Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 2701 – 2716 (2025)
www.ejabf.journals.ekb.eg

Effect of Tidal Fluctuations on Water and Soil Quality in Shrimp Ponds

Heri Ariadi[1*], Linayati Linayati[1], Tri Yusufi Mardiana[1], Abdul Wafi[2], Farchan Mushaf Al Ramadhani[3]

[1]Department of Aquaculture, Faculty of Fisheries, Pekalongan University, Sriwijaya Street No. 03, Pekalongan 51111, Central Java, Indonesia
[2]Department of Aquaculture, Faculty of Sains and Technology, Ibrahimy University, KHR. Syamsul Arifi Street No. 01-02, Situbondo 68374, East Java, Indonesia
[3]Department of Agrotechnology, Faculty of Agriculture, Pekalongan University, Sriwijaya Street No. 03, Pekalongan 51111, Central Java, Indonesia

***Corresponding Author: ariadi_heri@yahoo.com**

ARTICLE INFO

Article History:
Received: Oct. 28, 2024
Accepted: Sep. 20, 2025
Online: Oct. 18, 2025

Keywords:
Climate change,
WQI,
Shrimp,
SQI,
Weather

ABSTRACT

The effect of tidal fluctuations on rising sea levels has altered the ecological dynamics of coastal waters. Therefore, this study aimed to evaluate water and soil quality in shrimp farming ponds due to the effect of tidal fluctuation. A causal *ex-post facto* design concept was used with observed indicator variables, including water quality, soil quality, and tidal wave fluctuation data. The results showed that TOM 152.64-169.56 mg/L and NO_2 1.064 mg/L exceeded the threshold values for water quality parameters. Soil pH values, redox potential, organic carbon, organic matter, and CEC ranged from 7.7 to 7.9, 11.79 to 16.80 mev, 0.36 to 0.45 mg/L, 0.45 to 0.50 mg/L, and 27 to 30 mg/L, respectively. Meanwhile, WQI and SQI of ponds ranged from 0.11 to 0.60 and 0.09 to 0.54, within the poor (0.33) and interval III (0.31) categories, respectively. The average tidal wave height in Probolinggo Waters over one year ranged from 0.84 to 2.90m. Additionally, the relationship between WQI, SQI, and tidal waves was described by the model Y = 1.000 + 2.480x. Several parameters had significant effect on the relationship, including TOM, Mg, hardness, CO_3, HCO_3, alkalinity, NH_4, NO_2, OM, and CEC. The increase in sea level is linked to changes in the biophysical environment and is associated with the impact of climate change on sea level rise. This study concluded that water and soil quality conditions in shrimp pond ecosystems in the coastal area of Probolinggo deteriorated in terms of suitability due to the intense and dynamic effects of rising tidal waves.

INTRODUCTION

Climate change has altered the biophysical conditions of coastal environments, leading to a rise in sea levels **(Toledo *et al*., 2024)**. This is caused by the melting of ice in the polar regions due to global temperatures, which are affected by the intensifying release of carbon elements into the air **(Mahmood *et al*., 2023)**. This condition has implications for activities in coastal areas **(Cepic *et al*., 2022)**. Additionally, a visible effect of climate change is the unstable fluctuation of tidal periods **(Hayford *et al*., 2021)**.

Shrimp farming is a fishery activity widely developed in coastal areas and extensively practiced due to the profitable nature and promising business prospects **(Soeprapto *et al*., 2023)**. Moreover, the activity is highly vulnerable to the effects of climate change and unstable tidal conditions **(Pereira *et al*., 2023)**. This is inseparable from the phenomenon of tidal fluctuations as a timing mechanism for filling water into shrimp ponds **(Martínez-Córdova *et al*., 2013)**.

The quantity and quality of seawater affected by tidal fluctuation are essential considerations for farmers **(Ni *et al*., 2021)**. In this context, seawater serves as a source for shrimp habitat in ponds and water quality significantly affecting the stability of the ecosystem **(Ferreira *et al*., 2011; Ariadi *et al*., 2019a)**. The success of the farming cycle is also affected by the composition structure of soil **(Musa *et al*., 2020)**. Good soil conditions support the success rate of shrimp farming. Furthermore, quality of water and soil are biophysical parameters considered to support the operational cycle of shrimp farming **(Ariadi *et al*., 2019a; Musa *et al*., 2020)**.

Effect of rising sea levels is believed to affect ecological changes in coastal areas through the fluctuating effects of tidal surges **(Pereira *et al*., 2023)**. Fluctuations occurring in coastal areas change the biophysical conditions of coastal waters **(Chapman *et al*., 2020)**. Some of the changes in biophysical conditions include soil erosion, the presence of permanent waterlogging, as well as changes in water and soil quality **(Alducci & Hynes, 2023)**. Based on the analysis, this study aimed to evaluate water and soil quality conditions in shrimp farming ponds due to the effect of tidal phenomena. This research is expected to provide information regarding the status of climate change impacts on aquaculture activities in coastal areas.

MATERIALS AND METHODS

This research was carried out in the shrimp ponds of PT. Manunggal Setia Makmur in Probolinggo, Indonesia (7°45′S 113°13′E and 7.750°S 113.217°E). The location of the research pond is an area designated for active intensive shrimp farming in that region. The research method used was a causal *ex-post facto* design, which included data collection based on real conditions in the field without changing the variables. In addition, the data included parameters of pond water quality, pond soil quality, and tidal fluctuations, and the data collection was conducted periodically every 4 days.

The observed parameters of water quality were pH, salinity, total organic matter (TOM), Ca, Mg, hardness, CO_3, HCO_3, alkalinity, NH_4, and NO_2. The pH of pond water and salinity were measured using ecotestr 07 pH meter and ATAGO series 1911 hand refractometer. In addition, parameters such as Ca, Mg, hardness, CO_3, HCO_3, and alkalinity were measured using titrimetry method **(López *et al*., 2019)**. NH_4 and NO_2 parameters were obtained using the spectrofotometry method **(Ruwoldt *et al*., 2023)**. For soil parameters such as pH, redox potential, organic carbon (OC), organic matter (OM), and cation exchange capacity (CEC), the compulsive exchange method was used for measurement **(FAO, 1980)**. Tidal data were obtained from records by Meteorological, Climatological, and Geophysical Agency of Probolinggo City.

The study data were analyzed descriptively using qualitative methods with the assistance of Microsoft Excel 2013 and dynamic modeling analysis with Stella software version 9.02. Furthermore, the estimation of WQI and SQI values was calculated based on the formula **(Ma *et al*., 2013)**.

Table 1. Classification of water quality index (WQI) and soil quality index (SQI) values

The value of WQI	Water/soil condition	Interval classes	The value of SQI
>0.80	Excellent	I	>0.75
0.60 < WQI < 0.80	Good	II	0.50 < SQI < 0.75
0.30 < WQI < 0.60	Poor	III	0.25 < SQI < 0.50
0.05 < WQI < 0.30	Badly	IV	0.03 < SQI < 0.25

RESULTS AND DISCUSSION

1. Water quality

The parameters of water quality in shrimp ponds are reported in Table (2) within the standard quality values for farming **(Ariadi *et al*., 2019a)**. The parameters above the standard quality threshold are TOM 152.64-169.56 mg/L and the concentration of OM for shrimp farming is <90 mg/L **(Chapman *et al*., 2020)**. The nitrite (NO_2) concentration in pond 1 was at 1.064 mg/L and the high levels caused methemoglobin in shrimp hemocyanin **(Li *et al*., 2023)**.

Table 2. Water quality parameters in research ponds

Location	Water Quality Parameters										
	pH	Salinity (gr/L)	TOM (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	Alkalinity (mg/L)	NH_4 (mg/L)	NO_2 (mg/L)
Pond 1	8.0 ± 0.33	31 ± 5.10	157.48 ± 0.29	515 ± 3.42	2226 ± 3.21	2741 ± 3.42	8 ± 4.53	123 ± 4.95	130 ± 1.48	0.982 ± 1.11	1.064 ± 1.08
Pond 2	8.0 ± 0.31	31 ± 5.96	169.56 ± 0.10	507 ± 3.65	2190 ± 3.75	2697 ± 3.68	11 ± 6.39	122 ± 2.29	132 ± 2.18	0.910 ± 1.10	0.476 ± 0.70
Pond 3	8.0 ± 0.30	31 ± 5.99	152.64 ± 1.44	515 ± 2.45	2255 ± 2.35	2770 ± 3.48	9 ± 6.23	124 ± 2.12	133 ± 3.41	1.158 ± 1.32	0.741 ± 1.02

The dynamic water quality parameters in ponds correlate with the productivity of farming and the quantity of inputs. The provision of farming inputs such as feed, lime, and fertilizer can also affect the ecosystem dynamics **(Satanwat *et al*., 2020)**. Furthermore, shrimp are organisms sensitive to changes in water patterns within the habitats **(Bhatt *et al*., 2024)**. These organisms become stressed and die when water quality conditions are poor **(Ariadi *et al*., 2023)**.

The stability of pond water quality is an indicator of the condition of shrimp farming medium. Poor water quality can be interpreted as the environmental conditions being unsuitable for farming **(Huang *et al*., 2022)**. This is also affected by unpredictable weather conditions due to the effect of climate change **(Ariadi *et al*., 2023)**. In addition, fluctuations in air temperature and sunlight intensity indirectly affect water quality in shrimp ponds **(Chapman *et al*., 2020)**.

2. Soil quality

Soil quality in silvofishery land is presented in Table (3). The parameters tend to be stable and within the standard values for farming activities. Soil pH, redox potential, OC, OM, and CEC values range from 7.7 to 7.9, 11.79 to 16.80 mev, 0.36 to 0.45 mg/L, 0.45-0.50 mg/L, and 27-30 mg/L. The stable soil condition is due to pond construction using HDPE model to minimize direct contact between fish farming activities and soil **(Chen *et al*., 2024)**.

Table 3. Soil quality parameters in research ponds

Location	Soil Quality Parameters				
	pH	**Redox (mev)**	**OC (mg/L)**	**OM (mg/L)**	**CEC (mg/L)**
Pond 1	7.8 ± 0.09	14 ± 5.02	0.45 ± 0.12	0.47 ± 0.17	27 ± 4.91
Pond 2	7.9 ± 0.11	16.8 ± 5.81	0.36 ± 0.06	0.45 ± 0.10	28 ± 6.56
Pond 3	7.7 ± 0.16	11.79 ± 5.63	0.39 ± 0.07	0.50 ± 0.12	30 ± 4.93

Soil is an important indicator analyzed before constructing farming ponds. Compact soil conditions will affect the biophysical parameters of farming sites **(Hasibuan *et al*., 2023)**. In this context, soil that tends to be porous also has a negative effect on shrimp farming activities due to the ease of water seepage **(Ariadi, 2020)**. Indirectly, soil quality conditions also affect the cation exchange process and nutrient elements in the surrounding pond environment **(Du *et al*., 2024)**.

Microorganisms in soil under certain conditions are also described as more diverse than in water. This is attributed to the high level of primary productivity and soil also acts as a biophysical parameter affecting the process of OM decomposition **(Rocha *et al*., 2022; Hasibuan *et al*., 2023)**.

3. Water quality index (WQI) and soil quality index (SQI)

The estimated values of WQI and SQI during the study period are interpreted in Fig. (1) and the values vary each month. WQI and SQI values of ponds range from 0.11 to 0.60 and 0.09 to 0.54, within the poor (0.33) and interval III (0.31) categories, respectively. The poor status is due to effect of biotic and abiotic factors from the surrounding environment **(Musa *et al*., 2020)**.

The poor values of WQI and SQI show that the aquatic land conditions at shrimp farm location are not very ideal for farming. The status of the values can change when self-purification processes are used and there is a decrease in the intensity of pollutant waste in the surrounding aquatic environment **(Ni *et al*., 2021)**. The poor values of WQI and SQI can also be caused by high pollution from shrimp farming activities and runoff from domestic waste **(Ma *et al*., 2013)**. Additionally, poor quality of water and soil is due to unstable weather conditions, affecting biological, physical, and chemical processes in the land and pond waters **(Ariadi *et al*., 2023; Soeprapto *et al*., 2023)**. These situations require environmental engineering processes to prevent the disruption of shrimp farming operations.

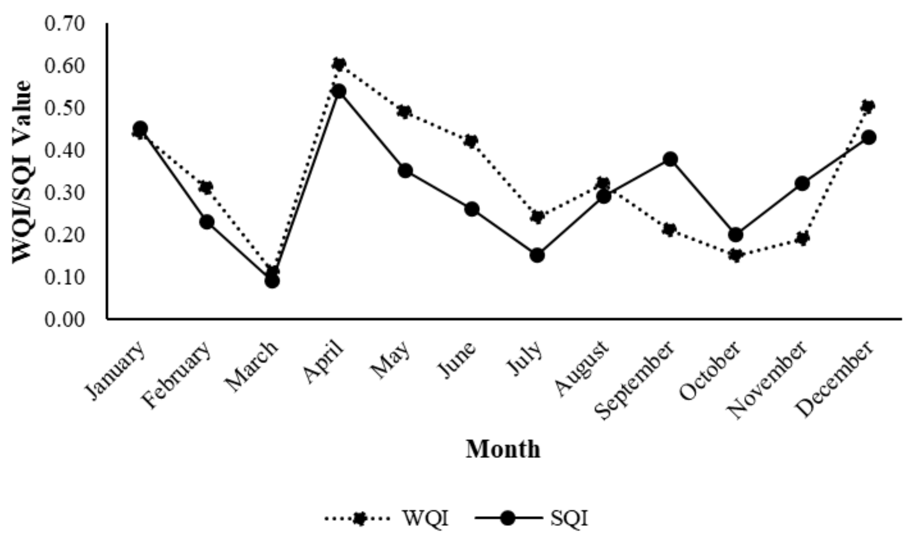

Fig. 1. WQI and SQI fluctuations values in research ponds

WQI and SQI are quantitative analysis methods for determining land suitability status from a perspective **(Mardiana *et al.*, 2024)**. Data from the WQI and SQI analyses can serve as a reference for establishing land use patterns and resource management **(Cavalcante *et al.*, 2021)**. Low WQI and SQI scores indicate that the land is contaminated and may have low nutrient content **(Linayati *et al.*, 2024)**. Additionally, WQI and SQI scores reflect the status of land use in that area, which is often intensive due to resource management activities or runoff **(Pravalie *et al.*, 2020)**.

4. Seawater tides

The dynamics of tidal fluctuations are described in Fig. (2) and the height in waters of Probolinggo ranges from 0.84 to 2.90 meters throughout the year. Therefore, the coastal waters of Probolinggo have a fluctuating tide level. The highest and lowest tides occur in February and December, respectively. The highest and the lowest tides in February and December occur as the peak of the rainy and transitional season. The dynamics of tidal fluctuations continue to fluctuate over time following climate change patterns **(Liu *et al*., 2022; Wang *et al*., 2023)**.

Tidal fluctuations affect the sea level dynamically as well as the rate of evaporation, and rainfall **(Wang *et al*., 2023; Koutitonsky *et al*., 2024)**. Rainfall increases when the sea level rises significantly during rainy conditions **(Ariadi *et al*., 2023)**. Tides also affect the distribution patterns of organisms in aquatic ecosystems **(Liu *et al*., 2022)**.

Tidal fluctuations impact the patterns of biophysical cycle changes in the environment **(Aziz *et al.*, 2024)**. Changing environmental conditions will affect the natural state of an ecosystem. This can occur due to the influence of various related parameters **(Mardiana *et al.*, 2024)**. In some cases, the effects of tidal fluctuations have physically altered environmental conditions in coastal areas **(Dong *et al.*, 2024)**. The rise of tidal and soil erosion due to changes in natural vegetation affect the physical land changes in coastal regions **(Liu *et al.*, 2022; Dong *et al.*, 2024)**.

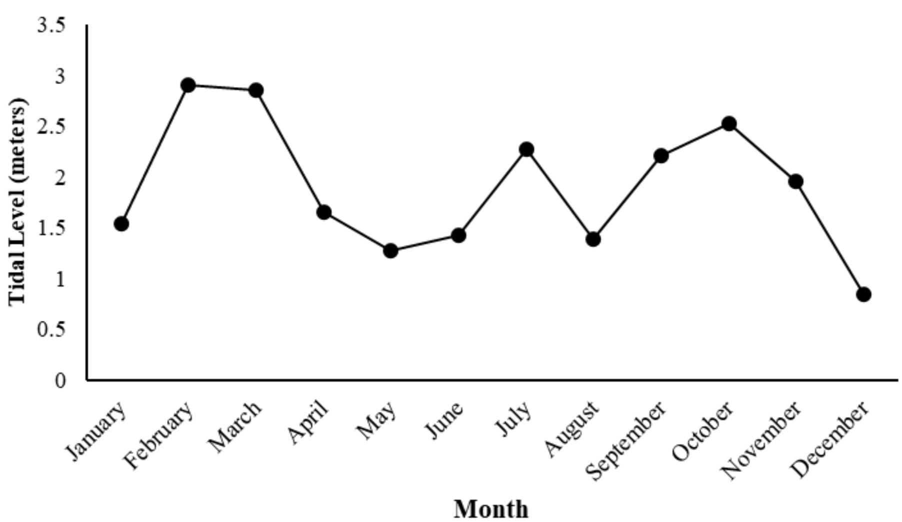

Fig. 2. Fluctuations in tidal dynamics of sea water

Coastal areas are highly susceptible to extreme tidal fluctuations due to effect of climate change **(Sabdaningsih *et al.*, 2023)**. Meanwhile, intensive climate change has affected unstable weather and wind distribution patterns simultaneously **(Parvin *et al*., 2023; Pereira *et al*., 2023)**. This shows a correlative relationship between the dynamics of tidal fluctuations and effects of global climate change.

5. Correlative relationship between WQI, SQI, and tidal wave

The values of WQI and SQI correlate with the dynamics of tidal fluctuations, as shown in Fig. (3). WQI and SQI values range from 0.11 to 0.60 and 0.09 to 0.54, fluctuating correlatively with tidal waves of 0.84 to 2.90 meters. The graph shows that when the values decrease, there is an increase in tidal wave (Fig. 3). Therefore, the decline in the status of WQI and SQI in farming ponds is affected by the increase in tidal wave level **(Mahmood *et al*., 2023)**.

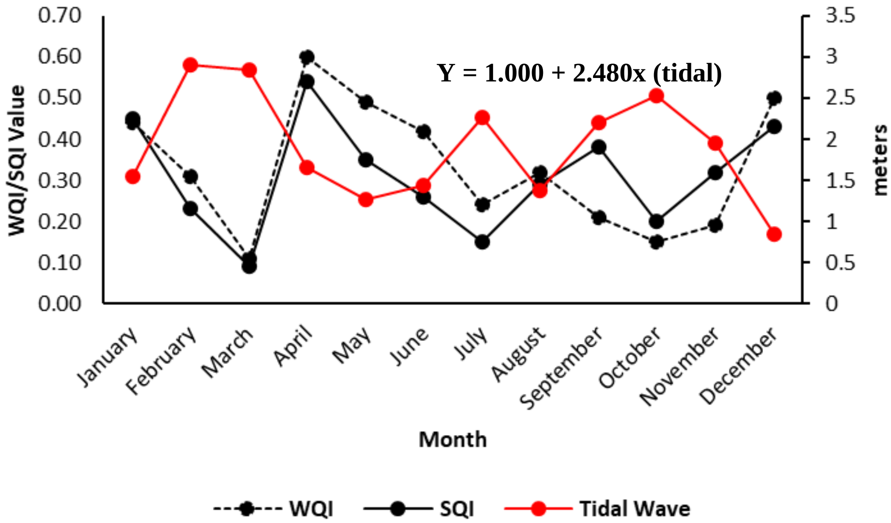

Fig. 3. Correlation of WQI, SQI values and tidal wave

High tidal waves are detrimental to farming ecological sites, affecting the level of pollutant waste **(Kim *et al*., 2022; Fanous *et al*., 2023)**. The abnormal conditions in tidal waves can affect land and water conditions in farming sites **(Fuentes-Santos *et al*., 2021)**. This provides options for the development of eco-friendly practices in shrimp farming activities.

Shrimp are organisms sensitive to changes in environmental conditions **(McLean *et al*., 2020)**. Changes in water and land conditions automatically affect the operational cycle of shrimp farming **(Ariadi *et al*., 2019b)**. The intense effect in coastal waters necessitates a more effective shrimp farming model **(Pereira *et al*., 2023)**.

The regression model shows the value Y = 1.000 + 2.480x, suggesting that there is a decrease in WQI and SQI values by 2.48 for every increase of 1 meter in tidal wave. The model interprets the correlative effect between variables, where WQI and SQI may change over time following the surrounding environmental conditions **(Ma *et al*., 2013)**. The dynamic changes in environmental conditions and the worsening impacts of climate change affect land suitability status **(Ariadi., 2023)**. Coastal areas, which consist of brackish water, will experience significant dynamic changes due to the alterations in their surrounding environment **(Aziz *et al*., 2024)**.

6. Correlation water and soil quality

Several water quality parameters showing a high correlation degree include TOM, Mg, hardness, CO_3, HCO_3, alkalinity, NH_4, and NO_2. The parameters with low correlation levels include salinity, TOM, CO_3, and NO_2 (Table 4). Furthermore, the dynamics have a continuous correlative effect on aquatic ecosystems **(Wafi *et al.*, 2021)**.

Table 4. Correlation test results of water quality parameters

	pH	**Salinity**	**TOM**	**Ca**	**Mg**	**Hardness**	**CO_3**	**HCO_3**	**Alkalinity**	**NH_4**	**NO_2**
pH	1										
Salinity	.412*	1									
TOM	-.890**	-.369*	1								
Ca	.084	.188	-.118	1							
Mg	.123	.234	-.174	.989**	1						
Hardness	.116	.226	-.164	.993**	1.000**	1					
CO_3	.961**	.445*	-.895**	.048	.092	.084	1				
HCO_3	-.885**	-.063	.829**	-.024	-.047	-.043	-.892**	1			
Alkalinity	-.345	.573**	.336	.016	.036	.032	-.301	.699**	1		
NH_4	-.669**	-.656**	.533**	-.183	-.225	-.217	-.646**	.451*	-.073	1	
NO_2	-.377*	-.873**	.356	-.181	-.190	-.189	-.429*	.131	-.401*	.525**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Based on the test description, there is a strong correlation in water quality parameters. Therefore, the contamination of water parameter can affect others and the correlative relationship shapes the characteristics of a site **(Ariadi *et al.*, 2019a; Newman, 2023)**. This is because polluted waters also have poor-quality profiles **(Soeprapto *et al.*, 2023)**. In ponds, multi-parameter water correlations and developed farming patterns significantly affect shrimp life and pond waters' characteristics **(Ariadi, 2020; Satanwat *et al.*, 2023)**.

Soil parameters with a high level of correlation include OM with CEC, while those with low correlation comprise redox potential and OM (Table 5). The high correlation of OM with CEC is due to the release of anions and cations in soil material types **(Boyd *et al.*, 2007)**.

Table 5. Correlation test results of soil quality parameters

	pH	**redox**	**OC**	**OM**	**CEC**
pH	1				
redox	-.174*	1			
OC	.114	.254	1		
OM	-.320	.209*	-.207	1	
CEC	.263	-.137	-.302	-.303**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Soil parameters do not directly affect shrimp farming activities due to the presence of pond liner model. Meanwhile, most intensive shrimp ponds use HDPE liners as media to minimize soil porosity in coastal areas **(Lavoie *et al.*, 2022; Naranjo-Páramo *et al.*, 2022)**. Additionally, the use of HDPE ponds also affects the stability of water temperature **(Naranjo-Páramo *et al.*, 2022; Eldesouky *et al.*, 2023)**.

Effect of climate change, such as rising sea levels, affects the correlation between water and soil quality in coastal areas. Changes in water volume and the solubility of seawater cation ions also affect the biophysical structure **(Hayford *et al.*, 2021)**. The process of changing the biophysical characteristics of the environment due to rising sea levels occurs because of water intrusion processes **(Robinson *et al.*, 2015)**. Therefore, continuous seawater intrusion processes affect environmental sanitation conditions **(Protano *et al.*, 2000)**.

7. Global warming and tidal wave

The dynamic modeling system analysis shows that rising sea levels correlate with effect of changes in the biophysical environment. Additionally, there is a correlation between effects of climate change and rising sea levels, as shown in Fig. (4). Therefore, there is a cause-and-effect relationship between climate change, tidal waves, and changes in the biophysical conditions of the environment. Effect of climate change on the environment occurs partially and simultaneously depending on the level of effects produced **(Mahmood *et al.*, 2023)**.

Changes in soil physical structure in coastal areas are affected by erosion and sedimentation processes, which are slower in sandy soil compared to clay **(Hu *et al.*, 2022)**. Additionally, sandy soil tends to be porous, and susceptible to erosion by water **(Ariadi, 2020)**. The rate of soil erosion can also intensify with increasing tidal waves and seawater volume **(Koutitonsky *et al.*, 2024)**.

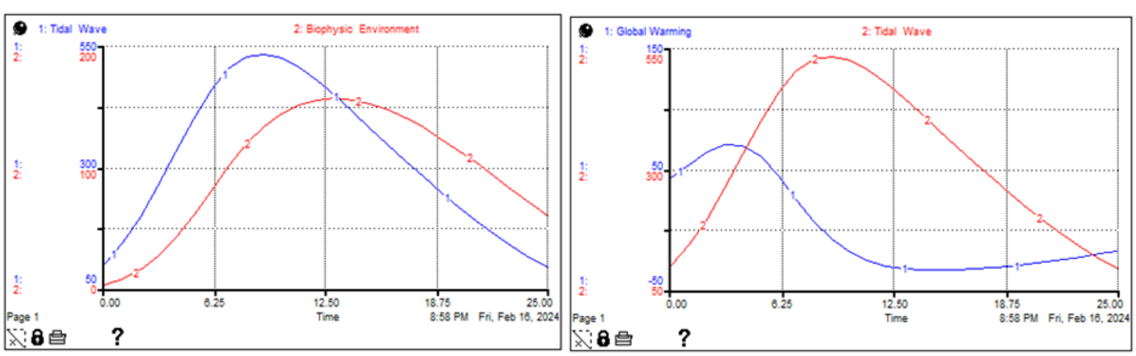

Fig. 4. Dynamic model analysis of the impact of increasing tidal waves on changes in environment biophysical conditions

Effect of tidal waves on the biophysical parameters of coastal water environments gradually affects the condition of water and soil quality **(Ya *et al*., 2023)**. In shrimp farming, water, and soil quality are the main resources managed for framing sites **(Ariadi *et al*., 2019a; Wafi *et al*., 2021)**. The unstable conditions of water and soil also affect the feasibility of land and water **(Pimentel *et al*., 2023)**.

The dynamic pattern of tidal waves affects the biophysical land conditions in shrimp farming areas. Meanwhile, intense tidal waves can affect the physical structure of soil and changes in the aquatic ecosystem **(Parvin *et al*., 2023; Ya *et al*., 2023)**. In this context, the indicators observed from changes in the biophysical structure of coastal land are WQI and SQI. Water and soil quality changes can also affect the environmental profile of shrimp farming activities **(Tong *et al*., 2020)**. In shrimp pond ecosystems, the parameters operate dynamically and are interrelated **(Alarcón-Silvas *et al*., 2021)**. These conditions affect coastal shrimp farming activities' feasibility status and biophysical environment.

Shrimp farming in coastal areas that relies on seawater resources is becoming increasingly resilient to the impacts of climate change. The effects of climate change, particularly the rise in tidal level, will influence the physical condition of the land in those areas **(Ya *et al.*, 2023)**. For farming activities, this situation is significant due to the increasingly limited land use conversions **(Ariadi., 2023)**. In addition to land conversion, another impact is the change in groundwater quality in coastal areas compared to conditions before the effects of climate change occurred.

CONCLUSION

The condition of water and soil quality in the shrimp pond ecosystem in the coastal area of Probolinggo is experiencing a decline in quality, affecting the suitability status of land and water due to the impact of the intensifying and dynamic tidal wave. The increase in tidal wave height correlates with the quality status of water and soil in the pond environment.

This issue requires serious attention, as it will affect the sustainability of shrimp productivity. Consequently, the communities in coastal areas may face difficulties in utilizing aquatic resources. Therefore, relevant studies are essential to understand the patterns of coastal resource use impacted by the effects of climate change. This improvisation is urgently needed in light of the increasingly serious impacts of climate change in coastal areas.

CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

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