Spatio-Temporal Salt Ponds in Madura Island in 2009-2019 for Managing Sustainable Coastal Environments

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Abstract. The salt pond ecosystem has a very important ecological function, especially for the coastal region of Madura. One of the ecological functions of the salt pond is supporting the economy of the community. The purposes of this study are: (1) To determine changes in salt ponds in Madura Island in the last 10 years (2009-2019) based on remote sensing data and Geographic Information System; (2) To make a simulation of structuring the Salt Pond area on Madura Island in the management of a sustainable coastal environment. This type of research is a descriptive-analytic survey method using remote sensing data and Geographic Information System. The object of the study is the Tambak Garam (salt pond) area in Madura Island focusing on Sampang Regency, Pamekasan Regency, and Sumenep Regency. Data collection techniques carried out by observation, interviews, and documentation. Changes in Salt Ponds data analysis were carried out using remote sensing data extraction method with true-color image input and NDVI. The results show that the area of salt ponds decreased from year to year in the district of Sampang, Pamekasan, and Sumenep. Management intensification using more modern technology is done to increase production in the declining salt pond areas. Salt production runs optimally if it is carried out in coastal areas with sloping morphology and soil that is not porous in the form of clay soil, which does not absorb seawater. Sloping morphology was chosen to support the entry of seawater into salt pond plots that use tidal power.

1. Introduction
The Madura Island region has experienced rapid development from year to year in the interests of expanding the Port of Brantas, the construction of airports, for settlements and trade. This causes vulnerability for the preservation of salt ponds, which have an important function as an economic source for the people of Madura Island. The importance of the function of salt ponds for the development of coastal cities requires optimal management to support the implementation of spatial planning and improve the regional economy [1,2].

The amount of salt production in Indonesia is targeted to continue to increase from year to year. National salt production comes from the people's salt industry by 70% and PT. Garam by 30% [3]. The modern salt industry, such as PT. Garam also helps to improve the quality of the people’s salt by reproducing the salt in a modern process. Salt is grouped into three types [4], namely: (1) K-1, which is the best quality that meets the requirements for industrial materials and for consumption, (2) K-2, which is medium quality, has a slightly brownish and damp color, and (3) K-3, is the lowest quality of salt, which is brownish in color and mixed with mud.

The function transfer of salt lands, poor salt trade management (i.e. falling the salt prices during harvest), and not absorbing people's salt in the industry, causes some owners to convert the salt land into ponds or other more profitable businesses. This will, certainly, have an impact on the decrease in the area of salt land and the amount of national salt production [5]. Therefore, it needs to be resolved properly. One possible solution is improving the salt production technology so that national salt production can increase even though the used land is narrower [6]. Several policies have been issued by the government, including increasing the production and quality of people's salt through the intensification, extension, and revitalization of the salt ponds [7,8].

Salt production by the community is generally traditional, so it has a very high dependence on climate or weather [9,10]. Technically, the best weather conditions for salt production are: (1) high evaporation/evaporation (average> 650 mm/year); (2) Wind speed above 5 m/sec; (3) The air
temperature is greater than 320°C; (4) 100% solar radiation; (5) Air humidity less than 50% H; (6) Low rainfall (between 1,000-1,300 mm/year or below 100 mm/month); and (7) Dry, long dry season without interspersed with rainy days of at least 140 days (14 decades) [11,12]. These weather conditions must be met, otherwise, salt cannot be produced.

Incoming seawater is usually 0 to 3 degrees Be3 and evaporation must continue until it reaches above 20 degrees, until grains of salt are ready to be harvested [13]. Therefore, water that already has a high Be level (seawater salinity levels) must not be exposed to rainwater for three consecutive days. If water that already has a high Be level is exposed to rainwater, the old water will return to young water (water that has a low Be level). Similarly, salt that has crystallized will turn back into saltwater.

Salt farmers who carry out salt production activities must continuously pay attention to natural phenomena, especially weather conditions. Based on the survey results, the most pronounced climate impacts on ponds are rain, overheating, strong winds, tidal waves, abrasion, and arising land [13–17].

Based on BMKG’s last ten years’ measurement and interpolation of the rainfall data in several districts in Sampang Regency, the distribution of rainfall in the Sampang Regency region is at least 889.9 mm/year with the highest of 1,707.99 mm/year. This shows that Sampang Regency is very suitable for salt production [18].

In Sampang and Sumenep districts, data from BMKG shows that the dry season from 1971 to 2000 ranged between April and November, while the rainy season ranged from December to March each year. It is estimated that salt production occurs in eight months, between April and November. Even so, the results of interviews found that the average production time each year is only 4 months with the time of land cultivation carried out previously for 1 month, thus the total production time was 5 months.

Heat in the dry season is needed by salt farmers [19]. However, an extremely hot dry season can trigger drought, so salt farmers complain about the difficulty to get the water. In addition to falling water levels, the silting of seawater channels also contributes to the difficulty of seawater entering the pond. In addition, the cost of repairing gutters is very high compared to the selling price, so the production is not profitable. Therefore, sewer problems are still difficult to solve.

Strong wind is one of the factors that influence the process of salt production, because wind can, both, accelerate and inhibit salt production. Wind speed of 5m/sec can accelerate production [19]. Therefore, salt farmers use windmills to irrigate their salt ponds, which serve to lift the seawater from the water reservoir into the salt ponds. Hence, highly strong winds can spin the propeller too fast which could lead to damage. The damage can inhibit salt production as it needs reparation before the production.

Ponds that are destroyed in the rainy season due to high waves require greater repair costs compared to ponds that are not exposed to high waves. In addition, fish farming in the rainy season is also lost due to the waves. Moreover, high tides can sink salt ponds as well as road infrastructure that connects their farms. Likewise, a high wave will damage the salt pond embankment so the salt farmer must rearrange the farm.

The objectives of this study are: (1) To find out the changes of salt ponds in Madura Island in the last 10 years (2009-2019) based on remote sensing data and Geographic Information System; (2) To make a simulation of structuring the salt ponds area on Madura Island for sustainable coastal environmental management.

2. Methods
A descriptive-analytic survey method is used in this research by using remote sensing data and Geographic Information Systems. The object of the study is the salt ponds area in Madura Island focusing on Sampang Regency, Pamekasan Regency, and Sumenep Regency.

Tools and Materials: (1) Tools: a. Computers, b. ENVI/ErMapper Software for satellite image analysis, c. GIS software with ArcGIS 10.2 for spatial data analysis, d. Global Position System (GPS), e. Camera. (2) Material: a. Map of Rupa Bumi Indonesia scale 1:25,000; b. Map of Rupa Bumi Indonesia Scale 1:10,000; c. Map of Bathymetry/Indonesian coastal environment scale of 1:50,000; d. Map of Madura Island Spatial Plan; e. Landsat ETM + and Landsat 8 Satellite Imagery; e. Citra Sentinel-2.

The primary and secondary data collection techniques carried out by doing observations, interviews, and documentation. Primary data includes data on existing land use and the measurement of salt ponds in improving the community’s economy. Secondary data includes satellite imagery, maps, and government documentation data related to salt ponds. Remote sensing data in the form of Landsat
and Sentinel-2 satellite imagery are used to identify the temporal changes of Salt Ponds over the last 10 years, 2009-2019. Temporal remote sensing data is an effective approach to obtain on-land changes data [20–22].

Changes in Salt Ponds data analysis was carried out using the Normalized Difference Vegetation Index (NDVI). NDVI extraction is used to provide a strict line between vegetation and water [23,24]. The NDVI formula is as follows:

\[
\text{NDVI} = \frac{(\text{NIR channel} - \text{Red channel})}{(\text{NIR channel} + \text{Red channel})}
\]

Where NDVI is a vegetation index, NIR channel is an image band belonging to the near-infrared spectral range (band 4 on Landsat 7, band 5 on Landsat 8, and band 8 on Sentinel-2), and Red channel is an image band belonging to red spectral range (band 3 on Landsat 7, band 4 on Landsat 8, and band 4 on Sentinel-2).

Spatial Simulation of Salt Pond Structuring used land cover classification to predict land-use changes, in the arrangement of Salt Ponds [25,26]. Analysis of the data used in this study is Spatio-temporal analysis using remote sensing and GIS. Data analysis results were then compared between data elements and described.

3. Results and Discussion
Based on remote sensing extraction, the land-use changing of Madura Island was obtained within a period of 10 years, spatially presented in Figure 1. Vacant land in 2009 was identified as 950.98 km², experiencing an increase to 1258.94 km². The changes can be in the form of land clearing or fields/paddy fields before-planting phenomenon, which has different spectral values [27]. In 2019, the area of vacant land has decreased (1101.59 km²), indicating that the land has been re-utilized or acquired during the planting period.

Overall, the vegetation area with high and low density are dominantly occupied Madura Island every year. The yearly area change is caused due to the spectral reflection differences, especially in low-density vegetation (paddy fields and fields) which have growth phases. The developed land was identified as 594.34 km² in 2009, while 547.89 km² in 2014. There were obstacles in land use extraction using Landsat 7 image in 2009 so that it illustrates the appearance of more extensive settlements than in 2014, subsequently, the developed land class increased to become 707.10 km² in 2019.

Pond classes and water bodies have a smaller number each year. Compared to other land classes, pond areas are located in coastal areas and close to the sea. Some water bodies are identified such as rivers and other puddles. Brief information regarding the extent of land use is described in Figure 2.

![Figure 1. Changes in land use in Madura Island every 5 years.](image_url)
Based on these data, land use that has been identified in the research locations are Sampang, Pamekasan, and Sumenep. The types and extent of land use are presented in Tables 1, 2 and 3.

Table 1. Sampang Regency land use in 2009, 2014 and 2019

| Land Use             | 2009       | 2014       | 2019       |
|----------------------|------------|------------|------------|
| Bare land            | 306.62     | 442.7      | 363.13     |
| Built-up land        | 40.82      | 42.93      | 49.73      |
| High Density Vegetation | 238.52   | 229.38     | 387.12     |
| Low Density Vegetation | 576.01   | 457.23     | 377.96     |
| Pond/Water Body      | 67.1       | 56.82      | 51.12      |

Source: Data processing for Landsat 7/8 and Sentinel 2

Table 2. Land use in Pamekasan Regency in 2009, 2014, 2019

| Land Use             | 2009       | 2014       | 2019       |
|----------------------|------------|------------|------------|
| Bare land            | 328.47     | 440.94     | 268.11     |
| Built-up land        | 64.98      | 46.36      | 53.14      |
| High Density Vegetation | 90.17    | 92.24      | 288.91     |
| Low Density Vegetation | 275.36   | 194.55     | 168.24     |
| Pond / Water Body    | 39.76      | 24.65      | 20.34      |

Source: Data processing for Landsat 7/8 and Sentinel 2

Table 3. Land use of Sumenep Regency in 2009, 2014, 2019

| Land Use             | 2009       | 2014       | 2019       |
|----------------------|------------|------------|------------|
| Bare Land            | 429.22     | 482.65     | 457.12     |
| Built-up land        | 55.42      | 47.17      | 58.29      |
| High Density Vegetation | 242.91   | 304.03     | 323.47     |
| Low Density Vegetation | 433.74   | 346.87     | 338.68     |
| Pond / Water Body    | 72.03      | 52.6       | 55.77      |

Source: Data processing for Landsat 7/8 and Sentinel 2

The identification of ponds in Sampang Regency is focused on the southwest region bordering the Madura Strait, such as in Jrengik, Sreseh, Torjun, and Sampang Districts. Based on [28], the recorded pond areas of Sampang Regency in Figures in 2009, 2014, and 2019 experienced a decline. This is in line with the figures obtained from the results of land use extraction indicating the existence of a decline in pond areas (Figure 3). Based on visual observations of water bodies/ponds classification results, the concentration has decreased due to the increasing number of mangrove forests/high-density vegetation around the ponds and appears some developed land (Figure 4).
The total salt land in Sampang Regency is 4,629.8 Ha, consisting of 3,583.8 Ha of people's salt ponds and 1,046 Ha owned by PT. Garam. The plastered land is spread in 7 subdistrict areas consisting of 4 villages in Sampang District covering an area of 690.4 hectares, 3 villages in Camplong District covering an area of 90.6 hectares, 3 villages in Pangarengan district covering 686 hectares, 2 villages in Jrengik Subdistrict covering an area of 336 Ha, 8 villages in Sreseh Subdistrict covering an area of 1,746.8 Ha and 1 village in Banyuates Subdistrict covering an area of 34 Ha. The land owned by PT. Garam is mostly located in Pangarengan District.

Galis Subdistrict, Pademawu Subdistrict, and Tlanakan Subdistrict are areas that have ponds in Pamekasan Regency. The center of salt production is located in the coastal area that adjacent to the Madura Straits [29]. Based on the extraction using remote sensing, the area of ponds and bodies of water in Pamekasan Regency decreased, in 2009 ponds and bodies of water area of 39.76 km², in 2014 the area of ponds and bodies of water was reduced to 24.65 km², whereas in 2019 the area of ponds or an identified water body area of 20.34 km². The results of the extraction data were then compared with the pond area data from the Central Statistics Agency of Pamekasan Regency in 2009, 2014 and 2019 [30] with the following results.

![Figure 3. Pond area from remote sensing extraction and BPS data that has decreased in the last 10 years](image)

![Figure 4. Class appearance of pond land use in Sampang Regency](image)

![Figure 5. Pond area from remote sensing extraction and BPS data that has decreased in the last 10 years](image)
There is an 8-19 km² difference between remote sensing extraction and BPS data each year. This is because the results of remote sensing extraction translate other bodies of water such as inundated paddy fields, rivers, and other land uses that have spectral values similar to wet ponds. The need for complex identification such as spectral textures to distinguish between inundated paddy fields and wet ponds [31]. The changes in land cover that can be observed are seen in the southern part of the Pademawu District, which is presented in Figure 6.

![Figure 6. Map of land use in Pamekasan Regency in 2009, 2014 and 2019](image)

The condition of pond land use in Sumenep Regency is focused on the downstream area of the southeast, precisely in the District of Gapura, Kalianget, Saronggi, and Sumenep City. Based on land use extraction, the area of ponds in Sumenep Regency was 72.03 km² in 2009, while in 2014 the area of ponds was reduced to 52.6 km². Based on the interpretation of the results of the pond classification contained in the downstream river is covered by high-density vegetation. In some locations, ponds are turned into vacant land or in the form of ponds that are changing their use phase from salt ponds to milkfish ponds. The owner of the pond will convert his land into a milkfish or shrimp pond as a substitution effort to earn income while not producing salt in the rainy season [29]. Furthermore, in 2019 the area of ponds detected in Sumenep Regency was 55.77 km². Spatially, information on location and area of ponds in 2009, 2014 and 2019 is presented in Figure 5.

![Figure 7. Map of land use in Sumenep Regency in 2009, 2014 and 2019](image)

Salt fields in Sumenep Regency are on the east coast of Madura Island with a total area of salt land of 4,272 ha, consisting of 1,944 ha of community salt land and 2,328 ha of PT Garam land [32]. People's salt ponds are spread in Gapura District covering an area of 303 ha, Kalianget covering an area of 495 ha, Sumenep City covering an area of 5 ha, Dungkek District covering an area of 144 ha, Pruruan District covering an area of 258 ha, and Saronggi District 339 ha.

Along with the development of science and technology the prerequisites of natural conditions that support to make salt gradually began to unfold. Salt production will run optimally if coastal areas are carried out with sloping morphology and soil that is not porous, does not absorb seawater, in the form of clay soil. Sloping morphology was chosen with the consideration that the entry of seawater into plots making land using tidal power. The crystallization process will optimally take place in conditions with a maximum rainfall of 1,200 mm per year, with a minimum wind speed of 2-3 m per second. The minimum temperature must also be around 31° to 33°C with a maximum humidity of 70 percent and a maximum water content in the air of 70 percent [33]. Other requirements that must be met are the duration of dry season reaching 4.5 to 5 consecutive months with a maximum rainfall tolerance of 10 mm per day. All these prerequisites are owned by Madura Island, especially in the southern coastal region.
Today salt farmers are assisted by the windmills to maintain production. In the MP3EI document, the Java Economic Corridor (KE) emphasized to encourage national industries and services and for East Java with a planned cluster of petrochemical, shipping, food and beverage industries along the coast of Gresik, Surabaya, and Sidoarjo [34]. Integrating the PuGaR and MP3EI policies, encouraging the industrialization of community salt is one of the solutions going forward by preparing Madura people's salt to become salt and salt derivatives of a quality that can be accepted by various industries in the Surabaya, Gresik and Sidoarjo regions.

Towards that direction, two approaches can be done. The first is to prepare a more productive and quality system for producing public salt through technical and capital assistance, strengthening the institutional management of community salt exploitation, strengthening the infrastructure of the production system, storage, and distribution of harvests and salt trading, people and their derivative products. The second approach is to include Madura in the framework of MP3EI, especially TO Java by viewing the Suramadu Bridge as an important interconnection between the regions supplying industrial raw materials to the East Java industrial estate. The Suramadu Bridge is directed not only to be a link between Madura Island and Java Island, but its role must be played to lift Madura's economy through the industrialization of people's salt. The acceleration and expansion of the Madurese salt economic activities are expected to erode the economic gap between the two regions.

Community salt business clusters with comparative advantages that exist in 2 (two) types of clusters or a combination of them, namely the producing salt cluster and salt processing cluster. Crude salt-producing clusters are prioritized in the area of salt ponds with the structure of traditional society who make crude salt from generation to generation. In this cluster, the structuring and development of the irrigation system and water pumping system with filtering to strengthen the circulation of good quality seawater to the ponds are the main components.

In the community groups that have not been directly related to the process of producing Crude Salt, but have business activities related to Crude Salt either as an agent or other types of business as an effort to provide added value to Crude Salt can be directed at the group of salt processors. For this community group developed a salt processing cluster equipped with infrastructure, in the form of a salt processing unit to process cross salt and salt waste to produce derivative salt products that are equipped with a product packaging and storage system.

4. Conclusions

The development of remote sensing technology and GIS facilitates regional studies, especially studies of land-use change. Large areas can be identified at different times effectively and quickly. The results obtained in this research indicate the same conditions as the related agencies’ data. Even though the generated data is still relatively rough, it can be used as basic information, identification, and decision making.

The results showed the area of salt ponds decreased from year to year in all districts of Sampang, Pamekasan, and Sumenep. Management intensification and modern technology utilization in salt production can balance the decreasing area of salt ponds. Salt production runs optimally if it is carried out in coastal areas with sloping morphology and soil that is not porous in the form of clay soil, which does not absorb the seawater. The sloping morphological conditions were chosen to support the entry of seawater into salt pond plots that use tidal power.

Acknowledgments

This paper is the result of the State University of Malang's PNBP research program in 2019, therefore we would like to thank all those who have helped in this research, especially the State University of Malang with the PNBP research program. We would also like to thank the Madura Mina-Garam research team who assisted in data collecting and processing.

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