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Assessment of Prevention Costs and Strategies for Mitigating the Impact of Flooding in Sampang Regency, Madura Island: An Averting Behavior Method (ABM) Approach

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Abstract Tidal flooding is an annually occurring natural disaster affecting hundreds of households in Sampang Regency, with numerous studies conducted on its causes. The regency's topographical location is a primary factor, with rainfall further exacerbating the situation. The most severely impacted areas are the urban region and the central government administration district. Using stratified random sampling, 100 households were selected across two groups: those affected by water inundation of <50 cm (stratum 1), and those affected by water inundation of >50 cm (stratum 2). This study estimates the prevention costs incurred by households using the Averting Behavior Method approach, used to approximate the prevention costs borne by affected communities across six research locations. The analysis indicates that the prevention costs incurred by the households affected by flooding amount to IDR 54 billion, with an average prevention expenditure of IDR 3.6 million. Factors influencing the magnitude of prevention costs include total economic loss, age of the household head, inundation depth, distance from the flood source, a dummy variable representing trauma experience, and a population density dummy variable. The results of the weighted sum method analysis were used to evaluate three main programs considered most beneficial by the community: installation of Corrugated Concrete Sheet Piles (CCSP), pump house rehabilitation, and channelization (usually termed as 'normalization') of the Kemuning River. The Sampang Regency government is expected to formulate more collaborative and sustainable programs and strategies to mitigate the impact of tidal flooding, which can be based on the findings of this study.

Keywords Preventive Expenditure, Averting Behavior Method, Flash Flooding, Tidal Flooding

1. Introduction

Flooding is a natural phenomenon often regarded as a negative impact of climate change [1-4]. According to IPCC [3], climate change refers to shifts in the physical conditions of the Earth's atmosphere, such as temperature and rainfall distribution, that have far-reaching consequences across many sectors of human life. The negative impacts include flooding, sea-level rise, and extreme weather, which can cause damage to national and regional economies [3-5]. The primary drivers of flooding are higher rainfall intensity and sea-level rise [1-3, 6, 7].

Among the impacts of climate change is increased flooding due to rising sea levels, known in Indonesia as banjir rob, or tidal flooding [8, 9]. Tidal flooding is a natural event characterized by the inundation of land by seawater during high tide conditions, attributed to both natural dynamics and human activities. Natural contributing factors include changes in tidal elevation, while anthropogenic causes include excessive groundwater extraction, the dredging of shipping channels, coastal reclamation, and other interventions [1, 9, 10]. Tidal flooding is a common phenomenon in coastal areas, but its severity is exacerbated during increased frequencies of La Niña, the condition which is the cooling of the eastern central Pacific Ocean and warming of the western Pacific Ocean. La Niña events can contribute to sea-level rise and flooding in low-lying coastal areas. Furthermore, the frequency and intensity of coastal flooding are influenced by lunar cycles and prevailing wind systems [11].

According to their studies [12], a primary driver of tidal flooding is the melting of the polar ice caps in the Arctic, contributing to rising sea levels that accelerate the process of coastal erosion (abrasion) and saltwater intrusion, damaging coastal wetlands and submerging small islands [13, 14]. Furthermore, the loss of small islands affects socioeconomic conditions and ecosystems while also carrying geopolitical implications, given that outermost islands demarcate territorial boundaries with other nations [15, 16].

Flooding is a recurring problem in Sampang Regency, and its impact is especially severe because it mainly affects urban areas where government offices and public service facilities are concentrated [2]. The affected zones include those along main provincial arteries and highways. The National Disaster Management Agency (BNPB) reports that the annual flooding in February has a significant economic impact on Sampang Regency, as the affected zone covers more than a dozen villages and/or urban wards (*kelurahan*) [6]. The most severely impacted areas are the communities residing in Banyumas Village, Kamuning Village, Tanggumong Village, Pangilen Main Road, Panggung Main Road, and Imam Bonjol Street. According to BNPB [6], the number of households affected annually ranges from 100 to 150.

The causes, effects, and impacts of flood disasters in Indonesia have been studied and researched extensively. The findings can serve as advice and recommendations for the Sampang Regency government in managing flood disasters, alongside potential further studies on anticipatory actions to address flooding. As such, the economic losses borne by affected communities can be reduced. Sampang Regency’s position (between 0 – 300 meters above sea level) renders the area highly susceptible to flooding.). In addition, heavy rainfall causes the river flow to rise and further exacerbates the condition of the Kemuning River [6]. This means that heavy rainfall in the northern part of Sampang Regency often results in floodwaters flowing southward, requiring the southern areas to prepare for what can be classified as flash floods. However, according to BNPB [7], flooding in Sampang is also caused by high tidal seawater, which is categorized as tidal flooding (*banjir rob*) [6, 7].

Recurring tidal flooding results in significant losses for communities, including property loss, limited access to clean water, and the spread of post-flood illnesses [8, 17]. This is also true for communities affected by flooding in Sampang Regency, particularly for those residing in urban areas who are often forced to evacuate to flood-free locations. This research focuses on assessing the prevention expenditures incurred by households in Sampang Regency, utilizing the Averting Behavior Method (ABM) approach. This study also examines several existing government programs. Insights from key informant interviews were used to assess and rank the effectiveness of these programs in delivering benefits to affected communities. The findings are expected to serve as an evaluation and offer recommendations for policymakers in developing strategies to mitigate the impact of flooding in Sampang Regency.

2. Material and Methods

2.1. Research Location and Sample Selection

This study was conducted in Sampang Regency, which was purposively selected due to the high frequency of flooding during the rainy season. The selection of villages was based on data provided by the Sampang Regency Government and the Sampang Regency National Disaster Management Agency (BNPB), which identified Banyumas Village, Kamuning, and Tanggumong as the most severely affected areas. The research was undertaken from January to May 2025, coinciding with the peak of the rainy season, a period characterized by the highest rainfall intensity and increasingly severe flood impacts.

The selection of the research sites was based on data from the regional BNPB, which indicated that Banyumas Village was the most severely affected area, with floodwater depths reaching up to 80 cm, while the other two locations experienced water levels of approximately 20–50 cm. Accordingly, the research sample was divided into two strata: stratum 1 comprising respondents from

Banyumas Village, and stratum 2 comprising respondents from Tanggumong Village and Kamoning Village. Respondents were selected using an incidental method sampling, provided they met the following criteria: (1) floodwater levels consistent with the assigned stratum, (2) experience of economic losses resulting from flooding, and (3) implementation of measures to prevent or mitigate flooding (see Figure 1).

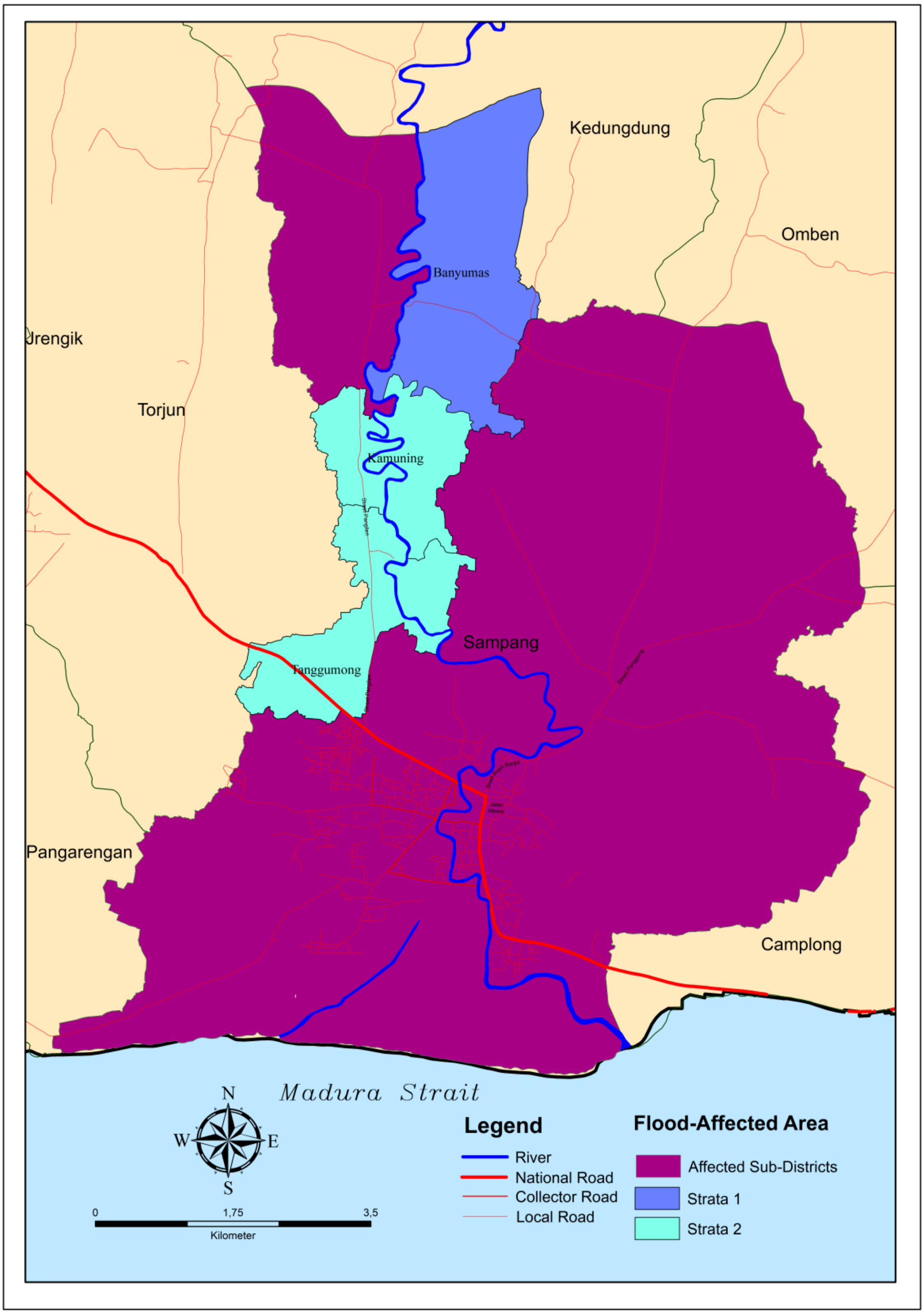

Figure 1. Study Area in Sampang Regency, West Java

The data used in this study consist of both primary and secondary data. Primary data were gathered through direct interviews with respondents using a questionnaire. These data encompassed detailed information on physical damage attributable to tidal flooding and documented the community response actions taken. The secondary data comprising contextual and supporting information about the study area were sourced from relevant government institutions and various literature, including books, journals, and online resources. Secondary data were sourced from government institutions and comprised records of flooding history in Sampang Regency, assessments of existing flood conditions, and documentation of government policies and strategic measures related to flood mitigation and prevention.

This study utilized a stratified random sampling method, selecting respondents based on the proximity of their households to the Kemuning River. The research area was categorized into two strata: Strata 1, comprising areas experiencing tidal flood inundation depths of 0–50 cm, and Strata 2, consisting of areas with inundation depths exceeding 50 cm. To complement this approach, incidental method sampling was employed to identify and recruit competent informants, whereby respondents were selected based on their compliance with the defined criteria, during the collection of primary data and for targeted interviews, ensuring access to specific expertise required for the study [18, 19]. A total of 100 respondents were selected, with equal representation of 50 respondents from each stratum.

The research also engaged key stakeholders to inform strategies for mitigating the impacts of flooding in Sampang Regency. These key persons included influential policymakers and local leaders such as the Head of the Sampang Regency Environmental Agency, the Head of the Regional Disaster Management Agency (BNPD) of Sampang Regency, the Head of the Sampang Regency Public Works Agency, local village and ward heads, and several community or traditional leaders within the research locations.

2.2. Methods

2.2.1. Estimation of Prevention Costs Using the Preventive Expenditure Method

One methodological approach for quantifying economic losses from pollution employs both the averting behavior method and the human capital approach. Averting behavior encompasses actions households take to mitigate or avoid harm resulting from ecosystem damage [20, 21]. The averting behavior method constitutes a cost-based, non-market valuation technique, whereas the human capital approach serves as a benefit-based, non-market valuation method [13], consisting of three sub-approaches:

1. Preventive expenditure

Preventive expenditure is demonstrated by the willingness of residents in frequently flooded riverside communities to incur costs that mitigate or eliminate the adverse effects of flooding [22].

2. Replacement cost

The replacement cost method involves a comparative analysis between the expense of a proposed program and the costs associated with rehabilitating a damaged resource. For example, the value of preserving groundwater in good condition can be quantified by estimating the future cost of injecting freshwater should over-exploitation cause its degradation.

3. Shadow project

This sub-approach posits that there are multiple ways to address a single environmental issue. For instance, solutions for tidal flood mitigation could range from constructing a full sea wall with a compensatory artificial lake for recreation to reinforcing existing river dikes or implementing a partial barrier alongside a retention pond. The value of environmental quality is then inferred from the cost of implementing a chosen alternative.

In contrast, the human capital approach is founded on the premise that a deterioration in clean water quality leads to a decline in human health. Sohrabizadeh et al. [23] also identified three methods to evaluate this decline that are applicable individually or in combination: (1) lost earnings that are attributable to premature mortality, morbidity, or work absenteeism; (2) elevated medical expenses (cost of illness); and (3) increased psychological costs.

The Averting Behavior Method (ABM) is an approach used to estimate the scale of a community's adaptation costs [21]. This method quantifies expenditures undertaken by communities to prevent or mitigate the impacts of environmental degradation [13]. Its application is limited to scenarios where households directly spend financial resources to offset experienced environmental impacts [19]. Methodologically, ABM is subdivided into two primary categories.

a. Preventive expenditure

This approach estimates an individual's willingness to pay to avoid damages from environmental degradation, defining the value of the environment by the level of a community's financial preparedness to address such degradation [13]. These costs are specifically incurred to safeguard household welfare from decline [20].

b. Replacement cost

This approach values an asset based on the current market price required for its substitution by estimating the expenses a community would bear to fully restore a damaged environment to its original, pre-degradation state [13].

ABM serves as a methodology for estimating losses attributable to natural resource and environmental damage by quantifying community-incurred expenses aimed at preventing or mitigating the effects of environmental degradation [13]. A key limitation of this study is the restriction of ABM to estimating economic losses derived solely from tangible household expenditures, specifically preventive costs and replacement expenses.

As a component of ABM, this approach quantifies expenditures undertaken to prevent flood occurrences. These costs represent expenses by the community to safeguard against welfare losses resulting from flooding. The estimation process involves three stages: (1) assessing the environmental impact, (2) documenting community-deployed flood prevention strategies, and (3) calculating the total costs associated with these preventive measures. The aggregated preventive costs are computed using Equation (1).

$$PE = \frac{\sum_{i=1}^{n} PEi}{n} \qquad (1)$$

where:

PE = Preventive expenditure (IDR/household)

PEi = Preventive expenditure for the *i*-th respondent (IDR)

n = the Number of respondent households (persons)

i = *i*-th respondent (1, 2, 3, …, n)

To account for temporal valuation, the calculated prevention costs are converted to present value using prevailing interest rates. This adjustment is performed through Equation (2) [2, 13, 14]:

$$PV = PEi\ (1+r) \qquad (2)$$

Where:

PV = Present value (IDR)

PEi = Preventive expenditure for respondent *i* (IDR)

t = Difference between the present time and the time of the cost incurred (in years)

r = Bank interest rate (percent)

2.2.2. Estimating Factors Influencing Household Expenditure on Tidal Flood Prevention Costs in Sampang Regency

A multiple regression model was employed to analyze the factors influencing household expenditures on prevention costs for flooding. In this study, the dependent variable—prevention costs—constitutes the total financial outlay households incur specifically for tidal flood mitigation measures. This value is expressed as a function of multiple independent variables, formalized in Equation (3). The explanatory variables incorporated into the model include: total economic loss (X_1), building area (X_2), respondent age (X_3), inundation depth (X_4), time allocated moving goods to safety (X_5), distance from the household to the flood source (X_6), income (X_7), a dummy variable representing trauma experience (D_1), and population density dummy variable (D_2).

$$Y_t = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots\ldots + \beta_8 D_1 + \beta_9 D_2 + \varepsilon \qquad (3)$$

Where:

Y = Economic loss due to tidal flooding (IDR)

β_0 = Intercept

β_1-β_{10} = Regression coefficients

X_i = Independent variable

D_i = Dummy independent variable

ε = Error term

The model incorporates variables derived from theoretical reviews, findings of previous studies, and insights gathered through field interviews. Furthermore, factors that influence the magnitude of the loss were analyzed using the multiple regression analysis method in the IBM SPSS Statistics 20 software.

2.2.3. Formulating Strategies to Mitigate the Impact of Flooding in Sampang Regency

2.2.3.1. Weighted Sum Model (WSM) Method

The Weighted Sum Model (WSM) is a multi-criteria decision analysis technique used to identify the optimal choice among a set of alternatives by evaluating them against weighted criteria [22]. In WSM-based decision-making, the potential outcomes of alternatives are quantified using a normalized scale, often ranging from 0 to 1, to represent their performance relative to each criterion. These valuations incorporate subjective probabilities reflecting the decision-maker's confidence, expertise, experience, and contextual understanding. The overall value of each alternative is computed using a simplified WSM equation, denoted as Equation (4) [23, 24].

$$Total\ Value_i = \sum_{j=1}^{m} Score_{ij}\ \ (Crit_j) \qquad (4)$$

Where:

$Total\ Value_i$ = The final total score for alternative i

$Score_{ij}$ = The score of alternative i on criterion j

$Crit_j$ = The importance level (weight) of criterion j

i = 1,2,3,...,n; n = number of alternatives

j = 1,2,3,...,m; m = number of criteria

2.2.3.2. WSM Criteria

Decision-making entails selecting an optimal action, a, from a set of possible actions (a). This must be made with knowledge of the consequences of the chosen action, which are typically a function of the state of nature. Each state of nature, θ, describes an actual, real-world situation or condition in which the action will be applied. The performance value of each action and state of nature is represented using a payoff matrix, where θ denotes external conditions, selection criteria, or constraints; a denotes a specific action, strategy, or option; and x signifies the measurable outcome for each combination. If the units of measurement for every x are identical, this matrix can be used directly for action selection calculations. However, if the units of x differ, the matrix must first be converted into a Comparative Performance Index (CPI). The WSM criterion formalizes a decision-making process that relies exclusively on prior probability distributions, absent experimental data. Within this framework, the decision-maker identifies the action that minimizes the expected loss, computed based on these prior probabilities. For discrete states of nature θ, the expected loss, $l(a)$, is derived using Equation (5) [25, 26].

$$l\ \ (a) = E\ \ [l, (a, \theta)]\ \ =\ \ \sum l\ \ (a, k)\ \ P\theta\ \ (k) \quad (5)$$

The calculation for expected loss with a continuous θ is performed using Equation (6).

$$l\ \ (a) = E\ \ [l, (a, \theta)] = \int^{\infty} l\ \ (a, y)\ \ P\theta\ \ (y) dy \quad (6)$$

2.2.3.3. WSM Procedure

Empirical data inform the decision-making process within this framework. The posterior probability distribution of θ is defined as the conditional probability distribution of θ given the observed data $X = x$. The procedure involves first computing this posterior distribution for each possible observed outcome, after which the action that minimizes the expected loss, denoted as *l(a)*, is selected. This expected loss function incorporates both the consequences of the decision and any associated experimentation costs, serving as a comprehensive risk measure. If θ is discrete, the expected loss is calculated according to Equation (7):

$$\ln(a) = E\ \ [(l\ \ (a, 0)] = \sum |\ \ (a, k) h_{\theta|\ X=x}\ \ (k) \quad (7)$$

Where $h\theta|X = x\ (k)$ is the discrete posterior probability distribution.

If θ is continuous, the posterior probability distribution is expressed as $h(\theta \mid X = x)(y)$, and the expected loss is calculated according to Equation (8):

$$\ln(a) = E\ \ [(l\ \ (a, 0)] = \int^{\infty} l\ \ (a, y) h_{\theta|\ X=x}\ \ (y) dy \quad (8)$$

3. Results and Discussion

3.1. Respondent Characteristics

The general characteristics of respondents across the six research locations are grouped according to their social and economic profiles. The sample comprised 100 respondents, with 50 representing each stratum, the majority of whom were heads of household. As presented in Table 1, As shown in Table 1, males constituted 56% of respondents in Stratum 1 and 54% in Stratum 2. The predominance of male respondents reflects the tendency for interviews to be conducted with male household heads, as housewives were generally less inclined to participate, consistent with social norms that position men as the primary decision-makers and representatives of the household [23, 27, 28]. Residential status was consistent across both groups, with most respondents being officially registered residents of Sampang Regency. Regarding age composition, 40% of respondents in Stratum 1 and 44% in Stratum 2 were under 30 years of age. Age constitutes an important factor in disaster preparedness, as higher age levels are commonly associated with greater maturity and accumulated experience, which may enhance responsiveness and preparedness in disaster situations [29, 30].

Educational attainment appears to significantly influence household decision-making regarding strategies to mitigate and prevent impacts from flooding. Analysis of educational profiles reveals distinct differences between strata. In Strata 1, 40% of respondents completed senior high school (*Sekolah Menengah Atas*/SMA), 30% completed junior high school (*Sekolah Menengah Pertama*/SMP), and 26% held university degrees. Conversely, Strata 2 demonstrated higher educational attainment, with 46% possessing university degrees, 38% completed senior high school (SMA), and 24% junior high school (SMP). This educational disparity between strata primarily reflects socioeconomic constraints, as financial limitations prevented many respondents from pursuing higher education, leading them to enter the workforce to support family welfare [31-34].

Household income levels, largely determined by the occupation of the household head, significantly influence flood prevention investment decisions [27, 35, 36]. Occupational distributions showed notable patterns: in Strata 1, 36% worked in diverse sectors including agriculture, fisheries, and homemaking (categorized as “Other”), 28% were engaged in commerce, 18% were civil servants (*Pegawai Negeri Sipil*/PNS) or employees of state-owned enterprises (*Badan Usaha Milik Negara*/BUMN), and 18% were factory workers. Strata 2 exhibited a comparable occupational distribution: 34% in “Other” occupations, 28% in commerce, 20% in factory workers, and 18% in civil service or state enterprise roles.

Households with higher incomes tend to have a greater capacity to implement mitigation measures compared to those with lower incomes [23, 37-39]. The income levels of respondents varied. Survey results indicate that 46% of respondents in Strata 1 fell within the range of IDR 1.5 million to IDR 2.5 million. Similarly, respondents in Strata 2 showed the same trend, with 32% within this income range. This indicates that the majority of respondents have a moderate-income level, generally aligning with the Sampang Regency minimum wage (UMR) of IDR 2.3 million.

3.2. Estimation of Total Prevention Costs for Flooding in Sampang Regency

Prevention costs encompass all expenditures undertaken by households to mitigate flood impacts. Recurrent damage from flooding necessitates substantial investment in preventive measures to reduce future vulnerability. As detailed in Table 2, household-level mitigation strategies include relocating possessions to elevated areas, moving vehicles to safe zones, constructing protective barriers or small dikes, elevating floor levels, adding additional stories to structures, and miscellaneous adaptations. The aggregate prevention costs for respondent households during the most recent rainy season reached IDR 360 million, yielding an average annual expenditure of IDR 3.6 million per household. Extrapolated to the six most severely affected communities, total prevention spending across the study area amounted to IDR 54 billion during the latest tidal flood cycle. This study aligns with earlier research highlighting the substantial prevention costs that households impacted by flash floods face at both regional, like in Semarang [4], Luwu [5], East Java [9], Ciliwung Hulu [10], Samarinda [40], and global scales [31-34, 37, 41].

Table 1. Socioeconomic Characteristics of Respondents Affected by Flooding in Sampang Regency

Characteristic	Category	Total	Percentage
Gender			
Strata 1	Female	22	44
	Male	28	56
Strata 2	Female	13	26
	Male	37	54
Residence			
Strata 1	Resident of Sampang	37	74
	Non-resident of Sampang	13	26
Strata 2	Resident of Sampang	42	84
	Non-resident of Sampang	8	16
Age			
Strata 1	Young (<30)	20	40
	Mature (30-59)	15	30
	Senior (>59)	15	30
Strata 2	Young (<30)	22	44
	Mature (30-59)	12	24
	Senior (>59)	16	32
Education Level			
Strata 1	Elementary School (SD)	2	4
	Junior High School (SMP)	15	30
	Senior High School (SMA)	20	40
	University	13	26
Strata 2	Elementary School (SD)	6	12
	Junior High School (SMP)	12	24
	Senior High School (SMA)	19	38
	University	23	46
Occupation			
Strata 1	Factory worker	9	18
	Commerce	14	28
	PNS/BUMN officer	9	18
	Other	18	36
Strata 2	Factory worker	10	20
	Commerce	14	28
	PNS/BUMN officer	9	18
	Other	17	34
Income			
Strata 1	IDR <1,500,000	10	20
	IDR 1,500,001 – IDR 2,500,000	23	46
	IDR 2,500,001 - IDR 3,500,000	10	20
	IDR >3,500,000	7	14
Strata 2	IDR <1,500,000	12	24
	IDR 1,500,001 – IDR 2,500,000	16	32
	IDR 2,500,001 - IDR 3,500,000	8	16
	IDR >3,500,000	14	28

Table 2. Prevention Costs Incurred by the Community Affected by Flooding in Sampang Regency

No.	Prevention Measures Undertaken by the Community	Value (IDR)
1.	Relocating Belongings	19,457,500
	Strata 1	6,420,975
	Strata 2	13,036,525
2.	Moving Vehicles	8,927,200
	Strata 1	1,785,440
	Strata 2	7,141,760
3.	Constructing Dikes/Barriers	98,450,700
	Strata 1	14,767,605
	Strata 2	83,683,095
4.	Elevating Floor Levels	145,392,500
	Strata 1	109,044,375
	Strata 2	36,348,125
5.	Adding Additional Stories	78,052,900
	Strata 1	31,221,160
	Strata 2	46,831,740
6.	Miscellaneous Costs	10,187,200
	Strata 1	2,546,800
	Strata 2	7,640,400
Total Prevention Cost (IDR)		360,468,000
Strata 1		165,786,355
Strata 2		194,681,645
Total Number of Respondent Households (Persons)		100
Average Loss Per Household Per Period (IDR/Household/Period)		3,604,680
Total Households in Research Locations (Persons)		150
Total Flood Prevention Costs Incurred by the Community in Affected Locations (IDR)		54,070,200,000

3.3. Factors Influencing Household Expenditure on Flood Prevention Costs in Sampang Regency

A multiple linear regression analysis was conducted to identify factors determining household expenditure on flood prevention measures. The model incorporated ten independent variables hypothesized to influence prevention costs: total economic losses, building area, age, inundation depth, time spent relocating goods, distance from flood source, a dummy variable representing trauma experience, perception of land subsidence, a population density dummy variable, and income.

The regression model demonstrated substantial explanatory power, with an R-Square value of 0.760, indicating that 76% of the variation in prevention costs is accounted for by the included variables. The remaining 24% is explained by other variables outside the model. The calculated F-value is 8.321 with a significance value (sig) of 0.000, indicating that the independent variables collectively exert a statistically significant influence on prevention expenditures at the 15% significance level.

The analysis detailed in Table 3 identifies several statistically significant predictors of household flood prevention expenditures. At the $\alpha = 0.1$ significance level, these include total economic loss (X_1), age of household head (X_3), inundation depth (X_4), distance from flood source (X_6), and the dummy variable representing trauma experience (D_1). The population density dummy variable (D_2) was significant at the $\alpha = 0.15$ level. This multiple linear regression model was tested for classical assumptions as follows:

- *Multicollinearity test*

Multicollinearity testing was conducted by examining the Variance Inflation Factor (VIF) values. A VIF value of < 10 indicates no multicollinearity issues. Based on the results in Table 3, all variables had VIF values less than 10, confirming the absence of multicollinearity concerns.

- *Heteroscedasticity test*

Using the Glejser test, results showed that the sig value in the ANOVA table was not significant at α=15%, indicating homoscedasticity and thus validating the assumption of constant variance in the model residuals.

- *Autocorrelation test*

The Durbin-Watson statistic of 1.642 falls within the acceptable range of 1.55 to 2.46, demonstrating no detectable autocorrelation in the residuals [42, 43].

- *Normality test*

The Kolmogorov-Smirnov test produced a non-significant result, with the Asymp. Sig. (2-tailed) value being 0.603, greater than the $\alpha = 0.15$ significance level. These diagnostic results indicate that the regression model meets all necessary classical assumptions, confirming the reliability and validity of the inferred relationships.

Earlier research also indicates that factors influence decisions on allocating spending for flood risk prevention expenditure, like the total economic losses [8, 13, 19, 44], age of household head [45], inundation depth [9], distance from flood source [28, 38, 46], and the dummy variable representing trauma experience [28, 29, 39, 47, 48], and the population density dummy variable [49, 50]. Variables that significantly influence the model can be utilized as policy instruments for formulating strategies to reduce the economic losses caused by floods. For example, the age of the household head may determine the ability to take earlier strategic actions, such as relocating goods, repairing the house construction, or elevating houses [31-34, 51, 52].

3.4. Identification of Government Programs for Mitigating Flooding in Sampang Regency

Tidal flooding in Sampang Regency's urban residential zones has become a recurrent natural phenomenon anticipated by local communities. While both residents and governmental authorities have implemented various measures to address these annual flood events, existing defensive infrastructure remains inadequate to fully protect the northern coastline from marine inundation. Approximately 40% of current flood protection systems fail to effectively prevent seawater intrusion [40].

Several factors exacerbate flooding vulnerability in the region, including: topographical depression below sea level, intensive upstream precipitation, rapid land-use changes within watersheds [46], diminished river capacity and drainage efficiency due to sedimentation and waste accumulation, land subsidence, sea-level rise, and limited public environmental awareness [53-55]. Based on interviews and literature analysis, three primary intervention initiatives have been identified as currently implemented by the Sampang Regency Government and East Java Provincial Government to mitigate flooding impacts.

(1) Corrugated Concrete Sheet Pile (CCSP) Installation

CCSP is a sheet-based construction material that is driven vertically into the ground to retain soil and prevent landslides. These structures function primarily as retaining walls to regulate river flow and prevent water overflow onto adjacent land, thereby reducing flood risk in vulnerable areas. Typically fabricated from reinforced concrete or steel, sheet piles are engineered to resist lateral earth pressures, which are determined by soil properties, including internal friction angle and cohesive forces between soil particles.

The Sampang Public Works and Spatial Planning Agency (PUPR), through its River Management Division, is implementing CCSP installation along the left bank of the Kemuning River. Current construction focuses on two primary locations: Dalpenang Ward and Rong Tengah. The project encompasses a 400-meter section on Dalpenang's eastern perimeter, with plans for subsequent extension along an additional 400 meters of the Pasean left bank. This infrastructure is anticipated to enhance protection for residential zones against the Kemuning River flood events.

Table 3. Factors Influencing Prevention Expenditure by Households Affected by Flooding, 2025

Independent Variable	**Coefficient**	**Sig.**	**VIF**
Constant	-38,310,000	0.005	
Total Economic Loss (X_1)	1.224	0.000*	1.283
Building Area (X_2)	127,526.570	0.662	1.225
Respondent Age (X_3)	372,026.214	0.023*	1.316
Inundation Depth (X_4)	3,114,412.786	0.000*	1.271
Time Allocated Moving Goods to Safety (X_5)	1,596,872.608	0.485	2.274
Distance From the Household to the Flood Source (X_6)	28,387.031	0.002*	1.235
Income (X_7)	0.026	0.856	1.315
Dummy Variable Representing Trauma Experience (D_1)	-10,130,210	0.012*	1.213
Population Density Dummy Variable (D_2)	7,575,780.714	0.101**	1.467
R-Square	0.760		
Adjusted R-Square	0.520		
Durbin Watson	1.642		
F-Statistic	8.321	0.000	
Asymp.Sig. (2-tailed)	0.603		

Note: *: Significant at $\alpha = 0.1$ level **: Significant at $\alpha = 0.15$ level

Complementing these efforts, the Regional River Basin Agency (BBWS) has advanced CCSP construction since 2017, achieving approximately 7 kilometers of installation to date. Concurrently, a 3.5-kilometer diversion channel with a 26-meter width is under development near the Kajuk water gate estuary in Polagan Village. A subsequent diversion project is planned for Panggung Village, featuring a proposed 12-kilometer channel with a 60-meter width to further improve water management capacity.

(2) Pump House Rehabilitation

As a near-term intervention strategy, the Sampang Regency Government has initiated a program to deploy pumping stations equipped with high-capacity pumps designed to divert floodwater from primary arterial roads directly into river systems. While major roadways and newer residential developments in the regency feature adequate drainage infrastructure, these systems operate in isolation rather than as part of an integrated network, significantly limiting their effectiveness. Over the past five years, the East Java Provincial Government, through its Water Resources Public Works Agency, has optimized the pumping capacity of five pump houses to the following rates: Teratai Pump House at 4.7 thousand liters per second; Delima Pump House at 4.7 thousand liters per second; Dagbukor Pump House at 9.5 thousand liters per second; Bahagia Pump House at 3.6 thousand liters per second; and Kajuk Pump House at 3.6 thousand liters per second.

(3) Kemuning River Channelization

Previous hydrological studies classify the Kemuning River in Sampang Regency, Madura, as a productive sediment-transporting system characterized by high runoff rates. The river's downstream segment bisects Sampang City's urban core while simultaneously functioning as a vital navigation channel for local fisheries and small-scale commercial vessels. This dual role exacerbates flood vulnerability, positioning the river as both a critical economic artery and a significant natural hazard for adjacent urban areas.

As a long-term strategy, the East Java Provincial Government has implemented sustained dredging operations by deploying eight heavy equipment units over the last five years. While officials note improved floodwater recession rates, comprehensive risk reduction will require complementary infrastructure, including floodways and retention basins (*bozem*). Flood control through this channelization effort (commonly termed ‘normalization’ in Indonesia) will also involve riverbank reinforcement and greening initiatives along the river.

3.5. Decision Analysis for Strategy Formulation to Mitigate Flooding Impacts in Sampang Regency

Decision analysis using WSM was employed to identify optimal mitigation strategies through multi-criteria evaluation [22]. Through a literature review, the three aforementioned governmental program alternatives for tidal flood mitigation were selected for WSM analysis. The key persons from agencies and institutions involved in evaluating these alternatives were the Head of the Sampang Regency Environmental Agency, the Head of the Regional Disaster Management Agency (BNPD) of Sampang Regency, the Head of the Sampang Regency Public Works Agency, local village and ward heads, and several community or traditional leaders from the research locations. The quantitative results of the WSM analysis are presented in Table 4.

The analysis identified Kemuning River channelization as the highest-ranked policy alternative for tidal flood mitigation. A key person from the Office of Maritime Affairs, Agriculture, and Food Security of Sampang Regency stated that this channelization constitutes a foundational intervention that enables subsequent infrastructure projects, including dike construction and pump installation. Successful implementation requires comprehensive community socialization programs to build consensus and prevent disputes, alongside securing dedicated funding for resident compensation and project financing.

Following the completion of the channelization program, the installation of CCSP can be implemented. These engineered retaining walls are designed to regulate river overflow during high tide events, particularly under extreme rainfall conditions. Local traditional leaders and technical experts affirm the potential effectiveness of these structures in reducing landward water intrusion during tidal surges.

Table 4. Decision Analysis for Strategy Formulation to Mitigate Flooding Impacts in Sampang Regency

	Program Effectiveness	**Program Socialization**	**Provision of Funding**	**Value**	**Rank**
Pump House Rehabilitation	5	4	4	4.25	2
CCSP Installation	4	4	4	4.00	3
River Channelization	4	5	5	4.75	1
	0.25	0.25	0.5		

Table 5. Results of Weighted Sum Model (WSM) Analysis in Developing Strategies to Reduce the Impact of Floods in Sampang Regency

Alternative	Respondent	1	2	3	4	5	6	7	8	9	10	11	12	13	Mode
Pump House Rehabilitation	Program Effectiveness	4	5	5	2	4	5	5	5	5	3	3	5	3	5
	Program Socialization	4	5	4	4	3	4	5	4	5	4	4	5	4	4
	Provision of Funding	5	5	4	5	5	4	5	4	4	4	4	5	4	4
	Value	0.25	0.25	0.4	0.4	0.25	0.6	0.25	0.35	0.4	0.25	0.5	0.3	0.2	0.25
CCSP Installation	**Respondent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Mode**
	Program Effectiveness	5	5	4	4	5	4	4	4	4	4	3	5	4	4
	Program Socialization	5	5	3	4	5	4	4	3	4	4	4	5	3	4
	Provision of Funding	5	5	4	3	5	4	5	4	4	4	4	5	3	4
	Value	0.5	0.5	0.25	0.4	0.5	0.3	0.5	0.25	0.25	0.4	0.25	0.5	0.6	0.5
River Channelization	**Respondent**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Mode**
	Program Effectiveness	4	4	4	4	3	4	4	5	5	4	3	4	5	4
	Program Socialization	3	5	3	4	4	4	5	3	5	4	3	5	5	5
	Provision of Funding	5	5	4	5	4	5	5	4	4	4	4	5	5	5
	Value	0.25	0.25	0.35	0.2	0.25	0.1	0.25	0.4	0.5	0.5	0.25	0.2	0.2	0.25

The tertiary prioritized intervention, pump house rehabilitation, addresses critical land subsidence issues identified by Public Works Agency data, which shows increasing elevation differentials between ground level and sea level. Strategic sequencing is essential, as CCSP installation without adequate pumping capacity would potentially exacerbate flooding by trapping tidal waters behind barriers. Therefore, the pump system deployment must be accompanied by community education programs to ensure proper operational maintenance and prevent equipment misuse. The complete decision analysis scoring and implementation framework is detailed in Table 5.

Governments worldwide have implemented various strategies and initiatives to prevent and mitigate the impacts of flooding. These strategies are developed by considering multiple factors, with the aim of establishing sustainable approaches that involve diverse stakeholders, including upstream and downstream communities [56, 57], local leaders [58-60], central and regional authorities [61-63], and, where possible, the private sector [43, 64, 65]. Such strategies need to be designed for the long term, ensuring benefits that extend beyond immediate outcomes. Although progress may be gradual, fostering a healthier ecosystem 1is expected to improve the preservation of river basin environments and reduce the adverse effects of flooding [66].

4. Conclusions

The research findings indicate that 150 affected households incurred total prevention costs of IDR 54 billion during the most recent rainy season. These expenditures encompassed multiple adaptive measures, including relocation of possessions to elevated areas, vehicle transfer, construction of protective barriers and dikes, house elevation, structural additions, and other essential interventions. This substantial financial burden demonstrates the urgent need for the Sampang Regency Government to establish dedicated emergency funding mechanisms specifically addressing recurrent tidal flood risks.

Regression analysis identified six statistically significant determinants of prevention expenditures: total economic loss, household head age, inundation depth, distance from flood source, trauma experience (binary variable), and population density (binary variable). These factors provide evidence-based guidance for policymakers and communities in developing targeted strategies to enhance resilience against flooding events. The findings emphasize the importance of integrating both economic and socio-demographic variables into comprehensive flood risk management planning for Sampang Regency.

5. Policy Implications

The findings of this study provide a foundation for developing evidence-based policies to mitigate flooding. Effective implementation requires active community participation in preventive measures, supported by the substantial documented prevention costs and significant economic losses that demonstrate the necessity of intervention. Households with members above 17 years of age (legal adults) show enhanced capacity to protect property and greater awareness of flood risk reduction. Officially registered residents of Sampang Regency demonstrate stronger investment in prevention, while community trauma from recurrent flooding can be alleviated through targeted risk reduction strategies. Inundation depth and the distance from a home to the flood source emerged as significant factors, supporting structural interventions such as house elevation and vertical expansion as viable damage reduction strategies.

The three existing programs implemented by the local and provincial governments, which have demonstrated benefits, should be evaluated annually. Programs failing to demonstrate significant impact should be replaced with more effective and sustainable alternatives.

The research team recommends enhanced collaborative governance among communities, government agencies, and institutions to implement adaptive measures along the Kemuning River. Proposed interventions include: (1) a participatory drainage maintenance program to reduce urban flooding; (2) development of upstream water catchment systems utilizing bio-retention and green infrastructure to control runoff; (3) agroforestry initiatives for long-term ecological flood control; and (4) community-based watershed management to restore upstream vegetation and stabilize soils. These recommendations require collaborative deliberation among all relevant stakeholders to formulate solutions that are both effective and sustainable.

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