

EVALUATION OF THE EFFECTIVENESS OF *GREEN BELT* MANGROVE IN MITIGATION OF ABRASION IN KABONGA BESAR VILLAGE, DONGGALA USING DRONE IMAGERY

Juan Imanuel^{1*}, Setiyawan², Fatimah Maulida³

^{1,2,3}Universitas Tadulako, Indonesia

Email: juanimanuel900@mail.com^{1*} setiyawan_sipil@untad.ac.id² fatimahmaulida@untad.ac.id³

Received : 03 May 2026

Accepted : 01 June 2026

Revised : 12 May 2026

Published : 20 June 2026

Abstract

Abrasion beach is one of the coastal area problems that can influence changes in coastal areas and lowering quality ecosystem coast. Mangroves have function important as *green belt* natural that plays a role in dampen energy waves, holding back sediment, and helps guard coastal area stability. Research This aim analyze role mangrove cover and density in mitigation abrasion beach in Kabonga Besar Village, Regency Donggala. Research use approach descriptive-quantitative based drone imagery and systems Information Geographic Information System (GIS). Research results show that wide mangrove cover reaches 1.1 hectares and is still form belt green natural in the area coastal areas. The mangrove density level is classified as Good with an average of 2,233 individuals /ha. Changes in the highest tide limit show three point experience accretion with EPR values are 1.62 m/ year, 0.29 m/ year, and 1.04 m/ year, while One point experience abrasion of -0.72 m/ year. Condition the indicates that the coastal area of Kabonga Besar Village tends to relatively stable, although potential abrasion Still found at the location certain. In particular Overall, mangrove cover and density contribute in support coastal area stability as well as help reduce potential abrasion.

Keywords: *Green Belt*, Mangrove, Abrasion Mitigation, Drone Imagery, Coastal Area

INTRODUCTION

Coastal areas is area with dynamics high and highly vulnerable environment to change physique consequence factor natural and activity human. One of the problem main in coastal areas is Coastal abrasion. Coastal abrasion is the process of erosion land by waves sea and tidal currents that cause coastline changes in a way significant. In the study change coast, the highest tide line (*high tide line*) is often used as reference coastline interpretation Because shows the maximum area interaction between potential sea and land experience abrasion. Increase intensity waves and rises sea level consequence change climate has speed up rate abrasion in various area world De Dominicis et al., 2023coast (; van Hespen et al., 2023). Impact abrasion No only in the form of degradation environment, but also give rise to loss social and economic for public coast, such as lost land, damage infrastructure, and decline quality ecosystem.

Mangroves are ecosystem coast that has function strategic in mitigation abrasion beach. As *green belt*, mangroves are able reduce energy waves, slow down speed current sea, and hold and accumulate sediment through system complex roots. According to Narayan et al., (2025) mangrove belt with adequate width and density can functioning as protector experience effective beach to erosion and flooding coastal areas. The effectiveness of mangroves as *green belt* affected by cover vegetation, density, composition species, as well as distribution mangrove spatial along beach. Condition the show that abrasion beach No only is phenomenon natural, but also can categorized as disaster coastal areas that result in damage environment as well as loss social economy. Therefore that, is necessary effort mitigation For minimize risks and impacts abrasion, one of them through approach *nature-based solution* with utilise mangrove ecosystem as protector experience coast. The mangrove ecosystem is known capable reduce energy waves, suppressing the erosion process, and increase coastal area resilience in a way sustainable (Yasmeen et al., 2024).

Approach mitigation abrasion based ecosystem or *nature-based solution* the more get attention in coastal area management. According to Temmerman et al., (2023) that ecosystem coast such as (mangroves and swamps) beach) able reduce energy wave storm at a time give benefit addition in the form of improvement diversity life and

protection social economy public coast . In addition , mangroves also provide benefit in the form of storage carbon as well as strengthening resilience social economy public coast .

Development technology *Unmanned Aerial Vehicle* (UAV) or drone provides opportunity new in evaluation environment coast in detail and accurately . UAVs are capable of produce image resolution effective height For mapping mangrove cover , analysis density vegetation , as well as monitoring coastline changes in a way fast and efficient (Ayub et al., 2021)In Indonesia, the use of drones in mangrove studies prove increase accuracy identification condition ecosystem compared to method survey field conventional (Maurya et al., 2021).Kabonga Besar Village , Regency Donggala is one of the coastal areas in Central Sulawesi Province which is experiencing ... pressure abrasion beach . Conditions This related with coastal area dynamics influenced by changes in the highest tide limit , energy wave sea , characteristics sediment , as well as existence vegetation protector natural . (Charoenlerkthawin et al., 2024). Situation the show importance existence mangrove ecosystem as buffer experience in guard coastline stability and reduce risk abrasion . Based on condition said , research This aim For evaluate the role of mangroves as *green belt* in mitigation abrasion beach in the Kabonga Besar area, Regency Donggala , with utilise drone technology as tool analysis main . Research This expected can give contribution scientific in development method evaluation ecosystem coast based technology , as well as become base for planning mangrove conservation and rehabilitation sustainable .

LITERATURE REVIEW

Coastal Abrasion and Coastal Area Dynamics

Abrasion beach is phenomenon geomorphology influenced by interactions between energy waves , currents sea , characteristics sediments and morphology beach . Abrasion beach accelerated by the increase frequency wave extreme and rising sea level consequence change global climate (De Dominicis et al., 2023; van Hespén et al., 2023).

Mangrove as *Green belt* (Green Belt)

Mangrove functions as protector experience beach through system capable roots reduce energy waves and traps sediment . the effectiveness of mangroves as *green belt* influenced by width vegetation , structure roots , composition species , and conditions health ecosystem (Narayan et al., 2025).

Mitigation Disaster Coast

Abrasion beach is phenomenon coast that is not only nature natural , but also can categorized as disaster Because cause impact environment and losses social economy . Mitigation efforts required For reduce risk abrasion , one of them through approach *nature-based solution* with utilise mangrove ecosystem as protector experience coast . Mangroves play a role in reduce energy waves , holding back sediment , as well as increase resilience coast in a way sustainable (Yasmeen et al., 2024).

Approach *Nature-Based Solution*

Approach mitigation abrasion based ecosystem or *nature-based solution* the more developed Because assessed more sustainable compared to approach structural hard . Mangrove and swamp restoration beach capable reduce energy wave storm at a time increase diversity life and resilience social economy public coast (Temmerman et al., 2023).

Utilization of drones in coastal studies

UAVs make it possible spatial data collection resolution effective height For mangrove mapping and analysis Coastline changes . Integrated use of drones with GIS to produce map distribution of mangroves with accuracy more tall compared to method conventional (Ayub et al., 2021; Maurya et al., 2021).

Research Gap

Study about the role of mangroves in mitigation abrasion beach has Lots done and shown that mangroves function as protector experience coast . However , some big studies Still evaluate the function of mangroves in general general , not yet differentiate in a way specific role mangrove cover and density as component *green belt* . In addition , the utilization of drone technology for evaluation quantitative-spatial the role of mangroves in mitigation abrasion beach Still limited , especially in the coastal areas of Central Sulawesi. Therefore that , research This important done For evaluate role mangrove cover and density as *green belt* in mitigation abrasion beach in Kabonga Besar Village , Regency Donggala , using approach drone -based .

Framework Thinking

EVALUATION OF THE EFFECTIVENESS OF *GREEN BELT* MANGROVE IN MITIGATION OF ABRASION IN KABONGA BESAR VILLAGE, DONGGALA USING DRONE IMAGERY

Juan Imanuel et al

Based on runway theories and *research gaps* that have been described , arranged framework thinking study For explain connection between variables research . Framework thinking This positioning mangrove cover and density as *green belt* which becomes variables independent whereas mitigation abrasion beach as variables dependent . Relationship between variables analyzed in a way descriptive-quantitative based spatial with utilise drone technology and systems Information Geographic Information System (GIS) as tool evaluation . The framework thinking in study This can seen in figure 1 below .

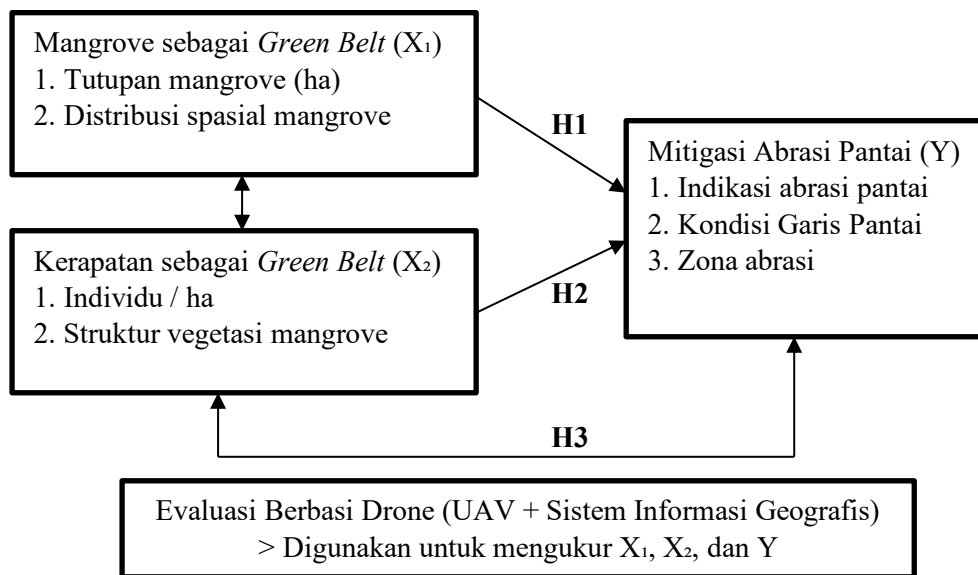


Figure 1. Framework Thinking

RESEARCH METHODS

Types and Approaches Study

Study This is study descriptive-quantitative which emphasizes spatial data collection and analysis use image taken by drone.

Location and Time of Research

Study carried out in the coastal area of Kabonga Besar Village , Regency Donggala , Central Sulawesi Province . Data collection was conducted in April . The map location study seen in figure 2 below .

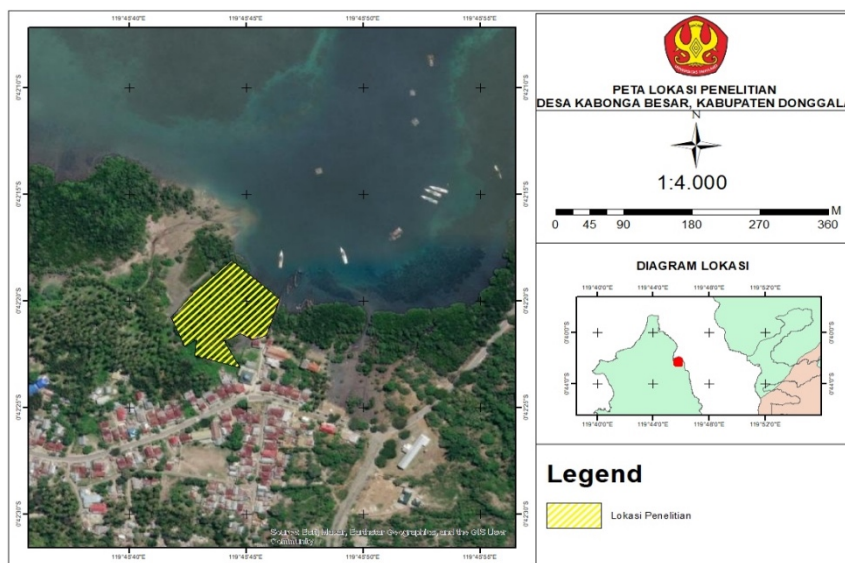


Figure 2. Research Location Map

Objects and Variables Study

Object study is mangrove ecosystem and highest tide limit as representation coastline changes . Variables study covering mangrove cover , mangrove density , and indications abrasion beach .

Data collection technique

Primary data was obtained through photo shoot air using the DGI Mavic drone and observation field . Secondary data obtained from maps and reports agency related .

Data Processing and Analysis

Drone image processing use device soft photogrammetry For produce orthophotos and maps mangrove cover . Stages processing image covering *image alignment*, *dense point cloud*, *digital surface model* (DSM), and *orthomosaic* . Photogrammetric method this drone -based general used in mangrove mapping because capable produce resolution spatial height and level good accuracy (Ayub et al., 2021 ; Maurya et al., 2021). Analysis mangrove cover is carried out through classification image orthophoto using (GIS) for get area and distribution mangrove spatial . The area of mangrove cover is calculated with add up all over polygon results classification in unit hectares (ha). Classification results Then used For evaluate role cover mangrove vegetation as *green belt* in mitigation abrasion beach .

Mangrove vegetation data collection was carried out use method *line transect plot* with draw a transect line in a way upright straight from direction sea going to mainland . On the route transect the placed observation plot measuring 10 × 10 m (100 m²) for identify amount individuals and conditions mangrove vegetation . This method chosen Because capable describe structure vegetation and patterns distribution of mangroves representative of the ecosystem coast as well as general used in inventory mangrove vegetation because own level good accuracy in describe condition stands in the research area (Fitra , 2022). Density mangrove vegetation analyzed based on amount mangrove individuals identified in each observation plot . The mangrove density value was calculated use formula density vegetation as following :

$$K = \frac{N}{A} \times 10.000 \dots \dots \dots (1)$$

Information :

- K= mangrove density (individuals /ha)
- Ni= amount mangrove individuals in observation plots
- A = area of observation plot (m²)

Calculation mangrove density in study This referring to the guidelines inventory mangrove vegetation used by the Ministry of Environment and Forestry (KLHK), where the density vegetation counted based on amount individual in unit wide certain and then converted to unit hectares For make it easier comparison between location research (KLHK, 2017). Analysis abrasion beach done through overlay technique using comparison drone image results survey field with Google Earth imagery in 2023 for identify changes in the highest tide line (*high tide line*) as representation changes in the coastline in coastal areas . Determining the coastline in study This refers to the boundary between land and sea at the highest tide conditions For get more detailed interpretation of the coastline consistent between time observation . Rate of change of the highest tide limit analyzed use End Point Rate (EPR) method for know change coastal area position during period observation . Equation EPR method is written as following :

$$EPR = \frac{L_2 - L_1}{T} \dots \dots \dots (2)$$

Information :

- EPR = rate coastline change (m/ year)
- L₁= initial position of the coastline
- L₂= final position of the coastline
- T = range time observation (year)

Use highest tide reference in coastline interpretation aim For minimize difference the position of the coastline is influenced by tidal fluctuations daily , so that results analysis coastline changes can more representative .

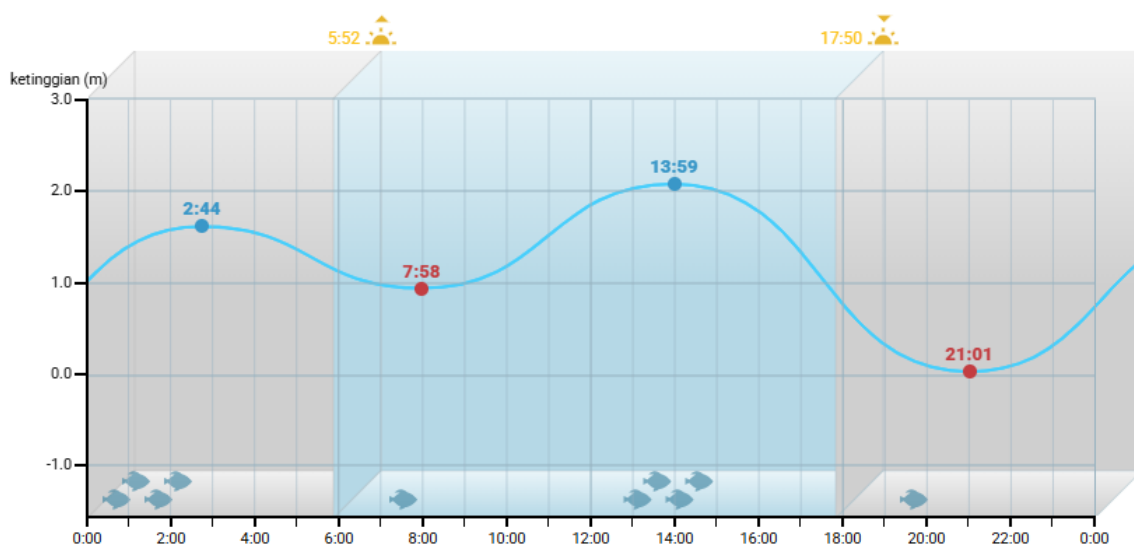
Negative value in the result calculation show occurrence abrasion or coastline retreat , whereas mark positive show accretion or addition mainland .

Next, the results analysis mangrove cover and density compared in a way spatial with coastline conditions. For identify indication mitigation abrasion. Analysis done in a way descriptive-quantitative based spatial through technique *overlay* map using GIS. Analysis results served in form maps, tables, and graphs as base interpretation the role of mangroves as *green belt* in support mitigation abrasion beach in accordance with approach *nature-based solution* (Temmerman et al., 2023).

RESULTS AND DISCUSSION

Study This carried out in the coastal area of Kabonga Besar Village, Regency Donggala, Central Sulawesi Province. The area is a coastal area that is overgrown mangrove vegetation and its function as protector experience to dynamics oceanography, in particular wave sea and abrasion beach. Based on results observation field, conditions environment coast influenced by several factors, including tidal fluctuations, characteristics waves, and existence mangrove vegetation spread along the coastline.

Figure 3. Ebb and flow of Donggala Sea water May 4, 2026

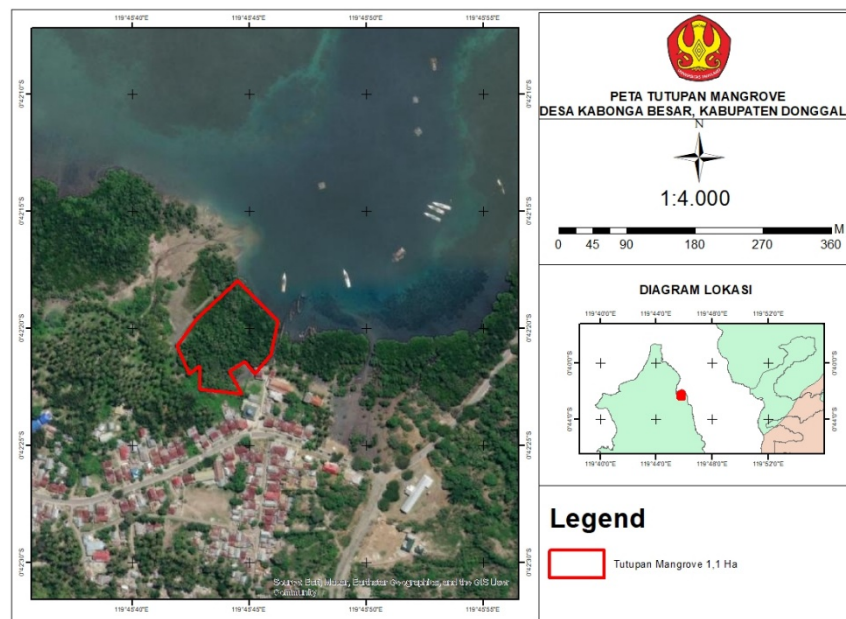


Tidal conditions, especially the highest tides, are one of the factors to consider in interpretation changes in the coastline at the location research. The highest tide used as reference in determine the coastline boundaries so that the results identification coastline changes more consistent and not too affected by fluctuations sea level at the time different observations. Tidal conditions in the waters Donggala show existence change sea level which also influence sustainability mangrove ecosystem. Ebb and flow own role important in the sedimentation process, distribution nutrients, as well as pattern growth Mangrove vegetation in the intertidal zone. Tidal dynamics influence supply nutrients, characteristics sediment, and conditions supportive environment mangrove growth (Zhang et al., 2024) tidal dynamics be one of factor dominant influencing zoning, distribution, and productivity of mangroves in coastal areas. In addition, changes in the coastline at the location research is also influenced by conditions oceanography, such as waves, currents, and tides, as well as existence mangrove vegetation in the area the coast plays a role in guard coastal stability through the detention process sediment and damping energy waves (Dewi et al., 2021).

The Role of Mangrove Cover as *Green belt* in Mitigation Coastal Abrasion

Interpretation results image show that mangrove vegetation at the location study Still spread following the coastline and forming natural *green belt* in the area coastal areas . Based on results mapping , area mangrove cover in the research area reaching 1.1 hectares . Distribution vegetation the generally is in the opposite area direct with sea , so that functioning as a buffer zone experience to influence dynamics coastal conditions This show that the mangrove ecosystem in Kabonga Besar Village is still potential support protection coast from threat abrasion through function ecologically as retainer sediment and damper energy helpful waves guard coastal area stability (Arief et al., 2023).

Figure 4. Mangrove Cover Map 1.1 Ha



Existence mangrove cover in Kabonga Besar Village shows role important in support function *green belt* as effort mitigation abrasion beach . Mangroves grow along the coast coast contribute in dampen energy waves , helping the sedimentation process sediment , as well as guard stability substrate beach . The coastal area is still overgrown mangrove vegetation in general own level protection more beaches Good compared to areas with cover low vegetation , because the existence of mangroves plays a role in dampen energy waves , holding back sediment , and helps guard coastline stability (Temmerman et al ., 2023; van Hespén et al., 2023). This show that mangrove cover in Kabonga Besar Village has contribution to subtraction risk abrasion through function protection experience coast . These results in line with Temmerman et al. (2023) who explained that existence mangrove ecosystem can increase coastal area resilience through ability vegetation in reduce impact energy waves and changes in the coastline .

The Role of Mangrove Density as *Green belt* in Mitigation Coastal Abrasion

Based on results observation field , number mangrove individuals found show variations in each plot. Calculation results show that the first plot own level density of 2,600 individuals /ha, second plot of 2,100 individuals /ha, and the third plot of 2,000 individuals /ha. The average value mangrove density throughout location observation reached 2,233 individuals /ha, as shown in Table 1.

EVALUATION OF THE EFFECTIVENESS OF *GREEN BELT* MANGROVE IN MITIGATION OF ABRASION IN KABONGA BESAR VILLAGE, DONGGALA USING DRONE IMAGERY

Juan Imanuel et al

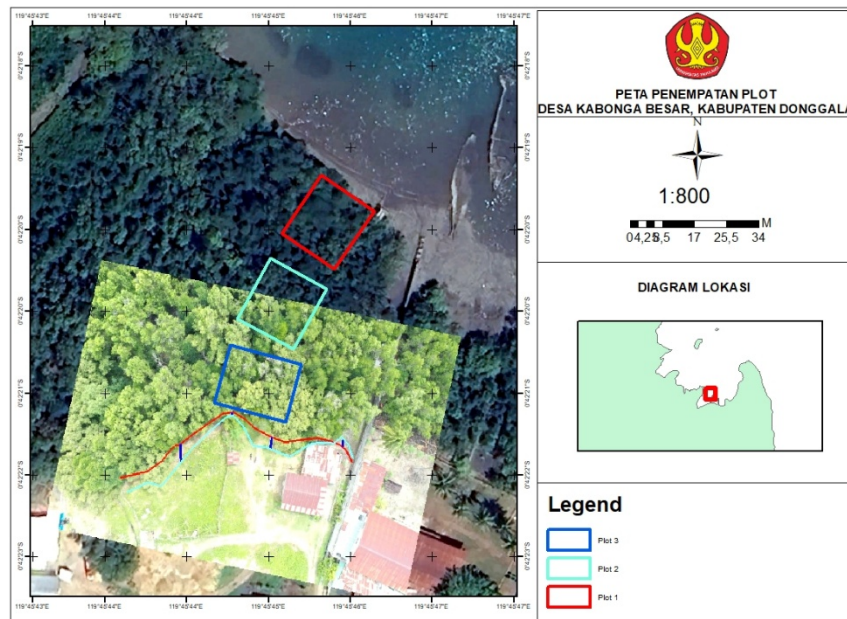


Figure 5. 3 Plot Placement Map

Table 1. Mangrove Density Results

| Plot | Density (Ind/Ha) | Criteria | Condition |
|---------|------------------|-----------|-----------|
| 1 | 2600 | Congested | Good |
| 2 | 2100 | Congested | Good |
| 3 | 2000 | Congested | Good |
| Average | 2,233 | Congested | Good |

Determination condition deep mangrove vegetation study This referring to the criteria standard mangrove damage based on Minister of Environment Decree No. 201 of 2004 as shown in Table 2.

Table 2. Standard Criteria for Mangrove Damage Based on Density Vegetation

| Criteria | Density (Trees /Ha) | Condition |
|-----------|----------------------|-----------|
| Congested | ≥ 1500 | Good |
| Currently | 1000 – <1500 | Currently |
| Seldom | < 1000 | Damaged |

Analysis results show that mangrove density in all observation plots is in the range of 2,000–2,600 individuals /ha with an average of 2,233 individuals /ha. Based on classification Minister of Environment Decree No. 201 of 2004 in Table 2, the value the including in category Good with condition vegetation dense , because exceed minimum threshold of 1,500 trees /ha. All observation plots show mark density above standard said , so that condition mangrove vegetation at the location study can categorized Still classified as good . (KLHK, 2017) The height level mangrove density shows that vegetation in the area study own amount relative individuals tall so that form structure dense vegetation . Conditions the indicates that mangrove ecosystem at the location study Still own function good ecology in guard stability environment coastal structure dense vegetation also has the potential support the function of mangroves as *green belt* through his abilities in dampen energy waves , holding back sediment , as well as help guard stability of the coastline . Conditions This in line with research by Narayan et al. (2025) which explains that structure good mangrove vegetation own ability more tall in increase coastal area resilience to erosion and waves sea . In addition , Temmerman et al. (2023) stated that the effectiveness of mangroves as protector experience coast influenced by structure vegetation and levels density plays a role in reduce energy hydrodynamics in the area beach .

The Role of Mangrove Cover and Density Together in Mitigation Coastal Abrasion

Based on interpretation of the highest tide limit, results observation show that changes in the coastal area in Kabonga Besar Village differ each year point observation. Changes the counted use End Point Rate (EPR) method based on difference between highest tide limit position initial (L1) and highest tide limit position end (L2) in range 3 years time. At point 1, the value of L1 is recorded is 0 m and L2 is 4.86 m so that obtained EPR value of 1.62 m/year which shows existence accretion. Point 2 has The value of L1 is 0 m and L2 is 0.88 m with EPR value of 0.29 m/year. At point 3, it is obtained the value of L1 is 0 m and L2 is 3.12 m so that produce EPR value of 1.04 m/year. Meanwhile that, point 4 shows The value of L1 is 2.18 m and L2 is 0 m with EPR value of -0.72 m/year which indicates occurrence abrasion or coastal area decline during period observation. Condition This show that dynamics changes in the highest tide limit in coastal areas ongoing in a way varies and is influenced by factors environment, such as wave sea, currents, sedimentation, and existence mangrove vegetation as protector experience area coast (Irsadi et al., 2025).

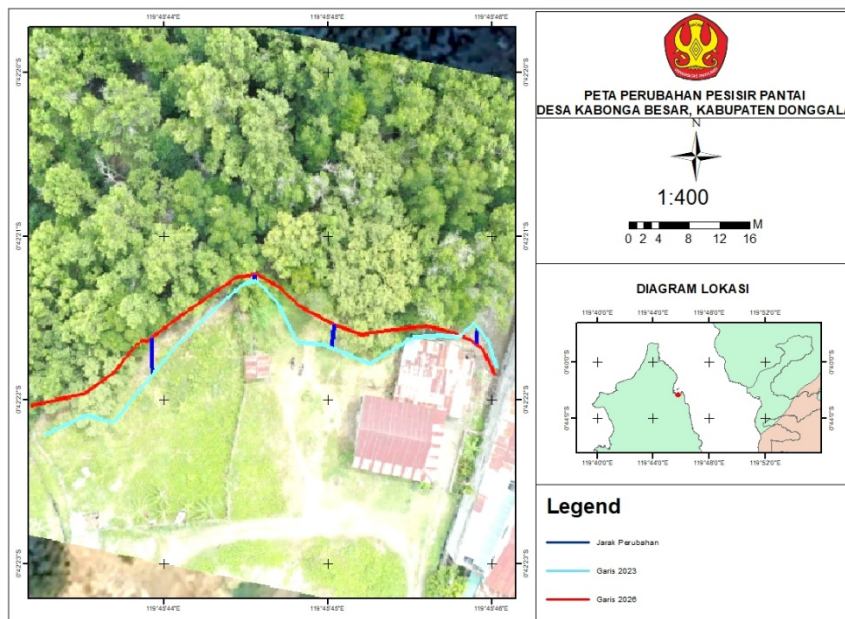


Figure 6. Map of changes in the highest tide limit

Findings the indicates that part large coastal area of Kabonga Besar Village is still show relatively good coastal conditions stable Because domination mark changes that are of a nature positive. Although Thus, it was found mark negative on one point observation show that area coast still own potential experience abrasion in certain areas. The difference condition the allegedly related with variation characteristics oceanography, distribution sediment, as well as level protection vegetation along the coastline (De Dominicis et al., 2023). Condition mangrove vegetation that is still available on site study estimated participate contribute in guard stability area coastal area. The area of mangrove cover is 1.1 hectares supported by an average density of vegetation reaching 2,233 individuals/ha shows that the mangrove ecosystem in Kabonga Besar Village is still be in sufficient condition good and forming *green belt* natural in the area coastal areas. Areas that have more mangrove vegetation wide and dense tend show better coastal conditions awake compared to area with more vegetation limited. This is show that the existence of mangroves has potential ecological in support protection coast to threat abrasion (Herawati et al., 2022).

In a way Overall, mangrove cover and density show mutual relationship support in operate function protection coastal area. Coverage mangrove vegetation plays a role in form area buffer natural along beach, while height level density vegetation increase the ability of mangroves in dampen energy waves, slow down current sea, catch sediment, as well as strengthen substrate beach. With Thus, the combination between wide cover and height density mangrove vegetation provides contribution to coastal area stability as well as help reduce potential abrasion in the coastal area of Kabonga Besar Village. Findings This in line with nature-based solution concept that places mangroves as infrastructure experience in protection area coast (Temmerman et al., 2023).

CONCLUSION

Based on results Research shows that mangrove cover in Kabonga Besar Village is 1.1 hectares . Still form *green belt* natural that plays a role in support coastal area protection . The mangrove density level is classified as Good with an average of 2,233 individuals /ha, so that show that mangrove vegetation at the location study Still be in sufficient condition dense and potential guard coastal area stability . Changes to the highest tide limit show that three point observation experience accretion with EPR values are 1.62 m/ year , 0.29 m/ year , and 1.04 m/ year , while One point experience abrasion of -0.72 m/ year . Condition the indicates that the coastal area of Kabonga Besar Village tends to relatively stable , although potential abrasion Still found at the location certain . In a way Overall , mangrove cover and density play a role as *green belt* natural support coastal stability and help reduce potential abrasion in Kabonga Besar Village .

SUGGESTION

Study furthermore recommended For use range time further observations long so that changes in coastal areas can observed in a way more representative . In addition , it is necessary added oceanographic parameters , such as waves , currents , and tides , in order to obtain more analysis comprehensive related coastal area dynamics . Use drone image with resolution more spatial height is also recommended For increase accuracy mangrove mapping and interpretation changes in the highest tide limit in coastal areas .

REFERENCES

- Arief, F. D., Herison, A., Zakaria, A., & Romdania, Y. (2023). Kemampuan Mangrove dalam Menjaga Garis Pantai. *Jurnal Rekayasa Sipil Dan Desain*, 11(1), 61–72. <https://doi.org/10.23960/jrsdd.v11i1.3050>
- Ayub, A. S., Feri Nugroho, An Nisa Nurul Suci, & Ari Anggoro. (2021). Utilization of Unmanned Aerial Vehicle (UAV) Technology for Mapping Mangrove Ecosystem. *Journal of Sylva Indonesiana*, 4(02), 70–77. <https://doi.org/10.32734/jsi.v4i02.6149>
- Charoenlerkthawin, W., Bidorn, K., Burnett, W. C., Sopon, A., Otarawanna, S., & Bidorn, B. (2024). Evaluating the effectiveness of mangrove rehabilitation: A novel approach for sustainable coastal management. *Journal of Environmental Management*, 365, 121673. <https://doi.org/10.1016/j.jenvman.2024.121673>.
- De Dominicis, M., Wolf, J., van Hespren, R., Zheng, P., & Hu, Z. (2023). Mangrove forests can be an effective coastal defence in the Pearl River Delta, China. *Communications Earth and Environment*, 4(1). <https://doi.org/10.1038/s43247-022-00672-7>
- Dewi, I. P., Nursalam, & Widyanata, D. (2021). Pengaruh dinamika oseanografi terhadap ekosistem mangrove di Desa Pagatan Besar. *Jurnal Geoelebes*, 5(1), 35–45. <https://doi.org/10.20956/geoelebes.v5i1.11975>
- Fitra, R. A. (2022). Kondisi ekosistem mangrove di Kecamatan Wundulako Kabupaten Kolaka. *Jurnal Ilmu Alam dan Lingkungan*, 13(2), 17–24. <https://doi.org/10.20956/jal.v13i2>
- Herawati, H., Hasan, Z., Sahidin, A., Nurruhwati, I., Hamdani, H., Apriliani, I. M., Lantun, D., Dewanti, P., Penulis, K., Perikanan, D., Perikanan, F., & Kelautan, I. (2022). Penyuluhan Pentingnya Green Belt dan Penanaman Mangrove di Muara Gembong Kabupaten Bekasi Counseling on the Importance of Green Belts and Mangrove Planting at Muara Gembong Bekasi Regency. *Farmers: Journal of Community Services*, 3(1), 36–40. <http://jurnal.unpad.ac.id/fjcshttps://doi.org/10.24198/fjcs.v3i1.37813>
- Irsadi, A., Jabbar, A., Dewi, N. K., Somantri, D., Khair, A. S. E., Sidiq, W. A. B. N., Mutiatari, D. P., & Martuti, N. K. T. (2025). Coastal Erosion Reduces Resilience and Disrupts Compositional Dynamics of The Mangrove Ecosystem. *Biosaintifika*, 17(1), 128–142. <https://doi.org/10.15294/biosaintifika.v17i1.17292>
- Irwansah, Usman, Muttaqin, M. Z. H., & Mahariyanti, E. (2024). Mitigasi bencana abrasi berbasis keanekaragaman vegetasi mangrove di pesisir Pantai Bagik Batu, Jerowaru. *Jurnal Ilmiah Global Education*, 5(4), 2062–2068. <https://doi.org/10.55681/jige.v5i4.3494>.
- Kementerian Lingkungan Hidup dan Kehutanan (KLHK). (2017). *Pedoman inventarisasi dan identifikasi mangrove*. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia.
- Maurya, K., Mahajan, S., & Chaube, N. (2021). Remote sensing techniques: mapping and monitoring of mangrove ecosystem—a review. *Complex and Intelligent Systems*, 7(6), 2797–2818. <https://doi.org/10.1007/s40747-021-00457-z>
- Narayan, S., Thomas, C. J., Nzerem, K., Matthewman, J., Shepard, C., Geselbracht, L., & Beck, M. W. (2025). The spatially variable effects of mangroves on flood depths and losses from storm surges in Florida. *Cell Reports Sustainability*. <https://doi.org/10.1016/j.crsus.2025.100531>

EVALUATION OF THE EFFECTIVENESS OF *GREEN BELT* MANGROVE IN MITIGATION OF ABRASION IN KABONGA BESAR VILLAGE, DONGGALA USING DRONE IMAGERY

Juan Imanuel et al

- Suryaningtias, S., Hidayat, J. W., & Helmi, M. (2026). Spatio-temporal dynamics of mangrove cover 1985–2025 based on geospatial analysis in Rembang. *Multidisciplinary Output Research For Actual and International Issue (MORFAI Journal)*, 6(3), 4095–4102. Radja Publika.
- Temmerman, S., Horstman, E. M., Krauss, K. W., Mullarney, J. C., Pelckmans, I., & Schoutens, K. (2023). Marshes and Mangroves as Nature-Based Coastal Storm Buffers. *Annual Review of Marine Science*, 15, 95–118. <https://doi.org/10.1146/annurev-marine-040422-092951>
- van Hespden, R., Hu, Z., Borsje, B., De Dominicis, M., Friess, D. A., Jevrejeva, S., Kleinhans, M. G., Maza, M., van Bijsterveldt, C. E. J., Van der Stocken, T., van Wesenbeeck, B., Xie, D., & Bouma, T. J. (2023). Mangrove forests as a nature-based solution for coastal flood protection: Biophysical and ecological considerations. *Water Science and Engineering*, 16(1), 1–13. <https://doi.org/10.1016/j.wse.2022.10.004>
- Yasmeen, A., Pumijumnong, N., Arunrat, N., Punwong, P., Sereenonchai, S., & Chareonwong, U. (2024). *Nature-based solution for coastal erosion protection in the muddy coasts: Empirical perceptibility from the Upper Gulf of Thailand*. *Ocean & Coastal Management*, 259, 107488. <https://doi.org/10.1016/j.ocecoaman.2024.107488>
- Zhang, X., et al. (2024). *The influence of tide-brought nutrients on microbial carbon metabolic profiles of mangrove sediments*. *Science of The Total Environment*, 906, 167732. <https://doi.org/10.1016/j.scitotenv.2023.167732>