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Research Article

Impact of sand mining on the changes of morphological and physical dynamics in Sa'dang River, Pinrang District, Indonesia

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Abstract: The research aimed to investigate the morphological changes and physical dynamics conditions of the Sa'dang River associated with river sand mining activities. The research is expected to benefit the efforts of the management of sand mining in this area and enrich knowledge about the issues of river sand mining. The study was conducted in Sa'dang River sand mining area, which includes villages of Pincara, Massewwae and Mangki of Pinrang District in South Sulawesi Province, Indonesia. A field survey was conducted in October to December 2019 to see the condition of the river along with the mining activities that were taking place. Field data analysis was combined with google earth imagery data for 2006, 2014, 2017 and 2019 using ArcGIS 10.5 software to see changes in river morphology, formation and extent of point bar and channel bar, as well as changes in the area of river water bodies and non-water river bodies. The results showed that the changes in morphology and physical dynamics conditions of the Sa'dang River showed their own pattern. If sediment deposits forming point bars or channel bars were reduced, the area of river water bodies tended to increase. Or in other words, the width of the river is inversely proportional to the increase in the area of the river water body if the area of sediment deposits that form the point bar and channel bar tends to decrease.

Keywords: *production volume, replenishment rate, river sand, Sa'dang River, sand mining*

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Introduction

Sa'dang River is experiencing tremendous anthropogenic pressure in the form of sand mining activities. The number of miners continues to grow in the Sa'dang River sand mining area. In 2015 there were only 37 mining companies operating in the research area, but in 2019 increased to 80 mining companies. Increase number of miners is accompanied by an increase in the extraction of sediment. This number will continue to increase as market demand increases. Increasing in the number of mining companies and extraction of sediment can have an impact on changes morphology of Sa'dang River and important to be observed. Sosnowska (2020) argues that any morphological changes are very important and need close observation. Some other researchers also state that the physical impacts of sand mining that often occur, such as water quality degradation, destabilization of channel and river banks are important aspects that change due to this particular activity. Disruption of sediment supply, changes in channel shape and river depth. Downstream sedimentation, channel instability, sedimentation from mines in river basins and damage to public infrastructure are also negative impacts from these sand mining activities (Demetriades, 2007; Gunaratne, 2010; Ashraf et al., 2011; Kori and Mathada, 2012; Savior, 2012; Wang et al., 2012; Monica and Murthy, 2014).

In 2015, 37 mining companies did not have a business license to operate in the Sa'dang River Basin, with an area of 11,555 ha. The average of sand production volume reaches 40 m^3/day/miner, and the average of gravel production volume is 4 m^3/day/miner (OITEMR-Pinrang, 2015). Current condition estimated that the volume of extracted sand is around 2544.96 m^3/day or 890736 m^3/year. The volume will continue to grow in line with the need for sand as construction material (Hackney et al., 2020). UNEP report of 2014 estimated that sand and gravel are extracted each year globally with demand increasing, especially in developing countries (Bravard et al., 2013; Schandl et al., 2016; Prasad et al., 2016).

Extraction of large amounts of sediment accompanied increasing of number mining entrepreneurs susceptible to changes in morphology and dynamic physical conditions and how the patterns of morphology change and dynamic physical conditions of Sa'dang River. Therefore, this study aims to determine the impact of Sa'dang River sand mining on morphological changes and river dynamic physical conditions. In addition, this study also aims to determine the pattern of morphological changes and dynamic physical conditions of Sa'dang River. In order to know morphological changes and physical dynamics conditions of Sa'dang River and the pattern of these changes, the use of historical photographs and geographic information systems is very effective (Santo and Sanchez, 2002; Prasad et al., 2016).

Materials and Methods

The study was conducted in October to December 2019, covering research areas of the villages of Pincara, Massewwae and Mangki in The sub-district of Duampanua, Cempa and Patampanua of Pinrang District (Table 1 and Figure 1). Data on the number of miners was collected from each village office. Data of time-series imagery google earth in 2006, 2014, 2017, and 2019 using ArcGIS 10.5 were further analyzed to see changes in river morphology, formation and extent of point bars and channel bars, as well as changes in the area of river water bodies and river bodies. Use of historical aerial photographs and geographic information system serves as an effective tool of environmental analysis (Santo and Sanchez, 2002; Prasad et al., 2016).

A historical photo search on Google Earth shows that the photo of Sa'dang River in 2006 is the oldest photo recording we can find. Thus the year of 2006 became a reference to see the shape of morphology and physical dynamics conditions of Sa'dang River. Furthermore, as a comparison, historical photos in 2014, 2017 and 2019 are used. The use of historical photos in 2014, 2017 and 2019 provide a clear picture from Google Earth recording of Sa'dang River conditions in the study area, so it is used as a comparison.

In this type of river, sediment deposition is strong, due to erosion that occurs, in general, is weak, where vertical erosion is smaller than horizontal erosion, especially when floods occur so that river flows often move horizontally. We can observe this pattern of change by utilizing satellite data in geographical information systems, for example in environmental modelling, which utilizes this tool to model mining activities and the accompanying environmental impacts, such as changes in the direction of river flow and sediment patterns. Satellite data can provide a permanent and authentic record of the land use pattern of a particular area at any given time, which can be re-used for verification and re-assessment (Mitra and Singh, 2015).

The study area covers three villages, including the villages of Massewwae, Pincara, and Mangki. Lome and Bulu Kae are included in Massewwae Villiage. Masolo-Pincara is included in Pincara Village. Sali Salie. They are included in Mangki Village (Table 1). The selection of the study area was based on consideration of mining activities in three villages which were very massive. Based on data from the local village office in 2015 there were only 37 mining companies, but in 2017 it increased to 55, and in 2019 it became 80 companies.

Tabel 1. Study location and point.

Station	Latitude	Longitude	Location
SS1 – SS2	3°42'11.12"S - 3°42'9.29"S	119°37'39.50"E - 119°37'54.65"E	Lome
SS3 – SS4	3°42'17.25"S - 3°42'10.04"S	119°37'43.61"E - 119°38'7.04"E	Masolo
SS5 – SS6	3°42'15.41"S - 3°42'11.27"S	119°37'37.57"E - 119°37'22.49"E	Pincara
SS7 - SS8	3°42'10.47"S - 3°42'0.80"S	119°37'31.76"E - 119°37'18.69"E	Bulu Kae
SS6 – SS9	3°42'11.27"S - 3°42'5.50"S	119°37'22.49"E - 119°36'54.89"E	Sali Salie

Significant increase in mining activities in the three villages compared to other villages made it a research area. The three villages became research areas due to a significant increase in sand mining activities.

Results and Discussion

Physical characteristics of the Sa'dang River

The study area covers three villages, including the villages of Massewwae, Pincara, and Mangki. Lome and Bulu Kae are included in Massewwae Villiage. Masolo-Pincara is included in Pincara Village. Sali Salie is included in Mangki Village. The selection of the study area was based on consideration of mining activities in three villages which were very massive. Based on data from the local village office in 2015 there were only 37 mining companies, but in 2017 it increased to 55, and in 2019 it became 80 companies. Data presented in Table 2 show that critical potential of the Sa'dang River is the impact of upstream land use which results in high erosion rates. Related to this matter Gholap (2016) also reported that in general, it is noted that in a region where deforestation takes place, soil erosion becomes a serious problem which also gives rise to deposition of soil and silt in the channel.

Changes in morphology and physical dynamics in Sa'dang River in 2006

Data from 2006 shows the condition of the Sa'dang River with a smaller amount of water body compared to sedimentation, which forms point bars and channel bars. River curves in 2006 look sharper to form meandering where dominant sedimentary deposits occurred (Figure 1). Sediments deposited in 2006 are mostly located in Lome, Massewwae Village, between SS1 and SS2 station that forms a point bar, in SS6 - SSS9 station shown in Figure 2 that are included in Sali Salie, Pincara village which also forms point bars.

Table 2. Physical of Sa'dang River characteristics.

No	Sa'dang River characteristics	Sa'dang watershed	Source
1	Analysis of Sa'dang River morphology	Relatively straight flow direction US, steep slope, rectangular dendritic, moderate flow density (0.25 – 10 km/km²)	Final report on the preparation of Sa'dang River revitalization plan
2	Visual	Cross-section, quite wide (hundreds of meter), meandering downstream	
3	Erosion	High erosion rate, critical potential	
4	Sediment content/size	Sand / 37.475% >0.0063	
5	Min/Max debit analysis	Medium (range 35 -3000 m³/sec	

Source: Technical implementation unit of service Sa'dang Pinrang Watershed.

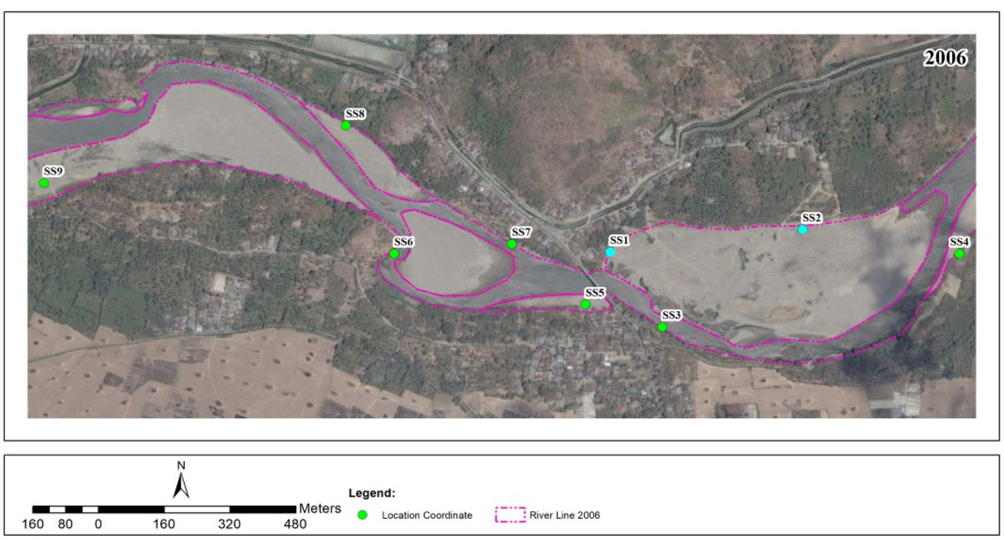

Figure 1. Areas of research condition in Sa'dang River 2006.

Sediments are more significant in those two areas due to the flow of water retained by the foot of the hill which is in the area result of water-borne sediments tend to precipitate formed point bar as it looks on the map. The formation of point bars in this area is a result of geological conditions (Chaiwongsaen et al., 2019). Sediment deposits are also found in SS8 station in the form of a point bar that is included in the area of Bulu Kae-Kaluppang hamlet, Massewwae village. In the SS5, SS6, SS7 station shown in Figure 4, on the middle of river, a channel bar is formed between villages of Pincara and Massewwae. In the SS2, SS3, SS4 station shown in Figure 2, that enters the Masolo village area also show sediment deposits in the form of point bars. This point bar approach is the formation of sediment deposits that are transported by streams and settles toward the outer arches of meander bends and are still affected by river geomorphic processes such as flooding, so-called floodplains (Morisawa, 1968). Based on Morisawa's view, the potential for the formation of point bars in the Sa'dang River flow is very large. This is caused by several factors, among others, Sa'dang River is a meandering-typed river which is a river that has many curves. Besides that, data from the Central office of Pompengan-Jeneberang river region in South Sulawesi (COPJRRSS) and Technical implementing unit of service Sa'dang Watershed (TIU-SSW) in 2015 indicated that the forest area that has become the Sa'dang River catchment area in the upstream area was mostly critical; this was what triggered high sedimentation in the Sa'dang River (COPJRSS and TIU-SSW, 2015). This shows that human activity causes changes in morphology and sediment of river sediments (Wang and Xu, 2017; Sosnowska, 2020). In related to that, Chaiwongsaen et al. (2019) argues that anthropogenic activities and geological conditions are the main factors responsible for these geometry changes of river.

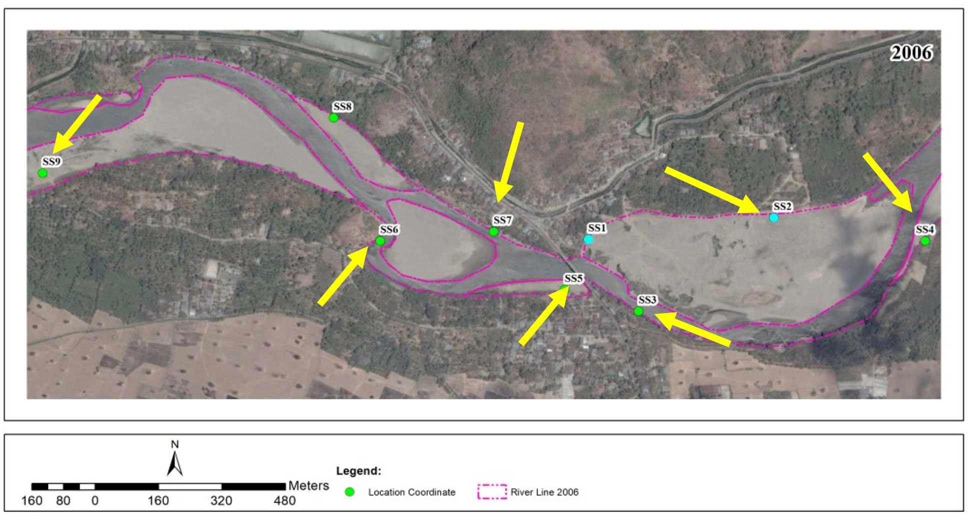

Figure 2. Station of SS2, SS3, SS4, SS5, SS6, SS7, SS9 in 2006.

The map of 2006 shows sediment deposits forming a point bar with an area of approximately 35 ha, as shown in Table 3. Sediments are mostly located on the north side of the river which is located in the hamlet of Lome, Massewwae village, Duampanua Sub-District. In addition to sediments that form a point bar, there are also sediments that form a channel bar with an area of approximately 4 ha (Table 3). This channel bar was formed from sand deposited by water and in the middle of the Sa'dang River. Sediment deposits that formed point bars and channel bars left a body of Sa'dang River water with an area of approximately 17 ha (Table 3) with the direction of flow tended to form the letter "S". Sediment deposits in 2006 covered an area that was still very large so that the area of the body of river water was only 43.59% and approximately 56.41% of the Sa'dang River area was sediment of sand. Thus a narrowing of river water bodies occurs more than 50 %. If the average depth of sediments is 3 m, the estimated size of the reserve volume of sediments of sand in 2006 amounted to 1.17 million m³.

Changes in 2014

Data of 2006 were the oldest Sa'dang River dataset that we could get from Google Earth, so the 2006 data became a reference in looking at changes in morphology and physical dynamics conditions of the Sa'dang River. The 2006 data were then compared with 2014 data to see changes in morphological shape and physical dynamics conditions of the Sa'dang River. Data on the area of river water bodies, the extent of point bars, and channel bars along with the accompanying changes are important to understand the extent of morphological changes and the dynamic physical conditions of the Sa'dang River from year to year. On the map (Figure 3), pink lines show the physical condition of the Sa'dang River in 2006, while blue lines describe the condition of the Sa'dang River in 2014. The 2014 map shows sediments which are mostly located in the Lome sub village of Massewwae village between SS1 and SS2 stations shown in Figure 3, forming point bar, reduced compared to 2006. The reduced sediment deposition in SS1 and SS2 station was caused by sand mining activities in the area.

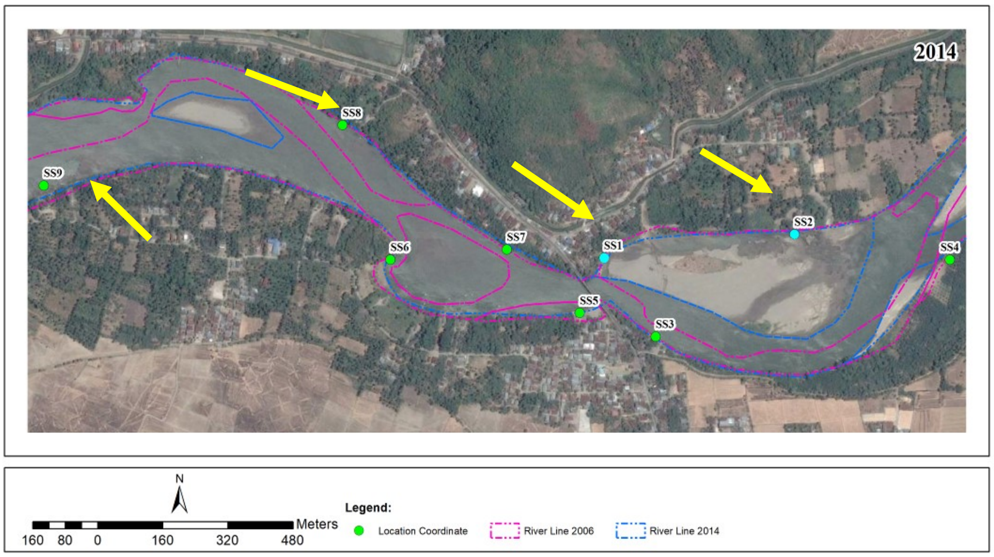

Figure 3. Station of SS1, SS2, SS8, SS9, in 2014.

In 2006 sediment point bar on SS9 station shown in Figure 3, that are included in Sali Salie Pincara village turned into a channel bar. While sediment deposits that were previously found in SS8 station shown in Figure 3 were included in Bulu Kae-Kaluppang, Massewwae village that based on 2014 data, they were lost and turned into river water bodies. Excessive mining of sediments in downstream disturbs the sediment transport and its show the sediment deficit in the downstream (Kamboj et al., 2018). In 2006 show that in the SS5 station of Pincara village there was sediment deposition forming a point bar. However, in 2014 the point bar was only left at the bottom of the Lasape bridge, where the location was not permitted for mining because it was feared that it would damage the foundation of the bridge. Sediments deposited on SS4 station in the Masolo village area also experienced a change in form compared to 2006. In 2006 sedimentary deposits formed channel bar between SS6 and SS7 stations or between Pincara and Massewwae villages. In 2014, the channel bar was lost altogether and re-formed a body of river water. This area is an area where massive sand mining activities take place that has an impact on morphological changes and sediment deposits. This shows that mining activity causes changes in morphology and sediment of river sediments (Gholap, 2016; Wang and Xu, 2017; Malawani et al., 2019; Sosnowska, 2020). Data for 2014 show that the area of a river water body or river water body is 39 ha, the area of the channel bar is 3 ha, and the area of the point bar is 13 ha (Table 3). When compared with 2006 data, in 2014 the river water body increased by 22 hectares compared to the river water body area in 2006 that was only 17 hectares. In 2014 the area of point bar decreased, namely the area of point bar in 2006 covering an area of 35 ha reduced to 13 ha. Thus a reduction in the area of the point bar amounted to 22 ha. In addition, the area of the channel bar also experienced a reduction in area, i.e. the area of the channel bar in 2006 of 4 ha was reduced to 3 ha in 2014. Data on changes in the area of river water bodies, point bars, and channel bars are listed in Table 3.

Table 3. Changes in the area of river water bodies, point bars and channel bars in 2014.

Year	River water body (ha)	Point Bar (ha)	Channel Bar (ha)
2006	17	35	4
2014	39	13	3
Change of extents	+22	-22	-1

Sa'dang River sand mining activity uses a machine to dredge sand sediments from the river which helps accelerate the reduction of point bar deposits in the area. Yuill et al. (2015) argued that mechanical dredging is commonly employed to excavate sandy material from submerged regions of the river channel bed and bars. Malawani et al. (2019) pointed out that mining activities continue on a large scale, causing sand to become deficit and rapidly changing river morphology and affecting slope stability. From 2006 to 2014, river water bodies accreting area of 129.4%, point the bar was reduced by 62.9%, and the channel bar was reduced by 25%.

Change in 2017

Data for 2017 show sediments were deposited on the north side of the river, i.e. on SS1 and SS2 stations (Figure 4) that tended to move to the south of the river SS3 station. Sediment deposition in the area around SS4 station (Figure 4), SS6, SS7, and SS8 stations (Figure 4), and SS9 station (Figure 4) was reduced and even disappeared. Data for 2017 show that the extent of the Sa'dang River water body was much broader with the direction of the flow tended to touch the entire river wall on the right and right sides. The area of the river body in 2017 was 51 ha with sediment deposits forming 3 ha of channel bar. In 2017 the formation of a point bar was not seen, but slowly a channel bar formed led to the south side of the river around the SS3 station entered the Pincara village area. The reduction in sediment deposits is accompanied by an increase in the area of river water bodies and changes in the direction of river flow. Green dotted lines show the physical condition of Sa'dang River in 2017.

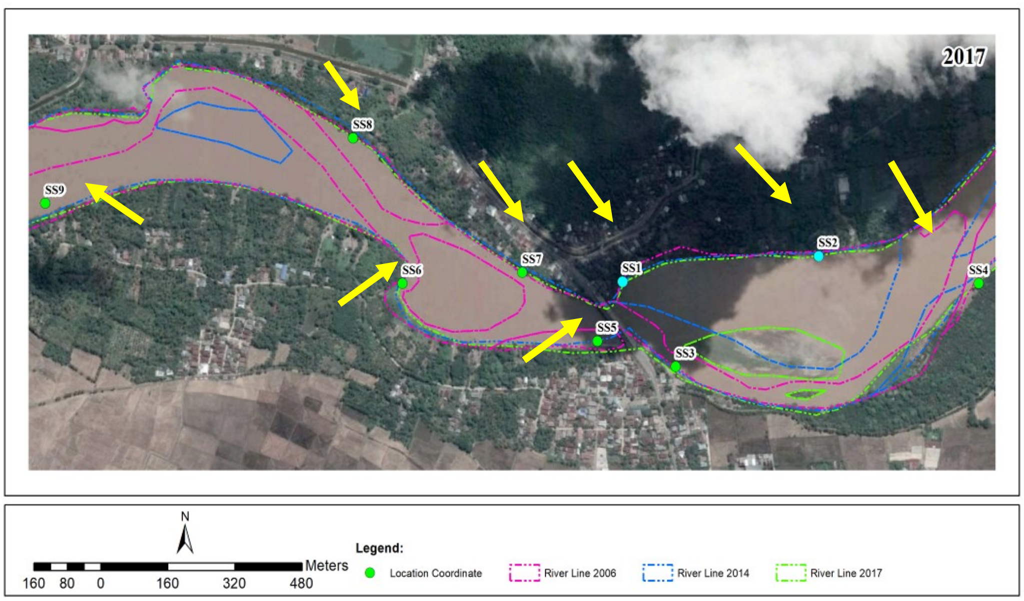

Figure 4. Station of SS1, SS2, SS4, SS6, SS7, SS8, SS9 in 2017.

On the 2017 condition map, there are three dotted lines with different colours showing the dynamic physical conditions of the river in different years. So the pattern of changes or physical dynamics of Sa'dang River based on the time span of 2006, 2014 and 2017 can be seen. Changes in the area of point bar, river water body and channel bar from 2014 to 2017 are listed in Table 4. The condition of river banks in 2017 experienced an increase in area at several points when compared to 2006 and 2014. The conditions in 2017 show that some areas had increased area on the river banks including, on the SS1, SS4, SS5 and SS6 stations as shown in Figure 4, or almost all of the Sa'dang River banks in the area of research has expanded widely. This means that there was a reduction in the width of the Sa'dang River as shown on the map in 2017. Thus, the physical dynamics of the Sa'dang River show that if sediment deposits that form the point bar or channel bar decrease. Islam et al. (2018) argued that the area of river water body increases, accompanied by a tendency to reduce the width of the river. Or in other words, the width of the river is inversely proportional to the increase in the area of the river water body if the area of sediment deposits that form the point bar and channel bar also decreases. The rise of mining activities causes the reduction of sediment deposits at several points. According to Zhang et al. (2019), the change of sediment load was dominated by human activities which caused approximately 80% of sediment reduction. Yuill et al. (2015) argued that dredging allows targeted removal of sediment from a borrow area while minimally disturbing the surrounding channel bed.

Table 4. Changes in the area of river water bodies, point bars and channel bars 2014 -2017.

Year	River water body (ha)	Point Bar (ha)	Channel Bar (ha)
2014	39	13	3
2017	51	0	3
Change of extents	+12	-13	0
%	+30.8	-100	0

Changes in 2019

On the map in 2019, there are four dashed lines with different colours. The pink dash shows the 2006 condition, the blue dash shows the 2014 conditions, the green dash indicates the 2017 condition, and the red dash shows the 2019 condition. We are giving different colours to indicate different years to provide information about the situation and condition of the physical dynamics of the Sa'dang River from 2006 to 2019. Thus, the map in 2019 collects all the conditions of the river physical dynamics and morphological changes in the Sa'dang River in 2006, 2014, 2017, and 2019. The condition of Sa'dang River in 2019 showed sediment deposition that formed the channel bar between SS3 and SS4 stations (Figure 5), which was more directed towards the south side of the river, as well as the point bar in the river curves between SS3 and SS4 stations that entered the Pincara village area of Patampanua Sub-District. The channel bar is formed as straight as or facing the point bar that existed in 2006 to 2014 on the north side of the river which is included in the Lome village, Massewwae village, Duampanua Sub-District. Channel bars formed between SS3 and SS4 stations began to be seen from 2017 with an area of around 3 ha, but in 2019 the area of the bar increased to 8 ha. Thus, an increase in the area of the channel bar by 5 ha or about 166.7%. In addition to the SS7 station formed a point bar where in previous years, sediment deposits at this point relatively did not occur (Figure 5.)

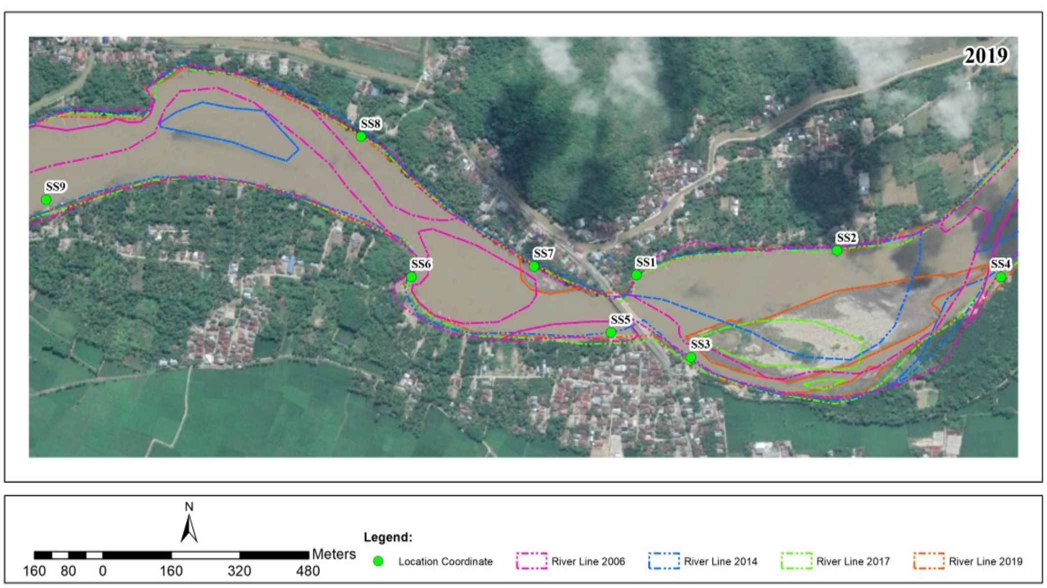

Figure 5. Station of SS3, SS4, SS7 stations in 2019.

Sa'dang River water body in 2019 covering an area of 44 ha and sedimentary deposits forming an 8 ha channel bar. A point bar was not formed in 2017, but in 2019 a point bar with an area of 1 ha was formed, namely on the SS7 station and in the inner river basin between SS3 and SS4 stations. Changes and reduction of sand sediment deposits in Sa'dang River are along with an increasing number of miners. In 2015 only 37 miners were operating in the study area, but in 2017 there was an increase in the number of miners by 48.6% or 18 mining businesses to 55 operating miners in the study area. This number continues to grow, where the number of miners operating reached 80 mining entrepreneurs in 2019.

Based on observation from Google Earth image, it can be seen that there were changes in the pattern of river flow and sediment deposition in Sa'dang River which takes place from year to year. Analysis of river's physical condition, especially changes in flow direction and river meandering due to mining activities based on time periods by utilizing geographic information systems (Sheela et al., 2018). Condition of Sa'dang River in 2016 is very different from the situation in 2019. There has been a considerable change morphology of the river. According to Buffington et al. (2012), rivers can exhibit a broad range of responses to changing in time scales from smallscale adjustment of channel characteristics (grain size, width, depth) to large-scale alteration of reach morphology. Figure 5 shows changes in river flow patterns between the year 2006, 2014, 2017 and 2019. Based on satellite imagery, in 2006 there were still sharp turns, after 2014, the turns tend to be increasingly sloping along with the growing river water bodies. By using remote sensing data, the management of Sa'dang River sand mining can provide a complete picture related to the changes in morphology and physical dynamics conditions of the river, based on time-series data. Google earth image data shows that river flow changes occur in places or areas where there are mining stations that are operating. This description is very helpful in the effort to manage sand mining in the Sa'dang River. Table 5 summarizes changes in the extent of river water bodies, point bars, and channel bars in 2006, 2014, 2017, 2019.

Data presented in Table 5 show that the condition of river water bodies with the lowest area is in 2006 which was 17 ha and the river water body with the highest area is in 2017 which was 51 ha. Sa'dang River point bar area is highest in 2006 with an area of 35 ha. Google Earth image in 2017 did not show the formation of point bar in the study area so that the area of point bar in 2017 was 0 ha. The area of the channel bar based on the lowest google earth image data seen in 2014 and 2017 is 3 ha, and the highest channel bar area in 2019 is 8 ha. Table 5 shows that the wider the sedimentary deposits that form the point bar and channel bar, the wider the river water body would be. In contrary, if the sediment deposits that form the point bar and channel bar decrease, the area of the river water body tends to increase.

Table 5. Compilation of extents of river water bodies, point bars, and channel bars.

Description	**Year**			
	2006	**2014**	**2017**	**2019**
River water body (ha)	17	39	51	44
Point Bar (ha)	35	13	0	1
Channel Bar (ha)	4	3	3	8

The reduced sediment deposition is caused by the increasingly widespread mining of sand in the Sa'dang River. River sediment extraction also triggers changes in river morphology, such as river bends (meandering), direction of flow, river width, and river depth. This was stated by Kondolf (1997), Luo et al. (2007) and Melton (2009), that the magnitude of the impact arising from sand mining in river flows depends on the amount of extraction relative to the sediment transport supply load.

Change in the shape of the river morphology along with physical dynamics' conditions of Sa'dang River based on time period data is strongly influenced by the increasing intensity of sand mining activities in Sa'dang River. The increasing number of miners contributed to change in morphology and physical dynamics of Sa'dang River. In addition, changes in production modes also affect changes in morphological shape and physical dynamics in Sa'dang River. Changes in river bed morphology due to sand mining activities cause changes in current patterns, and changes in current patterns also affect patterns of sediment movement. Therefore, anthropogenic factors such as sand mining activities an important thing in the change in river morphology (Ibisate et al., 2011; Wang and Xu, 2017; Chaiwongsaen et al., 2019; Sosnowska, 2020).

Using the analysis of the physical dynamics conditions of Sa'dang River based on google earth imagery, it can be explained that the morphological changes and physical dynamics of Sa'dang River showed their own patterns. If sediment deposits that form point bars or channel bars decrease, the area of river water bodies tends to increase accompanied by a tendency to reduce river width. Or in other words, the width of the river is inversely proportional to the increase in the area of the river water body if the area of sediment deposits that form the point bar and channel bar tends to decrease. Reduction of sediment in Sa'dang River is useful to control flooding. Thus, sand mining helps to restore the ecological function of the Sa'dang River in controlling and preventing flooding. Rinaldi et al. (2005) stated that exploitation of bed material from its channel might in some cases have beneficial effects for flood-control purposes, channel stability and restoration. Removal of material from a river can alter the channel, river hydraulics, or sediment budget, which in turn can alter the distribution of habitats and ecosystem functioning. These types of impacts can be difficult to attribute to sand mining, as they may require long time frames to emerge (Koehnken et al., 2020). Therefore, it is important to analyze time-series data in order to see the pattern of morphological changes over a long period.

Conclusion

The mining activities of Sa'dang River had an impact on morphological changes and dynamic physical conditions of Sa'dang River. Extraction of sand sediments from Sa'dang River in large quantities results in reduced sediment deposition and changes in flow patterns at several points. Morphological changes and physical dynamics conditions of Sa'dang River show their own patterns. If sediment deposits that form point bars or channel bars decrease, the area of river water bodies tends to increase accompanied by a tendency of the reduction in the river width. Or in other words, the width of the river is inversely proportional to the increase in the area of the river water body if the area of sediment deposits that form point bars and channel bars tends to decrease

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