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Geospatial Analysis for Delta Evolution of Jeneberang River in Makassar, South Sulawesi, Indonesia

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Abstract - This study aims to document and to elucidate the Jeneberang River delta evolution during 1922 -2022 by analyzing the transport of sediment in and out of the river through erosion and sedimentation. The method used is a geospatial analysis of the delta and river evolution using the Dutch map of 1922 and Landsat long-term data from 1972, 1981, 1991, 2000, 2010, 2020, and 2022 by dividing once every fifty to two years, so the delta pattern changes. The data collection was done by downloading data via Landsat, the data processing was simulated using ArcGIS software, and sedimentation and erosion were estimated. This study shows that the lowest sedimentation occurred in 2002 - 2004 with an area of 6.21 ha, and the highest one in 2004 - 2006 with an area of 34.99 ha. The lowest erosion occurred in 2014- 2016 with an area of 1.08 ha, and the highest in 2006 - 2008 with an area of 22.64 ha. The evolution of the delta occurred due to landform and river migrations. Landform migration occurs gradually starting with the direction of migration relative to the north to relative to the west resulting in the formation of a delta landform with an area of 5349.42 ha. Furthermore, the development of the landform no longer leads relatively north to west, but there is still sediment migration due to tides and sediment supply from rivers resulting in a delta landform with an area of 5586.56 ha. Then landform migration is derived from the river sedimentary supply stalled to the north because of water gate construction which caused the concentration of migration lead to the southern estuary. Tides then became a major factor in the migration, but were not as intensive as before with additional formation with an area of 5655.79 ha. The meandering changes or evolution of rivers occur naturally and are influenced by human activities. The emergence of changes is divided into five periods ranging from changes in the meandering direction to the south to the sedimentation and control of erosion with the construction of sluices and reclamation. Based on the study and by using the Galloway classification, Jeneberang delta is classified as an estuarine delta that is predominantly influenced by tides (tide-dominated) during its formation.

Keywords: Landsat imagery, delta evolution, Jeneberang River, tide-dominated, South Sulawesi

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INTRODUCTION

In Singh (1989) and Seybold *et al.* (2007), the word “delta” derived from the Greek can be defined as a coastal sedimentary deposit with each subaerial and subaqueous components. It is formed by river borne sediment which is deposited

at the edge of a standing water, like an ocean or sometimes a lake. The morphology and sedimentary sequences of a delta rely upon several factors such as the discharge regime, the sediment load of the river, and the relative magnitudes of tides, waves, and currents (Coleman, 1982). Moreover, the sediment grain length and the water intensity

at the depositional site are crucial for the shape of the deltaic deposition patterns (Coleman and Wright, 1975; Wright, 1985; Bhattacharya, 1992; Orton and Reading, 1993). This complex interplay of unique methods and conditions effects in a massive range of various patterns according to the local situations. Coleman and Wright (1973; 1975) described depositional facies in deltaic sediments, and concluded that they were resulted from a massive kind of interactive dynamic approaches (climate, hydrologic characteristics, wave power, and tidal movement) that modify and disperse the sediment transported by way of the river.

Erosion and sedimentation are two main processes that play an important role in the delta formation. Factors that affect erosion and sedimentation changes in the function of land cover from forest areas or green land to target areas influence the rate of erosion and sedimentation in the area, and cause inundation in the surrounding area which can also be called flooding (Seybold *et al.*, 2007; Alimin *et al.*, 2017; Negoro and Cholil, 2018). Another influencing factor is rainfall and the amount of runoff that has flowed in the watershed. In coastal areas, rivers and estuaries will never escape from the so-called sedimentation. Moreover, it is often to become an important issue, especially in the surrounding areas where there is human activity. Sedimentation is the process by which sediment is deposited, leading to its accumulation. The most common cause of deposition is the settling out of sediment from a transporting fluid (water, wind or ice) (Holden, 2017).

Jeneberang River delta is a land formed at the mouth of Jeneberang River located in the west of Makassar City with the length of 75 - 80 km. Jeneberang River is one of the major rivers in South Sulawesi with a dendritic pattern. The upper side of Jeneberang River reaches Mount Bawakaraeng in Gowa Regency, while the lower side reaches Makassar Strait (Whitten *et al.*, 1987; Sakka *et al.*, 2011). At the mouth of Jeneberang River, a delta is formed and constantly changes over time. Apart from being a catchment area, Jeneberang River delta area has intensively

developed since 2000 for settlements, business centres, and marine tourism. For the purpose of coastal management planning, a study on delta evolution is needed aiming to document and to record historical data on evolution of Jeneberang River delta. No comprehensive studies on this theme has been done before. This study is crucial to monitor and to manage the impact of the river and delta development. One of the methods to determine the delta evolution in the studied area is to calculate sedimentation and erosion using Landsat imageries to understand the landform migration, river pattern changes, and to classify the delta type.

Landsat satellite was chosen because this is the oldest one that is still operating today. Thus, data with long time series could be obtained. The need for satellite data over a long period of time is required to see changes that have occurred at the researched location.

DATA AND METHODOLOGY

This study took place in Jeneberang River delta, which is administratively included in to Makassar City, South Sulawesi Province, Indonesia (Figure 1). This study was performed by means of time series of Landsat imageries which were processed by ArcGIS software to calculate the erosion and sedimentation of fluvial materials in the Jeneberang River delta. Over the past forty years, remote sensing especially Landsat satellite imagery have improved studies on fluvial geomorphology. Some quantitative change detection methods identify objects, patterns, or phenomena, and observe their changes at different times (Singh, 1989; Lu *et al.*, 2004; Alesheikh *et al.*, 2007; Muskananfolo, 2020), which can be applied to time series of satellite imagery.

The data used in this study are images of 1922, 1922, 1972, 1981, 1991, 2000, 2010, 2020, and 2022, as well as rainfall data. (Table 1). Georeferencing Batavia mapping (scale 1: 50,000) was done using image georeferencing method. The Ground Control Point (GCP) was taken from the

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in Makassar, South Sulawesi, Indonesia (R. Langkoke)

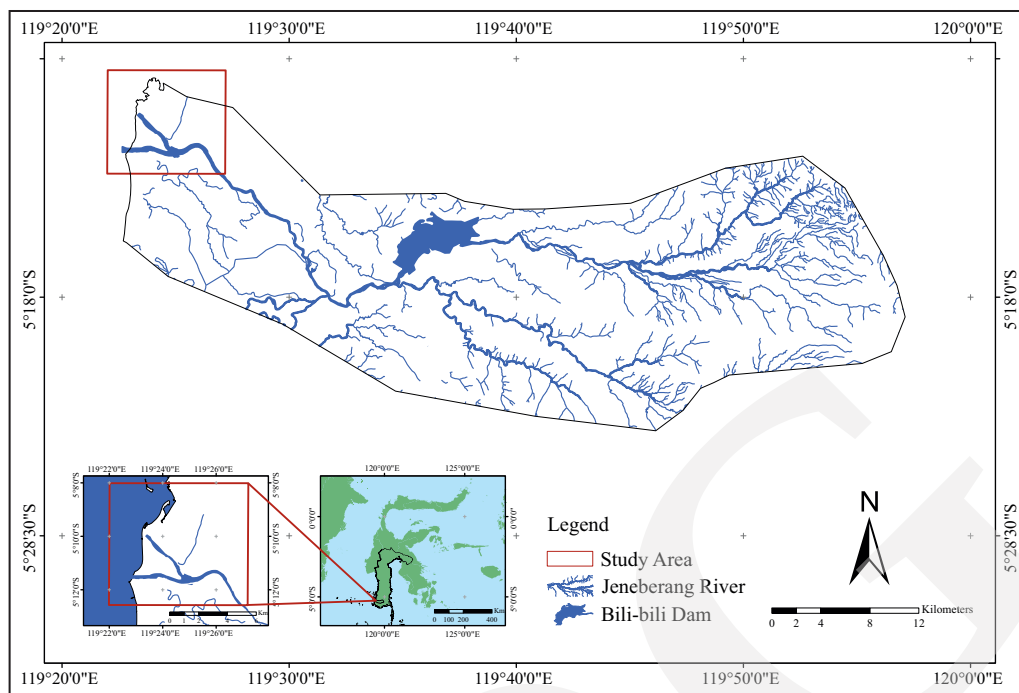


Figure 1. Location map of the studied area (red colour square), part of The Jeneberang River system (Source: RBI Map, modified by author).

Table 1. Data Type and Data Sources in this Study

Data	Acquisition time	Source	Resolution	Pansharpaned
1922 image map		Topography of Dienst (Batavia)		-
1972 image map	1972/09/04	Landsat 1 (Band 754)	60 m	-
1981 image map	1981/04/29	Landsat 2 (Band 754)	60 m	-
1991 image map	1991/09/22	Landsat 5 (Band 753)	30 m	15 m
2000 image map	2002/05/23	Landsat 7 (Band 743)	30 m	15 m
2010 image map	2010/04/11	Landsat 7 (Band 743)	30 m	15 m
2020 image map	2020/04/30	Landsat 8 (Band 754)	30 m	15 m
2022 image map	2022/09/11	Landsat 8 (Band 754)	30 m	15 m
Rainfall		Jeneberang Kampili River Station		

coordinates of the crossroads seen on the Landsat 8 satellite with a resolution of 3 m. Data collection was carried out by downloading data through Landsat and digitizing Jeneberang River delta using digitization tools available in the Google Earth Pro software, in the form of a feature line from the Google Earth Pro software having a kmz format, which is then converted to shp format using ArcMap from ArcGIS software Desktop 10.8. The limited data in this study caused the suboptimal digitization process of Landsat data, due

to the lack of existing qualified image. The delta landform is interpreted from Landsat imagery and verified through field observations by visiting the entire Jeneberang delta area and identifying landform in the area.

RESULTS AND DISCUSSION

Jeneberang River is located in Gowa Regency, South Sulawesi Province, Indonesia. It has a

length of about 80 km which flows from east to west, from Mount Bawakaraeng and Mount Lompobattang to Makassar Strait. Jeneberang River is the main river in the watershed. Physiographically, it is situated on the southern arm of Sulawesi Island, on the western slope of Mount Lompobattang Mountain range, a dormant strato-volcano-type. The geological conditions of Jeneberang River basin (watershed) are dominated by alluvium deposits of rivers, lakes, and beaches along the river flow. The alluvium deposits are sourced from Camba Formation which comprises marine and volcanic sedimentary rocks including breccias, lava, tuff, and konglongmerat, whereas Lompobattang Formation occupies the upper part of the river. Jeneberang River delta is influenced by marine and fluvial processes, including sedimentation and erosion of sedimentary material in Jeneberang River.

Stream Development in Jeneberang Watershed

In the development of stream from Jeneberang watershed, there are three river divisions based on characteristics and features, including (a) Young

stream with a gradual slope on Mount Bawakaraeng, (b) Mature stream with a medium slope at the Bili-Bili Dam, and (c) Old stream with a gentle slope to Jeneberang Estuary (Figure 2). Figure 2 also describes the characteristics and features of each types of Jeneberang stream development. The stream development is strongly controlled by several geological factors including lithological types and tectonics (Hirnawan, 2009). The extended description of each stream type is explained below.

a. Upstream/Young stream

The upstream area is located on the Mount Bawakaraeng. This area is the earliest part for the sediment supply to Jeneberang delta. Factors controlling the high rate of sedimentation and erosion includes high levels of rainfall, soil erodibility index, land slope, vegetation and soil management. The upstream area has the characteristics of a high slope of more than 55°, and has a high bedload causing erosion in the V-shaped upstream area. The material in the upstream area generally has lump sizes, composed of volcanic rock material

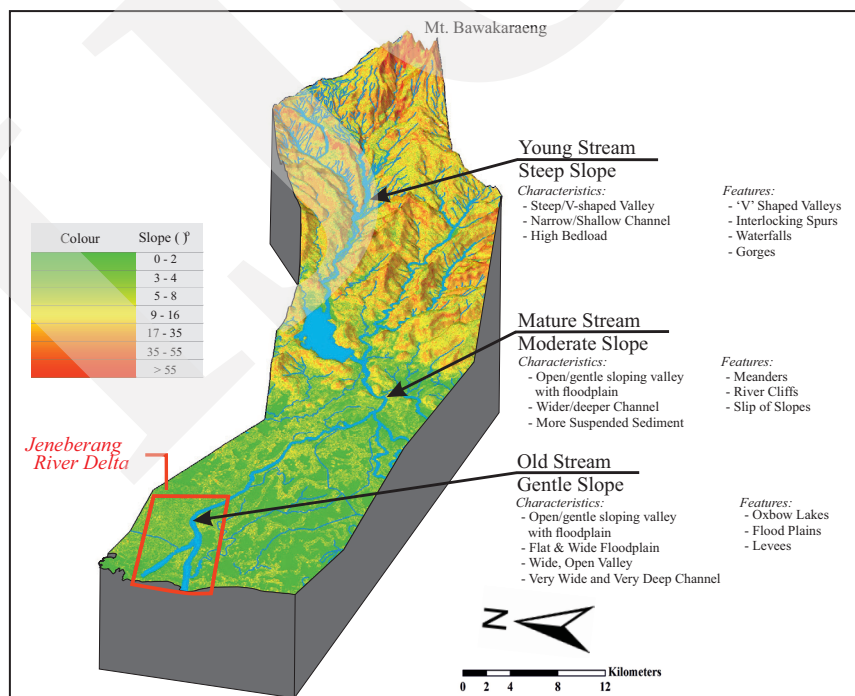


Figure 2. Stream development of the Jeneberang watershed (Source: DEMNAS, 2018, modified by author).

from Bawakaraeng Volcano. Aisyah (2022) estimated the amount of erosion in the upper Jeneberang watershed using the USLE equation in 2018 is 813.1 tons/m²/year with an average permissible erosion value of 28.9 tons/ha/year.

b. Middle flow/mature stream

In the middle flow, it has a slope with a range of 8 - 17°, and there is already a floodplain with material generally comprising sandy to gravel in size. The centre of the Jeneberang watershed is Bili-Bili Dam which was built with the aim at controlling floods, meeting irrigation water needs, providing raw water, and hydropower. The Bili-Bili Dam has a catchment area of 384.4 km² with a planned operating period of fifty years (Department of Public Works, 1989; JRBDP, 2004). Asrib *et al.* (2011) stated that there was a change in land use and also the occurrence of a caldera wall avalanche in 2004 which is the upstream of Jeneberang watershed with a sedimentary flow volume of 45,027,954 m³. The potential for sediment due to large enough avalanches will flow downstream if the rain intensity is high, so it is susceptible to high discharge concentrations.

c. Downstream/old stream

Downstream is the end part of Jeneberang watershed. In this part, a process of sedimentation, erosion, abrasion, and sediment migration occurs. The downstream area has a low slope with a range of 0 - 5°, so that the floodplain is wide. In addition, the material carried downstream is generally sand to clay in size. There is a delta in Jeneberang estuary that has undergone evolution caused by the sedimentation rate of Jeneberang watershed as well as tides dominated and waves from the sea.

Sedimentation and Erosion Analysis

By using satellite imagery data from 2000 - 2022 digitized on ArcMap 10.8, sedimentation and erosion data were obtained through changes (evolution) of rivers and deltas. The sedimentation and

erosion were then reviewed by comparing data from different years (Figure 3). The digitization of the image map displays the changes of the river patterns. The changes were then calculated in ArcMap 10.8 software to determine the area of sedimentation and erosion. The processed data is divided into periods with a longtime span, in 2000 - 2022. The supplied sediment in the river is mainly sourced from weathered rocks and soil from the upward part of the river (Omorinoye *et al.*, 2021).

Figures 3 and 4 show that the initial sedimentation occurred in 2000 - 2002 within an area of about 7.09 ha, then decreased and became the lowest sedimentation in 2002 - 2004 with an area of about 6.21 ha, and continued to increase to the highest in 2004 - 2006 with an area of about 34.99 ha. The highest sedimentation data in 2004 - 2006 coincide with the occurrence of landslide in the upper part of Jeneberang River in March 2004, which was due to the high rainfall in late 2003 to early 2004 (Table 2). This increased the supply of material in the downstream of Jeneberang River. The effect of sediment distribution is due to a large rainfall in November 2004 to February 2005 (Table 2). The rain caused avalanche material to be carried away, leading to the amount of water discharge to increase. The influence of Bili-bili Dam caused the sediment rate to stop and settle in the dam basin, so that the sedimentary material passing downstream of Jeneberang River was deposited over a large area of 34.99 ha. The sedimentation fluctuates until 2022, the highest after a landslide with an area of about 24.87 ha.

Erosion is not in harmony with sedimentation. The eroded area has increased and decreased. In 2000 - 2002, erosion area was of about 4.21 ha, then rose to the highest erosion in 2006 - 2008 with an area of approximately 22.64 ha. The erosion fluctuated in the next period until it reached the lowest erosion in 2014 - 2016 with an area of 1.08 ha. Until 2022, erosion has been occurred with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991, and 2000 - 2022 from Kampili station (Table 2).

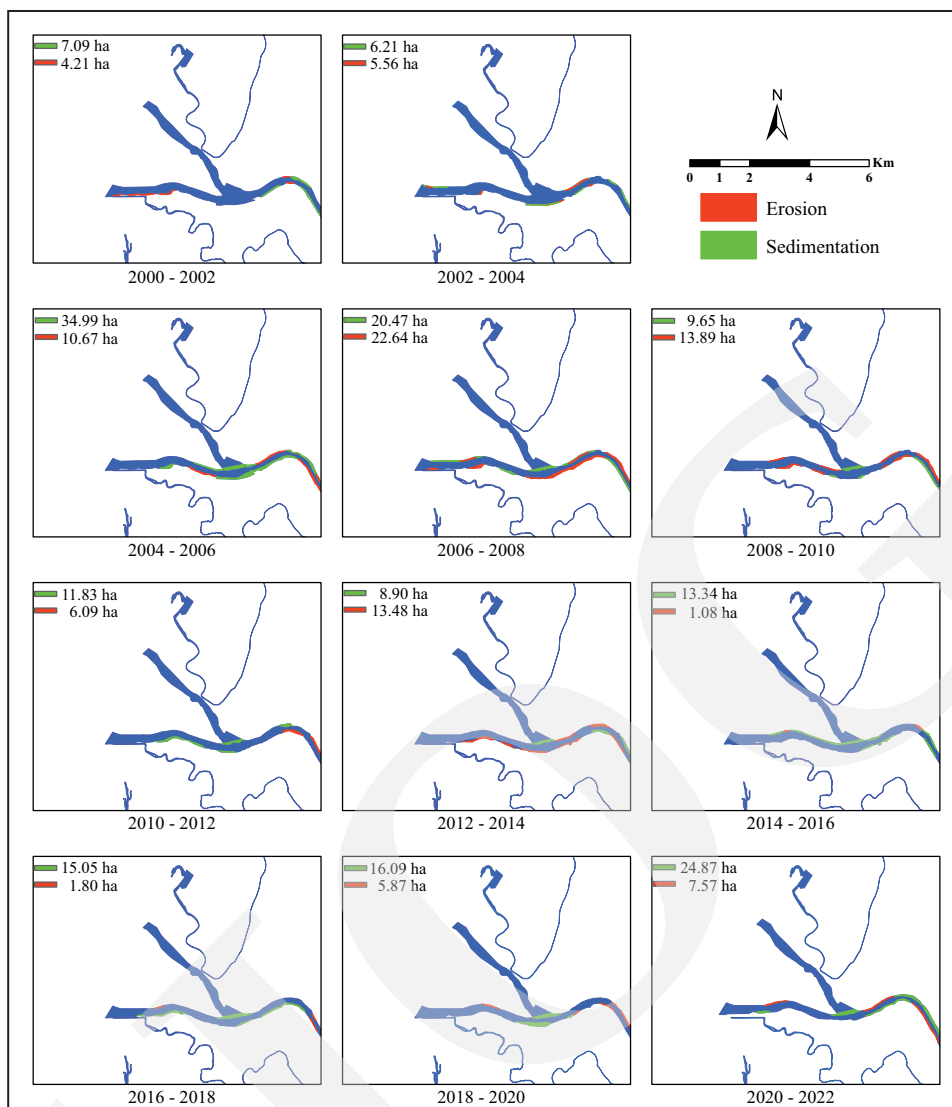


Figure 3. Sedimentation and erosion area of The Jeneberang River.

Delta Evolution of Jeneberang River Delta Landform Migration

The analysis evolution of Jeneberang delta used Landsat imagery data in 1922, 1972, 1981, 1991, 2000, 2010, 2020, and 2020. The data were processed using the ArcMap 10.8 using six colours classification of legend including land, sediment, river, water gate, jetties, and reclamation. It is obviously recognized that the delta pattern is significantly changed due to the influence of sediment supply from rivers and sea. The delta pattern changes are not only affected by the natural process of sedimentation, but are also influenced by human activities through delta reclamation (Figure 5). Based on the image data, the sediment

deposition and migration results of the Jeneberang delta landform area are tabulated in Table 3.

1922 - 1972 Period

The Landsat image (1922 - 1972; Figure 6) is the initial data of sediment migration during fifty years, with an area of about 5097.62 ha. The sediment migration occurred causing the delta develop relatively north to west with an area of 275.78 ha forming a delta with an area of 5373.40 ha in 1972 and forming a spit in the north (Figure 6).

1972 - 1981 Period

Sediment migration occurred from the beginning of 1972–1981 with an area of about 5373.40

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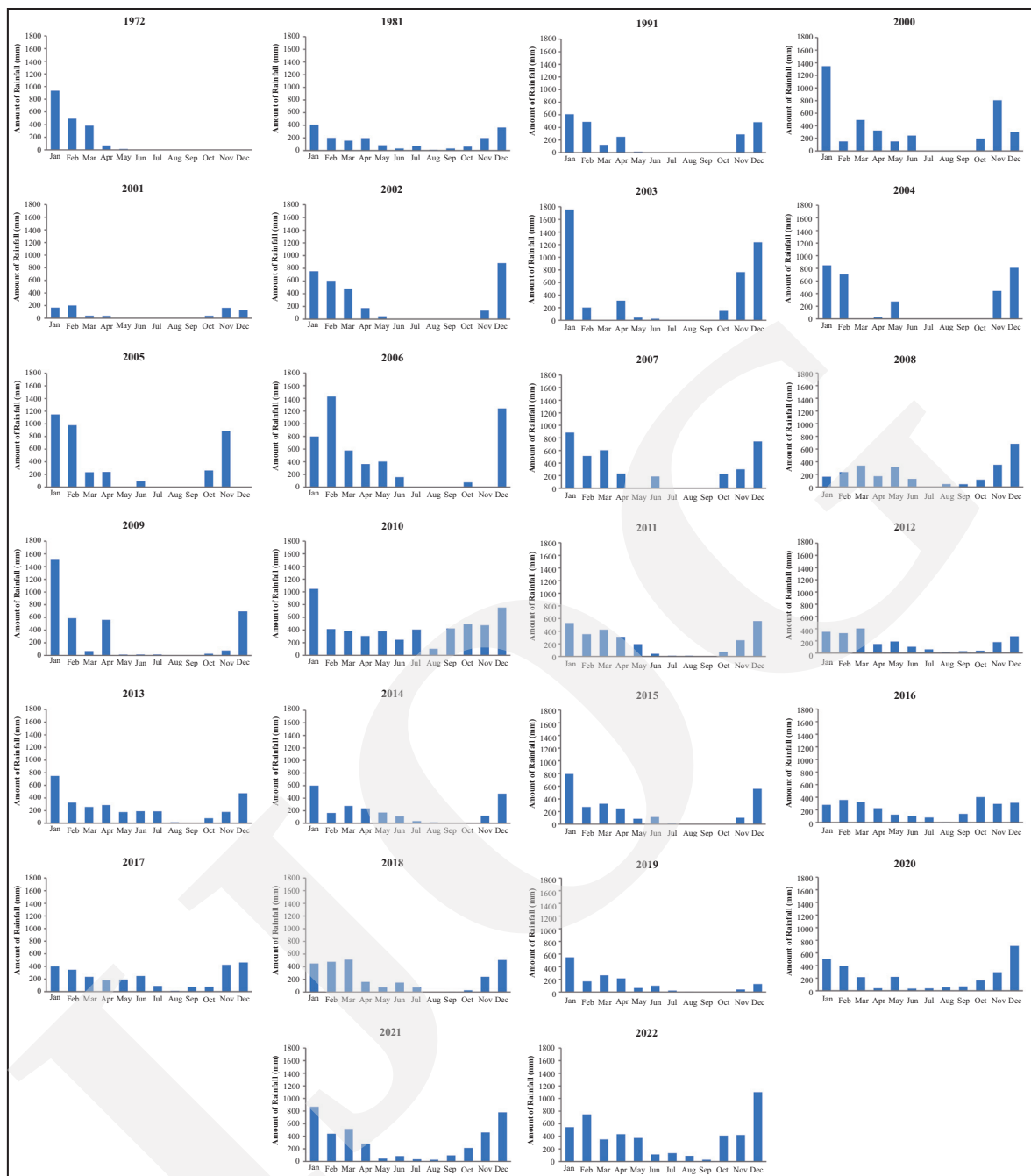


Figure 4. Rainfall diagram for Jeneberang Kampili River Station.

ha. The presence of migration occurred caused the delta still develop relatively to the north-west with an area of 23.98 ha forming a delta with an area of 5349.42 ha in 1981 (Figure 7).

1981 - 1991 Period

Sediment migration occurred in the period of 1981-1991 with an area of about 5349.42 ha. The occurrence of migrations caused by tides and sediment

supply from rivers with an area of 1.64 ha, formed a delta with an area of 5351.06 ha in 1991 (Figure 8).

1991 - 2000 Period

Sediment migration occurring in the period of 1991 - 2000 had an area of about 5351.06 ha. The migration caused by tides and sediment supply from rivers with an area of 235.5 ha, formed a delta with an area of 5586.56 ha in 2000 (Figure 9).

Table 2. Rainfall Data from Kampili Station of the Jeneberang River

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1972	935	494	383	69	15	0	0	0	0	0	0	0
1981	408	200	157	198	85	33	70	13	32	62	199	366
1991	609	489	123	251	15	0	0	0	0	0	289	483
2000	1348	151	493	325	151	244	0	0	0	199	806	298
2001	169	203	40	37	1	7	0	0	0	38	165	127
2002	754	605	481	175	46	0	0	0	0	0	136	883
2003	1758	202	0	312	45	25	0	0	0	150	765	1239
2004	849	706	0	24	276	0	0	0	0	0	443	808
2005	1150	978	234	240	0	91	0	0	0	262	888	0
2006	799	1429	578	364	404	158	0	0	0	75	0	1243
2007	886	514	605	232	0	188	0	0	0	228	301	746
2008	164	237	338	172	317	129	8	47	44	117	352	682
2009	1507	588	70	563	15	17	17	0	0	28	80	695
2010	1047	415	386	305	380	247	407	105	426	490	475	753
2011	530.91	352.73	425.15	311.36	196.67	44.34	13.11	13.78	6.3	74.37	256.61	560.65
2012	349.52	326.13	404.59	147.93	190.06	104.79	60.33	17.04	30.59	39.64	179.72	275.48
2013	749.79	329.17	258.08	288.08	177.58	191.84	188.47	14.95	8.01	78.84	178.9	476.15
2014	599.21	165.38	276.34	237.62	172.41	113.45	33.53	15.36	1.14	8.94	120.86	472.15
2015	792.8	272.52	322.46	247.82	85.62	113.81	13.49	3.42	4	3.85	99.6	558.67
2016	281.23	357.69	323.16	228.44	124.2	103.95	80.07	9.07	137	403.29	295.23	313.76
2017	402.58	349.19	234.99	181.3	193.52	248.64	89.84	14.22	77.25	77.8	426.38	462.8
2018	452.19	478.7	511.96	162.21	76.11	149.61	75.05	3.93	8.05	27.56	241.77	507.23
2019	549.55	169.29	264.58	217.43	65.35	101.57	24.04	8.68	6.43	1.38	42.04	127.49
2020	505	393	215	41	221	35	38	57	71	167	296	711
2021	869	440	518	285	46	84	34	27	96	215	462	781.5
2022	547.5	749	251	433.5	374	112.2	134	90.3	29	412	421.9	1103.1

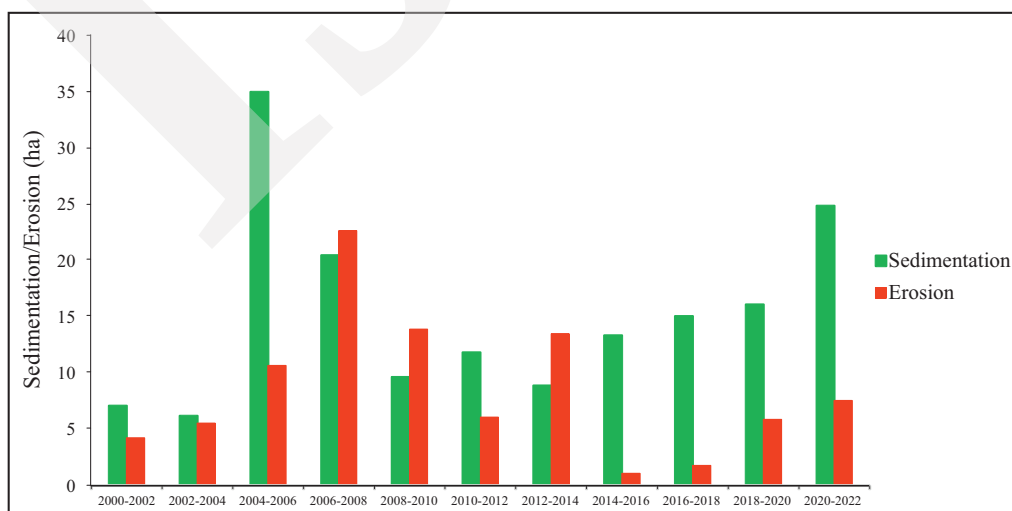


Figure 5. Histogram of sedimentation and erosion area of the Jeneberang River.

Table 3. Delta Landfrom Migration Data of the Jeneberang River

Year	Area (ha)	
	Sediment Deposited	Sediment Migrated
1922	5097.62	275.78
1972	5373.40	23.98
1981	5349.42	1.64
1991	5351.06	235.5
2000	5586.56	69.23
2022	5655.79	-
Cummulative	4370 4.97	635.93

2000 - 2022 Period

Sediment migration occurred in the 2000's period with an area of about 5586.56 ha. As a result of the construction of water gates in the northern estuary and jetties in the southern estuary, the sediment supply from the river stagnated. Therefore, the migration was caused only by tides with an area of 69.23 ha, forming a delta with an area of 5655.79 ha in 2022 (Figure 10).

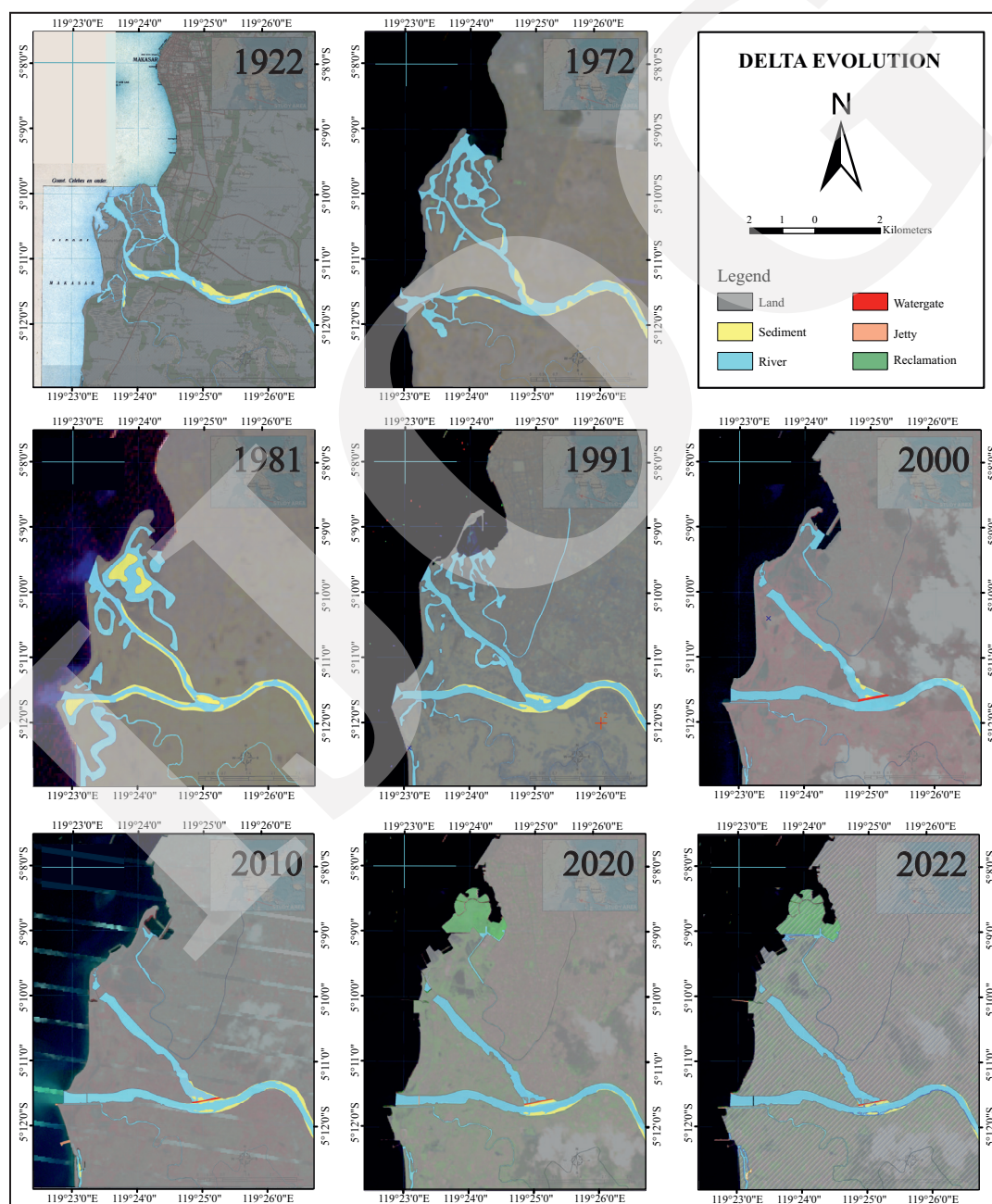


Figure 6. Delta evolution landform migration of The Janeberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022.

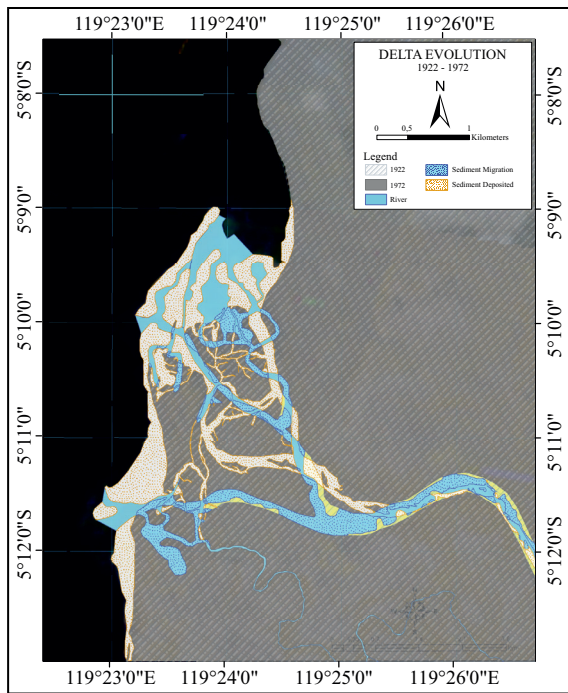


Figure 7. Delta evolution during 1922 - 1972.

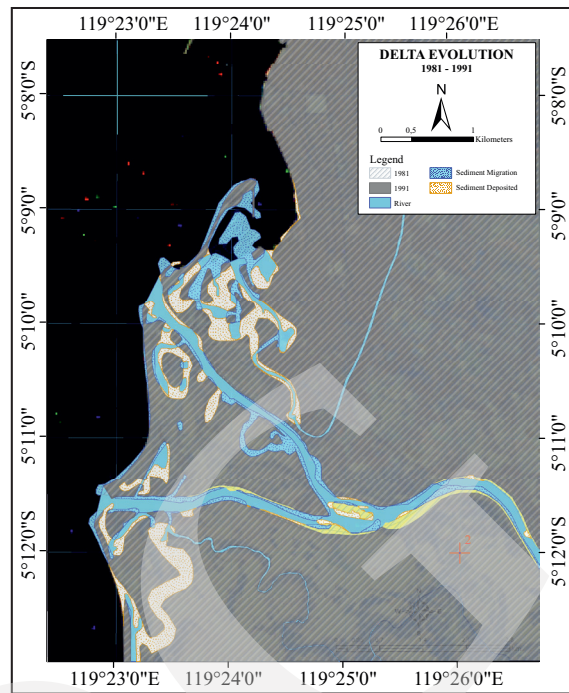


Figure 9. Delta evolution in 1981 - 1991.

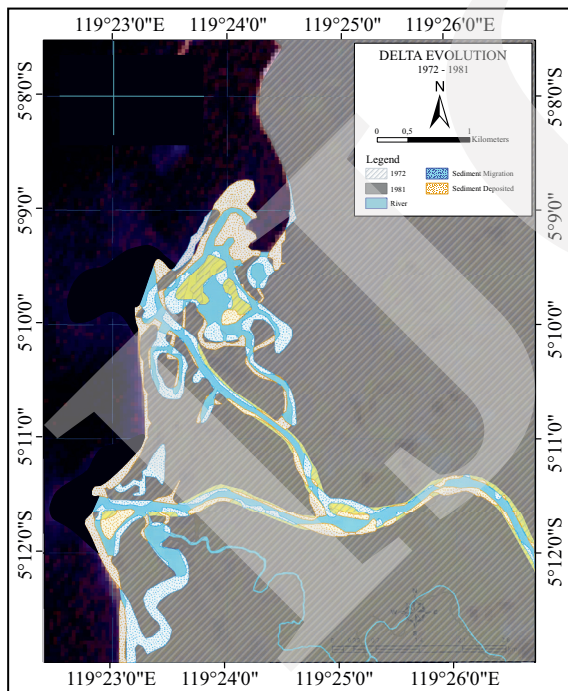


Figure 8. Delta evolution in 1972 - 1981.

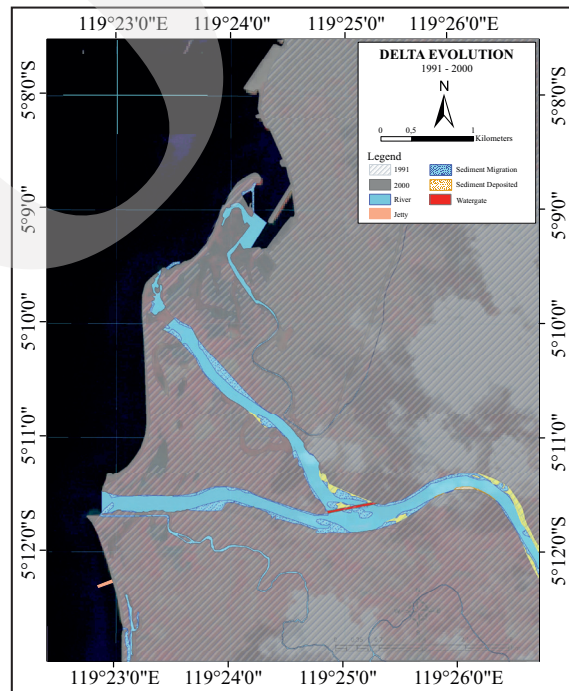


Figure 10. Delta evolution in 1991 - 2000.

Jeneberang River Migration Pattern

The significant evolution of Jeneberang River was observed in three periods, namely 1922 - 1972, 1981 - 1991, and 2000 - 2022. The data per year is then overlaid every two years as a

comparison of changes in the river model. The data used is then drawn in three colours: blue reflecting a river, green is a migration or change of the river, and red is the initial river (Figures 11 and 12).

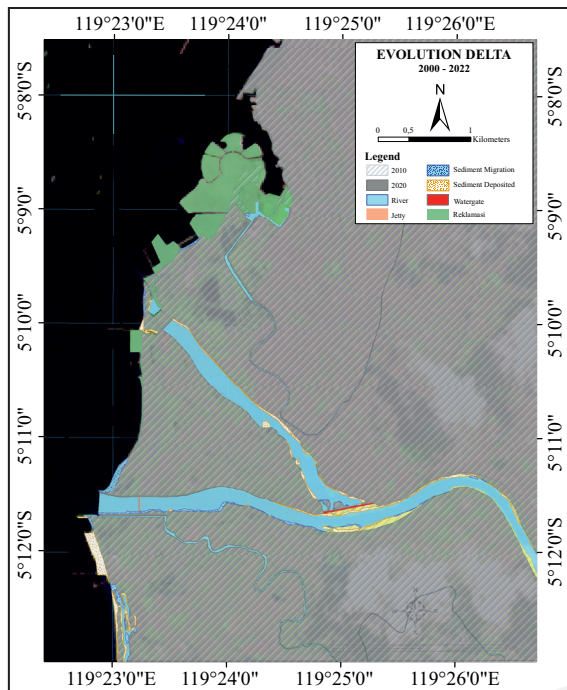


Figure 11. Delta evolution in 2000–2022.

1922 - 1972 Period

During 1922 - 1972 period, the Jeneberang River showed a significant change (evolution). In 1922 the direction of the river flow was towards the estuary relative to the north–northwest with the branching of the river in a relatively similar direction. The branching of the river, was in co-

ordinates of 119°25'0" S and 5°11'30" E for 300 m. Further significant changes were also seen in the northern estuary in 1922 where the direction of movement of the river underwent a displacement to the north with a displacement of 600 m. The change in the river branch also occurred in a westward direction relative to the west with a displacement from the beginning of the point as far as 450 m. In this period, the sedimentation is no longer dominantly concentrated to the north, which initially headed north in 1922 and in 1972 underwent a meandering turn, so that sedimentation and erosion were divided.

1972 - 1981 Period

During this period, no more sedimentation and erosion concentrated in one direction, causes not only the northern part undergo a change in the course of the river, but also the southern estuary. In 1972, in the northern part, there was the same river junction that went relatively north, but had a wider river on the western branch. In the southern part of the estuary, there were also branches of the river formed, and on the branches of the main river there are material deposits causing the river flow to divide and then reconnect in the northern part. In 1981, a canal was built in the northern

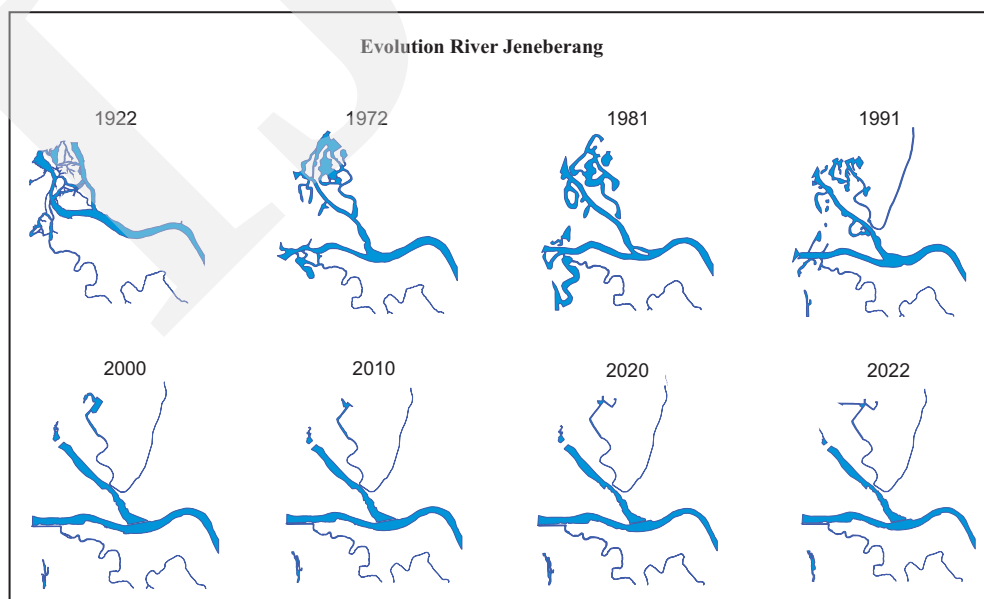


Figure 12. Evolution of the Jeneberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022.

part of the Jeneberang River separating the tributary from the main river, in order to control the direction of sedimentation and erosion, as a result of which the supply of sediment from the river decreased, causing part of the river become a swamp.

1981 - 1991 Period

The period 1981 - 1991, sedimentation and erosion were controlled relative to the southwest and no longer spread. In 1991, the existing river became narrower because it was covered with sediment turning part of it into a swamp. The southern part of the estuary also experienced a decrease in erosion, but there was an increase in sedimentation. In 1981, part of the river was covered with sediment.

1991 - 2000 Period

During this period, human activities seem to begin influencing the concentration of material sedimentation in Jeneberang delta. A tributary in the northern part was then separated from Jeneberang River with the construction of sluices at the river junction and the northern estuary.

The river was no longer going to north but was concentrated to the southern estuary. At the river junction, in 1995, a sluice was built, so the sedimentation from Jeneberang River was no longer to the north but to the south. It was seen in 1991 that the southern estuary that had previously branched in 2000 no longer exists.

2000 - 2022 Period

In this period, there was continuing human activity in the use of the northern part of the delta for development. This is done by reclaiming, so river erosion is strongly influenced by human. In the southern part, a pier was built to reduce erosion that caused the widening of the river, so that the sedimentation went directly to the sea and was no longer scattered.

Type of Jeneberang River Delta

Galloway (1975, in Bhattacharya, 1992) classified the delta according to dominated processes during its formation into three main types including: river-dominated, wave-dominated, and tide-dominated delta (Figure 13). On the basis of this study, Jeneberang River delta is character-

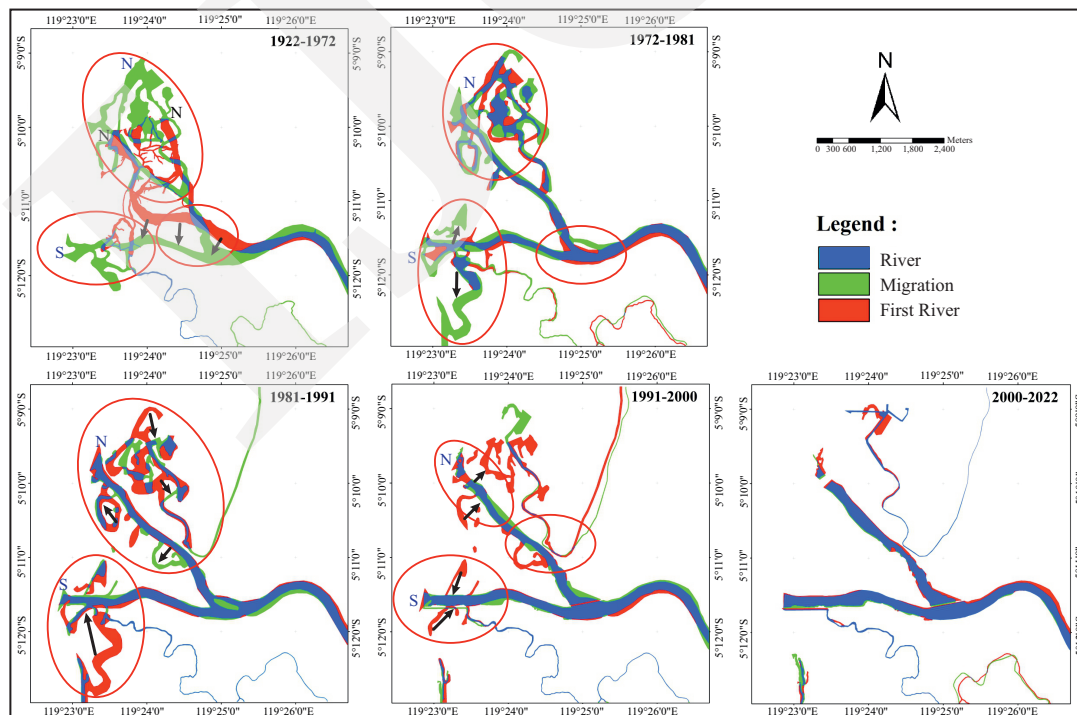
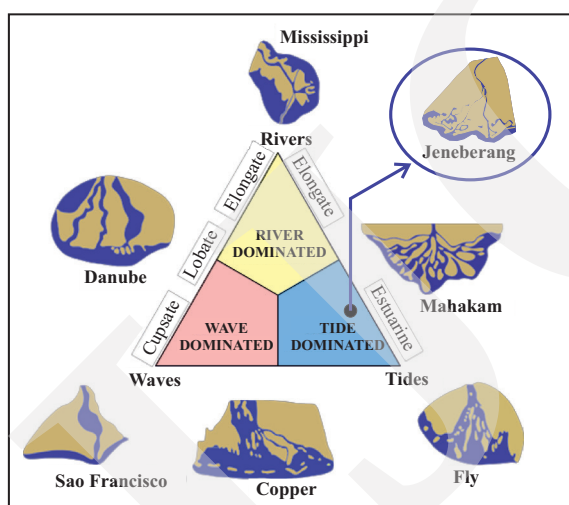


Figure 13. Migration and change of the Jeneberang River pattern from 1992–1972, 1981–1991, 1991–2000, to 2000–2022.

ized by the presence of deposit (sediment) in front of the river mouth, which becomes to be one of diagnostic indications for the role of tide current for the formation of the delta. This condition is obviously recorded during the periods of 1922 - 1981. The sediment occurring in front of the river mouth was commonly typified by fine-grained sand to clay, which also coincided with the previous studies conducted by Bhattacharya (1992), Orton and Reading (1993), and Wright (1985) in other deltas. Moreover, the existence of Tanjung Bunga spit in the northern part supports this phenomenon (Langkoke, 2011). Based on the mentioned characteristics, the delta of Jeneberang River is categorized into an estuarine pattern, which is predominantly formed by tide currents. Therefore, the delta of Jeneberang River is classified as *tide-dominated delta* (Figure 14; modified from Galloway, 1975, in Bhattacharya, 1992).



Gambar 14. Jeneberang River delta classified into tide-dominated/estuarine type (modified from Galloway, 1975; in Bhattacharya, 1992).

CONCLUSIONS

This study indicates that the Jeneberang River delta is very dynamic and underwent pattern evolution over the periods. The delta evolution is strongly controlled by sedimentation and erosion factors. The Landsat imagery analysis by using ArcGIS software reveals that the lowest

sedimentation occurred in 2002 - 2004 with an area of 6.21 ha and the highest in 2004 - 2006 with an area of 34.99 ha. The lowest erosion occurred in 2014 - 2016 with an area of 1.08 ha and the highest in 2006 - 2008 with an area of 22.64 ha. The evolution of the Jeneberang delta is due to landform and river migration. The landform migration occurred gradually starting in 1922 - 1981, where the direction of migration is relative to west and resulted in a delta landform formation with an area of 5349.42 ha. In 1981 - 2000, the development of landform no longer occurred, but sediment migration was still happening due to tides and sediment supply from the river resulting in a delta landform with an area of 5586.56 ha. In 2000 - 2022, landform migration originating from river sediment supplies was stalled to the north due to water gate construction which led to migration concentrations leading to the southern estuary. Tides became the major factor in sediment migration, although the tides roles were not that intensive as before with additional delta formation with an area of 5655.79 ha.

The Jeneberang River evolution occurs naturally and is influenced by human activities. The river evolution occurred into several periods, started from the river meandering to the south, until the sedimentation and erosion controls by the construction of sluices and reclamation. On the basis of Galloway classification, the Jeneberang River delta is categorized into an estuarine delta, which is predominantly influenced by tides during its formation.

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