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MODEL PREDIKSI UNTUK PENGENDALIAN BANJIR ROB MENGGUNAKAN SKEMA *ONE-WAY COUPLING* DI PONTIANAK, KALIMANTAN BARAT

PREDICTION MODEL FOR TIDAL FLOOD CONTROL USING ONE-WAY COUPLING SCHEME IN PONTIANAK, WEST KALIMANTAN

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ABSTRACT

Tidal flood prediction is an important part of action plans in disaster mitigation. The lack of information about the time, duration and location of potential events in the pre-disaster stage, can lead to greater damage and losses. This study aims to fill the pre-disaster information gap by designing a short-term prediction system for tidal flood in the Pontianak City using one-way coupling model scheme. The scheme collaborates weather prediction model (WRF-ARF), hydrodynamic model (DELFT3D), and hydraulic model (HEC-RAS). The validation of the flood prediction map using the contingency table method by 67 survey points, indicates a good accuracy with a Hanssen-Kuipper Skill score = 0.77 – 0.91. Furthermore, based on the simulation, it was found that the potential for flood areas in Pontianak is around 15.10% - 16,03% of the city area. Hence, this area should be the focus for the local government to take preventive action to reduce the potential disasters in the future. Generally, this study has succeeded in integrating models in various dynamic aspects to predict tidal flood and the model framework can be recommended in tidal flood early warning systems.

Keywords: *Prediction; Tidal Flood; WRF-ARW; DELFT3D; HEC-RAS 2D; Pontianak*

ABSTRAK

Prediksi banjir rob merupakan bagian penting dari rencana aksi dalam mitigasi bencana. Minimnya informasi waktu, durasi dan lokasi potensi kejadian pada tahap pra-bencana dapat menyebabkan dampak kerusakan dan kerugian yang lebih besar. Penelitian ini bertujuan untuk mengisi celah informasi pra-bencana tersebut dengan merancang sistem prediksi jangka pendek untuk banjir rob di Kota Pontianak menggunakan skema one-way coupling model. Skema ini mengkolaborasikan model prediksi cuaca (WRF-ARF), model hidrodinamik (DELFT3D), dan model hidrolik (HEC-RAS). Hasil validasi peta prediksi banjir dengan metode tabel kontingensi terhadap 67 titik survei menunjukkan kemampuan prediksi yang baik, dengan skor Hanssen-Kuipper Skill = 0,77 – 0,91. Selain itu, dari simulasi model ditemukan bahwa potensi daerah banjir di Kota Pontianak adalah sebesar 15.10% - 16,03% dari total luas kota. Daerah ini dapat menjadi fokus pemerintah daerah, dalam mengambil tindakan penataan dan pencegahan untuk mengurangi potensi bencana tersebut di masa yang akan datang. Secara umum, studi ini telah berhasil mengintegrasikan model dalam berbagai aspek dinamis untuk memprediksi banjir rob dan skema model ini dapat direkomendasikan menjadi bagian sistem peringatan dini banjir rob.

Kata Kunci: *Prediksi; Banjir Rob; WRF-ARW; DELFT3D; HEC-RAS 2D; Pontianak*

INTRODUCTION

Tidal flood is one of the disaster phenomena which occur frequently in Pontianak, Indonesia. This flood is caused by the overflow of the Kapuas River which is triggered by the rise in water level during high tides. The Kapuas watershed has a river length about 1143 km (Widjonarko et al., 2021). The confluence of this tributary (Kapuas River) and the Landak River makes the city divided into three region (**Figure 1**). Beside that, this city is also located in a low-lying area with elevation height is 0.8 m to 1.5 m above sea level with a land slope around ± 2% (BPIW, 2017).

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Hence, most places in the city are vulnerable to tidal flood (Wuysang and Yudianto, 2013; Purnomo et al., 2019). In some cases, heavy rains can increase tidal flood risk if it coincides with high sea level conditions (Kuntinah et al., 2021). Furthermore, the presence of a wind surge in the Kapuas river mouth pushes sea water upstream and meets high river discharge, which can also trigger and exacerbate tidal flood conditions in Pontianak (Sampurno et al., 2022). This happens because the wind pressure creates a tangential force which then moves the water towards the direction of the wind direction (Ismanto, et al., 2019). Tidal flood in Pontianak is strongly influenced by the Asian monsoon (Kästner et al., 2018). During this period, the air-sea interaction in the coastal waters of West Kalimantan became more active due to the westerly wind blowing from the Natuna Sea.

In order to reduce the impact of losses due to this flood, the availability of flood early warning information as improved pre-disaster mitigation strategies in threatened areas is very necessary (Qi et al., 2021). Modeling is considered a solution to provide this information. The model can be simulated repeatedly with different model scheme to approach the actual conditions. The previous research about collaboration models have been carried out in research related to floods, such as Investigation typhoon induced storm surge and high wave in Vietnam (Anh et al., 2021), land cover changes after the flooding induced by typhoons (Yin et al., 2020) and tidal flood due to heavy rains and sea-level rise in Semarang (Efendi et al., 2021). Research on tidal flood by collaborating models in various aspects in Pontianak is still relatively rare.

This study utilizes several models in various aspects, including atmospheric, hydrodynamics, and hydraulics into an interrelated framework to improve tidal flood prediction capabilities. It is an important discussion as a starting point for studying how this model framework works in Pontianak. The results can be used as a reference for stakeholder goverment in providing tidal flood early warning information as disaster mitigation.

METODOLOGY

The research was conducted by one-way coupling model for three models including WRF-ARW, DELFT3D and HEC-RAS 2D to make short-term tidal flood predictions (**Figure 2**). One-way coupling model is computations which are transferred from one model and used as an input in another model (Santiago-Collazo et al., 2019). The Weather Research Forecast – Advanced Research WRF (WRF-ARW) is atmospheric model which provided by the National Center for Atmospheric Research (https://www.mmm.ucar.edu/). This model has been widely used to study atmospheric science and has good results in predicting weather parameters (Ardianto, 2017).

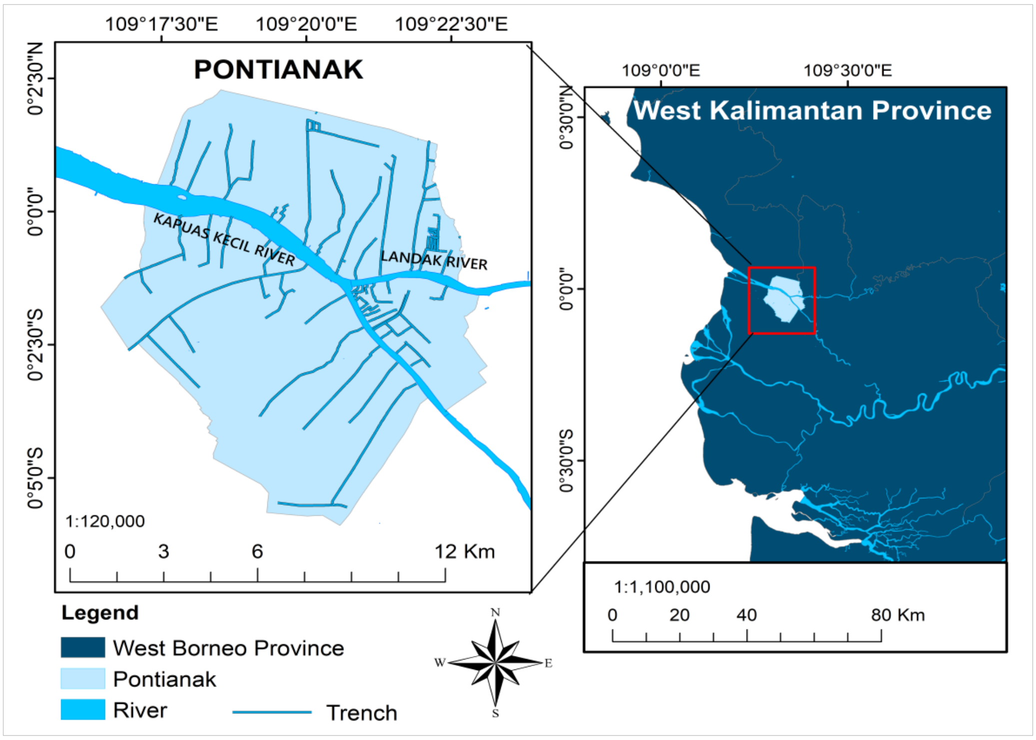

Figure 1 Pontianak is represented by the red box area. Data/Maps Copyright 2018 Geofabrik GmbH and OpenStreetMap Contributors | Map tiles: Creative Commons BY-SA 2.0 Data: ODbL.

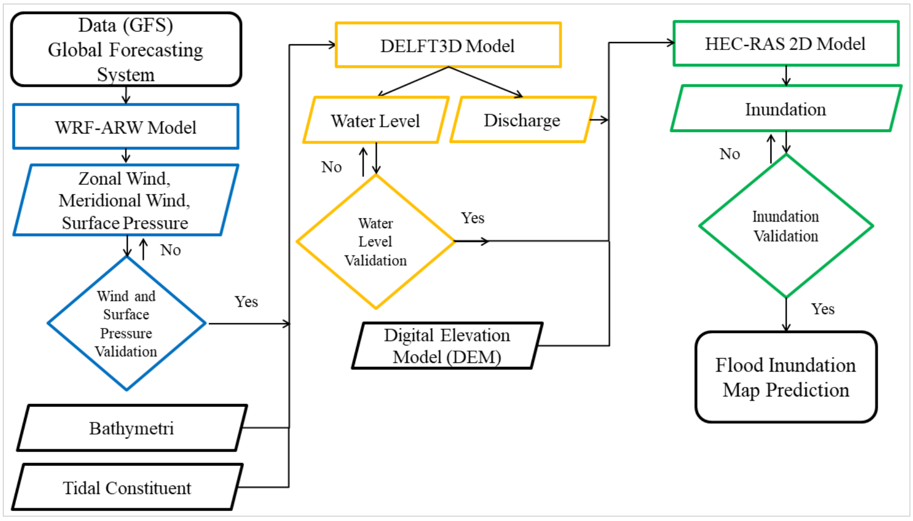

Figure 2 Schematic diagram of the collaboration model.

In this study, the model was built in two domains for downscaling. The first domain (**Figure 3a**) with grid resolution 27 x 27 km covers the western part of Indonesia. The first domain is expected to capture atmospheric phenomena in the wider region and then downscaled in the second domain (**Figure 3b**) with a third proportion of the first domain. This domain has resolution 9 x 9 km with focusing on the Natuna Sea, Coast of West Kalimantan and Pontianak City.

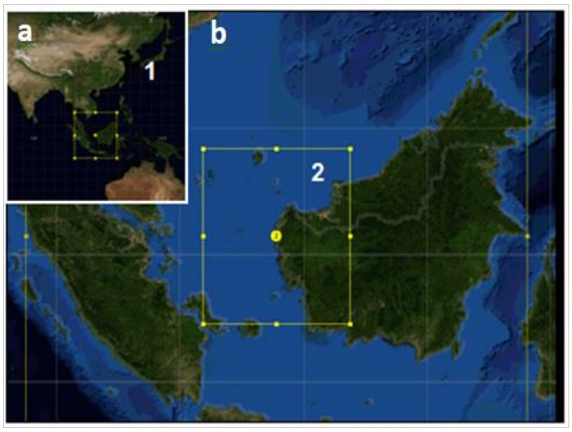

Figure 3 WRF-ARW model domain. (a). First domain (b). Second domain.

The model input data uses the Global Forecast System (GFS) with a spatial resolution of 0.25° x 0.25° and a temporal resolution of 3 hours (NCEP, 2015) obtained from Research Data Archive (https://rda.ucar.edu/). We used the data start on December 6, 2021 for t+72 hours in case study of the tidal flood on December 7 and 8, 2021. The simulation was carried out three times by using cumulus parameterization schemes which available on the WRF-ARW model including Kain-Fritcsh (KF), Grell-Devenyti (GD), and Betts-Miller-Janjic (BMJ) (Kurniawan et al., 2014). According to Sulung et al (2011) parameterization is a way to calculate the effects caused by a process without directly modeling the process. It can provide appropriate choices in the process of describing atmospheric dynamics. This output model will be converted into the DELFT3D input format using python 3.8.7 which consists of three surface parameters, including zonal wind, meridional wind and pressure.

The DELFT3D model version 4.01 is provided by Deltares (https://www.deltares.nl/). DELFT3D is a model that can be used for simulations on coasts, rivers and estuaries in studying hydrodynamics, tides, sediment transport, morphology and water quality (Deltares, 2022). This model is used to obtain predictions of water level and river discharge. For the input model, bathymetric data from the Indonesian Navy (Kästner et al., 2019) with 100 × 100 m grid resolution will be blended with bathymetry obtained from Indonesian Geospatial Information Agency's (BIG) with 180 × 180 m grid resolution. Open boundary conditions using the tidal component at the coastal area using the tide model driver with the TPXO08 database (Egbert and Erofeeva, 2002). The domain was built with grid resolution of 0.25 x 0.25 km covering the estuary until to the city which is about 14-20 km away (**Figure 4**). This aims to capture the hydrodynamic processes in the estuary that affect tidal flooding in Pontianak. The running process is carried out three times with time step 30 seconds. Water level and discharge data output will be made every 10 minutes. The simulation results will be validated with observation data to choose the prediction scheme with the highest accuracy to be used as the boundaries HEC-RAS 2D model in the tidal flood simulation. Flood Inundation was simulated using the Hydrologic Engineering Center River Analysis System (HEC-RAS) 2D 6.1 version provided open source by the US Army Corps of Engineers (www.hec.usace.army.mil). According to (Sarchani et al. (2020) 2D HEC-RAS simulation produces detailed and accurate 2D mapping of the flood level at peak discharge, maximum flood depth and flow velocity at each point of the modeled mesh.

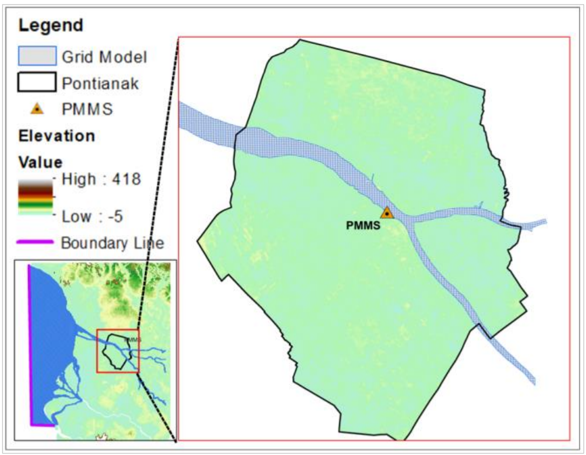

Figure 4 DELFT3D model grid domain. The enlarged red box represents the grid on the river.

This 2D simulation using water level and discharge of the Kapuas Kecil River from the output DELFT3D model as the boundaries. Water level every 10 minutes will be set at the boundary condition (BC) line 2-3 and the river discharges set at BC line 1(**Figure 5a**). The digital elevation model input data (DEM) used for the simulation is data from the Indonesian Geospatial Information Agency's (BIG) with 0.27-arcsecond (8.1 meters) resolution. Computation time step model is 30 seconds. Domain model area is 118.3 km^2 arranged in two grid resolution. In general grid resolution is 10 x 10 m. The maximum resolution is 8 x 8 m in the breakline's areas (pink line: tributary and trench), while the refinement area (orange line: Kapuas River area) (**Figure 5a**). In addition, the roughness coefficient is divided into 3 areas (**Figure 5b**) which refers to the National Land Cover Database 2016 and manual guide model (Dewitz, 2019; HEC-RAS, 2021) including rivers (light blue = 0.025), low development area (green = 0.06) and medium area development (red = 0.08). In addition, the energy slope value used is 0.0006 which is obtained from the riverbed contour approach from upstream to downstream.

Model validation was carried out using hourly observation data such as wind speed, surface pressure and water level from the Pontianak Maritime Meteorology Station (PMMS). All parameters will be evaluated based on the statistical performance criteria of root mean square error (RMSE) and Nash-Sutcliffe model efficiency coefficient (NSE).

Root Mean Square Errors (RMSE) is used to error metric for the model's ability, where 0 would indicate a perfect fit to the data. RMSE calculated by:

$$\mathrm{RMSE} = \frac{\sqrt{\sum_{i=1}^{n}(M_i - O_i)^2}}{n} \quad \text{.....................................(2)}$$

Where n is the number of the total data, M_i is the prediction data at time i and O_i is the observed data at time i.

Nash-Sutcliffe model efficiency coefficient (NSE) evaluates how far individual observations are from simulated predictions. This index was developed by Nash and Sutcliffe (1970) for the assessment of hydrologic model. The NSE coefficient is calculated by:

$$\mathrm{NSE} = 1 - \frac{\sum_{t=1}^{T}(Q_0^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_0^t - \overline{Q}_0)^2} \quad \text{...................................(3)}$$

Where Q_m^t the predicted water level at time t is, Q_0^t is the observed water level, and $\overline{Q}_0$ is the mean of observed water level. The interpretation of the NSE is based on the criteria (Motovilov et al., 1999) NSE ≥ 0.75 means good value, 0.36 <NSE < 0.75 means satisfactory.

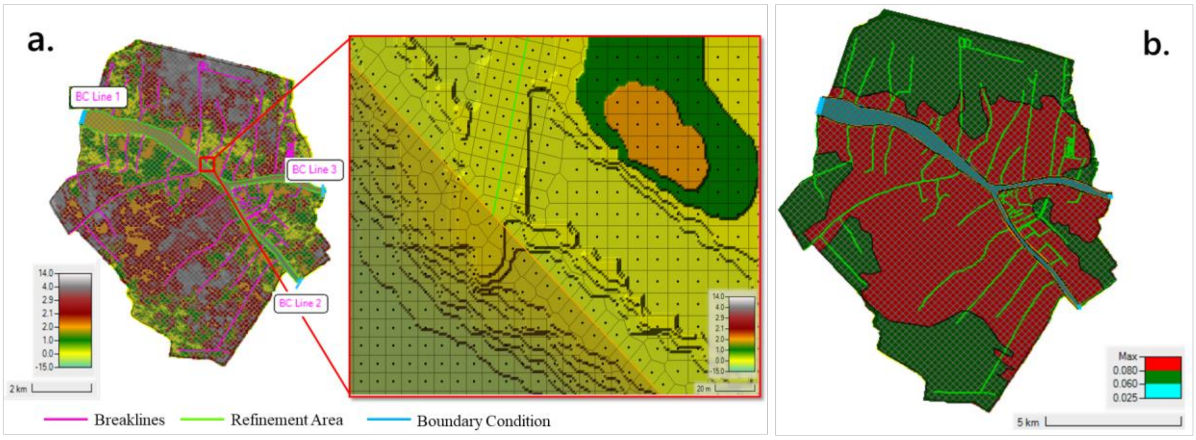

Figure 5 Domain setup HEC-RAS 2D model. (a). Grid model area (b). Manning's value n area.

Table 1 Contingency Table

Flood event forecast	**Flood event observed**		**Total**
	Yes	No	
Yes	Hit	False Alarms	Forecast Yes
No	Misses	Correct Negatives	Forecast No
Total	Observed Yes	Observed No	Summary Total

$$Hits\ Rate = H = \frac{Hits}{Hits+Misses} \quad (4)$$

$$False\ Alarm\ Ratio = F = \frac{False\ Alarms}{Hits+False\ Alarms} \quad (5)$$

$$Hanssen - Kuipper\ Skill\ = H - F = \frac{Hits}{Hits+Misses} - \frac{False\ Alarms}{Hits+False\ Alarms} \quad (6)$$

Inundation flood area will be evaluated with contingency table method (**Table 1**) with two category (dichotomous), floods and no flood without considering the depth of the flood. A contingency table summarizes information of multiple discrete random variables (Sugiyama, 2016). The validation data used are 67 points, which 27 points of flood survey data on 7 December 2021, obtained from community correspondence by sending photos. Flood surveys on 8 December 2021, there are 40 points observations by the author. Hanssen-Kuipper Skill Score (Hanssen and Kuipers, 1965) is also known as True Skill Statistics (TSS) ranges between -1 and 1. This index is used to see the correspondence between predictions and flood survey data, which represents the hit rate and this index is a more realistic and practical method for evaluating an accuracy prediction models (Notarnicola et al., 2011; Shabani et al., 2018).

RESULT AND DISCUSSION

The spatial wind prediction from WRF-ARW model on the first day flood event (**Figure 6, a-c**) shows all the simulation results almost have the same pattern. The wind in the Natuna Sea, Karimata Strait and Coastal of West Kalimantan blows from west to north with speeds varying from 6 to 20 knots. The prediction of the WRF-ARW model in the case of tidal flooding on the second day flood event (**Figure 6, d-f**) shows a significant difference, especially for the GD Scheme. In this scheme there is the Borneo Vortex which is a cyclonic wind circulation that forms on the northern side of West Kalimantan. Except for that, all schemes indicate there was an increasing wind speed in the Natuna Sea and Karimata Strait compared from the previous day. The wind speed ranged from 15 to more than 20 knots. As previously stated, a tidal flood occurs due to the interaction process of hydrodynamics and the atmosphere, especially wind speed and tides. Hence, this could potentially provide greater wind forced to the movement of water masses which causing higher tides than the previous day.

The comparison between model predictions and observation at the Pontianak Maritime Meteorological Station (**Figure 7**) show that on the observation data, the dominant wind direction blows from the north to northwest. In the model prediction for KF Scheme, dominant wind blows from the north. The GD Scheme, dominant wind blows from the northeast, and for the BMJ Scheme, dominant wind blows from the northwest. Based on these data, KF Scheme and BMJ Scheme are the most similar schemes to the observation data.

The comparison of surface air pressure between prediction and observation (**Figure 8a**) indicates daily pattern fluctuation where the pressure will be increasing in the morning and evening, and then it is tend to decrease in the afternoon and early morning. The distribution data between prediction and observation (**Figure 8b**) shows the regression trend line KF Scheme is underestimated against the observation data with Root Mean Square Error (RMSE) value is 1.120. While the others prediction model schemes tend to almost coincide above the KF scheme and have smaller errors. The RMSE value in the GD Scheme is 0.666 and the BMJ Scheme is 0.564. Based on the meteorological parameters validation from the output of the WRF-ARW model, it can be concluded that the BMJ Scheme tends to be better than the KF Scheme and the GD Scheme.

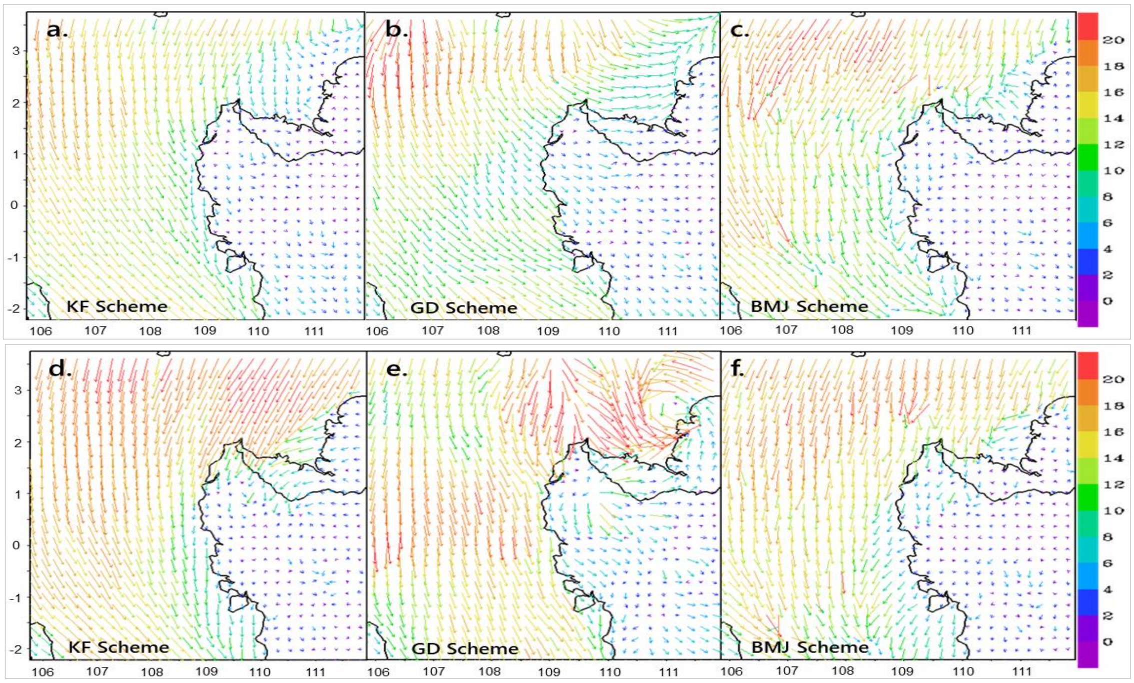

Figure 6 Spatial wind prediction from Model WRF-ARW.
(a-c) 07 December 2021 00.0 UTC, (d-f) 08 December 2021 02.00 UTC.

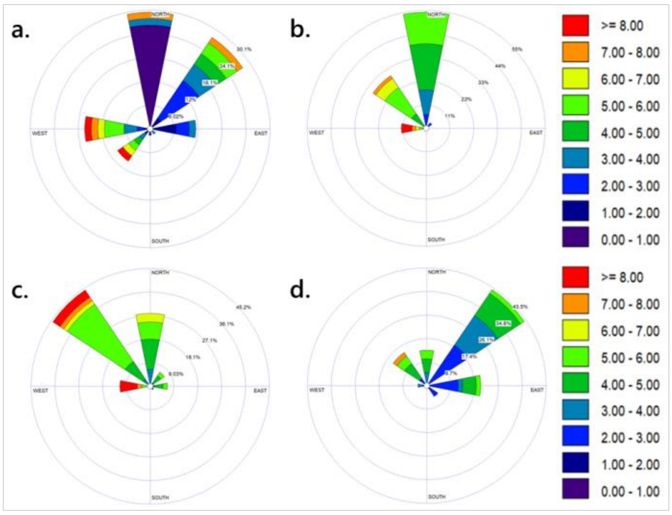

Figure 7 Comparison of windrose diagram between prediction and observation at PMMS
(a) Observation (b) KF Scheme (c) GD Scheme (d) BMJ Scheme.

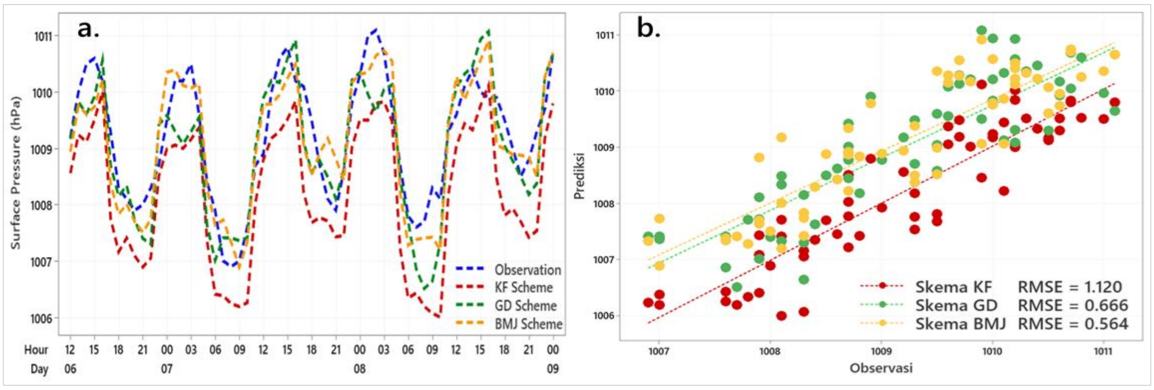

Figure 8 (a) Comparison of surface pressure between prediction and observation. (b) Scatterplot diagram between surface pressure prediction and observation at PMMS.

Observation data on water level during December 2021 (**Figure 9a**) indicates that on 7 and 8 December 2021 high tides was occurred. Based on the observations at PMMS, the tides are main cause of tidal flood because the recorded rainfall on both days is 0 mm. In addition, the observation station area will start to inundate when the water level reaches above 2.5 meters. The comparison of water level between prediction and observation (**Figure 9b**) shows almost the same tidal pattern. However, there is a time lag for the peak tide from the model, around one hour from the observation. Beside that, the lowest tide produced by the model is also lower than the observed data. This happens because the forcing factor that given into the simulation model is different from the actual condition. Furthermore, the grid resolution, time step computation and DEM data greatly affect the prediction results. The highest tide observation data on 7 December 2021 occurred at 01.00 - 02.00 UTC is 2.76 to 2.78 m, while the peak tide from the prediction model occurred at 00.00 - 01.00 UTC with heigh level 2.85 - 2.88 m (KF Scheme), 2.86 – 2.87 m (GD Scheme), 2.85 – 2.87 m (BMJ Scheme). The highest tide observation data on 8 December 2021 occurred at 02.00 - 03.00 UTC is 2.83 to 2.85 m, while the peak tide in the prediction model occurred at 01.00 - 02.00 UTC with heigh level 2.83 - 2.86 m (KF Scheme), 2.83 – 2.87 m (GD Scheme), 2.83 – 2.87 m (BMJ Scheme). Based on calculation data between obaervation and prediction, the root mean square error (RMSE) ranged from 0.143–0.145 and the nash-sutcliffe model efficiency coefficient (NSE) indicates that all of schemes have good accuracy with not big different assessment values. However, the water level with meteorological input from the BMJ scheme has the best accuracy, and then it will be the input for inundation simulation on HEC-RAS 2D models. In other side, the predicted discharge for the Kapuas Kecil River (**Figure 9c**) shows not much difference between the three schemes. The discharge value generated by DELFT3D with the input of the KF Scheme model is 132 – 1384 m^3/s, the GD Scheme is 144 – 1366 m^3/s and the BMJ Scheme is 125 – 1414 m^3/s. According to the calculations of Kästner et al., (2019), the Kapuas Kecil River discharges ranged from 170 m^3/s (dry season) to 1700 m^3/s (rainy season). Based on this calculation, the discharge prediction is still within the range and can be used as input for the HEC-RAS 2D model.

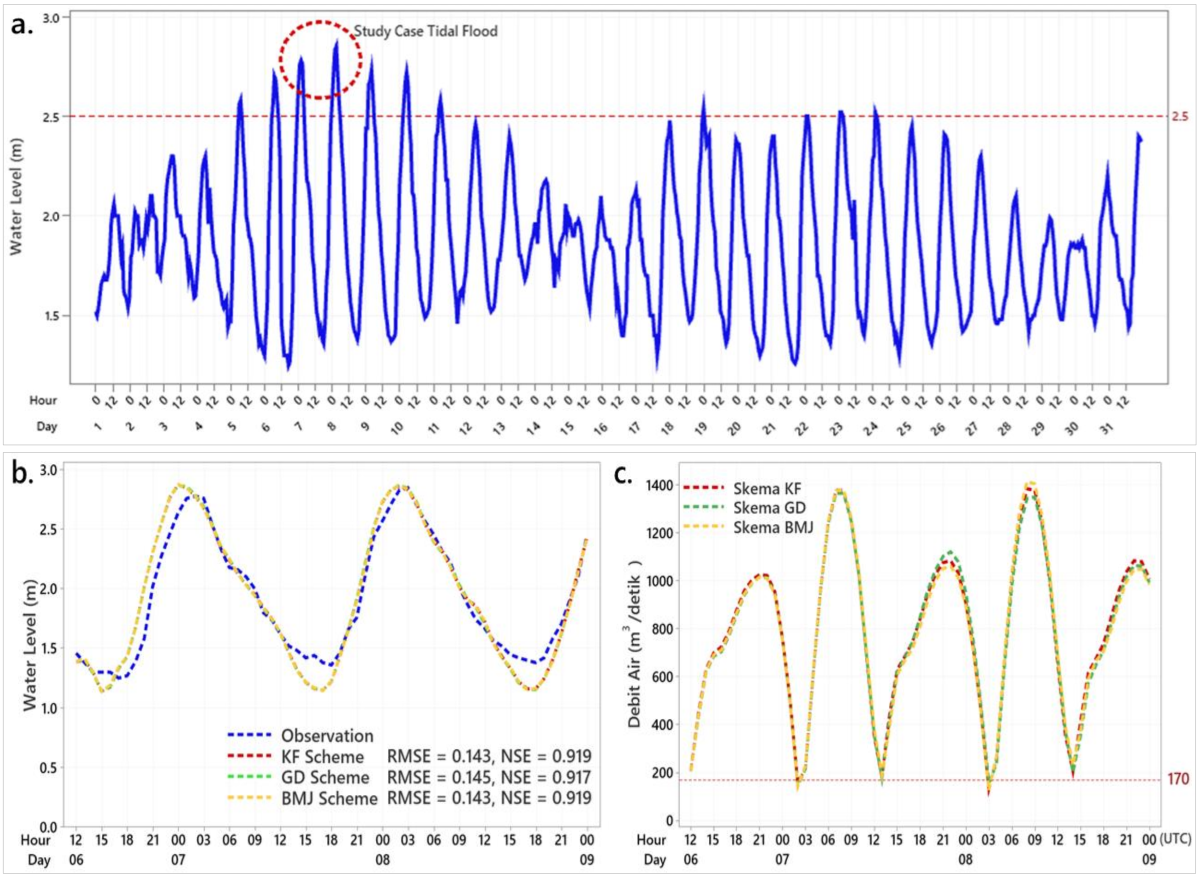

Figure 9 (a) Water level observation in December 2021 at PMMS (b) Comparison of water level between prediction and observation (c) Comparison of prediction river discharge from the DELFT3D Model.

The tidal flood inundation map from HEC-RAS 2D model simulation shows that before the flood occurred (minimum depth), there was no overflow in the rivers and trenches (**Figure 10a**) while during the flood event (maximum depth), the simulation shows some areas were inundated with varying heights (**Figure 10b**). According to water level simulation data, the tidal flood peak on 7 December 2021 occurred at 00.00 UTC (**Figure 10c**) and for the second flood event on 8 December 2021 occurred at 02.00 UTC (**Figure 10d**). If we look at this prediction map, most of the wet survey sample points (turquoise blue dots) are in inundated areas and the dry point surveys (pink dots) are in non-flooded areas. The flood area prediction (**Table 2**) shows the flood area at the peak for 7 December 2021 is covering an area around 1786.82 Ha while on 8 December 2021 covering an area around 1896.91 Ha. There was an increasing flood area compared to the previous day. Beside that, changes in the depth color scale on the second day indicate an increasing trend of flooding from low to medium-high levels. This strengthens the relationship between the flood and water level observation data, where there is an increase in peak tides on the second day of the flood event. Based on this simulation, if the total city area is 11830 Ha (DEM data), it can be concluded that the coverage area affected by the flood ranges from 15.10% to 16.03%.

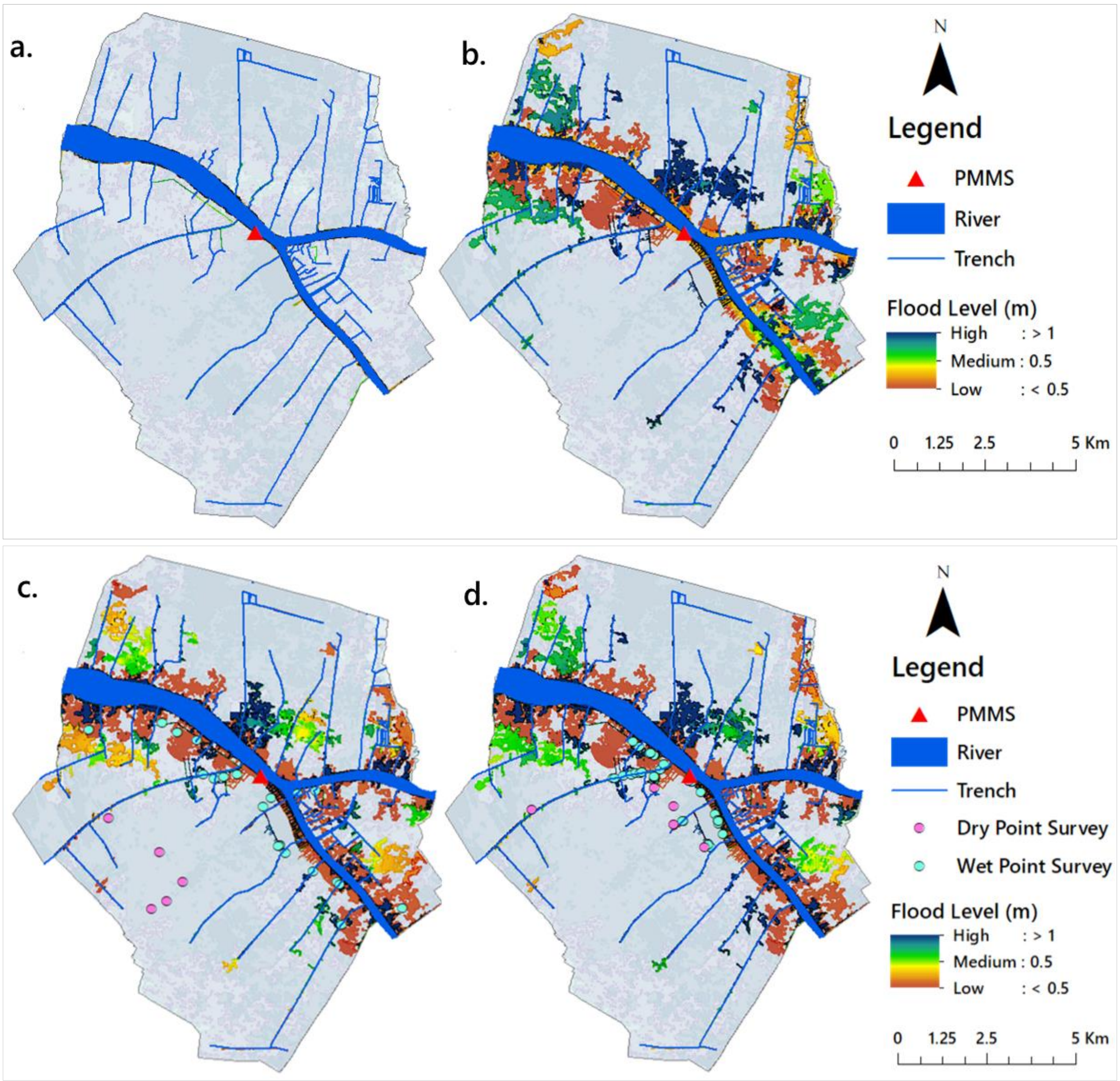

Figure 10 Tidal flood prediction model during the flood period 7 – 8 December 2021. (a). Before flood event (minimum depth) (b). Flood event (maximum depth) (c). Peak of the flood on 7 December 2021 (d) Peak of the flood on 8 December 2021.

Tabel 2 Predicted area of flood inundation (Km^2)

Flood Map Simulation	Flood Area (< 0.5 m)	Flood Area (0.5 – 1.0 m)	Flood Area (> 1.0 m)	Total
Minimum depth (Before Flood Event)	0	0	0	0
Peak flood on 07 December 2021	1233.26	371.50	182.06	1786.82
Peak flood on 08 December 2021	1165.35	543.31	188.26	1896.91
Maximum Depth (Peak of Flood Event)	967.54	690.37	377.81	2035.72

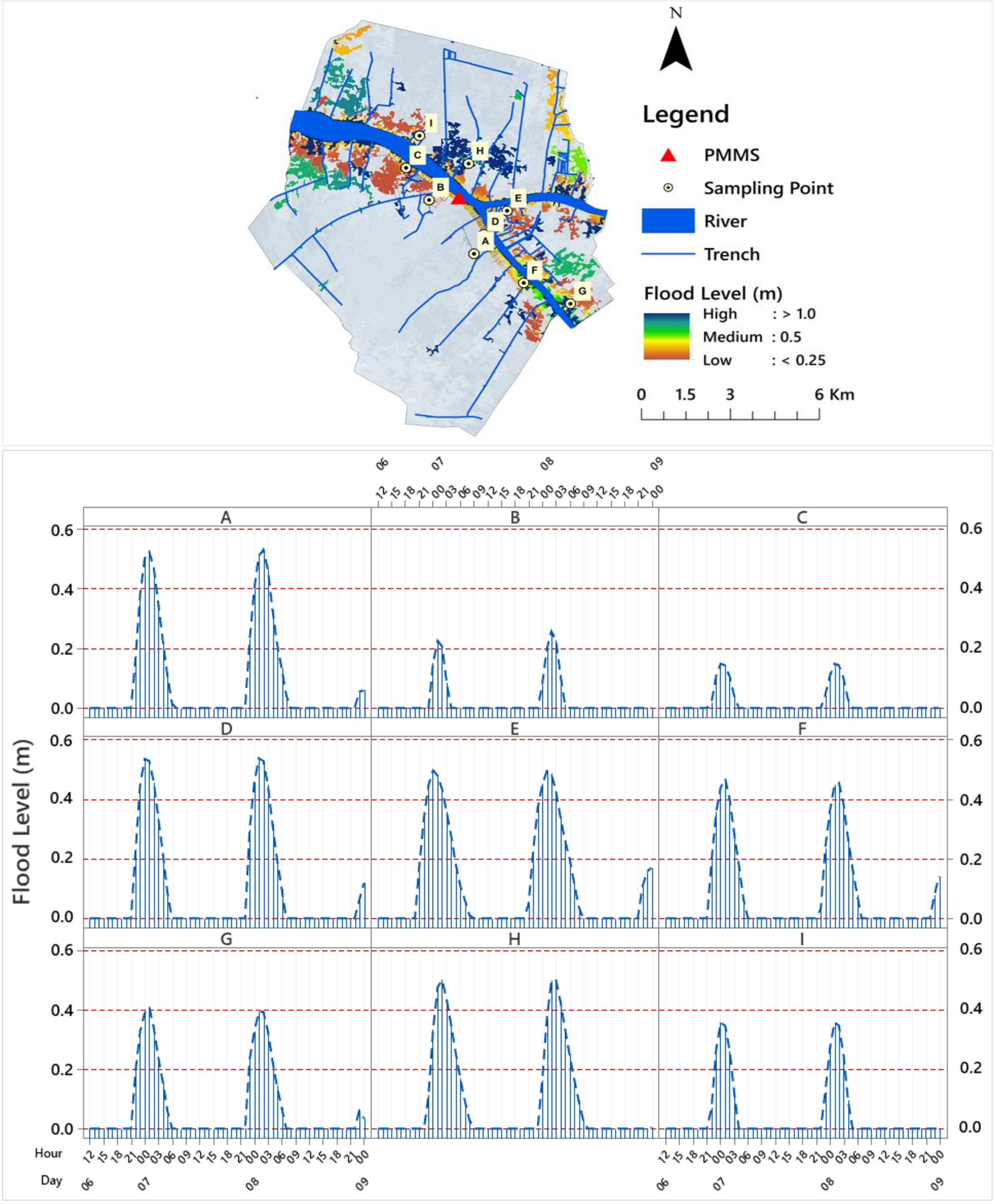

Figure 11 Random sampling point of flood event (maximum depth).

The flood depth on 9 random sampling points during 7-8 December 2021 (**Figure 11**) shows that the average flood duration ranges from 4 to 6 hour. This is in accordance with the character of the flood which is mainly triggered by the tides, such as the tidal flood in Semarang, maximum duration around 6 hours (Gultom et al., 2018) and 2 until 5 hours in Pekalongan (Marfai, et al., 2017; Sauda and Nugraha, 2019). Generally, in post-flood conditions, the land will be dry without inundation, but the simulation in this case shows different things. There are several points of post-flood land that should not have been flooded, but there are still a few inundations. We suspect that in some areas of Pontianak with low elevation, especially those areas that close to the trench (**Figure 12**), even during normal conditions (without flood) the land remains submerged all the time with height level around 0.1 to 0.2 meters (**Figure 11**). This is the reason why even though the flood has ended, there are some location are still inundated.

Based on the contingency table results (**Table 3-4**), the flood inundation validation shows the Hits Rate score and Hanssen-Kuipper skill score on both flood predictions range from 0.77 to 0.91. (**Table 5**). This indicates that the model has good skills in predicting tidal flood from available survey location points. However, in this contingency table, there is no false alarm ratio. This means that there is no forecast that it should be dry but is predicted to be flooded. It can be concluded that the model is tend to underestimate than overestimate in predicting flood. To strengthen this statement, it is necessary to add more survey points to further research.

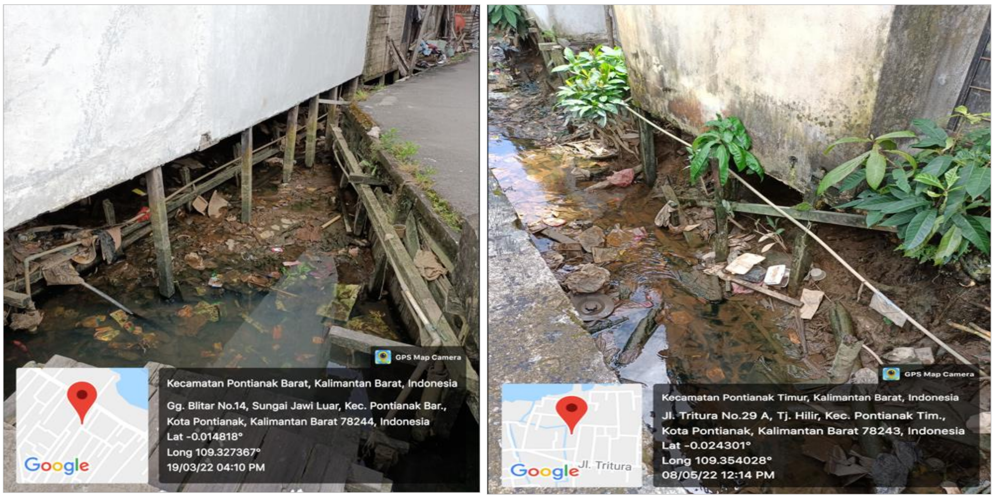

Figure 12 House building at low elevation close to the trench (normal conditions without tidal flood).

Tabel 3 Contingency table flood simulation on 07 December 2021

Flood event forecast	**Flood event observed**		**Total**
	Yes	No	
Yes	17	0	17
No	5	5	10
Total	22	5	27

Table 4 Contingency table flood simulation on 08 December 2021

Flood event forecast	**Flood event observed**		**Total**
	Yes	No	
Yes	31	0	31
No	3	6	9
Total	34	6	40

Table 5 Calculation results of flood inundation validation parameters

No	**Date Event**	**Hits Rate (H)**	**False Alarm Ratio (F)**	**Hanssen-Kuipper Skill (H-F)**
1.	2021/12/07	0.77	0	0.77
2.	2021/12/08	0.91	0	0.91

CONCLUSION

Tidal flood prediction is important pre-disaster information as an early warning. Collaborating models in various aspects such as atmosphere, hydrodynamics and hydraulic systems is one step in designing a tidal flood prediction system. Generally, the validation results for wind and surface pressure from the output WRF-ARW, water level dan discharge from the output DELFT3D, inundation flooding from the output HEC-RAS 2D, shows good performance. This research has been successful in designing a collaborative model framework in tidal flood prediction. Therefore, these results can be implemented as part of the tidal flood early warning system in disaster mitigation

However, the input of forced meteorological data on DELFT3D which are generated from WRF-ARW did not have significant difference in the three model simulations. Therefore, it is necessary to do more variations of the WRF-ARW configuration model in future studies. In addition, the high resolution of the digital elevation model (DEM) also can improve the quality of model predictions.

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