

# Spatial Analysis of the Growth of the Bengawan Solo Delta, Gresik Regency, East Java Province, Indonesia 1995-2023

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## Abstract

The objective of this research is to conduct a spatial analysis of the development of the Bengawan Solo River Delta, Gresik Regency, East Java Province from 1995 - 2023. This research method uses both remote sensing technology and Geographic Information Systems (GIS), such as supervised classification and overlay techniques, kappa accuracy, and direct field verification (ground check). The results of this research indicate that deltaic growth has occurred in the Bengawan Solo delta region. This is demonstrated by the increasing amount of land advancing towards the sea, also known as *oloran* land. Analysis was done from 1995 - 2000, 2000 - 2005, 2005 - 2010, 2010 - 2015, and 2015 - 2023 to find the development rate of this difference. Quite high growth occurred in the range of 1995 - 2000 which was an area of 472.33 ha. and in 2010 - 2015 which was an area of 423.48 ha. While the range of 2000 - 2005 is an area of 253.82 ha. and 2015 - 2020 which is an area of 259.94 ha experienced growth of no more than the growth in 1995 - 2000 and in 2010 - 2015. This area experienced land erosion from 2005 - 2010, with eroded soil spanning an area of -278.38 ha. Then it will grow once more from 2010 - 2023, totaling 517.63 hectares. The new land utilization of Delta Bengawan Solo is mostly grown from mangroves naturally and planting results (44%), some are used by the surrounding community for the expansion of land (33%), and some are still empty land (19%) as well as for other provision (1%).

**Keywords:** Delta Bengawan Solo, Growth, Spatial

## 1. Introduction

Indonesia is a maritime nation, a unified state comprised of thousands of islands separated by straits and seas. A country with a tropical climate, high precipitation, and a large number of permanent and non-permanent rivers. These rivers transport water from upstream to downstream and discharge it into the sea. The river mouth is special because it is a gathering point for land and marine ecosystems. The river mouth is the section of the river that connects to the sea. Problems at the mouth of the river can be reviewed at the mouth of the river (*River Mouth*) and estuary [1]. The river's estuary is a very productive region due to the constant influx of organic materials from the land via the river flow and nearby waterways. The mixing of the two water bodies at the river's mouth can produce shifts in the physical oceanographic circumstances of the area.

Bengawan Solo River is the largest river in Java Island, located in Central Java and East Java Province with a river area  $\pm 12\%$  of the entire Java Island area. In the provinces of Central Java and East Java, there are 20 regencies/cities that make up the Bengawan Solo River Watershed officially. With a land mass of 20,125 km<sup>2</sup>. The coastal waters of the estuary of Bengawan Solo River play a crucial role in satisfying the requirements of management businesses, such as companies located in close proximity to the Bengawan Solo River Basin. In contrast, the estuary region of the Bengawan Solo River is undergoing a rapid sedimentation process due to the estuary of numerous watersheds that transport sediment burdens. Based on the bathymetry data, the Bengawan Solo River's waters have varying depths. The morphology of the waters is primarily determined by the deposition of sediment from the river, with distribution governed by the river's activity. The configuration of the seafloor influences the direction and velocity of currents, whereas currents have a substantial impact on sediment movement patterns.

In the East Java Province's Ujung Pangkah District of Gresik Regency, one of the ports of Bengawan Solo River can be found. Because the rivers work together to deposit silt, the estuary region experiences rapid sedimentation, which leads to the formation of a river delta (the locals call it "The land of oloran"). Social disputes frequently occur in this region and occasionally they even result in fatalities because the local community is battling for the recently created delta (oloran/tank arise) to become ponds. The creation of a new delta will alter the shoreline and cause land expansion in the area. Deltas develop as a result of erosion in the upper basin, which is influenced by flow characteristics, land use, plant characteristics, geological structure, and morphometric parameters [2]. Furthermore, physical and non-physical variables contribute to the settling process. Physical factors include tides, marine currents, and river flow, while non-physical factors include development activities in other regions that cause shifts in the hydrodynamic pattern of these waterways, resulting in sediment buildup [3]. As a consequence, one of the major issues in the estuary region is the high rate of erosion and sedimentation, which results in decreased water level [4]. The purpose of this research is to understand and examine the delta growth rate of the Bengawan Solo River Delta spatially from 1995 to 2023 using remote sensing technology.

## 2. METHODOLOGY

This research was conducted in the mouth of bengawan solo river located in Ujung Pangkah District, Gresik Regency, East Java Province, Indonesia. Geographically, Ujung Pangkah Subdistrict is located between 6°56'8.81" South Latitude and 112°32'54.05" East Longitude. The map of the study location is shown in Figure 1.



Figure 1 Research sites

The materials used in this research are Google Earth satellite images recording in 1995, 2000, 2010, 2015 and 2023 which have been georeferencing processes, administrative maps of Gresik Regency, administrative maps of Ujung Pangkah District, and East Java administration maps. This research used the ArcGIS 10.8 program, which was made available by ESRI. Coastal areas, the river delta, and areas outside the river delta in 1995, 2000, 2005, 2010, 2015, and 2023 are among the statistics required for this research. This research utilizes observational methods to make direct observations of the development of deltas, which are emerging regions, in addition to deciphering satellite images. In-depth interviews with the Ujung Pangkah District government and pond farmers, the majority of whom are locals, were performed for this research.

The region of the delta from the outcomes of image analysis in 1995, 2000, 2005, 2010, 2015, and 2023 was compared to determine the delta development rate. To identify changes, this procedure is carried out either using the OVERLAY approach or the *Raster Calculator* analysis available in ArcGIS 10.1. So that the findings of a comparison of the Bengawan Solo river delta's area and development rate in the Ujung Pangkah-Gresik District could be acquired. The following is used in the method for calculating the differential growth rate:

$$\Delta = L2 - L1 / L$$

### 3. RESULT & ANALYSIS

#### 3.1 Description of the Research Area

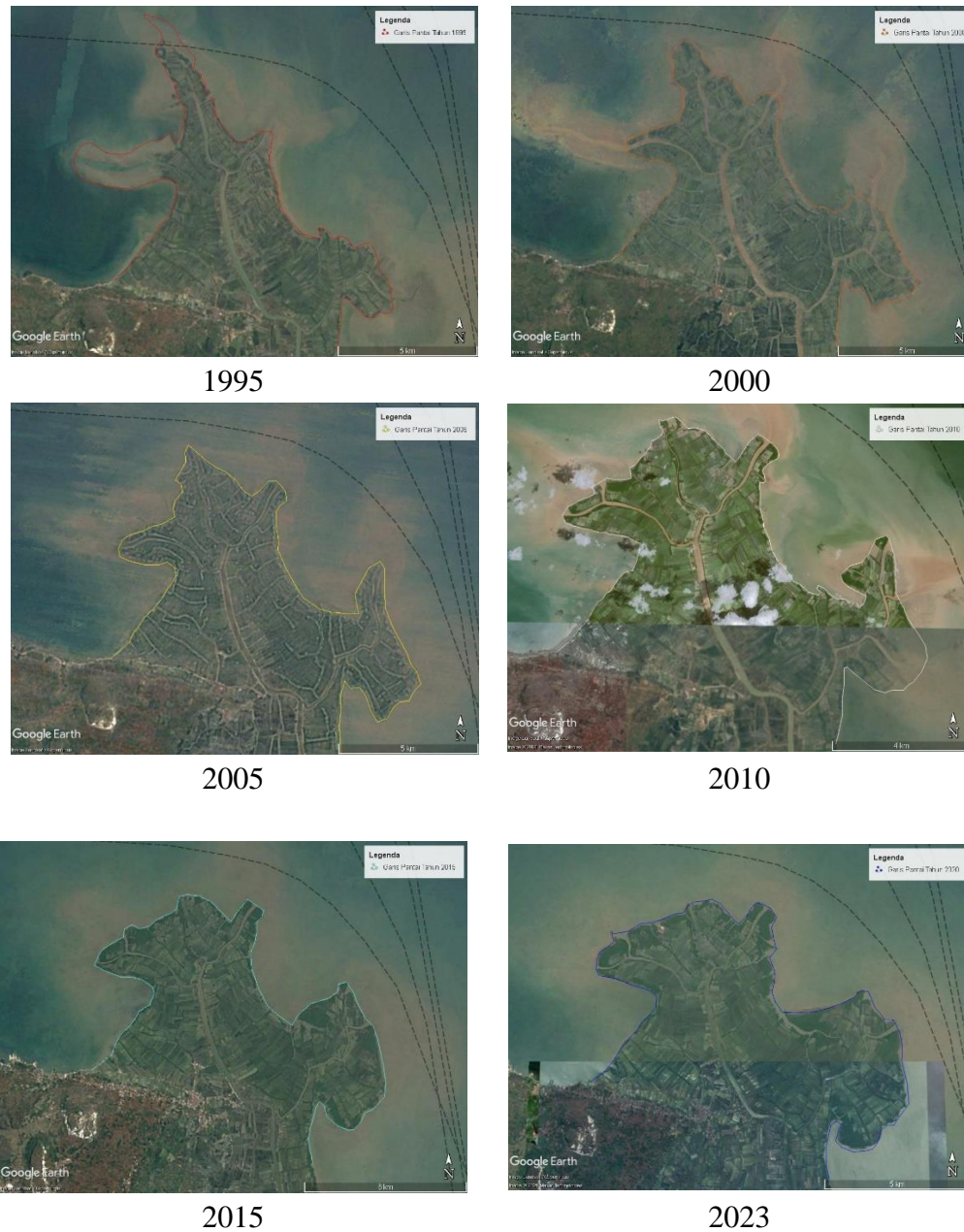
Bengawan Solo River Basin (WS) is divided into 96 -ninety-six- Watersheds (DAS). The major watersheds found in Bengawan Solo River Area are Bengawan Solo watershed with an area of 15,602 km<sup>2</sup>, the Corong watershed with an area of 8,304 km<sup>2</sup>, and the Kali Lamong watershed with an area of 7,748 km<sup>2</sup>, while the other watersheds are smaller in area than the three watersheds. The Bengawan Solo watershed is the largest watershed in the Bengawan Solo River Area which includes the Bengawan Solo Hulu Sub-Watershed, the Kali Madiun Sub-Watershed and the Bengawan Solo Hilir Sub-Watershed.

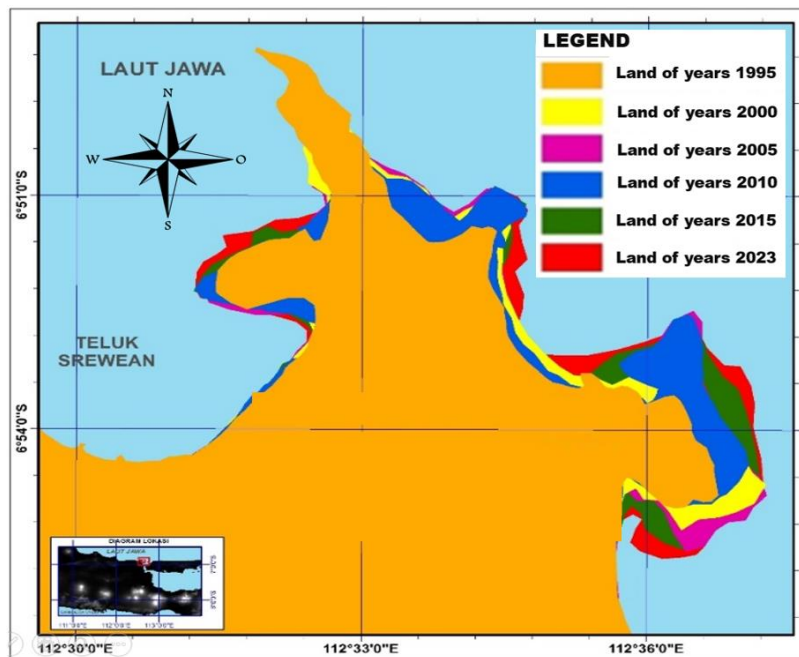
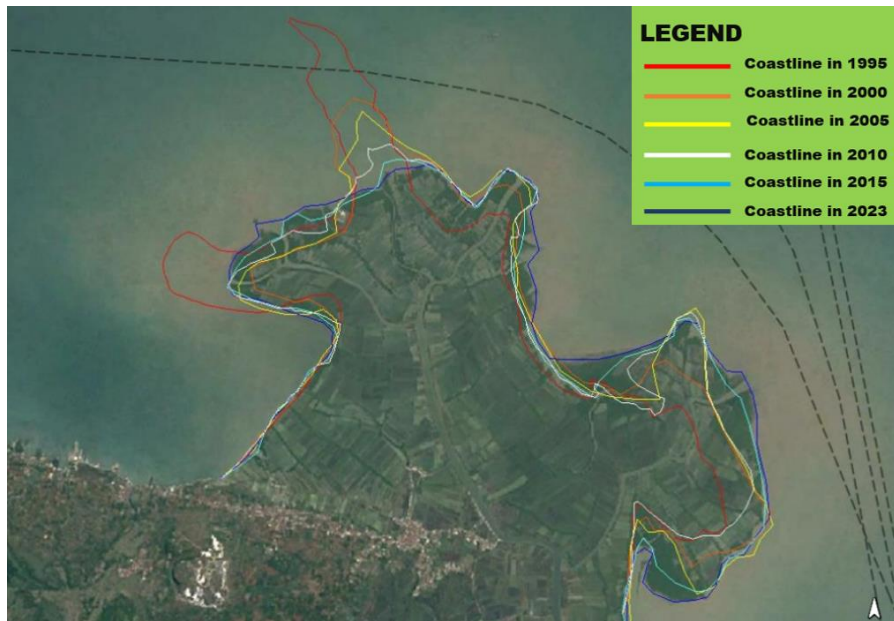
The Bengawan Solo Hulu Sub-Watershed and the Kali Madiun Sub-Watershed have an area of ± 6,072 km<sup>2</sup> and ± 3,755 km<sup>2</sup>, respectively, while the area of the Bengawan Solo Hilir Sub-Watershed is ± 6,273 km<sup>2</sup>. Bengawan Solo Hulu and Kali Madiun drain water from the cone-shaped mountain slopes, namely Mount Merapi (± 2,914 m), Mount Merbabu (± 3,142 m) and Mount Lawu (± 3,265 m). The major river in the Bengawan Solo River Basin is the Bengawan Solo River, which rises at Mount Lawu and drains into the Java Sea after flowing north and then east. This river originally flows into the Madura Strait, but to lessen sedimentation in the Madura Strait, it was subsequently rerouted to the Java Sea.

Bengawan Solo River also gets supplies from Madiun River. Besides the Bengawan Solo River, in the southern part there are two quite important rivers, namely the Grindulu River and the Lorog River, both of which emptied into the Indian Ocean. In the eastern part there is the Lamong River which empties into the Madura Strait. Meanwhile, in the north-east part, it empties into the Gresik upaten district and many small rivers that directly emptied into the Java Sea.

### 3.2 Spatial Analisis Growth Rate of Bengawan Solo Delta Bengawan Solo Hilir Watershed in Pangkah End District, Gresik Regency Based on Image.

It is evident that the Bengawan Solo delta has altered between 1995 and 2023 based on the findings of a study of Google Earth imagery for 1995, 2000, 2005, 2010, 2015, and 2023. The supply of sediment carried by river currents causes new land to form around the mouth of the river that forms as a result [5]. Changes in the coastline of the Bengawan Solo Delta and the Bengawan Solo watershed are presented in Figure 2 and Table 1.

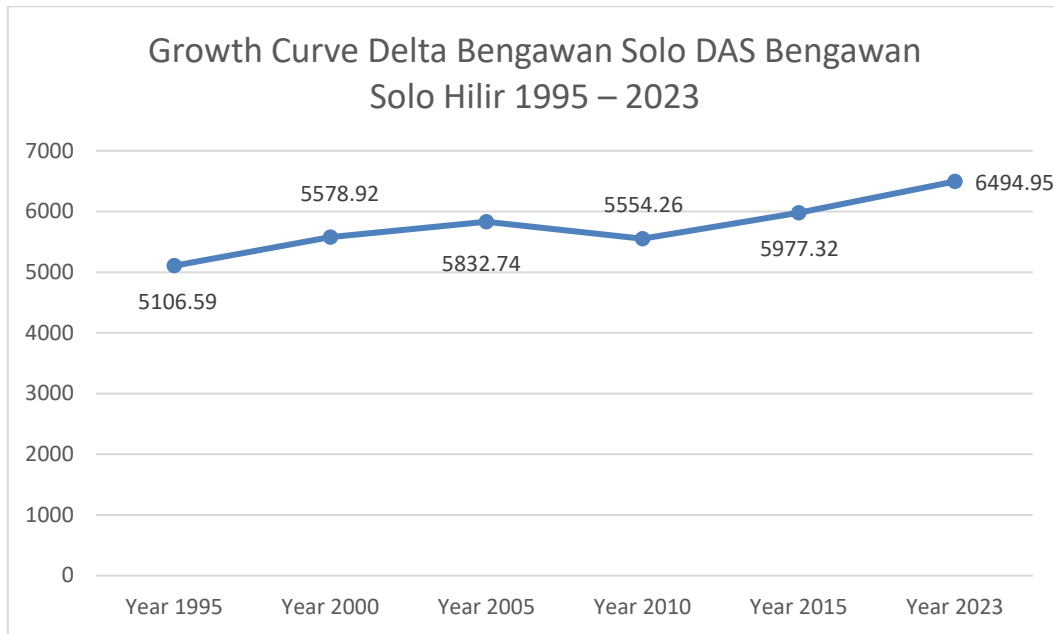




**Figure 2** Bengawan Solo Delta Growth Bengawan Solo DAS

**Table 1** The Area of the Bengawan Solo Delta in 1995, 2000, 2005, 2010, 2015 and 2023

Width (Ha)					
Year 1995	Year 2000	Year 2005	Year 2010	Year 2015	Year 2023
5106,59	5578,92	5832,74	5554,26	5977,32	6494,95



**Figure 3** Growth Curve Delta Bengawan Solo DAS Bengawan Solo Hilir 1995 – 2023.

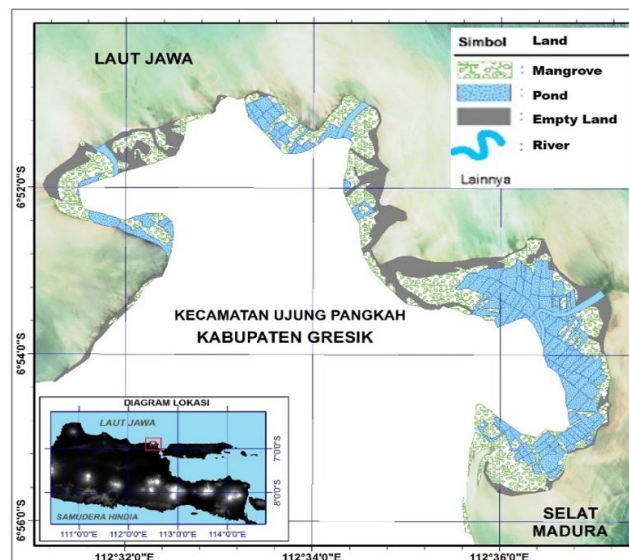
Based on table 4.2.5, figure 4.2.3, and figure 4.2.4 seen in 1995 Bengawan Solo Delta of the Bengawan Solo Hilir watershed only has an area of 5106 ha, The territory expanded significantly between 1995 - 2000, adding 472.33 hectares to the area, bringing it to 5578.92 ha. Then, in 2005, the area expanded once more, growing to 5832.74 ha. Since the form of the delta is affected by three factors, namely fluvial processes, wave processes, and tidal dynamics, the addition of this delta is due to the high sedimentation transported by the river as well as a number of other factors, according [6]. Land erosion occurred between 2005 - 2010, resulting in a reduction in size to 5554.26 hectares in 2010. This occurred as a result of the erosion occurrence, which affected several locations in the area. In Ujung Pangkah District, one of the primary causes of shoreline erosion is the decline in mangrove vegetation along the coastline as a result of land conversion operations into ponds. In addition, activities the same as cutting mangrove forests, mining for sand, and the occurrence of strong waves and waves have an effect on shoreline erosion [7].

Then, between 2010 and 2015, the region underwent significant development once more, adding 423.06 ha to its total new land area, which stood at 5977.23 ha in 2015. Continue to see the development of new land until 2020, and according to survey findings, new land emerges just southeast of the river bank, still in the shape of mud land that has been overrun by various kinds of *mangroves*, So that in 2023 the total area of the delta will be 6494,95 ha. Based on the description above, it can be seen that a fairly high growth occurred in the range of 1995 - 2000, covering an area of 472.33 ha. and in 2010 - 2015 which was an area of 423.48 ha. While the range of 2000 - 2005 is an area of 253.82 ha. and 2015 - 2020 which is an area of 259.94 ha experienced growth of no more than the growth in 1995 - 2000 and in 2010 - 2015. This region witnessed land erosion between 2005 - 2010, with eroded soil spanning an area of - 278.38 ha. Then it will grow again from 2010 - 2023, totaling 517.63 hectares. Based on the type of facies and depositional environment, Sedimentary facies that are inseparable and have an uneven distribution, such as the debris facies or coarse sand sized detritus, are discovered near Ujung Pangkah. This facies makeup typically results from the process of detritus coming from the bedrock as crushed sand as a result of wave impact [8].

The increase of sediment volume in the estuary streams changes the shape of the river mouth. Deltas that were originally Elongate and finger-like are anticipated to change over time to *Lobate Fan-Shapte Delta* [9]. Prograding deltas, exhibit fluvial power and a large supply of fluvial sediments [10]. Sedimentation is the final process of exogenous action, namely the deposition of rock or earth material in a location following erosion and movement [11].

### 3.3 Land Utilization of New Area As a Result of Bengawan Solo Delta Growth in Bengawan Solo Hilir Watershed

Based on the findings of interpretation analysis and field assessments (GROUND CHECK) conducted on new territory created by the expansion of the Bengawan Solo Delta Bengawan Solo Hilir Watershed in Ujung Pangkah District, Gresik Regency, the majority of new land is used for different reasons by the local population, such as ponds, waterways (trenches), mangrove land, and empty land. Ponds take up the majority of the freshly formed territory. As illustrated in Figure 4.



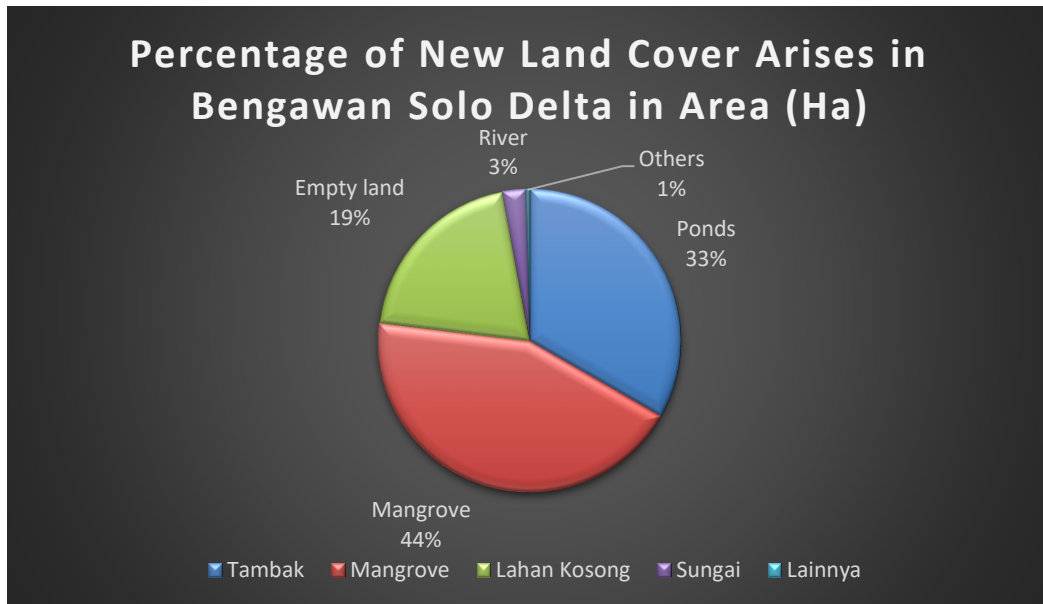
**Figure 4** Map of New Land Cover Arising in the Bengawan Solo Watershed Delta Bengawan Solo in 2023.

**Table 2** New Land Cover Arises Bengawan Solo River Area Watershed Bengawan Solo Hilir Ujung Pangkah District, Gresik Regency.

No.	Land Cover	Area (Ha)
1.	Pond	579,56
2.	Mangrove	759,36
3.	Vacant Lots	351,37
4.	River	44,02
5.	Other	6,59
<b>Total</b>		<b>1.740,90</b>

Based on table 2, it can be seen that the majority of the newly formed land in the Bengawan Solo Delta, Bengawan Solo Hilir Watershed is dominated by mangrove vegetation, which is 759.36 ha (44%),

specifically, an area of 579.56 ha (33%) is used for ponds and is maintained by the neighborhood, while an area of 351.37 ha (19%) is left empty. A recently created water body makes up the remaining 44.02 ha (3%) and 6.59 ha (1%) of the remaining property is used by the community for other uses. Figure 6 explains in more depth the percentage of land use in the new Bengawan Solo Delta DAS Bengawan Solo Hilir region.



**Figure 5** Percentage of New Land Use in Bengawan Solo DAS Bengawan Solo Delta in 2023.

Figure 5 demonstrates how the new territory in Bengawan Solo Delta is largely covered in mangrove vegetation and how some of it has been turned into community ponds. The ponds in this region are the result of mangrove areas that were turned into ponds, according to [12] study findings, this is accurate (2017) There have also been instances of turning woods into ponds; one such instance involved low density mangrove woodlands that were turned into ponds that covered an area of 1.89 hectares. In addition, reservoirs were constructed on territory that had previously been very low density mangrove forest, spanning an additional 730.89 hectares. Spatially, the state is obligated to protect all coastal areas and communities from natural impacts such as abrasion and high waves; therefore, it is crucial that coastal land be designated as protected areas under direct state control [13]. However, what occurred in this region was that the local population used a significant amount of the embossed soil, which was created as a result of sediment deposits, as private property. Several interconnected driving variables, such as governmental, economic, demographic, socio-cultural, and regional factors, have an impact on land use [14].

#### 4. CONCLUSION

According to the findings of picture analysis, the area that will be added by new deltas in the Bengawan Solo delta between 1995 - 2023 is 1388.6 hectares. The development rate study covered the years 1995 - 2000, 2000 - 2005, 2005 - 2010, 2010 - 2015, and 2015 - 2023. In the years 1995 - 2000, an area of 472.33 ha was added, and in the years 2010 - 2015, an area of 423.48 hectares was added. While the range from 2000 - 2005 was 253.82 ha, the range from 2015 - 2023, at 259.94 ha, did not grow any more than the ranges from 1995 - 2000 and 2010 - 2015. This region experienced land erosion from 2005 - 2010, with a total area of -278.38 ha of eroded land. From 2010 - 2023, the area will increase to 940.6 ha. Some local



residents took advantage of the recently emerging land use in the form of aquaculture, while other lands, such as mangroves, developed naturally in certain of these new areas and were also planted by the local community or groups. Ponds cover 759.36 ha, mangroves cover 579.56 ha, vacant land covers 351.37 ha, and there are others that cover 6.59 ha that are used by locals for 125 other reasons. These are the specifics of the region of land use that has recently come to light. The distribution of new land uses by village is distributed across four villages: Banyu Urip Village, Pangkah Kulon Village, Pangkah Wetan Village, and Ketapanglor Village. The greatest land use in the village of Pangkah Wetan is mangrove land, which encompasses a total area of 583.53 hectares. 529.58 hectares of the remainder of the village's land is occupied by reservoirs of considerable size.

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