Optimization of coastal land in Modung District, Bangkalan Regency as a conservation effort

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Abstract. The coast of Modung District is one of the areas in the south of Bangkalan Regency that is vulnerable to coastal erosion. This study focuses on optimizing coastal land in the vulnerable Modung District of Bangkalan Regency to address coastal erosion while enhancing agricultural productivity, economic valuation of mangrove forests, and minimizing soil erosion. Using Geographic Information System (GIS) analysis, Total Economic Value (TEV) assessment of mangrove forests, and the Universal Soil Loss Equation (USLE) model for soil erosion estimation, the research employs goal programming techniques to optimize land allocation. The findings reveal valuable insights: agricultural productivity ranges from 57.07 to 5892.39 tons/Ha in the Modung coastal area, while the economic valuation of mangrove forests is estimated at IDR 55,748,386/Ha. Soil erosion potential is identified, with agricultural and residential areas facing 0.53 and 2.01 tons/ha/year, respectively, while mangrove areas experience 0.06 tons/ha/year. The total potential soil erosion loss in the area is estimated at IDR 11,941,375,649. The optimization analysis presents a scenario allocating 3897.85 Ha for agricultural use, 788.63 Ha for settlements, and 120.51 Ha for mangrove conservation. This approach aims to enhance agricultural productivity, mitigate soil erosion, and conserve mangrove areas, contributing to coastal land conservation efforts.

1 Introduction

Management of land needs due to changes in land use situations requires good planning [1]. Mistakes in human and land management will threaten sustainable urban management and development. Effective urban land use is an important part of sustainable urban land development and management [2]. One area that is developing rapidly for various industries is the coastal area. In general, interested parties in coastal areas include the agricultural/fishing sector, tourism, mining, maritime transportation, maritime industry and conservation. Coastal areas have richness and diversity of biological resources in various forms of natural resources, heroic structures, customs, culture, and various other related resources as well as high environmental services [3]. Coastal areas also often experience threats of environmental damage such as erosion, abrasion, loss of resources, decreased biodiversity, pollution and etc. Coastal erosion and its management have been the focus of recent research. Not only global climate change, erosion in coastal areas is also caused by a reduction in the amount of river sediment due to sand mining and dam construction, land conversion, disruption of sediment transport along the coast due to coastal structures and other anthropogenic activities [4-5].

Rapid urbanization of coastal zones and increasing habitat loss, is critical to understanding how urban development affects coastal biodiversity and the provision of ecosystem services. Additionally, it is important to understand how habitat fragments can be incorporated into broader land use planning and coastal management, to maximize the environmental benefits they provide [6]. Rapid economic development will result in rapid urban development as well. Significant urban growth will alter much of the arable land and forest resources, giving rise to food security problems [2]. This is because agricultural land use encompasses a variety of interrelated ecological and socio-economic aspects [7]. On the other hand, forest resources also represent a dynamic and complex socio-ecological system for achieving sustainability [8], while agriculture with its broad benefits for society including nutritional, social, economic and cultural is an important sector in achieving development sustainable goals [9-11]. Thus, the Sustainable Development Goals have a close relationship between biodiversity and human welfare [12]. Thus, agricultural system sustainability analysis can use an interdisciplinary approach [13-14].

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Coastal land use planning have to fulfill three basic planning elements, namely rational and comprehensive planning, value-based planning and ecosystem-based management [15]. These elements characterize trade-offs between (a) urban development and individual mangrove environmental indicators (habitat quality and ecosystem services), and (b) between various environmental indicators. The indicators used are biological, biophysical, and cultural indicators, including carbon, charcoal production, support for offshore fisheries, recreation, and habitat quality for threatened species. Land use optimization using boundaries can be a useful decision support tool for understanding how changes in land use and coastal management will impact the ability of ecosystems to provide environmental benefits [6].

Land optimization is a method that helps decision makers determine the best scenario from various land use options without sacrificing the economic value of land use that provides benefits [16], and sustainable [17]. Optimization is also a tool that aims to achieve balanced long-term urban development through efficient use of resources, environmental protection, social justice and economic prosperity [18]. Land use optimization assessments generally focus on trade-offs between conflicting objectives due to limited land which has the potential to give rise to conflicts between economic and environmental interests [19]. Predicting future scenarios and exploring sustainable urban development options requires modelling. Specific ecological and environmental conditions are applied as spatial constraints for the model and predict four future scenarios, namely a planning-oriented urban planning scenario and an ecosystem protection-oriented ecological scenario. The plan scenario is taken as a baseline as the existing condition. The urban land size simulated from the Plan Scenario in the future is taken as a target to accommodate the projected population increase in a city area which is then applied in the previous development scenario. Modeling is expected to not only help in assessing and adapting urban planning schemes but also evaluating planning in coastal cities [20].

The aim of the programming model is to optimize land use arrangements, minimize environmental impacts and increase land use benefits. The essence of management science, as reflected in modelling and programming approaches, is seen as a key instrument for wisely allocating scarce resources to maximize benefits [16]. The government manages land use in such a way as to achieve optimal land use and in reality there are overlapping interests [17-21]. Determining economic and ecological objectives often uses environmental services research. However, these assessments are unable to determine spatial locations to limit land use [19]. Therefore, Therefore, a decision making model is needed to combine the economic and ecological interests of an area.

One of the multi-criteria decision making models in land optimization is Goal programming. This type of decision making is related to situations where the decision maker makes an assessment of certain alternatives based on more than one criteria that usually conflict with each other [22]. The Goal programming method is a development of linear programming. This method is able to solve a problem by making decisions for more than one goal [23]. This modeling determines optimal decisions to achieve certain goals which consist of three important elements, namely a) decision variables, b) objective function, and c) constraint function [24-25]. This technique has developed widely and is widely used in general management systems, one of which is in land use management by studying land productivity and optimal use of resources.

The coast of Modung District is one of the areas in the south of Bangkalan Regency that is vulnerable to erosion. Land use in this area in the form of agricultural land, aquaculture, residential areas, and mangrove areas requires optimization to maintain agricultural and fisheries productivity, increase the economic value of mangrove forests, and reduce the risk of soil erosion. Based on the description above, this research aims to optimize the allocation of land area for mangrove conservation areas, agricultural land, and settlements. This land optimization is an effort to optimize agricultural productivity, increase the beneficial value of mangrove forests, and minimize the potential for soil erosion as a conservation effort using goal programming model. Land optimization in Modung District can prevent economic growth conflicts and a decline in environmental services. Apart from that, it is also an effort to plan and manage sustainable coastal areas.

2 Method

2.1 Time and place

This research took at the coastal area of Modung District, Bangkalan Regency, East Java below the Fig. 1.

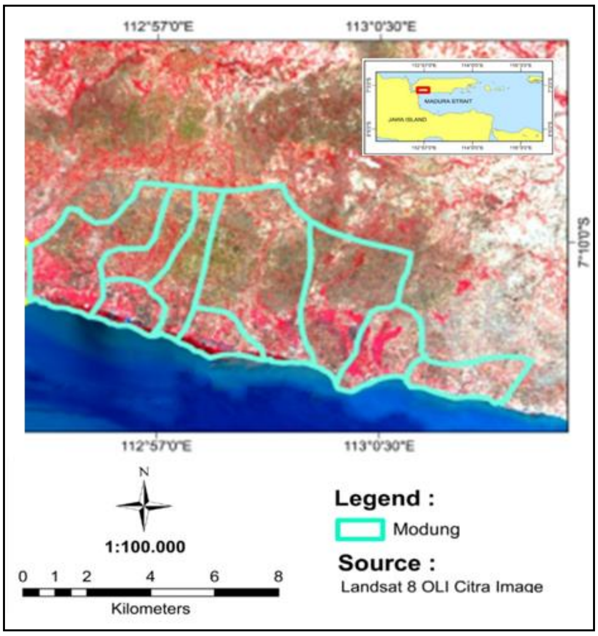

Fig 1. Study area.

2.2 Land use analysis

Calculation of land use area using 2019 LandSat 8 OLI satellite image analysis with land cover classes referring to Indonesian national standards No. 7645 of 2010. Land cover classification includes settlements, rice fields, moors, plantations, mangroves and rivers. Image correction begins the analysis stage which consists of radiometric correction and geometric correction. The next stage is land use classification using Supervised Classification with the Maximum Likelihood algorithm [26].

2.3 Analysis of agricultural productivity

Assessment of agricultural land productivity at the research location uses secondary data from the Central Regional Statistics Agency of Bangkalan Regency. The data collected in this research are data on production and harvest area of agricultural crops, plantations and aquaculture.

2.4 Economic valuation of mangrove forests

There are two value components that make up the total economic value of a mangrove resource, namely use value (UV) and non-use value (NUV). Use value includes direct use value (DUV), indirect use value (IUV), and option value (OV). Non-use value consists of existence value (XV) based on willingness to pay for moral, altruistic, or other reasons. Value that is not related to use value or option value and bequest value (BV) measures a person's willingness to pay as an heir for the use of these resources in the future. Total economic value can be expressed by [27]:

$$TEV=UV+NUV=(DUV+IUV+OV)+(XV+BV) \tag{1}$$

2.5 Soil erosion estimation

Soil erosion is estimated using the universal soil loss equation (USLE) model method formula [28]:

$$A = R.K.LS.C.P \tag{2}$$

Information:
A = Soil erosion (tons/ha/year)
R = Rain erosivity factor
K = Soil erodibility factor
LS = Slope length and slope factor
C = Land cover vegetation factor
P = Soil conservation action factor

2.5.1 Rain erosivity factor (R)

The calculation of rain erosivity is shown in the following formula [28]:

$$R = 6.12\ Pb^{1.21}\ N^{-0.47}\ Pmax^{0.53} \tag{3}$$

Information:
R = Rain erosivity index (ton.cm/hour)
Pb = Monthly rainfall
N = Monthly number of rainy days
P_{max} = Maximum rain

2.5.2 Soil erodibility factor

The soil erodibility factor (K) shows the resistance of soil particles to exfoliation and transport of these soil particles by the kinetic energy of rainwater. The classification of soil erodibility factors is written in Table 1.

Table 1. Soil erodibility factors.

No.	Soil clasification	K factor
1.	Latosol	0.31
2.	Regasol	0.12
3.	Lithosol	0.29
4.	Gumosol	0.21
5.	Grey hydromaof	0.20

Source: [29].

2.5.3 Length and slope factors (LS)

Assessment of length and slope factors (LS) using Table 2.

Table 2. Length and slope factors (LS).

No.	Slope (%)	LS factor
1.	0 – 5	0.25
2.	5 – 15	1.20
3.	15 – 35	4.25
4.	35 – 50	7.50
5.	> 50	12.00

Source: [30].

2.5.4 Land cover vegetation factors

Plant management factors are factors that show the overall influence of vegetation, litter, soil surface conditions, and land management on the amount of soil lost (erosion). Therefore, the C number is not always the same within one year (Table 3).

Table 3. Land cover vegetation factors.

No.	Land use	CP factor
.	Fresh water	0
2.	Shrubs	0.3
3.	Building	0
4.	Forest	0.03
5.	Plantattion	0.4
6.	Settlement	0
7.	Swamp	0
8.	Meadow	0.07
9.	Irrigated rice fields	0.05
10.	Rain-fed rice fields	0.05
11.	Moor	0.75

Source: [30].

2.5.5 Soil conservation action factors

Soil conservation action factors are available in Table 4.

Table 4. Soil conservation action factors.

No.	Land use classification		P factor
1.	Without erosion control measures		1.00
2.	Terras Bench	Medium construction	0.04
		Good construction	0.15
		Poor construction	0.35
		Traditional terrace	0.40
3.	Plant strips	Bahia Grass	0.40
		Clotararia	0.64
		with a contour of	0.20
4.	Tillage and planting according to contour lines	Slope: 0 - 8 %	0.50
		8 - 20 %	0.75
		> 20 %	0.90

Source: [31].

The P factor is the ratio between the average eroded soil from land that has received certain conservation treatment to the average eroded soil from land treated without conservation measures, provided that other erosion-causing factors do not change in value.

2.6 Land use optimization model

Preparation of a land use optimization model on the coast of Modung District, Bangkalan Regency using Goal Programming analysis which is a development of linear programming. This method is able to solve a problem with decisions that must be taken to fulfill several or more than one goal. The programming goals in this research were analyzed using LINGO 11 software.

The main components of the model are based on the general framework of optimization modeling (mathematical programming), namely decision variables or instruments; option space (opportunity sets) which is formulated with several functions limiting the value of decision variables called constraint functions; and objective function.

2.6.1 Decision variables or instruments

Mathematical model that provided specific values and proportions for the allocation of land, indicating the optimized combination of land use proportions for agricultural land, settlements, and mangrove forest conservation.

2.6.2 Objective function

It is a linear mathematical relationship that explains resource objectives in terms of decision variables with a maximizing/minimizing target. The objective function is structured based on optimization targets to maximize profits and minimize erosion. For this dual purpose, the optimization technique used is Goal Programming.

2.6.3 Constraint functions

The constraint function in this research consists of:

a. Hard Constraints: Set the hard constraint regarding the availability of land to be optimized, representing the area of coastal villages in Modung District.
b. Goal Constraints: Formulated goal constraints related to increased agricultural productivity, enhancing the beneficial value of mangroves, settlement growth, and reducing soil erosion risk.

The space utilization optimization model in this research is for problems with multiple objectives with the same importance (omnibus goal programming). In omnibus goal programming, each goal does not have a priority order [32]. The mathematical formula used in this model is as follows [33],

Objective function:

$$Minimize \quad Z = \sum_{t=1}^{m} (d_i^+ + d_i^-) \qquad (4)$$

Goal constraints:

$$C_{11}X_1 + C_{12}X_2 + \ldots + C_{1n}X_n + d_1^- - d_1^+ = b_1 \qquad (5)$$

$$C_{21}X_1 + C_{22}X_2 + \ldots + C_{2n}X_n + d_2^- - d_2^+ = b_2 \qquad (6)$$

$$C_{m1}X_1 + C_{m2}X_2 + \ldots + C_{1n}X_n + d_m^- - d_m^+ = b_m \qquad (7)$$

and

$$X_j, d_i^-, d_i^+ \geq 0$$
$$\text{for } i = 1, 2, \ldots, m \text{, and } j = 1, 2, \ldots, n \qquad (8)$$

Information:

Z = objective function
C_{ij} = coefficient of the objective constraint function, which is related to the objective of the decision making variable (X_j)
X_j = decision-making or activity variable (sub-goal)
b_1 = goal or target to be achieved
d_m^+ = number of units in excess (+) of the goal (b_m)
d_m^- = number of deviation units that are short (-) towards the goal (b_m)

3 Results and discussion

3.1 Land use

Land use on the Modung coast includes agricultural areas, moorlands, plantations, ponds, seattlements, mangroves, and rivers are presented in Figure 2 and Table 5.

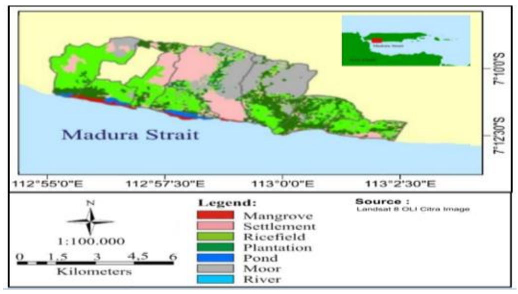

Fig 2. Land use on the Modung coast.

Table 5. Area of Modung coastal land use.

Land use	Area (Ha)
Ricefield	1,768.93
Moorlands	1,391.15
Plantations	659.90
Ponds	77.87
Settlements	800.70
Mangroves	108.44
Rivers	168.58
Total	**4,975.57**

Land use is a human activity carried out on certain land and is greatly influenced by population growth. Population development with various activities in it is one of the things that influences the process of land use change [34]. Population growth and activities in coastal areas in developed and developing countries cause rapid changes in land use [35]. Rapid changes in land use are caused by factors, namely (1) population concentration with various activities in it, (2) accessibility of city centers and activity centers, (3) road networks and transportation facilities, (4) orbit of an area with service centers [36]. Area function direction is needed when land use changes occur. This is because arrangement that is appropriate to its function will create an area that is safe, comfortable, productive and sustainable [37].

3.2 Optimization of modung coastal land

3.2.1 Objective function

The objective function in goal programming is the minimum deviation equation from the goals to be achieved. There are two types of deviation, namely positive deviation and negative deviation. Optimal conditions can be achieved if deviations towards the goals to be achieved can be minimized until they are close to or right at the optimal point. The objective function in this research is to obtain optimal land area. The optimal combination of land area that will be sought is agricultural land area (X1), seattlement area (X2), mangrove area (X3). The objective function of optimizing coastal land in Modung District is as follows:

$$Minimize\ Z = d_1^- + d_2^- + d_3^+ \quad (9)$$

Where:
d_1^-= the magnitude of the shortfall from the target for increasing agricultural production
d_2^-= the magnitude of the shortfall from the target of increasing the economic value of mangroves
d_3^+= the amount of excess of the target to reduce the risk of erosion

3.2.2 Constraint function

Two types of constraint functions in land optimization formulation are hard constrains and goal constrains. Hard constraints are limiting functions that cannot be violated, while goal constraints are limiting functions related to the goal (target). The function of constraints in this research is as follows:

3.2.3 Hard Constraints

The hard constraint in this research is the availability of land to be optimized. Land availability represents the area of coastal villages in Modung District of 4975.57 Ha. The land area optimized in the model does not include the area of rivers and river borders. Based on this area, the hard constraint functions as follows:

$$X_1 + X_2 + X_3 \leq 4806.99 \text{ Ha} \quad (10)$$

Where:
X_1= Agricultural land area (rice fields, fields, gardens and fisheries cultivation)
X_2= Seattlement area
X_3= Mangrove forest area

3.2.4 Goal Constraints

This research has three objectives which are limited by several constraint functions as follows:

1. Increased agricultural productivity

Modung District is an agricultural, dryland and plantation area with commodities such as rice, chilies, eggplant, biopharmaceuticals, fruit, coconut and sugar cane. Agriculture on a wide scale, in the form of fisheries, at the research location is a pond area with the vanamae shrimp commodity. The formulation of the constraint function in this research is based on agricultural production and productivity values through data analysis from the Bangkalan Regency Central Statistics Agency of 2022 [38] (Table 6).

Crop planting structure optimization and modification have long been major study topics in agricultural geography and sustainable agricultural development. Combining contemporary technology and agricultural machinery has the potential to maximize resource utilization and efficiency. Thus, crop planting structure rationality not only directly promotes high agricultural yields and rises in farmer revenue, but also plays an essential role in the development of agricultural economics [39].

Table 6. Formulation of the agricultural productivity constraint function

Land use	Productivity (ton/ha)	Production (ton)	Formulation
Ricefield	29,60	52,358.11	$29.6X1 + d_1^- - d_1^+ \geq 52358.11$ (11)
Moor	4,24	5,892.39	$4.24X1 + d_1^- - d_1^+ \geq 5892.39$ (12)
Plantation	2,01	1,328.98	$2.01X1 + d_1^- - d_1^+ \geq 1328.98$ (13)
Aquaculture (pond)	0,67	52.07	$0.67X1 + d_1^- - d_1^+ \geq 52.07$ (14)

2. Increasing the beneficial value of mangroves

The utilization value of mangrove forests is IDR 55,748,386 per ha and the total economic value of mangroves at the research location is presented in Table 7.

Table 7. Total economic value (TEV) of mangroves in Modung Regency

Utilization	Value (IDR/Ha)
Direct use value	
Benefits of commercial wood	92,174,000
Benefits of firewood	299,403
Benefits of mangrove fruit	28,210,883
Fish catching	541,745,853
Shrimp fishing	29,504,464
In-direct use value	
Beach protector	144,663,623
Carbon stock provider	5,795,293,856
Optional value	
Benefits of choice	19,763,190
Bequest value	
Benefits of existence	66,365,280
Total economic value (TEV)	**6,718,020,552**

Increasing the beneficial value of mangroves in this research uses the following formulation:

$$55748386X_3 + d_3^- - d_3^+ \geq 6{,}718{,}020{,}552 \tag{11}$$

The goal of cost-benefit analysis is to help decision makers make decisions that are compatible with efficiency in resource allocation in a certain area. According to a long-held theoretical paradigm, mangrove diversity is significant because it enhances production and environmental stability. Understanding the role of mangroves in boosting the productivity and stability of coastal ecosystems might help raise awareness of their use and function. The derived monetary value estimates appear to provide substantial support for the view that mangrove ecosystems provide significant and positive social value at first glance. Because of the great potential economic value that can be gained from other activities and the need to protect mangrove forests from over-exploitation, a trade-off must be made between safeguarding stakeholders' rights to use mangrove forests and protecting mangrove forests from over-exploitation [27].

3. Settlement growth

The residential growth that may occur at the research location is formulated as follows:

$$X_2 + d_2^- - d_2^+ \geq 800.7 \text{ Ha} \tag{12}$$

4. Reducing the risk of soil erosion

Table 8 shows the potential for soil erosion based on land use in the coastal area of Modung District.Loss assessment is based on land nutrient losses amounting to IDR 2,400,000 per hectare [40]. Mitigation of soil erosion uses a soil erosion rate of 4444.39 tons/ha/year with a loss value of IDR 11,941,375,649.

Table 8. Soil erosion rate based on land use

Land use	Soil erosion simulation (tons/ha/year)
Agriculture	0.53
Settlement	2.01
Forest	0.06

Based on this, the formulation of the soil erosion risk constraint function in this research is :

$$0.53X_1 + 2.01X_2 + 0.06X_3 + d_1^- - d_1^+ + d_2^- - d_2^+ + d_3^- - d_3^+ = 11{,}941{,}375{,}649 \tag{13}$$

3.3 Land optimization

Optimazion land use allocation is one of the main steps in sustainable space planning. Limited resources and conflicting use plans make it difficult to achieve sustainable use goals. Therefore, a mathematical method is needed to optimize conflicting objectives. Programming is a mathematical model that is widely used to optimize land use allocation in a sustainable manner [41]. The allocation of land area for each type of land use is based on analysis using LINGGO 11 through the output solution report in Table 9.

Table 9 shows how much land is allocated for agriculture, settlements and mangrove conservation. The objective value showing the number 0 indicates that its function is optimal because it is able to minimize deviations from the optimal position to 0. The objective value D2 shows that the optimization of coastal land in Modung District must suppress residential growth to reduce the impact of soil erosion.

Table 9. Results of land allocation analysis in coastal Modung District.

Variabel	Value	Reduce cost
D1	0	0
D2	12.066	0
D3	0	1
X1	3897.85	0
X2	788.63	0
X3	120.51	0

The combination of optimal land use proportions with agricultural land area (X1) is 3897.85 Ha, land area for settlements (X2) is 788.63 Ha, and the area of mangrove forest conservation land (X3) is 120.51.Model-based methodologies combined with scenario analysis, backcasting procedures, or multi-objective optimization techniques can be used to solve land allocation challenges. Thus, the optimization approach can investigate various land use/management options [42].

4 Conclusion

The combination of optimal land use proportions with agricultural land area (X1) is 3897.85Ha, land area for settlements (X2) is 788.63 Ha , and the area of mangrove forest conservation land (X3) is 120.51. Omnibus objective programming can be used to solve land allocation management in the coastal area of Modung District. A preemptive goal programming model also needs to be implemented to accommodate stakeholder desires and resource sustainability.

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