

This manuscript has been submitted for publication to the INTERNATIONAL JOURNAL OF REMOTE SENSING AND EARTH SCIENCES. Please be advised that future manuscripts may have different content. If accepted, the final version of this manuscript will be updated in the 'Peer-reviewed Publication DOI' link. For feedbacks and comments, please feel free to contact any of the authors.

Hydro-Meteorological Aspects of the 2021 South Kalimantan Flood: Topography, Tides, and Precipitation

Munawir B. Pratama¹, Rafida M. Withono², Ismail N. Azkiarizqi²

¹Ocean Engineering Department, Institut Teknologi Bandung

²Water Resources Engineering and Management Department, Institut Teknologi Bandung

e-mail: munawirbintang@gmail.com

Abstract. The 2021 South Kalimantan Flood is said to be the greatest flood ever take place in the province. This study aims to provide an overview of the disaster and assisting future research. Hydro-meteorological conditions such as topography, tides, and precipitation are described. Between January 10 – 19, extreme rain events occurred in South Kalimantan, a province dominated by low lying land with elevation < 7 m. The total precipitation during those 10 days reached 672.8 mm, resulting in a massive water accumulation at downstream. The peak was on January 14, the precipitation in Banjarbaru recorded a 250 mm/day, a 25-year return period value. Furthermore, the spring tide occurred at the same time, slowing the flushing in the tidal river, Barito River. Assessment of ERA5, TRMM, and GPM prediction data indicated that the latter is the most suitable to study the extreme rain events in South Kalimantan. Using the 20-year of GPM data, it is found that ENSO and IOD coexist with both the highest and lowest anomalies. With La Nina at the end of 2020, a positive precipitation anomaly in 2021 should be expected. This extreme precipitation is suspected as the main driver of the 2021 South Kalimantan Flood, and the impact gets amplified by the spring tides. Nevertheless, the significance of other factors, such as the land-use change is crucial to be studied.

Keywords: *Natural Disaster, Hydrological Hazard, Meteorological Hazard, Indonesia, Extreme Events, Precipitation Anomaly.*

1 INTRODUCTION

Natural disasters are categorized into 6 groups, geophysical, hydrological, meteorological, climatological, biological, and extraterrestrial (IRDR 2014). Since the early of 2020, the biological hazard, namely Covid-19, had hit and kept the Indonesian government and various countries busy across the globe. In addition to that, geophysical, hydrological, and meteorological disasters had occurred in various regions and in a short period in early 2021.

In South Kalimantan Province, extreme rainfall lasted for days resulting in flooding. Floods in South Kalimantan were not the first time. In 1928, there were documentations regarding flooding in Barabai, Hulu Sungai Selatan Regency (KITLV 83630 1928). The Central Bureau of Statistics (Badan Pusat Statistik - BPS) of South Kalimantan recorded 286 flood events from 2012 to 2019. Banjarmasin was the least affected location, with only 1 incident, meanwhile, Balangan Regency had 78 flood histories (BPS Kalimantan Selatan 2021). Even so, the floods that hit South Kalimantan in January 2021 were said to be more intense than previous events. As of January 14, BNPB reported that 24,379 houses were inundated and 39,549 people were evacuated (BNPB 2021a).

This study aims to provide an overview of the South Kalimantan Flood 2021, by summarizing reports and information from other sources. Natural conditions during the disaster will be provided, such as topography, tides, and precipitation. It is hoped that the information and hypotheses in this paper will provide a basis and may assist further studies in this case.

2 MATERIALS AND METHODOLOGY

2.1 Area of Study

The study discusses the South Kalimantan Flood 2021. The domain of study is shown in Figure 1, including 13 cities with details provided in Table 1. The total population of South Kalimantan in 2019 is 4.24 million people with an area of 38,744.23 km² (BPS Kalimantan Selatan 2021). However, 22.36% of the population is concentrated in the cities of Banjarmasin

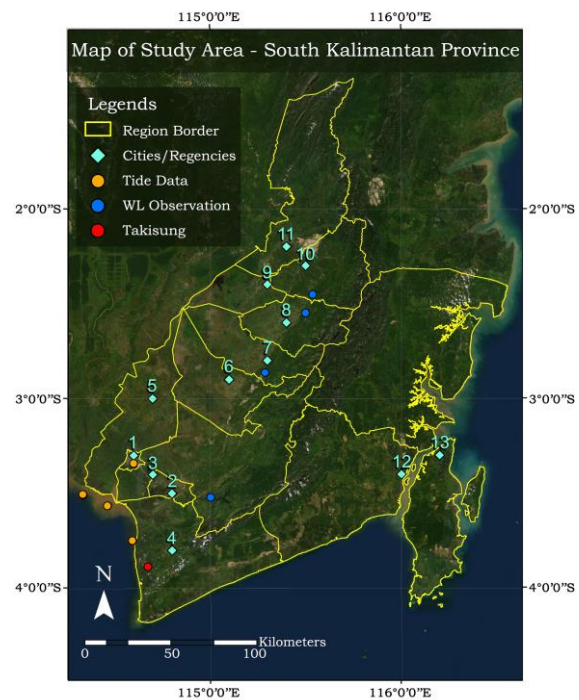


Figure 1 Overview of South Kalimantan Province. Area of interest is cities 1 – 11.

Table 1 List of cities, main districts, and its elevation (BPS Kalimantan Selatan 2021).

No	Cities	Main Districts	Elevations ^a (m)
1	Banjarmasin	-	5
2	Banjarbaru	-	27
3	Banjar	Martapura	13
4	Tanah Laut	Pelaihari	64
5	Barito Kuala	Marabahan	9
6	Tapin	Rantau	8
7	HSS*	Kandangan	11
8	HST*	Barabai	9
9	HSU*	Amuntai	6
10	Balangan	Paringin	29
11	Tabalong	Tanjung	16
12	Tanah Bumbu	Batulicin	2
13	Kotabaru	Kotabaru	32

^a Datum in Mean Sea Level (MSL)

* HSS: Hulu Sungai Selatan

* HST: Hulu Sungai Tengah

* HSU: Hulu Sungai Utara

and Banjarbaru which only occupy 1.5% of the province's area.

According to the literature, 30.16% of land in South Kalimantan is forest and shrubs, and 20.09, 10.98, 2.33 and 1.44% respectively are for plantations, rice fields, settlements, and mining.

Geographically, the province's average height is 17 m with 38.809 hectares used for rivers, lakes, reservoirs, and ponds (BPS Kalimantan Selatan 2021). The Barito River is the largest river in South Kalimantan and the widest river in Indonesia.

2.2 Flood Records

The schematization of the Barito River system at South Kalimantan Province is illustrated in Figure 2 (Manalu 2021). The eleven flooded cities are visualized in the figure. The general summary of the flood events is given in Table 2. These data were compiled from field observation and disaster report provided by BPBD. Since January 10, there were 5 cities affected by the flood. The water levels at the four weirs (upstream side) on January 10 – 13 were at 100, 26, 42, and 25 cm in Banjar (Karang Intan), Balangan (Pitap), HSS (Amandit), and HST (Batang Alai).

After heavy rains on January 14 – 15, observations at the weirs surged to 230, 202, 150, and 260 cm for each location. Consequently, the flood hit 8 cities with a considerable inundation on January

14. The most severe impacts were felt in Banjar (Pengaron), Tanah Laut (Bumi Makmur), Tapin (Binuang), and HST (Barabai and Hantakan), where water rose from about 50 cm to more than 150 cm in just 1 night (BNPB 2021b). Banjarmasin which was not flooded before, was inundated about 30 – 50 cm. Tanah Laut, which had experienced flooding since January 10, was suffering a significant increase in flood height due to a collapsed retaining wall at the Takisung Pond (Balai Hidrologi dan Lingkungan Keairan 2021).

From January 16 – 19, the rain lasted 3 days with moderate to heavy intensity (BMKG 2021a). The series of extreme rain events contributed to increasing the discharge of the Barito River to 2.08 billion m³, far exceeding its capacity of 230 million m³ (Tirto 2021). Table 2 shows that 11 cities were flooded on January 16. Meanwhile, observations at the weirs showed a gradual decline, namely 69 - 36, 110 - 40, and 22 - 6 cm for Balangan, HSS, and HST. However, in Banjar, the water level still fluctuated between 150 - 170 cm.

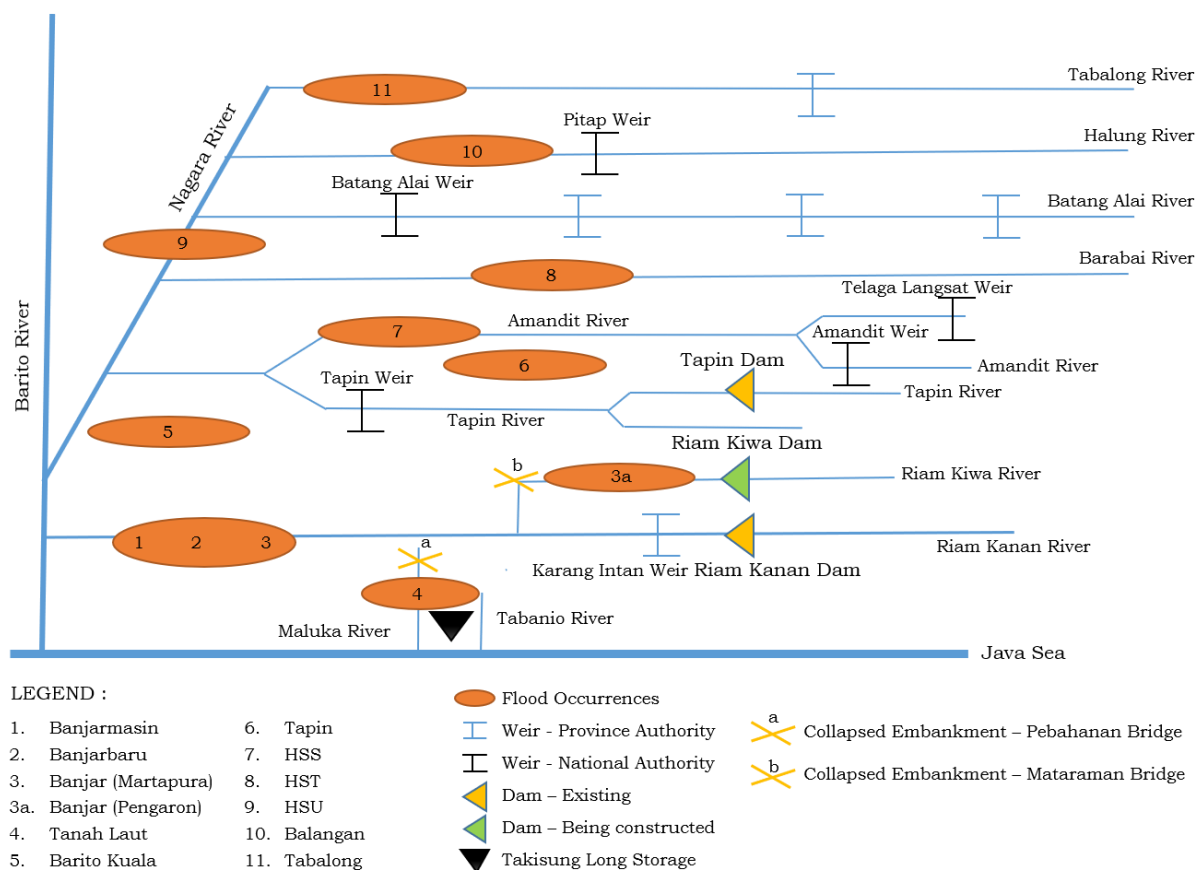


Figure 2 Schematization of Barito River system at South Kalimantan Province.

Table 2 General records of the 2021 South Kalimantan Flood, numbers 1-11 represent cities.

Dates	Times	1	2	3	4	5	6	7	8	9	10	11					
10/01	07:00	-	20 -	-	20 -	-	-	-	-	-	-	< 50					
	14:00	-	40	-		-	-	-	-	-	-						
	22:00	-	30 -	30		-	-	-	-	-	-						
11/01	07:00	-	30 -	40	20	-	-	20 -	-	-	-	-					
	14:00	-		40		-	-		-	-	-	-					
	22:00	-		20		-	-		-	-	-	-					
12/01	07:00	-	< 30	30	40 -	-	20 -	40	-	-	-	-					
	14:00	-				-			-	-	-	-					
	22:00	-				-			-	-	-	-					
13/01	07:00	-	20	50 -	70	-	20 -	40	-	-	-	-					
	14:00	-				-			-	-	-	-					
	22:00	-				-			-	20	20	-	20 -	-			
14/01	07:00	30 -	< 50	200 ^b	50 -	-	150 ^c	60	50 -	-	70 -	-					
	14:00					50			100 -	-	100	-					
	22:00					-			200	-	-	-					
15/01	07:00	50 -	< 20	50 -	60	-	60	70 -	100 -	50	30 -	-					
	14:00					60			150	-	100	-					
	22:00					-			-	-	-	-					
16/01	07:00	30 -	< 10	(250)	< 100	< 40	30 -	60	70 -	10 -	60	50 -					
	14:00					60			100			-	60	-			
	22:00					-			-			-	-	-			
17/01	07:00	30 -	-	< 70	< 30	40 -	20 -	30	50 -	< 20	30 -	< 40					
	14:00								60				70	-	60	-	
	22:00								-				-	-	-	-	
18/01	07:00	-	30 -	50	< 30	40 -	-	-	< 50	< 20	20	-					
	14:00								-				20 -	-	20	-	
	22:00								-				40	-	-	-	
19/01	07:00	< 40	-	10 -	< 10	40 -	-	-	-	-	10	-					
	14:00												-	50	-	-	-
	22:00												-	< 70	-	-	-

As of January 19, there were still 5 districts inundated as shown in Table 2. Based on the visualization of the Sentinel-1 satellite on January 20 (see Figure 3), large-scale inundation occurred in the downstream areas of Barito Kuala, Tanah Laut, and Banjar (Copernicus Sentinel 2021; Purwonegoro 2021). Flood events were also observed upstream and identified as lower elevation areas, namely in several areas in Barito Kuala to HSU.

2.3 Data Compilation

Topography

Topography or digital elevation model (DEM) used DEMNAS data, which are publicly available. DEMNAS is

topographic data with a resolution of 8.3 x 8.3 m² for the Indonesian regional area, provided by the Geospatial Information Agency – Badan Informasi Geospasial, BIG (BIG 2021a). The data is an integration of IFSAR, TERRASAR-X, and ALOS PALSAR. Previous studies had shown that DEMNAS offers better accuracy than SRTM (Nurtyawan and Fiscarina 2020). Elevation discrepancy between DEMNAS and measurement data is generally influenced by land cover, only a small part is influenced by elevation.

Tides

The tidal observation station of BIG in South Kalimantan was less relevant since the location was out of the area of

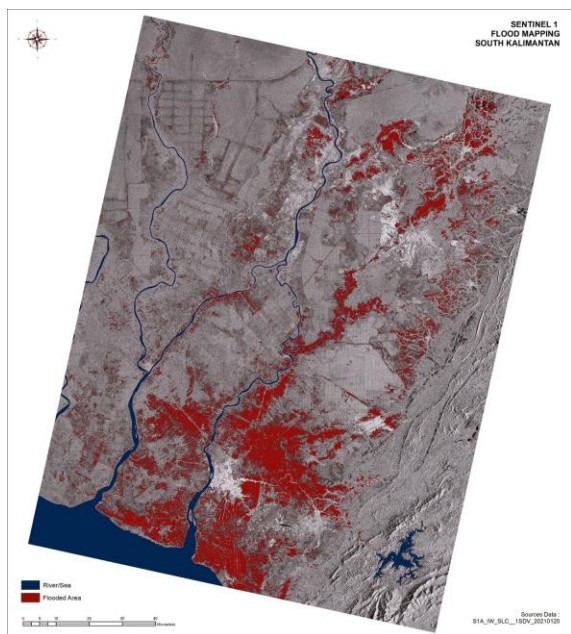


Figure 3 Satellite imagery of inundated area on January 20. Red, Blue, and Grey represent inundated area, water bodies, and dry area.

Note: Raw data were downloaded from Copernicus Sentinel (2021) and processed by Purwonegoro (2021) using Multi-Temporal SAR thresholding. Reprinted with permission.

interest (BIG 2021c). As an alternative, the tide predictions provided by BIG (BIG 2021b) and IHO (Deltares 2021) were used, which are publicly available. BIG data is a regional tide elevation prediction available hourly. Meanwhile, IHO data consists of tidal constituents and can be generated into elevations using DelftDashboard.

Precipitation

Precipitation analysis requires a consistent and continuous data over a long time, for example, > 10 years. Due to the limitation of the observation data, the predicted data such as modelling data or indirect observations (satellite) were needed. However, it is necessary to conduct a comparative analysis between the observed and predicted data to ensure the reliability of the predicted data (Fatkhuroyan 2019; Supari and Setiawan 2013).

BMKG Monitoring

BMKG or *Badan Meteorologi, Klimatologi, dan Geofisika* is an Indonesian government agency that focuses on and is responsible for meteorology, climatology, air quality and geophysics fields (BMKG 2021a). One of

the instruments is the precipitation monitoring station, which can be found at a meteorological or climatological station.

There are three publicly available monitoring stations in South Kalimantan, namely Syamsuddin Noor, Banjarbaru, and Gusti Syamsir Alam. Data for each station can be accessed on the BMKG portal (BMKG 2021a). Considering the study domain coverage, the data used are data from the first two stations, both located in Banjarbaru.

ERA5-Land Prediction (Model)

ERA5 or ECMWF Re-Analysis 5 is a global atmospheric model developed by the European Center for Medium-range Weather Forecast (ECMWF). ERA5_Land has 0.1 arc degree resolution. Hourly precipitation from 1981 to 2020 are available globally for the land region. Previous studies had shown that the ERA5-Land model is accurate and reliable (Tarek, Brissette, and Arsenault 2020).

TRMM Prediction (Satellite)

TRMM is the Tropical Rainfall Measuring Mission which is a joint collaboration between NASA and Japan's National Space Development Agency. TRMM covers the 50oN - 50oS region with a resolution of 0.25 arc degree and is available up to sub-daily intervals. TRMM data is publicly available with a user-friendly portal (Acker and Leptoukh 2007).

GPM Prediction (Satellite)

GPM (Global Precipitation Measurement Mission) is a continuation of TRMM, launched in February 2014, a collaboration between NASA and JAXA. Apart from being able to detect moderate and heavy rain, GPM is also capable of detecting light rain and snow. Data available from 2000 to 2020, smoother resolution, 0.1 arc degree per 30 minutes with coverage from 60oN - 60oS (NCAR 2017). GPM data can be accessed in Giovanni's portal at specific points, time frames, and intervals (Acker and Leptoukh 2007).

3 RESULTS

3.1 Topography Analysis

The topography of South Kalimantan is given in Figure 4, obtained from the DEMNAS dataset (BIG 2021a). In general, the topography is dominated by low-lying land (elevation < 7 m) with a presentation of 40.5%, and with 61.8% of a low slope (< 2%) (BPS Kalimantan Selatan 2021). There is a mountainous area in the middle with the highest elevation of 1,840 m surrounded by areas with low elevations, where most residential takes place.

The flood and evacuation points of the South Kalimantan Flood 2021 are given in Figure 4, obtained from (Kalsel 2021). Flood points were concentrated at the east of the mountainous area and

distribute from the North to the South of the province. Balai Hidrologi dan Lingkungan Keairan (2021) stated that flooding occurred in 10 cities within the Barito River Basin, where the inundation ranging from 50 to 347 cm. Detailed visualizations at 4 cities indicated in Figures 5 and 6 are provided, namely Banjarmasin, Tanah Laut, Banjar, and HSU.

Figure 5 presents the case for Banjarmasin and Tanah Laut. Banjarmasin is situated around 5 m above the MSL governed by several rivers, such as the Barito and Riam Kanan River. The inundation was around 50 cm, relatively low compared to other

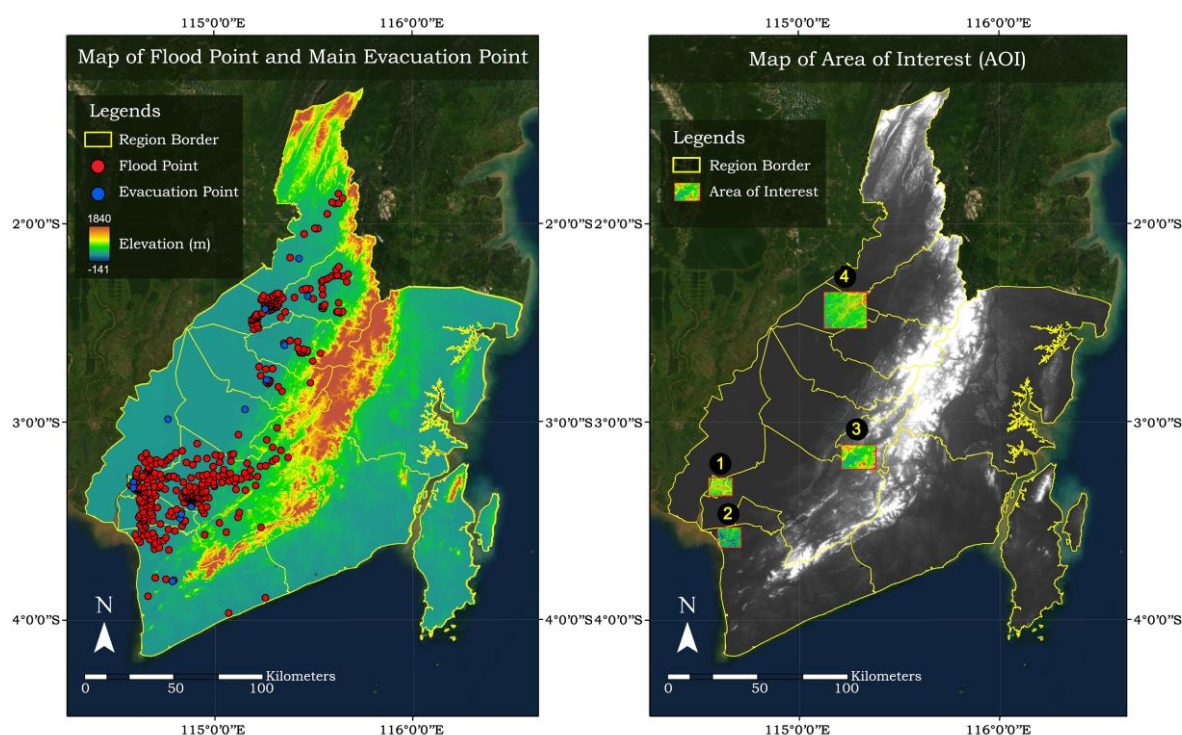


Figure 4 (Left) Flood and evacuation points and (Right) area of interest for detailed visuals.

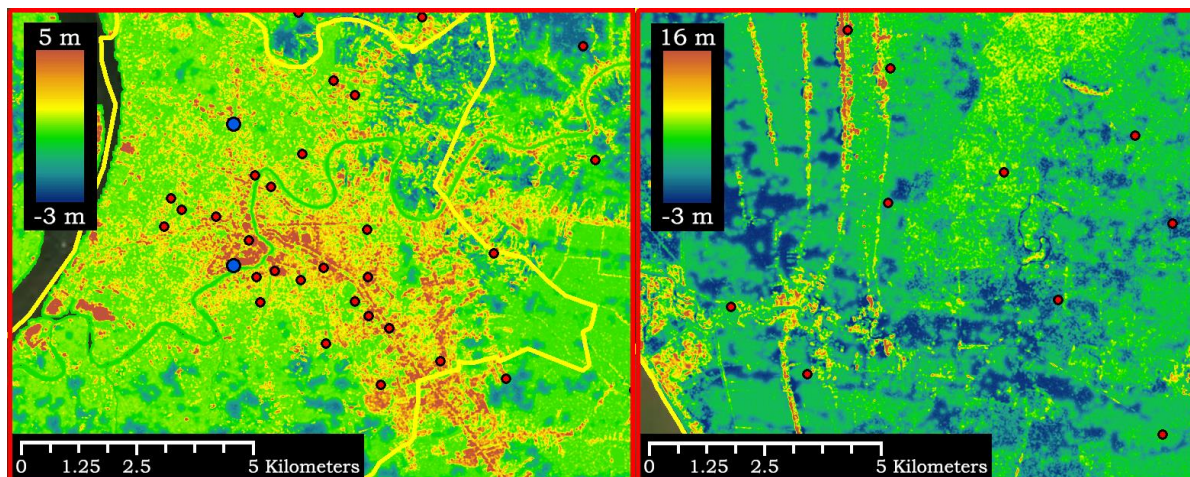


Figure 5 DEM, flood, and evacuation points (Left) Banjarmasin and (Right) Tanah Laut.

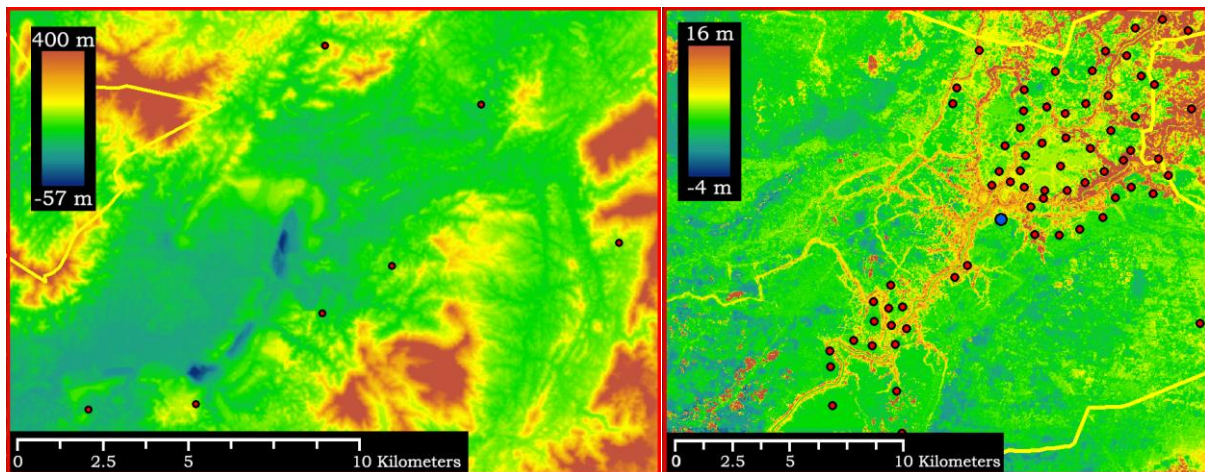


Figure 6 DEM, flood, and evacuation points (Left) Banjar and (Right) HSU.

areas. However, flooding occurred in densely populated areas, just around the main road and Riam Kanan River. In Tanah Laut, Bumi Makmur and Kurau Districts were observed located at an elevation of -3 to 16 m. This area is traversed by a river and most of the land use is rice farms. The depth of the flood reached 200 cm, found at rice farms and settlements.

Visualization of DEM and flood points for Banjar and HSU is given in Figure 6. Banjar also suffered a serious inundation. Some of the points shown in the image are flooded around 300 cm. This area is higher however located just downstream of the mountainous area. In the figure, several basins were observed with a depth of -57 m. HSU is a lowland area which the main district, Amuntai only 6 m altitude above MSL, although it is 150 km from the coast. This area is a confluence area for two large rivers originating from Balangan and Tabalong. Many flood points were scattered around the junction of the two rivers with inundation reaching a depth of 60 cm.

3.2 Tides Analysis

Four points were reviewed using both tidal data alternatives, as shown in

Table 3. The correlation between BIG and IHO predictions showed a positive value (> 0.92), however, BIG could not predict tides in Banjarmasin because it's inland. The IHO data revealed a formzhal value of 2.50 - 2.89 indicating a mixed mainly diurnal tide (Ko et al. 2018).

Considering the distance from the area of interest and the constituent adequacy, only Banjarmasin and Barito Entrance 1 were used to analyze the flood event. The tide elevation for the last 20 years was analyzed using ErgElv (open-ware for tide least-square analysis) and produced a tidal range of 2.73 and 2.93 m for each point, close to the value of the previous study (JICA 2010). Meanwhile, the Mean High-Water Spring (MHWS) values were 1.09 and 1.04 m respectively.

Furthermore, the tide in January 2021 was analyzed, the time series chart is given in Figure 7. The flood critical condition began to occur from January 13 at night and reached its peak on January 15. The graph shows that spring tide occurs during critical flood conditions. The peak elevations on the evening of January 15 reached 1.21 and 1.14 m in Banjarmasin and Muara Barito, exceeding the MHWS category.

Table 3 Details of tides points.

Points	Lat.	Long.	r ^a	Constituent ^b	Formzhal ^c
Banjarmasin	-3.3333	114.6000	-	K1, O1, P1, S1, M2, S2, N2, K2	2.53
Barito Entrance 1	-3.5667	114.4833	0.95	K1, O1, P1, Q1, S1, M2, S2, N2, K2	2.62
Tabanio	-3.7500	114.6000	0.99	K1, O1, P1, M2, S2	2.89
Barito Entrance 2	-3.5000	114.3333	0.92	K1, O1, P1, M2, S2, N2, K2	2.50

^a Correlation between IHO and BIG data from 1/1/2021 – 27/1/2021.

^b Available constituents at IHO dataset.

^c Computed based on IHO constituents.

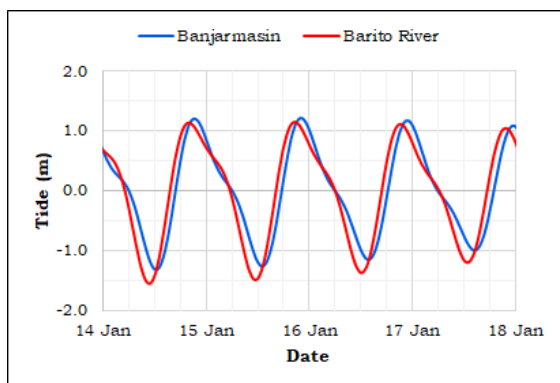


Figure 7 Tides around flood critical time.

3.3 Precipitation Analysis

Precipitation is said to be the main driver of the flood and will be analyzed extensively in this research (Balai Hidrologi dan Lingkungan Keairan 2021). The analysis aimed to identify how extreme the precipitation and to understand the behaviour of precipitation anomalies due to global phenomena, such as ENSO and IOD.

Comparison between Observed and Predicted Data

Signal detection theory (SDT) is used to determine the best data in detecting large rainfall events, especially from moderate to extreme categories ($R > 20$ mm/day). Meanwhile, the threshold used is the lower limit of heavy rain, which is 50 mm/day (BMKG 2021b). SDT was also performed to see the ability of prediction data to detect rainy days with a threshold of 1 mm/day. SDT defines the value of Hit (A), False Alarm (B), Correct Negative (C), and Miss (D) (Harvey et al. 1992).

The derived parameters based on SDT calculations are frequency bias (FBS), probability of detection (POD),

false alarm ratio (FAR), critical success index (CSI), and the Heidke skill score (HSS) which are calculated using the Equations 1 – 5.

$$FBS = \frac{A + B}{A + C} \quad (1)$$

$$POD = \frac{A}{A + C} \quad (2)$$

$$FAR = \frac{B}{A + B} \quad (3)$$

$$CSI = \frac{A}{A + B + C} \quad (4)$$

$$HSS = \frac{2(A \times D - B \times C)}{(A + C)(C + D)(A + B)(B + D)} \quad (5)$$

The calculated values are presented in Table 4. Generally, the daily precipitation prediction gave a low coefficient correlation (CC). The table shows that the predicted data tend to overestimate the frequency of rain events ($FBS > 1$), while the frequency of extreme rains (Table 4) tends to be underestimated ($FBS < 1$). The data ability to detect daily rainfall resulted in a fairly good value with a $POD > 0.72$. However, it is weak in detecting large precipitation ($POD < 0.31$). The HSS value had a low value.

In general, discrepancies between the observed and predicted data are seen. It is expected due to several factors, namely: differences in time zones, location of data points, and adequacy of observation data. TRMM was better for detecting rain events. However, in detecting heavy rainfall, the GPM performed well, by giving the best values for the CC, FBS, POD, CSI, and HSS

Table 4 SDT statistics for rain event and moderate rain testing.

Parameters	Rain event; Threshold > 1 mm				Moderate rain; Threshold > 50 mm			
	ERA5	TRMM	GPM	Corrected GPM	ERA5	TRMM	GPM	Corrected GPM
CC	0.384	0.494	0.603	0.597	0.014	0.246	0.324	0.316
FBS	1.469	1.000	1.214	0.993	0.006	0.262	0.373	0.390
POD	0.933	0.729	0.860	0.771	0.000	0.197	0.303	0.316
FAR	0.365	0.270	0.291	0.224	0.006	0.247	0.190	0.190
CSI	0.607	0.574	0.636	0.631	0.000	0.185	0.283	0.294
HSS	0.321	0.459	0.458	0.550	-0.012	0.210	0.338	0.348

parameters, and will be used in the extreme value analysis.

The predicted monthly precipitation provided a better correlation value than daily data. The CC data from ERA5, TRMM, and GPM were 0.803, 0.778, and 0.896. Hence, GPM will also be used in anomaly analysis.

The GPM data were then corrected to resemble the observed data. A correction factor (C) is applied which is determined based on Equation 6, where P_{O_i} and P_{P_i} are the i^{th} observed and predicted precipitation, respectively. The graph between C and monthly precipitation is given in Figure 8. The trend was divided into 3 regions, each of which applied a different correction factor governed by the regression equation, except for values above 123 mm. Statistically, the corrected data provided a satisfactory agreement to the observed data, with a correlation of 0.896. The detailed statistics for the corrected GPM data are given in Table 4.

$$C = \frac{P_{O_i}}{P_{P_i}} \quad (6)$$

Extreme Value Analysis

In mapping flood hazard, it is important to consider the extreme rain events. The World Meteorological Organization (2017) defines extreme precipitation as a value that exceeds the threshold set in a certain area and a

certain duration. In this study, the analysis aims to determine the extreme precipitation threshold for a certain return period (Tr) of 1, 2, 5, 10, and 25 years for each of the 13 cities in South Kalimantan. The spatial averaged daily precipitation of GPM data is used.

The extreme precipitation analysis was carried out by determining data distribution using four methods, namely the normal method, normal log, type I Gumbel. Further, the Log Pearson Type III method was employed once the analysis does not meet the requirements for the coefficient of skewness, kurtosis, and variation. Furthermore, the selected distribution was reviewed again with the suitability test using the Smirnov-Kolmogorov test. The outputs of the extreme value analysis are given in Table 5, given in daily and 3-days units (Gebremichael and Hossain 2010).

In the Tr 10 of the daily data, the smallest extreme rainfall is found in Kotabaru, 90.85 mm/day. Compared to the BMKG probabilistic standards, this value falls into the category of heavy rain (50 – 100 mm/day). BMKG defined extreme events as precipitation greater than 150 mm/day.

In general, the regions with the highest and smallest value at Tr 1 year are Barito Kuala (57 mm/day) and Tanah Bumbu (21 mm/day). For 3-days precipitation, Banjarbaru is accounted for the highest number (Tr 1 year = 105 mm/3 day). While Banjarmasin has the

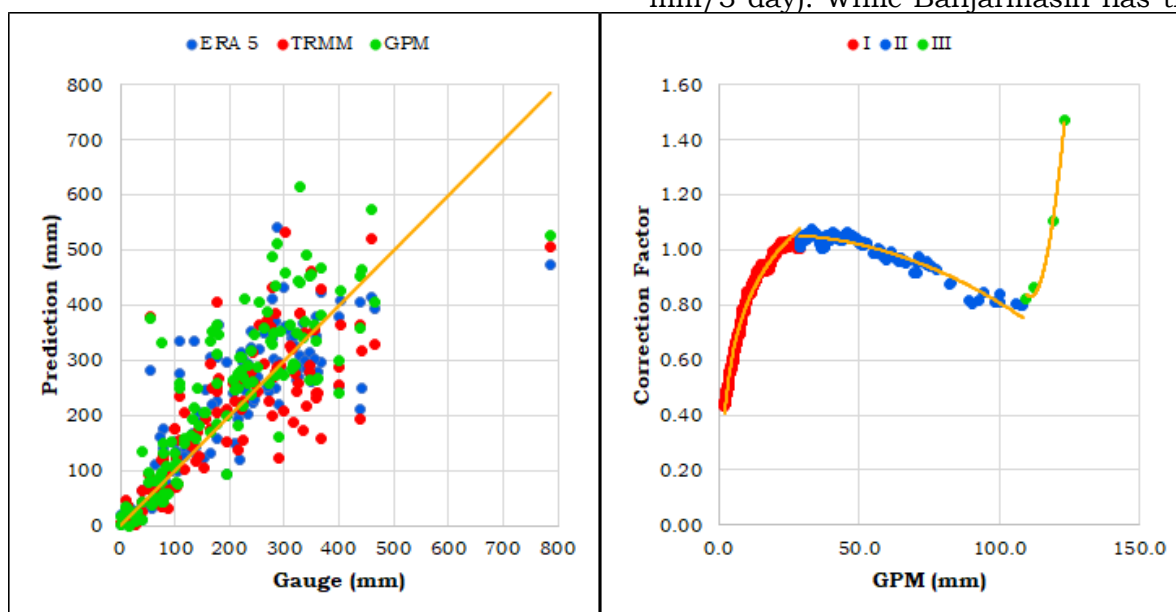


Figure 8 (Left) Scatters of comparison between Observed and ERA5, TRMM, and GPM data and (Right) range of correction factors application.

Table 5 Return periods (Tr) of precipitation at 13 cities.

No	Cities	Daily precipitation (mm/day)					3-days precipitation (mm/3 days)				
		1	2	5	10	25	1	2	5	10	25
1	Banjarmasin	39	102	159	206	279	89	144	195	237	302
2	Banjarbaru	36	127	172	198	227	105	165	204	232	269
3	Banjar	49	114	132	144	158	82	114	132	144	158
4	Tanah Laut	52	77	93	105	120	94	135	166	187	217
5	Barito Kuala	57	66	85	105	139	97	119	140	157	180
6	Tapin	46	81	118	149	202	85	135	173	201	241
7	HSS	40	96	135	164	205	78	136	176	204	241
8	HST	49	72	91	105	124	77	113	134	147	164
9	HSU	37	93	129	154	186	58	143	175	191	207
10	Balangan	42	71	96	116	145	57	112	143	163	188
11	Tabalong	30	66	89	104	124	35	109	136	149	161
12	Tanah Bumbu	21	70	94	108	123	46	119	148	163	179
13	Kotabaru	23	69	84	91	97	59	115	146	165	189

potential to experience the most extreme 3-days precipitation (Tr 25 years = 302 mm/3 day).

Anomaly Analysis

Anomaly analysis was conducted to characterize the trend of yearly precipitation. This analysis referred to the method proposed by WMO to determine climate normal, which is defined as the average of the climatological data calculated in long and continuous duration, ideally 30 years (World Meteorological Organization 2017). In this study, the sum parameter is analyzed to determine the annual precipitation anomaly, based on the obtained normal climate.

Previous analysis showed that the GPM was the closest to the observed data behaviour. However, the GPM data only covers the period between June 2000 and February 2021. This duration is not as ideal as the ERA5_Land data. However, in the WMO guidance, tolerance is given, namely for mean and sum analysis, 12 years of data are still

able to provide normal climate values close to ideal conditions, a period of 30 years (World Meteorological Organization 2017). Furthermore, spatially averaged data is employed with domains around x.

From the analysis, the climate normal (averaged yearly precipitation from 2001 – 2012) was 2,520.6 mm/year, only 5% lower compared to the climate normal of ERA5_Land 30-year data. The graph of the GPM anomaly from 2001 - 2020 is provided in Figure 9, where 2009 and 2010 were the years with the lowest (2,013.3 mm/year) and the highest value (3,399.1 mm/year). It was also observed that the precipitation anomaly fluctuated past the average value at the longest after three years.

4 DISCUSSIONS

4.1 Flood Mechanism

Table 6 presents the observation and GPM precipitation data at several locations in South Kalimantan in January 2021. At Banjarbaru station, 255.3 mm/day of precipitation was

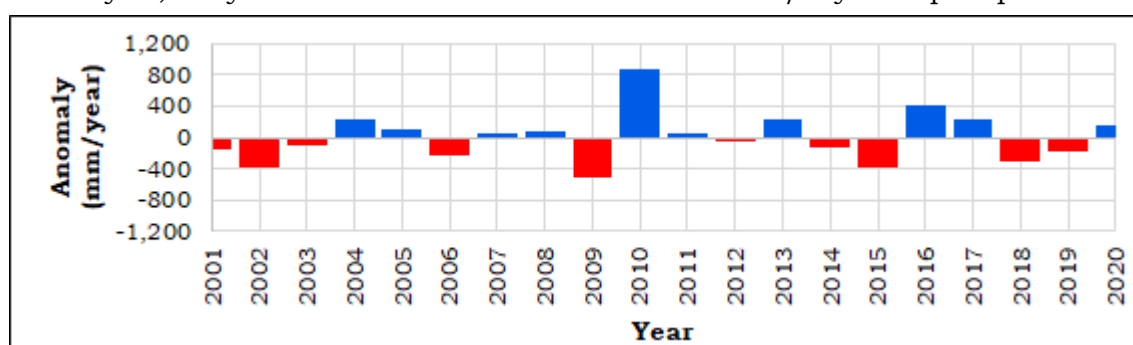


Figure 9 Precipitation anomalies at the highly inundated area from 2001 – 2020.

Table 6 Recorded and predicted precipitation at Banjarbaru, Balangan, and HSS.

Locations	Daily Precipitations (mm/day)									
	10	11	12	13	14	15	16	17	18	19
Banjarbaru	104.0	61.9	21.6	15.9	255.3	97.3	72.6	0.0	21.9	22.3
S. Noor, Banjarbaru	124.6	30.2	na	na	na	131.0	58.1	na	na	11.0
GPM Banjarbaru	17.9	35.6	15.9	70.7	49.2	26.3	1.2	13.2	5.3	0.8
Bihara, Balangan	0.0	1.0	9.0	49.0	32.0	na	na	na	na	na
GPM Balangan	3.1	1.9	1.5	37.7	15.5	21.8	3.7	2.7	11.4	0.3
Sei Langsat, HSS	116.0	75.0	51.0	157.0	36.0	na	na	na	na	na
GPM HSS	25.3	0.9	0.0	53.0	13.0	33.9	1.4	1.1	18.9	3.0

na : not available

recorded on 14 January, exceeding Tr 25 years. Meanwhile, the Syamsuddin Noor, Bihara, and Sei Langkat stations showed there were 4 days with precipitation exceeding Tr 2 years.

In addition, the maximum GPM precipitation of daily and 3-days during January 2021 was also analyzed. Daily data displayed a moderate range, with the largest value occurring at Barito Kuala Regency, 68.3 mm/day (Tr 2.3). For 3-days precipitation, the values in 12 cities were Tr 1 - 2 years. Meanwhile, Banjar experienced a Tr 9 years (141.5 mm). The rainfall intensity explains the severe flooding that occurred.

On the provincial scale, this series of rain events resulted in flooding in 11 cities. The direct impact given was a massive runoff flowing to areas with a dominantly low topography and gentle slope. Indirectly, the amount of water accumulation also caused the collapse of part of the retaining wall at Takisung Pond in Tanah Laut, inundated the surrounding area with depth up to 200 cm.

Meanwhile, the tides acted as a secondary driver, occurring simultaneously with extreme precipitation. This spring tide resulted in delays in the freshwater flushing, thus the flood held longer on the mainland (Ajiwibowo and Pratama 2020). With the predominantly diurnal type, twelve hours after the high tide, the tides will reach the peak ebb tide and provide a large flushing space. After 15 January, the high and low tide continued to decline until it reaches the neap tide on 22 January.

Based on the Sentinel satellite imagery in Figure 3, the inundations were often found close to rivers, for

instance, those in Banjarmasin, Banjar, Barito Kuala, and HSU. This is presumed to be due to excessive river discharge and lower elevation, further intensified by the possibility of flow obstruction due to flood debris. Previous studies had shown that debris reduced river cross-sections and causes water to overflow onto the banks (Wyźga et al. 2016). The material got carried by the flow and contained a great momentum, further resulting in a high hazard risk (Hajdukiewicz et al. 2016). As reported, two crucial bridges were collapsed, the Pabahanan (Tanah Laut) and Mataraman (Banjar) Bridges (AntaraKalsel 2021).

Future studies are recommended to scrutinize the flooding mechanism in more detail, using analytical calculations, field surveys, or numerical modelling. These studies are expected to identify the factor whose significance is yet to be known (Borga et al. 2010). In this case, the effects of land-use change (plantation and mining) are certainly important to be investigated.

4.2 Precipitation Anomaly

The compatibility test of the three predicted data showed that the GPM gave the smallest error. For daily data, GPM data cannot mimic the exact trend of extreme precipitation (Table 4). However, in monthly value, GPM provided a promising correlation value of 0.896. This error is due to the inaccuracy of satellite pinpoint to the monitoring station.

The analysis of GPM data from 2001 – 2020 indicated that the precipitation anomaly is influenced by global climate phenomena. Previous studies had underlined the significance of ENSO and IOD in Indonesia climate (Hidayat and

Ando 2018). ENSO or El Nino-Southern Oscillation and IOD or Indian Ocean Dipole are defined as the interaction between the sea and the atmosphere in the Pacific Ocean and the Indian Ocean.

ENSO consists of three conditions, namely El Nino, neutral, and La Nina. Meanwhile, IOD is categorized into positive, neutral, and negative IOD. The intensity of ENSO and IOD can be characterized based on the value of ONI (Oceanic Nino Index) and DMI (Dipole Mode Index) (BOM 2021; GGWS 2021), the values are publicly available (JAMSTEC 2021; Trenberth and NCAR 2020).

The larger positive anomalies were obtained in 2010, 2016, and 2017 where La Nina or Negative IOD occurred. Meanwhile, in 2002, 2009, 2015, and 2018 with El Nino or positive IOD conditions induced negative anomalies (Bramawanto and L. Sagala 2016). The biggest anomalies in 2009 and 2010 coincided with moderate El Nino and strong La Nina, respectively. Interestingly, with normal ENSO and IOD conditions, 2013 resulted in a significant positive anomaly.

Regarding the 2021 South Kalimantan Flood, the ONI value for October-November-December was recorded at -1.3 (Medium La Nina). Meanwhile, DMI for December and January were -0.17 and 0.21 (Normal). This figure tends to indicate a positive precipitation anomaly. In December 2020 alone, 10 rain events > 100 mm were recorded (Banjarbaru 2021).

Moreover, according to Table 6, the observed total precipitation during 10 – 19 January was 672.8 mm. This value doubles the monthly (30 days) average value in January from 2001 – 2020 using GPM data. Although, this comparison is not necessarily equivalent due to data type (site-specific and regional data); however, it is mentioned to demonstrates the severity of the occurred rainfall.

5 CONCLUSIONS

This study presented a description, chronology, as well as topographic, tidal, and precipitation analysis relevant to the 2021 South Kalimantan Flood. The precipitation reached the Tr 2 and 25 and lasted for 10 days, the total precipitation was 672.8 mm/10 days.

This rain coexisted with the spring tide, resulting in massive water accumulation at the low and sloping topography. Inundation is evident at the downstream and along Riam Kanan River in Banjarmasin, Martapura River in Banjar and Banjarbaru, and Amuntai District in HSU (150 km from the coast).

Furthermore, GPM data is reliable in predicting monthly precipitation. Analysis using 20 years of data indicated a correlation between precipitation and ENSO-IOD. La Nina and neutral IOD at the end of 2020 will be an early warning for the next extreme rain events in 2021. To increase local awareness, an early warning system and mitigation education are needed.

Numbers of community suspected that land use, particularly palm plantations and coal mining contributed significantly to this disaster, which is beyond the scope of this study. Thus, further studies are suggested to investigate the interaction between multiple aspects: such as hydrology, meteorology, climatology, oceanography, and land-use changes. The significance of each aspect is still in question and essential in determining disaster risk and designing flood resilience in the South Kalimantan.

ACKNOWLEDGEMENTS

Authors present gratitudes to the Indonesian and International agencies, those who made the data used in this research publicly available. Indonesia: BWS Kalimantan III, BMKG, BIG, BNPB, BPBD, BPS, and Hengki Purwonegoro. International: CDS, GSFC-NASA, IHO, and Sentinel. The authors also would like to express gratitude to the Journal Editorial Team and Reviewer for the valuable comments.

REFERENCES

- Acker, James G., and Gregory Leptoukh. 2007. 'Online Analysis Enhances Use of NASA Earth Science Data'. *Eos* 88 (2): 14–17. <https://doi.org/10.1029/2007EO020003>.
- Ajiwibowo, Harman, and Munawir Bintang Pratama. 2020. 'Hydrodynamic Changes Impacted by the Waterway Capital Dredging 9in Cikarang Bekasi Laut Channel, West Java,

- Indonesia'. *Water Practice and Technology* 15 (2): 450–59.
<https://doi.org/10.2166/wpt.2020.032>.
- AntaraKalsel. 2021. 'Severe Flooding Submerges Most of S Kalimantan, Road Cut off - ANTARA News Kalimantan Selatan'. Antara. 15 January 2021.
<https://kalsel.antaranews.com/berita/227572/severe-flooding-submerges-most-of-s-kalimantan-road-cut-off>.
- Balai Hidrologi dan Lingkungan Keairan. 2021. 'Laporan Analisis Bencana Banjir, Kabupaten Banjar, Kabupaten Tanah Laut, Kabupaten Balangan, Dan Kota Banjarmasin'. Bandung.
- Banjarbaru, BMKG. 2021. 'Buletin Iklim Kalimantan Selatan'. Banjarbaru.
- BIG. 2021a. 'DEMNAS'. BIG. 2021.
<http://tides.big.go.id/DEMNAS/index.html>.
- . 2021b. 'Online Tide Prediction/Prediksi Pasang Surut (Pasut) Online'. BIG. 2021.
<http://tides.big.go.id/pasut>.
- . 2021c. 'Realtime Tidal Observation/Pengamatan Pasang Surut Realtime'. BIG. 2021.
<http://tides.big.go.id:8888/dash/prov/Kalsel.html>.
- BMKG. 2021a. 'Data Online - Pusat Database - BMKG'. BMKG. 2021.
<https://dataonline.bmkg.go.id/home>.
- . 2021b. 'Probabilistik Curah Hujan 20 Mm (Tiap 24 Jam)'.
<https://www.bmkg.go.id/cuaca/probabilistik-curah-hujan.bmkg>.
- BNPB. 2021a. '[Update] - 10 Kabupaten/Kota Terdampak Banjir Di Kalimantan Selatan'. BNPB. 2021.
<https://bnpb.go.id/berita/-update-10-kabupaten-kota-terdampak-banjir-di-kalimantan-selatan>.
- . 2021b. 'Ribuan Rumah Warga Sejumlah Kabupaten Di Kalimantan Selatan Dilanda Banjir'. BNPB. 2021.
<https://bnpb.go.id/berita/Ribuan-Rumah-Warga-Sejumlah-Kabupaten-di-Kalimantan-Selatan-Dilanda-Banjir>.
- BOM. 2021. 'About ENSO and IOD Monitoring Graphs'. BOM. 2021.
<http://www.bom.gov.au/climate/ensoi/indices/about.shtml>.
- Borga, M., E. N. Anagnostou, G. Blöschl, and J. D. Creutin. 2010. 'Flash Floods: Observations and Analysis of Hydro-Meteorological Controls'. *Journal of Hydrology*.
<https://doi.org/10.1016/j.jhydrol.2010.07.048>.
- BPS Kalimantan Selatan. 2021. 'Badan Pusat Statistik Provinsi Kalimantan Selatan'. BPS Kalsel. 2021.
<https://kalsel.bps.go.id/statistictable>.
- Bramawanto, Rikha, and Sophia L. Sagala. 2016. 'Meteorological and Physical Conditions of Salt Pan Areas with Filtering-Threaded Technology (TUF) in Cirebon Regency, Indonesia'. *Jurnal Segara* 12 (2): 81–90.
<https://doi.org/10.15578/segara.v12i2.7678>.
- Copernicus Sentinel. 2021. 'Copernicus Open Access Hub'. Copernicus Sentinel. 2021.
<https://scihub.copernicus.eu/dhus/#/home>.
- Deltares. 2021. 'Tide Stations - Delft Dashboard - Deltares Public Wiki'. Deltares. 2021.
<https://publicwiki.deltares.nl/display/DDB/Tide+Stations>.
- Fatkhuroyan. 2019. 'Perbandingan Sebaran Curah Hujan Hasil Observasi Satelit GPM Dengan Model Cuaca WRF Studi Kasus: Siklon Tropis Cempaka Dan Dahlia, 27 Nov – 3 Des 2017'. In *Seminar Nasional Geomatika 2018: Penggunaan Dan Pengembangan Produk Informasi Geospasial Mendukung Daya Saing Nasional*, 1063–69.
- Gebremichael, Mekonnen, and Faisal Hossain. 2010. *Satellite Rainfall Applications for Surface Hydrology*. *Satellite Rainfall Applications for Surface Hydrology*. Springer Netherlands.
<https://doi.org/10.1007/978-90-481-2915-7>.
- GGWS. 2021. 'El Nino and La Nina Years and Intensities'. GGWS. 2021.
<https://ggweather.com/enso/oni.htm>.
- Hajdukiewicz, Hanna, Bartłomiej Wyzga, Paweł Mikuś, Joanna Zawiejska, and Artur Radecki-Pawlik. 2016. 'Impact of a Large Flood on Mountain River Habitats, Channel Morphology, and Valley Infrastructure'. *Geomorphology* 272 (November): 55–67.
<https://doi.org/10.1016/j.geomorph.2015.09.003>.
- Harvey, L. O., K. R. Hammond, C. M. Lusk, and E. F. Mross. 1992. 'The Application of Signal Detection Theory to Weather Forecasting

- Behavior'. *Monthly Weather Review* 120 (5): 863–83.
[https://doi.org/10.1175/1520-0493\(1992\)120<0863:TAOSDT>2.0.CO;2](https://doi.org/10.1175/1520-0493(1992)120<0863:TAOSDT>2.0.CO;2).
- Hidayat, Rahmat, and Kentaro Ando. 2018. 'Variabilitas Curah Hujan Indonesia Dan Hubungannya Dengan ENSO/IOD: Estimasi Menggunakan Data JRA-25/JCDAS'. *Agromet* 28 (1): 1.
<https://doi.org/10.29244/j.agromet.28.1.1-8>.
- IRDR. 2014. *Peril Classification And Hazard Glossary*. Beijing: IRDR Data Publication.
- JAMSTEC. 2021. 'JAMSTEC :: Visualization'. JAMSTEC. 2021.
<http://www.jamstec.go.jp/virtualearth/general/en/index.html>.
- JICA. 2010. 'The Study On Guidelines For Assessing Port Development Priorities Including Acceptable Performance Levels In ASEAN'. Tokyo.
- Kalsel, Geoportal. 2021. 'Geoservis Kalsel'. Geoportal Kalsel. 2021.
<http://geoservice.kalselprov.go.id>.
- KITLV 83630. 1928. 'Overstroomde Straten Te Barabai'. Kalimantan Selatan.
<http://hdl.handle.net/1887.1/item:774858>.
- Ko, Dong Hui, Shin Taek Jeong, Hong Yeon Cho, and Keum Seok Kang. 2018. 'Analysis on the Estimation Errors of the Lowest and Highest Astronomical Tides for the Southwestern 2.5 GW Offshore Wind Farm, Korea'. *International Journal of Naval Architecture and Ocean Engineering* 10 (1): 85–94.
<https://doi.org/10.1016/j.ijnaoe.2017.03.004>.
- Manalu, Arman. 2021. 'Mengkaji Penyebab Banjir Kalsel (Understanding the Driver of South Kalimantan Flood)'.
 NCAR. 2017. 'GPM: Global Precipitation Measurement Mission'. NCAR. 2017.
<https://climatedataguide.ucar.edu/climate-data/gpm-global-precipitation-measurement-mission>.
- Nurtyawan, Rian, and Nadia Fiscarina. 2020. 'Assessment of the Accuracy of Dem From Panchromatic Pleiades Imagery (Case Study: Bandung City, West Java)'. *International Journal of Remote Sensing and Earth Sciences (IJReSES)* 17 (1): 34.
<https://doi.org/10.30536/j.ijreses.2020.v17.a3329>.
- Purwonegoro, Hengki. 2021. 'Flood Mapping South Kalimantan'. LinkedIn. 2021.
https://www.linkedin.com/posts/hengki-purwonegoro-18242250_flood-mapping-south-kalimantan-activity-6762294784892788736-wzQK.
- Supari, and Nur Setiawan. 2013. 'Rainfall Variability Over Bangka Belitung Island Based On Validated TRMM Product'. *Jurnal Meteorologi Dan Geofisika* 14 (1).
 10.31172/jmg.v14i1.140.
- Tarek, Mostafa, François P. Brissette, and Richard Arsenault. 2020. 'Evaluation of the ERA5 Reanalysis as a Potential Reference Dataset for Hydrological Modelling over North America'. *Hydrology and Earth System Sciences* 24 (5): 2527–44.
<https://doi.org/10.5194/hess-24-2527-2020>.
- Tirto. 2021. 'Penyebab Banjir Kalsel Menurut Analisis LAPAN, Aktivistis, Dan KLHK'. Tirto. 2021.
<https://tirto.id/penyebab-banjir-kalsel-menurut-analisis-lapan-aktivis-dan-klhk-f9uk>.
- Trenberth, Kevin, and NCAR. 2020. 'The Climate Data Guide: Nino SST Indices (Nino 1+2, 3, 3.4, 4; ONI and TNI)'. NCAR. 2020.
<https://climatedataguide.ucar.edu/climate-data/nino-sst-indices-nino-12-3-34-4-oni-and-tni>.
- World Meteorological Organization. 2017. *Guidelines on the Calculation of Climate Normals*. WMO-No. 1203. 2017 editi. WMO. Geneva: WMO.
https://library.wmo.int/doc_num.php?explnum_id=4166.
- Wyźga, Bartłomiej, Zbigniew W. Kundzewicz, Virginia Ruiz-Villanueva, and Joanna Zawiejska. 2016. 'Flood Generation Mechanisms and Changes in Principal Drivers'. In *GeoPlanet: Earth and Planetary Sciences*, 0:55–75. Springer Verlag.
https://doi.org/10.1007/978-3-319-41923-7_4.