High tide event and its impact upon solar salt production area in Cirebon, West Java, Indonesia

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Abstract. High tide event has been acknowledged as a major cause of inundation in urban coastal area. This event is expected to increase in the future as an impact of global climate change. Meanwhile, there is still a gap of interest on tidal flood impact of marginal land use such as salt production with its traditional process. This study aims to identify high tide event in Cirebon waters and its impact on solar salt production area. Here we combine hydrodynamic simulation and Geographic Information System (GIS) within inputs from national seamless Digital Elevation Model (DEM) data from National Geospatial Agency, bathymetry, and wind record in May 2018 event. Additionally, this study also proposes coarse analysis of potential loss due to tidal flood event through productivity and pricing data from recent studies. From this research, it is found that 6,570 ha (84%) of the salt production area has been inundated in that peak event with € 48.69 million of potential loss. This model exposes beneficial information for Indonesia salt sufficiency program as well as coastal disaster risk management.

1. Introduction
Tidal flooding resembles daily flood events that influence socio-economic and health impacts to coastal communities [1]. In Indonesia, flood inundation triggered by high tide is mostly recorded in part of coastal cities, including Semarang [2] and Jakarta [3]. However, in less developed region where agriculture mostly shapes the landscape including salt production land is rarely discussed. For centuries, salt-making has been one of the cultural landscapes in some parts of the coastal area in Indonesia. This traditional type of agriculture supports local income for about 30,000 people including farmers, intermediaries, and post-processing companies. Solar salt ponds in Indonesia cover 25,064 hectares in 9 provinces and produce 1.1 million tons in 2012 [4]. Until 2015, the production capacity of the country reached only 2.84 million tons (2.5 million tons of people’s salt, and 345,000 from PT. Garam (Persero)1). It is recorded that tidal flooding has covered hundreds hectare of the ponds in Cirebon and devastated the harvests [5].

High tide is mainly driven by solar and lunar gravity from which can be forecasted [2]. Tidal flood itself is referred to as “nuisance flood” escalates in upcoming decades [6]. As impact of climate change, the occurrences of tropical storms and tidal surges have increased in tropical countries including India, Myanmar and Bangladesh [7]. Currently, coastal communities struggle to the occurrences of this type

1 PT. Garam is the only state-owned enterprises (BUMN) engaged in the processing industry and trade of salt in Indonesia. This company is the biggest salt company with 28% market share and primarily produces non-iodized salt accounting for 62% of total production [27].
of flood, especially on the economic aspect [8]. Mechanical destruction and ecological changes that caused by inundation events, affect massive costs in agriculture and aquaculture activities [9]. Additionally, currently salt farming has been comprised the impact of tidal flooding during seasonal production period. Meanwhile, there have been the small applications of geospatial technology for assessment in this type of agriculture. Until now, research on flood impact in coastal region still needs to improve and expand in various objects such as salt production land.

The existing literature dealing with tidal flood reveals a potential impact in the community through raster-based data and GIS modelling [10]. Geospatial technologies including remote sensing and GIS respectively improve mapping techniques and collaborate within algorithms and computational software. Common practice of utilizing DEM to estimate flood hazard in the coastal area is based on projected water levels [11]. It is mostly reflected that the increase of the mean sea level (MSL) will promptly transform into a higher storm surge risk [12]. At this point, the hydrodynamics of the tide corresponds on the magnitude of tide range. Furthermore, this technique requires fine resolution of DEM to provide better visual on flood distribution using GIS application [13]. Therefore, the availability of geospatial data constructs possible measurement in flood mapping, particularly in the coastal area. In this particular procedure, DEMs are used to parameterize a 2D hydrodynamic flood simulation algorithm and predictions are compared with published flood maps and observed flood conditions [14]. This research employs uncertainty factor especially from DEM resolution of the height spot interpolation. In Vietnam, the impact of climate change on pangasius farmers in Mekong delta mainly due to sea-level rise has been studied by Anh [15].

In this study, tidal flood is recreated on the salt production area of Cirebon, West Java. This method is implemented during May 2018 event, which narrated in the local media [16]. This approach retrieves the values of the flood impact on the parcel of salt pond from 2D (floodplain flow) tidal inundation simulation. However, there have been small applications of geospatial technology for assessment in solar salt production. Still, no information on tidal flood impacts provided using detailed topographical datasets (DEM). Based on previous background, the objectives of this study are to (1) examine the high tide event that occurred on May 2018 using a hydrodynamic model and consider maximum depth and its distribution; (2) maps inundated area of solar salt production during the peak of the event; (3) calculate potential economic damage.

2. Study area description

Cirebon is astronomically located 6°30’- 7°00’ S and 108°40’ - 108°48’ E. It covers an area of 990.36 km². Administratively, Cirebon is a part of the West Java Province and is bordered by the Java Sea and by Indramayu in the north, Kuningan in the south, Central Java Province in the east, and Majalengka in the west. The economy of this region has been growing through trading and service sectors. Meanwhile, agriculture and fisheries sectors also provide opportunities for many of inhabitants. According to BPS West Java [17] around 26,819 people or 23.5% of the rural population work in the agriculture and fishery sectors as primary income in 2016. In this area, the salt ponds cover 7,819.32 ha and labour to 3,707 people, including owners, workers, and intermediaries [18].

The model is taken in Cirebon waters. Salt production mostly lies in coastal area that covers eight districts directly adjacent to Java Sea. Here, the salt production season begins during southeast monsoon; where farmers start to store seawater around April-June depend on the weather. Basically, they work in 4 months annually and one month construction period [19]. During this period, coastal flood due to tidal cycle commonly occurs in the level of nuisance to destructive.
3. Methodology

3.1. Data requirements

This study aims to examine the implication of flooding upon artisanal salt farming in Cirebon, West Java, especially in further economic implication based on our previous study on Nirwansyah and Braun [20]. Through hydrodynamic model (HDM) using MIKE, the research employs several datasets, including spatial data and non-spatial data. Firstly, we collect national bathymetry of Indonesia (BATNAS) and digital elevation model of DEMNAS from Indonesia Geospatial Information Agency (BIG) (accessed freely on http://tides.big.go.id/DEMNAS/). Additionally, BIG also provides latest version of salt parcel (updated 2015) in scale of 1:15,000. Finally, we also collect tidal record from Cirebon port of May 2018 period. Wind data of Jatiwangi station is obtained from OGIME [21] (free accessed on http://ogimet.com).

3.2. Data analysis

3.2.1. Tidal simulation. This research was started by simulate water level and identify the tidal flood occurrence in the selected period. Here we used MIKE 21 Flexible Mesh (FM) and cover 11,515.20 km² [20]. The tidal height was identified through hourly record of tidal gauge. Here, the wind force and tilt feature within Navier-Stokes equation improves overtopping of wave and handles hydrodynamic complexity that involved wave breaking and another restriction [22]. We validate the simulation by comparing the simulated sea level to global tide model from TPXO9. Following previous method of Ningsih et al. [23], we use this free MATLAB package (can be accessed on http://volkov.oce.orst.edu/tides/global.html). This platform was used to perform harmonic constituents and making prediction of height and current [24]. The validation points were located in Tawangsari, Pangenan, and Bungko (as pointed S1-S3 in Figure 2). We also express the statistical error (RMS Error) through Pearson value. The correlation of the tidal height simulation is in the range of 0.848 and 0.903 with RMS Error approximately 0.075-0.088. The u-velocity correlation is on range 0.570-0.877 within RMS Error in range of 0.019-0.190 m/s. In addition, u-velocity component shows a good agreement of correlation coefficient; whereas the number of correlation is about 0.683-0.824 and RMS Error are about 0.040-0.061 m/s.

Figure 1. Location of the study area
3.2.2. *Inundation mapping using GIS.* Tidal flood mapping using GIS generally practice planar approach where lower land from expected maximum water level will be inundated [25]. This technique has been done previously by Marfai et al. [2]. By using simple raster modification in GIS, the expected inundated area will be identified, including water-depth for each cell. Here we use maximum tidal height and Mike2Grid tools to export the spatial distribution of inundation and superimpose with vector data of salt production area by BIG. Meanwhile, this study assumes that no land subsidence and rainfall extended during the period of simulation.

3.2.3. *Potential economic loss due to tidal inundation.* The inundation based on hydrodynamic simulation, salt parcel and economic value per hectare of salt production has been overlaid to describe potential economic losses. Further, during data collection most of farmers said that the salt price in May 2018 had reached 2,000 IDR/kg or 0.12 €/kg. Productivity of the salt pond for each hectare is 60 tons/hectare [26]. A simple rough approach was used in this study by using production and price of the product data. Those two parameters are multiplied by total of inundated area.

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\text{Flood loss} = \text{productivity} \times \text{price} \times \text{inundated area}
\]

(1)

4. Results and discussion

4.1. *High tide event on May 2018*

Based on the simulation, the spring tide emerged on 23-25 May 2018 during the end of moon phase. Here, the wave rising is majorly influenced by moon gravity \((M_2)\). MIKE simulation shows that \(M_2\) has generated 0.143 m of tide. Furthermore, those three verification points (S1-S3) have shown the correlation of the tide event to lunar phase (see Figure 3 a-c). Then, as we input the wind data from OGIMET in the simulation, the model performs small difference of tidal pattern as the low velocity has occurred during May 2018. Around 0-1.49 ms\(^{-1}\) of the wind velocity averagely flows from the north in production season. Finally, the water elevation during peak of tidal event in Cirebon has reached 0.40 m on 25\(^{th}\) May 2018 11:00 UTC (Figure 3 d).
Figure 3. Water level correlation between simulation and TPXO on May 2018 (at a) S1 - Tawangsari; b) S2 - Pangenan; and c) S3 – Bungko. Scatterplot and RMS error of simulated water elevation with tide gauge records on May 2018 within peak level of water during simulation on 25 May 2018 11:00 UTC

4.2. Inundated salt production area in peak of event

The superimposed map between the peak of tide from MIKE with salt parcel dataset shows that significant inundation is distributed along north part of Cirebon within maximum of 0.40 m height. The tidal inundation model has been created based on DEM data (here we used DEMNAS) and planar model in a raster format. The planar calculation is operated on each pixel of the digital map. Single value of water depth has been used in the process. The water level input from MIKE was setup into grid and used in the GIS spatial analysis in ArcGIS. The reclassification process has been done to get single value of water depth in each of parcel in vector data. Then, this step can give an understanding of impacted salt production land.

The result based on 0.40 m water level shows significant inundation occurred upon solar salt pond on the peak of the tide. It can be seen that approximately 6,569.99 ha (84.02%) of the salt pond has been flooded which distributed at eight districts of Cirebon. The most suffered district was Losari where almost 1,990.55 ha (99.9%) of salt pond affected by the event. Meanwhile, smaller effect of the tidal flood has occurred in Kapetakan and Astanajapura which around 1568.34 ha (57.22%) and 93.69 ha (62.91%) of the salt pond submerged during the incidence. Meanwhile, in Mundu, Pangenan, and Suranenggala the tidal have drowned around more than 95% of the total salt production area. The map of Figure 4 shows spatial distribution of tidal flooding in Cirebon on May 2018 event. Moreover, the percentage of inundated pond against total production area is drawn in Figure 5.
Figure 4. Estimated inundation level for each pond of during peak of event on 25 May 2018 11:00 UTC (each parcel contains single value of inundation depth)

Figure 5. Percentage distribution of inundated pond during peak of event on 25 May 2018 11:00 UTC
4.3. Potential loss on salt production due to high tide
Salt production is one of laborious economic sector in Cirebon. Currently, national government has promoted this region as one of the salt production centre in Indonesia. The total production in 2015 was recorded more than 435 thousand tons [18]. Moreover, the salt production environment itself has potential site for tourism and research. Previous tidal flood occurrence has affected large scale of this sector. Regarding the calculation, the total loss of all salt production area is expected around €48.69 million. In the tide event, Losari also records as the most affected area, which suffered €14.76 million. Meanwhile, Kapetakan also suffers huge loss with €11.62 million has collapsed due to tidal flood. Astanajapura has recorded minimum loss where only loss €694 thousand from total revenue. Table 1 draws potential distribution of salt production of each district in Cirebon.

Table 1. Potential loss during the peak of high tide upon salt production area in Cirebon

| District      | Inundated area | Total potential loss (€) |
|---------------|----------------|--------------------------|
| Kapetakan     | 2,740.98       | 11,623,396               |
| Suranenggala  | 384.92         | 2,831,255                |
| Gunungjati    | 302.7          | 2,191,958                |
| Mundu         | 156.89         | 1,135,703                |
| Astanajapura  | 148.93         | 694,362                  |
| Pangenan      | 1,276.44       | 9,401,571                |
| Gebang        | 816.32         | 6,049,971                |
| Losari        | 1,992.15       | 14,763,775               |
| **Total**     | **6,570.00**   | **48,691,991**           |

5. Conclusion
This article combines the simulation of the hydrodynamic and GIS to extract post-event of tidal inundation based on several datasets. The gravitational force of the moon ($M_f$) has potentially forced tidal event in May 2018. The models are able to simulate physical aspects of tidal flood in Cirebon coast, where moon gravity force dominates the local tidal properties during salt production period. As simulated within 0.40 m water level, the flood impact on solar salt pond was distributed around 6,569.99 hectares or 84.02% of area. The economic impact of the event was roughly around €48.69 million. However, rough estimation for economic loss has been performed in this study. Further research is still necessary, particularly to identify the impacts of tidal flood on comprehending economic aspect through Cost/Benefit Analysis (CBA), and scenario of sea level rise as major part of global climate change.

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