Study Of The Effectiveness Of Integrating Adaptation And Mitigation Actions To The Impacts Of Climate Change In Coastal Areas: A Case Study Of Botanical Gardens Surabaya Mangroves

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***Abstract*.**

Climate change has led to an increased risk of abrasion, tidal flooding, and ecosystem degradation in coastal areas, particularly in urban areas such as Surabaya. The Surabaya Mangrove Botanical Garden (KRMS) serves as an ecosystem-based conservation area that also plays a crucial role in climate change mitigation through carbon sequestration and protection against extreme climate impacts. This study aims to assess the effectiveness of integrating adaptation and mitigation actions in KRMS based on three main aspects: technical, social, and institutional. The research approach uses a combination of quantitative and qualitative methods, using the Analytic Hierarchy Process (AHP) method to assess expert perceptions and Structural Equation Modeling (SEM) to analyze community perceptions. Vegetation analysis was conducted using the Normalized Difference Vegetation Index (NDVI) for the period 2015–2025. The results show an increase in the NDVI value from 0.21 (2015) to 0.63 (2025), indicating successful vegetation rehabilitation and improved ecosystem quality. AHP shows that the social aspect has the highest weighting (0.3712), followed by the technical aspect (0.3228) and the institutional aspect (0.3059). SEM results show that institutional ($\beta = 0.557$; $p < 0.001$) and technical ($\beta = 0.251$; $p = 0.0079$) aspects significantly influence the effectiveness of integration, while social aspects are not statistically significant. This study concludes that the effectiveness of adaptation and mitigation integration in KRMS depends on the synergy between these aspects. Strengthening institutional governance, increasing community ecological literacy, and optimizing the function of mangrove vegetation as blue carbon are the keys to adaptive and sustainable coastal area management.

Keywords: *Adaptation; mitigation; climate change; mangrove; NDVI; AHP; SEM and sustainable coastal management.*

I. INTRODUCTION

Climate change is a global environmental challenge with far-reaching implications for human life and ecosystem balance. Rising global temperatures, increased extreme rainfall, and rising sea levels have worsened coastal conditions. Indonesia, as an archipelagic nation with approximately 108,000 km of coastline, is among the most vulnerable to the impacts of climate change.The Pamurbaya area (Surabaya's East Coast) is a coastal area with high ecological value and vulnerability to climate change. This area serves as a natural barrier against the threats of tidal flooding, abrasion, and seawater intrusion. Located within this area is the Surabaya Mangrove Botanical Garden (KRMS), developed by the Surabaya City Government since 2018 as the first mangrove ecosystem-based thematic conservation area in Indonesia.KRMS plays a crucial role in vegetation conservation, controlling carbon emissions (blue carbon), and strengthening communities' adaptive capacity to climate change. However, to date, few studies have evaluated the extent to which adaptation (adjusting to climate impacts) and mitigation (reducing emissions and increasing carbon sequestration) actions are integrated and effective in the region. Some of the identified problems are: there has been no comprehensive evaluation of the effectiveness of integrating ecosystem-based adaptation and mitigation; quantitative measurements of vegetation conditions and mangrove carbon stocks are needed as technical indicators of mitigation; and social participation and institutional support in adaptive management have not been systematically measured.Therefore, this research is expected to assess the existing conditions of adaptation and mitigation implementation in KRMS; analyze the effectiveness of adaptation and mitigation integration based on three aspects: technical, social, and institutional; determine priority indicators of integration effectiveness using the AHP and SEM methods; and formulate adaptive management strategies based on the results of the analysis.

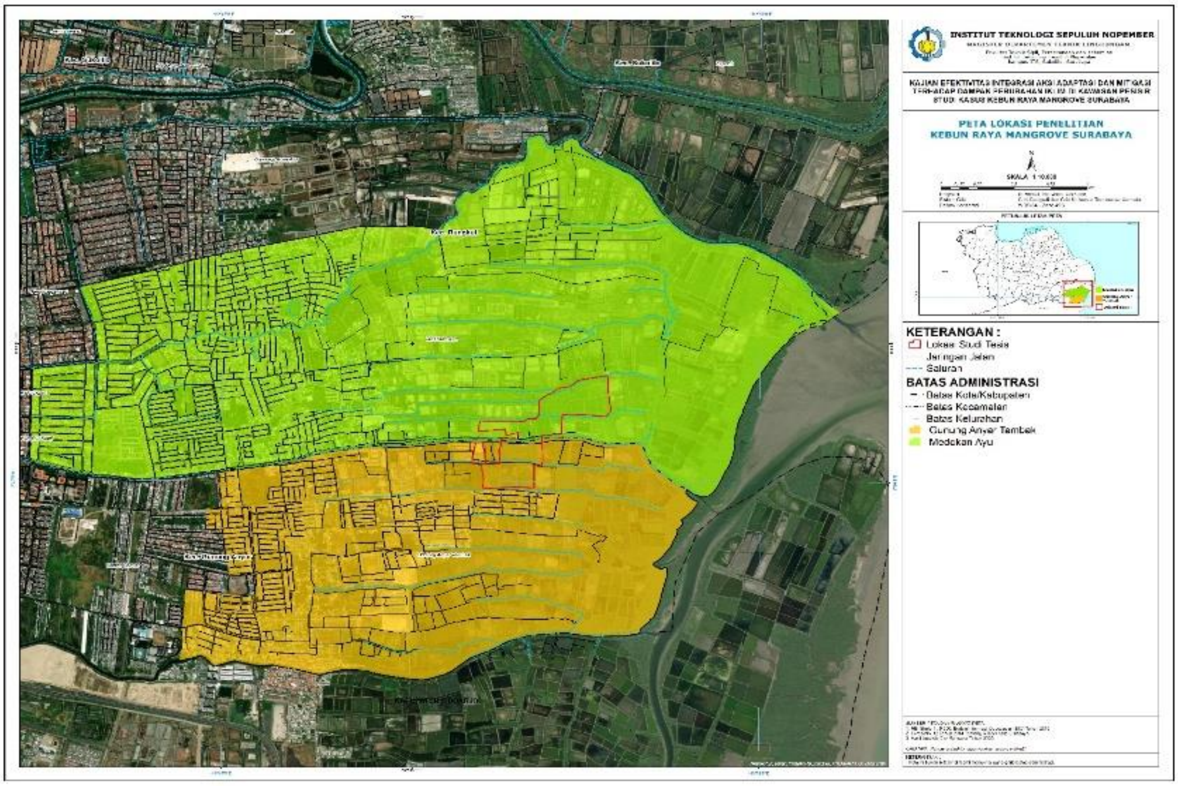

Fig 1. Research Location Map

II. METHODS

The research was conducted in two main KRMS zones: Gunung Anyar and Medokan Ayu. The analysis used a mixed methods approach (quantitative and qualitative).

- Spatial analysis: using satellite imagery to calculate the Normalized Difference Vegetation Index (NDVI) values for 2015–2025.
- AHP analysis: involves experts to determine the priority weights of technical, social, legal and institutional aspects.
- SEM analysis: testing public perceptions of the effectiveness of adaptation–mitigation integration.
- Supporting data: field observations, in-depth interviews, questionnaire surveys, and secondary data from related agencies.

Three main aspects are analyzed:

- Technical Aspects: NDVI, carbon stocks, adaptive infrastructure, and air quality.
- Social Aspects: community participation, adaptive awareness, environmental literacy.
- Institutional Aspects: coordination between agencies, policies, institutional support.

III. RESULT AND DISCUSSION

Mangrove Vegetation Change (NDVI 2015–2025)

Be based on the results of the analysis, te become pe that upgrade there significant healthy vegetation in the KRMS area. In the year n 2015, the area with high NDVI values only covers p se around 0.8% of the total area, se shallow on tofu n 2025 increased me become se around 37%. This increase is heading will ensure the success of rehabilitation and counseling efforts rvasi vege tations that have been implemented by the area manager.

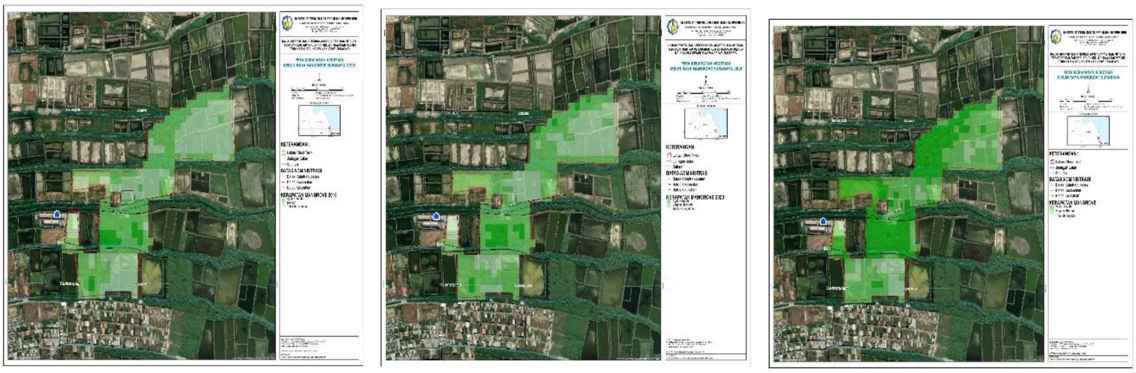

Fig 2. Mangrove Vegetation Density Map in 2015, 2020 and 2025

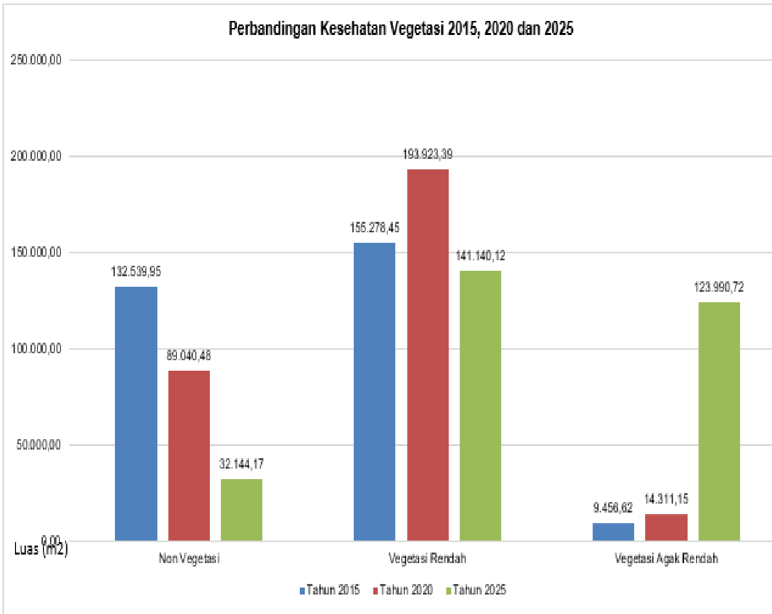

Fig 3. Mangrove Vegetation Health Graph in 2015, 2020 and 2025

The increase in NDVI was distributed primarily in the Gununganyar and Wonorejo zones, which are active rehabilitation areas operated by the UPT KRMS and the Surabaya Environmental Agency (DLH). The dominant species growing include Avicennia marina, Sonneratia alba, Rhizophora mucronata, and Bruguiera gymnorhiza. This rehabilitation also had a positive impact on hydrological stability, soil quality, and reduced sedimentation in natural canals. Akhiruddin et al. (2019) stated that the increase in NDVI values is directly proportional to the effectiveness of rehabilitation and increased soil organic carbon stocks, while Donato et al. (2011) emphasized that mangrove ecosystems including k is the highest carbon absorber in the world, so increasing vegetation cover has an important role in mitigating climate change.

Carbon Stocks and Ecosystem Functions

The results of the analysis of the potential mangrove carbon stock in the Surabaya Mangrove Botanical Gardens (KRMS) area show the highest value when compared to other mangrove ecosystem zone locations in Pamurbaya, as in Table 1. The high carbon stock value in KRMS and Gunung Anyar indicates that the mangrove carbon stock in the KRMS area is the highest in the Surabaya Mangrove Botanical Gardens (KRMS). kkan that this area berperan as the main “carbon sink” in the coastal areas of Surabaya. Based on the IPCC classification (2014), the ecosystem de with a value of >7,000 tons/ha termasuk kate very high gori for k forest pe tropical comb.

Table 1. E Carbon Stock E estimation kosiste m Mangrove Su City Rabaya

No	Mangrove Ecosystem Zone	Observation Location/Subzone	Area (ha)	Estimated Average Carbon Stock (ton/ha)	Estimated Total Carbon Stock (tons)	Dominance of Main Types
1	Pantu rbaya (U Beach) Tara Su (rabaya)	We Pond at 1–2, Kenje ran 1–2, Kepu tih 1–2	177.63	4,915.72	872,950	*Rhizophora mucronata*, Avice *nnia alba*
2	Pamu rbaya (East Coast) r Su (rabaya)	Wonore jo 1–3 (te rmasu k Mangrove Botanical Garden Su rabaya), Gu nu ng Anyar 1–2, Me Ayu's doctor	915.51	8,020.13	7,338,300	*Avice nnia marina*, Sunne *ratia alba*, Avice *nnia alba*
3	Forest Area n Mangrove Kingdom Su rabaya (KRMS) (part of Pamu *(rbaya)*	Wonore jo (1–3) & Gu nu New (1)	91.5	8,304.00	759,800	*Avice nnia marina*, Sunne *ratia alba*
4	Me Ayu's doctor (su *bzone pene additional research)*	Me Ayu's doctor Timu r–West	63.7	7,480.00	476,000	*Avice nnia alba*, Rhizophora stylosa
	TOTAL Su Rabaya	See you ru h mangrove zone (U Tara + Timu r)	1,093.14	7,387.63 (re *flat gabu (with)*	8,687,250	—

This increase in carbon stocks indicates strong ecosystem recovery, coupled with sustainable mangrove rehabilitation and planting. In Aldea's (2025) study, which used predictive modeling of mangrove biomass, above ground (Above) *Group and Biomass*/AGB) with integration of field data and index ks spe ktral (NDVI, NDWI, CMRI). Pe sampling was carried out in 40 plots of land on the East Coast r Su Rabaya, te rmasu k Gu District nu ng Anyar, which is also not meru Kebu location feed n Mangrove Kingdom , which leads to yield range of 6,000–8,500 tons/ha u that mangrove tropical in Asia Te nggara. Aldea (2025) ju didn't note that je nis Avice *nnia marina* me dominated by 2,590 trees ru my r, followed Ti Bru *gu ie ra gymnorhiza*(505 trees) and Sonneratia alba (630 trees). Kore positive correlation between NDVI and carbon stock no me until show that pe upgrade to ve meeting directly proportional vibration s de with carbon absorption capacity. This potential strengthens the function of KRMS as an ecosystem-based mitigation element that supports the achievement of Surabaya City's Net Zero Emission target by 2060.

Animals in the Mangrove Ecosystem

The diversity of animals, especially birds, is indicator feed pe important in assessing the health of mangrove ecosystems . Hurry Water has an ecological role as a bioindicator, a regulator balance of trophic chains, as well as full ecosystem service coverage m, both in cycle s nutrients as well as in supporting the adaptation and mitigation functions of peru climate materials.To strengthen fauna diversity data, Bird Banding (wild bird tagging) activities were carried out by a team of certified experts in collaboration with PT. United Tractors Tbk and the Indonesian Bird Banding Scheme. (IBBS) in 2022-2024 in the KRMS area. Based on the results of bird banding conducted by United Tractors from 2022 to 2023, 11 species were recorded. s birds were successfully marked with a total of 30 individuals as in Table 2.

Table 2. Animals at KRMS Based on Bird Banding Results in 2023

No	Species Name (Scientific)	Protection Status	IUCN Status	this	pi = ni/N	Dominance (%)
1	*Rhipidu ra javanica*	Not protected ngi	LC	7	0.2333	23.33
2	*Ge rygone su lphurea*	Not protected ngi	LC	5	0.1667	16.67
3	*De ndrocopos mace i*	Not protected ngi	LC	5	0.1667	16.67

4	*Lonchu ra leucogastroide s*	Not protected ngi	LC	3	0.1000	10.00
5	*Alcedo meninting*	Protected	LC	2	0.0667	6.67
6	*Alce do coe ru le sce ns*	Protected	LC	2	0.0667	6.67
7	*Pachycephala grisola*	Not protected ngi	LC	2	0.0667	6.67
8	*Todiramphu s chloris*	Protected	LC	1	0.0333	3.33
9	*Pycnonotu s goiavie r*	Not protected ngi	LC	1	0.0333	3.33
10	*Crypsirina te Mia*	Not protected ngi	LC	1	0.0333	3.33
11	*Collocalia linchi*	Not protected ngi	LC	1	0.0333	3.33

Source: Calculation Analysis

Markmaximum diversity (H'max) = 2.3979, Evenness Index (J') = 0.9017 approaching 1shows that there is no very dominant species, and the structure your community structure bird population in KRMS te rclassified as stable (Odum, 1996; Magurran, 2004).Meanwhile, the results of the 2024 bird appeal show that even though n te there is a slight decrease in the number of species and individuals compared to tofu n 2023, stru time r komu reproductive activity and identity wild bird action in KRMS continues to show stability good ecological condition. The existence of this type of water meaning Sea Crow and Blue King Prawn mene emphasize that this area is still functional optimal function as an important habitat for resident and some migrant waterbirds.From the adaptation side, to the existence of water birds RTI*Alcedo meninting*,*Alcedo coeru lessons*, And*Todiramphus chloris*berfu ngsi as a bioindicator of environmental quality ngan. From a mitigation perspective, animals have a contribution important in supporting the function of the blue carbon ecosystem (blue *carbon ecosystem*)**.**Fruit-eating birds perti Merbah ce ru kcuk**(Pycnonotus** *s goiavie r)*plays a role in seed dispersal and natural regeneration of mangroves , which contributes to increased soil carbon sequestration and biomass. The activity of the bottom fauna is like mangrove crab **(Scylla spp.)**also me help soil aeration and cycle s organic carbon**,**that mempe strengthen the mitigation capacity of the area against greenhouse gas emissions mah kaca. Integration of animal management in the content adaptation and mitigation ks in KRMS te go to kkan positive results.

Legal and Institutional Aspects

The management of KRMS is within a multi-level regulatory framework, which forms the basis for the following climate change adaptation and mitigation governance:.

1. Presidential Decree No. 83 of 2023 concerning the Management of Botanical Gardens
   This regulation emphasizes KRMS's role as a mangrove ecosystem conservation center, education and research center, blue carbon laboratory, and greenhouse gas emission mitigation component. This Presidential Decree provides legal legitimacy for coastal botanical gardens like KRMS's strategic role in climate risk reduction.
2. Surabaya City Regional Regulation Number 3 of 2025 te Regarding the Surabaya City Spatial Planning Plan (RTRW) for 2025–2045
   In the Regional Regulation it is stated ma'am t, Pamurbaya area, te rmasu k To ma'am n Mangrove Kingdom Surabaya, dite designated as a City Strategic Area (KSK) with fu ngsi u protected park and ecosystem conservation m coast, as stated in Article 54 and the Attachment to the Spatial Pattern Map of the RTRW. This area also includes k in Su b-Mangrove Ecosystem Protection Zone and Coastal Buffers
3. Surabaya Mayor Regulation Number 41 of 2019 n 2023 te Potato Pembe that UPT Ke Mangrove Forest
   UPT KRMS carries out the function of conse rvation and edu public service at once s me have a mandate to old development alternative food ingredients based on sugar mbe mangrove resources , se walk with you Food Security and Agriculture Service (DKPP) office
4. The plan to transfer the UPT KRMS from DKPP to BRIDA, in accordance with the mandate of Presidential Regulation Number 83 of 2023 concerning the Management of Botanical Gardens

Social Aspects of Society

The effectiveness of adaptation and mitigation measures at the Surabaya Mangrove Botanical Gardens (KRMS) is closely related to the social and demographic conditions of the surrounding communities, particularly in the Gununganyar Tambak and Medokan Ayu sub-districts. These two areas have distinct socio-economic characteristics, yet complement each other in supporting the sustainable management of ecosystem-based conservation areas.In socio-economic terms, the existence of KRMS provides provide real benefits for local residents by increasing employment opportunities in the ecotourism sector, river transportation, and mangrove processing production. like sir p, batik, and typical mangrove fruit-based foods This model supports the principle of community-based adaptation, where improving community welfare aligns with climate change mitigation and adaptation efforts (Agus et al., 2022; BRIN, 2025).

AHP–SEM Analysis of Integration Effectiveness

In the context of the In this study, AHP was used use for k collect expert assessments te towards priority aspects k and indicators of adaptation and mitigation peru climate materials in Kebu n Mangrove Kingdom Surabaya (KRMS), specifically The results are related to technical aspects, social aspects and legal and institutional aspects, and the results obtained are as in Table 3.

Table 3. Priority Weight of Main Aspects of Adaptation-Mitigation Integration based on AHP Analysis

Aspect	Priority Weight	Information
Social Aspects	0.3712	Participation, education, benefits community economy
Te Aspect knis	0.3228	Mangrove rehabilitation , concept wildlife conservation, coastal hydrology
Legal & Institutional Aspects	0.3059	Team lation, collaboration, and governance adaptive lola

Meanwhile, SEM is used to analyze the results of the community questionnaire on perceptions and effects. implementation activities of adaptation and mitigation strategies peru climate materials in KRMS, including: perceptions of the impacts of tidal flooding and climate change, perceptions of on infrastructure effectiveness time r adaptive, to the perception of te towards participation and institutional support. Respondents were residents or workers who lived around KRMS, including p in the Gununganyar Tambak and Medokan Ayu sub-districts, with results as in Table 4.

Table l 4. Results of SEM Analysis of Effect Mitigation Adaptation Integration Activities in KRMS

Construct	Cronbach's α	Path Coefficient (β)	p-value	Significance Statement
Te knis (X1)	0.899	0.251	0.0079	Significant (+)
Social (X2)	0.863	0.135	0.2644	Not significant
To le structure (X3)	0.877	0.557	<0.001	Very significant (+)
Mode l (R^2)	—	—	—	0.638

Pe nde katan gabu ngan antara Analytic Hie Rarchy Proce ss (AHP) and Stru ctu ral E qu ation Mode ling (SE M) used what do you do that to me until role h pe mahaman the le more compressed he nsif me nge nai e fe internet activity adaptation and mitigation action pardon ru climate materials in the Ke region ma'am n Mangrove Kingdom Su rabaya (KRMS). AHP analysis me nce prioritize to be wise based on pe rse psy expert, se SE shallow M me describe pe rse community psychology te rhadap imple me inte ntation adaptation–mitigation grace in the field. Be Riku t pe comparison between AHP and SE results M as in Table 5.

Table 5. Comparison of Main Results of AHP and SEM

Aspect	AHP (Expert)	SEM (Society)	Integrative Interpretation
Technical (X1)	Weight 0.3228 – priority II. Focus s main on ve ge mangrove forest (0.49) and the concept animal rvation (0.32).	Significant te rhadap e fe internet activity grace (β = 0.251; p = 0.0079).	In harmony: both experts want pu n society me rehabilitation and concept values mangrove conservation as a foundation for u adaptation and mitigation.
Social (X2)	Te weight rtinggi 0.3712 – priority I. E two kasi (0.38) and community participation (0.38) me become a pillar of u first.	Not statistically significant (β = 0.135; p = 0.264).	Difference: experts assess aspects social k as me main key, te but society be you m me feel the effect social activities real ways in the field.
Aspect	**AHP (Expert)**	**SEM (Society)**	**Integrative Interpretation**
Law &	Weight 0.3059 – priority III,	Most significant te rhadap	Complete me nte r: me society du

Institutions (X3)	de just focus s on re gu lasi pe longing with mangroves (0.21) and collaboration to le instruments (0.19).	e fe activity (β = 0.557; p < 0.001).	value my just re gu layout and layout the most adaptive lola that right to be program results.

Sumber : Analysis Results

Inte approach This grative underlines that the social and safety emotional instrument s runs parallel to with the action knis. Integration to both of them produce a strategy of the le KRMS lolaan more powerful continue tan:

1. Dime nsi Te knis – peng atan fu ngsi e ecological through i vege rehabilitation concept, concept rvation ma'am ru ng water, and penge hydrological control pe comb. Me referring on AHP weights and SE results M is significant, this strategy is te thousand kti efe actively increase pe rse positive psi of the community te rhadap pe nge KRMS's lolaan.
2. Social Dimension – pe capacity increase and public awareness. AHP me ne gas pe the important thing is two kasi (0.38) and participation (0.38); SE results M me remind pe rlu his pe ngu atan imple me real tation so that pe rse psi pu back there ru t me increase.
3. Dime nsi Ke le mbagaan – pe ngu atan tata ke Lola, re gu lation, and cross-sector collaboration ctor. To two a result me ndu my ng pe the importance of wise se pe rti Pe rda RTRW No. 3 Tahu n 2025 and Pe Mayor No. 41 Know n 2023 u that to me until rku at pe ran U PT KRMS in pe nge adaptive lolaan

IV. CONCLUSION

1. Condition E ksisting Pe ne Adaptation and Mitigation Action Plan in KRMSKasan Ke ma'am n Mangrove Kingdom Su rabaya (KRMS) me nu nju kkan pe significant improvement in ve condition ge mangrove forest in me ru n time 2015–2025. Increase in NDVI values nu nju will go to be re results habilitation ve ge tasi and pe upgrade to se hatan e kosiste m. This result is rku at de with te your an area that is nu nju kkan pe upgrade to me diversity ma'am ru ng air and e physio nsi se carbon rapan (blu *e carbon stock*) se be sar ±134 tons/ha in the Gu zone nu nganyar. This is mene emphasize that adaptation and mitigation actions are lah te rinte ecological grace
2. Priority Indicators Pe ngu atan Inte The most important indicator of grace rpe ngaru h me nu ru t AHP and SE analysis M is:
   a. Cross-le coordination copper and ke adaptive wisdom (high AHP weight and SE loading M significant),
   b. To ve meeting ge tasi and ke se hatan e kosiste mangrove forest ,
   c. Environmental education and pe community empowerment, se rta
   d. *Monitoring, Re porting, and Verification (MRV)* te towards climate action.

   These indicators are become a basic pillar of pe ngu atan e fe adaptation–mitigation activities in KRMS.
3. Pengu Strategy Ecosystem-Based Adaptation and Mitigation Based on the integration of AHP–SEM analysis and the results of the implications for wisely, an integrative management strategy is developed that emphasizes:
   a. The approach ecological-clinical through vegetation rehabilitation, pest control water quality, and inte blue data grace *carbon*;
   b. Social-participatory approach through increasing community capacity and awareness;
   c. The kele approach my stuff Then i order to adaptive lola be BRIDA base;
   d. Pe nde scientific words–adaptive de with pe ne report on rise results t in ke wise land rah.

   Sine rgi between aspe k-aspe k te rse ma'am t me mbe that k mode l pe nge KRMS's favorite rke continue tan and can be dire application on the ma'am n raya pe another comb.

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