land areas:

$$\textit{Vertical deformation (LOS)} = \frac{2\pi\Delta r}{\lambda} = \frac{(4\pi * B * q)}{(\lambda * R)} \quad (3)$$

$$\textit{Vertical deformation (true)} = \textit{vertical deformation (LoS)} * \cos\theta \quad (4)$$

$\theta$ = incidence angle; $B$ = the perpendicular baseline; $q$ = the displacement between the resolution cell along the perpendicular to the slant range; $R$ = the radar target distance; $\lambda$ = synthetic aperture radar (SAR) wavelength.

## 3. Results

The results based on the dynamics topography in Pantura include vertical deformation dynamics, geoforensics of the horizontal deformation dynamics on the coastline, and geodynamics classification. Based on a combination of vertical deformation dynamics and geoforensics of the coastline, it is classified which areas experience uplift and subsidence. The results of dynamics topography include the Western Pantura, the Central Pantura, and the Eastern Pantura. Table 1 shows the topography of dynamics in the Pantura Region.

Table 1. *Dynamics Topography in the Pantura Region.*

| No | Area | Dynamics Topography (Dominant) | Panturan Region |
|---|---|---|---|
| 1. | Banten–Tangerang | alternating subsidence and uplift | Western Pantura |
| 2. | Tangerang–Jakarta | Subsidence | Western Pantura |
| 3. | Jakarta | Subsidence | Western Pantura |
| 4. | South Tangerang–Depok–Bogor–Bekasi | Subsidence | Western Pantura |
| 5. | Jakarta–Bekasi–Citarum estuary | Subsidence | Western Pantura |
| 6. | Citarum estuary–Karawang | alternating subsidence and uplift | Western Pantura |
| 7. | Seribu Islands (North) | Uplift | Western Pantura |
| 8. | Seribu Islands (South) | Uplift | Western Pantura |
| 9. | Karawang–Subang | Uplift | Western Pantura |
| 10. | Subang–Indramayu | Uplift | Western Pantura |
| 11. | Indramayu–Cirebon | Uplift | Central Pantura |
| 12. | Cirebon–Brebes | Uplift | Central Pantura |
| 13. | Brebes–Tegal | alternating subsidence and uplift | Central Pantura |
| 14. | Tegal–Pemalang | alternating subsidence and uplift | Central Pantura |
| 15. | Pemalang–Pekalongan | Subsidence | Central Pantura |
| 16. | Pekalongan–Batang | Subsidence | Central Pantura |

| | | | |
|---|---|---|---|
| 17. | Batang–Kendal | Subsidence | Central Pantura |
| 18. | Kendal–Semarang | Subsidence | Central Pantura |
| 19. | Semarang | Subsidence | Eastern Pantura |
| 20. | Semarang–Demak–Jepara | Subsidence | Eastern Pantura |
| 21. | Karimun Jawa Islands | Uplift | Eastern Pantura |
| 22. | Jepara–Pati | alternating subsidence and uplift | Eastern Pantura |
| 23. | Pati–Rembang–Tuban–Lamongan | alternating subsidence and uplift | Eastern Pantura |
| 24. | Lamongan–Gresik–Surabaya | Subsidence | Eastern Pantura |
| 25. | Surabaya–Sidoarjo | Subsidence | Eastern Pantura |
| 26. | Sidoarjo–Pasuruan | Subsidence | Eastern Pantura |

### 3.1. The Western Pantura Region

The western Pantura region includes 10 study areas, namely (1) Banten–Tangerang; (2) Tangerang–Jakarta; (3) Jakarta; (4) South Tangerang–Depok–Bogor–Bekasi; (5) Jakarta–Bekasi–Citarum estuary; (6) Citarum estuary–Karawang; (7) Seribu Islands (North); (8) Seribu Islands (South); (9) Karawang–Subang; (10). Subang–Indramayu. Figure 3 shows the topography of dynamics in the Western Pantura Region.

The Banten–Tangerang area experiences dominant subsidence with vertical deformation values of –2 to –11 cm/year. This area is experiencing subsidence because there are many industrial areas and groundwater extraction. Tectonically, the rate of subsidence in this region is still relatively low because the faults and sub-faults are still low (passive) in activity. Non-tectonic factors are the main factors in subsidence in this area. In 2022, this area will experience uplift with a vertical deformation value of 3 to 6 cm/year. This condition is caused by the sedimentation rate of the rivers having a higher vertical deformation value compared to the subsidence rate. The Banten–Tangerang area is affected by alternating subsidence and uplift. The Tangerang–Jakarta area generally experiences dominant subsidence in 2018–2021. The vertical deformation value is –2 to –14 cm/year. The highest vertical deformation value occurred in 2019. However, in 2022, uplift occurred with a vertical deformation value of 2 to 7 cm/year. This uplift condition is caused by the sedimentation rate (2022) being higher than the influence of tectonics and groundwater extraction.

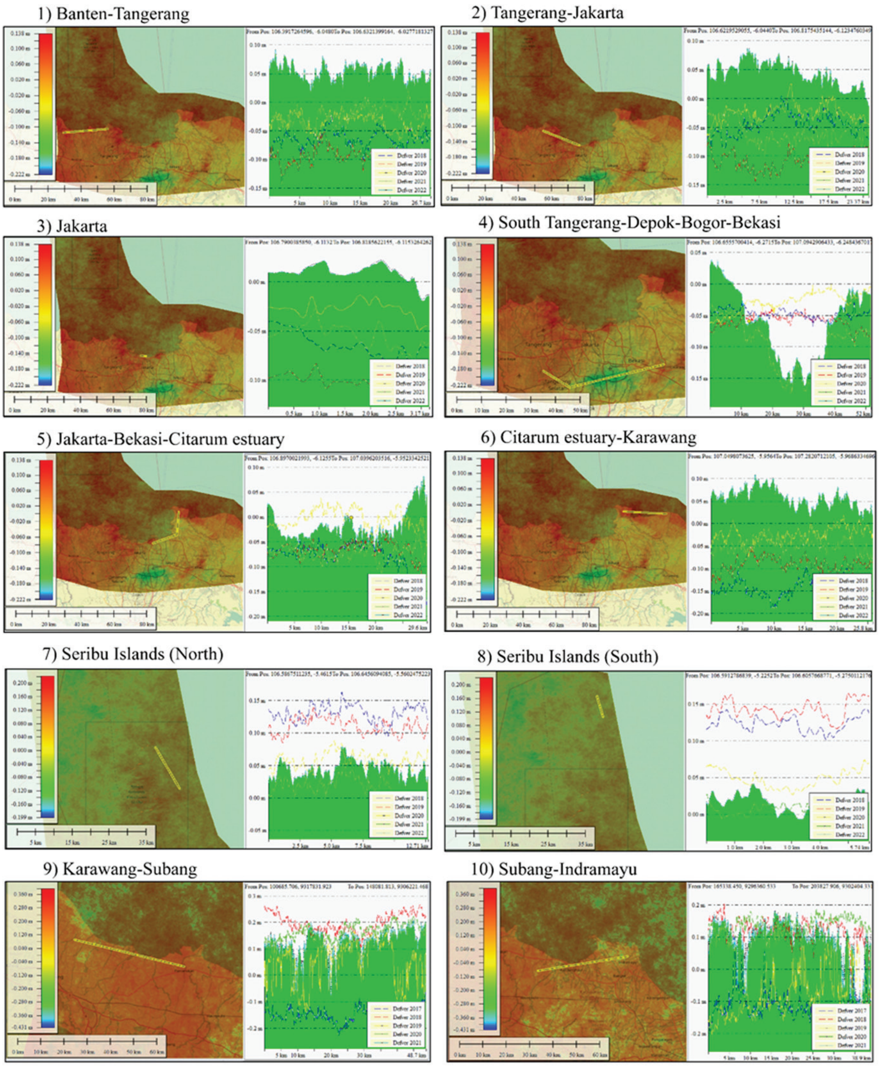



Figure 3. *The dynamics topography in the Western Pantura region.*

The Jakarta area experiences dominant subsidence with vertical deformation values of –3 to –10 cm/year. This condition is caused by this area being located in the Alluvial lowlands, where there are many buildings. This region is one of the areas that experiences pseudo-dynamics. However, overall, the north coast of Java is also experiencing pseudo-dynamics. The South Tangerang–Depok–Bogor–Bekasi area experiences subsidence of –2 to –16 cm/year; the average is –5 to –7 cm/year. In 2021–2022, there will be high vertical deformation of –14 to –16 cm/year. This area is predominantly subsidence. The high subsidence rate in the Jakarta to Bekasi area is caused by excessive groundwater extraction. Subsidence caused by tectonics is still of low value because the faults and subfaults in the area still have low movement. The Jakarta–Bekasi–Citarum estuary area is experiencing dominant subsidence. This condition is characterized by a vertical deformation value of 0 to –11 cm/year in 2018–2022. Swamps and residential areas dominate this area. Most coastal areas also have industries and ponds. This area is dominated by soft soil.

The Citarum estuary–Karawang is an area with a dominant uplift in 2022. High sedimentation rates from large rivers such as the Citarum River cause the uplift that occurs in this region. The uplift that arises can be seen in the vertical deformation value in 2022, with a value of 2 to 10 cm/year. However, in 2018–2021, this region experienced subsidence with vertical deformation values of 0 to –18 cm/year. The highest subsidence occurred in 2018. Dynamics topography in this region experienced a balance in the vertical deformation values so that in certain periods, uplift occurred, and in other periods, subsidence occurred. This condition is caused by the region being bordered by Karawang–Subang, which is predominantly uplifted, and the Jakarta–Bekasi–Citarum estuary area, which is dominantly subsidence. The Citarum estuary–Karawang area is influenced by alternating subsidence and uplift.

The Seribu Islands (North) and the Seribu Islands (South) area experience dominant uplift with vertical deformation values of 0 to 16 cm/year. The Seribu Islands, Karimun Jawa Islands, and Bawean Island areas in the north of Java are the main geodynamics nodes that cause equilibrium in dynamics topography on Java. The dynamic topography equilibrium in question is that there is dominant subsidence in several areas on the north coast of Java. In contrast, on the adjacent side in the north coast area, there is also a dominant uplift. This condition is due to the tectonic attraction of the Seribu Islands, Karimun Jawa Islands, and Bawean Island towards Java Island.

Karawang–Subang area is dominated by uplift due to sedimentation. Tectonically, this area experienced subsidence, but the influence of sedimentation was much greater. The conditions in this area cause the soil to be soft and dominated by emergent land. The uplift value in this area is 0 to 25 cm/year. The uplift occurred in 2018–2021. In 2017, there was a dominant subsidence of –10 to –20 cm/year. Subang–Indramayu area generally experiences dominant uplift due to sedimentation. Tectonically, this area is experiencing subsidence. The Subang–Indramayu area has extensive emergent land with soft soil conditions caused by high sedimentation rates and large rivers in this region. One example of a large river in this region is the Cimanuk River and Cipunagara River. In 2018 and 2020–2021, the Subang–Indramayu area experienced an uplift of 12 to 19 cm/year. Subsidence–dominant events were experienced in 2017 and 2019 with vertical deformation values of –10 to –16 cm/year.

## 3.2. The Central Pantura Region

The Central Pantura region includes 8 study areas, namely (11) Indramayu–Cirebon; (12) Cirebon–Brebes; (13) Brebes–Tegal; (14) Tegal–Pemalang; (15)

Pemalang–Pekalongan; (16) Pekalongan–Batang; (17) Batang–Kendal; (18) Kendal–Semarang. Figure 4 shows the topography of dynamics in the Central Pantura Region. The Indramayu–Cirebon area experiences relatively high deformation dynamics. This area has a lot of sedimentation, which causes emergent land. Even though in some areas, subsidence (tectonic) occurs. Overall, this area is dominated by uplift due to sedimentation. This area has a high dynamic topography, so changes in the shape of coastal and estuaries still have a high potential for change. The addition of land covers the entire Indramayu area of Cirebon, and the subsidence value has begun to decrease on the Cirebon border with Brebes. The uplift value in the Indramayu–Cirebon region is at 0 to 14 cm/year, while the subsidence value for this region is at 0 to –18 cm/year. Uplift dominantly occurred in 2017, 2019–2021, while subsidence was dominant in 2018.

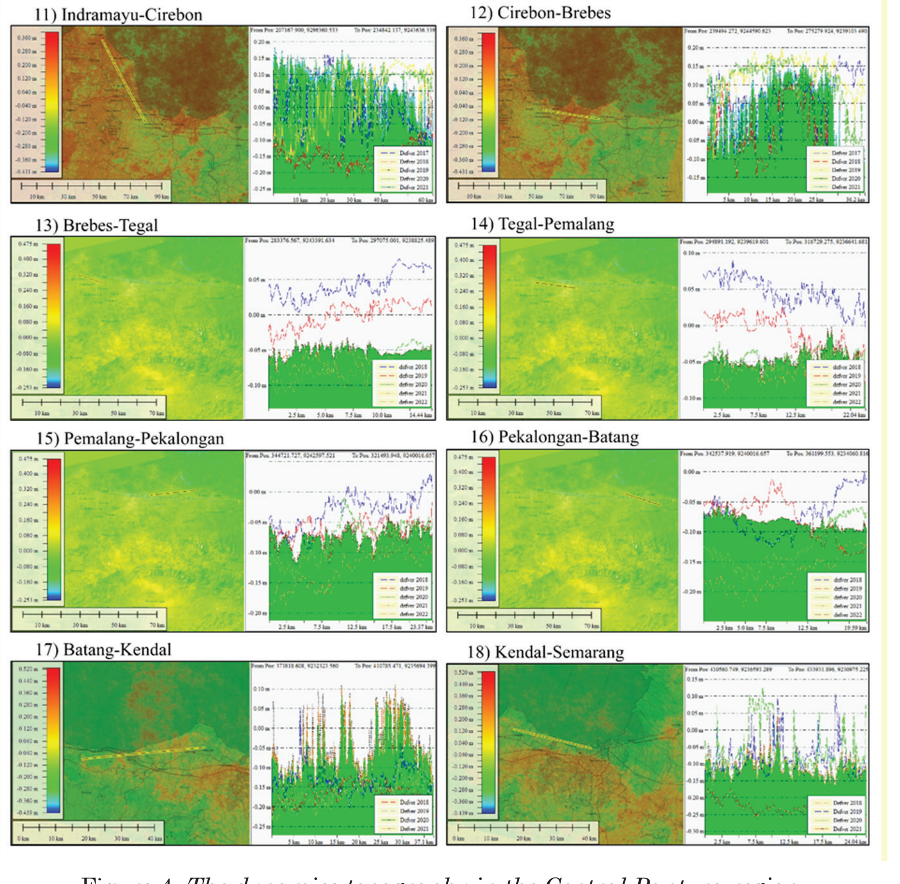



Figure 4. *The dynamics topography in the Central Pantura region.*

The Cirebon–Brebes area was dominated by an uplift in 2019–2020 in the value range of 5 to 15 cm/year. Meanwhile, in 2017–2018 and 2021, this area is dominated by subsidence of 0 to –7 cm/year. The Cirebon area is still affected by the uplift effect due to sedimentation from the Indramayu–Cirebon area. In contrast, the Brebes area is affected by the subsidence effect from the Brebes–Tegal area. The border between Cirebon and Brebes is an example of geodynamics equilibrium on the north coast of Java. The equilibrium in question is that there is an area where there is uplift, and in the neighboring area, there is subsidence so that the Earth's equilibrium remains 7:3. The Brebes–Tegal area is located in the eastern part of the Cirebon–Brebes area. This area is dominated by subsidence, characterized by the vertical deformation value (–1 to –9 cm/year) in 2019–2022. In 2018, this region was dominated by an uplift of 1 to 5 cm/year. This area also has soft soil conditions and dynamic topography. This is characterized by the dynamic value of vertical deformation, which changes very dynamically every year. The Brebes–Tegal area is influenced by alternating subsidence and uplift dynamics.

The Tegal–Pemalang area is also dominated by subsidence with higher values compared to the western region. This area has dominant subsidence in 2019–2022 with a value range of –3 to –8 cm/year. Meanwhile, in 2018–2019, uplift was affected by 1 to 8 cm/year. Like other areas of the North Coast, this area also has soft soil, but less than in the previous western areas. The Tegal–Pemalang area is influenced by alternating subsidence and uplift dynamics. The Pemalang–Pekalongan area is an area dominated by subsidence of 0 to –18 cm/year in the 2018–2021 period. The Pekalongan–Batang area also has similarities with the Pemalang–Pekalongan area. This area is also dominated by subsidence of –3 to –22 cm/year. These two areas also have soft soil that was previously formed due to sedimentation. However, due to the geodynamics equilibrium process, especially in the West Pantura region (uplift-dominant) and Karimun Jawa Islands (uplift-dominant). This area has experienced dominant subsidence. For the north coast of Java, the highest subsidence values are located in these two regions.

The Batang–Kendal area experiences subsidence with vertical deformation values of –5 to –24 cm/year. In 2020 there was dominant subsidence. The global vertical deformation anomaly in 2020 caused an uplift to occur in 2021. The uplift was 0 to 6 cm/year. This anomalous condition still had a good impact on this area because it minimized subsidence at that time. However, after 2021, there will be subsidence again. The eastern region, especially Kendal, needs special attention because it experiences very high subsidence due to massive land conversion, excessive groundwater extraction, massive industrial areas, etc. The Kendal–Semarang area has a vertical deformation value of –6 to –25 cm/year. This area predominantly experiences high subsidence. Various causes of subsidence in this area are caused by soft soil dominated by industrial areas, dense settlements, excessive groundwater extraction, massive land conversion, etc. In 2018, very high subsidence occurred in this region. The vertical deformation value in that year was –25 cm/year. This area needs mitigation and special attention regarding dynamics topography and pseudo-dynamics.

### 3.3. The Eastern Pantura Region

The Eastern Pantura region includes 8 study areas, namely (19) Semarang; (20) Semarang–Demak–Jepara; (21) Karimun Jawa Islands; (22) Jepara–Pati; (23) Pati–Rembang–Tuban–Lamongan; (24) Lamongan–Gresik–Surabaya; (25) Surabaya–Sidoarjo; (26) Sidoarjo–Pasuruan. The Semarang area predominantly experiences subsidence with vertical deformation values of 0 to –25 cm/year. Every year, the Semarang area experiences subsidence with an average vertical deformation value of –12 cm/year. However, in 2020, this area was affected by global vertical deformation anomalies, causing an uplift of 0 to 11 cm/year. Figure 5 shows the topography of dynamics in the Eastern Pantura Region.

The Semarang–Demak–Jepara area predominantly experiences subsidence with vertical deformation values of –11 to –28 cm/year. Overall, this region has an average vertical deformation of –15 cm/year. Geoforensically, this area was once a sea (Muria Strait) that separated Java Island from Mount Muria Island. Then, due to the high uplift in the Karimun Jawa Islands, high sedimentation, and uplift in the Muria Strait, new land was formed with soft soil conditions. This condition also causes new land to emergent land, which causes subsidence vulnerability to be higher than that of tectonic uplift. Many factors cause this, such as the filling up of lakes into ponds and settlements, the river network being cut off, excessive extraction of groundwater, and many mangroves being cut down. This condition can be seen forensically on old Dutch maps. The vulnerability of this region is of particular concern, especially the influence of humans, who are more dominant than nature. Human impact on the North Coast of Java is generally more dominant than natural tectonic influences. The Semarang–Demak–Jepara region is also affected by global vertical deformation anomalies with vertical deformation values of 0 to –12 cm/year.

The Karimun Jawa Islands predominantly experience an uplift of 10 to 14 cm/year. Every year, the land area in Karimun Jawa Islands experiences an expansion and land uplift. Several islands have also had their land unification. The uplift that occurred in Karimun Jawa Islands influenced the dynamics of subsidence and uplift that happened on the North Coast of Central Java. Uplifted seabed coral dominates the Karimun Jawa Islands. The Jepara–Pati area predominantly experiences subsidence of –10 to –17 cm/year. This area has a lot of soft soil and experiences alternating dynamics of subsidence and uplift. This condition is influenced by the tectonic attraction of Karimun Jawa Islands and Java Island towards the Jepara–Pati area. Uplift conditions can be proven by the 2019 uplift event with a vertical deformation value of 20 to 25 cm/year. The alternating dynamics of subsidence and uplift in this region are classified as high and vulnerable to infrastructure and natural disasters. The Pati–Rembang–Tuban–Lamongan area has conditions similar to those of the Jepara-Pati area. This similarity is in the form of alternating subsidence and uplift dynamics but with smaller vertical deformation values. From 2019 to 2021, it will be 0 cm to 25 cm/year. However, in 2018 and 2022 there will be subsidence of –2 to –9 cm/year. This area has the resultant vertical tectonic deformation, which is relatively balanced in terms of subsidence and uplift.

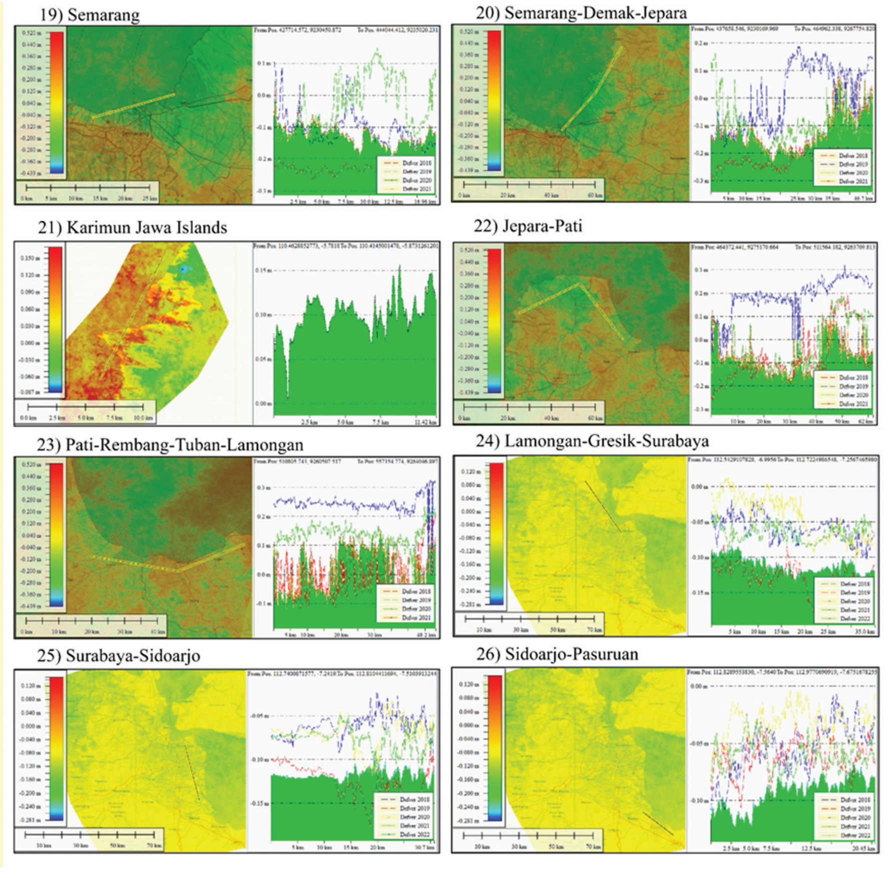



Figure 5. *The dynamics topography in the Eastern Pantura region.*

The Lamongan–Gresik–Surabaya is an area with dominant subsidence with a vertical deformation value of –1 to –13 cm/year. The average vertical deformation in this region is –7 cm/year. Generally, the influence of subsidence in this region is influenced by soft soil, dense settlements, large numbers of industrial buildings, excessive groundwater extraction, and tectonic dynamics that move down (subsidence). Human influence is much more dominant as the cause of subsidence in this region. The influence of uplift from Bawean Island is also the main factor in tectonic subsidence in this region. The Surabaya–Sidoarjo area predominantly experiences subsidence with vertical deformation values of –4 to –14 cm/year in 2018–2022. This region has an average vertical deformation value of –8 to –10 cm/year. The Surabaya–Sidoarjo area has similar causes and conditions of subsidence to the Lamongan–Gresik–Surabaya area. Subsidence in this area is influenced by excessive human activity and a small part is influenced by nature due to tectonic movements. High uplift events in the Surabaya–Sidoarjo area only occurred along the areas affected by the Lapindo mud, namely from the Gempol Sidoarjo area to the Porong River estuary and

Lusi Island, which is located in the eastern part of the region. The Sidoarjo–Pasuruan area also predominantly experiences subsidence with a value of –3 to –11 cm/year and an average vertical deformation of –7 cm/year. The main cause of subsidence is still the same as the Lamongan–Gresik–Surabaya area and the Surabaya–Sidoarjo area.

## 3.4. Comparison of Pseudo-Dynamics of the Pantura with Old Topography Maps

Vertical deformation data is used to determine whether pseudo-dynamics events are experiencing subsidence or uplift. Old maps (three topography maps), the latest DTM (2022), and satellite imagery (2022) can be used as input data in this geoforensics analysis. The three topography maps have an equalized map projection system according to the latest DTM (2022) and satellite imagery (2022). The information extracted from the three topography maps is the coastline and lakes (water bodies) in coastal areas. These four data are overlaid so that we can see information on 2D dynamics topography from the period 1817–2022, see Figure 6.

The Banten–Tangerang area (number 1) has the potential for alternating subsidence and uplift. Based on maps (1817–1944), the western region experienced subsidence or a receding coastline. However, in the eastern part, there is an uplift or advancing coastline. Based on the vertical deformation (2018–2022), this region also experienced alternating subsidence and uplift. From various available geospatial data (1817–2022), it is proven that the region experienced alternating subsidence and uplift events. Based on the maps (1817–1944), the Tangerang–Jakarta area (number 2) experienced high subsidence. These conditions are similar and support the results of monitoring vertical deformation (2018–2022), which is dominated by subsidence. From various available geospatial data (1817–2022), it is proven that this region experienced high subsidence events.

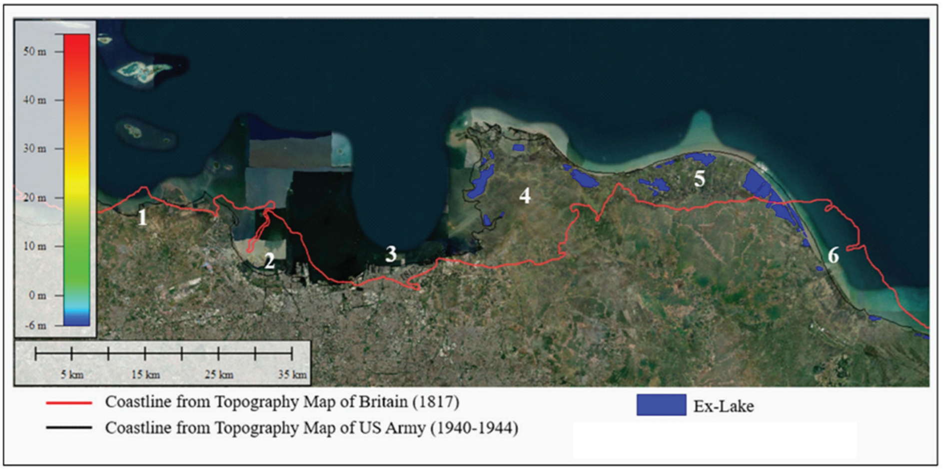
The Jakarta area (number 3) experienced uplift (1817–2018) caused by sedimentation from upstream (Bogor). This area is an alluvial plain, and parts of it also contain swamps, so sedimentation makes it easier to make emergent land. However, in the period 1944–2022, there was an increase in residential areas and high industry, as well as LULC conversion and excessive groundwater extraction, causing subsidence. One of them is proven by the coastline, which retreated during this period. Apart from that, it is also supported by the results of monitoring vertical deformation (2018–2022), which is dominated by subsidence. Subsidence conditions are high because the land uplift (1817–1944) is emergent land. Based on the maps (1817–1944), the Jakarta–Bekasi–Citarum estuary (number 4) experienced high uplift caused by high sedimentation rates. In this period, there were many lakes in this region. These lakes are flood-inundated swamps and lakes caused by trapped land. However, from 1944 to 2022, there was high subsidence in this region, which was caused by the influence of high subsidence in the Jakarta area. In this period, the lakes and swamps in this area had disappeared. Apart from that, it is also caused by high LULC conversion, filled swamps, excessive groundwater extraction, massive additions, and high levels of residential and industrial area additions.

This condition can be seen from the results of monitoring vertical deformation (2018–2022), which is dominated by subsidence.

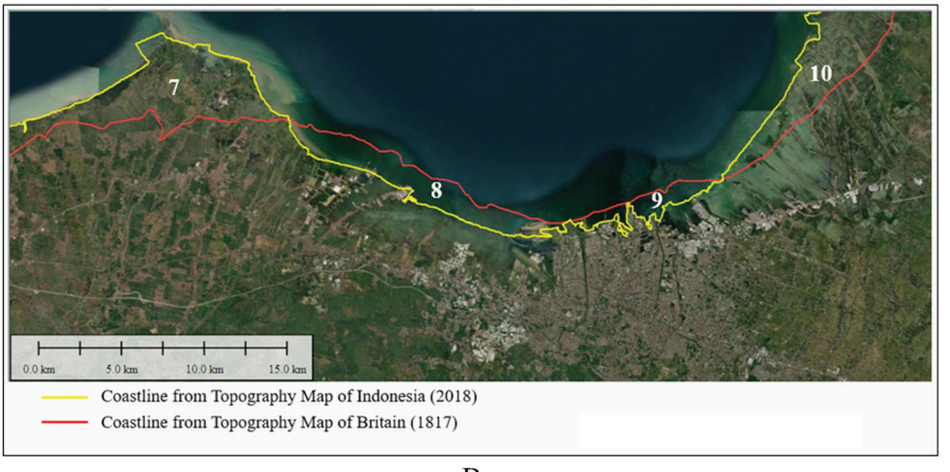
The Citarum estuary–Karawang area (number 5) also experienced high uplift caused by high sedimentation rates according to the maps (1817–1944). In this period, there were also many lakes and swamps. This area is an emerging land with soft soil conditions. In the period 1944–2022, this area was also affected by subsidence caused by the influence of high subsidence from the Jakarta–Bekasi–Citarum estuary area. The eastern area is affected by uplift due to the impact of the Karawang–Subang area. In the period 1944–2022, the lakes and swamps have disappeared. The Citarum estuary–Kawarang region experiences alternating subsidence and uplift. This condition is also proven by the results of monitoring vertical deformation (2018–2022) and geoforensics analysis of old maps and satellite images (1817–2022).

Based on the 1817–1944 map, the Karawang–Subang area (number 6) experienced high subsidence caused by earth equilibrium due to uplift due to high sedimentation rates in the western and eastern areas. Subsidence occurs due to erosion of the coastline and the influence of long-shore currents, causing sedimentation to be carried to the Citarum Estuary–Karawang area and the Subang–Indramayu area. However, in the 1944–2022 period, the opposite occurred from the previous period. In this period, a high uplift occurred due to sediment from the Jakarta–Bekasi–Citarum estuary–Karawang area and the Subang–Indramayu area. Earth equilibrium and pseudo-dynamics apply in this area to normalize uplift and subsidence events. The area that has increased due to uplift is emerging land with soft soil conditions and is vulnerable to infrastructure development. Many areas of emergent land were also converted into ponds and new settlements in the 1944–2022 period. Based on the results of the vertical deformation monitoring for 2017–2021, this area is dominated by uplift, and it is predicted that the amount of emergent land will expand.

The Batang–Kendal area (number 7) experienced an uplift, which was marked by the addition of land according to the 1817–2018 map. The land is in the form of emergent land caused by high sedimentation rates, mainly receiving sediment supply from the Kendal–Semarang area. The addition of land from the east is also caused by the movement of long-shore currents that move along the Pantura (the movement from the east to the west). In the period 1817–2018, there needed to be more land addition because it was affected by subsidence from the east and west sides of this area. Based on the results of vertical deformation calculations for 2018–2021, this area is dominated by subsidence. Based on the maps (1817–2018), the Kendal–Semarang area (number 8) experienced high subsidence, which was characterized by a lot of land reduction. This reduced land becomes sediment and becomes emergent land in the Batang–Kendal area. Based on the maps (2018–2022), the subsidence rate is still high in this region. This condition follows the results of the vertical deformation (2018–2021) calculation, which is predominantly subsidence.




A




B

Figure 6. *The geoforensics of the Pantura are based on topography maps (1817–2018) and satellite imagery (2022). A. The western Pantura (1817–2022). B. The central and eastern Pantura (1817–2022).*

The Semarang area (number 9) on the maps (1817–2018) also experienced subsidence, with the coastline receding towards the mainland. Most of this reduced land becomes sediment and emergent land in the Semarang–Demak area. Based on the maps (2018–2022), the rate of subsidence in this region is getting higher, caused by excessive groundwater extraction, increasing numbers of settlements and industries, and LULC conversion. This condition follows the results of the vertical deformation (2018–2021) calculation, which is predominantly subsidence.

The Semarang–Demak area (number 10) in 1817–2018 experienced an uplift caused by high sedimentation rates from the Semarang area and its surroundings. The Semarang–Demak area is dominated by emergent land and swamps, and there are many small lakes. However, in the maps (2018–2022), this region is dominated by subsidence. There are several causes, namely the filling up of small lakes and swamps, the conversion of land into fish ponds, the massive rate of addition of settlements in emerging land areas, and the influence of high uplift in the northern region (Karimun Jawa Islands). Based on vertical deformation (2018–2021) calculations, this area is dominated by subsidence.

## 4. Discussion

Research related to the dynamics topography of the Pantura region has yet to be carried out thoroughly. The research is only carried out in certain areas such as Jakarta, Semarang, Pekalongan, Demak, and Cirebon. Research in certain regions only examines static topography. Research related to dynamic topography in Jakarta has been conducted by Ardha et al. 2021. The results obtained show that the North Jakarta area experienced the highest land subsidence in the entire Jakarta area, with the annual average rate from 2017 to 2019 being –3.4 cm. This value is the average value of all samples in the North Jakarta area. The second area with high land subsidence is West Jakarta, with a maximum subsidence value (of –2.8 cm). Vertical deformation information extraction was carried out using the D-InSAR method with Sentinel-1 image data. Another study was conducted by Ng et al., 2012 which discussed the observed subsidence rates in the Bekasi area, which were as high as 115 mm/year. Extraction of vertical deformation information is carried out using the PS-InSAR method with L-band ALOS PALSAR and global positioning system (GPS) surveying data.

Subsidence research in the Semarang area was carried out by Gumilar et al. 2013. They measure the subsidence based on estimations from leveling, InSAR, microgravity, and GPS survey methods. The rate of land subsidence (1999–2011) was –19 cm/year. Results derived from GPS from 2008 up to 2011 show that land subsidence in Semarang has a rate of –6 to –7 cm/year. Subsidence research in the Cirebon area was carried out by Bramanto et al. 2023. This research used the InSAR time series and global navigation satellite system (GNSS) time series (2010–2021), and the land subsidence result in the Cirebon area was –2.6 mm/year. The subsidence value in highly populated areas was up to –17 mm/year. The subsidence in prominent land along the coastline was up to –32 mm/year, and the fastest subsidence rate was observed over the salt evaporation field area, which was about –50 mm/year. Meanwhile, research on vertical deformation in the Surabaya area was carried out by Handoko et al. 2011. Research in the Surabaya region was carried out in 2007 and 2010, with the result being a relatively large subsidence of –2.79 cm/year.

## 5. Conclusion

This research concludes that pseudo-dynamics identification can be done using dynamics topography data. Dynamics topography (1817–2022) uses three topography maps (1817, 1944, 2018), the latest DTM (2022), satellite imagery (2022), and time-series vertical deformation (2017–2022). Pseudo-dynamics is often overlooked in planning and observations, especially in areas where emergent land is dominant and areas of subsidence with a track record of originating from emergent land (soft soil). Dynamics topography is a geomodelling and geoforensics approach by integrating the latest DTM, time-series topography, and time-series vertical deformation (modified D-InSAR method) so that it is known how to classify the dynamics topography changes in the areas being studied. The research results obtained three criteria for areas experiencing pseudo-dynamics, namely subsidence, uplift, and alternating subsidence-uplift. Areas experiencing subsidence (13 areas) are Tangerang–Jakarta, Jakarta, South Tangerang–Depok–Bogor–Bekasi, Jakarta–Bekasi–Citarum estuary, Pemalang–Pekalongan, Pekalongan–Batang, Batang–Kendal, Kendal–Semarang, Semarang, Semarang–Demak–Jepara, Lamongan–Gresik–Surabaya, Surabaya–Sidoarjo, and Sidoarjo–Pasuruan. The areas experiencing uplift (7 areas) are Seribu Islands (North), Seribu Islands (South), Karawang–Subang, Subang–Indramayu, Indramayu–Cirebon, Indramayu–Cirebon, and Karimun Jawa Islands. The areas experiencing alternating subsidence and uplift (6 areas) are Banten–Tangerang, Citarum estuary–Karawang, Brebes–Tegal, Tegal–Pemalang, Jepara–Pati, and Pati–Rembang–Tuban–Lamongan. This pseudo-dynamics study with dynamics topography must be carried out in dynamic movement areas such as the Pantura. Disaster mitigation, defense, and regional planning must be considered.

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### References

Adam, N., Eineder, M., Breit, H., Suchandt, S. (2000): Shuttle Radar Topography Mission: DLR's Interferometric SAR Processor for the Generation of a Global Digital Elevation Model, European Space Agency, (Special Publication) ESA SP, 478, 91–98.

Amighpey, M., Arabi, S. (2016): Studying land subsidence in Yazd province, Iran, by integration of InSAR and leveling measurements, Remote Sensing Applications: Society and Environment, 4, https://doi.org/10.1016/j.rsase.2016.04.001.

Ardha, M., Suhadha, A. G., Julzarika, A., Yudhatama, D. (2021): Utilization of Sentinel-1 satellite imagery data to support land subsidence analysis in

DKI Jakarta, Indonesia, J. Degrade. Min. Land Manage, 8 (2), 2587–2593, https://doi.org/10.15243/jdmlm.2021.082.2587.

BIG (2019): DEMNAS, http://tides.big.go.id/DEMNAS/, Accessed on April 1st, 2024.

Bramanto, B., Gumilar, I., Sidiq, T. P., Rahmawan, Y. A., Abidin, H. Z. (2023): Geodetic evidence of land subsidence in Cirebon, Indonesia, Remote Sensing Applications: Society and Environment, 30, 100933, https://doi.org/https://doi.org/10.1016/j.rsase.2023.100933.

Caló, F., Notti, D., Galve, J. P., Abdikan, S., Görüm, T., Pepe, A., Şanli, F. B. (2017): DInSAR-based detection of land subsidence and correlation with groundwater depletion in Konya plain, Turkey, Remote Sensing, 9 (1), https://doi.org/10.3390/rs9010083.

Castellazzi, P., Martel, R., Galloway, D. L., Longuevergne, L., Rivera, A. (2016): Assessing Groundwater Depletion and Dynamics Using GRACE and InSAR: Potential and Limitations, In Groundwater (Vol. 54, Issue 6), https://doi.org/10.1111/gwat.12453.

Dalponte, M., Jucker, T., Liu, S., Frizzera, L., Gianelle, D. (2019): Characterizing forest carbon dynamics using multi-temporal lidar data, Remote Sensing of Environment, 224 (September 2018), 412–420, https://doi.org/10.1016/j.rse.2019.02.018.

Ferretti, A., Guarnieri, A. M., Prati, C., Rocca, F. (2007): InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation, In K. Fletcher (Ed.), Proceedings of the National Academy of Sciences of the United States of America. European Space Agency, ESA Publication ESTEC, Postbus 299 220 AG Noordwijk, The Netherlands.

Fukuda, T., Tokuhara, T., Yabuki, N. (2016): A dynamic physical model based on a 3D digital model for architectural rapid prototyping, Automation in Construction, 72, 9–17, https://doi.org/10.1016/j.autcon.2016.07.002.

Gumilar, I., Abidin, H. Z., Sidiq, T. P., Andreas, H., Maiyudi, R., Gamal, M., Fukuda, Y. (2013): Mapping And Evaluating The Impact Of Land Subsidence In Semarang (Indonesia), In Indonesian Journal of Geospatial, Vol. 2, Issue 2.

Hakiki, I. A., Sembiring, L. E., Nugroho, C. N. R. (2021): Sedimentation Analysis of Segara Aanakan Lagoon using Cohesive Sediment Transport Numerical Modelling, Jurnal Teknik Hidraulik, 12 (1), 1–14, https://doi.org/10.32679/jth.v12i1.642.

Handoko, E. Y., Kurniawan Akbar, Sukma, A. (2011): Land Subsidence di Surabaya (2007–2010), Geoid, 7 (1), 38–43.

Hengl, T., Gruber, S., Shrestha, D. P. (2004): Reduction of errors in digital terrain parameters used in soil-landscape modeling, International Journal of Applied Earth Observation and Geoinformation, 5 (2), 97–112, https://doi.org/10.1016/j.jag.2004.01.006.

Hofmann-Wellenhof, B., Moritz, H. (2006): Physical Geodesy, Springer, Wien, New York, https://doi.org/https://doi.org/10.1007/978-3-211-33545-1.

Horstmann, J., Borge, J., Seemann, J., Carrasco, R., Lund, B. (2015): Chapter

16 – wind, wave, and current retrieval utilizing X-band marine radars, In: Liu, Yonggang, Kerkering, Heather, Weisberg, Robert H. (Eds.), In Coastal Ocean Observing Systems, Academic Press, 281–304.

Julzarika, A. (2023): Land Subsidence Dynamics in Malaysia Based On Time-Series Vertical Deformation Using Modified D-InSAR Sentinel-1, Planning Malaysia, 21 (29), https://doi.org/10.21837/pm.v21i29.1374.

Julzarika, A. (2024): Land Surface Dynamics and Underwater Topography from the Latest DTM Extraction to Measure the Antarctica Ice Sheet Thickness, Ocean and Polar Research, 46 (1), 1–18, https://doi.org/10.4217/OPR.2024002.

Julzarika, A., Djurdjani, D. (2018): DEM classifications: opportunities and potential of its applications, J. Degrade. Min. Land Manage, 5 (53), https://doi.org/10.15243/jdmlm.

Julzarika, A., Harintaka, H. (2019): Indonesian DEMNAS: DSM or DTM? AGERS 2019 – 2nd IEEE Asia-Pacific Conference on Geoscience, Electronics and Remote Sensing Technology: Understanding and Forecasting the Dynamics of Land, Ocean and Maritime, Proceeding, 31–36, https://doi.org/10.1109/AGERS48446.2019.9034351.

Julzarika, A., Nugroho, J. T. (2022): Monthly Dynamic Groundwater Estimation using GRACE over Indonesia, 12 (3), 1113–1119.

Julzarika, A., Suhadha, A. G., Prasasti, I. (2020): Plate and faults boundary detection using gravity disturbance and Bouguer gravity anomaly from space geodesy, Sustinere: Journal of Environment and Sustainability, 4 (2), 117–131, https://doi.org/10.22515/sustinere.jes.v4i2.108.

Julzarika, A., Aditya, T., Subaryono, Harintaka, Dewi, R. D., Subehi, L. (2021): Integration of the latest Digital Terrain Model (DTM) with Synthetic Aperture Radar (SAR) Bathymetry, J. Degrade. Min. Land Manage, 8 (3), 2502–2458, https://doi.org/10.15243/jdmlm.

Julzarika, A., Aditya, T., Subaryono, S., Harintaka, H. (2022): Dynamics Topography Monitoring in Peatland Using the Latest Digital Terrain Model, Journal of Applied Engineering Science, 20 (1), 246–253, https://doi.org/10.5937/jaes0-31522.

Julzarika, A., Laksono, D. P., Subehi, L., Iswandono, E., Dima, A. O. M., Nugraha, M. F. I., Kayat, K. (2023): The Latest Bathymetry and Topography Extraction of Lake Ledulu from Multi-Source Geospatial Data, Geographia Technica, 18 (2), 180–195, https://doi.org/10.21163/GT_2023.182.14.

Lazecký, M., Hlaváčová, I., Martinovič, J., Ruiz-Armenteros, A. M. (2018): Accuracy of Sentinel-1 Interferometry Monitoring System based on Topography-free Phase Images, Procedia Computer Science, 138, 310–317, https://doi.org/10.1016/j.procs.2018.10.044.

Li, Z., Zhu, Q., Gold, C. (2004): Digital terrain modeling: Principles and methodology, In Digital Terrain Modeling: Principles and Methodology, https://doi.org/10.1201/9780203357132.

Lubis, A. M., Sato, T., Tomiyama, N., Isezaki, N., Yamanokuchi, T. (2011): Ground subsidence in Semarang-Indonesia investigated by ALOS-

PALSAR satellite SAR interferometry, Journal of Asian Earth Sciences, 40 (5), 1079–1088, https://doi.org/10.1016/j.jseaes.2010.12.001.

Mulyaningsih, T. R., Irmawati, M., Istanto, Alfian. (2020): Assessment of heavy metals pollution in the sediment of Ciliwung River, Journal of Physics: Conference Series, 1436, 012038, https://doi.org/10.1088/1742-6596/1436/1/012038.

Nelson, D. A., Cottle, J. M. (2017): Long-Term Geochemical and Geodynamic Segmentation of the Paleo-Pacific Margin of Gondwana: Insight from the Antarctic and Adjacent Sectors, Tectonics, 36 (12), 3229–3247, https://doi.org/10.1002/2017TC004611.

Ng, A. H. M., Ge, L., Li, X., Abidin, H. Z., Andreas, H., Zhang, K. (2012): Mapping land subsidence in Jakarta, Indonesia using persistent scatterer interferometry (PSI) technique with ALOS PALSAR, International Journal of Applied Earth Observation and Geoinformation, 18 (1), 232–242, https://doi.org/10.1016/j.jag.2012.01.018.

Pham, H. T., Marshall, L., Johnson, F., Sharma, A. (2018): A method for combining SRTM DEM and ASTER GDEM2 to improve topography estimation in regions without reference data, Remote Sensing of Environment, 210, https://doi.org/10.1016/j.rse.2018.03.026.

Pradhan, B., Abokharima, M. H., Jebur, M. N., Tehrany, M. S. (2014): Land subsidence susceptibility mapping at Kinta Valley (Malaysia) using the evidential belief function model in GIS, Natural Hazards, 73 (2), 1019–1042, https://doi.org/10.1007/s11069-014-1128-1.

Rau, M. I., Julzarika, A., Yoshikawa, N., Nagano, T., Kimura, M., Setiawan, B. I., Ha, L. T. (2024): Application of topographic elevation data generated by remote sensing approaches to flood inundation analysis model, Paddy and Water Environment, https://doi.org/10.1007/s10333-023-00967-1.

Ruffell, A., McKinely, J. (2008): Geoforensics, John Wiley & Sons, Ltd.

Sefercik, U., Jacobsen, K. (2006): Analysis of SRTM Height Models, Fifth International Symposium Turkish-German Geodetic Days, http://www.ipi.uni-hannover.de/uploads/tx_tkpublikationen/SRTM_Berlin.pdf.

Serrano-Juan, A., Pujades, E., Vázquez-Suñè, E., Crosetto, M., Cuevas-González, M. (2017): Leveling vs. InSAR in urban underground construction monitoring: Pros and cons, Case of la sagrera railway station (Barcelona, Spain), Engineering Geology, 218, 1–11, https://doi.org/10.1016/j.enggeo.2016.12.016.

Setyawan, A., Fukuda, Y., Nishijima, J., Kazama, T. (2015): Detecting Land Subsidence Using Gravity Method in Jakarta and Bandung Area, Indonesia, Procedia Environmental Sciences, 23 (Ictcred 2014), 17–26, https://doi.org/10.1016/j.proenv.2015.01.004.

Simons, M., Rosen, P. A. (2015): Interferometric Synthetic Aperture Radar Geodesy. In Treatise on Geophysics: Second Edition, Vol. 3, Elsevier B.V., https://doi.org/10.1016/B978-0-444-53802-4.00061-0.

Suhadha, A. G., Julzarika, A. (2022): Dynamic Displacement using DInSAR of

Sentinel-1 in Sunda Strait, Trends in Sciences, 19 (13), 4623, https://doi.org/10.48048/tis.2022.4623.

Suhadha, A. G., Julzarika, A., Ardha, M., Chusnayah, F. (2021): Monitoring Vertical Deformations of the Coastal City of Palu after Earthquake 2018 Using Parallel-SBAS. Proceedings – 2021 7th Asia-Pacific Conference on Synthetic Aperture Radar, APSAR 2021, March, https://doi.org/10.1109/APSAR52370.2021.9688380.

Suhadha, A. G., Chusnayah, F., Julzarika, A. (2023): Seismic-Induced Displacement Dynamics in Banten's Irrigation Zones: DInSAR Monitoring (2017–2020), Doklady Earth Sciences, https://doi.org/10.1134/S1028334X23602444.

Thomas, B. F., Famiglietti, J. S., Landerer, F. W., Wiese, D. N., Molotch, N. P., Argus, D. F. (2017): GRACE Groundwater Drought Index: Evaluation of California Central Valley groundwater drought, Remote Sensing of Environment, 198, 384–392, https://doi.org/10.1016/j.rse.2017.06.026.

Turcotte, D., Schubert, G. (2014): Geodynamics, Cambridge University Press., https://books.google.co.id/books?id=qksHAwAAQBAJ.

Vanicek, P., Krakiwsky, E. J. (1986): Geodesy: the concepts, http://public.eblib.com/choice/publicfullrecord.aspx?p=1838220.

# Pseudodinamička identifikacija (1817–2022) na Sjevernoj obali Jave (Pantura) primjenom dinamičke topografije

*SAŽETAK. Pantura je jedna od regija na sjevernoj obali otoka koja je osjetljiva na nepogode slijeganja tla. Međutim, u stvarnosti, slijeganje i izdizanje događa se u obliku kopna u nastajanju zbog visokih stopa sedimentacije. Slijeganje i izdizanje su dio Zemljine dinamičke ravnoteže u održavanju omjera vodene površine od 71% prema površini kopna od 29%. Taj proces dovodi do pseudodinamike, koja se često zanemaruje, što rezultira pogreškama koje se često pojavljuju u ublažavanju katastrofa, regionalnom planiranju i razvoju infrastrukture. Ovo istraživanje ima za cilj identificirati pseudodinamiku u Panturi primjenom dinamičke topografije. Dinamička topografija je pristup geomodeliranja i geoforenzike integracijom najnovijeg DTM-a, topografije vremenske serije i vertikalne deformacije vremenske serije (modificirana D-InSAR metoda) tako da se zna kako klasificirati promjene dinamičke topografije u područjima koja se proučavaju. Upotrijebljeni su podaci topografske karte izrađene u Engleskoj (1817), topografske karte izrađene u američkoj vojsci (1944), topografska karta Indonezije (2018), WorldView 2/3 iz World Imagery (2022) i Sentinel-1 (2017–2022). Područje istraživanja nalazi se u 26 regija, podijeljenih na Zapadnu Panturu (10 područja), Središnju Panturu (8 područja) i Istočnu Panturu (8 područja). Rezultatima istraživanja dobivena su tri kriterija za područja s pseudodinamikom, naime slijeganje, izdizanje i naizmjenično slijeganje–izdizanje. Područja u kojima dolazi do slijeganja (13 područja) su Tangerang–Jakarta, Jakarta, Južni Tangerang–Depok–Bogor–Bekasi, ušće Jakarta–Bekasi–Citarum, Pemalang–Pekalongan, Pekalongan–Batang, Batang–Kendal, Kendal–Semarang, Semarang, Semarang–Demak–Jepara, Lamongan–Gresik–Surabaya, Surabaya–Sidoarjo i Sidoarjo–Pasuruan. Područja u kojima dolazi do izdizanja (7 područja) su otoci Seribu (sjever), otoci Seribu (jug), Karawang–Subang, Subang–Indramayu, Indramayu–Cirebon, Indramayu–Cirebon i otoci Karimun Jawa. Područja u kojima dolazi do naizmjeničnog slijeganja i izdizanja (6 područja) su Banten–Tangerang, ušće Citaruma–Karawang, Brebes–Tegal, Tegal–Pemalang, Jepara–Pati i Pati–Rembang–Tuban–Lamongan. Rezultati ovog pseudodinamičkog istraživanja s dinamičkom topografijom mogu se primijeniti za razmatranje ublažavanja katastrofa i regionalnog planiranja u Panturi.*

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