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1. Manuscript Submission

Paper Submission

R

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Sab, 18 Februari, 12.39

kepada IJOG

Dear Editor-In-Chief of IJOG,

Herewith attached, we would like to submit our manuscript entitled " **Geospasial Analysis for Delta Evolution of Jeneberang River in Makassar, South Sulawesi, Indonesia".**
Thank you for your kind support. We are looking forward to hearing from you.

Sincerely,
Rohaya Langkoke

STATEMENT OF AUTHORSHIP

I am enclosing herewith a manuscript entitled "**Geospasial Analysis for Delta Evolution of Jeneberang River in Makassar, South Sulawesi, Indonesia"** for publication in Indonesian Journal on Geoscience for possible evaluation. The Corresponding author of this manuscript is "**Rohaya Langkoke**" and contribution of the authors as mentioned below with their responsibility in the research. The authors in the order of contribution and indicate corresponding author using an asterisk (*) at the end of the name. This paper has never been published and is not in the process of being published by any journal.

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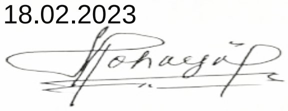

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Geospasial Analysis for Delta Evolution of Jeneberang River in Makassar, South Sulawesi, Indonesia

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Abstract – This study is aimed to document and elucidate the delta evolution during 1922-2022 of Jeneberang river, South Sulawesi by analyzing the transport of sediment in and out of the river. 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 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022 by dividing once every 50 to 2 years so that the delta pattern changes can be simulated using ArcGIS software and sedimentation and erosion can be estimated. This study shows 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 delta occurred due to landform migration and river migration. 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 landforms had 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's sedimentary supply stalled to the north due to watergate construction which caused the concentration of migration to lead to the southern estuary. Tides then became a major factor in 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 5 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.

[INTRODUCTION]

In Seybold (2007) and Singh (1989), the word ‘‘delta’’ derived from the Greek can be defined as a coastal sedimentary deposit with each subaerial and subaqueous component. It's formed by river borne sediment which is deposited at the edge of a standing water, in maximum instances 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 (Bhattacharya, 1992; Coleman & Wright, 1975; Orton & Reading, 1993; Wright, 1985). This complex interplay of unique methods and conditions effects in a massive range of various patterns according to the local situations. Coleman & Wright (1973;

1975) described depositional facies in deltaic sediments and concluded that they are resulted from a massive kind of interacting 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 can affect erosion and sedimentation are changes in the function of land cover from forest areas or green land to target areas that will affect the rate of erosion and sedimentation in the area and cause inundation in the surrounding area which can also be called flooding (Alimin et al., 2017; Negoro & Cholil, 2018; Seybold et al., 2007). 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. What's more, it is often an important issue, especially in the surrounding areas where there is human activity. Sedimentation is the process of sediment deposition caused by water, wind or ice. Sedimentation is a dynamic process. In the event of an increased supply of sedimentary loads in coastal environments, silting occurs on the coast (Holden & Joseph, 2005).

Jeneberang river delta is a land formed at the mouth of Jeneberang river which is located in the west of Makassar City with a length of 75-80 km. Jeneberang river is one of the major rivers in South Sulawesi with a dendritic flow pattern. The upper reaches of Jeneberang river are on Mount Bawakaraeng in Gowa Regency, while the lower reaches are to the Makassar Strait (Whitten et al., 1987; Sakka et al., 2011). At the mouth of Jeneberang river is formed a delta that constantly changes over time. Apart from being a catchment area, Jeneberang river delta area has been intensively developed since 2000 for settlements, business centers and marine tourism. For the purposes of coastal management planning, study on delta evolution is needed at aiming to document and record historical data on evolution in the Jeneberang river delta. No comprehensive studies on this theme have been done before. This study is crucial to be used in monitoring and managing the impact of the development on the river and delta environment. One of the methods to determine the delta evolution in the study area is to calculate sedimentation and erosion, using Landsat imagery to understand the landform migration, river pattern changes, and to classify the delta type.

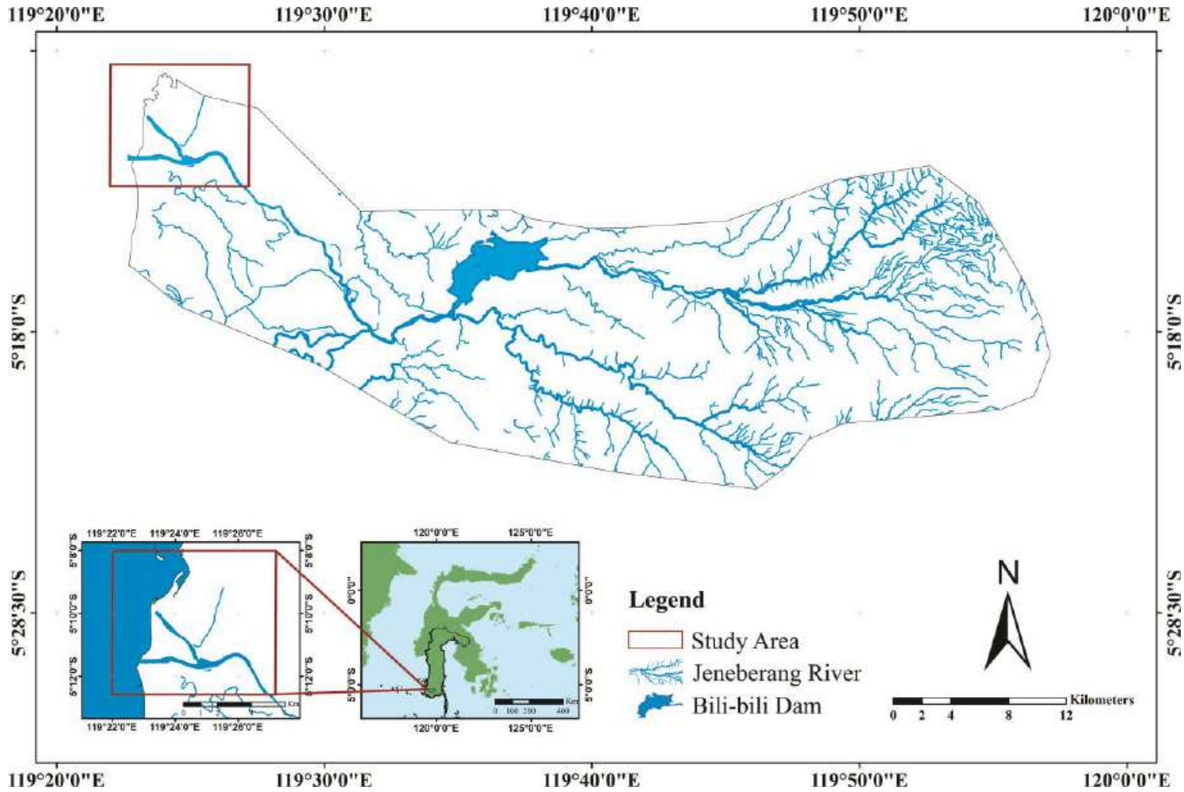


Figure 1. Location map of the study area (red color square), a part of the Jeneberang river system. The maps were generated using ArcMap from ArcGIS Desktop 10.8

[DATA AND METHODOLOGY]

This study took place in Jeneberang river delta, which is administratively included in Makassar City, South Sulawesi Province, Indonesia (Figure 1). This study is performed by means of time series 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 40 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 (Alesheikh et al., 2007; Lu et al., 2004; Muskananfola, 2020; Singh, 1989), which can be applied to time series satellite imagery.

The data used in this study are images for 1922, 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022, as well as rainfall data (Table 1). Data collection is 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 ArcGIS software. The limited data in this study caused the suboptimal digitization process of Landsat data, due to the lack of existing image quality. 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.

Table 1. Data type and data sources in this study

Data	Source
1922 image map	Topography of Dienst (Batavia)
1972 image map	Landsat 1 (Musical group 754)
1981 image map	Landsat 2 (Bands 754)
1991 image map	Landsat 5 (Musical group 754)
2000 image map	Landsat 7 (Musical Group 764)
2010 image map	Landsat 7 (Musical Group 764)
2020 image map	Landsat 8 (Band 754)
2022 image map	*Google Earth Pro*
Rainfall	Jeneberang Kampili River Station

[RESULTS & DISCUSSION]

Jeneberang river is a river 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 the Makassar Strait. Jeneberang river is the main river in the watershed. Jeneberang is situated on the southern arm of Sulawesi Island, precisely on the western slope of the Mount Lompobattang mountain range, a dormant stratovolcano-type volcano. The geological conditions of the Jeneberang river basin (watershed) are dominated by alluvium deposits of rivers, lakes and beaches along the river flow downstream. The alluvium deposits are sourced from Camba Formation which is comprised of marine and volcanic sedimentary rocks including breccias, lava, tuff and konglongmerat, whereas the Lombobattang Formation occupies in the upper part of the river. Jeneberang river delta is influenced by marine and fluvial processes. The processes include sedimentation and erosion of sedimentary material in Jeneberang river.

Stream Development in Janeberang Watershed

In the development of stream from Jeneberang watershed, there are 3 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 the 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 types is explained below.

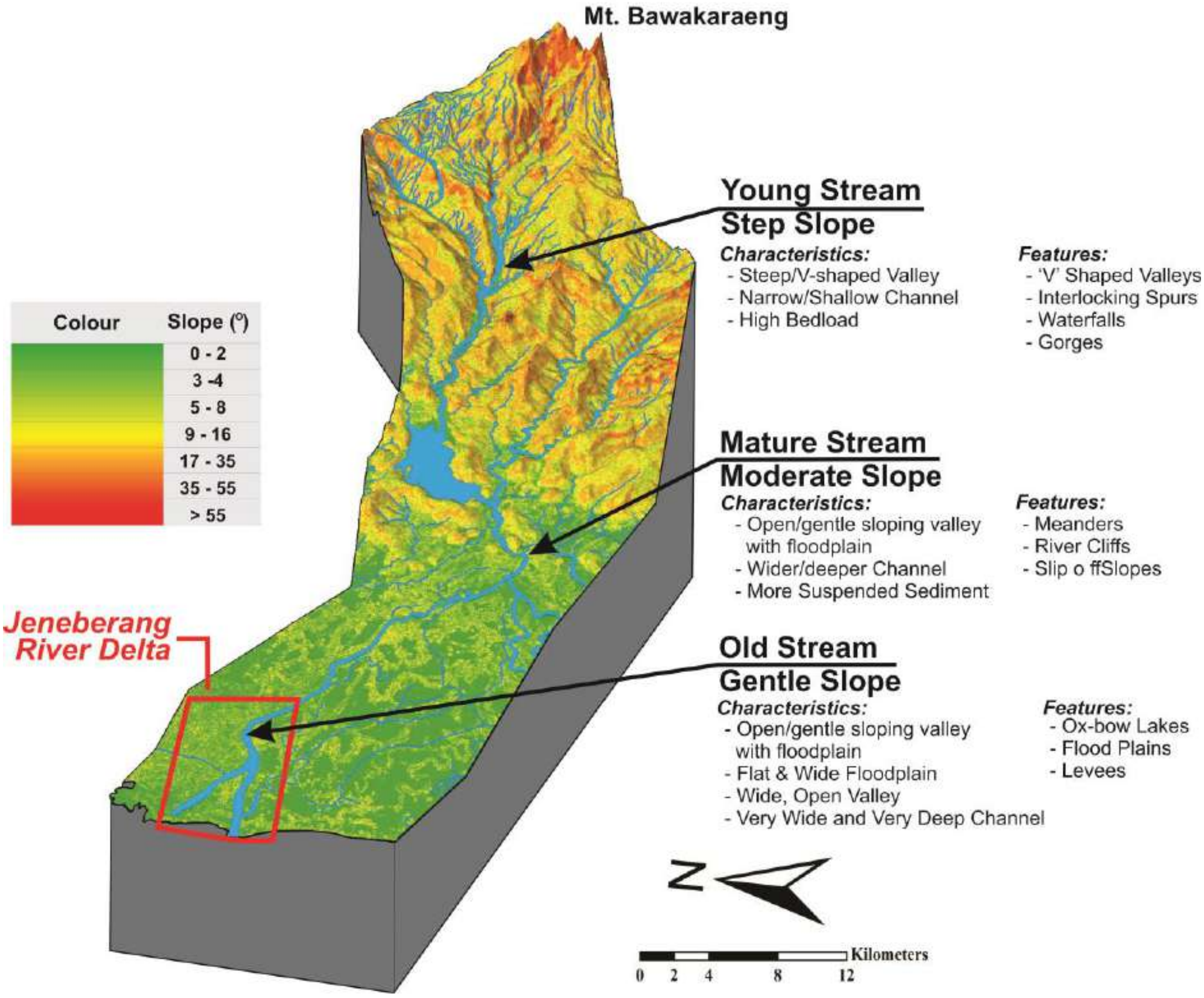


Figure 2. Stream development of the Janeberang watershed. The model is generated by using ArcMap from ArcGIS 10.8

(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. Aisyah et al. (2022) estimated amount of erosion in the upper Jeneberang watershed using the USLE equation in 2018 is 813.1 tons/m^2/year with an average permissible erosion value of 28.9 tons/ha/year. The highest estimated erosion is 5,160.2 tons/m^2/year in open land and the lowest is 3.8 tons/m 2/year in paddy fields. The application of land cover in the 2012–2032 Gowa

Regency Spatial Planning and Regional Planning scenario with soil conservation measures is the scenario with the lowest erosion estimate as land cover in watershed management in the upper Jeneberang watershed, with an average erosion estimate of 27.8 tons/m^2/year or 667,270 tons/year. This scenario was able to reduce the rate of erosion below the permissible erosion and produce sediments suspected to be below the target sediment by 96.58% of the existing conditions.

(b) Middle flow/mature stream

The center of the Jeneberang watershed is the 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 km^2 with a planned operating period of 50 years (Department of Public Works, 1989; JRBDP, 2004). The completion of the construction of this dam in 1999 causes sediment sedimentation (blockage) so that the downstream sedimentation rate stagnated compared to before construction. 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 m^3. The potential for sediment due to large enough avalanches will flow downstream if the rain intensity is high so that it is susceptible to high discharge concentrations. The condition of Jeneberang river which continues to drain sediment during flooding and settles along the river channel to the dam.

(c) Downstream/old stream

Downstream is the end part of Jeneberang watershed. In this part, a process of sedimentation, erosion, abrasion, and sediment migration are occurred. 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 are then calculated in ArcMap 10.8 software to determine the area of sedimentation and erosion occurred. The processed data is divided into periods with a longtime span,

namely 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).

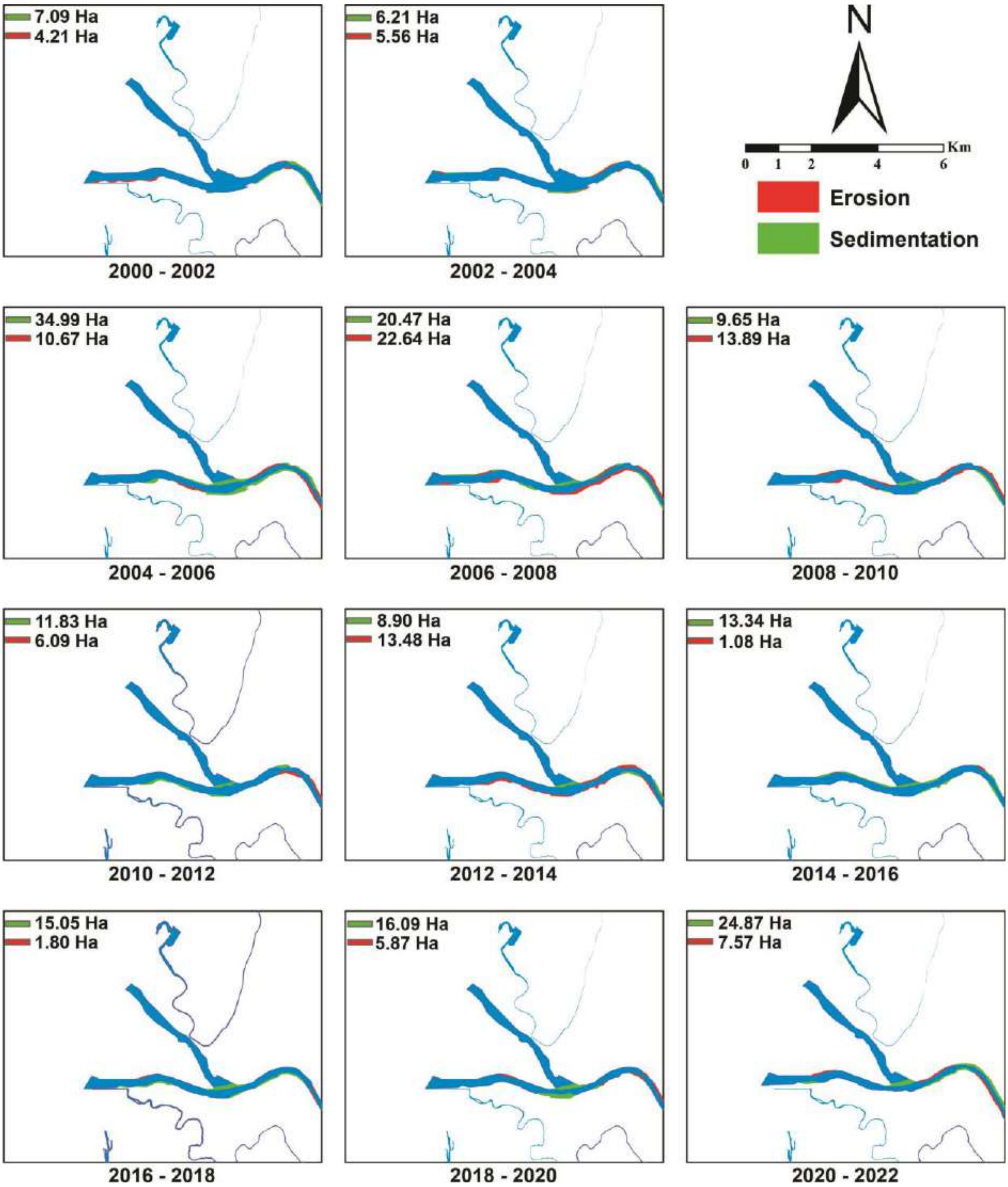


Figure 3. Sedimentation and erosion area map of the Jeneberang River. The map was generated by using ArcMap from ArcGIS 10.8

Figure 3 and 4 show that the initial sedimentation occurred in 2000-2002 with an area of about 7.09 ha then decreased and became the lowest sedimentation data 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 the 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 the Jeneberang river. The effect of sediment distribution is due to large rainfall in November 2004 to February 2005 (Table 2). The rain that occurs causes avalanche material to be carried away by rain and causes the amount of water discharge to increase. The influence of the 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 and 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 it had an erosion area of about 4.21 ha, then rose to the highest erosion in 2006-2008 with an area of approximately 22.64 ha, 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 occurs with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991 and 2000-2022 from the Kampili station (Table 2).

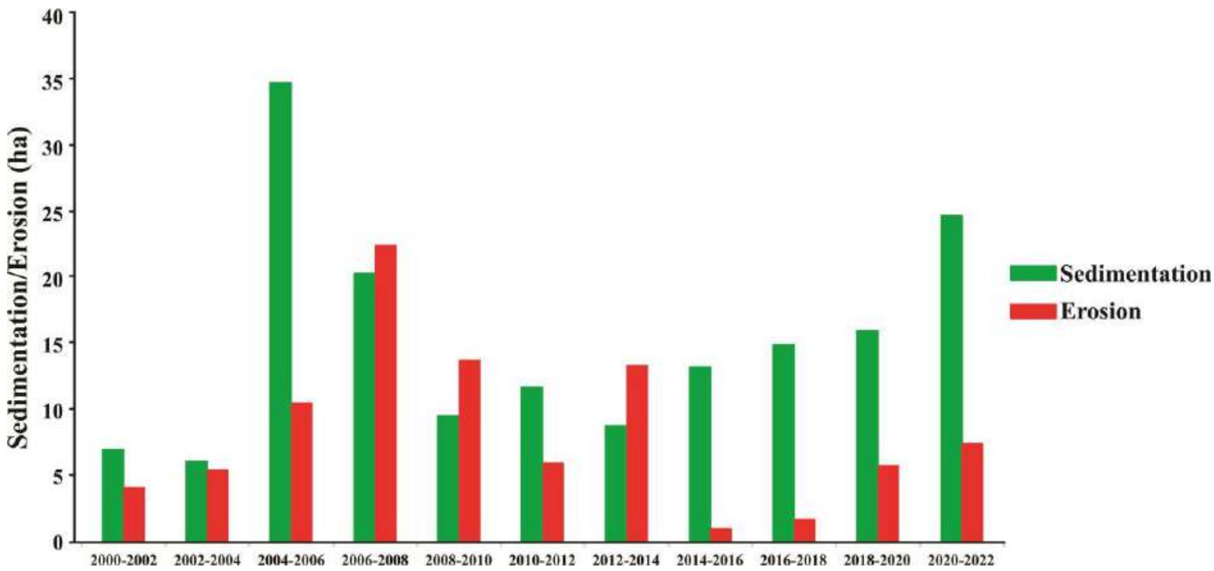


Figure 4. Histogram of sedimentation and erosion area of the Jeneberang river

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

Delta Evolution of Jeneberang River

Delta Landform Migration

The evolution of Jeneberang delta uses Landsat imagery data for 1922, 1972, 1981, 1991, 2000. 2010, 2020 and 2020. The data were processed using the ArcMap 10.8 using 6 colors classification of legend including land, sediment, river, watergate, 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.

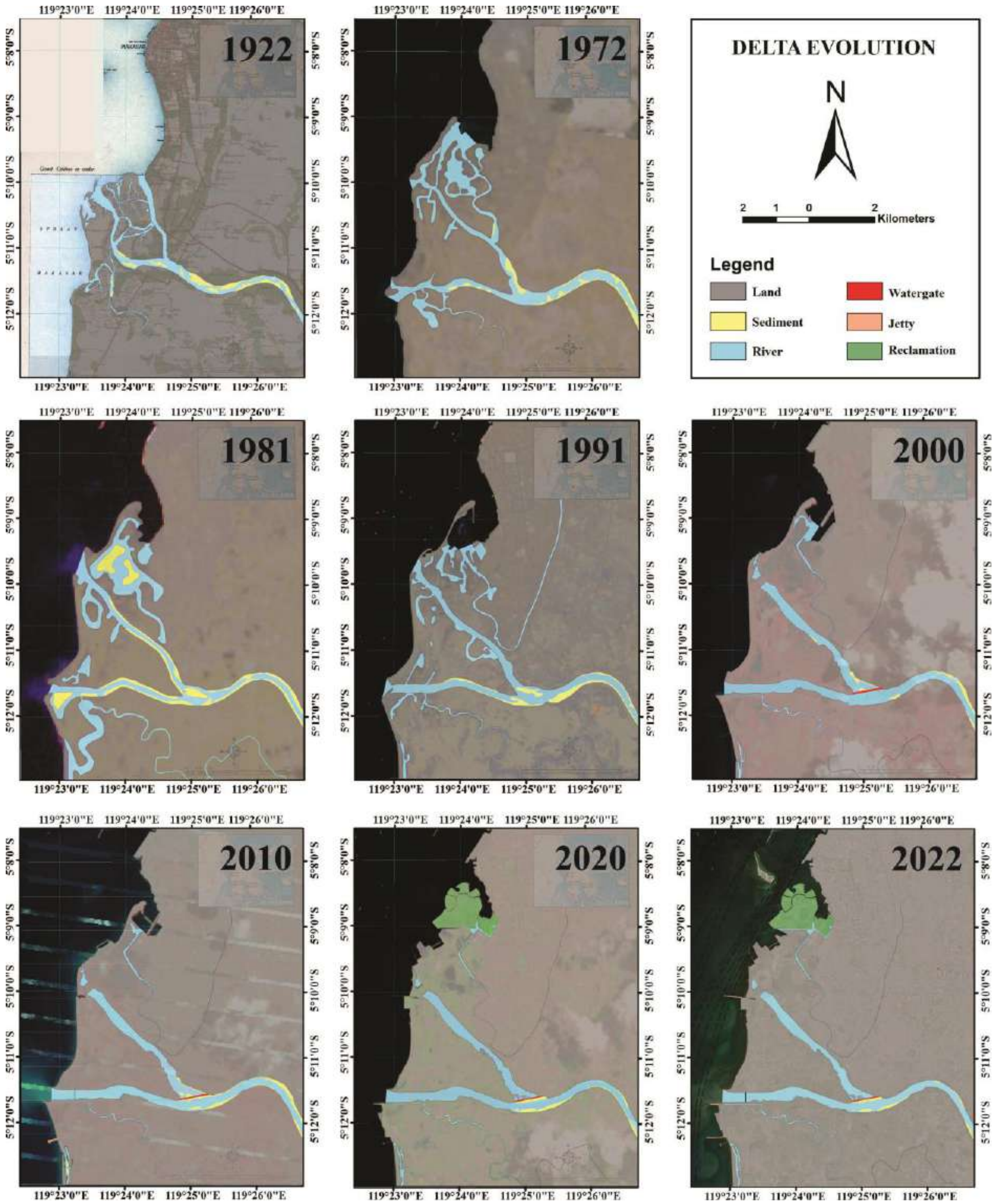


Figure 5. Delta landform migration of the Janeberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022. The map generated using ArcMap from ArcGIS 10.8

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**

1922 – 1972 Period

The Landsat image (1922-1972; Figure 6) is the initial data of sediment migration, during 50 years, with an area of about 5097.62 ha. The sediment migration occurred causing the delta to 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).

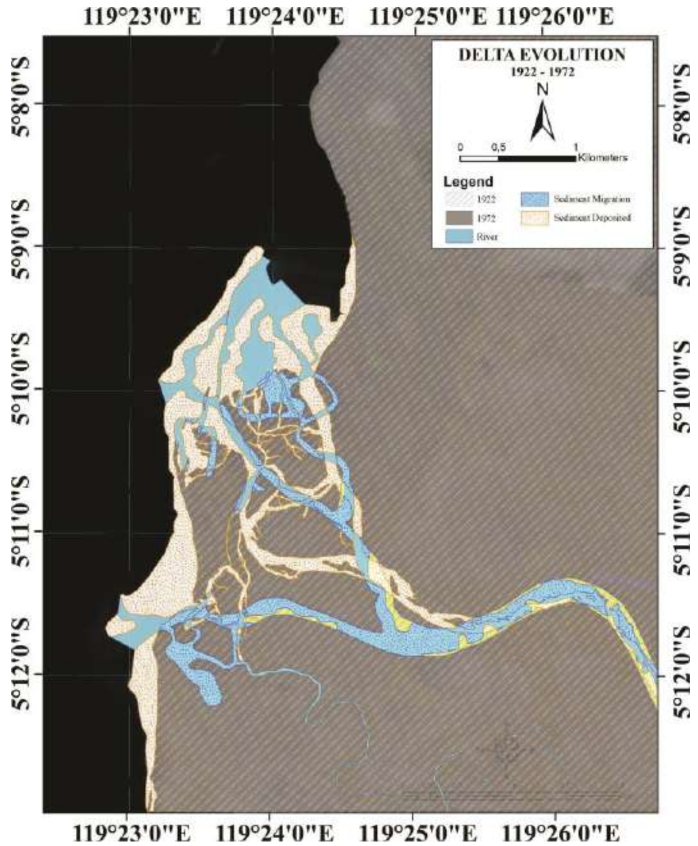


Figure 6. Delta evolution during 1922-1972. The map is generated using ArcMap from ArcGIS 10.8

1972 – 1981 Period

Sediment migration occurred in the period from the beginning of 1972-1981 with an area of about 5373.40 ha. The migration occurred causing the delta to still develop relatively to the north to west with an area of 23.98 ha forming a delta with an area of 5349.42 ha in 1981 (Figure 7).

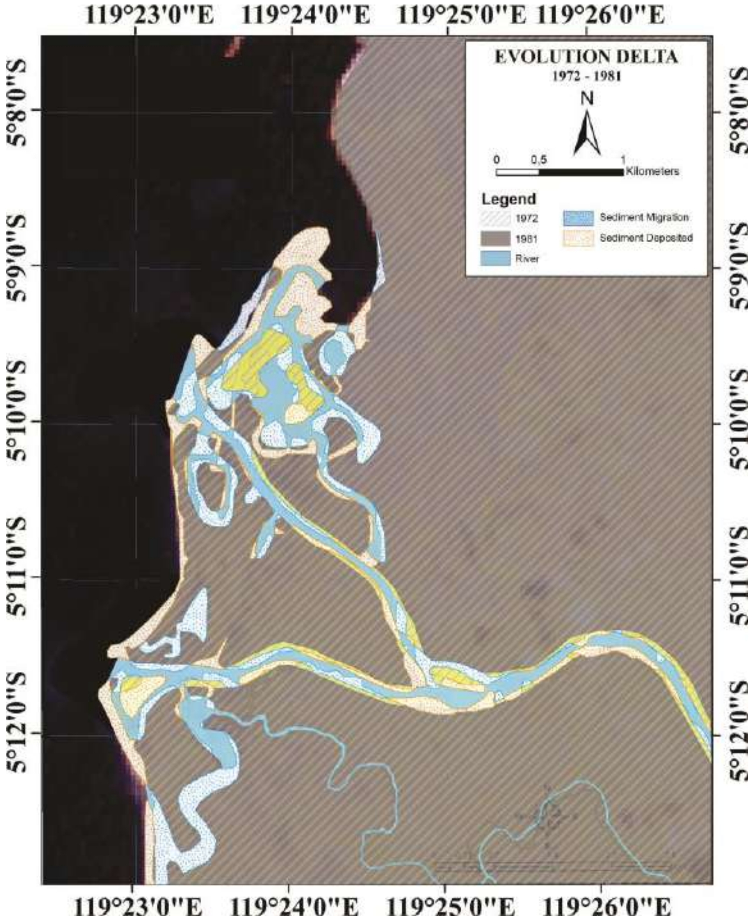


Figure 7. Delta evolution in 1972 - 1981. The map is generated using ArcMap from ArcGIS 10.8

1981 – 1991 Period

Sediment migration occurred in the period 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, forming a delta with an area of 5351.06 ha in 1991 (Figure 8).

1991 – 2000 Period

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

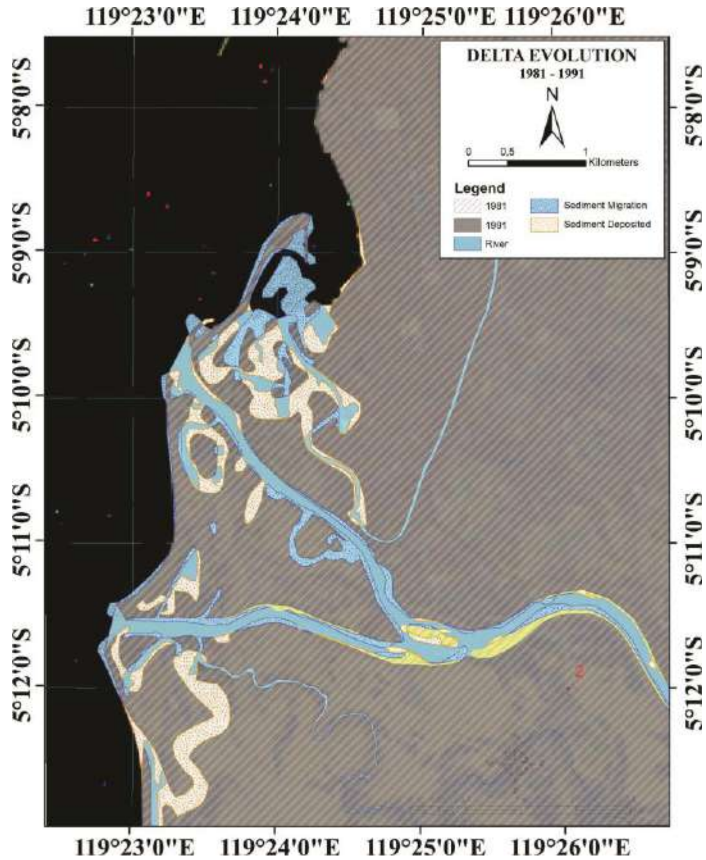


Figure 8. Delta evolution in 1981-1991. Map is generated using ArcMap from ArcGIS 10.8

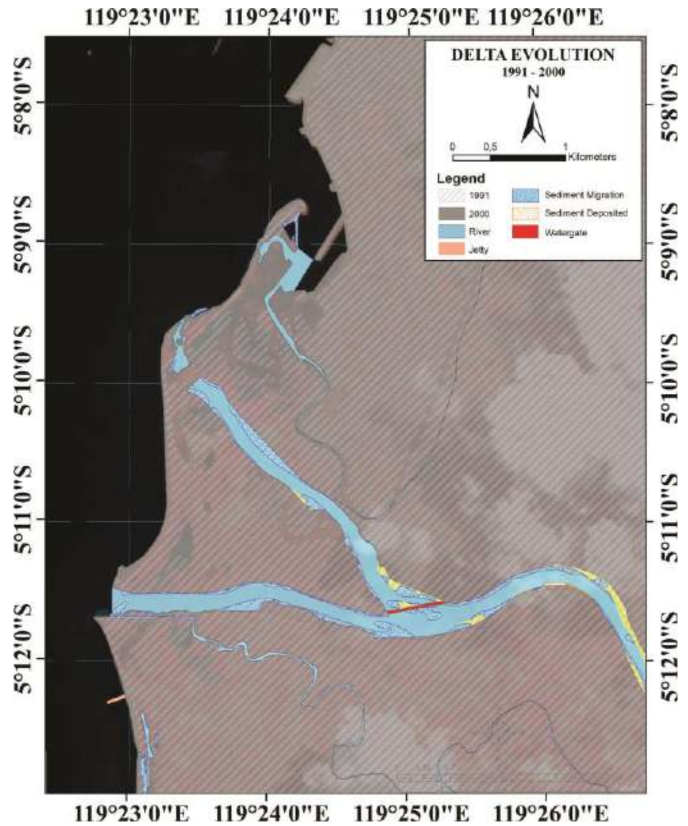


Figure 9. Delta evolution in 1991-2000. The map is generated by ArcMap from ArcGIS 10.8

2000 – 2022 Period

Sediment migration occurred in the 2000 period with an area of about 5586.56 ha. As a result of the construction of watergates in the northern estuary and jetties in the southern estuary, causing the sediment supply from the river to stagnate, so that migration is caused only from tides with an area of 69.23 ha, forming a delta with an area of 5655.79 ha in 2022 (Figure 10).

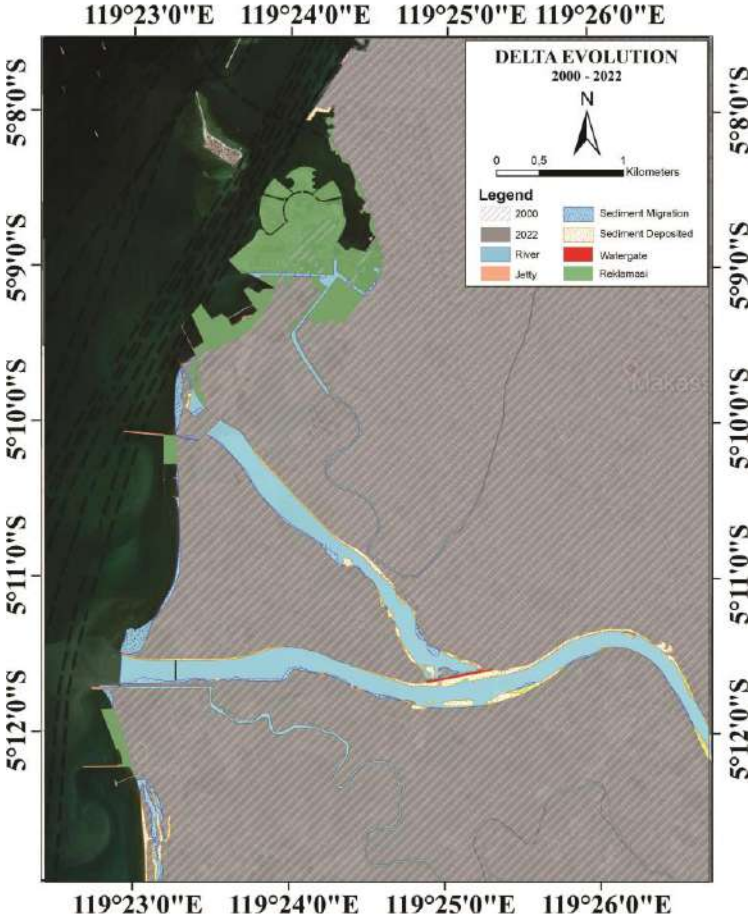


Figure 10. Delta evolution in 2000-2022. The map is generated using ArcMap from ArcGIS 10.8

Jeneberang River Migration Pattern

The significant evolution of the Jeneberang river is observed in 3 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 3 colors, namely blue reflecting a river, green is a migration or change of river, and red is the initial river (Figure 11 and Figure 12).

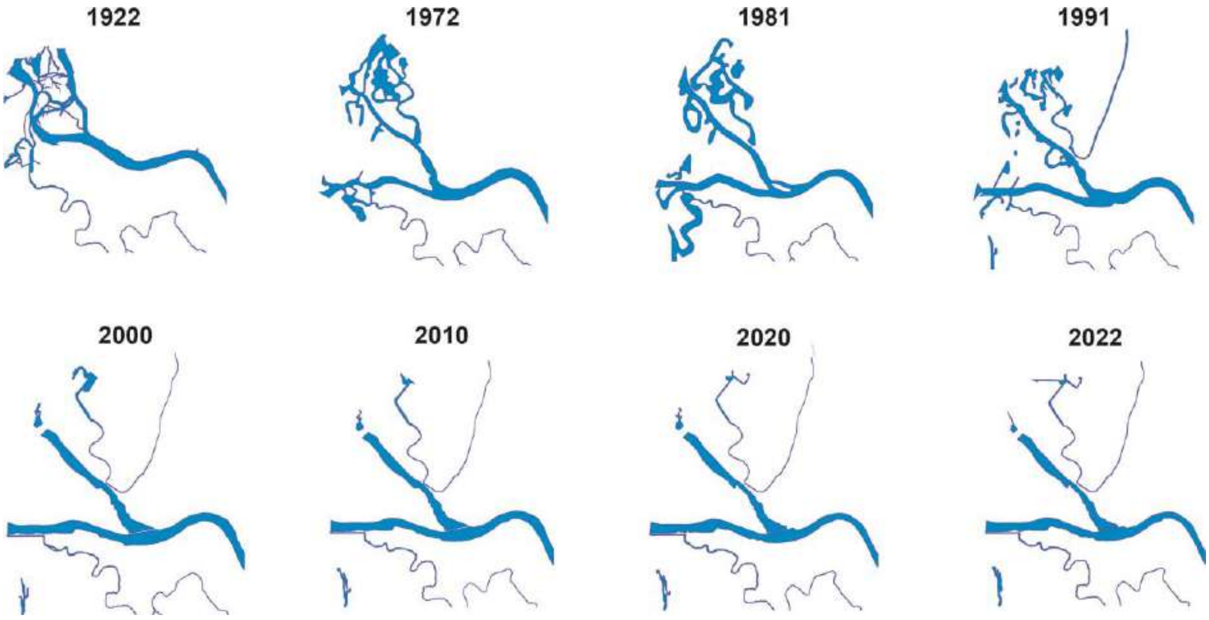


Figure 11. Evolution of the Jeneberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022. The map is generated using ArcMap from ArcGIS 10.8.

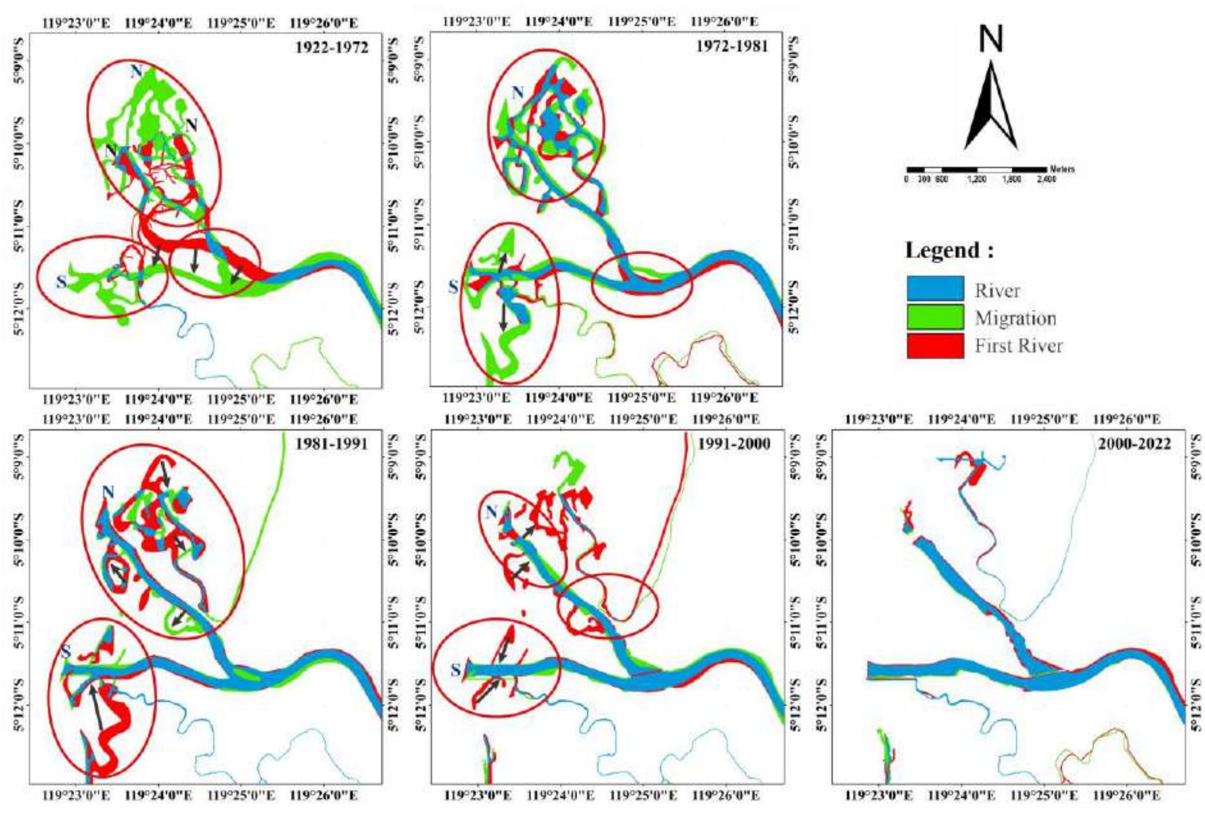


Figure 12. Migration and change of the Jeneberang river pattern from 1992-1972, 1981-1991, 1991-2000, to 2000-2022. The map is generated using ArcMap from ArcGIS 10.8

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, i.e. coordinates 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 occurs 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 to 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 are also branches of the river formed, and on the branches of the main river there are material deposits that cause the river flow to divide and then reconnect in the northern part. In 1981, a canal was built in the northern 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 to become a swamp.

1981-1991 Period

The period 1981-1991, sedimentation and erosion were controlled relative to the southwest and no longer spread so that in 1991 the existing river became narrower because it was covered with sediment and turned 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 so that in 1981 part of the river was covered with sediment.

1991-2000 Period

During this period, human activity seems to begin influencing the concentration of material sedimentation in Jeneberang delta. A tributary in the northern part and then separated from

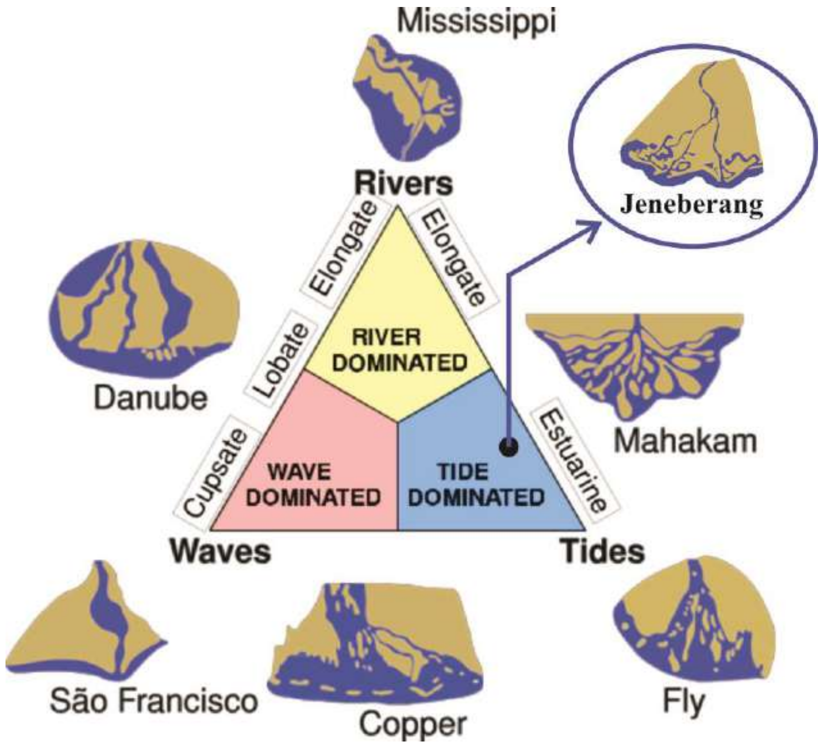
Jeneberang river with the construction of sluices at the junction of the river and the northern estuary so that the sedimentation of sediment from Jeneberang river. The river is no longer going to north but is concentrated to the southern estuary. At the junction of the river in 1995 a sluice was built so that the sedimentation of sediment 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

This period was observed continuing human activity in the use of the northern part of the delta for development. This is done by reclaiming so that river erosion is strongly influenced by humans. 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, delta of the Jeneberang river is chracterised 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 periods of 1922-1981. The sediment occurred in front of the river mouth is commonly typified by fine-grained sand to clay, which also coincides with previous studies conducted by Bhattacharya (1992), Orton (1993) and Wright (1985) in other deltas. Moreover, the existence of the Tanjung Bunga spit in the northern part supports this phenomenon (Langkoke, 2011). Based on the mentioned characteristics, delta of the 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 13; modified from Galloway, 1975 in Bhattacharya, 1992).



Gambar 13. 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 dynamics and underwent pattern evolution over the periods. The delta evolution is strongly controlled by sedimentation and erosion factors. 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. Landform migration occurred gradually starting in 1922-1981, where the direction of migration is relative to west led to migration and resulted a delta landform formation with an area of 5349.42 ha. Since 1981-2000 the development of landforms is no longer but sediment migration still occurred 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 watergate construction which led to migration concentrations leading to the southern estuary. Tides became to be a major factor in sediment migration, although the tides roles were not so intensive as before with additional delta formation with an area of 5655.79 ha.

The Jeneberang river evolution occurs naturally and 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 estuary delta, which is predominantly influenced by tides during its formation.

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*2. [*IJOG*] Two Reviewers Comments/Revisions*

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Komentar 2 Reviewer

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Yth. Penulis,

Berikut kami lampirkan komentar dari 2 reviewer untuk makalah berjudul : "Geospasial Analysis for Delta Evolution of Jeneberang River in Makassar, South Sulawesi, Indonesia".

Kami tunggu perbaikannya.

Salam,
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GUIDELINES FOR REVIEWERS

General:

- Please comment objectively to provide the author(s) with the means to improve their paper. Feel free to make extended comments on separate sheets.
- If a paper repeats previously published work please point this out to the editor.
- Please explain the reasons for your comments on separated sheets, keying your comments to the numbers 1 – 13.
- Some questions below should be answered on a scale of A to D, **where A is the highest rank and D is the lowest.**

***Manuscript*:**

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

1. Is this topic	A. Suitable for the journal?	**yes no**	yes
	B. Of broad national interest?	**yes no**	yes
	C. Significant?	**yes no**	yes

Please explain your answers to item 1A – C briefly.

2. Clarity of objectives:	**A B C D**	A
3. Quality of methods:	**A B C D**	C
4. Quality of data:	**A B C D**	B
5. Validity of assumptions and analyses:	**A B C D**	B

6. Is this paper	A. Properly organized?	**yes no**	yes
	B. To the point and concise?	**yes no**	yes
	C. Written clearly using correct grammar?	**yes no**	yes

Please explain your answers to item 6A – C briefly.

7. Are the approach, results and conclusions intelligible from the abstract?	**yes no**	no

8. Is the title informative and a reflection of the content? **yes** **no** yes

9. Are the illustrations/tables A. Useful and all necessary? **yes** **no** yes
B. Of good quality? **yes** **no** yes

Please explain your answers to item 9A – B briefly.

10. Is the referencing relevant, up to date and accessible? **yes** **no** yes

11. Overall quality of the work: **A** **B** **C** **D** B

12. Can you suggest any improvements to the paper or any parts that could be shortened or removed? [use separate sheet of paper if necessary to answer this]

- The Introduction needs to explain the importance of geospatial and the use of satellite image data.
- Need better explanation on research method
- The use of imagery data and map data that have different spatial resolutions will require careful geometric correction before being used for area calculations.
- The timing of the acquisition of the Landsat imagery used also greatly affects the results of the area calculation.
- Each band in a Landsat image has a different use. The selection of composite images 754 and 756 needs to be explained.

13. Reviewer's decision:

A. Minor revision	……………………
B. Moderate revision	Moderate revision
C. Major revision	……………………
D. Rejected	……………………

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

Abstract – This study is aimed to document and elucidate the delta evolution during 1922-2022 of Jeneberang river, South Sulawesi by analyzing the transport of sediment in and out of the river. 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 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022 by dividing once every 50 to 2 years so that the delta pattern changes can be simulated using ArcGIS software and sedimentation and erosion can be estimated. This study shows 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 delta occurred due to landform migration and river migration. 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 landforms had 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's sedimentary supply stalled to the north due to watergate construction which caused the concentration of migration to lead to the southern estuary. Tides then became a major factor in 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 5 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.

[INTRODUCTION]

In Seybold (2007) and Singh (1989), the word ‘‘delta’’ derived from the Greek can be defined as a coastal sedimentary deposit with each subaerial and subaqueous component. It's formed by river borne sediment which is deposited at the edge of a standing water, in maximum instances 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 (Bhattacharya, 1992; Coleman & Wright, 1975; Orton & Reading, 1993; Wright, 1985). This complex interplay of unique methods and conditions effects in a massive range of various patterns according to the local situations. Coleman & Wright (1973;

1975) described depositional facies in deltaic sediments and concluded that they are resulted from a massive kind of interacting 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 can affect erosion and sedimentation are changes in the function of land cover from forest areas or green land to target areas that will affect the rate of erosion and sedimentation in the area and cause inundation in the surrounding area which can also be called flooding (Alimin et al., 2017; Negoro & Cholil, 2018; Seybold et al., 2007). 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. What's more, it is often an important issue, especially in the surrounding areas where there is human activity. Sedimentation is the process of sediment deposition caused by water, wind or ice. Sedimentation is a dynamic process. In the event of an increased supply of sedimentary loads in coastal environments, silting occurs on the coast (Holden & Joseph, 2005).

Jeneberang river delta is a land formed at the mouth of Jeneberang river which is located in the west of Makassar City with a length of 75-80 km. Jeneberang river is one of the major rivers in South Sulawesi with a dendritic flow pattern. The upper reaches of Jeneberang river are on Mount Bawakaraeng in Gowa Regency, while the lower reaches are to the Makassar Strait (Whitten et al., 1987; Sakka et al., 2011). At the mouth of Jeneberang river is formed a delta that constantly changes over time. Apart from being a catchment area, Jeneberang river delta area has been intensively developed since 2000 for settlements, business centers and marine tourism. For the purposes of coastal management planning, study on delta evolution is needed at aiming to document and record historical data on evolution in the Jeneberang river delta. No comprehensive studies on this theme have been done before. This study is crucial to be used in monitoring and managing the impact of the development on the river and delta environment. One of the methods to determine the delta evolution in the study area is to calculate sedimentation and erosion, using Landsat imagery to understand the landform migration, river pattern changes, and to classify the delta type.

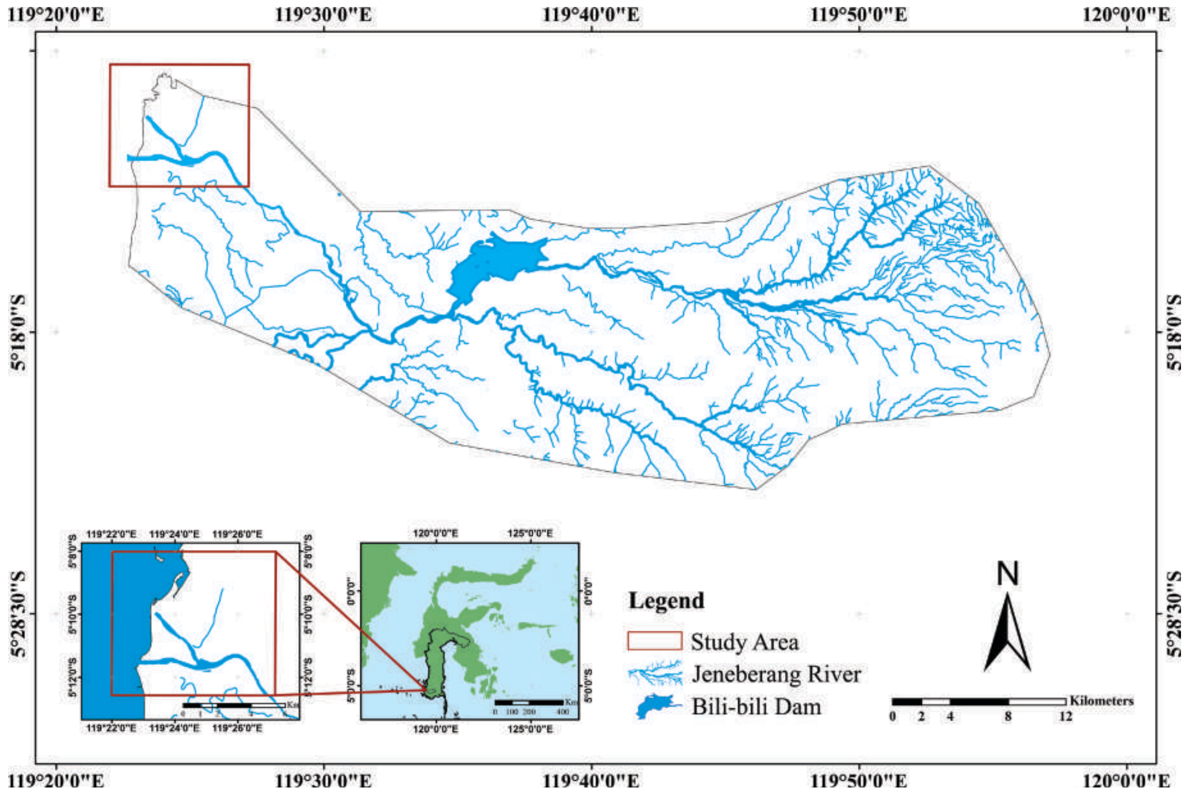


Figure 1. Location map of the study area (red color square), a part of the Jeneberang river system. The maps were generated using ArcMap from ArcGIS Desktop 10.8

[DATA AND METHODOLOGY]

This study took place in Jeneberang river delta, which is administratively included in Makassar City, South Sulawesi Province, Indonesia (Figure 1). This study is performed by means of time series 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 40 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 (Alesheikh et al., 2007; Lu et al., 2004; Muskananfola, 2020; Singh, 1989), which can be applied to time series satellite imagery.

The data used in this study are images for 1922, 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022, as well as rainfall data (Table 1). Data collection is 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 ArcGIS software. The limited data in this study caused the suboptimal digitization process of Landsat data, due to the lack of existing image quality. 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.

Table 1. Data type and data sources in this study

Data	Source
1922 image map	Topography of Dienst (Batavia)
1972 image map	Landsat 1 (Musical group 754)
1981 image map	Landsat 2 (Bands 754)
1991 image map	Landsat 5 (Musical group 754)
2000 image map	Landsat 7 (Musical Group 764)
2010 image map	Landsat 7 (Musical Group 764)
2020 image map	Landsat 8 (Band 754)
2022 image map	*Google Earth Pro*
Rainfall	Jeneberang Kampili River Station

[RESULTS & DISCUSSION]

Jeneberang river is a river 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 the Makassar Strait. Jeneberang river is the main river in the watershed. Jeneberang is situated on the southern arm of Sulawesi Island, precisely on the western slope of the Mount Lompobattang mountain range, a dormant stratovolcano-type volcano. The geological conditions of the Jeneberang river basin (watershed) are dominated by alluvium deposits of rivers, lakes and beaches along the river flow downstream. The alluvium deposits are sourced from Camba Formation which is comprised of marine and volcanic sedimentary rocks including breccias, lava, tuff and konglongmerat, whereas the Lombobattang Formation occupies in the upper part of the river. Jeneberang river delta is influenced by marine and fluvial processes. The processes include sedimentation and erosion of sedimentary material in Jeneberang river.

Stream Development in Janeberang Watershed

In the development of stream from Jeneberang watershed, there are 3 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 the 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 types is explained below.

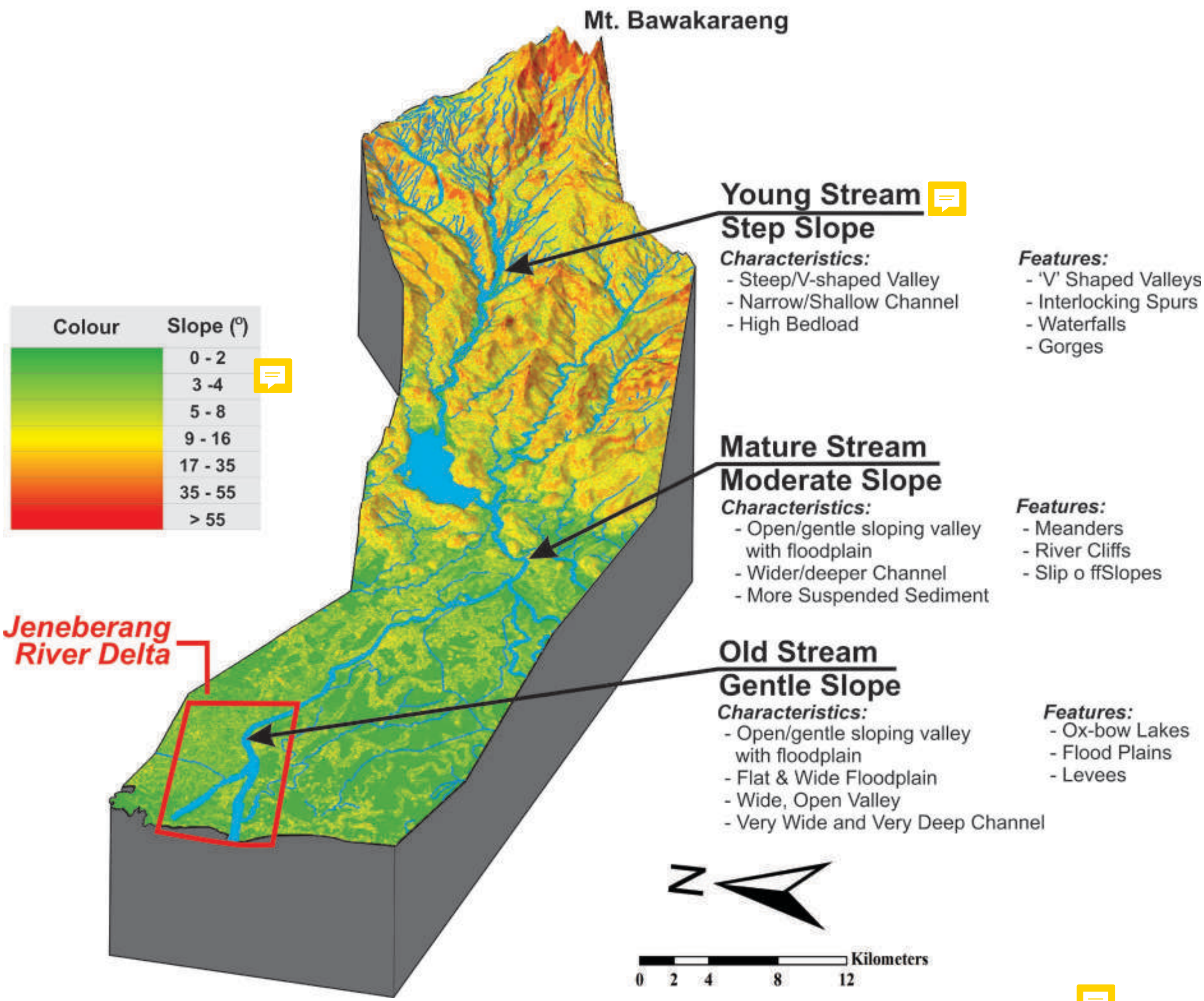


Figure 2. Stream development of the Janeberang watershed. The model is generated by using ArcMap from ArcGIS 10.8

(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. Aisyah et al. (2022) estimated amount of erosion in the upper Jeneberang watershed using the USLE equation in 2018 is 813.1 tons/m^2/year with an average permissible erosion value of 28.9 tons/ha/year. The highest estimated erosion is 5,160.2 tons/m^2/year in open land and the lowest is 3.8 tons/m 2/year in paddy fields. The application of land cover in the 2012−2032 Gowa

Regency Spatial Planning and Regional Planning scenario with soil conservation measures is the scenario with the lowest erosion estimate as land cover in watershed management in the upper Jeneberang watershed, with an average erosion estimate of 27.8 tons/m^2/year or 667,270 tons/year. This scenario was able to reduce the rate of erosion below the permissible erosion and produce sediments suspected to be below the target sediment by 96.58% of the existing conditions.

(b) Middle flow/mature stream

The center of the Jeneberang watershed is the 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 km^2 with a planned operating period of 50 years (Department of Public Works, 1989; JRBDP, 2004). The completion of the construction of this dam in 1999 causes sediment sedimentation (blockage) so that the downstream sedimentation rate stagnated compared to before construction. 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 m^3. The potential for sediment due to large enough avalanches will flow downstream if the rain intensity is high so that it is susceptible to high discharge concentrations. The condition of Jeneberang river which continues to drain sediment during flooding and settles along the river channel to the dam.

(c) Downstream/old stream

Downstream is the end part of Jeneberang watershed. In this part, a process of sedimentation, erosion, abrasion, and sediment migration are occurred. 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 are then calculated in ArcMap 10.8 software to determine the area of sedimentation and erosion occurred. The processed data is divided into periods with a longtime span,

namely 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).

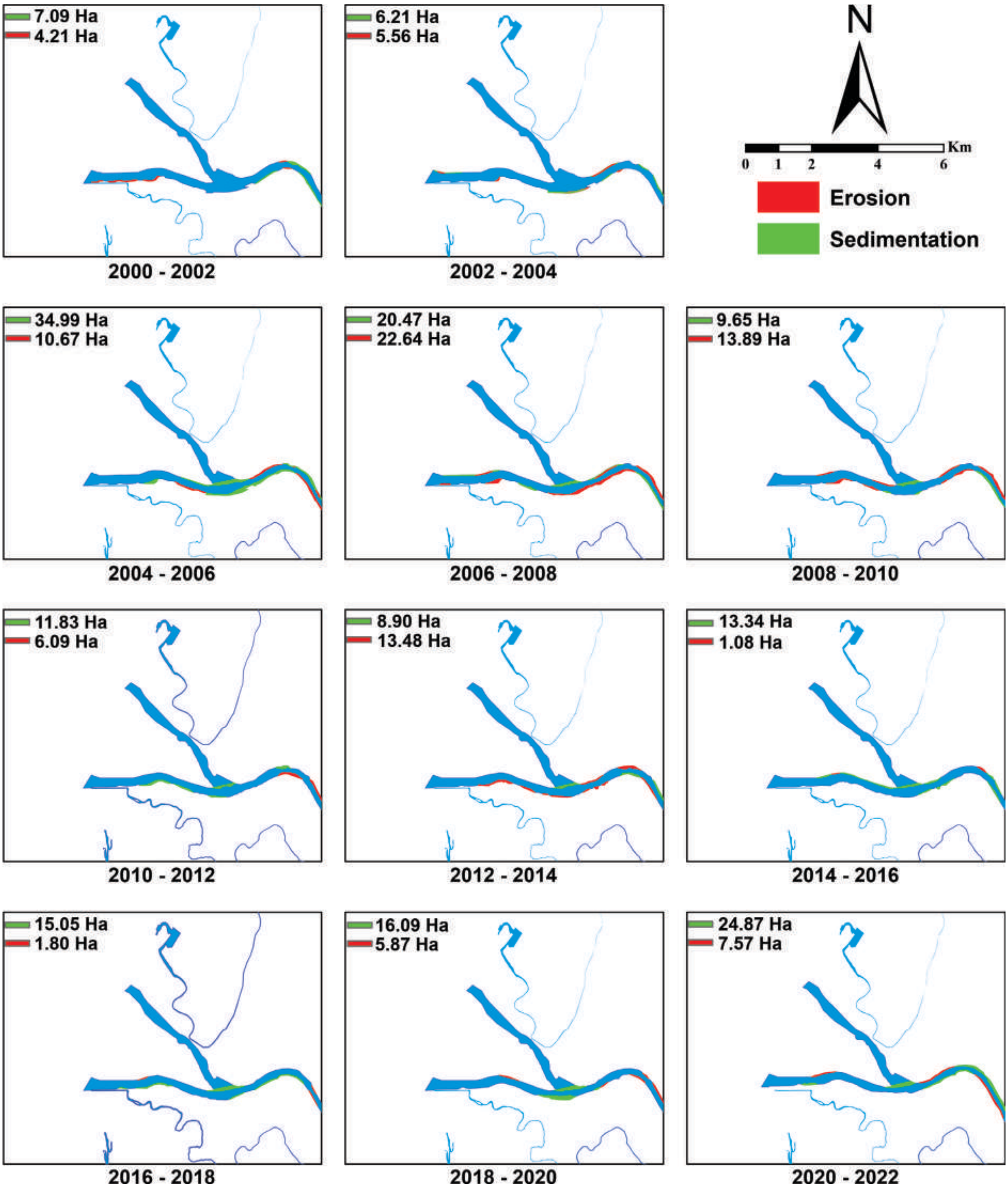


Figure 3. Sedimentation and erosion area map of the Jeneberang River. The map was generated by using ArcMap from ArcGIS 10.8

Figure 3 and 4 show that the initial sedimentation occurred in 2000-2002 with an area of about 7.09 ha then decreased and became the lowest sedimentation data 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 the 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 the Jeneberang river. The effect of sediment distribution is due to large rainfall in November 2004 to February 2005 (Table 2). The rain that occurs causes avalanche material to be carried away by rain and causes the amount of water discharge to increase. The influence of the 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 and 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 it had an erosion area of about 4.21 ha, then rose to the highest erosion in 2006-2008 with an area of approximately 22.64 ha, 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 occurs with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991 and 2000-2022 from the Kampili station (Table 2).

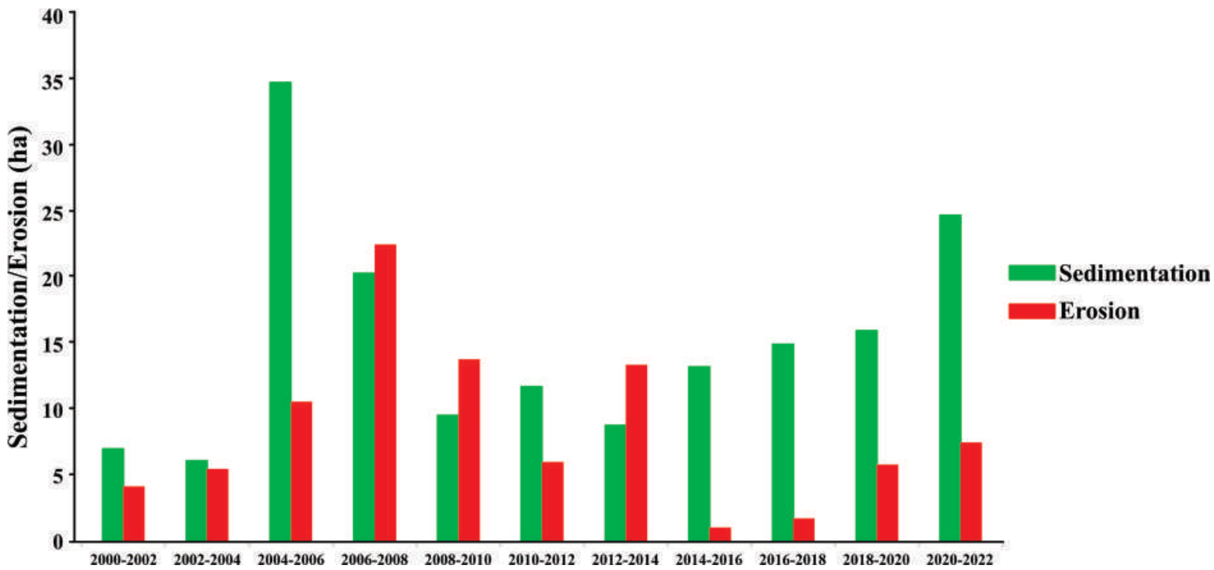


Figure 4. Histogram of sedimentation and erosion area of the Jeneberang river

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

Delta Evolution of Jeneberang River

Delta Landform Migration

The evolution of Jeneberang delta uses Landsat imagery data for 1922, 1972, 1981, 1991, 2000. 2010, 2020 and 2020. The data were processed using the ArcMap 10.8 using 6 colors classification of legend including land, sediment, river, watergate, 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.

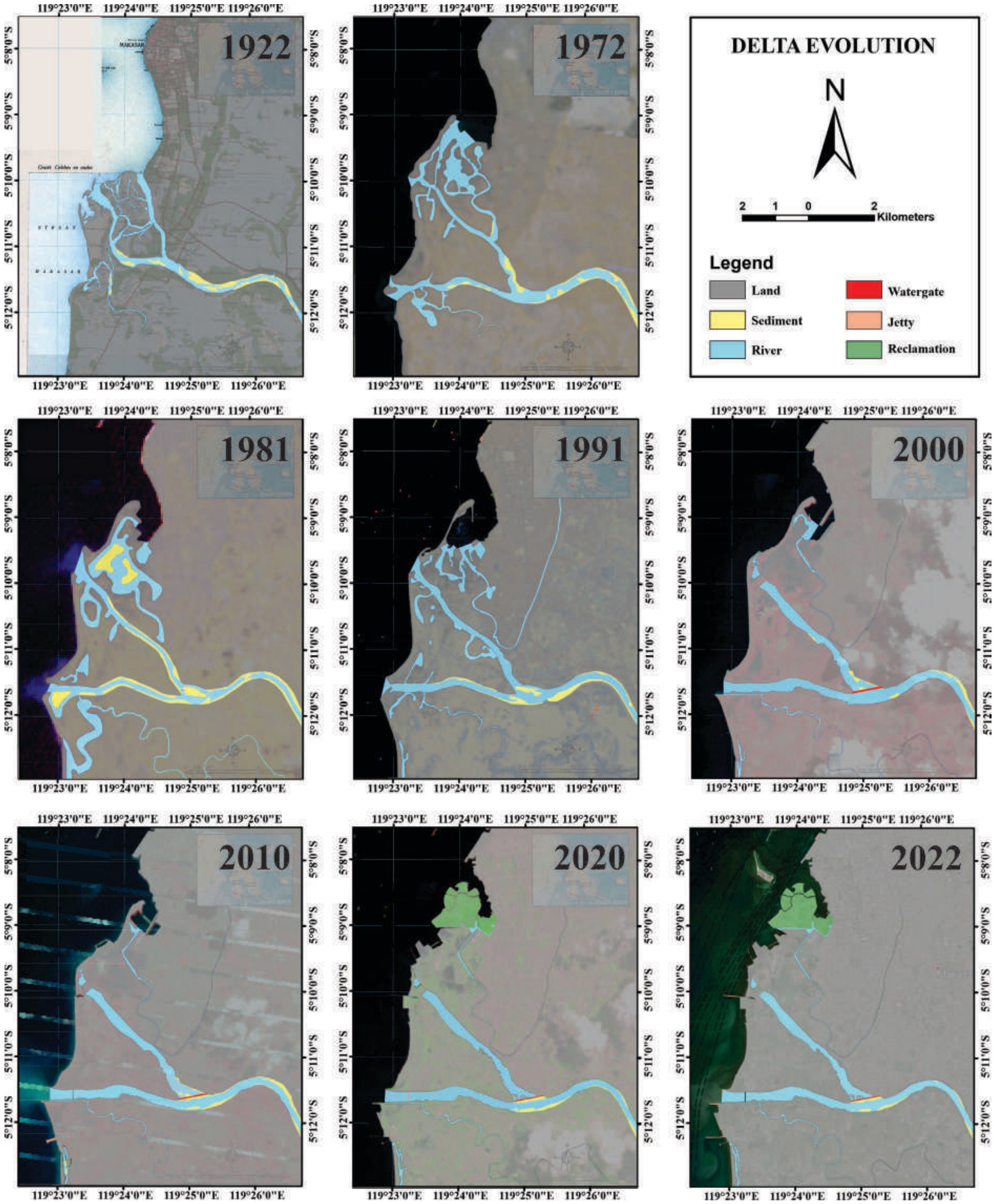


Figure 5. Delta landform migration of the Janeberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022. The map generated using ArcMap from ArcGIS 10.8

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**

1922 – 1972 Period

The Landsat image (1922-1972; Figure 6) is the initial data of sediment migration, during 50 years, with an area of about 5097.62 ha. The sediment migration occurred causing the delta to 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).

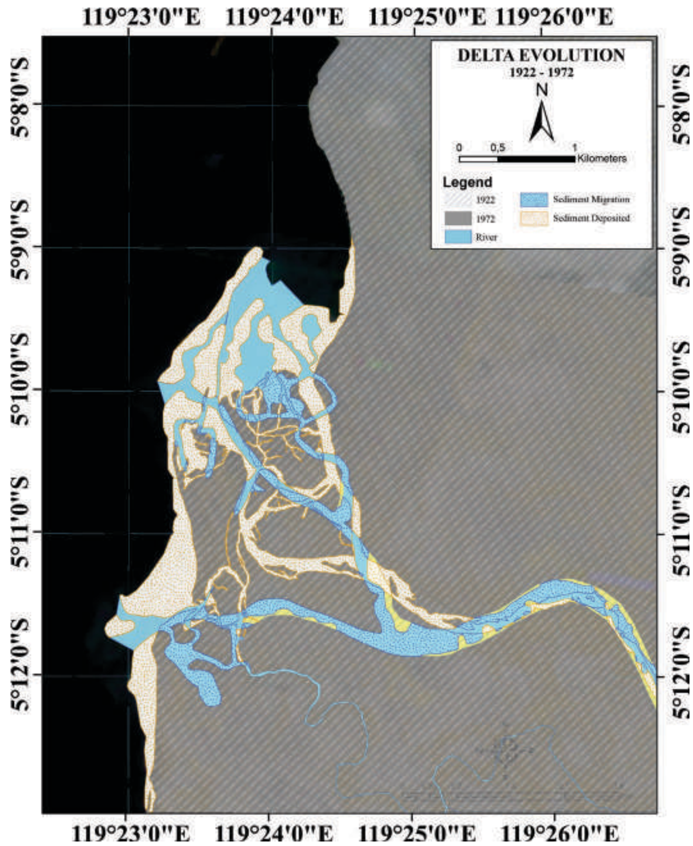


Figure 6. Delta evolution during 1922-1972. The map is generated using ArcMap from ArcGIS 10.8

1972 – 1981 Period

Sediment migration occurred in the period from the beginning of 1972-1981 with an area of about 5373.40 ha. The migration occurred causing the delta to still develop relatively to the north to west with an area of 23.98 ha forming a delta with an area of 5349.42 ha in 1981 (Figure 7).

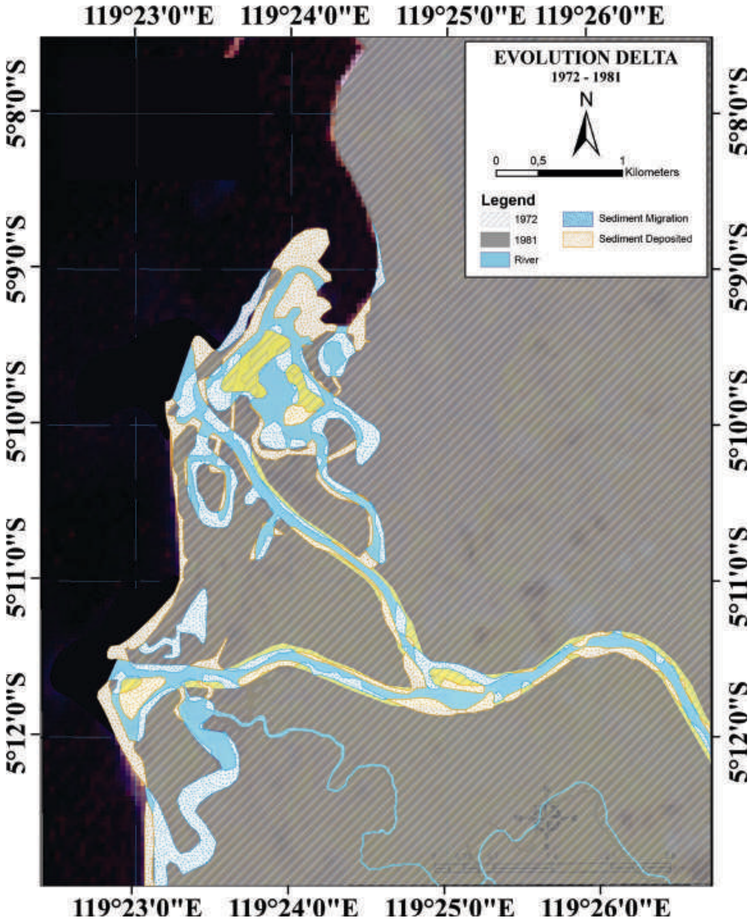


Figure 7. Delta evolution in 1972 - 1981. The map is generated using ArcMap from ArcGIS 10.8

1981 – 1991 Period

Sediment migration occurred in the period 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, forming a delta with an area of 5351.06 ha in 1991 (Figure 8).

1991 – 2000 Period

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

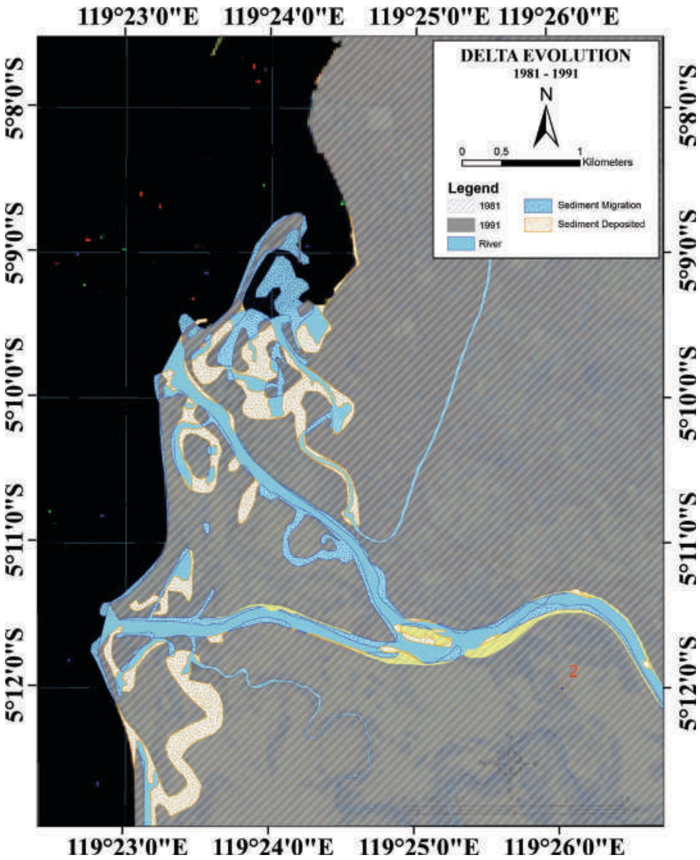


Figure 8. Delta evolution in 1981-1991. Map is generated using ArcMap from ArcGIS 10.8

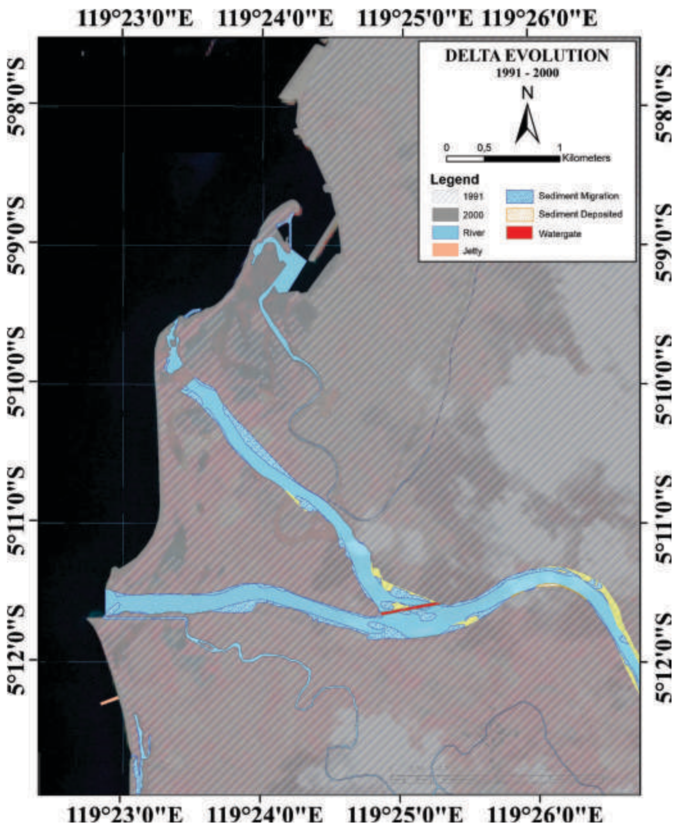


Figure 9. Delta evolution in 1991-2000. The map is generated by ArcMap from ArcGIS 10.8

2000 – 2022 Period

Sediment migration occurred in the 2000 period with an area of about 5586.56 ha. As a result of the construction of watergates in the northern estuary and jetties in the southern estuary, causing the sediment supply from the river to stagnate, so that migration is caused only from tides with an area of 69.23 ha, forming a delta with an area of 5655.79 ha in 2022 (Figure 10).

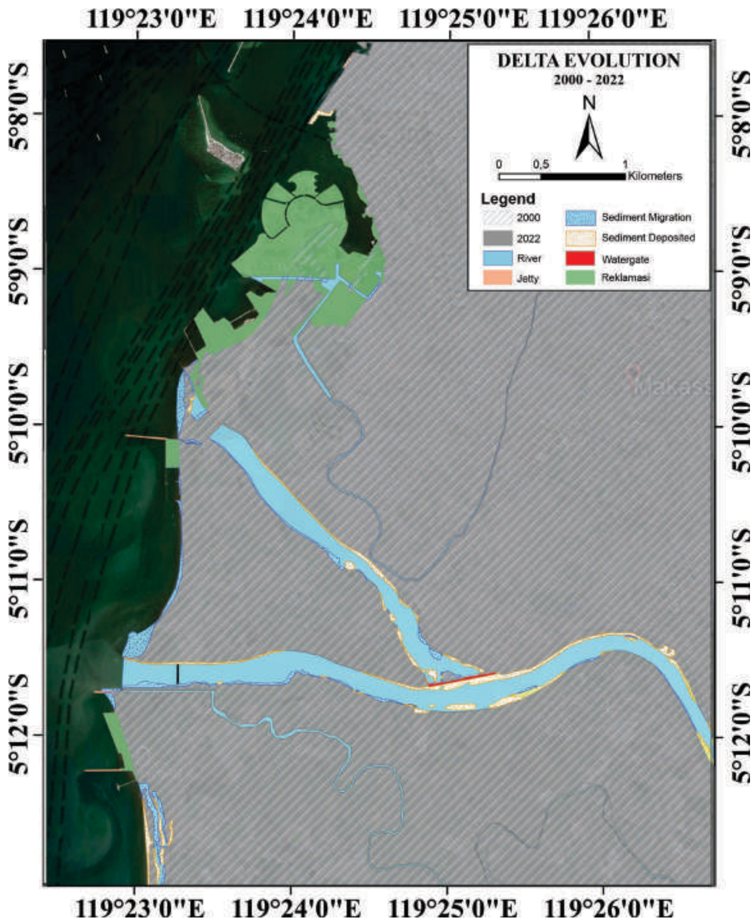


Figure 10. Delta evolution in 2000-2022. The map is generated using ArcMap from ArcGIS 10.8

Jeneberang River Migration Pattern

The significant evolution of the Jeneberang river is observed in 3 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 3 colors, namely blue reflecting a river, green is a migration or change of river, and red is the initial river (Figure 11 and Figure 12).

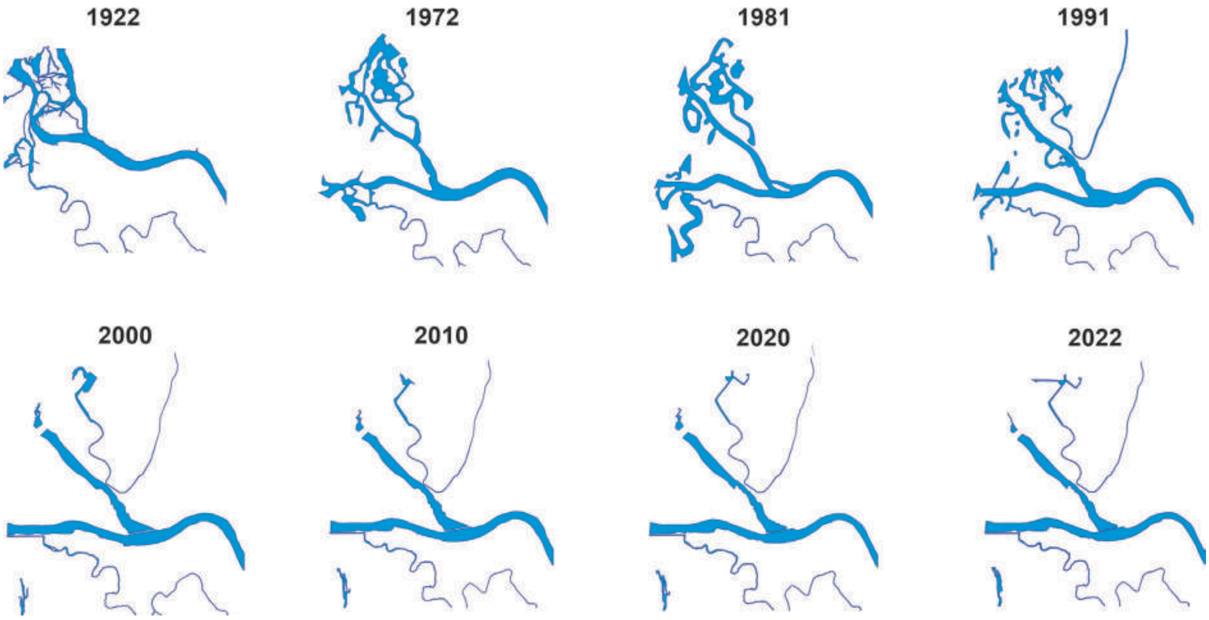


Figure 11. Evolution of the Jeneberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022. The map is generated using ArcMap from ArcGIS 10.8.

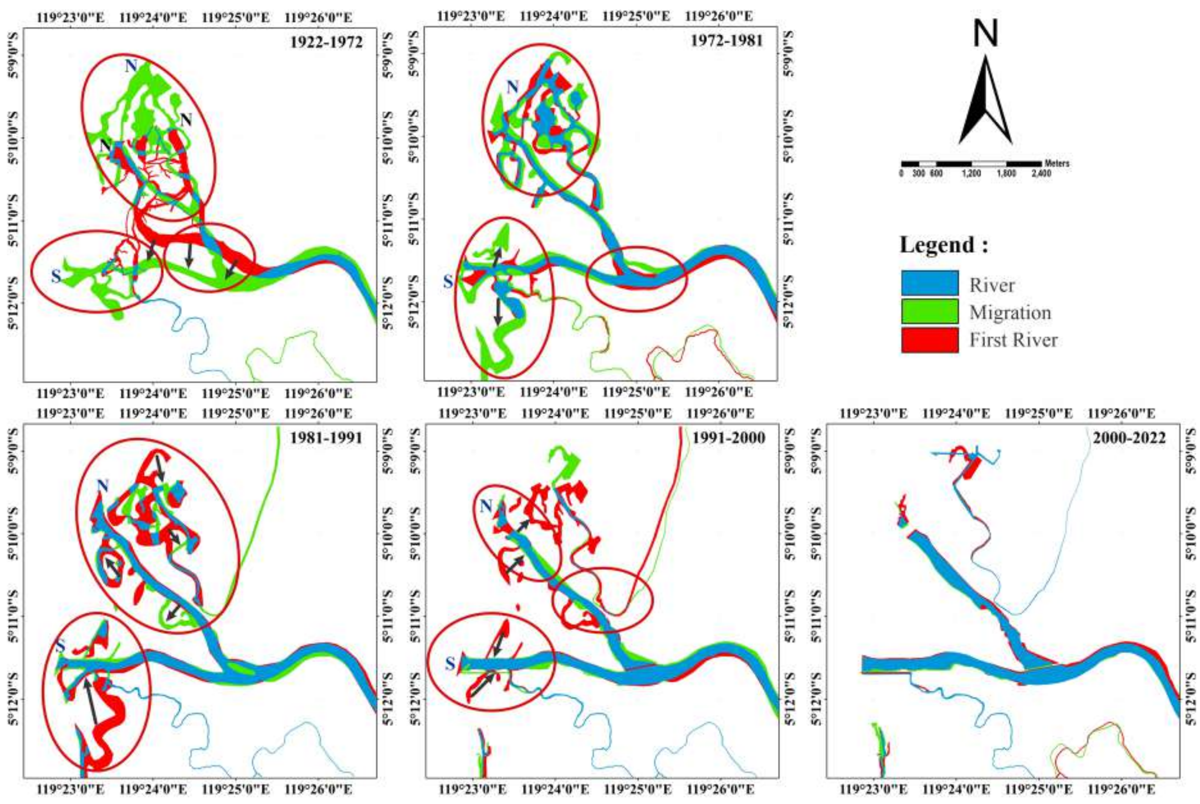


Figure 12. Migration and change of the Jeneberang river pattern from 1992-1972, 1981-1991, 1991-2000, to 2000-2022. The map is generated using ArcMap from ArcGIS 10.8

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, i.e. coordinates 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 occurs 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 to 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 are also branches of the river formed, and on the branches of the main river there are material deposits that cause the river flow to divide and then reconnect in the northern part. In 1981, a canal was built in the northern 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 to become a swamp.

1981-1991 Period

The period 1981-1991, sedimentation and erosion were controlled relative to the southwest and no longer spread so that in 1991 the existing river became narrower because it was covered with sediment and turned 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 so that in 1981 part of the river was covered with sediment.

1991-2000 Period

During this period, human activity seems to begin influencing the concentration of material sedimentation in Jeneberang delta. A tributary in the northern part and then separated from

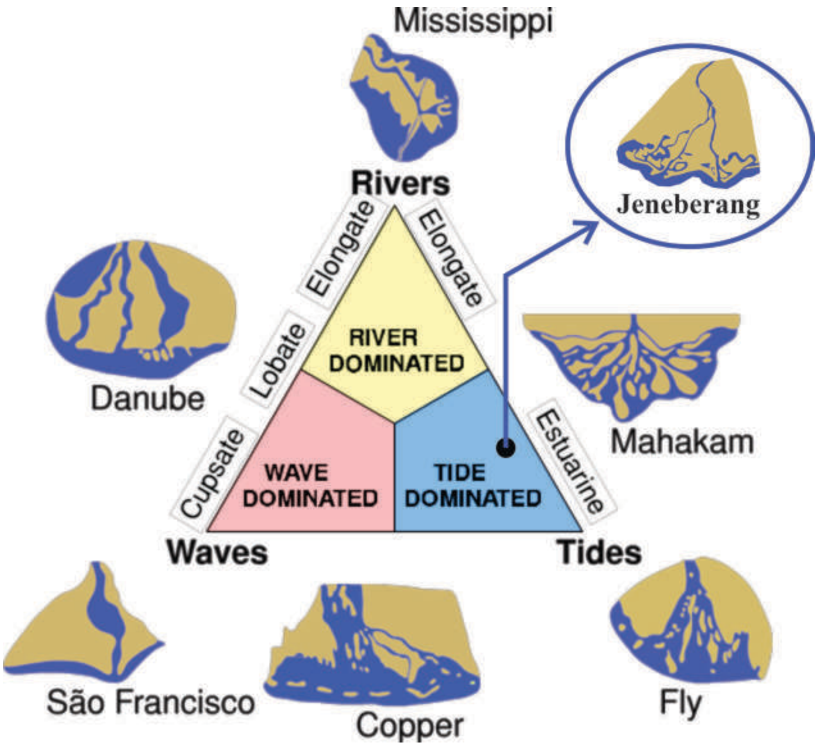
Jeneberang river with the construction of sluices at the junction of the river and the northern estuary so that the sedimentation of sediment from Jeneberang river. The river is no longer going to north but is concentrated to the southern estuary. At the junction of the river in 1995 a sluice was built so that the sedimentation of sediment 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

This period was observed continuing human activity in the use of the northern part of the delta for development. This is done by reclaiming so that river erosion is strongly influenced by humans. 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, delta of the Jeneberang river is chracterised 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 periods of 1922-1981. The sediment occurred in front of the river mouth is commonly typified by fine-grained sand to clay, which also coincides with previous studies conducted by Bhattacharya (1992), Orton (1993) and Wright (1985) in other deltas. Moreover, the existence of the Tanjung Bunga spit in the northern part supports this phenomenon (Langkoke, 2011). Based on the mentioned characteristics, delta of the 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 13; modified from Galloway, 1975 in Bhattacharya, 1992).



Gambar 13. 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 dynamics and underwent pattern evolution over the periods. The delta evolution is strongly controlled by sedimentation and erosion factors. 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. Landform migration occurred gradually starting in 1922-1981, where the direction of migration is relative to west led to migration and resulted a delta landform formation with an area of 5349.42 ha. Since 1981-2000 the development of landforms is no longer but sediment migration still occurred 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 watergate construction which led to migration concentrations leading to the southern estuary. Tides became to be a major factor in sediment migration, although the tides roles were not so intensive as before with additional delta formation with an area of 5655.79 ha.

The Jeneberang river evolution occurs naturally and 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 estuary delta, which is predominantly influenced by tides during its formation.

[ACKNOWLEDGMENTS]

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GUIDELINES FOR REVIEWERS

General:

- Please comment objectively to provide the author(s) with the means to improve their paper. Feel free to make extended comments on separate sheets.
- If a paper repeats previously published work please point this out to the editor.
- Please explain the reasons for your comments on separated sheets, keying your comments to the numbers 1 – 13.
- Some questions below should be answered on a scale of A to D, **where A is the highest rank and D is the lowest.**

Manuscript:

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

1. Is this topic A. Suitable for the journal? **yes no** ....yes.........
B. Of broad national interest? **yes no** ....no..........
C. Significant? **yes no** ....yes..........

Please explain your answers to item 1A – C briefly.
The topic is suitable enough to publish in this journal, the delta evolution is more important especially those located in big cities where human impact is higher than nature itself

2. Clarity of objectives: **A B C D** ......B............

3. Quality of methods: **A B C D** ......B............

4. Quality of data: **A B C D** ......B............

5. Validity of assumptions and analyses: **A B C D** ......B............

6. Is this paper A. Properly organized? **yes no** ......yes............
B. To the point and concise? **yes no** ......no............
C. Written clearly using correct grammar? **yes no** ......yes............

Please explain your answers to item 6A – C briefly.

7. Are the approach, results and conclusions intelligible from the abstract? **yes no** ......yes........

8. Is the title informative and a reflection of the content? **yes** **no** ……yes……..

9. Are the illustrations/tables A. Useful and all necessary? **yes** **no** ……yes……
B. Of good quality? **yes** **no** ……yes……
Please explain your answers to item 9A – B briefly.

10. Is the referencing relevant, up to date and accessible? **yes** **no** ……yes……..

11. Overall quality of the work: **A** **B** **C** **D** ………B……….

12. Can you suggest any improvements to the paper or any parts that could be shortened or removed? [use separate sheet of paper if necessary to answer this]

It is better if the author put the formula how to calculate the amount of sedimentation and erosion and write the result concisely. There are many items explained in the discussion which is not author's result.

13. Reviewer's decision:

A. Minor revision	………A…………….
B. Moderate revision	…………………….
C. Major revision	…………………….
D. Rejected	…………………….

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

Abstract – This study is aimed to document and elucidate the delta evolution during 1922-2022 of Jeneberang river, South Sulawesi by analyzing the transport of sediment in and out of the river. 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 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022 by dividing once every 50 to 2 years so that the delta pattern changes can be simulated using ArcGIS software and sedimentation and erosion can be estimated. This study shows 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 delta occurred due to landform migration and river migration. 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 landform had 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's sedimentary supply stalled to the north due to watergate construction which caused the concentration of migration to lead to the southern estuary. Tides then became a major factor in 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 5 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.

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

[INTRODUCTION]

In Seybold (2007) and Singh (1989), the word ‘‘delta’’ derived from the Greek can be defined as a coastal sedimentary deposit with each sub-aerial and sub-aqueous component. It's formed by river borne sediment which is deposited at the edge of a standing water, in maximum instances 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 (Bhattacharya, 1992; Coleman & Wright, 1975; Orton & Reading, 1993; Wright, 1985). This complex interplay of unique methods and conditions effects in a massive range of various patterns according to the local situations. Coleman & Wright (1973;

1975) described depositional facies in deltaic sediments and concluded that they are resulted from a massive kind of interacting 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 can affect erosion and sedimentation are changes in the function of land cover from forest areas or green land to target areas that will affect the rate of erosion and sedimentation in the area and cause inundation in the surrounding area which can also be called flooding (Alimin et al., 2017; Negoro & Cholil, 2018; Seybold et al., 2007). 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. What is more, it is often an important issue, especially in the surrounding areas where there is human activity. Sedimentation is the process of sediment deposition caused by water, wind or ice. Sedimentation is a dynamic process. In the event of an increased supply of sedimentary loads in coastal environments, silting occurs on the coast (Holden & Joseph, 2005).

Jeneberang river delta is a land formed at the mouth of Jeneberang river located in the west of Makassar City with a length of 75-80 km. Jeneberang river is one of the major rivers in South Sulawesi with a dendritic pattern. The upper reaches of Jeneberang river are on Mount Bawakaraeng in Gowa Regency, while the lower reaches are to the Makassar Strait (Whitten et al., 1987; Sakka et al., 2011). At the mouth of Jeneberang river is formed a delta that constantly changes over time. Apart from being a catchment area, Jeneberang river delta area has been intensively developed since 2000 for settlements, business centers and marine tourism. For the purposes of coastal management planning, study on delta evolution is needed at aiming to document and record historical data on evolution in the Jeneberang river delta. No comprehensive studies on this theme have been done before. This study is crucial to monitor and manage the impact of the river and delta development. One of the methods to determine the delta evolution in the study area is to calculate sedimentation and erosion using Landsat imageries to understand the landform migration, river pattern changes, and to classify the delta type.

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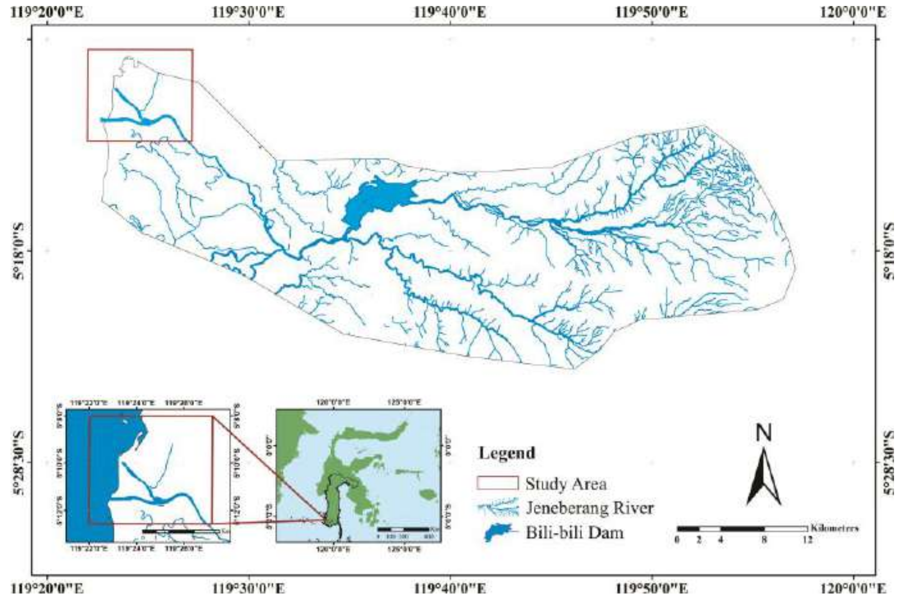

Figure 1. Location map of the study area (red color square), a part of the Jeneberang river system. The maps were generated using ArcMap from ArcGIS Desktop 10.8

[DATA AND METHODOLOGY]

This study took place in Jeneberang river delta, which is administratively included in Makassar City, South Sulawesi Province, Indonesia (Figure 1). This study is performed by means of time series 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 40 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 (Alesheikh et al., 2007; Lu et al., 2004; Muskananfola, 2020; Singh, 1989), which can be applied to time series satellite imagery.

The data used in this study are images for 1922, 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022, as well as rainfall data (Table 1). Data collection is 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 ArcGIS software. The limited data in this study caused the suboptimal digitization process of Landsat data, due to the lack of existing image quality. 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.

Table 1. Data type and data sources in this study

Data	Source
1922 image map	Topography of Dienst (Batavia)
1972 image map	Landsat 1 (Musical group 754)
1981 image map	Landsat 2 (Bands 754)
1991 image map	Landsat 5 (Musical group 754)
2000 image map	Landsat 7 (Musical Group 764)
2010 image map	Landsat 7 (Musical Group 764)
2020 image map	Landsat 8 (Band 754)
2022 image map	*Google Earth Pro*
Rainfall	Jeneberang Kampili River Station

Commented [A1]: What is musical group, is that mean FCC /False color composite? please explain, image map --raster map

[RESULTS & DISCUSSION]

Jeneberang river 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 the Makassar Strait. Jeneberang river is the main river in the watershed. Physiographically situated on the southern arm of Sulawesi Island, on the western slope of the Mount Lompobattang mountain range, a dormant stratovolcano-type volcano. The geological conditions of the 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 is comprised of marine and volcanic sedimentary rocks including breccias, lava, tuff and konglongmerat, whereas the Lombobattang Formation occupies in 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.

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Stream Development in Jeneberang Watershed

In the development of stream from Jeneberang watershed, there are 3 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 the 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 types is explained below.

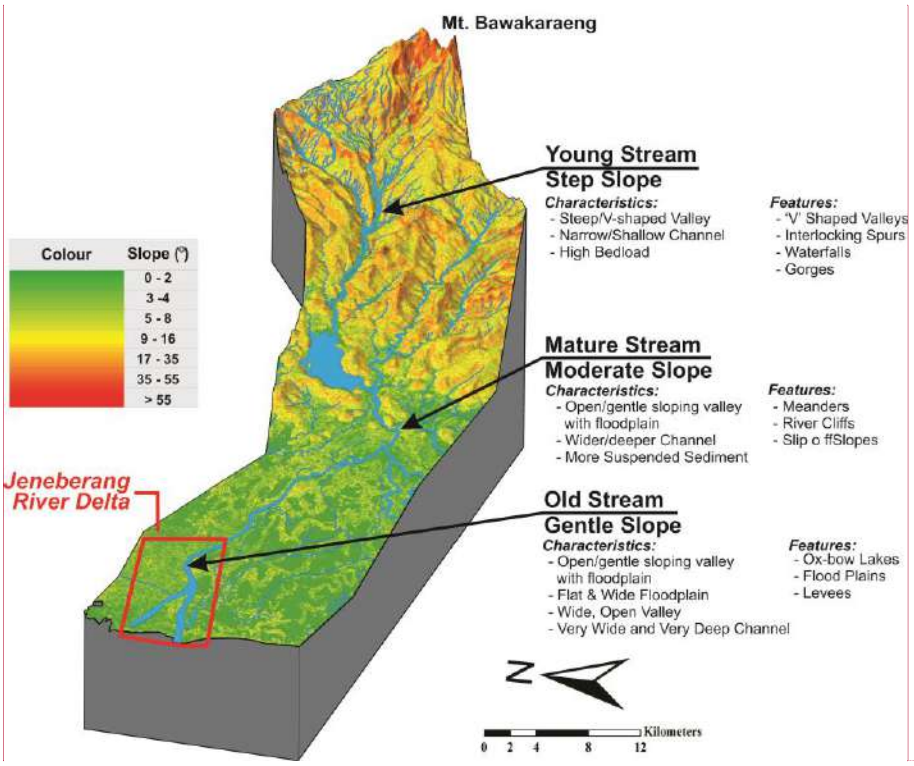

Figure 2. Stream development of the Janeberang watershed. The model is generated by using ArcMap from ArcGIS 10.8

(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. Aisyah et al. (2022) estimated amount of erosion in the upper Jeneberang watershed using the USLE equation in 2018 is 813.1 tons/m^2/year with an average permissible erosion value of 28.9 tons/ha/year. The highest estimated erosion is 5,160.2 tons/m^2/year in open land and the lowest is 3.8 tons/m 2/year in paddy fields. The application of land cover in the 2012−2032 Gowa

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Commented [A4]: The stream development part (a.b,c,d) shouldn't be too detail since it is someone else result, just put on the table what the concern of those two (erosion & sedimentation on each part of the stream). This part is your result analysis not others. Be concise

Regency Spatial Planning and Regional Planning scenario with soil conservation measures is the scenario with the lowest erosion estimate as land cover in watershed management in the upper Jeneberang watershed, with an average erosion estimate of 27.8 tons/m^2/year or 667,270 tons/year. This scenario was able to reduce the rate of erosion below the permissible erosion and produce sediments suspected to be below the target sediment by 96.58% of the existing conditions.

(b) Middle flow/mature stream

The center of the Jeneberang watershed is the 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 km^2 with a planned operating period of 50 years (Department of Public Works, 1989; JRBDP, 2004). The completion of the construction of this dam in 1999 causes sediment sedimentation (blockage) so that the downstream sedimentation rate stagnated compared to before construction. 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 m^3. The potential for sediment due to large enough avalanches will flow downstream if the rain intensity is high so that it is susceptible to high discharge concentrations. The condition of Jeneberang river which continues to drain sediment during flooding and settles along the river channel to the dam.

(c) Downstream/old stream

Downstream is the end part of Jeneberang watershed. In this part, a process of sedimentation, erosion, abrasion, and sediment migration are occurred. 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

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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 are then calculated in ArcMap 10.8 software to determine the area of sedimentation and erosion occurred. The processed data is divided into periods with a longtime span,

namely 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).

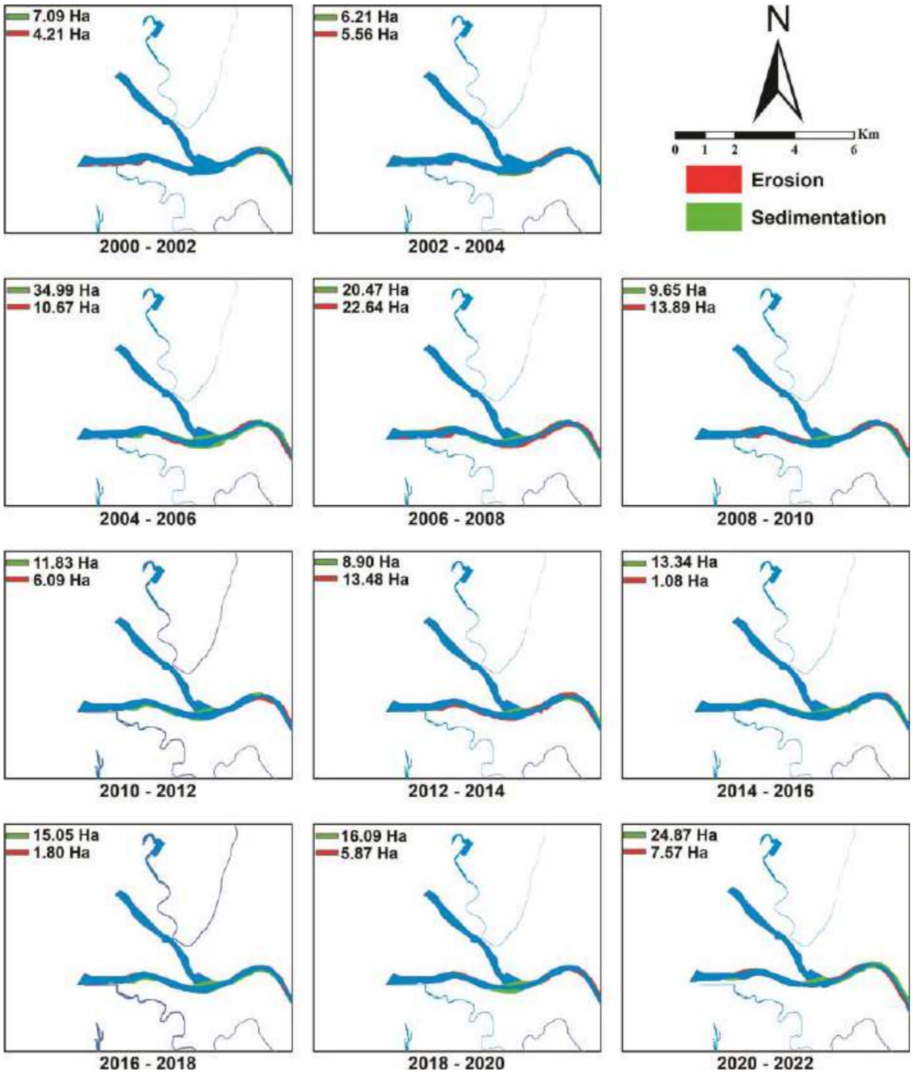

Figure 3. Sedimentation and erosion area map of the Jeneberang River. The map was generated by using ArcMap from ArcGIS 10.8

Commented [A6]: Please explain how to calculate erosion and sedimentation, what formula? If any, write it down

Figure 3 and 4 show that the initial sedimentation occurred in 2000-2002 with an area of about 7.09 ha then decreased and became the lowest sedimentation data 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 the 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 the Jeneberang river. The effect of sediment distribution is due to large rainfall in November 2004 to February 2005 (Table 2). The rain that occurs causes avalanche material to be carried away by rain and causes the amount of water discharge to increase. The influence of the 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 and 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.

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Erosion is not in harmony with sedimentation. The eroded area has increased and decreased. In 2000-2002 it had an erosion area of about 4.21 ha, then rose to the highest erosion in 2006-2008 with an area of approximately 22.64 ha, 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 occurs with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991 and 2000-2022 from the Kampili station (Table 2).

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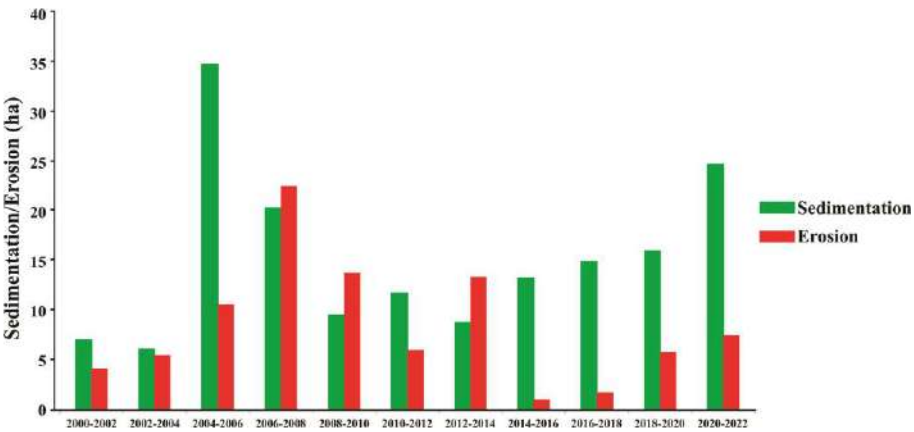

Figure 4. Histogram of sedimentation and erosion area of the Jeneberang river

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

Delta Evolution of Jeneberang River

Delta Landform Migration

The analysis evolution of Jeneberang delta uses Landsat imagery data for 1922, 1972, 1981, 1991, 2000. 2010, 2020 and 2020. The data were processed using the ArcMap 10.8 using 6 colors classification of legend including land, sediment, river, watergate, 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.

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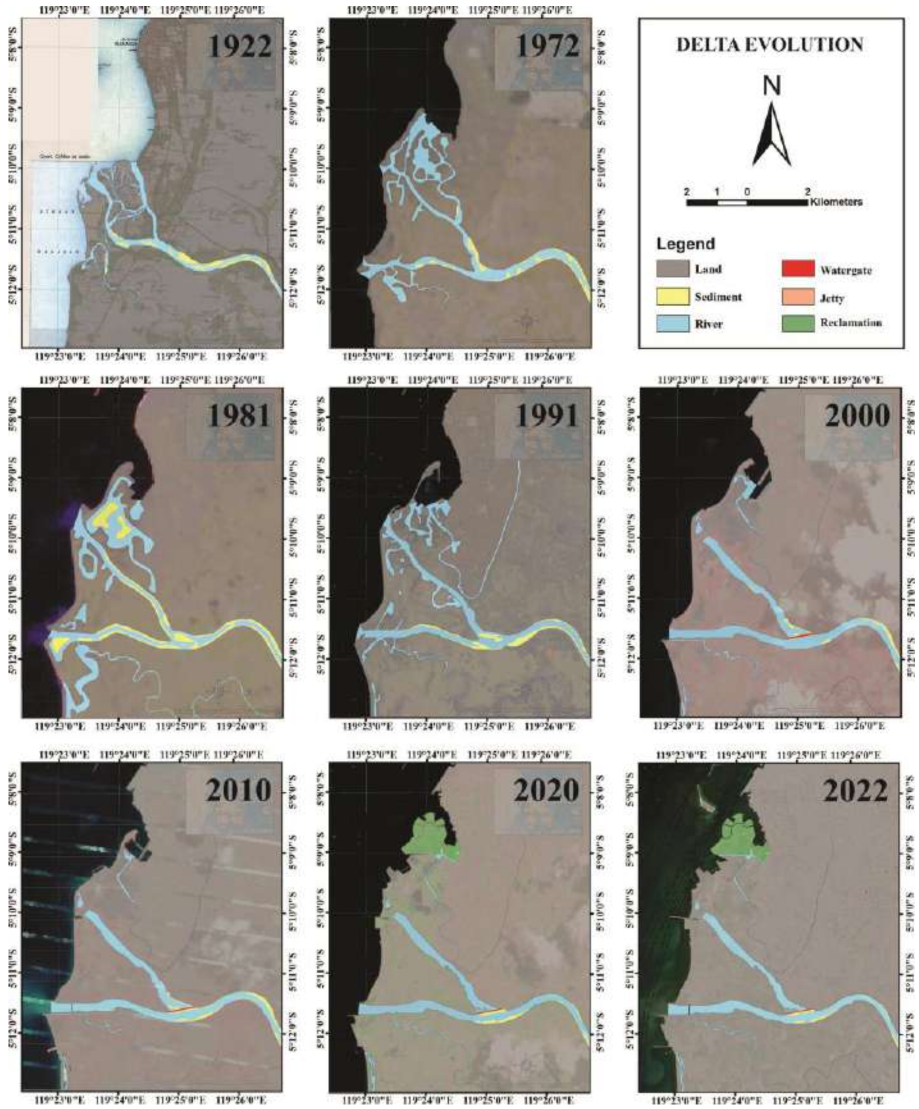

Figure 5. Delta landform migration of the Janeberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022. The map generated using ArcMap from ArcGIS 10.8

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**

1922 – 1972 Period

The Landsat image (1922-1972; Figure 6) is the initial data of sediment migration, during 50 years, with an area of about 5097.62 ha. The sediment migration occurred causing the delta to 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).

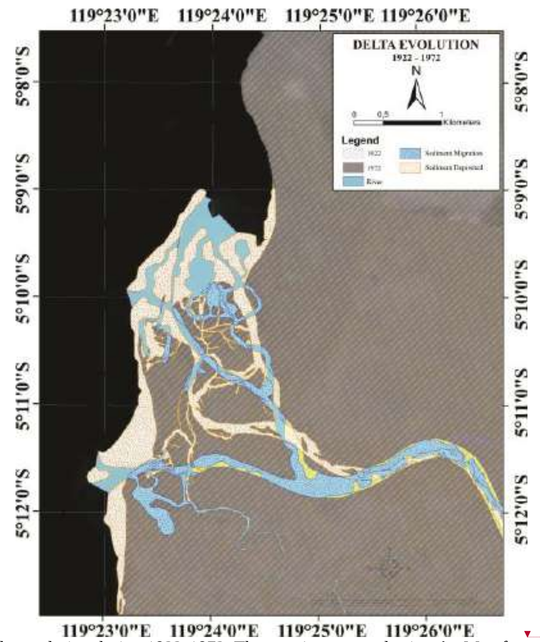

Figure 6. Delta evolution during 1922-1972. The map is generated using ArcMap from ArcGIS 10.8

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1972 – 1981 Period

Sediment migration occurred in the period from the beginning of 1972-1981 with an area of about 5373.40 ha. The migration occurred causing the delta to still develop relatively to the north to west with an area of 23.98 ha forming a delta with an area of 5349.42 ha in 1981 (Figure 7).

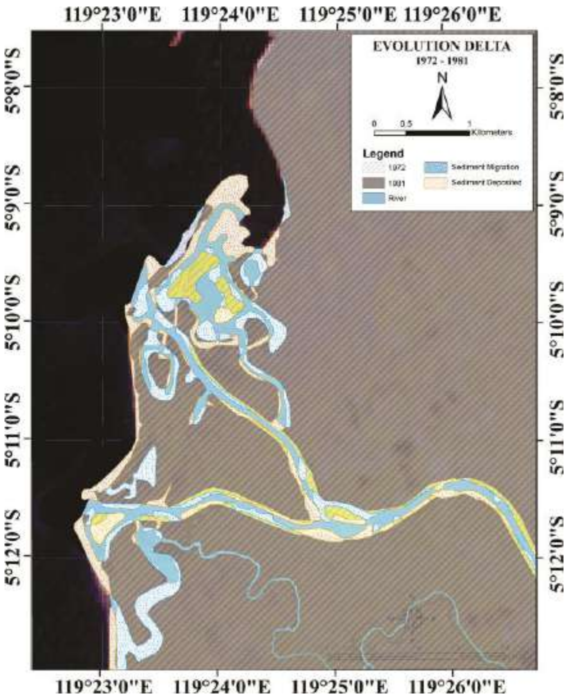

Figure 7. Delta evolution in 1972 - 1981. The map is generated using ArcMap from ArcGIS 10.8

1981 – 1991 Period

Sediment migration occurred in the period 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, forming a delta with an area of 5351.06 ha in 1991 (Figure 8).

1991 – 2000 Period

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

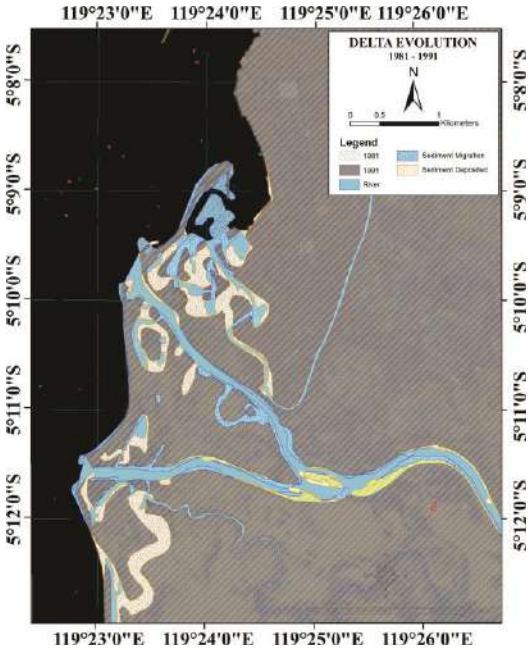

Figure 8. Delta evolution in 1981-1991. Map is generated using ArcMap from ArcGIS 10.8

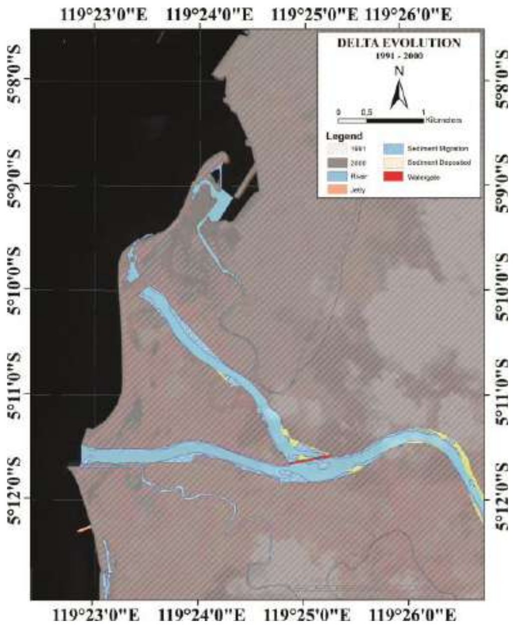

Figure 9. Delta evolution in 1991-2000. The map is generated by ArcMap from ArcGIS 10.8

2000 – 2022 Period

Sediment migration occurred in the 2000 period with an area of about 5586.56 ha. As a result of the construction of watergates in the northern estuary and jetties in the southern estuary, causing the sediment supply from the river to stagnate, so that migration is caused only from tides with an area of 69.23 ha, forming a delta with an area of 5655.79 ha in 2022 (Figure 10).

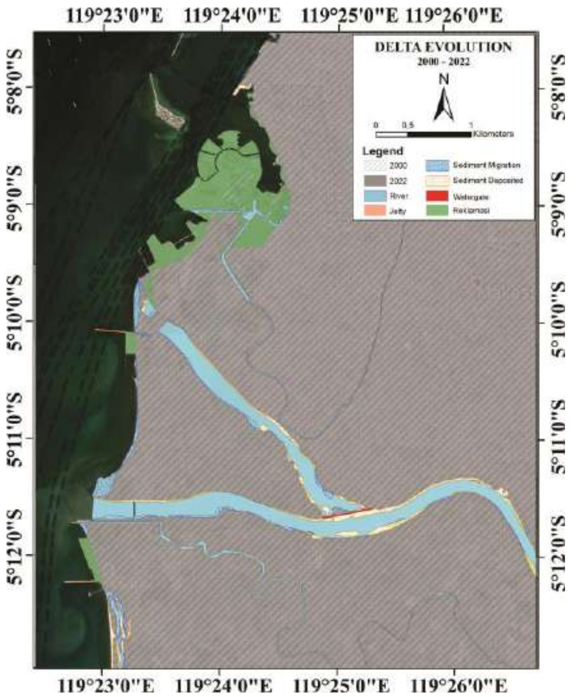

Figure 10. Delta evolution in 2000-2022. The map is generated using ArcMap from ArcGIS 10.8

Jeneberang River Migration Pattern

The significant evolution of the Jeneberang river is observed in 3 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 3 colors, namely blue reflecting a river, green is a migration or change of river, and red is the initial river (Figure 11 and Figure 12).

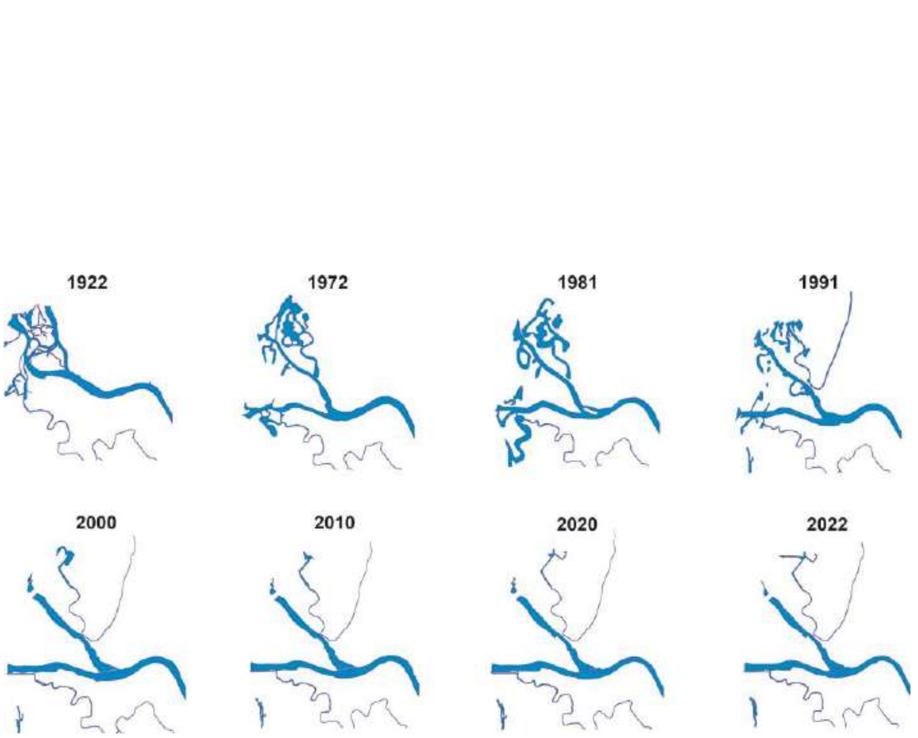

Figure 11. Evolution of the Jeneberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022. The map is generated using ArcMap from ArcGIS 10.8.

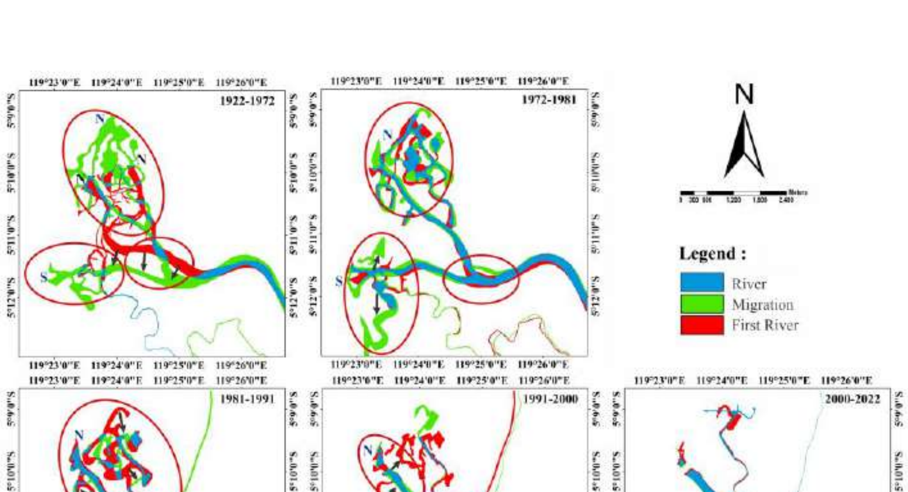

Figure 12. Migration and change of the Jeneberang river pattern from 1992-1972, 1981-1991, 1991-2000, to 2000-2022. The map is generated using ArcMap from ArcGIS 10.8

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, i.e. coordinates 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 occurs 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 to 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 are also branches of the river formed, and on the branches of the main river there are material deposits that cause the river flow to divide and then reconnect in the northern part. In 1981, a canal was built in the northern 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 to become a swamp.

1981-1991 Period

The period 1981-1991, sedimentation and erosion were controlled relative to the southwest and no longer spread so that in 1991 the existing river became narrower because it was covered with sediment and turned 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 so that in 1981 part of the river was covered with sediment.

1991-2000 Period

During this period, human activity seems to begin influencing the concentration of material sedimentation in Jeneberang delta. A tributary in the northern part and then separated from

Jeneberang river with the construction of sluices at the junction of the river and the northern estuary so that the sedimentation of sediment from Jeneberang river. The river is no longer going to north but is concentrated to the southern estuary. At the junction of the river in 1995 a sluice was built so that the sedimentation of sediment 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

This period was observed continuing human activity in the use of the northern part of the delta for development. This is done by reclaiming so that river erosion is strongly influenced by humans. 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, delta of the Jeneberang river is characterized 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 periods of 1922-1981. The sediment occurred in front of the river mouth is commonly typified by fine-grained sand to clay, which also coincides with previous studies conducted by Bhattacharya (1992), Orton (1993) and Wright (1985) in other deltas. Moreover, the existence of the Tanjung Bunga spit in the northern part supports this phenomenon (Langkoke, 2011). Based on the mentioned characteristics, delta of the 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 13; modified from Galloway, 1975 in Bhattacharya, 1992).

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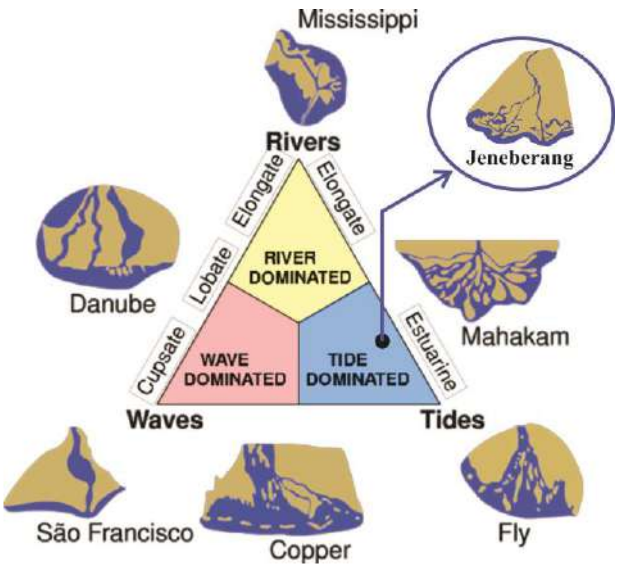

Gambar 13. Jeneberang river delta classified into tide-dominated/ estuarine type (modified from Galloway, 1975 in Bhattacharya, 1992)

[CONCLUSIONS]

This study indicates that the Jeneberang river delta is very dynamics and underwent pattern evolution over the periods. The delta evolution is strongly controlled by sedimentation and erosion factors. 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. Landform migration occurred gradually starting in 1922-1981, where the direction of migration is relative to west led to migration and resulted a delta landform formation with an area of 5349.42 ha. Since 1981-2000 the development of landforms is no longer but sediment migration still occurred 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 watergate construction which led to migration concentrations leading to the southern estuary. Tides became to be a major factor in sediment migration, although the tides roles were not so intensive as before with additional delta formation with an area of 5655.79 ha.

The Jeneberang river evolution occurs naturally and 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 estuary delta, which is predominantly influenced by tides during its formation.

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Dear Editor-in-Chief of IJOG,

Please kindly find two files attached below: (1) revised and annotated file of our manuscript submitted to IJOG; and (2) a file of Responses to Reviewers. It is informed that we have revised by following all of the reviewers corrections and suggestions. Please kindly note that Responses to Reviewer 1 is highlighted in yellow, whereas the one for Reviewer 2 is highlighted in green.
We do hope that our manuscript could proceed further as soon as possible.
We express our gratitude for your kind support and cooperation.

Sincerely,
Rohaya Langkoke

Pada tanggal Sen, 8 Mei 2023 pukul 14.01 IJOG GEOLOGI <ijog.geologi@gmail.com> menulis:

> Yth. Penulis,
>
> Berikut kami lampirkan komentar dari 2 reviewer untuk makalah berjudul : "Geospasial Analysis for Delta Evolution of Jeneberang River in Makassar, South Sulawesi, Indonesia".
>
> Kami tunggu perbaikannya.
>
> Salam,
> IJOG
>
> Revised_IJOG_fullpaper_Jeneberang_Langkoke_2023...

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Responses to the Reviewers

Reviewer 1 (highlighted by yellow):

1. The explanation of the research results in the explanation of the research results in the abstract is too long, not comparable to the explanation of the background/objectives and research methods which are to short.
   Answer: It has been changed for the purpose and method of research. The results do highlight the processed sedimentation data based on the landsat data used.

2. In the introduction, there is no explanation about the importance of geospatial and why to use satellite imagery (landsat) data in this analysis.
   Answer: Added

3. All maps used in this paper must have a citation.
   Answer: Added

4. the Landsat data used has different spatial resolutions, there is no information on how to solve this problem for area calculation.
   Answer: Landsat 5, Landsat 7 and Landsat 8 before being compared to Landsat 1 and Landsat 2, first downgrade the resolution to 60 meters.

5. How to equate the Landsat coordinates and the Batavia map should be explained. Because this is very influential on the calculated area.
   Answer: Added

6. Landsat data acquisition time should be shown in more detail, with the date and month.
   In addition, there is no explanation why bands 754 and 764 are used.
   Answer: Composite Band aims to get a clear visualization of the differences in the appearance of water bodies and land. Band Choice refers to: https://www.usgs.gov/faqs/what-are-best-landsat-spectral-bands-use-my-research

   Different band names in each type of landsat imagery cause the composite bands in each type of imagery to be different.

   Comparison of Band of Landsat 8, Landsat 7, Landsat 5, Landsat 2 and Landsat 1.

Band Name	Landsat 8	Landsat 7	Landsat 5	Landsat 2	Landsat 1
Coastal aerosol	1				
Blue	2	1	1		
Green	3	2	2	**4**	**4**
Red	**4**	**3**	**3**	**5**	**5**
Near Infrared (NIR)	**5**	**4**	**4**	6	6
Shortwave Infrared (SWIR) 1	6	5	5		
Shortwave Infrared (SWIR) 2	**7**	**7**	**7**	7	7
Panchromatic	8	8	8		
Cirrus	9				
Thermal Infrared (TIRS) 1	10	6	6		
Thermal Infrared (TIRS) 2	11				

7. Landsat and Google Earth data with very different spatial resolutions will not be comparable for area comparison.
Answer: The source of data has been changed to landsat

8. The determination of young, mature and old streams is based on previous research or your own opinion?
Answer: The theory is based on existing research, and the determination is done by yourself.

9. For example, there is a slope of 2.5 degrees, which class will it be in?
Answer: Class division is based on direct field data, which is generally not decimal

10. This model is created using DEM data for which there is no explanation.
all data used must be cited
Answer: Added

11. too many sentences: generated by using ArcMap from ArcGIS 10.8. It is better to explain at the beginning that all data is generated by using ArcMap from ArcGIS 10.8.
All maps must have coordinates
Answer: It has been adjusted. Figure 3 is not a map, but a model

12. Table 2 would be helpful if there was a histogram like Figure 4, so that we can easily see the effect of high rainfall on high erosion and sedimentation.
Answer: Added

Reviewer 2 (highlighted by green):

1. What is musical group, is that mean FCC /False color composite? please explain, image map --raster map
   Answer: The words Music Group should be changed to Band
   Landsat 7 (Musical Group 764) changed to Landsat 7 (Band 743)
   Landsat 1 (Musical Group 764) changed to Landsat 1 (Band 743)

2. Consists of … (what rocks formation)
   Answer: The formation in the redaction of the sentence is appropriate

3. Add é' in figure 2 for Young Stream /Steep slope - edit figure
   Answer: *Step* Slope has been changed to *Steep Slope*

4. The stream development part (a.b,c,d) shouldn't be too detail since it is someone else result, just put on the table what the concern of those two (erosion & sedimentation on each part of the stream). This part is your result analysis not others. Be concise
   Answer: The explanation of each section has been made more concise

5. This is the author's result
   Answer: The paragraph is the result of the author except the last sentence.

6. Please explain how to calculate erosion and sedimentation, what formula? If any, write it down
   Answer: The sedimentation and erosion were then reviewed by comparing data from different years, The changes are then calculated in ArcMap 10.8 software to determine the area of sedimentation and erosion occurred

7. Write the general trend of sedimentation over the time period according to the graph in fig.4)
   Answer: The sedimentation trend in the Jeneberang River changes up and down in each period. So that the discussion is made more concise by not discussing sedimentation changes in each period.

8. It is better in the new paragraph
   Answer: The discussion of erosion analysis is already in the new paragraph.

9. What kind of classification: supervised or unsupervised, both are mention in ArcGIS tool.
   Answer: The color determination for legends does not use a specific classification. The color of each legend needs to be distinguished to facilitate the reading of the map.

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

Abstract – This study is aimed to document and elucidate the delta evolution during 1922-2022 of Jeneberang river, South Sulawesi 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 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022 by dividing once every 50 to 2 years so that the delta pattern changes. Data collection is done by downloading data via Landsat, data processing can be simulated using ArcGIS software and sedimentation and erosion can be estimated. This study shows 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 delta occurred due to landform migration and river migration. 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 landform had 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's sedimentary supply stalled to the north due to watergate construction which caused the concentration of migration to lead to the southern estuary. Tides then became a major factor in 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 5 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.

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

[INTRODUCTION]

In Seybold (2007) and Singh (1989), the word ‘‘delta’’ derived from the Greek can be defined as a coastal sedimentary deposit with each sub-aerial and sub-aqueous component. It's formed by river borne sediment which is deposited at the edge of a standing water, in maximum instances 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 (Bhattacharya, 1992; Coleman & Wright, 1975; Orton & Reading, 1993; Wright, 1985). This complex interplay of unique methods and conditions effects in a massive range of various patterns according to the local situations. Coleman & Wright (1973;

1975) described depositional facies in deltaic sediments and concluded that they are resulted from a massive kind of interacting 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 can affect erosion and sedimentation are changes in the function of land cover from forest areas or green land to target areas that will affect the rate of erosion and sedimentation in the area and cause inundation in the surrounding area which can also be called flooding (Alimin et al., 2017; Negoro & Cholil, 2018; Seybold et al., 2007). 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. What is more, it is often an important issue, especially in the surrounding areas where there is human activity. Sedimentation is the process of sediment deposition caused by water, wind or ice. Sedimentation is a dynamic process. In the event of an increased supply of sedimentary loads in coastal environments, silting occurs on the coast (Holden & Joseph, 2005).

Jeneberang river delta is a land formed at the mouth of Jeneberang river located in the west of Makassar City with a length of 75-80 km. Jeneberang river is one of the major rivers in South Sulawesi with a dendritic pattern. The upper reaches of Jeneberang river are on Mount Bawakaraeng in Gowa Regency, while the lower reaches are to the Makassar Strait (Whitten et al., 1987; Sakka et al., 2011). At the mouth of Jeneberang river is formed a delta that constantly changes over time. Apart from being a catchment area, Jeneberang river delta area has been intensively developed since 2000 for settlements, business centers and marine tourism. For the purposes of coastal management planning, study on delta evolution is needed at aiming to document and record historical data on evolution in the Jeneberang river delta. No comprehensive studies on this theme have been done before. This study is crucial to monitor and manage the impact of the river and delta development. One of the methods to determine the delta evolution in the study 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 imagery was chosen because this type of Landsat satellite imagery is the oldest satellite that is still operating today. So data with long time series can be obtained. The

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need for satellite data over a long period of time is needed to see changes that have occurred at the research location.

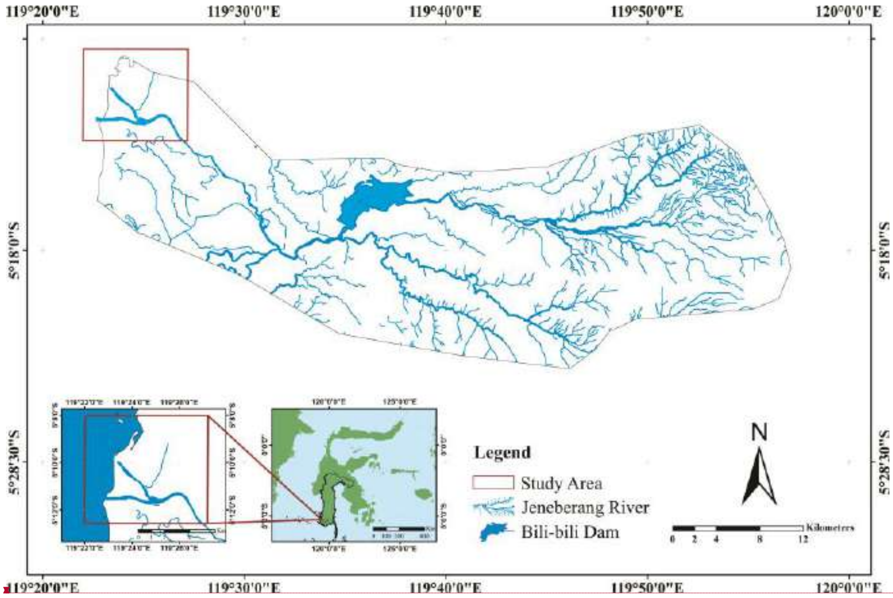

Figure 1. Location map of the study area (red color square), a part of the Jeneberang river system (Source: RBI Map, modified by author).

[DATA AND METHODOLOGY]

This study took place in Jeneberang river delta, which is administratively included in Makassar City, South Sulawesi Province, Indonesia (Figure 1). This study is performed by means of time series 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 40 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 (Alesheikh et al., 2007; Lu et al., 2004; Muskananfola, 2020; Singh, 1989), which can be applied to time series satellite imagery.

The data used in this study are images for 1922, 1922, 1972, 1981, 1991, 2000, 2010, 2020 and 2022, as well as rainfall data. (Table 1). Georeferencing Batavia map (scale 1: 50,000) is done using the image to image georeferencing method. The Ground Control Point (GCP) is taken from the coordinates of the crossroads seen on the Landsat 8 satellite with a resolution

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of 3 meters. Data collection is 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 image quality. 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.

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		

[RESULTS & DISCUSSION]

Jeneberang river 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 the Makassar Strait. Jeneberang river is the main river in the watershed. Physiographically, situated on the southern arm of Sulawesi Island, on the western slope of the Mount Lompobattang mountain range, a dormant stratovolcano-type volcano. The geological conditions of the 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 is comprised of marine and volcanic sedimentary rocks including breccias, lava, tuff and konglongmerat, whereas the Lompobattang Formation occupies in the upper part of the river. Jeneberang river delta is influenced by marine and

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fluvial processes including sedimentation and erosion of sedimentary material in Jeneberang river.

Stream Development in Janeberang Watershed

In the development of stream from Jeneberang watershed, there are 3 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 the 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 types is explained below.

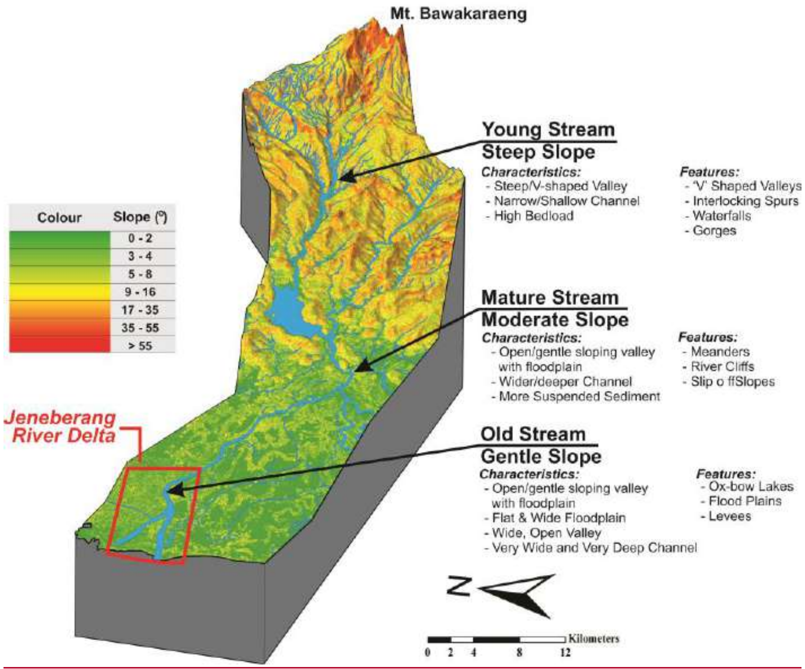

Figure 2. Stream development of the Janeberang watershed (Source: DEMNAS 2018, mofified by author).

(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

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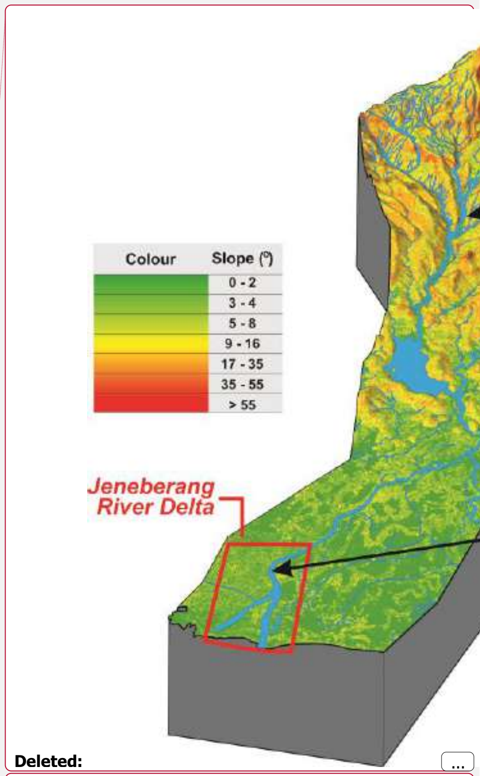

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(b) Middle flow/mature stream

In the middle flow, it has a slope with a range of 17-8 degrees and there is already a floodplain with material that is generally sandy to gravel in size. The center of the Jeneberang watershed is the 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 km^2 with a planned operating period of 50 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 m^3. The potential for sediment due to large enough avalanches will flow downstream if the rain intensity is high so that 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 are occurred. The downstream area has a low slope with a range of 0-5 degrees 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

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(Figure 3). The digitization of the image map displays the changes of the river patterns. The changes are then calculated in ArcMap 10.8 software to determine the area of sedimentation and erosion occurred. The processed data is divided into periods with a longtime span, namely 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).

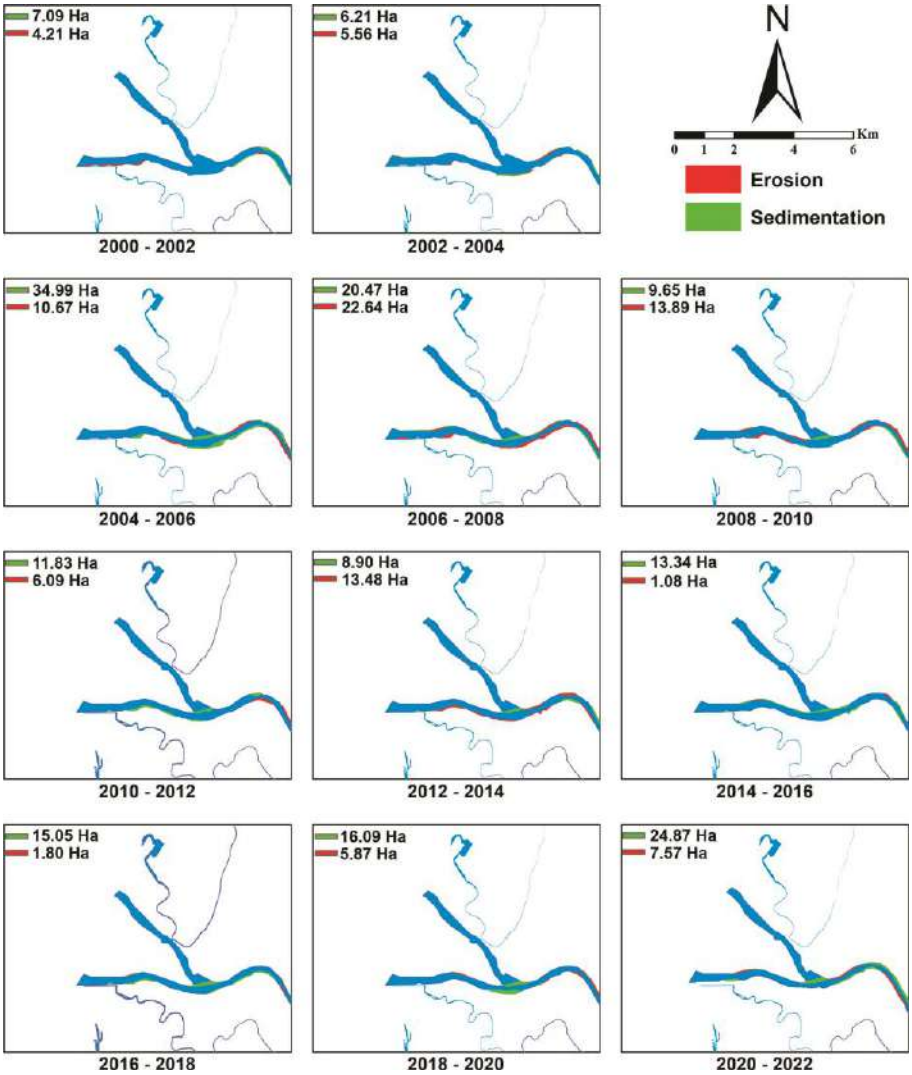

Figure 3. Sedimentation and erosion area of the Jeneberang River.

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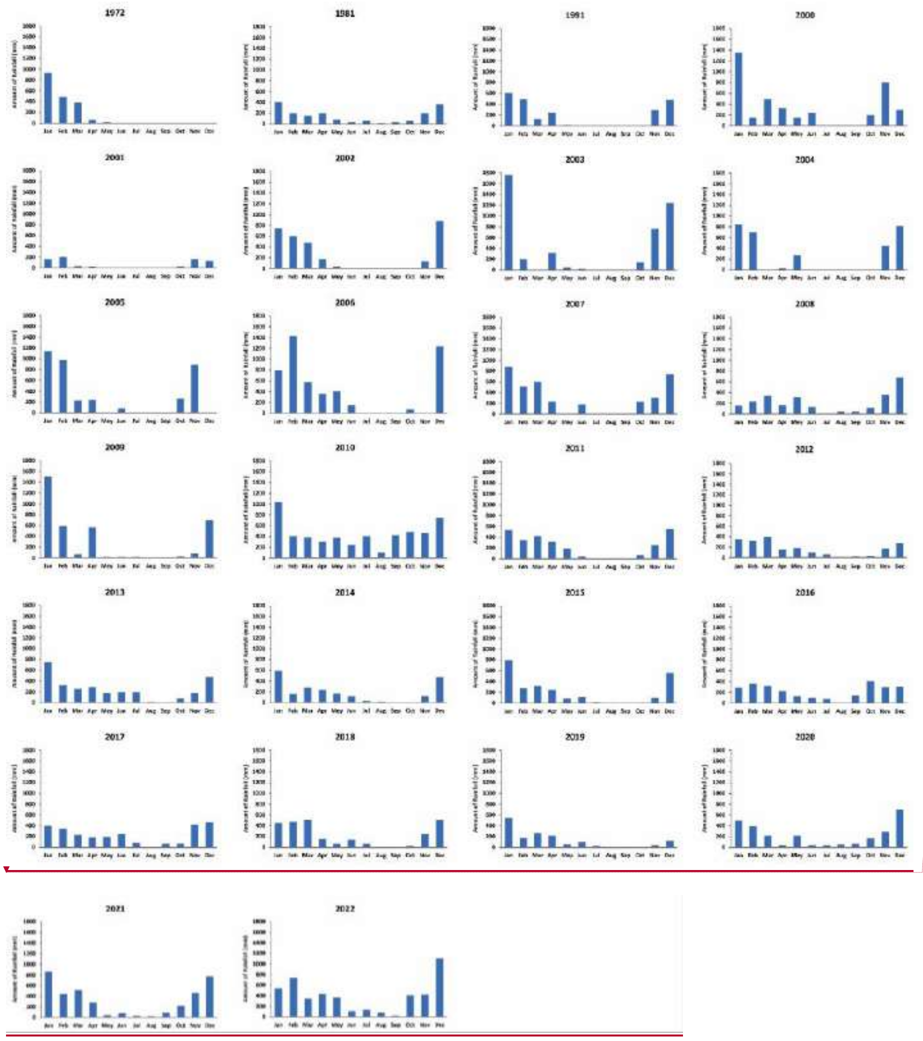

Figure 4. Rainfall diagram for Jeneberang Kampili River Station

Figure 3 and 4 show that the initial sedimentation occurred in 2000-2002 with an area of about 7.09 ha then decreased and became the lowest sedimentation data 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 the 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

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Commented [A7]: Write the general trend of sedimentation over the time period according to the graph in fig.4) downstream of the Jeneberang river. The effect of sediment distribution is due to large rainfall in November 2004 to February 2005 (Table 2). The rain that occurs causes avalanche material to be carried away by rain and causes the amount of water discharge to increase. The influence of the 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 and 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 it had an erosion area of about 4.21 ha, then rose to the highest erosion in 2006-2008 with an area of approximately 22.64 ha, 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 occurs with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991 and 2000-2022 from the Kampili station (Table 2).

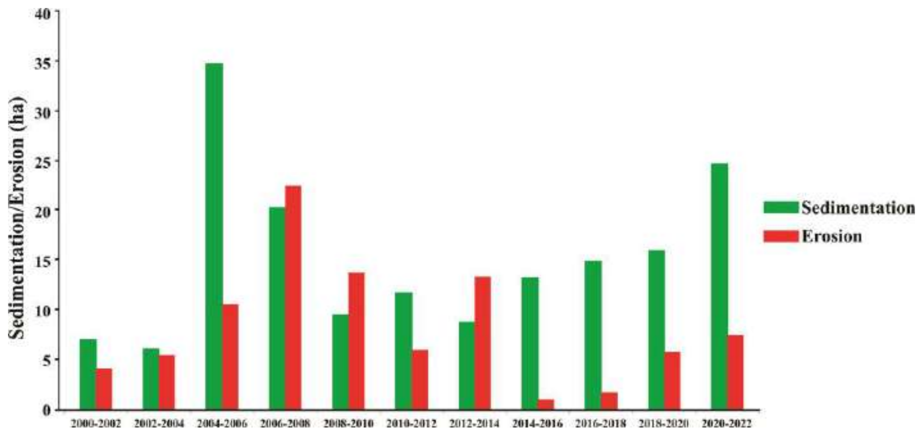

Figure 5. Histogram of sedimentation and erosion area of the Jeneberang river

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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

Delta Evolution of Jeneberang River

Delta Landform Migration

The analysis evolution of Jeneberang delta uses Landsat imagery data for 1922, 1972, 1981, 1991, 2000. 2010, 2020 and 2020. The data were processed using the ArcMap 10.8 using 6 colors classification of legend including land, sediment, river, watergate, 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.

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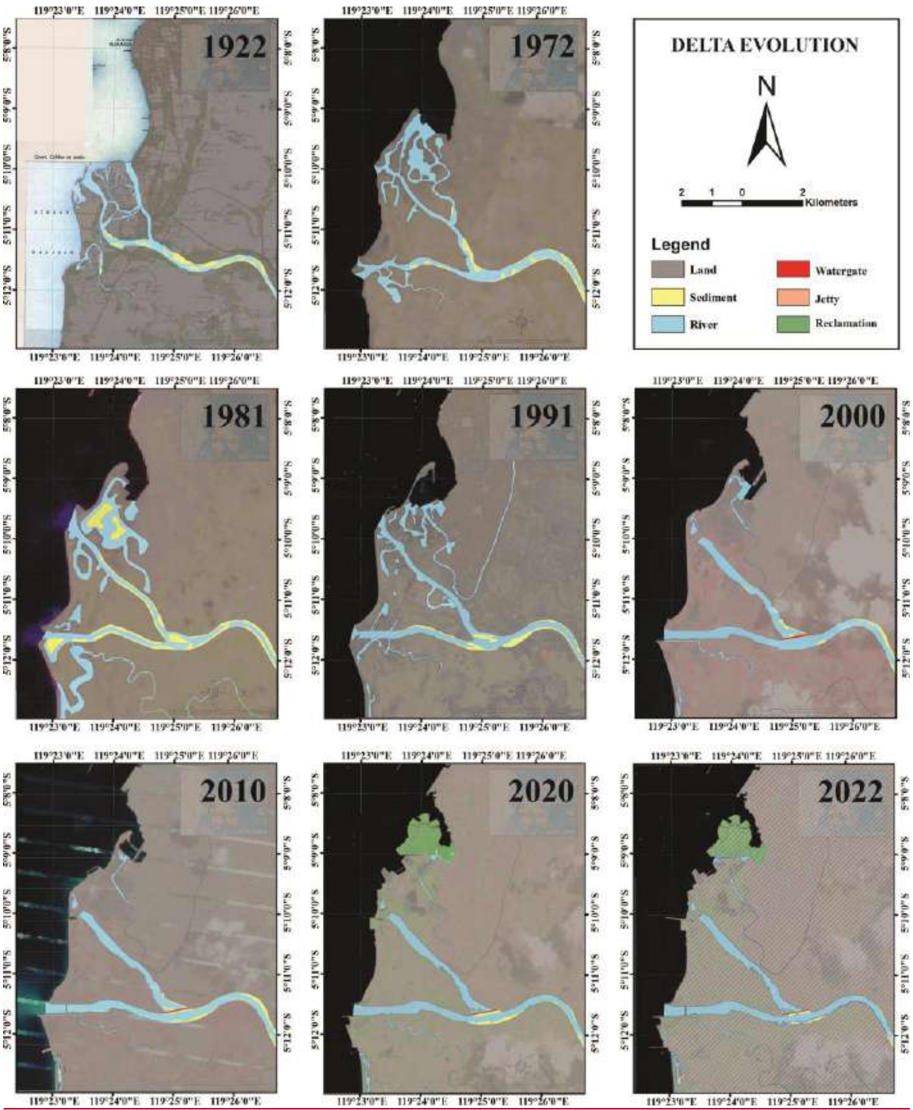

Figure 6. Delta landform migration of the Janeberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022.

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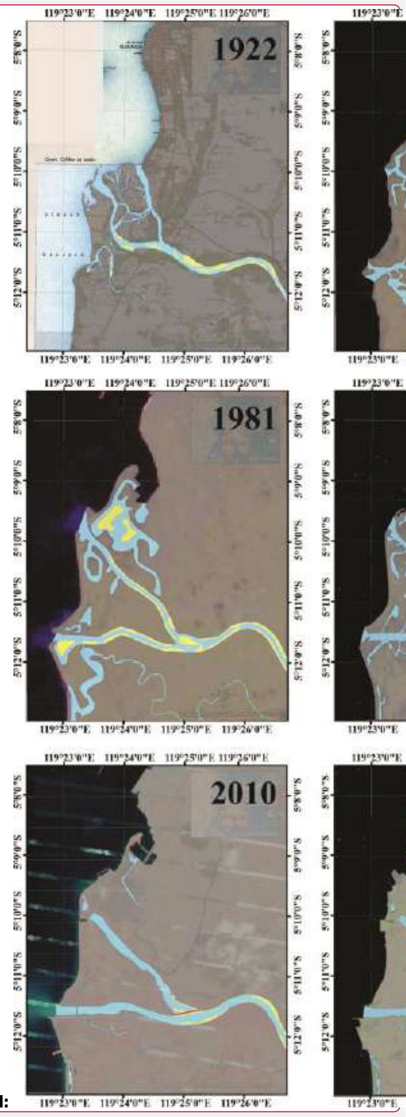

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Table 3. Delta landfrom migration data of the Jeneberang river

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**

1922 – 1972 Period

The Landsat image (1922-1972; Figure 6) is the initial data of sediment migration, during 50 years, with an area of about 5097.62 ha. The sediment migration occurred causing the delta to 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).

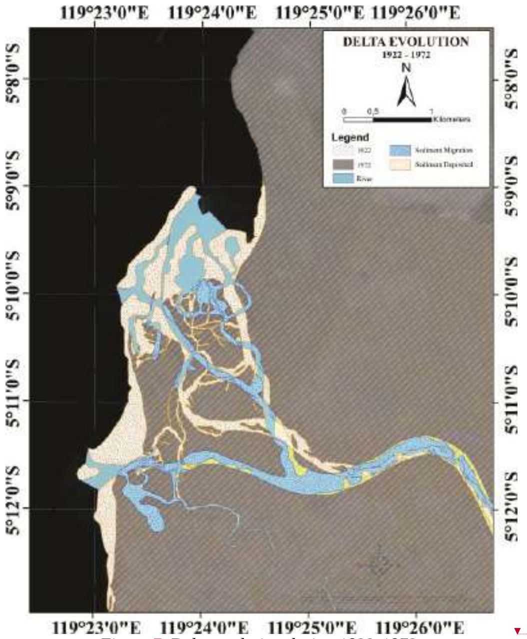

Figure 7. Delta evolution during 1922-1972

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1972 – 1981 Period

Sediment migration occurred in the period from the beginning of 1972-1981 with an area of about 5373.40 ha. The migration occurred causing the delta to still develop relatively to the north to west with an area of 23.98 ha forming a delta with an area of 5349.42 ha in 1981 (Figure 7).

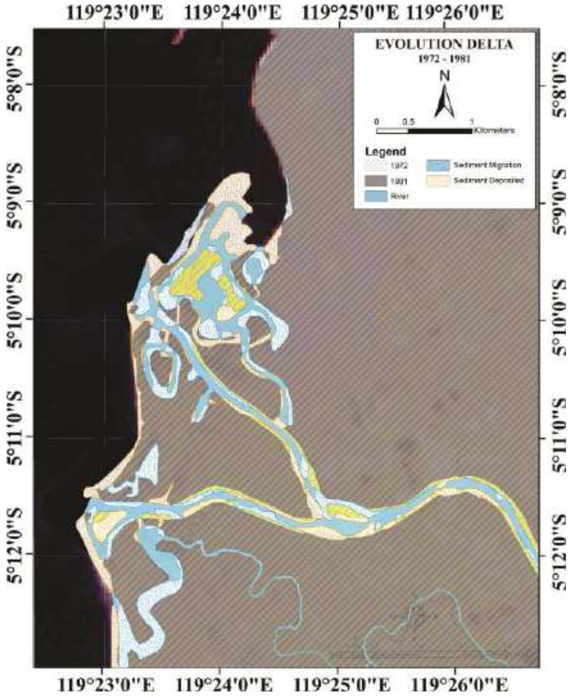

Figure 8. Delta evolution in 1972 - 1981.

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1981 – 1991 Period

Sediment migration occurred in the period 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, forming a delta with an area of 5351.06 ha in 1991 (Figure 8).

1991 – 2000 Period

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

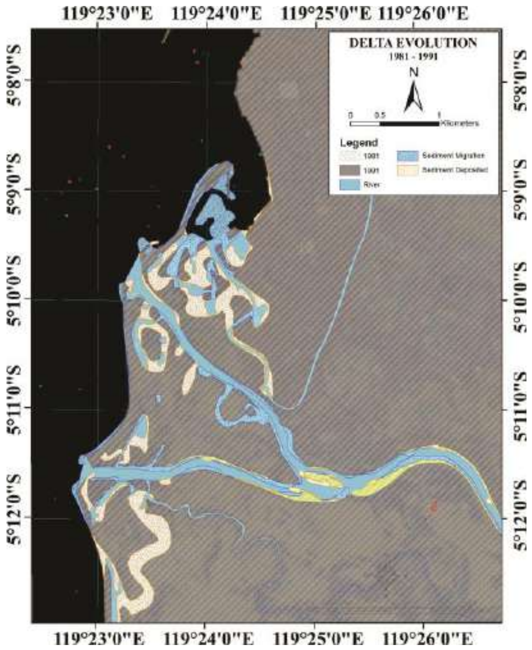

Figure 9. Delta evolution in 1981-1991.

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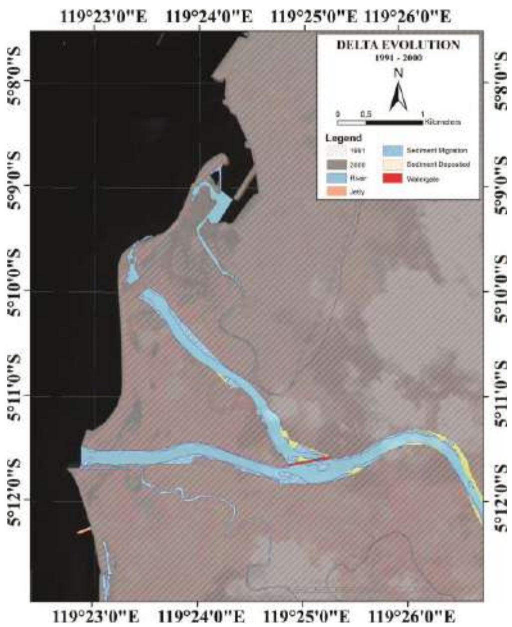

Figure 10. Delta evolution in 1991-2000.

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2000 – 2022 Period

Sediment migration occurred in the 2000 period with an area of about 5586.56 ha. As a result of the construction of watergates in the northern estuary and jetties in the southern estuary, causing the sediment supply from the river to stagnate, so that migration is caused only from tides with an area of 69.23 ha, forming a delta with an area of 5655.79 ha in 2022 (Figure 10).

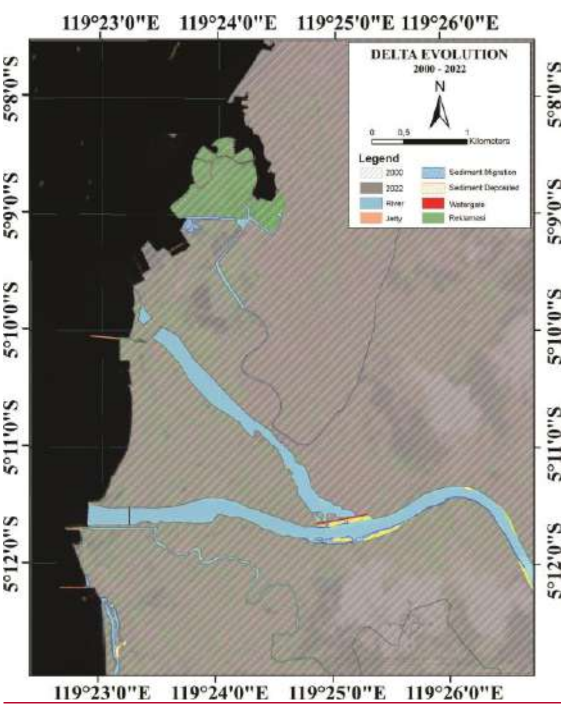

Figure 11. Delta evolution in 2000-2022.

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Jeneberang River Migration Pattern

The significant evolution of the Jeneberang river is observed in 3 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 3 colors, namely blue reflecting a river, green is a migration or change of river, and red is the initial river (Figure 11 and Figure 12).

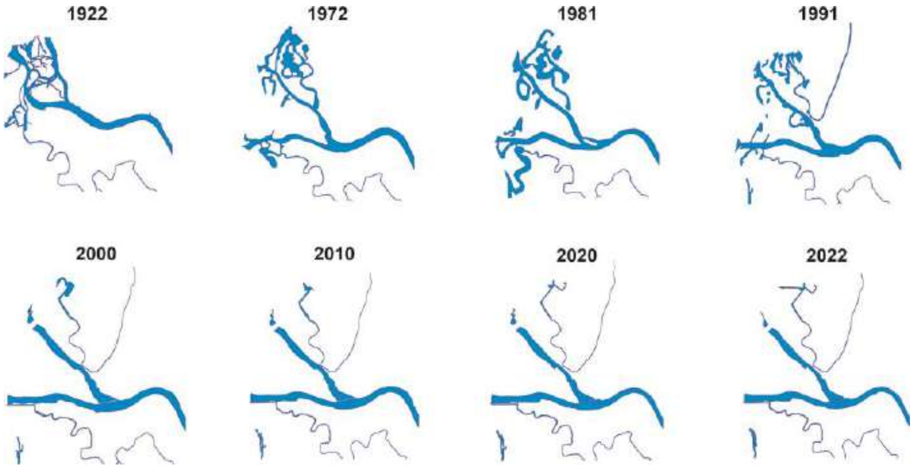

Figure 12. Evolution of the Jeneberang river from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022.

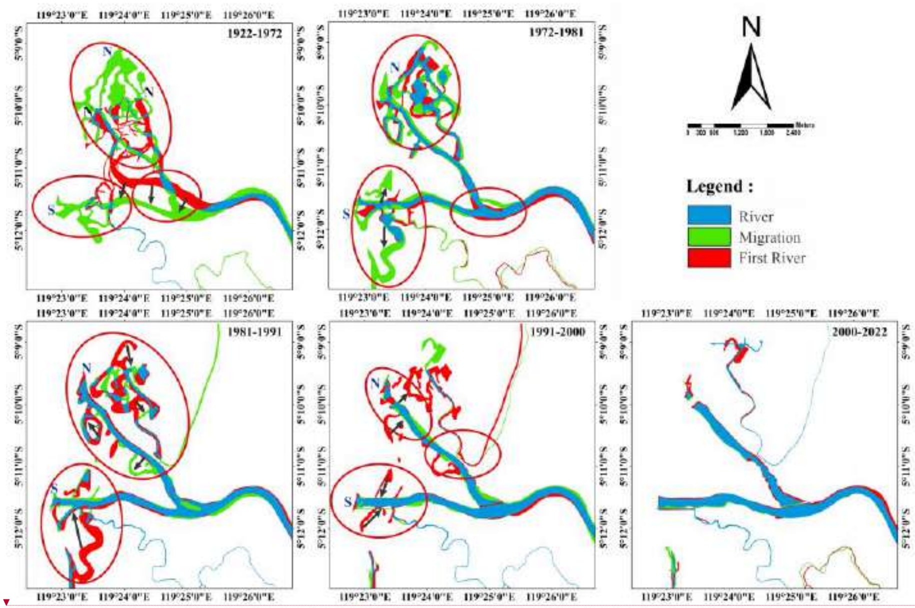

Figure 13. Migration and change of the Jeneberang river pattern from 1992-1972, 1981-1991, 1991-2000, to 2000-2022.

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

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with the branching of the river in a relatively similar direction. The branching of the river, i.e. coordinates 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 occurs 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 to 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 are also branches of the river formed, and on the branches of the main river there are material deposits that cause the river flow to divide and then reconnect in the northern part. In 1981, a canal was built in the northern 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 to become a swamp.

1981-1991 Period

The period 1981-1991, sedimentation and erosion were controlled relative to the southwest and no longer spread so that in 1991 the existing river became narrower because it was covered with sediment and turned 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 so that in 1981 part of the river was covered with sediment.

1991-2000 Period

During this period, human activity seems to begin influencing the concentration of material sedimentation in Jeneberang delta. A tributary in the northern part and then separated from Jeneberang river with the construction of sluices at the junction of the river and the northern estuary so that the sedimentation of sediment from Jeneberang river. The river is no longer going to north but is concentrated to the southern estuary. At the junction of the river in 1995 a sluice was built so that the sedimentation of sediment 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

This period was observed continuing human activity in the use of the northern part of the delta for development. This is done by reclaiming so that river erosion is strongly influenced by humans. 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, delta of the Jeneberang river is characterized 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 periods of 1922-1981. The sediment occurred in front of the river mouth is commonly typified by fine-grained sand to clay, which also coincides with previous studies conducted by Bhattacharya (1992), Orton (1993) and Wright (1985) in other deltas. Moreover, the existence of the Tanjung Bunga spit in the northern part supports this phenomenon (Langkoke, 2011). Based on the mentioned characteristics, delta of the 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 13; modified from Galloway, 1975 in Bhattacharya, 1992).

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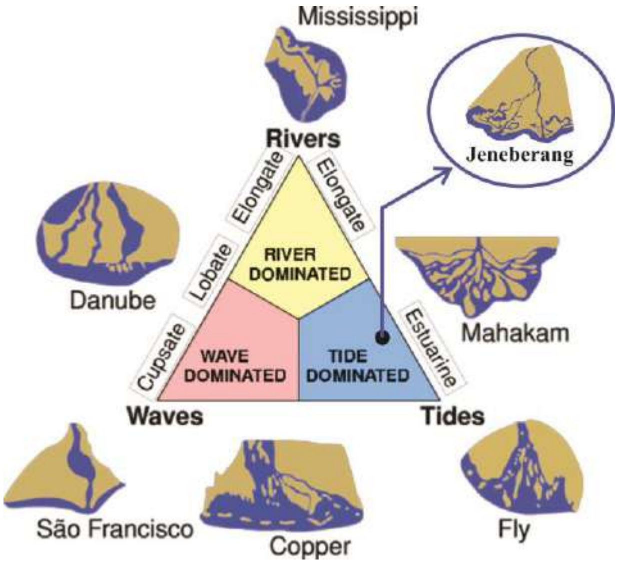

Gambar 14. Jeneberang river delta classified into tide-dominated/ estuarine type (modified from Galloway, 1975 in Bhattacharya, 1992)

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[CONCLUSIONS]

This study indicates that the Jeneberang river delta is very dynamics and underwent pattern evolution over the periods. The delta evolution is strongly controlled by sedimentation and erosion factors. 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. Landform migration occurred gradually starting in 1922-1981, where the direction of migration is relative to west led to migration and resulted a delta landform formation with an area of 5349.42 ha. Since 1981-2000 the development of landforms is no longer but sediment migration still occurred 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 watergate construction which led to migration concentrations leading to the southern estuary. Tides became to be a major factor in sediment migration, although the tides roles were not so intensive as before with additional delta formation with an area of 5655.79 ha.

The Jeneberang river evolution occurs naturally and 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 estuary delta, which is predominantly influenced by tides during its formation.

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Geospasial 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 1922, 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 a dynamic process of sediment deposition caused by water, wind, or ice. In the event of an increased supply of sedimentary loads in coastal environments, silting occurs on the coast (Holden and Joseph, 2005).

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; Muskananfola, 2020), which can be applied to time series of satellite imagery.

Tidak ada di daftar Referensi?

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

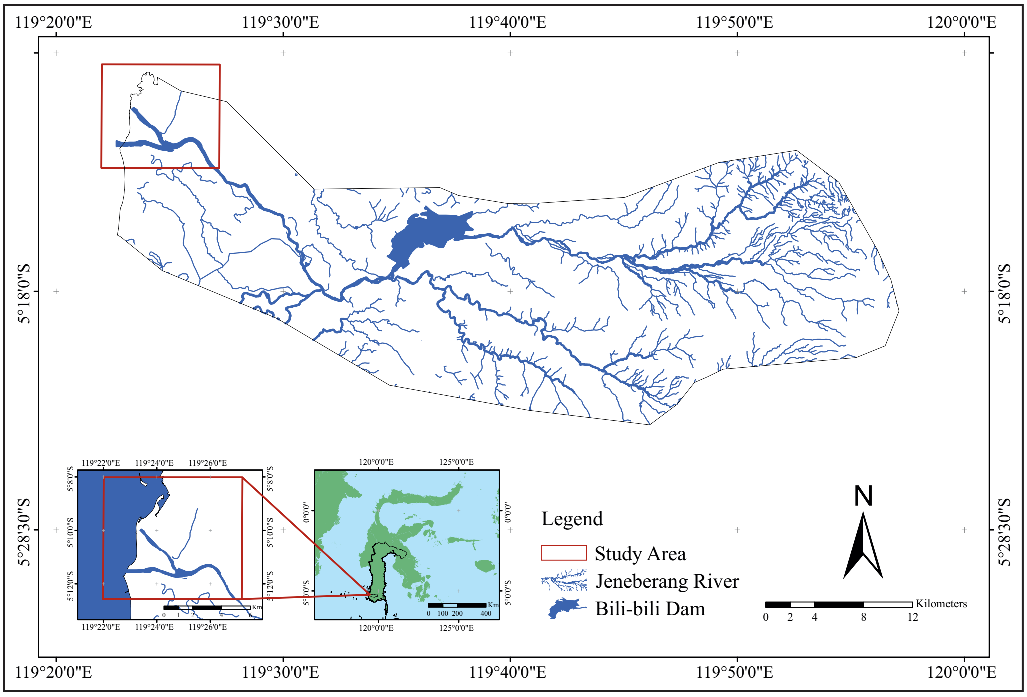

Figure 1. Location map of the studied area (red colour square), part of The Jeneberang River system (Source: RBI Map, modified by author).

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

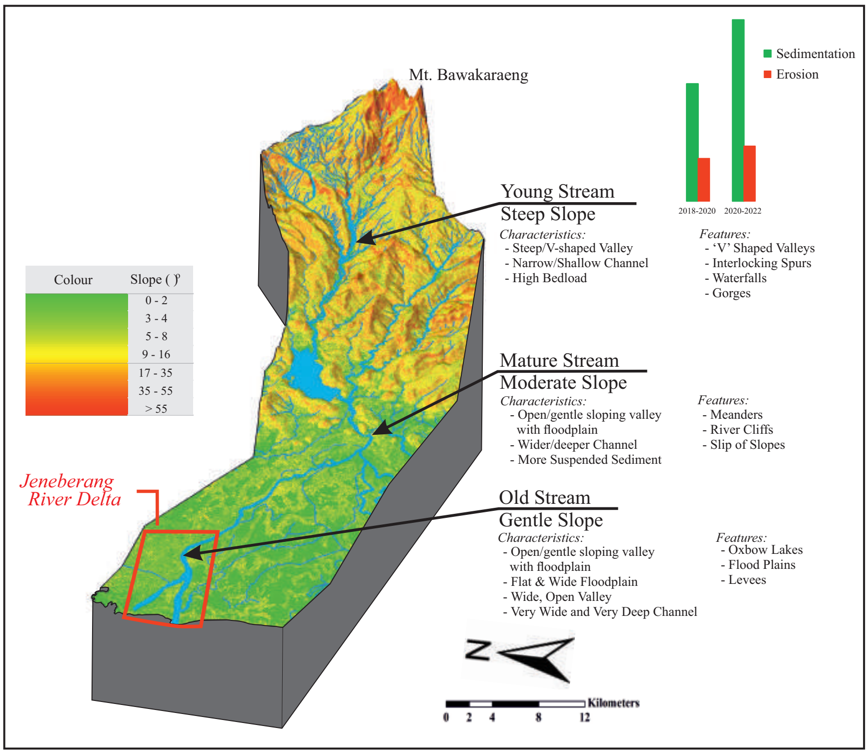

Figure 2. Stream development of the Jeneberang watershed (Source: DEMNAS, 2018, mofified by author).

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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/m^2/year with an average permissible erosion value of 28.9 tons/ha/year.

b. Middle flow/mature stream

Apakah ini 17 - 8° atau 8 - 17°??

In the middle flow, it has a slope with a range of 17 - 8°, 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 km^2 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 landuse 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 m^3. 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 occurrs. 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 occured with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991, and 2000 - 2022 from Kampili station (Table 2).

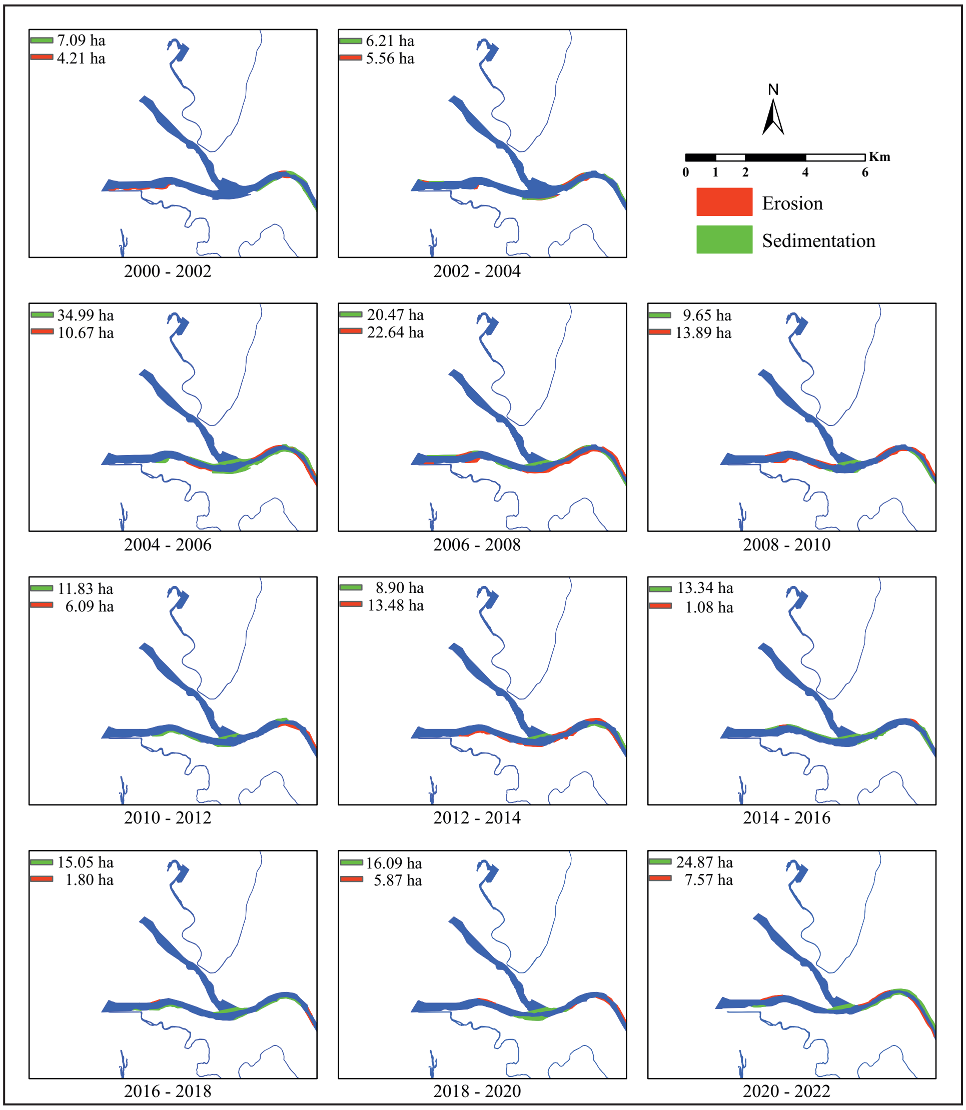

Figure 3. Sedimentation and erosion area of The Jeneberang River.

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

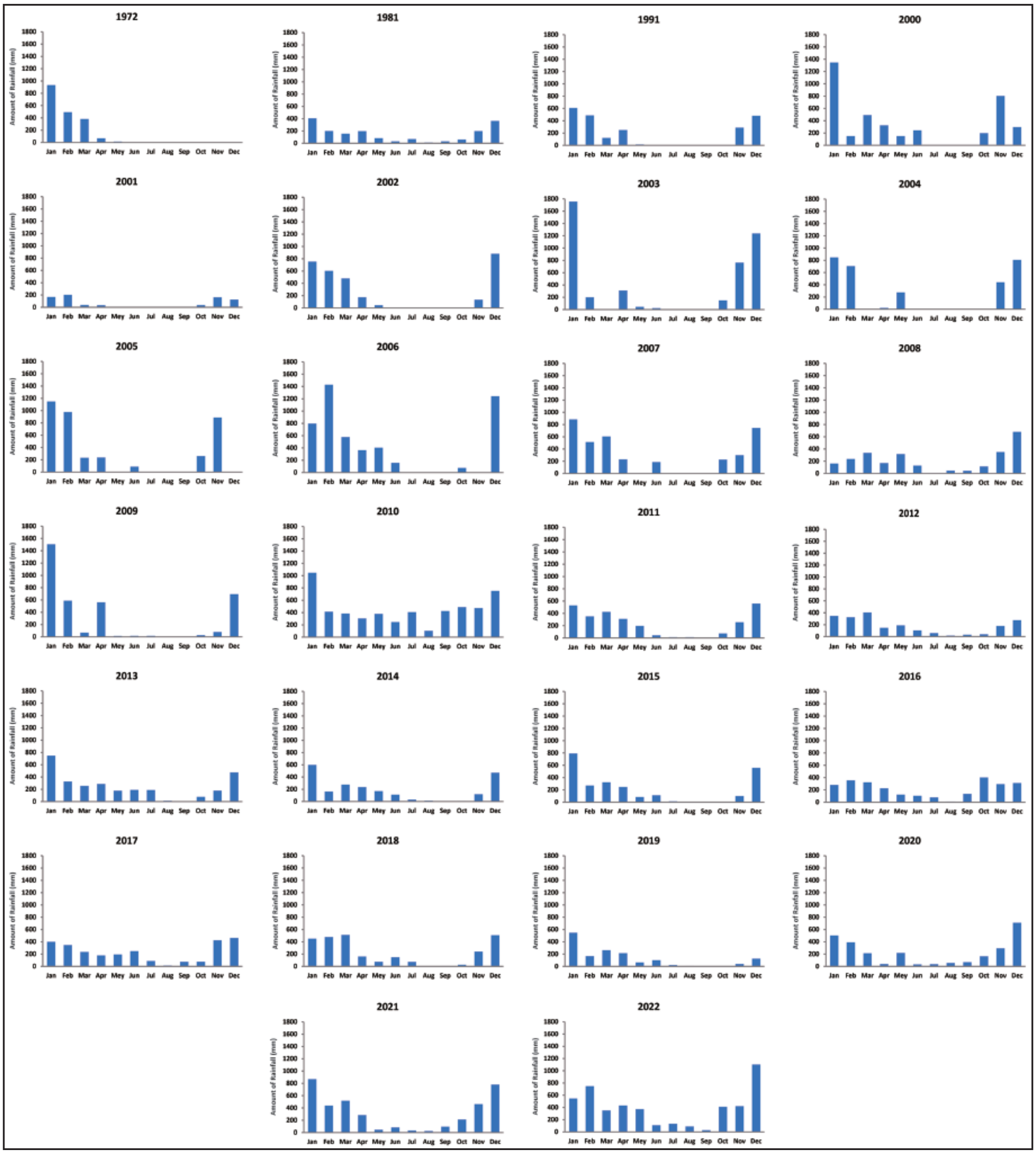

Figure 4. Rainfall diagram for Jeneberang Kampili River Station.

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

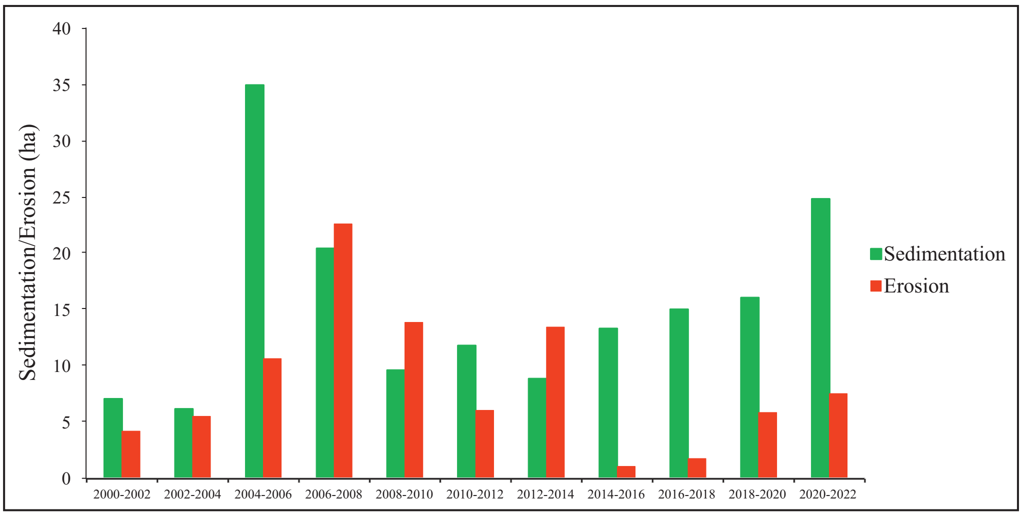

Figure 5. Histogram of sedimentation and erosion area of the Jeneberang River.

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).

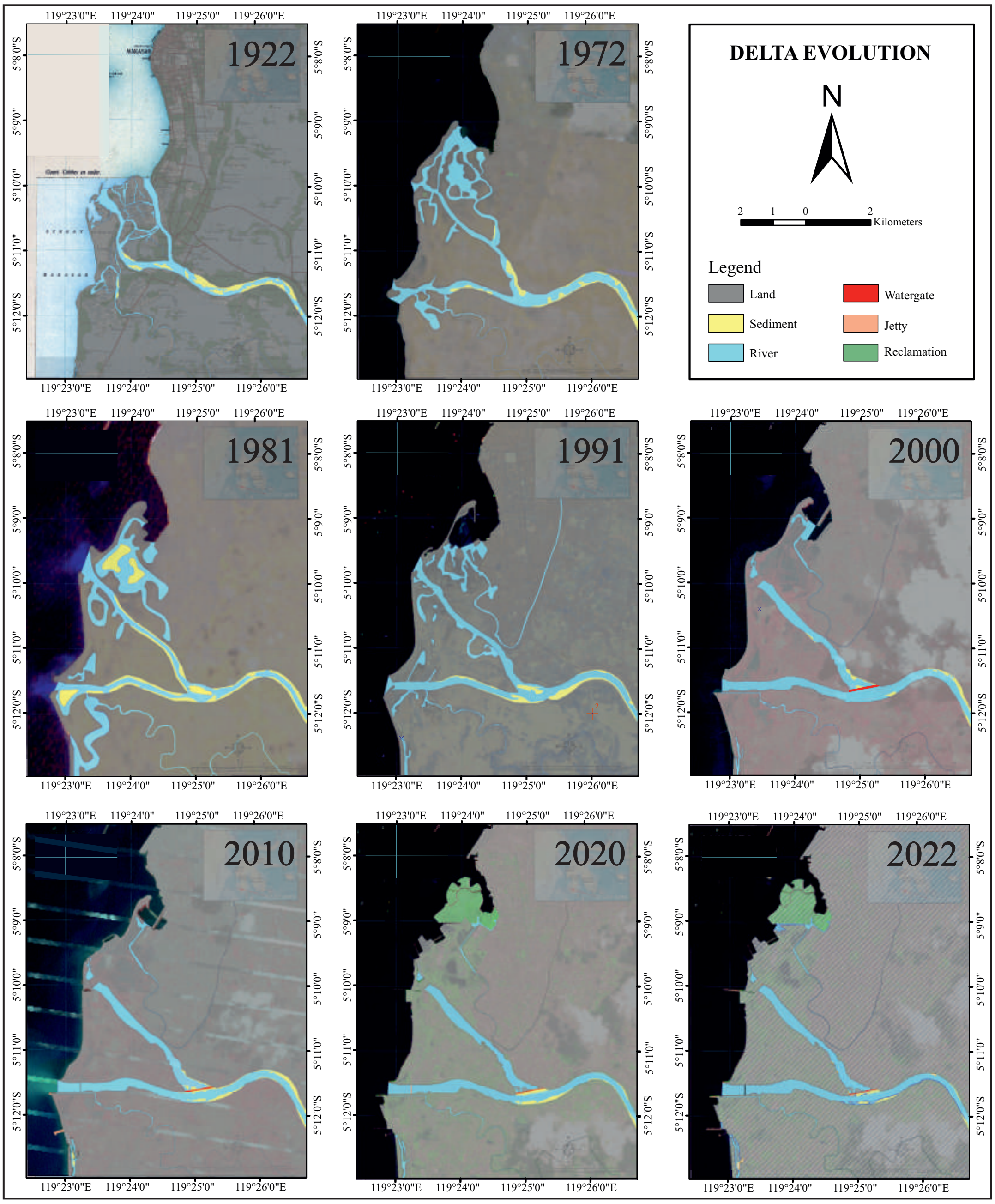

Figure 6. Delta evolution landform migration of The Janeberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022.

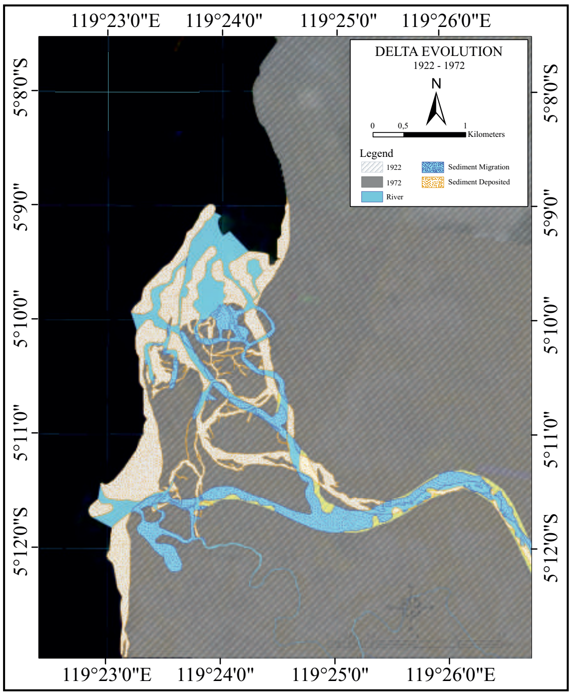

Figure 7. Delta evolution during 1922 - 1972.

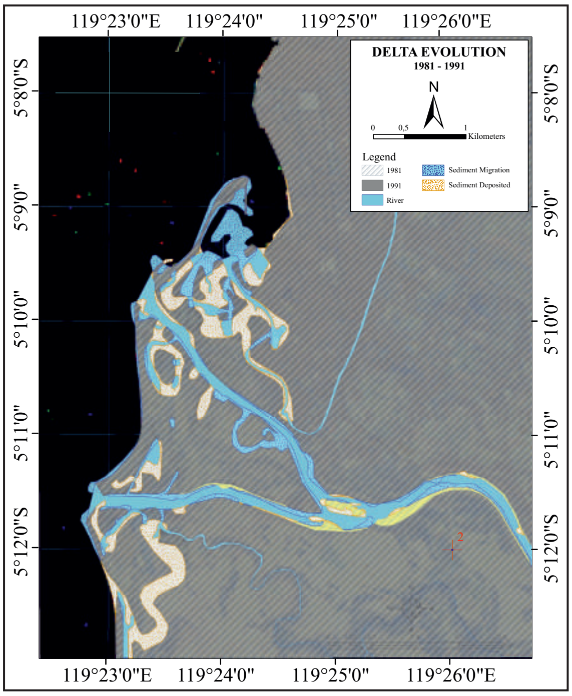

Figure 9. Delta evolution in 1981 - 1991.

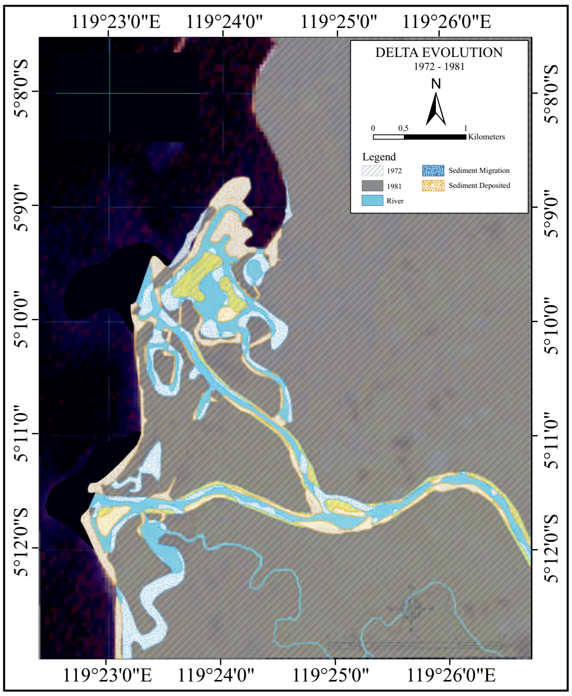

Figure 8. Delta evolution in 1972 - 1981.

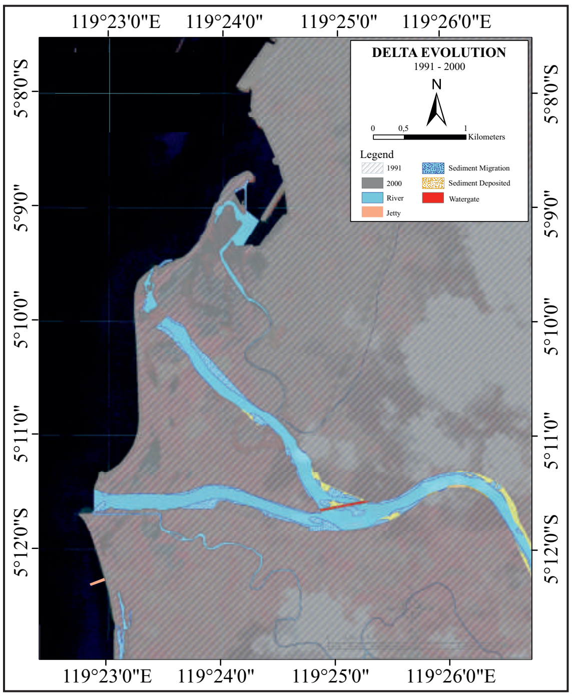

Figure 10. Delta evolution in 1991 - 2000.

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).

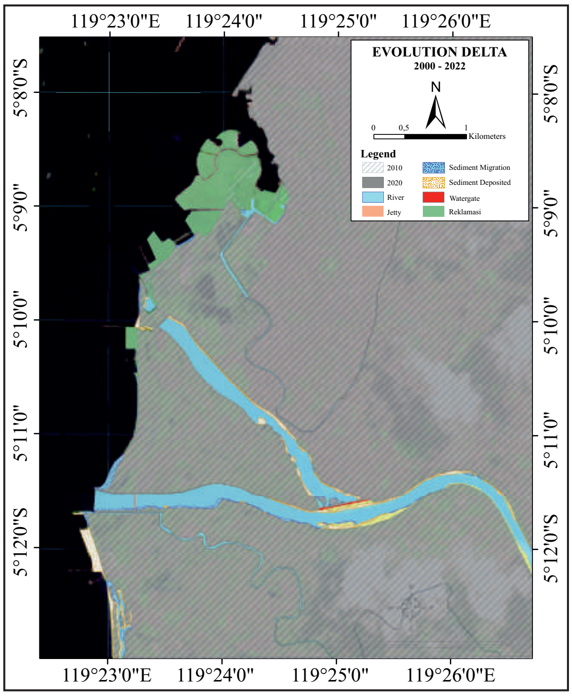

Figure 11. Delta evolution in 2000–2022.

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

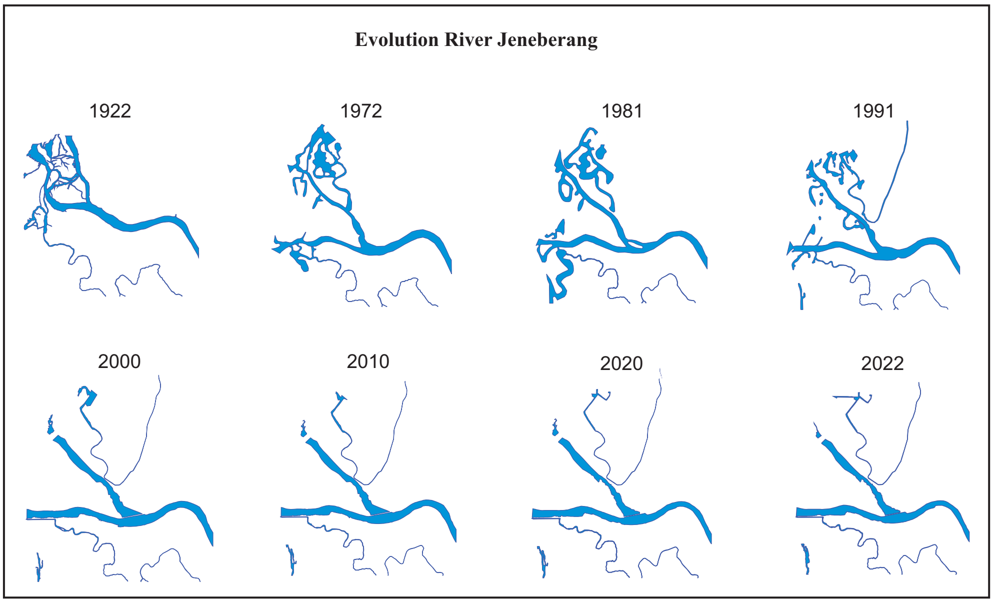

Figure 12. Evolution of the Jeneberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022.

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-

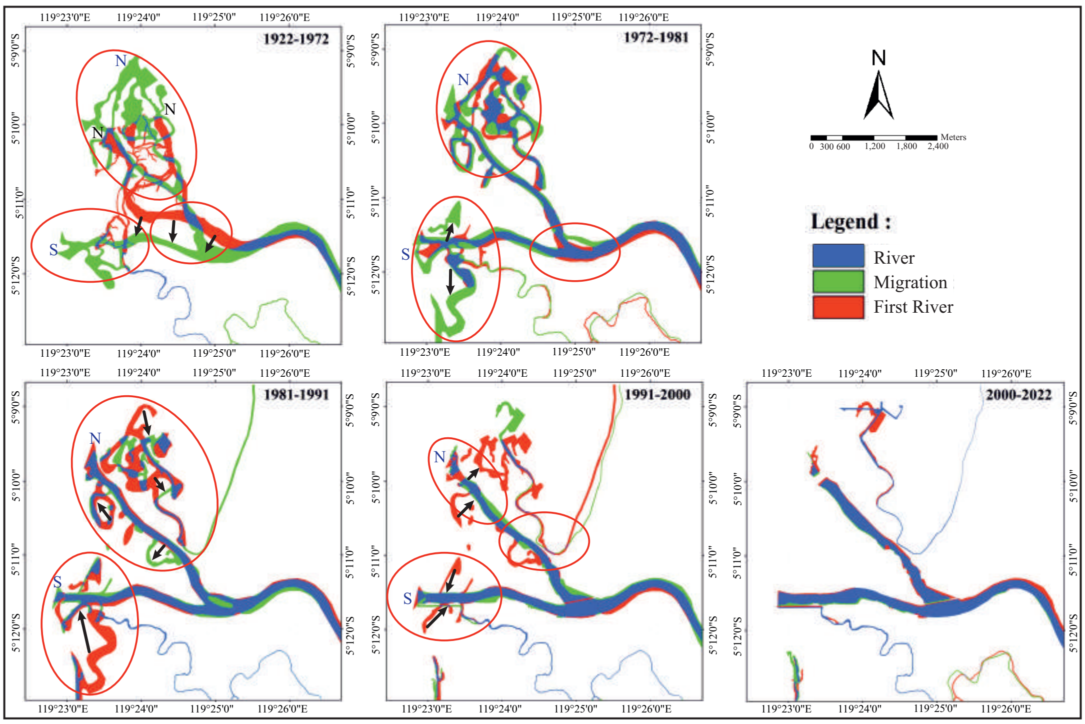

Figure 13. Migration and change of the Jeneberang River pattern from 1992–1972, 1981–1991, 1991–2000, to 2000–2022.

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 13; modified from Galloway, 1975, in Bhattacharya, 1992).

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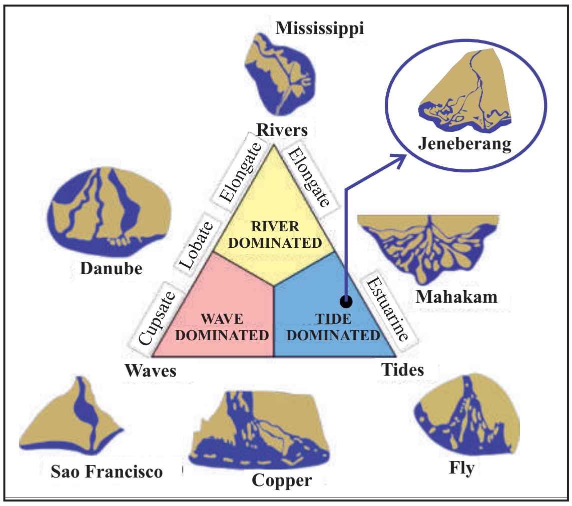

Gambar 14. Jeneberang River delta classified into tide-dominated/estuarine type (modified from Galloway, 1975; in Bhattacharya, 1992).

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 occured, 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 estuary delta, which is predominantly influenced by tides during its formation.

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6. Revised Manuscript according to Proof Reading

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Author's proofreading

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Geospasial 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 1922, 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 relativelynorth 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 stalledto 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 forma-tion 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 meanderingdirection 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 isdeposited, leading to its accumulation. The most commoncause of deposition is the settling out of sediment from atransporting 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 - 80km. Jeneberang River is one of the major riversin 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; Muskananfola, 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

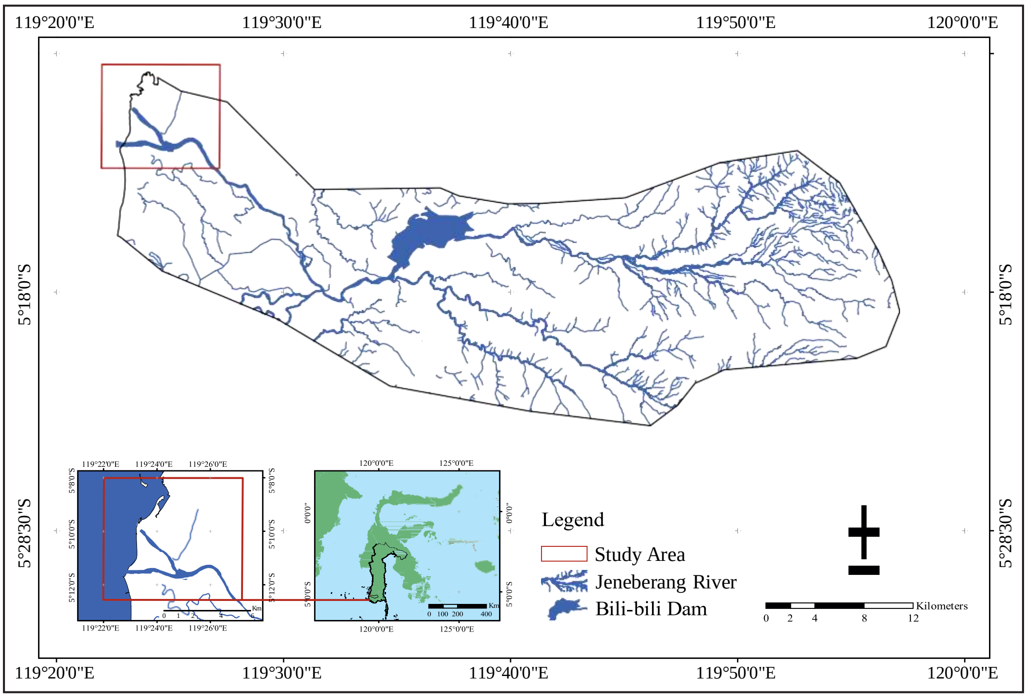


Figure 1. Location map of the studied area (red colour square), part of The Jeneberang River system (Source: RBI Map, modified by author).

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 stratovolcano-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 mate- rial in the upstream area generally has lump sizes, composed of volcanic rock material

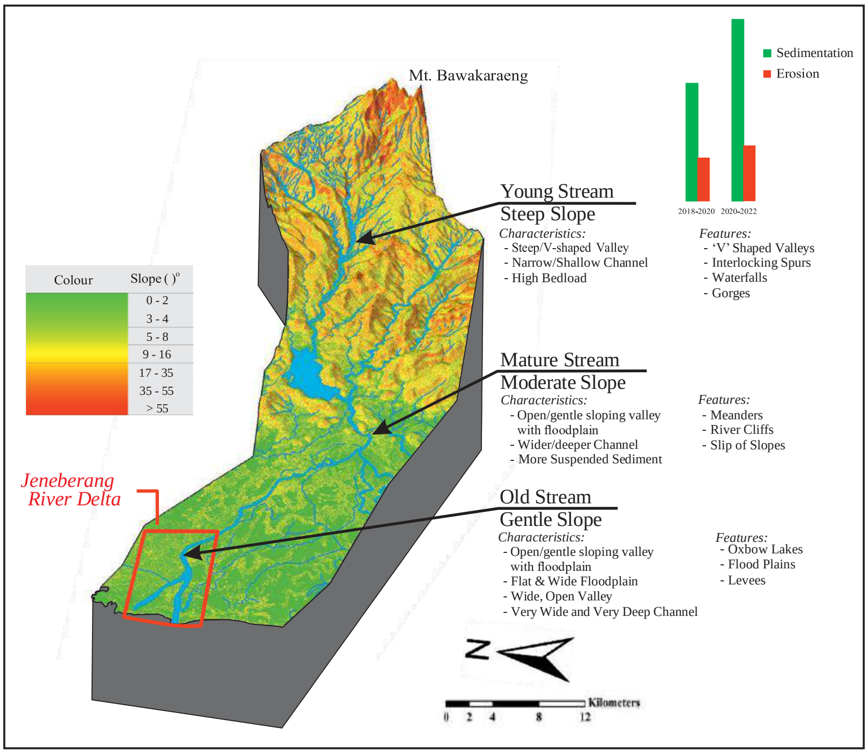


Figure 2. Stream development of the Jeneberang watershed (Source: DEMNAS, 2018, mofified by author).

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/m^2/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^o, 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 km^2 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 landuse 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 m^3. 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 occurrs. The downstream area has a low slope with a range of 0 - 5^o, 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 increaseto the highest in 2004 - 2006 with an area of about 34.99 ha. The highest sedimentation datain 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 increasedthe 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 occured with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991, and 2000 - 2022 from Kampili station (Table 2).

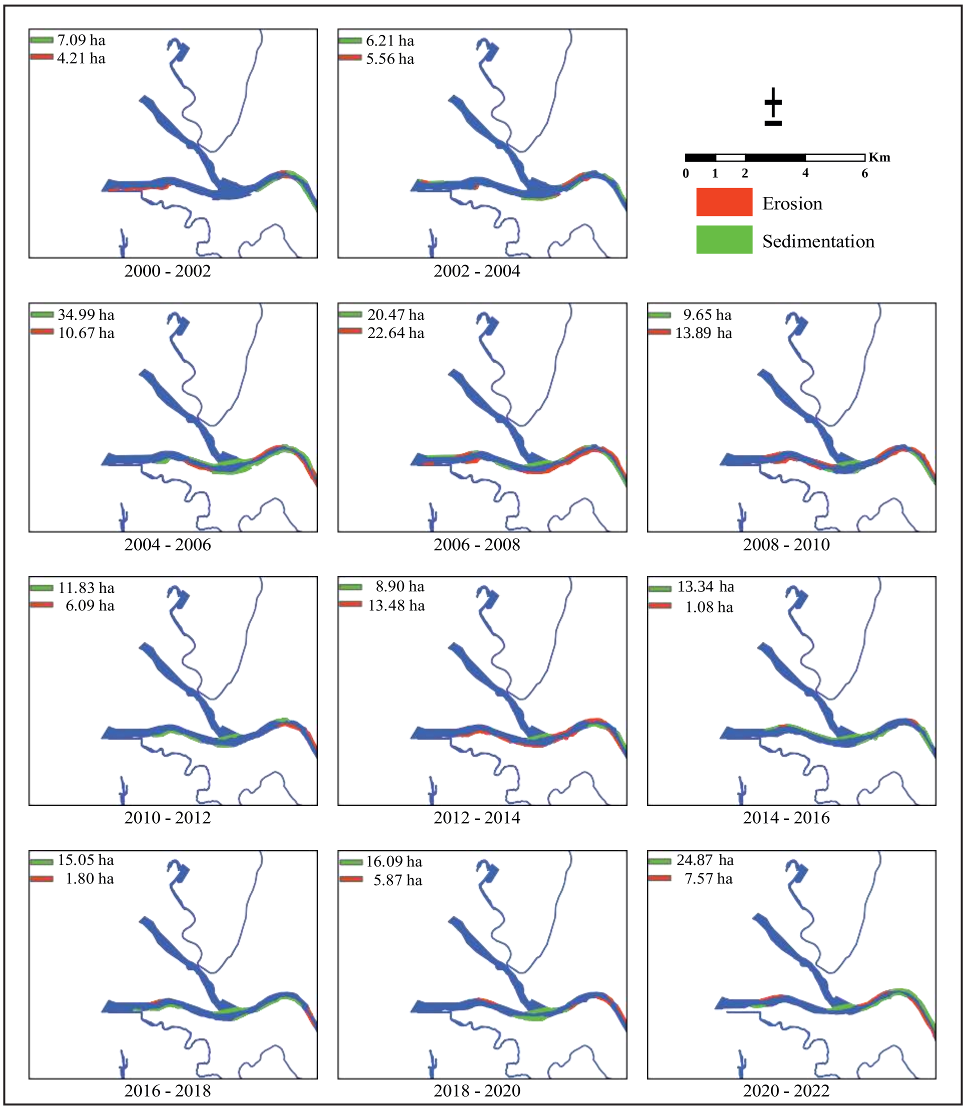


Figure 3. Sedimentation and erosion area of The Jeneberang River.

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

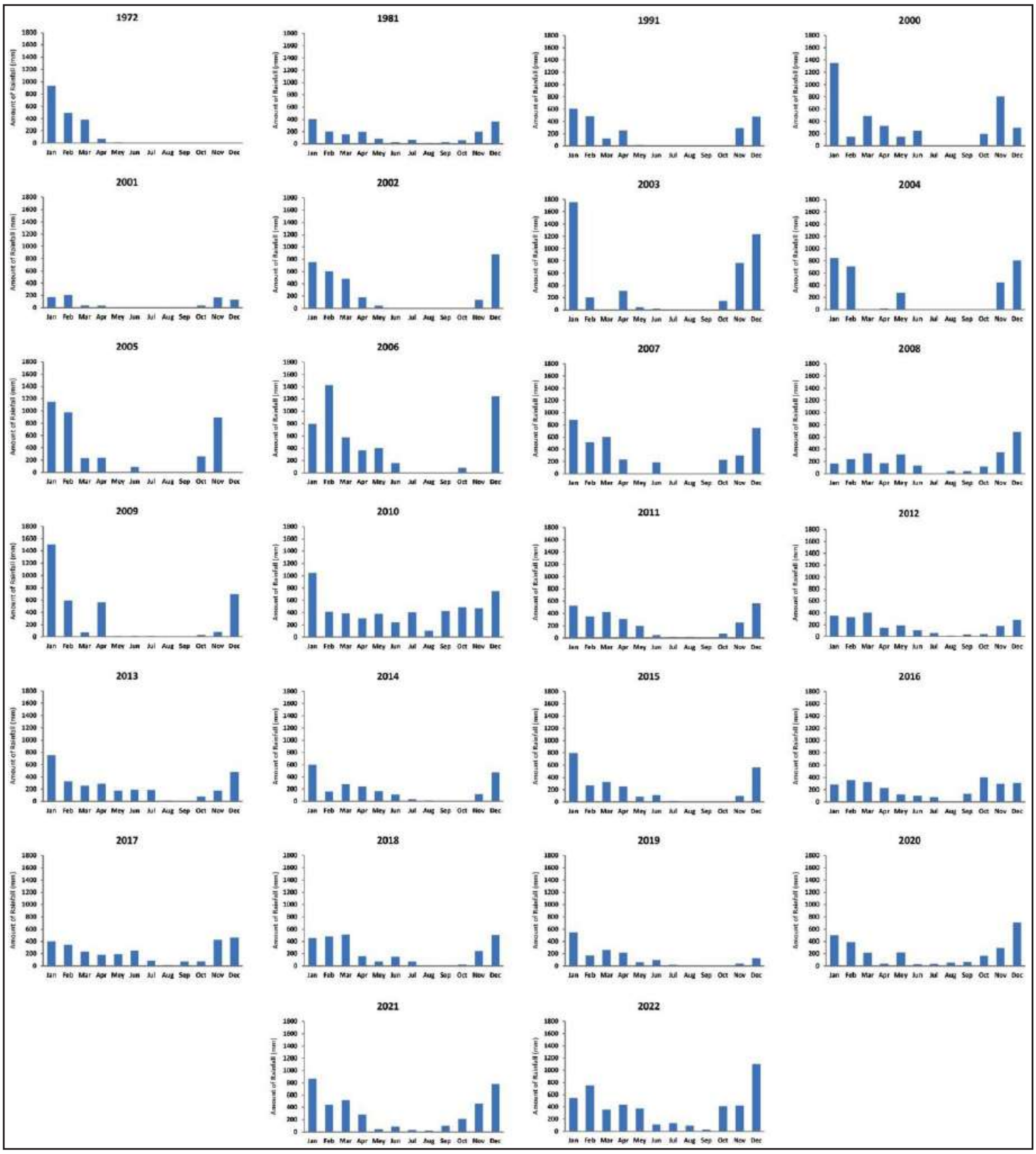


Figure 4. Rainfall diagram for Jeneberang Kampili River Station.

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

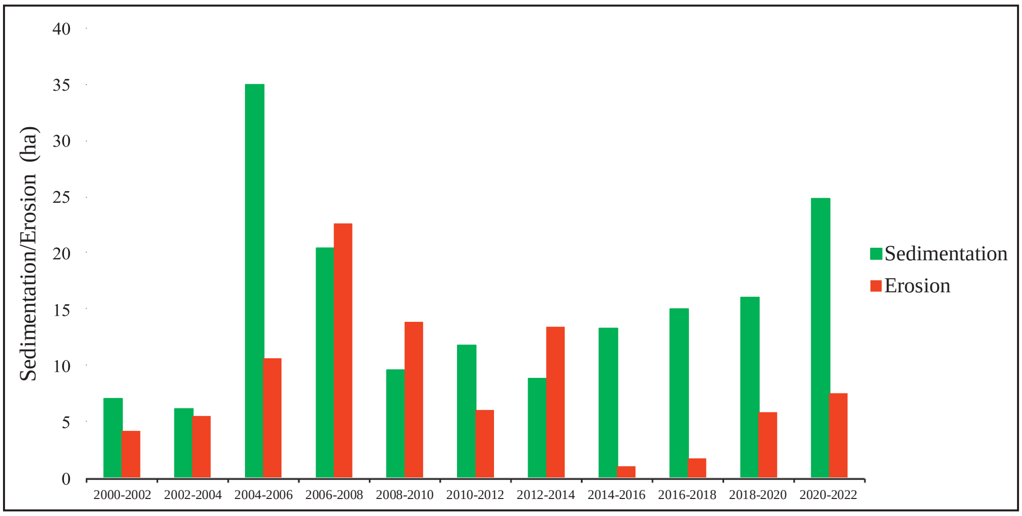


Figure 5. Histogram of sedimentation and erosion area of the Jeneberang River.

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).

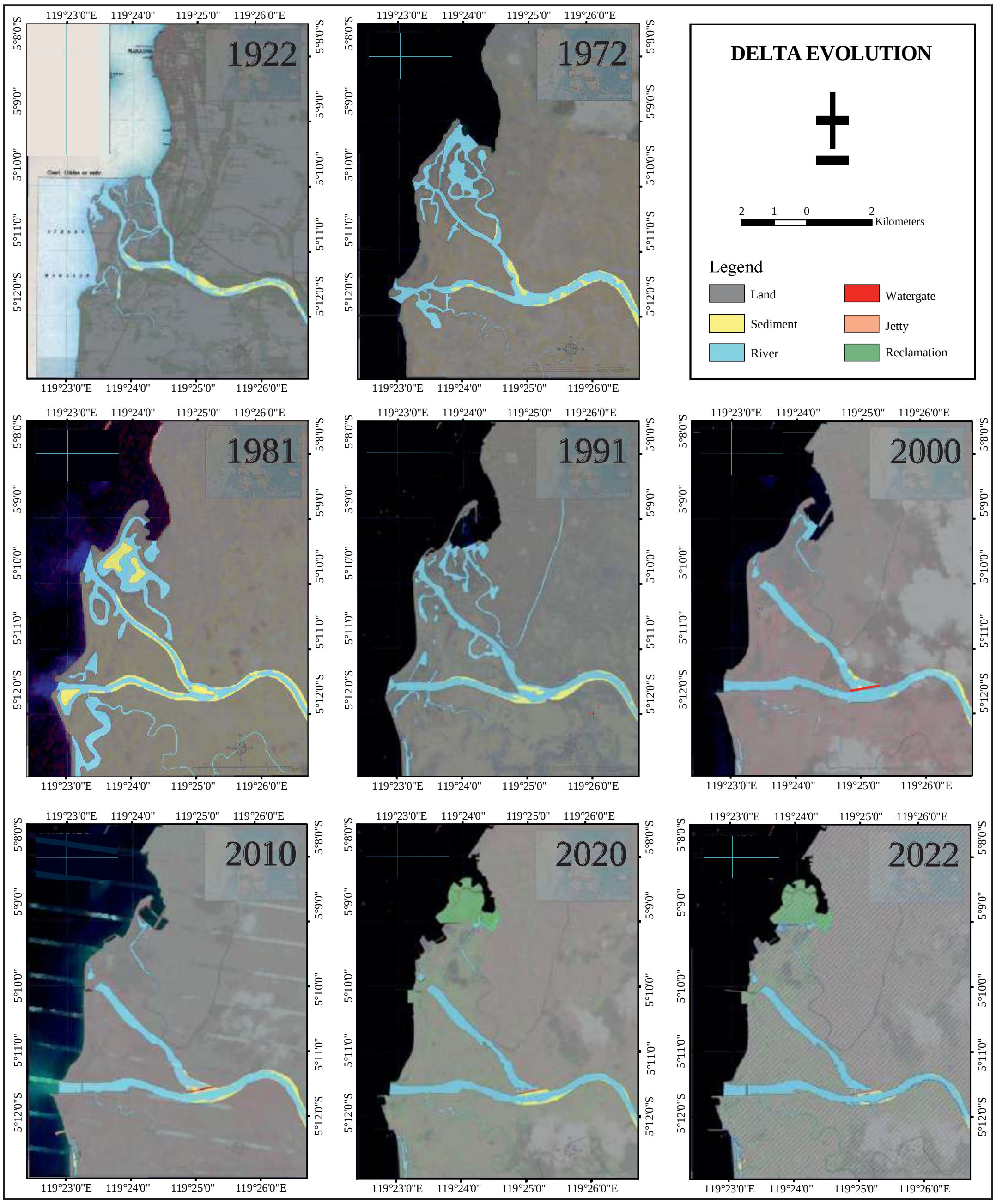


Figure 6. Delta evolution landform migration of The Janeberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022.

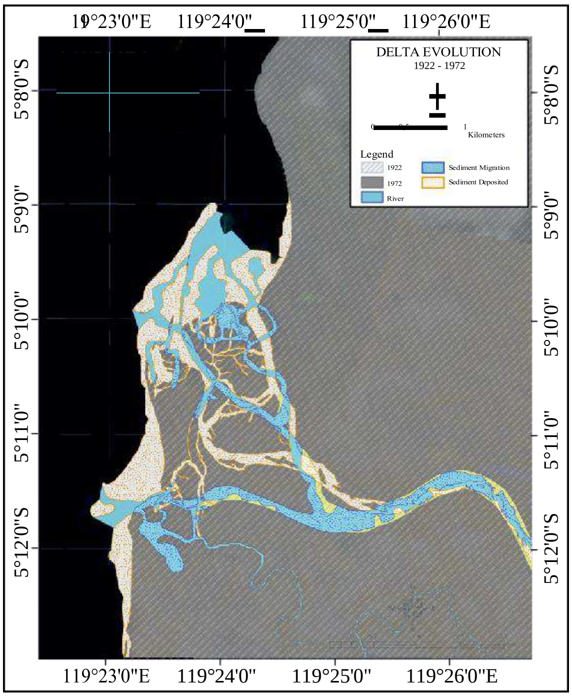


Figure 7. Delta evolution during 1922 - 1972.

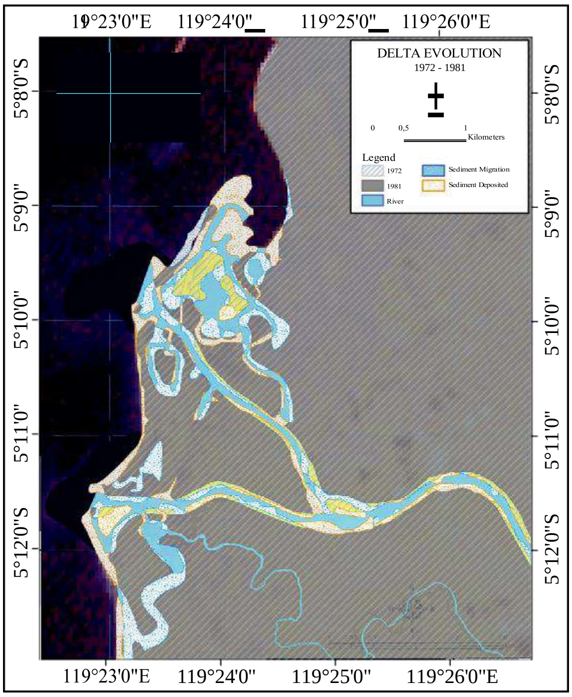


Figure 8. Delta evolution in 1972 - 1981.

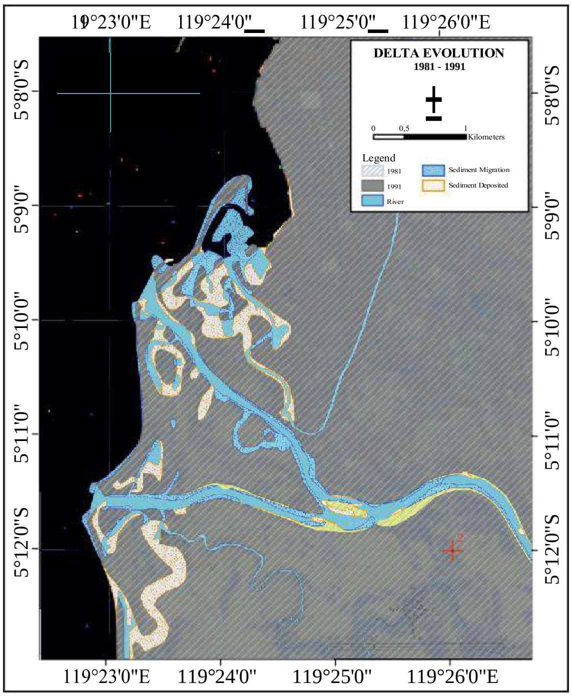


Figure 9. Delta evolution in 1981 - 1991.

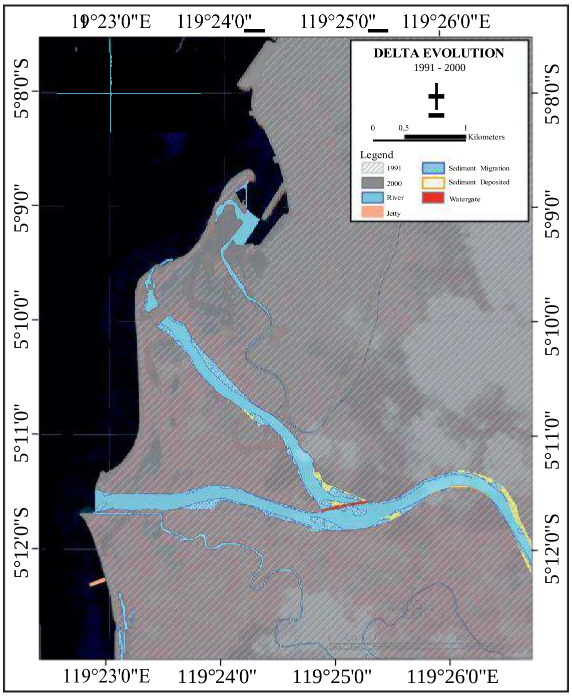


Figure 10. Delta evolution in 1991 - 2000.

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).

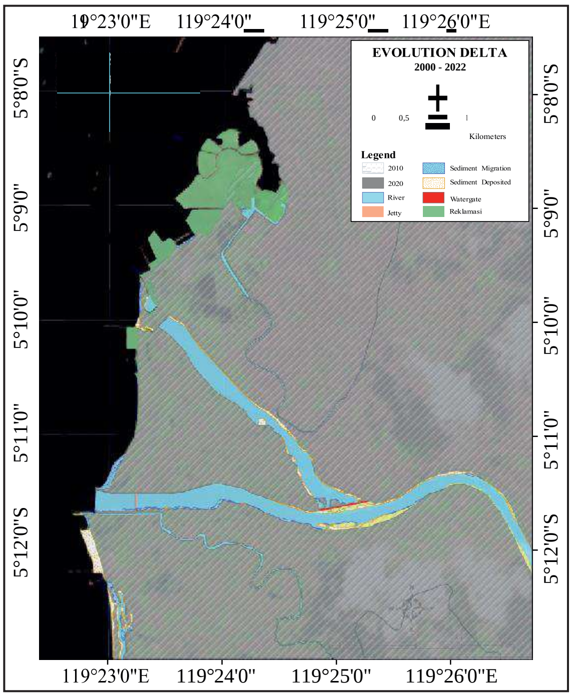


Figure 11. Delta evolution in 2000–2022.

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 coordinates 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

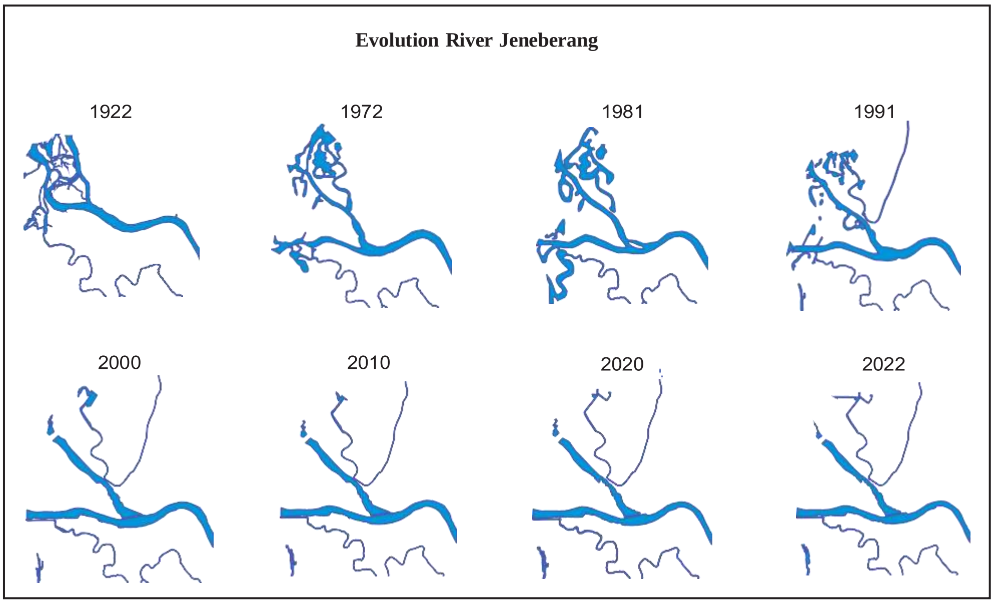


Figure 12. Evolution of the Jeneberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022.

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-

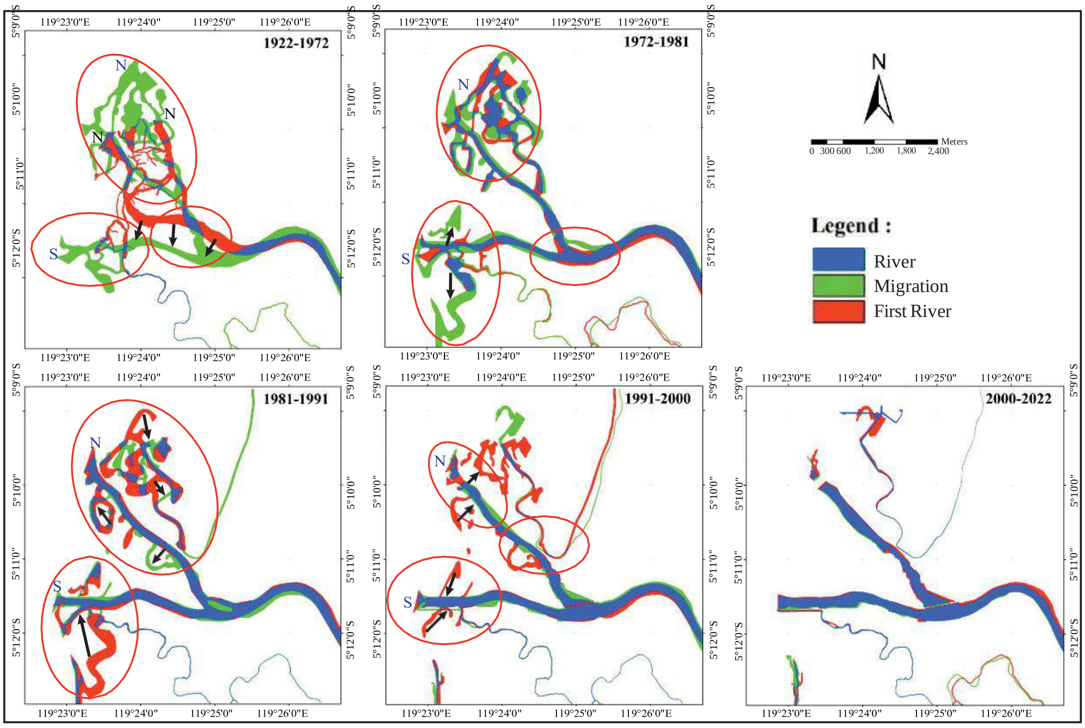
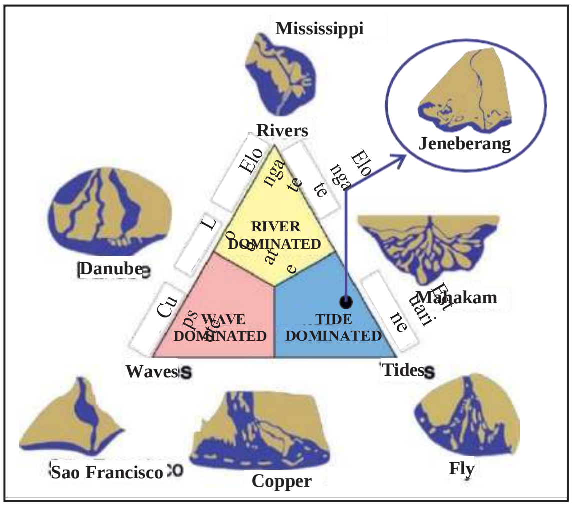


Figure 13. Migration and change of the Jeneberang River pattern from 1992–1972, 1981–1991, 1991–2000, to 2000–2022.

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 occured, 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 estuary delta, which is predominantly influenced by tides during its formation.

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Geospasial 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 isdeposited, leading to its accumulation. The most commoncause of deposition is the settling out of sediment from atransporting 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; Muskananfola, 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

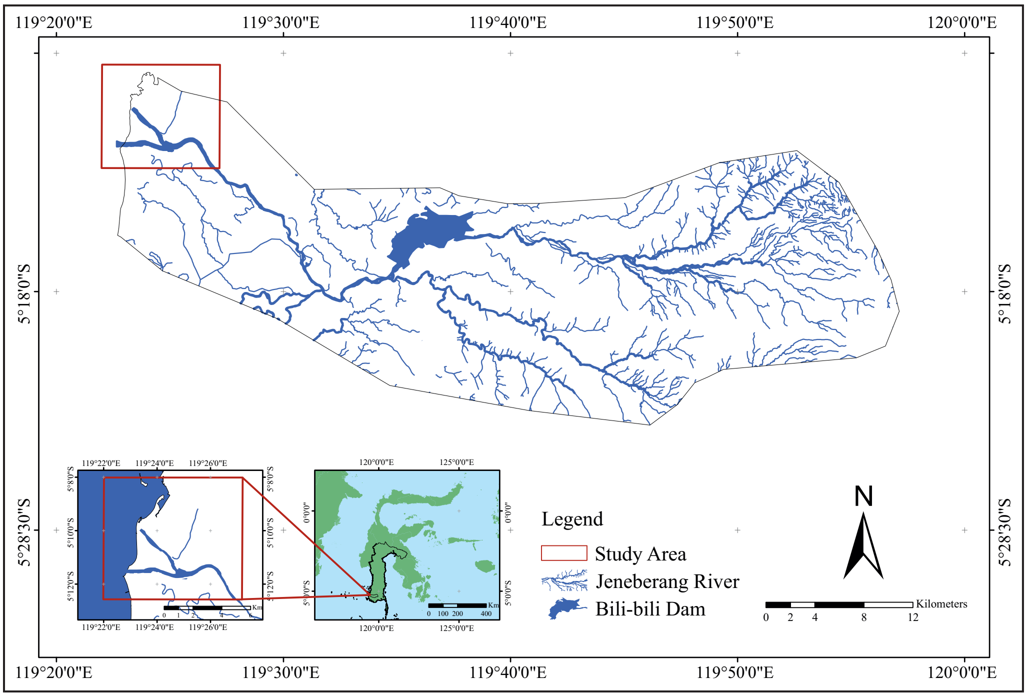


Figure 1. Location map of the studied area (red colour square), part of The Jeneberang River system (Source: RBI Map, modified by author).

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^{o}, 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

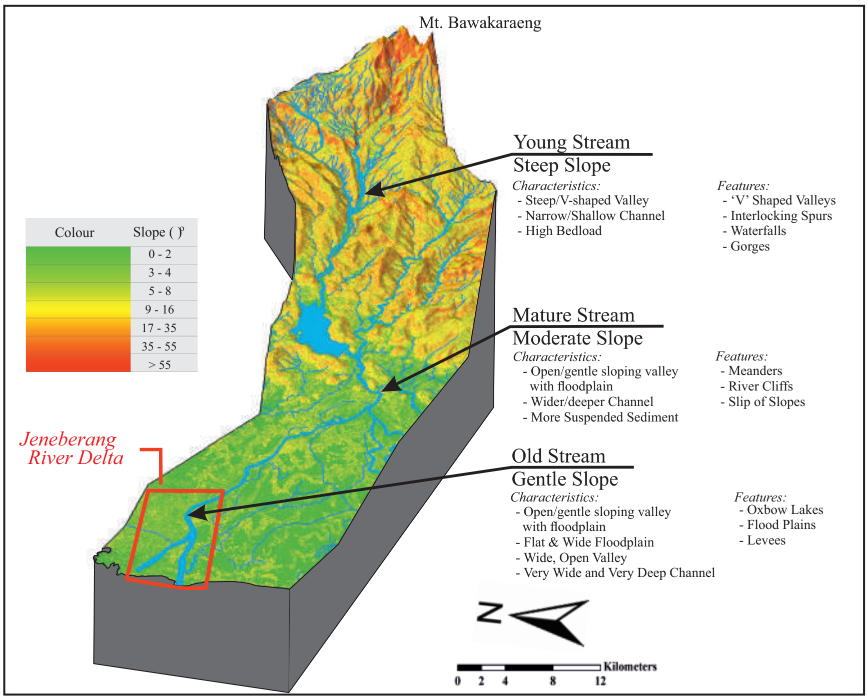


Figure 2. Stream development of the Jeneberang watershed (Source: DEMNAS, 2018, mofified by author).

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/m^2/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^o, 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 km^2 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 landuse 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 m^3. 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 occurrs. The downstream area has a low slope with a range of 0 - 5^o, 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 occured with an area of 7.57 ha. Rainfall data were obtained in 1972, 1981, 1991, and 2000 - 2022 from Kampili station (Table 2).

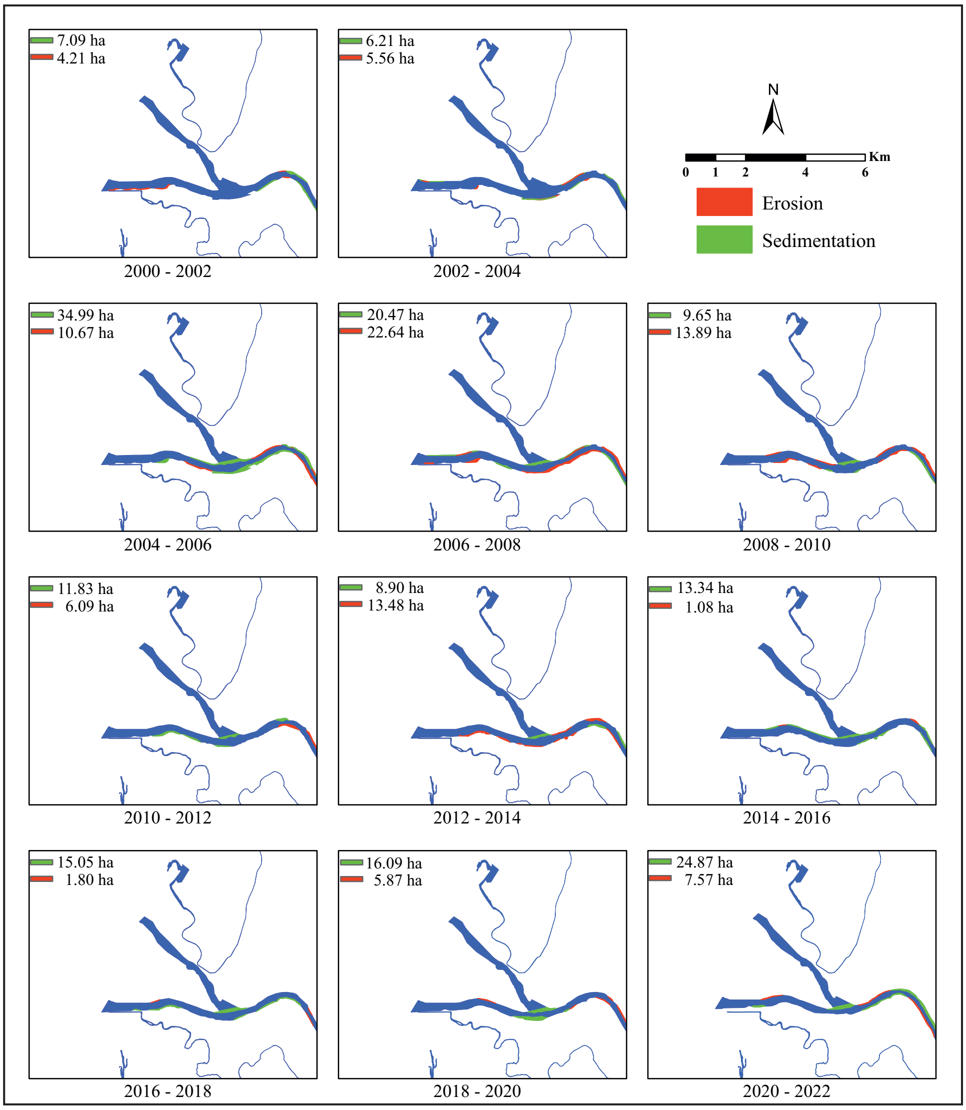


Figure 3. Sedimentation and erosion area of The Jeneberang River.

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

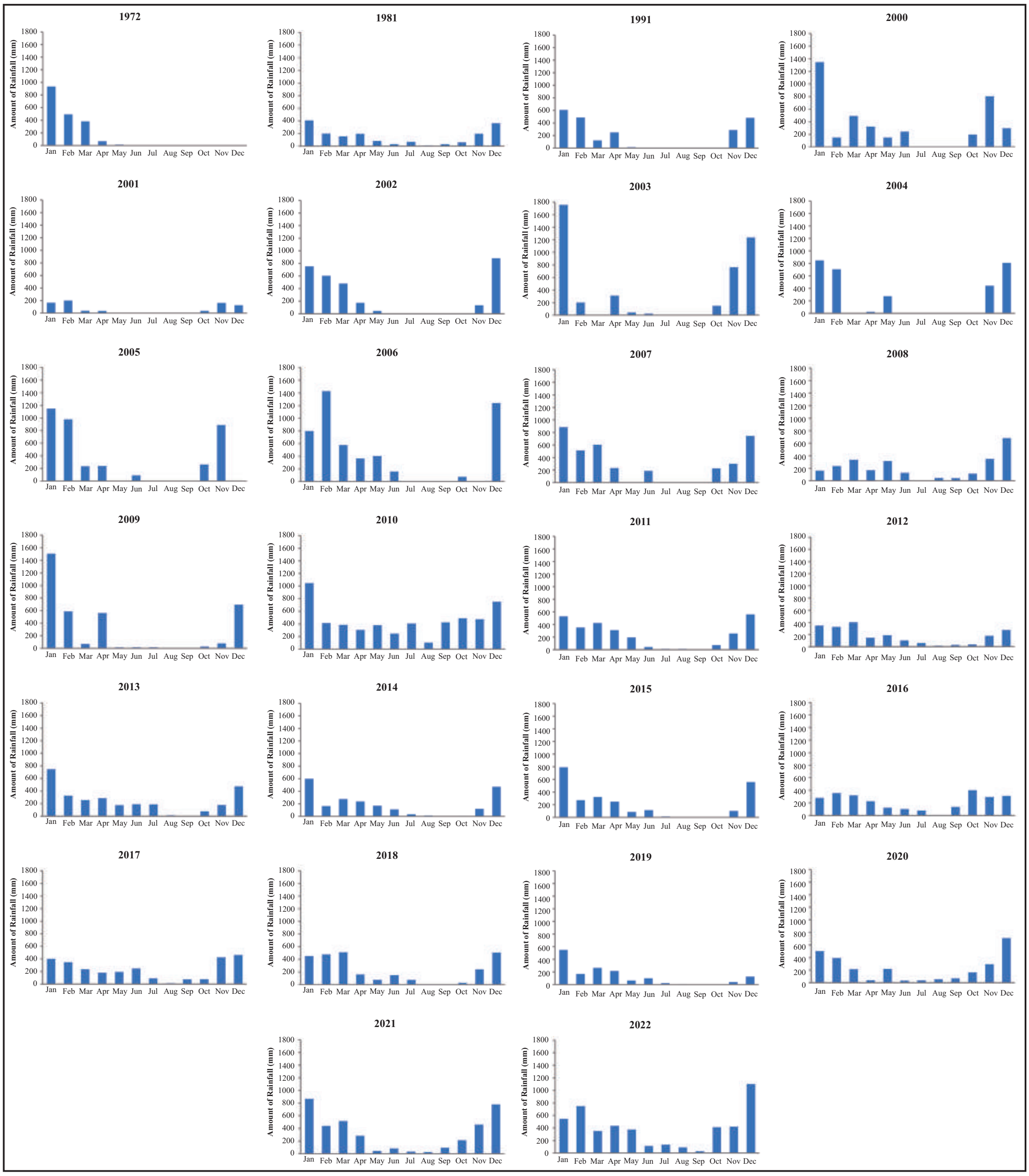


Figure 4. Rainfall diagram for Jeneberang Kampili River Station.

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

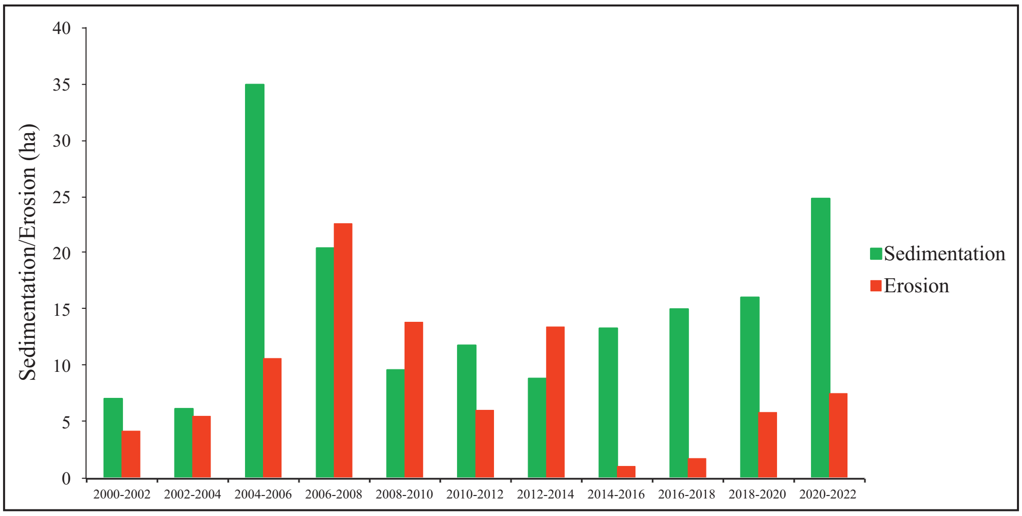


Figure 5. Histogram of sedimentation and erosion area of the Jeneberang River.

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).

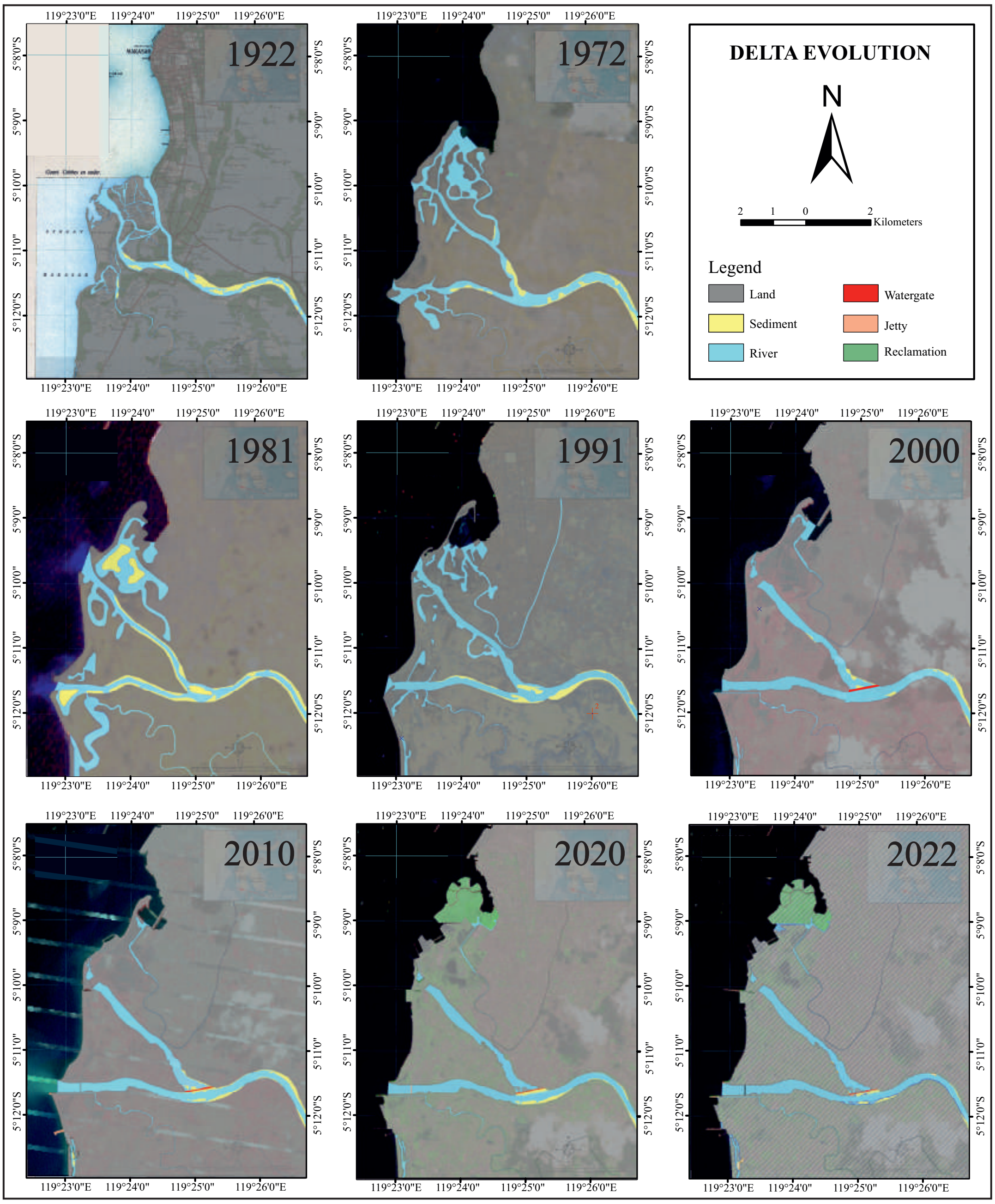


Figure 6. Delta evolution landform migration of The Janeberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020 to 2022.

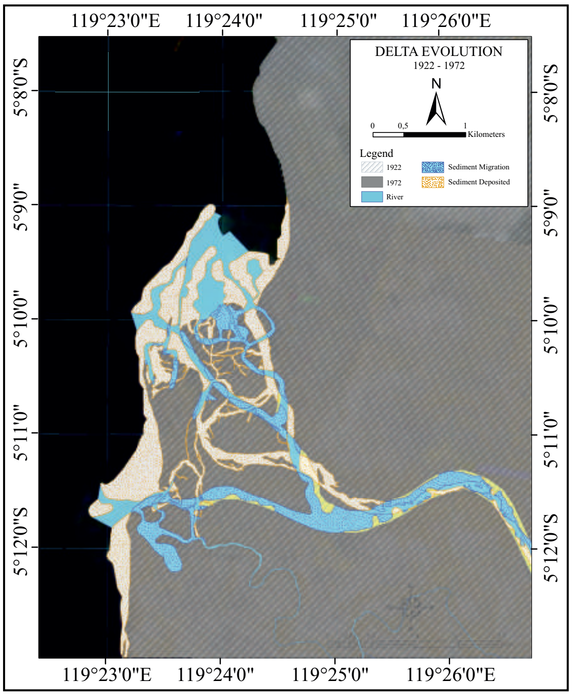


Figure 7. Delta evolution during 1922 - 1972.

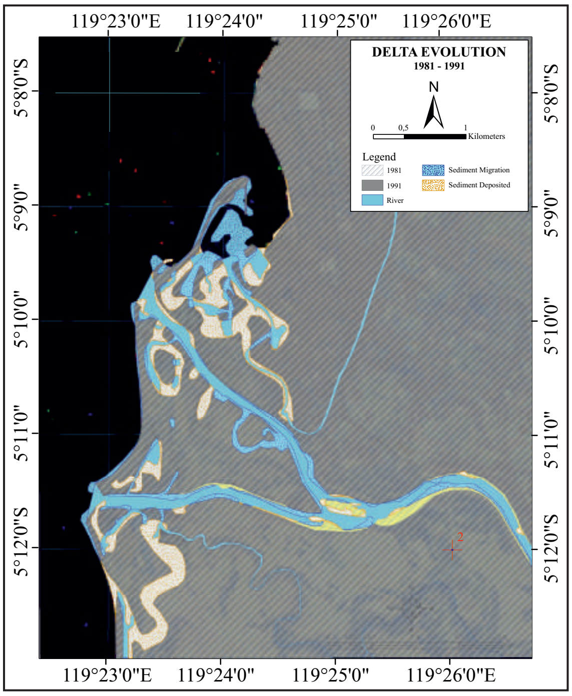


Figure 9. Delta evolution in 1981 - 1991.

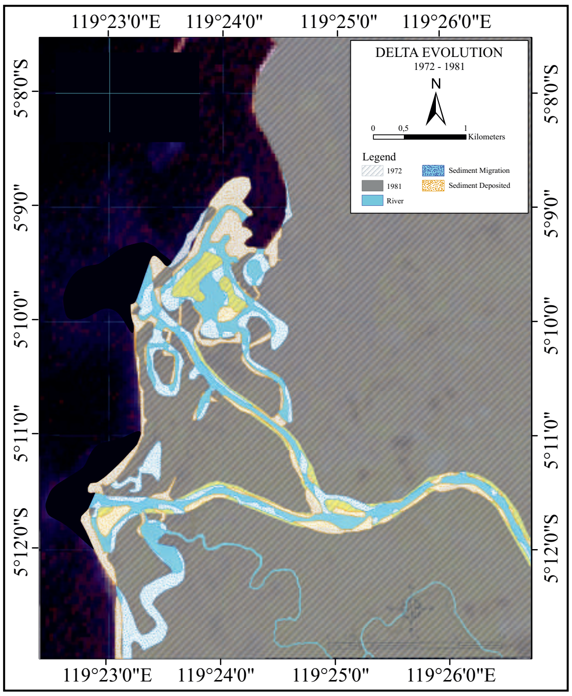


Figure 8. Delta evolution in 1972 - 1981.

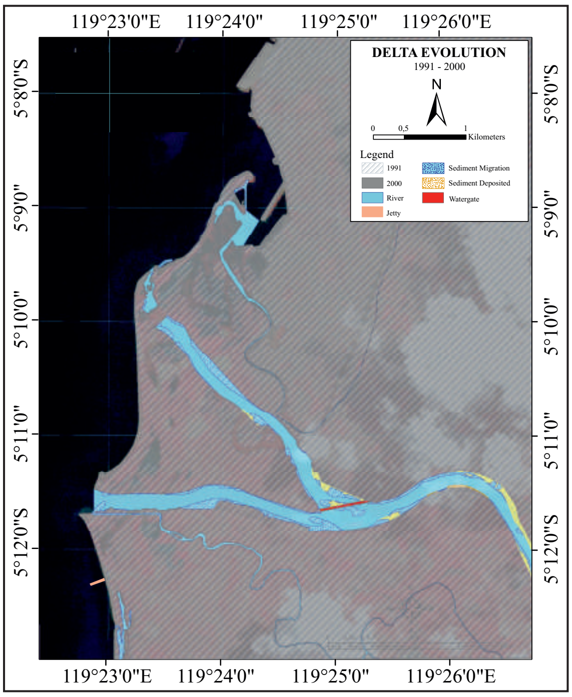


Figure 10. Delta evolution in 1991 - 2000.

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).

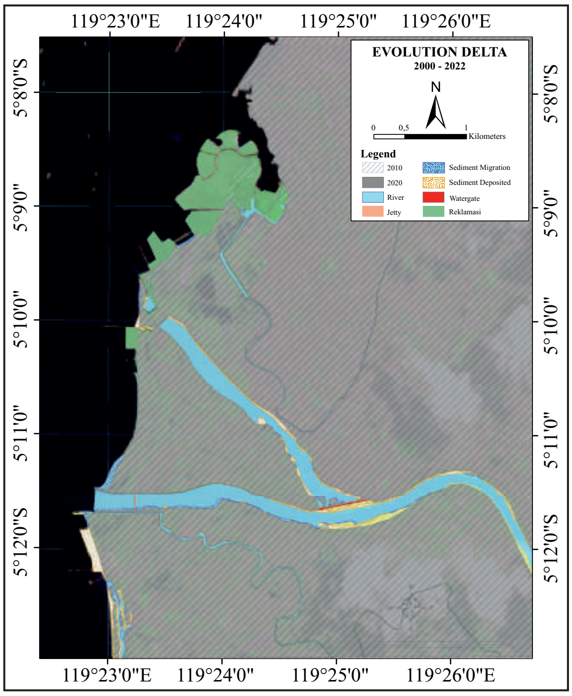


Figure 11. Delta evolution in 2000–2022.

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 coordinates 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

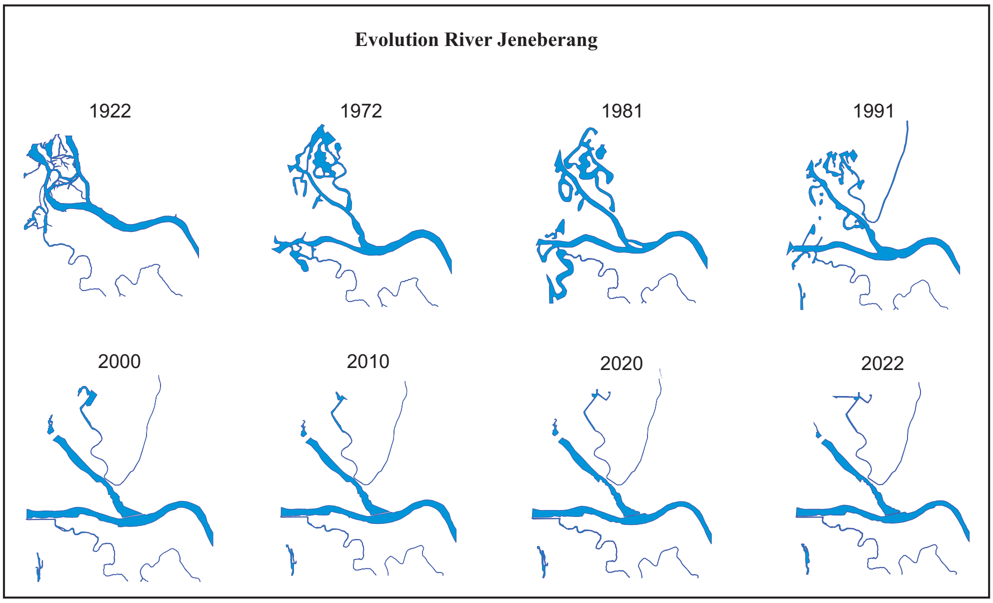


Figure 12. Evolution of the Jeneberang River from 1922, 1972, 1981, 1991, 2000, 2010, 2020, to 2022.

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-

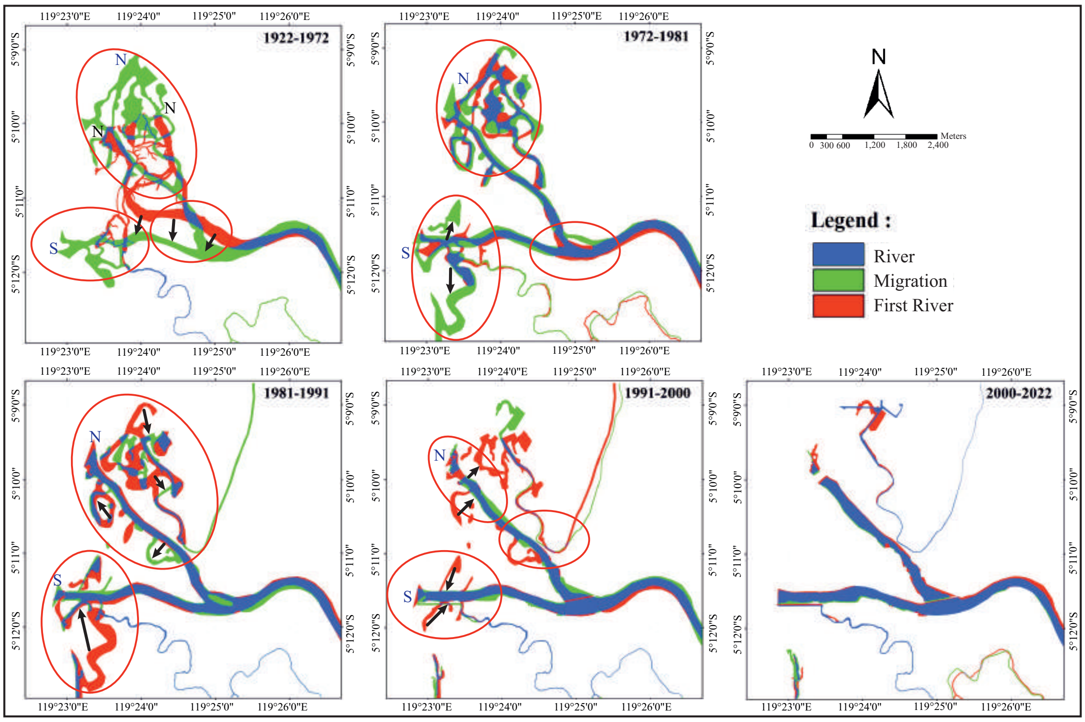
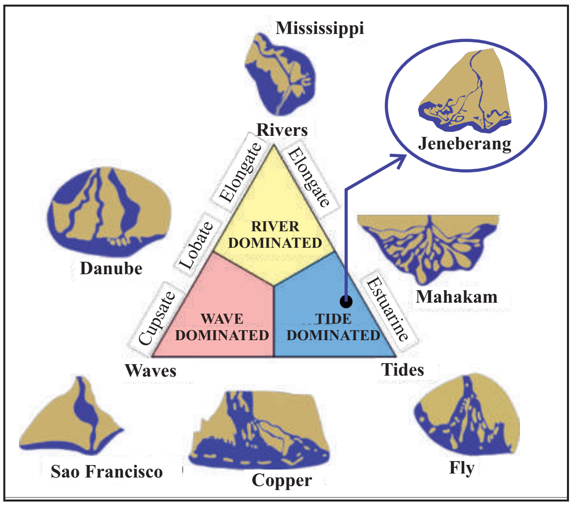


Figure 13. Migration and change of the Jeneberang River pattern from 1992–1972, 1981–1991, 1991–2000, to 2000–2022.

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 occured, 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 estuary delta, which is predominantly influenced by tides during its formation.

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