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Backshore Sand Infiltration Characterization for The Sustainable Waterfront City Tourism Development at Balikpapan Bay, Indonesia

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Abstract - The researched area is the waterfront city of Balikpapan City, where the east and south coast areas have been developed as tourist destinations. The east coastline has an attractive view with its extensive sand deposits, geologically known as quaternary alluvium deposits (QA). On the south coastline, sands are spotted and have a limited spread with a steeper slope. The infiltration rate measurement and sampling were conducted in fifteen locations on the east coast and ten locations on the south coast to assess the water inundation potential on coastal sand. The field observation of water inundation after rain was also conducted to locate the inundation areas. The subtraction of two satellite images was also conducted for validation. Actual sand infiltration rates of the east and south coasts range from relatively slow to very fast. The impact of slow to medium infiltration is the surface water inundation that disturbs the function of the coastal sand as a place for tourist activities. Based on the overall infiltration, the East Coast has greater vulnerability to water inundation than the South Coast. The implication of such a condition without proper engineering treatment in the long term will reduce tourist visits. As a consequence, the revenue will decrease, and cause negative multiplier effects on the economy of local inhabitants. Scientific findings will contribute to the geoscience knowledge; the origin of the sand deposits determines the differences in the physical characteristics of the east and south coast sands. The source of the south coastline sand is the Tertiary Miocene Balikpapan Formation (Tmbp). Meanwhile, the source of the east coastline sands is the Tertiary Pliocene Kampungbaru Formation (Tpkb).

Keywords: sand characterization, texture, infiltration, coastal tourism, NDVI, geology, clustering

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Introduction

Background

The research area is located in Balikpapan City, East Kalimantan, Indonesia, as illustrated in Figure 1. The coast of Balikpapan Bay and Makassar Strait borders half of this city (Meilana *et al.*, 2024). The city is the primary gateway to accessing neighbouring cities and regions, such as Samarinda City, Bontang City, Pasir Penajam Utara (PPU) Regency, Pasir Regency, and Kutai Kartanegara Regency. The city has an international airport and seaport for access from other islands and countries. The surrounding towns and areas are well known as the producers of coal, oil, gas, and palm oil (Tarigan *et al*., 2017). The area is also known as the buffer area of Indonesia's new capital city with complete infrastructure (Ramadhan *et al*., 2022). Therefore, this city actively serves as a service hub for neighbouring cities. One of this city's strengths is its coastal and marine tourism potential (Kreb *et al*., 2020). The local authority's short-term and long-term goals are to develop the coastal area as a tourist destination. Some coastal areas have been designed as beach and marine community-based tourism (Karim *et al*., 2019). Balikpapan Bay, on the south coast, has steeper coast slopes. That is the reason why the seaport was located on this coastal part. The challenge for the local government to serve this city is providing potable drinking water. Raw material sources of drinking water mainly come from the Manggar Dam and the Teritip Dam. In the dry season, the drinking water company can not meet the customer demands as the DAM does not have enough water. Meanwhile, in the rainy season, some parts of the river basins in Balikpapan have excessive run off and cause serious floods. Such conditions become a challenge for the local authorities in the water management system. This research aims to solve the problem of how to map the water inundation in the east and west coastal sand based on the actual infiltration rate that has been designed and developed as a tourist destination, and how geological conditions control the coastal sand characteristics. Based on the findings, the engineering solution can be formulated.

A lovely shore with sand deposits is an asset for local authorities in research areas geologically known as 'alluvium deposits' (Hidayat and Umar, 1994). Local authorities can invest further in developing infrastructure for tourism destinations and later obtain a return on investment from tourist activities. The development of marine tourist destinations, especially in coastal areas, must consider soil engineering and property aspects. The local authorities need to develop tourism infrastructure, such as hotels, roads, transportation networks, jogging tracks, and playground areas, to support tourism in the area (Rybchenko *et al*., 2022). The beach landscape with extensive sand can accommodate visitors doing sports, family gatherings, sightseeing, camping, *etc.* Developing infrastructure for coastal tourism should consider coastal ecology (Ulimaz and Jordan, 2020). The development of the coast should consider the ecological capacity and its negative impacts, as the previous study has revealed that the anthropogenic conversion of coastal dunes to vegetation and livestock agriculture has caused the destabilized dunes and wind-blowing sand to invade the human settlement and destroy the agricultural area (Sampath *et al*., 2024).

A critical aspect of the development of beach and marine tourism is the capacity of the coastal area to manage water, especially the water infiltration capacity of soil. Infiltration is part of the water cycle, where the water flows vertically into the soil and subsurface (Brutsaert, 1977). Such a process will divide water into infiltration and run-off water; that division is part of the natural water cycle. The run-off water will remain on the surface as inundation or flowing water. When trapped in the low infiltration capacity of soil, the run-off water will stay as inundation water, where the infiltration capacity strongly correlates to the sand beach texture (Sulistyo and Fauzi, 2023). On the beach sand of tourist areas, the inundation of water will disturb or even damage the function of the area infrastructure, such as the playground, jogging track, coastal road, *etc.* (Sadien *et al.*, 2024). Therefore, in solving the problem of inundating water in beach areas, a study of the potency of the inundation of water in beach sand as a tourist destination is needed. A few types of research on Balikpapan City about infiltration for other aims and objectives, such as general soil capacity, different terrain, and the correlation of textures with infiltration rate, have been conducted previously (Juwita and Santoso, 2019; Kiptiah *et al.*, 2020; Sulistyo and Fauzi, 2023). The geologic control of the actual soil infiltration model, based on artificial neural networks, has also been developed, where the geologic structure and lithology beneath the earth's surface play an important role in determining the downward infiltration of water to the aquifer layer (Sulistyo *et al*., 2026). There are also many papers that have been published about tourism studies that have been conducted in Balikpapan City, both in national and international journals. The beach ecotourism, tourist village, and community-based participation in marine tourism development have also been previously published (Karim *et al*., 2019; Mulyani *et al*., 2022; Nugroho *et al*., 2025). By analyzing published papers in tourism, soil, and geology of the area, the research gaps are revealed, such as beach sand infiltration, the development of a geotechnical map, identification of recharge areas for groundwater, *etc.*

The first aim of this research is determining a correlation between the actual infiltration rate and the location in beach sand deposits where tourists do their activities that have the potential to be covered by inundation water during and after rain. These findings can help address the problem by leveraging recently available technology and products. This research implies that it will create a sustainable and comfortable beach tourist destination in tropical areas in all kinds of weather. The second aim is to characterize the east and south coast sand deposits and explain the origin of both deposits based on geology and paleogeography. The novelty of this research is the implementation of the assessment of coastal sand and water inundation based on the integration of actual infiltration sand, sand grain characteristics, NDVI, and a geological point of view. Furthermore, the result of the assessment will be implemented for the coastal tourism development in the researched areas.

Geological/Stratigraphical Settings

The researched areas are located physically and geographically in the Kutai Basin (Bemmelen, 1949). The regional stratigraphy of this basin consists of crystalline, mafic, and ultramafic rocks in the lower Jurassic age, lying over such a basement is the volcanic rock of the Haruyan Formation that consists of lava, breccia, and tuff with granite and diorite intrusions and The Kintap Formation as the sedimentary rock, such as alternating of sandstone, greywacke, claystone, conglomerate, and limestone of the Cretaceous age. On the unconformity plane, there lies sedimentary rocks of the Tanjung Formation, Kuaro Formation, and Talakai Formation that have the same age. The Tanjung Formation consists of alternating sandstone, claystone, conglomerate, limestone, and marl with coal interbedded. The Kuaro Formation consists of sandstone and conglomerate with interbeds such as coal, marl, limestone, and shale.

Meanwhile, the Talakai Formation consists of claystone, sandstone, and shale with limestone and marl as interbeds. The age of those rock formations is Eocene. Conformably on the Talakai Formation lies the Tuyu Formation, which consists of alternating sandstone, greywacke, shale, and claystone. The Berai Formation has the same age as the Tuyu Formation. It consists of limestone, marl, and shale. The Pamaluan Formation was deposited above those formations during the Late Oligocene to Middle Miocene Epoch. That formation consists of claystone and shale, with marl as an interbed. Conformably, the Pamaluan Formation was deposited on the Babulu Formation, which consists of limestone with claystone and marl as interbeds. The Warukin Formation was deposited conformably on the Berai Formation, consisting of deltaic alternating sandstone and claystone with no fossils, so its age was estimated to be between the Middle and Late Miocene. Lying conformably over the Pamaluan Formation is the Pulaubalang Formation, an alternation of quartz sand, sandstone, and claystone with coal as an interbed. The Pulaubalang Formation was deposited in the Middle Miocene. The Balikpapan Formation was deposited conformably on the Pulaubalang Formation, consisting of quartz sandstone, siltstone, and shale, with marl, limestone, and coal interbedded. The Kampungbaru Formation lies conformably on the Balikpapan Formation, consisting of sandy claystone, quartz sand, and siltstone with interbeds such as coal, marl, limestone, and lignite. That formation was deposited in the Late Miocene to the Pliocene.

The youngest sediment is Quaternary alluvium deposits that consist of gravel, pebbles, sand, clay, and mud as sediments of swamps, rivers, shores, and deltas (Hidayat and Umar, 1994).

The local stratigraphy of the researched area consists of the Balikpapan Formation, the Kampungbaru Formation, and alluvium deposits. The Balikpapan Formation was deposited late during the Miocene Epoch of the Neogene Period. The Balikpapan Formation is dominated by sandstone with interbedded claystone, siltstone, marl, calcareous sandstone, and coal. The Kampungbaru Formation lies on the Balikpapan Formation, which was deposited during the Pliocene Epoch of the Neogene Period. The Kampungbaru Formation consists of marl and claystone with interbeds of sandstone and coal. Meanwhile, in the uppermost stratigraphic unit of the area are the alluvium deposits that consist of gravel, sand, and silt, which were deposited unconformably on the Balikpapan and Kampungbaru Formations in the Quarter after the uplift and erosion processes of the older formations (BAPPEDA Balikpapan, 2002; Hidayat and Umar, 1994; Moss and Chambers, 1999).

Structurally, the areas are located in the limb of the anticline (Samarinda Anticlinorium) (Hidayat and Umar, 1994). Some joints can be found on the south coast in the Balikpapan Formation outcrops. During the Quaternary, the area is characterized by inactive tectonics, so there are hardly ever perceptible earthquakes, and the location is far away from active volcanoes (Ramadhan *et al*., 2022).

Methods and Materials

Methods

The researched location is the east coast and south coast of Balikpapan City, East Kalimantan, Indonesia. Several river basins in this city are flood-prone as a result of the interaction of several parameters, such as land use, morphology, rainfall, and geology (Sulistyo *et al*., 2025; Sulistyo *et al*., 2026; Sulistyo and Respati, 2023). The coastal sand of the researched area has relatively poor natural drainage. After the rain, it always shows inundation in concave sand morphology; such phenomena can be seen directly in the field or remotely by subtracting different times of satellite images of the Global Water Surface .

In the research activities, researchers follow a series of steps. The steps start with assumptions and end with the conclusion. The detailed description of each step is provided in the following paragraphs.

The development of assumptions and hypotheses is the first step in this research, where researchers conduct field reconnaissance and a literature review. Field reconnaissance was conducted by visiting the location after the rain and recording the coordinates of the inundation-prone location. Meanwhile, a literature review was conducted by reviewing papers from reputable journals and making assumptions based on previous research and theoretical bases. Then, based on assumptions made, the researchers formulate hypotheses. Then, research questions and objectives can be made based on the hypotheses.

The second step is research planning based on the research objectives. This planning includes the measurement locations, sample and measurement counts, and the apparatus tests for both in-situ and lab tests. The planning also covered the budgeting and scheduling of all research activities. Research planning could be a checklist and guide the research team in the field, laboratory, and studio work.

Field measurement and sampling are the third step. This step is the implementation of the research planning. The exact location had been determined in the planning step, and the planned location was marked on the map and listed in longitude and latitude coordinates. The points of location of measurement are close to the sampling location, between 1 and 2 m, depending on the field conditions. Soil sampling was conducted using an auger, and infiltration measurement was performed using a double-ring infiltrometer. The measurement was recorded on the web application that had been developed based on the paper-based form (Sulistyo *et al*., 2025). The data was saved in a cloud server by this application

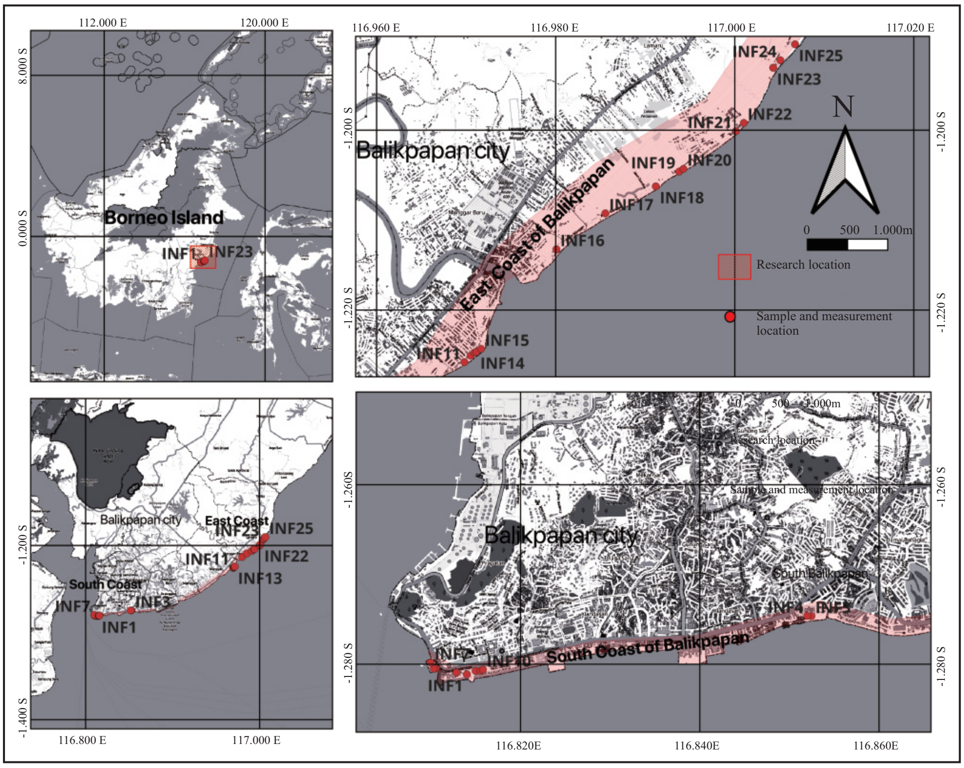

Figure 1. Map of research area location.

to enhance the data legibility using a paper-based form. The application also reduced the time in input data in the studio as the database can be downloaded as a spreadsheet file or a CSV file.

The fourth step is laboratory testing; soil samples were then analyzed for soil moisture or water content. The test procedure is that the soil specimens were directly taken from the sample plastic package, one day after the samples had been taken from the field. Such tests comply with the ASTM D2216 Standard. The other laboratory tests are the sieve analysis test and the hydrometer test, which were used to obtain the grain distribution profile for each soil sample. This test performed a grain distribution chart and the percentage of pebble, sand, silt, and clay. Based on the percentage of sand, silt, and clay, the sand can be classified based on the USDA soil classification system. For further analysis, the field data and laboratory data were incorporated as a table with columns of actual infiltration, initial water content, sand, silt, and clay.

The fifth step is the data analysis and synthesis. The field measurement data were calculated to obtain the actual, mean, and Horton infiltration rates. Then, the infiltration rate was analyzed for its correlation to other data, such as the soil texture, moisture contents, inundation location on the surface, and normalized difference vegetation index (NDVI) of the Sentinel 2 image from EOS Data Analytics http://eos.com. The correlation was used to locate the area prone to inundation. The k-means clustering algorithm was also employed to group the high-risk and low-risk areas of water inundation. The parameters of clustering were taken from the actual infiltration rate and the other strongest correlated variable from the matrix of the correlation plot. The number of optimum k's was determined using the elbow method. This analysis, based on the previous research results and available products in the market, problem-solving for the area's coastal tourist destination development can be offered to the local authorities. The different physical characteristics of the sand were also tracked and analyzed based on the origin of the sand deposits from the geological and paleogeographical points of view.

Discussion is the sixth step, which examines hypotheses and answers the research question by elaborating on relevant research findings. The research findings were used to scientifically validate the answer to the research problem statement. At this stage, the research team also verified that they had met the research objectives.

The last step is to formulate the conclusion based on the research results and the discussion outcomes. The conclusion is the final answer to the research problem. The previous publication, the best practices in the field, and the discussion provided the alternative solutions to the problem. The solutions are also presented as recommendations for local authorities. Additionally, we recommend further research into coastal sand subdrainage to enhance the enjoyment of coastal sand under all conditions and weather.

Materials and Tools

The material that was used in the field measurements and sampling consists of the following: Water was used for infiltration tests using a double-ring infiltrometer. The outer ring fills with water and maintains its stable level, and the inner ring fills with water and observes that the water level drops at every interval (DIN 19682-7:2015-08, 2015; Sulistyo *et al*., 2025). The plastic bucket was used to keep and reserve water during the measurement. During the observation, the data were written on data record sheets. Meanwhile, water and sodium hexametaphosphate were needed in the laboratory hydrometer test.

Tools that were needed in field measurement consist of: A double-ring Ring Infiltrometer was used as a tool for soil infiltration measurement; a sledgehammer was used in the double-infiltrometer setting on the soil, a ruler was used to observe the water-level drop inside the inner ring, and a stopwatch was used to inform the observer of the interval time during measurements. The latitude and longitude measurement location was determined using a handheld GPS or built-in GPS sensor in the smartphone app, considering its accuracy in northing and easting less than 0.6 m (Uradziński and Bakuła, 2020). Meanwhile, laboratory test apparatuses that were needed for the soil moisture and grain distribution consisted of an evaporating plate, hydrometer, and sieve set, and supporting tools consisted of an oven, balance, thermometer, timer, and mixer.

Result and Analysis

The results of the laboratory sieve and hydrometer test of fifteen sand samples were further calculated and presented as grain distribution on a semilogarithmic chart for further analysis. It shows the percentage of clay, silt, sand, and gravel in each sample, with an overlay of fifteen charts showing the similarity and the different textures of samples. Such a chart is depicted in Figure 2.

Grain distribution carts of east coast sands were illustrated using a black line, and grain distribution carts of south coast sand were drawn using a red line. The clay size contents in each east coast sample have an extremely close percentage of weight or are very uniform. Meanwhile, there are south coast samples where the clay size contents have relatively different percentages. Such a trend also happens in silt and very fine sand sizes, as shown by zoomed-in charts in Figure 2. Then, there is no difference in percentages between east coast and south coast samples in fine- to coarse-sand-size contents. A similar trend in silt and clay size percentages happened in very coarse to gravel-sized content, as shown in the right zoomed chart in Figure 2.

The results of sieve analysis, such as soil grain size distribution, the percentage of grain excluding the gravel, including sand, silt, and clay, can be classified using the USDA classification and processed using R Studio. All samples are classified as sand. By zooming in on the graph, it is known that the fifteen samples of east coast blue circles were positioned close to each other. Meanwhile, the ten samples of south coast sand are positioned separately, which have different patterns from the east coast samples, as depicted in Figure 3. The ternary plot of samples

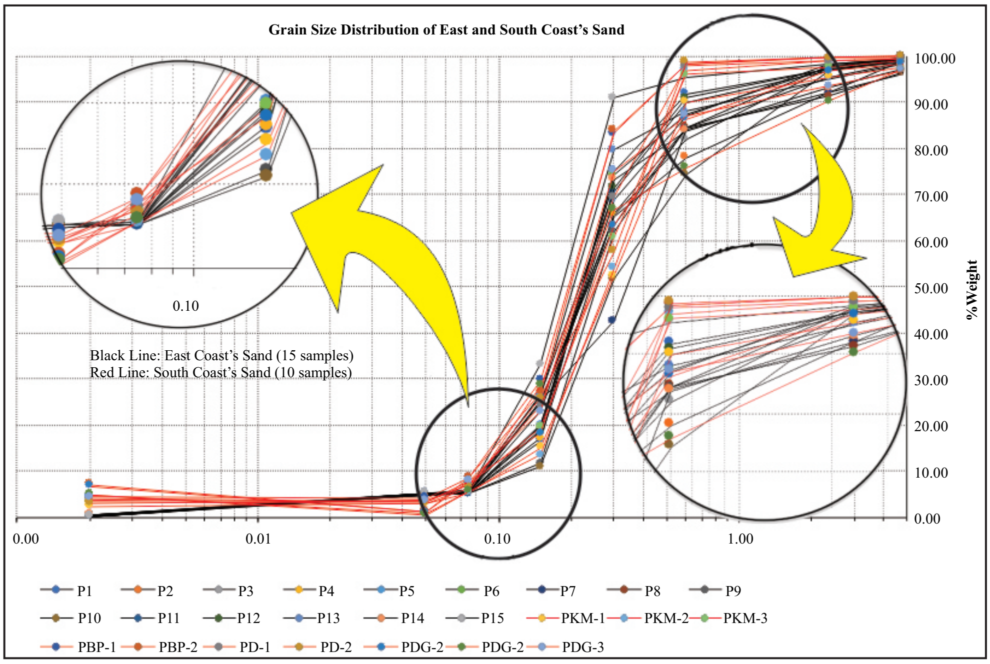

Figure 2. Grain distribution chart of the coast beach samples.

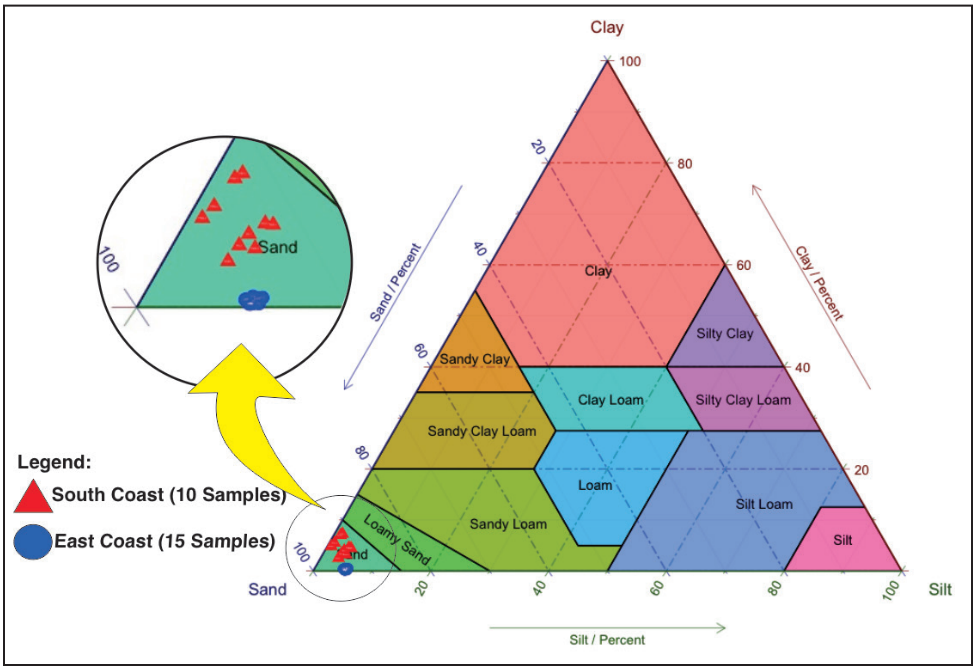

Figure 3. Soil sample classification.

shows that the east coast sand is relatively free of clay content, plotted on the bottom line of the ternary graph. Meanwhile, the south coast samples indicate that most samples relatively contain more clay-sized material than the east coast samples.

The actual infiltration rate of south coast sands is relatively higher than the actual infiltration rate of east coast sands. Such an actual infiltration rate comparison can be seen in Figure 4, where most blue lines at the beginning of measurement time are lower than the red lines.

Based on the classification of the actual soil infiltration rate (Jury and Horton, 2004), the actual infiltration of both east and south coast sands can be categorized as rather slow to very fast infiltration rates, with each actual infiltration rate category shown as blue and red ribbons of the chart in Figure 5. Both Figures 4 and 5 show that the south coast sands' infiltration rate is faster than the east coast sands. Such a phenomenon can be confirmed by available parameters on both coasts or in each location, such as grain distribution and NDVI.

The NDVI map from the Sentinel-2 images with the 10 m resolution was used to overlay the sampling location map. Then, the sampling locations obtained the NDVI of 10th June 2024 values, overlaying the map of the east and south coasts as shown in Figures 6a and 6b. The NDVIs were generated from selected available Sentinel-2 images that were taken at the closest time to the measurement that was conducted in early to mid-June 2024. The NDVI data, as the parameters, were used for further analysis of coastal sand infiltration.

Further analysis was the correlation of each parameter from primary data, such as percentages of gravel, sand, silt, clay, water content, actual infiltration rate, and NDVI, with secondary data. The analysis was conducted using a correlation plot in RStudio. The results of the correlation are illustrated in Figure 7. On the east coast, the strongest negative correlation is the water content or soil moisture to the actual infiltration rate, followed by silt and clay, NDVI, and only sand has a positive correlation to the actual infiltration rate. On the south coast, soil moisture has the strongest negative correlation to infiltration rate, followed by gravel contents, sand, and NDVI. Overall, the percentage of gravel, sand, water contents, and NDVI has a stronger correlation than on the east coast.

The impact of the actual infiltration rate on the function of the sand coast as the playground for tourist activity can be seen in the rainy season, as illustrated in Figure 8. After a rain observation, a few locations of P10 (fast), P11 (very fast), P13 (medium), and P15 (medium) gave the result that P10 and P11, with fast and very fast infiltration rate categories of observations, were not inundated by water. Meanwhile, P13 and P15, with fairly fast infiltration categories, were inundated with water. The result of clustering based on actual infiltration and soil moisture, with 2 clusters as the optimum k (the number of clusters), was determined using the elbow method, where the k-means clustering based on Euclidean distance of sample values was conducted on R Studio.

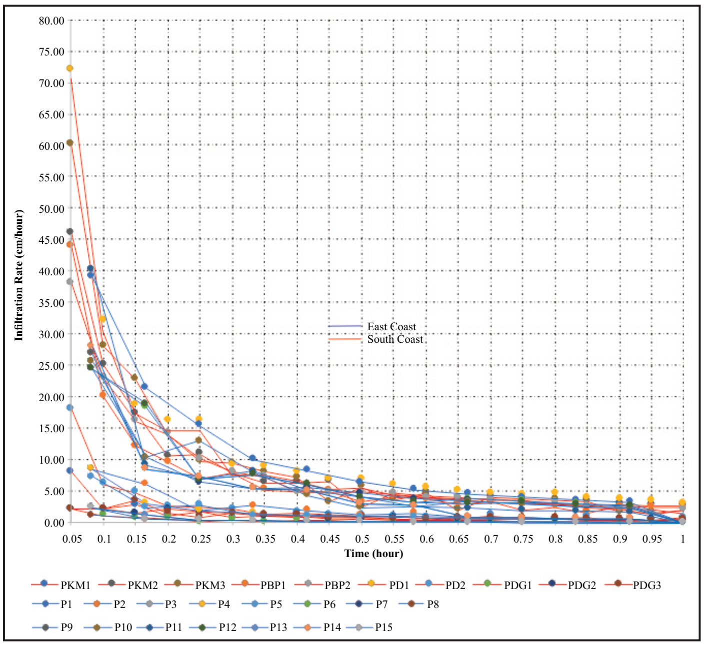

Figure 4. Infiltration rate measured at the sampling location

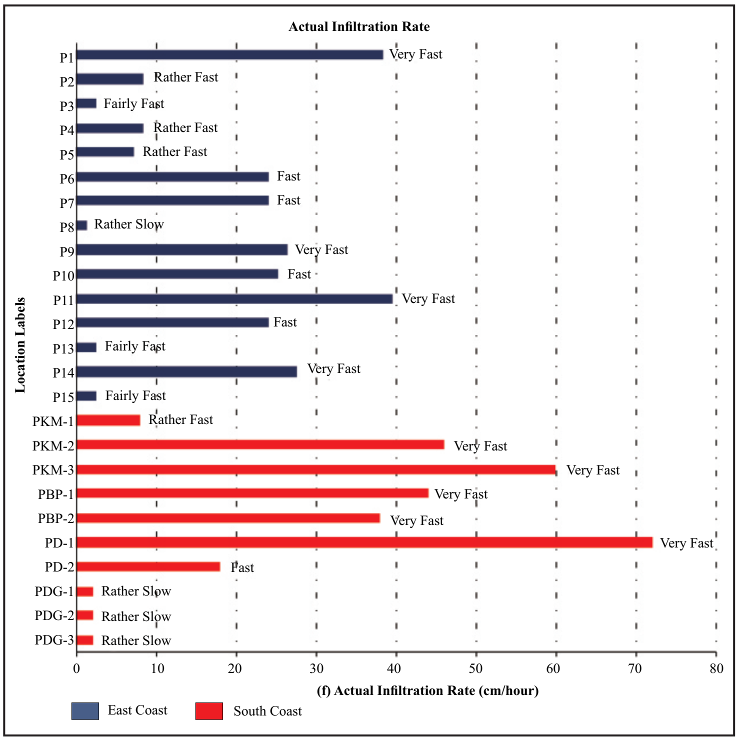

Figure 5. Classification of observed infiltration rates at each location.

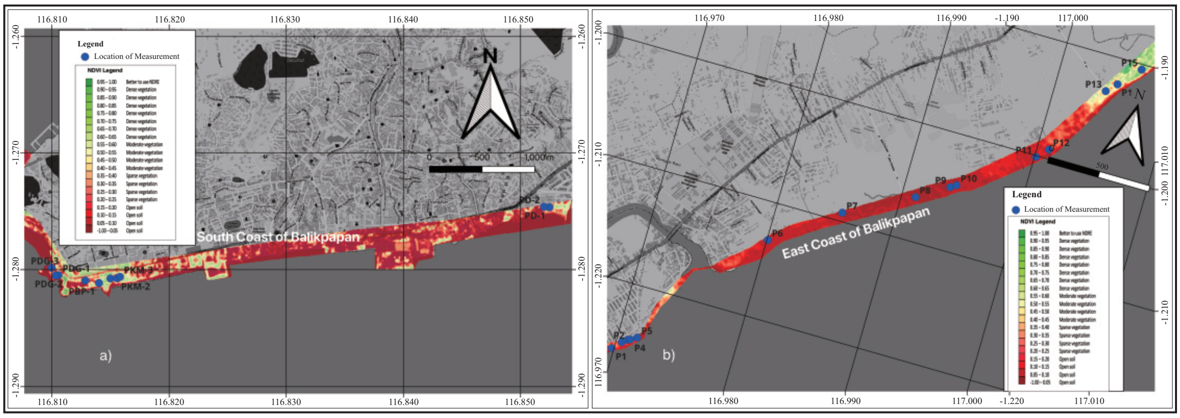

Figure 6. The NDVI map of (a) the south and (b) the east coast.

The results are two clusters, labelled as high risk of inundation and low risk of inundation'. The cluster inundation risks show similarity to the inundation presumption based on the actual infiltration category, as shown in Figure 9. The 2 clusters show that 66.66 % of locations of the samples on the east coast are prone to inundation, and in the south, about 30 % of sample locations are prone to inundation, as listed in Table 1. Based on the actual infiltration category, the locations with medium, rather slow, and slow infiltration rate categories have greater potency inundated by water after rain. Such conditions make the location unfavourable and inconvenient for tourists to do activities like jogging, sports, social gatherings, *etc*. The inundated water on the flat and concave surface of sand deposits can be of long duration. The duration of inundation is negatively correlated to the infiltration rate that can be drawn from the ratio of the infiltrated water and the rest of the water in the inner ring of the double-ring infiltrometer apparatus, but it also depends on

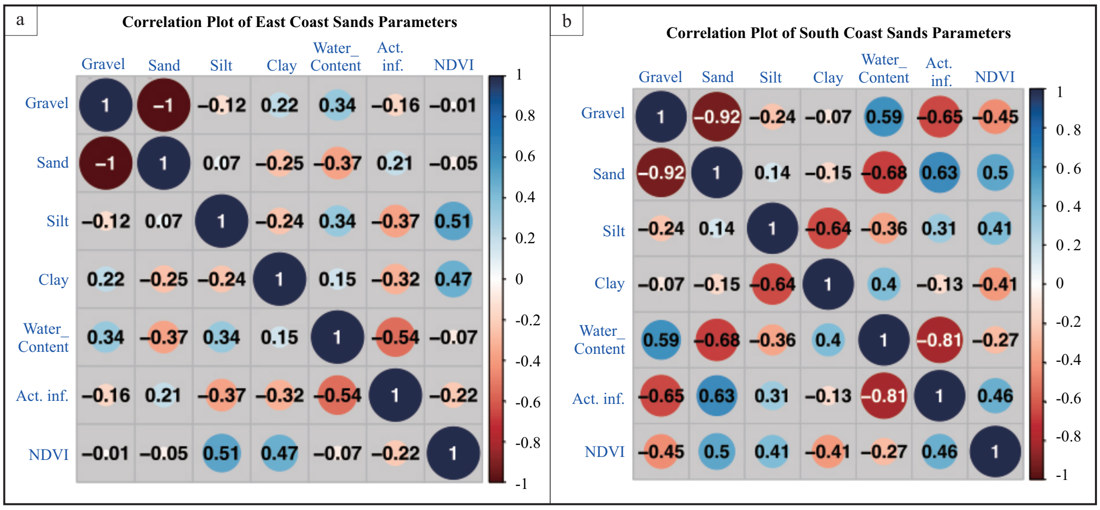

Figure 7. Matrix correlation plot of the sand parameters of a) the east and b) the south coast.

Figure 8. Collated photos of the measurement location condition after the rain.

the infiltration rate value, temperature, weather, wind, and vegetation of the area. Further research is needed to understand the influence of these parameters on water inundation duration.

Discussion

The east coast and the south coast sands show different physical and hydrological characteristics, such as textures, grain distribution, and actual infiltration rates, as proven by Figures 2, 3, 4, and 5. Figure 6 shows similar NDVI conditions on both the south and east coasts. Meanwhile, Figure 7 illustrates a correlation indicating that the physical properties of the sand deposits have determined the infiltration rate. The east coast sand's main governing physical properties are water content, silt, clay, and sand. Meanwhile, on the south coast sands,

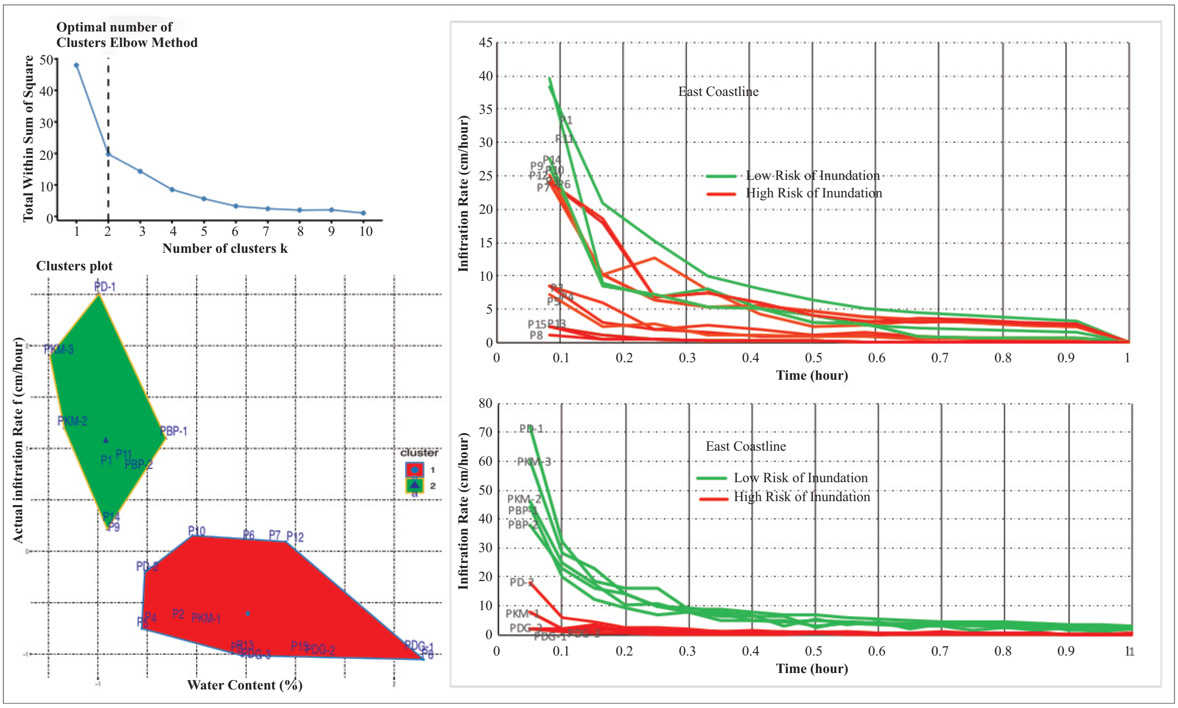

Figure 9. Result of k-means clustering of high-risk and low-risk areas of inundation.

Table 1. Infiltration Rate and Inundation Time Presumption Based on The Ratio of Infiltrated and Rest Water Volume in The Inner Ring of the Double Ring Infiltrometer During In Situ Tests

Code	f (cm/hour)	Criteria Infiltration	Class
P1	38.4	Very Fast	Low Inundation Risk
P2	8.4	Rather Fast	High Inundation Risk
P3	2.4	Medium	High Inundation Risk
P4	8.4	Rather Fast	High Inundation Risk
P5	7.2	Rather Fast	High Inundation Risk
P6	24.0	Fast	High Inundation Risk
P7	24.0	Fast	High Inundation Risk
P8	1.2	Rather Slow	High Inundation Risk
P9	26.4	Very Fast	Low Inundation Risk
P10	25.2	Fast	High Inundation Risk
P11	39.6	Very Fast	Low Inundation Risk
P12	24.0	Fast	High Inundation Risk
P13	2.4	Fairly Fast	High Inundation Risk
P14	27.6	Very Fast	Low Inundation Risk
P15	2.4	Medium	High Inundation Risk
PKM-1	8.0	Rather Fast	High Inundation Risk
PKM-2	46.0	Very Fast	Low Inundation Risk
PKM-3	60.0	Very Fast	Low Inundation Risk
PBP-1	44.0	Very Fast	Low Inundation Risk
PBP-2	38.0	Very Fast	Low Inundation Risk
PD-1	72.0	Very Fast	Low Inundation Risk
PD-2	18.0	Fast	High Inundation Risk
PDG-1	2.0	Rather Slow	High Inundation Risk
PDG-2	2.0	Rather Slow	High Inundation Risk
PDG-3	2.0	Rather Slow	High Inundation Risk

actual infiltration rates are governed principally by water content, gravel, sand, silt, and NDVI.

Why are the east coast sands physically different from the south coast sands? Studying the genesis and origin of both sand deposits can answer such questions. Geologically, the south coast sands are located on the Miocene Balikpapan Formation (Tmbp), which is dominated by quartz sandstone. Meanwhile, the east coast sands are part of the Quaternary alluvium (Qa) that lies on the Pliocene Kampungbaru Formation (Tpkb). The Qa is dominated by loose sand, and the Tpkb is dominated by marl with interbedding siltstone, shale, claystone, and coal. The geological formation of both locations is illustrated in Figure 10.

Based on the geological model and geological map as illustrated in Figures 10 and 11, the geological formations of the researched area also play an important role in the hydrologic system and flood phenomenon (Sulistyo and Respati, 2023). The possible main source of the south coast sand deposits is the material of eroded Tmbp. It was transported by the small and medium rivers that are scarcely distributed in the south coast area. They have a downstream on the south coast, such as the Ampal River and

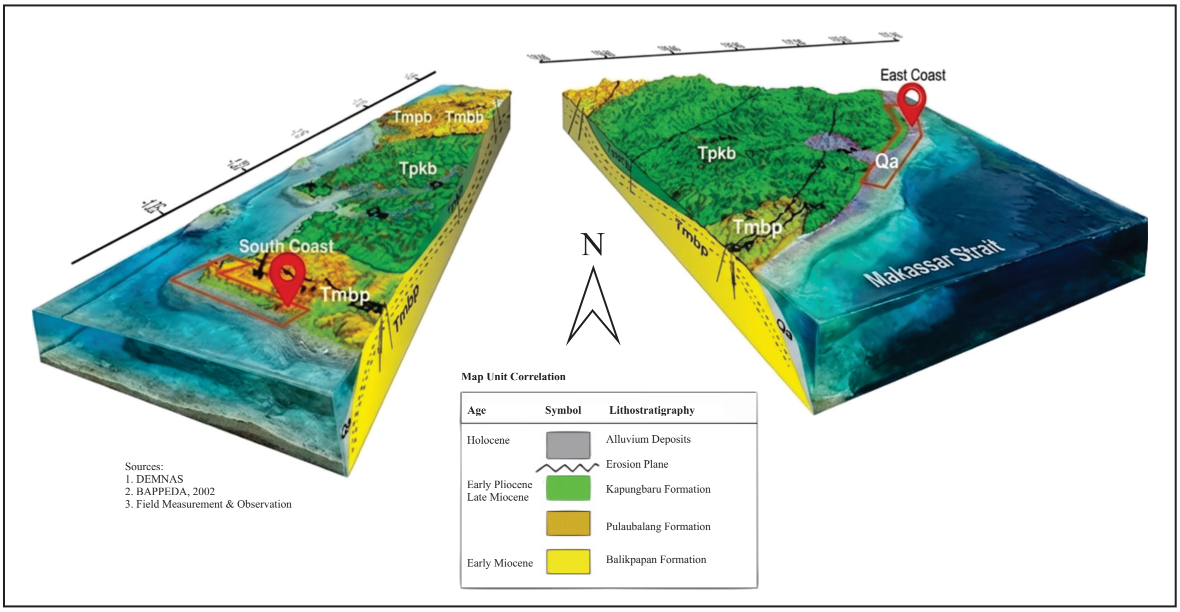

Figure 10. 3D geological model of Balikpapan City.

the Klandasan River, and then are dispersed along the south coast by the sea waves of Balikpapan Bay. The limited river basin area produced a limited sand deposit downstream. The east coast sand deposits possibly mainly came from the eroded materials of the Tpkb that were transported by the bigger and denser rivers than the south coast, as shown in Figure 11, such as the Lamaru River, Manggar Besar River, and Manggar Kecil River. The comparison of the east coast and south coast river catchment areas can be seen in Figure 11, which is overlaid on a geological map as a blue line network layer. After sands were deposited downstream of rivers, the sand deposits were dispersed along the east coasts by the sea waves of the Makassar Strait. The direction of sea waves is 72% westward, and the rest is northward (Riza *et al*., 2023), which seems to have a greater impact on the grain sortation and the spread of sand deposits on the east coast. Such genetic and origin parameters of sand deposits at both coasts have given rise to two differences and physical characteristics. The sands as an alluvium deposit on the east coastline lie onshore broader than the sands on the south coast, as the Quaternary alluvium is mappable on the geologic map of Balikpapan. Meanwhile, in the south coastline, the sand deposit, as alluvium deposits, is limited and not mappable in the geologic map. The result of direct observation of the lithology of Tmbp is dominated by sandstone and has more resistant lithology than the marl of Tpkb. This also explains why the density of river patterns in less resistant lithologies of Tpkb is greater than in more resistant lithologies of Tmbp. The Quarter alluvium deposit is a limited spread onshore, and is not mappable in the geologic map scaled 100.000 (Hidayat and Umar, 1994) and 25.000 (BAPPEDA Balikpapan, 2002).

The combination of source material, transportation energy of river currents, and sea waves determined the sortation (Bartholomä and Flemming, 2007), gradation, and volume of sand deposits of the east coastline and south coastline, which explains why the grain distribution and volume of sand of both places are different. In addition, the presence of vegetation, the initial moisture of sand deposits, and the textures of sand determine the actual infiltration rate (Ketsela *et al*., 2023). The actual infiltration rate determines whether rainwater will stay on the soil surface as run-off and inundation water or as infiltration water to the earth's subsurface. By providing de-

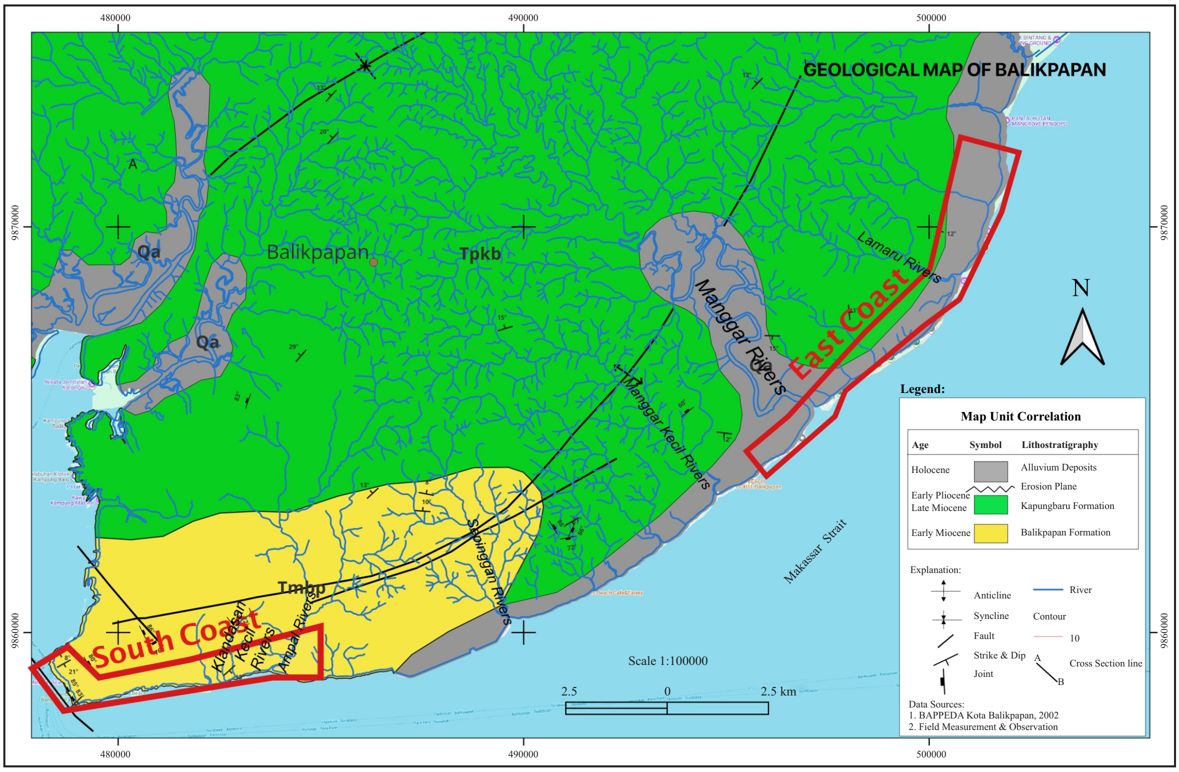

Figure 11. Geological layers and river layers in the researched area.

tailed mapping of soil infiltration, the inundation water on the low infiltration soil can be overcome by installing vertical and subdrainage systems that are available in the market (Prathapar *et al.*, 2018; Beyene *et al.*, 2023). Overall, the result shows the south coastal sand has greater actual infiltration than the east coastal sand. These sand characteristics induce the eastern coastal sand to be more susceptible than the southern coastal sand to water inundation after rain. The field observation was also validated by remote sensing analysis of the global water surface (GWS) image subtraction around June 2024. The map of inundation from the GWS image is displayed in Figure 12. On figures showing that the east coast has more dense inundation points, the red polygon is closer to the coastal line (blue line), rather than in the south coast.

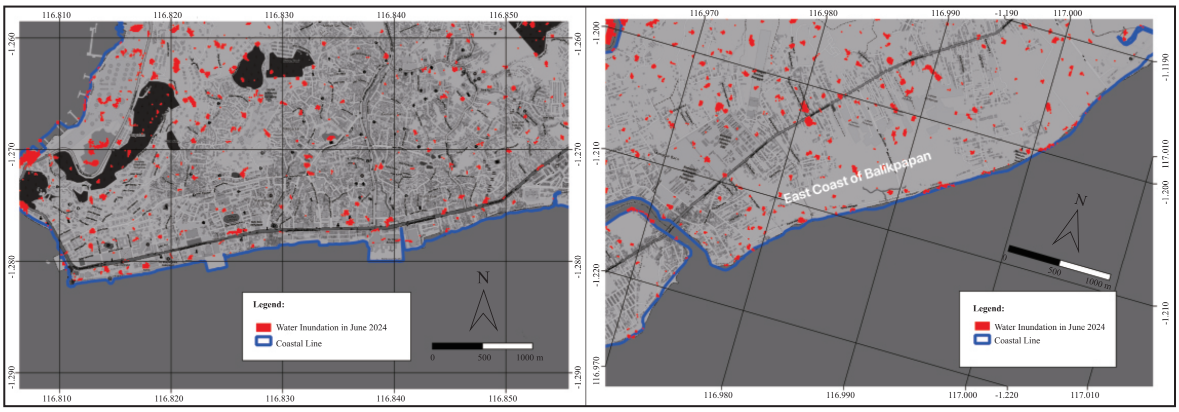

Figure 12. The distribution of inundation of water (red polygons) in the coastal line (blue line): a) south coastal sand, b) east coastal sand.

Conclusions

Based on the USDA soil classification systems, the east coast and south coast sands are classified as the same sand. Still, based on a scrutiny analysis of the sieve and hydrometer test results, the east coast sand has less clay and more silt than the south coast sands. The differences in sand's physical characteristics and NDVI parameters in both coastlines influence the actual infiltration rate of sand. The south coastline sands have a greater actual infiltration rate than the east coastline sands. Such a condition has implications for the flat surface and concave surface during and after raining, where the location with medium infiltration, rather slow, tends to be inundated by run-off water; the inundation water could be of long duration depending on the infiltration rate value, temperature, weather, and wind. Based on k-means clustering, 66.66% of the sample locations on the east coast are prone to water inundation, and 30% of the sample locations on the south coast are prone to water inundation. The observed inundated locations after rain tend to reduce and disturb the sand's function as a place for tourist activities.

The different characteristics and extent of spread for both types of coastline sands are due to variations in lithology from distinct geological formations, including sediment sources and the direction of the coastline. The source of the east coastline sands is the Kampungbaru Formation (Tpkb), which consists mainly of marl with interbedded sandstone, claystone, and coal. Meanwhile, the source of southern Balikpapan is the Balikpapan Formation (Tmbp), dominated by quartz sand. The direction of the east coastline is relatively perpendicular to the sea wave direction, and the direction of the south coastline is relatively parallel to the sea wave direction.

Recommendations for local authorities in overcoming the water inundation to avoid a decrease in tourist visits are:

- Some smart drainage systems can be implemented in the area of inundation to drain the inundated water.
- Conventional vertical and subsurface drainage systems that use pebbles wrapped in geotextile can be applied.
- Another alternative for quickly addressing the issue is to provide a surface water pump to drain the inundation.
- The natural base solution concept can also be implemented, such as dense revegetation of the coast. Leaves of the tree will help retain the rainwater drop directly in the soil or sand, and the vegetation will enhance the evapotranspiration.

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