Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/180316

Quantifying the Impact of Sea Level on Coastal Cities using Bayesian optimized Monte Carlo Simulation model

Awatif M. A. Elsiddieg

Department of Mathematics, College of Science and Humanities, Prince Sattam bin Abdulaziz University, P.O. Box 710, Al-Kharj 11942, Saudi Arabia

Received: 9 Sep. 2023, Revised: 2 Feb. 2024, Accepted: 5 Feb. 2024
Published online: 1 May 2024

Abstract: The immediate treatment of the increasing of sea levels represent on coastal cities around the globe is the subject of this research. Using an all-encompassing and probabilistic methodology, the study quantifies the complex effects of rising sea levels using a Bayesian-optimized Monte Carlo simulation framework. The current approaches for assessing the effects of rising sea levels frequently do not adequately capture the intrinsic complexity and unpredictability of changing structures. This work presents a novel method combining Monte Carlo simulation and Bayesian optimization to overcome these drawbacks. The present research is innovative since it incorporates Bayesian optimization methods into a Monte Carlo simulation framework. By constantly modifying distributions of probabilities according to observable results, this combination improves simulation performance. This constantly changing optimization methodology closes a significant gap within current methods by ensuring a more accurate portrayal of shifting conditions. In addition, the method used in this work emphasizes cooperation among mathematicians, coastal scientists, and climate researchers, thereby promoting a comprehensive knowledge of the complex issues raised by rising sea levels. This set of variables includes the current level of the sea, land height, frequency of storm surges, population density, and infrastructure resilience. The model's effectiveness is rigorously assessed, utilizing procedures for verification and calibration that use past information. Calculations are guided by various rising sea-level situations based on scientific forecasts and uncertainty ranges. Sensitivity analysis pinpoints important factors, guiding further efforts to gather data and improve the model. The structure for the performance assessment ensures that the model is dependable and applicable to those making decisions who want to prioritize flexible measures and create resilient communities along the coast.

Keywords: Bayesian optimization, Monte Carlo simulation, population density, probability distributions, sensitivity analysis.

1 Introduction

A sizable section of the globe's population lives in coastal areas, which are under a new threat from increasing sea levels brought on by changes in the climate. Rising sea levels present complicated difficulties that require an in-depth comprehension of its possible effects on coastal areas due to its increasing rate [1]. The Earth's temperature has changed significantly during the past 100 years, causing ice caps on the poles to melt and the ocean to expand thermally. These processes directly and increasingly threaten relatively low-lying coastlines by contributing to the observable increase in global average sea levels.

Coastal areas are especially susceptible to the broad implications of rising ocean levels since they are frequently highly populated and commercially important [2]. The potentially disastrous effects on environments, infrastructures, and communities highlight how urgent it is to tackle this problem. Current methods for evaluating how rising seas may affect coastal towns frequently fail to capture these complicated networks' constantly changing and unpredictable character. Traditional frameworks might fail to properly integrate changing information or simplify important elements [3]. Therefore, innovative methods that may extend beyond these constraints and give those making decisions precise and useful information are desperately needed. By presenting an innovative approach that blends the use of Monte Carlo simulations with Bayesian optimization methods, this research seeks to overcome the abovementioned constraints. By including Bayesian optimization, the simulated model's performance is increased as distributions of probabilities are updated continuously in response to measured results. Through dynamic optimization, changing conditions can be more

* Corresponding author e-mail: a.elsiddieg@psau.edu.sa

accurately represented, facilitating a greater comprehension of the possible effects of rising sea levels on coastal people [4].

This research presents a novel Bayesian-optimized Monte Carlo modelling framework to objectively evaluate the many aspects of rising sea levels to remedy this impending problem. This study aims to close current gaps in techniques by adopting a thorough and stochastic strategy, providing an improved and reactive instrument for assessing the consequences on coastal neighbourhoods [5].

This research is unusual since it incorporates Bayesian optimization methods into the Monte Carlo Simulation models. This integration introduces a flexible and adaptable component that reacts to shifting situations and integrates the most recent data, marking a break from standard techniques. This approach closes an important gap in existing approaches by continually enhancing distributions of probabilities according to observable results, giving those making decisions an even more reactive and dependable tool for evaluating the effects of rising sea levels. Moreover, this study employs a mixed approach that prioritizes cooperation among mathematicians, marine engineers, and climate researchers.

This partnership guarantees a comprehensive comprehension of the various aspects that rising sea levels present [6]. The objective is to create an extensive framework that considers the interdependence of ecological, social, and infrastructure issues in coastal areas by combining knowledge from several fields. Creating a Bayesian-optimized Monte Carlo simulator that can assess the effects of rising sea levels on coastal populations is the main goal of this research. Finding the key factors affecting these effects, incorporating Bayesian optimisation methods into the modelling structure, and rigorously calibrating and validating the model's assumptions are some of the specific objectives [7].

The main target of the suggested approach is to create a Bayesian-optimized Monte Carlo simulation framework that takes into account important factors including land altitude, density of people, storm surge rate, current ocean levels, and infrastructural resilience. By continuously adapting to fresh data, this framework will provide those making decisions a more precise and flexible instrument for evaluating the effects of rising sea levels [8].

A comprehensive assessment of effectiveness is going to be carried out via verification and calibration procedures utilizing historical information in order to guarantee the accuracy and practicality of the framework. Models will be guided by various rising sea levels situations, which are based on research forecasts and uncertain limits. The evaluation of sensitivity will pinpoint the important factors, directing subsequent attempts to gather information to improve the algorithm. The findings are going to be effectively conveyed to a variety of customers, such as legislators, researchers, and local populations, through clear descriptions and graphics. To sum up, this research aims to make a substantial contribution to existing knowledge of the effects of rising sea levels on coastal populations.

They hope to offer those making decisions a reliable and flexible tool for evaluating and tackling the many issues raised by rising seas by presenting a novel Bayesian-optimized Monte Carlo Simulation framework. This investigation aims to empower coastal populations to choose strategies for adaptation and create resiliency in the context of changing environmental conditions through multidisciplinary cooperation and a thorough approach. These are a few of the research's significant findings:

1. By incorporating Bayesian optimization into a Monte Carlo simulation that allows for ongoing distribution of probabilities updates, the research improves accuracy and flexibility when evaluating the effects of rising sea levels on coastal neighbourho
2. Through the use of Bayesian optimization in Monte Carlo simulation, the framework can overcome static modelling restrictions and become a flexible instrument for those making decisions, adjusting to changing circumstances and information to improve the precision in evaluating the implications of rising sea levels.
3. The framework provides holistic knowledge by integrating sea level, land height, surge rate, density of people, and infrastructural resiliency. This helps coastal towns make well-informed decisions.
4. In order to ensure an in-depth comprehension of the components leading to rising sea levels and their impacts, this research encourages interaction between climate researchers, mathematicians, and coastline architects. This increases the simulation's applicability and practicality in everyday life.
5. The research makes use of a strong framework that includes sensitivity evaluation, confirmation, and calibrating. It also includes a variety of rising sea level predictions and understandable visualizations.

The structure of the paper is as listed below: The setting is established in the first part introduction, which also highlights the constraints of present approaches and the necessity of tackling increasing sea levels, which leads to the main goals of the study. The linked articles are explained in part 2, and the issue that is mentioned in the associated works is provided in section 3. The construction of the Bayesian-optimized Monte Carlo Simulation models and its incorporation of significant factors, including present sea levels, land height, storm surge rate, density of people, and infrastructural resiliency, are covered further in section 4, which dives into the method used.

The collaborative approach and the way the model undergoes constant modification via Bayesian optimisation are also described in this part. The performance assessment of the suggested framework is covered in section 5 which follows. It includes procedures for verification and calibration that make use of previous information, possibilities of rising sea levels, and sensitivity analyses to determine key factors. After that, the findings and their consequences are discussed together with brief descriptions and graphics to facilitate efficient information sharing. In section 6, the main conclusions are summed up, the model's significant achievements are highlighted, and potential paths for study in the areas of resilience to coastal hazards and environmental adaptability are suggested.

2 Related Works

Kameshwar et al. [9] describes how a probabilistic decision-making structure, founded on performance goal-based rules like the National Institute of Standards and Technologies Communities Resiliency Organising Direct and the State of Oregon's Resiliency organise, is created in the present research for neighbourhood resilience organising in multiple risks. The combined likelihood of accomplishing robustness and rapidity-based performance objectives, which is measured using Bayesian networks as a measure, is the definition of resiliency in communal infrastructure frameworks in this context. In order to find actions that can enhance infrastructural efficiency and help communities achieve resilient objectives, the model evaluates the impact of alternatives for assistance in making decisions, including hazard choice, resilience objectives, and mitigating (ex-antes) and reaction (ex-post) methods.

The construction, transport, water-based, and electrical infrastructure components of the seaside, Oregon are assessed for resiliency using this model under the integrated risks of shaking from earthquakes and wave flooding, which represent varying return durations. The system uses Monte Carlo simulation (MCS) to openly assess and transmit uncertainty in harm, reconstruction, and financial damages. The Bayesian framework that assesses the combined resiliency of Seaside's infrastructure components is then informed by the MCS findings. The findings emphasise the effects on resilient infrastructure of taking into account diverse performance objectives, introducing beforehand as well as after the fact measurements, and highlighting connections across numerous infrastructure components.

The drawback is the lack of physics-based evaluations, which might be tackled in subsequent research. Examples of these evaluations include energy flow analysis for electrical systems along with pressure movement evaluation for water-based systems. A number of options are typically included in the current environmental change estimates that can be utilised to measure potential shifts in coastal and maritime ecosystems. Research on the environmental consequences of the changing climate often uses one of three climate situations: mild (RCP2.6), intermediate (RCP4.5), or extreme (RCP8.5), with no accounting for additional uncertainty related to these projections. Mészáros et al. [10] discusses how an approach is put forth to create more realistic situations using the data available to represent the unknowns brought on by environmental change accurately.

The EURO-CORDEX experiment's Local Climatic Modelling simulations serve as the foundation for the technique. A hierarchy Bayesian system is created to produce novel realizations regarding environmental factors like temperatures or radiation. A parameterization series framework is also shown, comprising a cumulative residue phrase, a seasonality form with variable magnitude and temporal change, and a trend element. The not parametric regionally balanced scatterplot smoothness is used to produce the seasonal form, and the term that remains consists of the autonomous, uniformly distributed noisy and the smoothing variances of leftovers. Using a Markov chain sampling by Monte Carlo (Gibbs sampler) and Bayesian parametric speculation, the probability distributions of the duration period model variables are computed.

Several additional statistically valid artificial situations, containing uncertainties projections, can be produced by selecting from the prediction distributions. As an instance situation, a likely simulation is carried out in order to transmit the impact of climate change-induced unpredictability to marine and coastline ecosystems indications using those generated artificial situations and physical-based environmentally friendly models (Delft3D-WAQ) that connect climate factors to ecological systems factors. Making choices may be impacted by the method's limited capacity to completely represent real-world uncertainty due to its dependence on artificial exposure situations.

Xu et al. [11] describes how food is becoming a few of the biggest hazards to people's lives, wellness, and properties in the era of urbanization and changing climates. A great deal of people, wealth, and industry are concentrated along coastlines, making them susceptible to the harmful effects of complex foods brought on by oceanic and hydrological cycles. Composite meals have far more complicated disaster processes with considerably more dire results. The paper clarifies various approaches, which include using mathematical equations to investigate the relationship among food motorists or joint likelihood and computational models for simulating increased food flooding and gathering through the primary tragedy reasons for compound food items in coastal regions according to the findings from previous studies. It also offers the features of various approaches. They also evaluate the uncertainty in the simulations and talk about their benefits and drawbacks. The relationship between rain, drainage, surges from storms, and the impact of changing the climate is rarely taken into account in current studies. Furthermore, there aren't many different types of publications that look into compound food hazards using both statistics and numerical approaches. Less attention is also paid to ambiguities in compounded food research methodologies.

Future research must to concentrate on the features and uncertainties of various models and take climate change's effects on complex foods into account. These will aid in the complete understanding of compound foods, study designs, and useful advice regarding how to take care of food in coastal regions needs additional studies on complex foods, to take into account changes in the environment in the decades to come, to investigate connected designs, and to create an organized uncertainties research structure that identifies subjects in need of more study and improvement.

Blanchard and Sapsis [12] present a group of acquisition algorithms for selecting samples that, when used in tasks pertaining to quantifying uncertainty and Bayesian designs of experiments, accelerate resolution. The method is based on the active education model, in which the following most relevant instance of a black-box functionality is optimized by using already existing examples. The suggested approach seeks to capitalize on the black-box function's tendency to show infrequent and significant occurrences in settings where certain input orientations have a greater influence on the result than alternatives.

This study introduces acquisition algorithms that take advantage of the characteristics of the probability ratio, a number that serves as a sampling probability weighting and directs the active-learning algorithms to the most pertinent areas of the input area. They show how the suggested method may be applied to the probabilistic characterization of uncommon occurrences in dynamical structures and the recognition of as many as thirty antecedents, in addition to the ambiguous characterization of a hydrologic network. Though it works effectively in highly dimensional environments, the suggested method might not be advantageous in other circumstances. It could also be improved by adding details on the structure or curves of the search area in order to lessen the impact of dimensions. Because the Baltic Sea's coastal areas are some of the most heavily utilized in the entire world, an all-encompassing management plan is required. Thus, methods that balance out seasonally are required in order to guarantee optimal use of infrastructures and resources from nature as well as to enhance the state of the economy and society.

Baltranaitė et al. [13] Numerous sets of information from earlier research were assembled in order to evaluate the efficacy of coastal area planning methods with regard to environmentally friendly travel as well as to determine the major natural geographic variables affecting the long-term viability of the southern Baltic vacation destinations. Continuous hydro meteorological information, a quantitative investigation of the requirements of visitors conveyed on a social networking site, and a qualitative inquiry (the material evaluation of organizing records) were utilized in an effort to enhance the sustainable development, financial viability, and social justice of the area around the coast.

In addition, the information from all of these sites was combined using a Bayesian network architecture. They offer a method for determining the environmental, social interactions, and financial factors affecting coastal hotel resilience. The findings presented in this research could be utilized for offering guidance to regional governments on a wide range of issues related to Integrating Coastal Administration, such as organizing beach growth and managing changing seasons of utilize, allocating funds to enhance beach excellence and prevent storm deterioration, and preserving beach facilities and sand excellence. Applying the knowledge gained to future studies on managing coastal areas can involve incorporating the opinions of experts and input from stakeholders into quantifiable present perceptions. There is a demand for more studies to forecast managerial choice consequences by running more modelling, which suggests that the predictive ability of the present models may be limited.

Al Alawi and Dutta [14] argues that developing management plans for ensuring the long-term viability of fisheries assets requires a thorough comprehension of the condition of these stocks. A Bayesian state-space application of the Schaeffer models (BSM) and the Monte Carlo catching yield maximization (CMSY) technique are two current, yet popular, techniques for evaluating stocks in scenarios with limited information. In this case, the seabream population's condition and degree of exploit have been evaluated using CMSY as well as BSM. The Ministry of Farming, Fisheries, as well as the Environment of Oman issued the Fishery Statistical Books, which contained a compilation of capture and efforts statistical corresponding to various time series from 1988 to 2021.

Similar outcomes from CMSY and BSM showed that the country's seabream population was being overfished, with $B/BMSY = 0.96$ (<1) and $F/FMSY = 1.25$ (>1). In 2021, there was a 53% chance that the fishery was excessively fished and experiencing excess fishing, compared to a 16.2% chance that the population was strong (high density with little fishery stress), even though the aim should have been greater than 75%. Because relatively novel approaches were used to derive the findings, which typically verify the circumstances and use of the individuals during the examination, the findings are exploratory in character. The findings indicate that Oman's seabream species is excessively fished which means less fishing is required to bring it back to its former level of richness. Because of the application of somewhat novel approaches, the findings regarding the excessively fished situation of the seabream demographic in Oman are initial, underlining the requirement for additional verification and evaluation regarding population circumstances.

This work covers a wide range of topics, including planning for resiliency, assessing the effects of changing climates, assessing fisheries stocks, compounding food safety in coastal regions, designing Bayesian experiments, and coastal region management for environmentally friendly tourism. Although this research offers insightful information, a number of prevalent shortcomings are noted. These involve the demand for more studies to tackle particular deficiencies like physics-based evaluations and taking into account compound food-related risks in various circumstances, constraints in recording every aspect of practical unpredictability, possible obstacles in accurately expressing unpredictability induced by changes in the climate as well as the demand to conduct additional verification and evaluation because of the use of relatively fresh approaches. These drawbacks highlight the continued work needed to improve and hone these approaches for more long-lasting and dependable implementations in leadership and choice-making settings.

3 Methodology

The current approaches used to evaluate the effects of rising sea levels frequently do not have the level of detail required to fully represent the constantly changing and unpredictable characteristics of coastal ecosystems. Impact evaluations may become inaccurate as a result of conventional methods' tendency to overgeneralize significant factors and their inability to take into account changing data [15].

A lot of the simulations that are now in use are static, which makes it difficult for them to adjust to evolving circumstances and reduces their usefulness in offering accurate and relevant observations. These negative effects highlight the requirement for an additional creative and adaptable strategy to deal with the intricate problems that rising sea levels is posing for coastal populations. By seamlessly incorporating Bayesian optimization methods into a Monte Carlo Simulations framework, the technique suggested presents a fresh and revolutionary strategy for analysing the implications of sea level rising on coastal populations. By enabling ongoing modifications to distributions of probabilities according to observable results, this novel mixture not only solves the constraints of static approaches but also guarantees a flexible and adaptable tool that can precisely represent changing circumstances.

The modelling framework's integration of Bayesian optimization marks a substantial divergence from conventional approaches and closes a crucial gap by giving those making decisions a more precise and adaptable evaluation of the complex issues brought on by ocean level rise. The aforementioned dynamic optimization technique is an innovation that improves the sophistication and effectiveness of impact evaluations in the context of changing climates since it is adapted to the unpredictable character of coastal environments. Creating a Bayesian-optimized Monte Carlo simulation framework is the suggested approach for evaluating the effects of rising sea levels on coastal areas in an in-depth way. Important factors that affect these effects are determined and incorporated into the simulation, including the present levels of the sea, land height, frequency of surges, the density of people, and infrastructural resiliency. In order to handle the constantly changing and unpredictable nature of coastlines, the simulation's reactivity is improved by including Bayesian optimization methods, which update the distributions of probabilities continually depending on observed results [16].

The investigation involves climate researchers, mathematicians, and coastline architects in an interdisciplinary effort to ensure a comprehensive grasp of the issues presented by rising sea levels. Several scenarios for rising sea levels use fuel models to estimate possible effects, and the algorithm is subjected to stringent verification and calibration procedures utilising historical information. The evaluation of sensitivity pinpoints significant factors that direct subsequent information-collecting initiatives and modelling improvements. Information transmission to a variety of stakeholders is facilitated by the findings' straightforward descriptions and visuals. The iterative modification according to suggestions, new information, and scientific discoveries is known as continuous enhancement, and it guarantees the framework's continued applicability and dependability in supporting those making decisions in prioritising adaptive actions and enhancing coastal resiliency.

3.1 Sea Level Rise Scenarios

Researchers are concerning to evaluate the structural impacts of destroyed structures following the floods. They can assess the region's historical trends of flooding using adaptation choices thanks to the above hypothesis. They combined the region's mean overall flooding damage over a given time period. The total amount of societal harm at the start of the experiment is between $17.7 million as well as $32 million when adaptations are not taken into account and between $9.57 million as well as $21.8 million once it is. Compared to other SLR scenarios, the small SLR model barely increases the total quantity of structure destruction over 100 years. Beyond 2070, structural damages are going to increase rapidly in tandem with the growth in SLR levels. At the conclusion of the simulations, the total amount of mean local damage caused by floods in the situation lacking adaptations varies from $43.2 million in the one with a low SLR case to $204 million in the extreme SLR case.

The overall yearly damages of structures with adaptive behaviours in the small SLR model vary from $18.1 million to $38.2 million at the conclusion of the experiment. At the conclusion of the simulations, the region's damage from flood assumptions ranges from $39.2 million to $110 million in the medium-high and elevated SLR situations, a substantial rise. This suggests that in spite of the moderating impacts of adaptation initiatives, coastal areas are projected to be more vulnerable to erosion when the amount of sea level rises. If adaptations are not taken into account, the mean yearly flooding damage on single-family structures in the higher SLR model could grow from $1650.01 to $3216.60 relative to the lower SLR model. As the SLR rates shift from very low to high, mobile devices' home damage averages vary from $684.11 to $1725.39 annually. Comparably, among both the low as well as high SLR situations, the mean yearly losses for multi-family/condo structures vary between $1488.25 to $2209.97, and for public/commercial structures, they vary from $5695.20 to $7047.65. As SLR levels rise, there is a more noticeable shift in mobile house damage from floods.

This suggests that SLR is extremely susceptible to mobile houses close to the coastline [17]. However, the transportable home flood danger might be greatly reduced with the use of adaptable strategies. They then divided the mean yearly damage to buildings into low, medium, high, and extremely high groups according to quantile loss levels in the initial year in order to assess the mean loss of every kind of structure in various SLR situations. The majority of seriously weakened buildings are single-family and transportable houses. These structures, often known as structures with recurring danger of flooding, are very susceptible to floods. If individual adaptation actions are taken into account, a greater number of structures will fall under the moderately damaged group. But when adaption is taken into account, the frequency of structures with substantial harm also rises noticeably. This phenomena is caused by the reality which, once adaptations is taken into account, a significant percentage of single-family homes from the extremely serious damage group will be moved to the higher harm group. This outcome also shows that water harm to structures cannot be completely mitigated by a risk mitigating choice determined by a CBA.

3.2 Monte Carlo Simulation Model

Applications of Monte Carlo simulation (MCS) to analyse probabilities in systems design are common. In MCS, mathematics equations' values are estimated, and complicated system operations are simulated through the use of statistical frameworks and random sampling. An MCS's clear benefit is that, by conducting multiple iterations, improves the assessment of outcomes' correctness and dependability. Defects due to mistakes made by humans and information collecting can be mitigated by this procedure. They consider every variable (water quality indicators) in the present investigation to have an average distribution. The document of support contains the matching formulas. Five significant variables are {x2013.1, x2013.2, x2013.3, x2013.4, and x2013.5}; utilizing 2013 for instance, 1000 samples are created in a distribution that's normal utilising MCS in eqn. (1):

$$\begin{bmatrix} & C^{TN} & C^{TP} & C^{COD}_{Mn} & C^{chl.a} & C^{SD} \\ s^1 & x^{1,1}_{MCS} & x^{1,2}_{MCS} & x^{1,3}_{MCS} & x^{1,4}_{MCS} & x^{1,5}_{MCS} \\ s^2 & x^{2,1}_{MCS} & x^{2,2}_{MCS} & x^{2,3}_{MCS} & x^{2,4}_{MCS} & x^{2,5}_{MCS} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ s^{999} & x^{999,1}_{MCS} & x^{999,2}_{MCS} & x^{999,3}_{MCS} & x^{999,4}_{MCS} & x^{999,5}_{MCS} \\ s^{1000} & x^{1000,1}_{MCS} & x^{1000,2}_{MCS} & x^{1000,3}_{MCS} & x^{1000,4}_{MCS} & x^{1000,5}_{MCS} \end{bmatrix} \quad (1)$$

where the measurement information of the jth water's overall quality indicators is represented by the average of $x^{i,j}_{MCS}$, as well as the last ith sample of information of the jth waters quality indicators is represented by $x^{i,j}_{MCS}$ [18].

3.3 Bayesian Optimization

The globally optimum location for a parameter with high evaluating cost can be found using a sequential BO technique. Implementation of this approach to the surveillance function isn't simple as finding the maximum/minimum amount for an equation is never the primary goal in this instance. Nevertheless, shall show that BO is a useful technique that can produce accurate simulations with a limited amount of data if the essential elements, including the base kernel and the gathering operation, are chosen well. With surrogacy modelling, BO derives the subsequent opinion of a black box functional based on a probability value and a previous belief using the Bayes theorem in Eq. (2) [19].

$$P(f \mid D) = P(D \mid f) \times P(f) \quad (2)$$

According to the phrase, the previous assumption (f) and the information gathered by the equipment's sensors (D|f) are proportional to the knowledge-based surrogacy models (f | D). The previous step takes into account the perception of the desired function's roughness or form. Within the framework of water-related tracking, it encompasses the understanding of the quality goal models. The reconstructed posterior is the revised equation after the fresh observations are taken into account, and the probability component represents the information that the ASV is collecting. The following models can forecast values for the search area once it has been fitted using a Gaussian Regression Process (GPR). The best place for a fresh dataset sample D_{i+1} is then found by applying an AF across the following algorithm's recommendations. Consequently, the ASV's next motion is dictated by the optimization performed by the AF. Once the simulation reaches a predetermined level of certainty, tracking stops. Next, they go over the GPR that was utilized for fitting the design, the traditional AFs in BO, as well as the suggested adjustments made specifically for an ASV's surveillance duty.

Many popular methods for machine learning have many different variables that need to be chosen. The choice between these hyper parameters affects how well every algorithm performs. Amongst numerous additional approaches, grid searching, random searching, and algorithmic evolution are commonly used during parameters. These methods necessitate numerous function assessments.

By optimizing a function with objective parameters that are costly to analyse, substitute-modelling techniques like Bayesian optimization (Bayes Opt) can minimize the number of real-world function assessments needed. It is based on Gaussian methods and Bayesian deduction and may be used when the goal functional closed-form equation is unknown but measurements of the purpose at sampling levels can be obtained.

Bayes Opt uses the results of previous studies as training information to create a probability surrogate approach to the goal. Although the substitute framework is far less expensive to compute, it may nevertheless give us enough insight into how to best assess the fundamental goal or functions in order to produce a useful outcome. For a collection of hyper parameters that need to be adjusted, let's suppose the vector P= $\{p_1,\ldots.p_m\}$. For the purpose of trying to determine in eqn. (3)

$$P^* = \underset{P}{\operatorname{argmin}}\, g(P|\{(x_i,y_i)\}_{i=1}^n \qquad (3)$$

given a collection of learning paradigm $\{(x_i,y_i)\}_{i=1}^n$, and g is a function of costs [20].

A suitable acquisition functional (AF), which indicates the next area to be examined, serves as the guidance for the entire optimization process. Therefore, every AF must strike an equilibrium between mining and exploring. In order to locate an additional set of variables that enhance the efficiency of the approach, exploring means region searches where there is a significant degree of uncertainty. Conversely, exploiting is an area of search that is conducted near previously determined high-value estimates.

4 Results

The precision and dependability of the Bayesian-optimized Monte Carlo simulation framework are demonstrated by its strong overall performance evaluation. Qualification verifies the model's capacity to accurately predict future occurrences, whereas calibrating versus past information guarantees an accurate portrayal of prior events. The evaluation of sensitivity pinpoints important variables that will direct subsequent attempts to gather data and improve the model. The inclusion of sea level rising possibilities in the entire evaluation methodology reinforces the practicality of the approach, giving those making decisions a reliable tool to prioritise adaptation efforts and improve coastal resiliency.

4.1 Sensitivity Analysis

According to the stage of the evaluation that has been evaluated and if regional or global approaches have been employed, the identified parameter sensitivity differ significantly. For instance, the one-at-a-time (OAT) sensitivity for the revised rising sea levels models demonstrates that three of its goals are significantly impacted by the timing when t*, and rates, c*, of sudden rising sea levels [21]. The value of the sensitivity that is linked to a variable is shown by the dimension of the bar adjacent to its explanation. Yet, the GEV variables take precedence over the sensitivity values whenever the OAT techniques are fitted to the enhanced storm surge models. This is in line with the previously mentioned finding that significant storm surge occurrences have the ability to overwhelm the signals of the relatively little impacts from rising sea levels. It makes sense that the elevating parameter's cost rate, which serves k, would be responsible for each of the variations in the spending expenditures goal for each iteration of the framework.

Comparable outcomes are obtained by a worldwide sensitivity analysis based on storm surge and financial variables. The variance breakdown of the study's initial and overall impacts' magnitudes are indicated by the dimensions of the intersections at every node. Total-order impacts are an estimation of the total amount of weight of the parameters (individuals plus interactions terms), whereas first-order impacts show the influence of all parameters on the algorithm's outcome. The width of the lines indicates the second-order interaction scales. The k value alone determines the investment's price goal in this case as well. Discounting total expenses, flood likelihood, and discounting damages are all significantly influenced by the GEV variables, with the form of the variable (ξ) accounting for the majority of these effects. Relationships among the GEV variables result in high total-order sensitivity even though the absence of large first-order sensitivity. These interactions between factors are essential to comprehending the behaviour of the simulation since they most significantly affect the way the highest and lowest tail-area numbers are extended, together with the size and shape variables. The most recent release of the simulation mostly ignores the implications of the levels of rise variables, probably because sea-level estimates are only taken into account for a 75-year investing period. They predict that the implications of sudden rises in sea levels will manifest more strongly in the sensitivity assessments over more extended periods.

To assess every contributing factor's effectiveness and look into the connection between it and the desired outcome, a sensitivity analysis is carried out. Following the application of the suggested methodology, 1000 pairings of datasets (xi, 1(norm) MCS, xi, 2(norm) MCS, xi, 3(norm) MCS, xi, 4(norm) MCS, and xi, 5(norm) MCS, Q1 1) (i=1..., 1000) have matching evaluation findings. Five collections of influencing variables

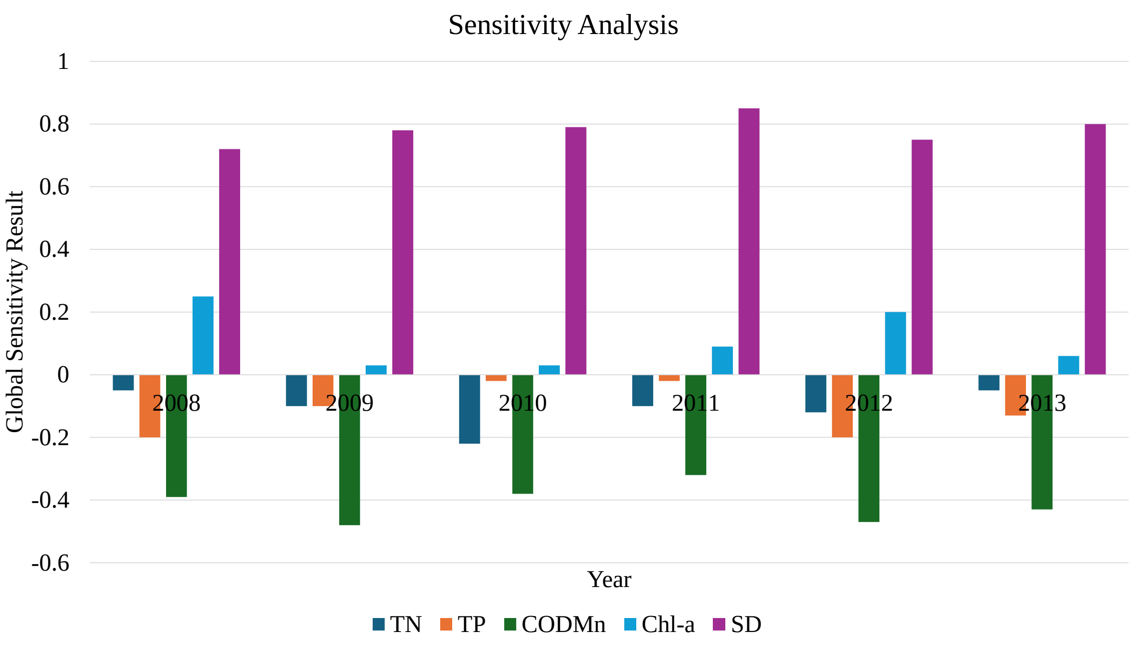

Fig. 1: Global Sensitivity Analysis.

(x1,j(norm) MCS, x2,j(norm) MCS,..., x1000,j(norm) MCS; Q1 1, Q1 2,..., Q1 1000) (j = 1,..,5) may be obtained using these 1000 pairs of observations [22]. After that, a GSA is used to assess each of the five categories listed above in order to determine how important every input variable is. The GSA findings of five important parameters, determined within measurements of errors and human variables on the measured information within 5%, are displayed in Fig. 1 for the years 2008–2013 [23].

The global sensitivity of the five important factors influencing the water quality may differ in the chosen years, as shown in Fig 1. The global sensitivity findings are higher for the variables SD and COD_{Mn}. When it comes to the assessed index (Q1 i), the SD shows the strongest positive association, whereas the COD_{Mn} has the strongest negative relationship. The global sensitivity of the important parameters, TN, TP, and COD_{Mn}, is negative. In other words, there is a negative link between these characteristics and the findings from the assessment of the water quality.

4.2 Cumulative Probability Distribution Function

The probability of detecting different storm surge height readings in a specific set of data is represented clearly by the cumulative distribution of storming surge height. The storm surge height is shown on the x-axis in this figure. 2, and the cumulative chance of seeing a surge height equivalent to or less than a given value is shown on the y-axis. Although a flatter slope at higher levels suggests a greater chance of seeing severe surge incidents, a steeper starting slope signifies a higher likelihood of seeing lesser storm surge levels. In order to lessen the effects of surges from storms on coastal cities, solid structures as well as methods for adaptation must be developed. This distribution offers important insights about both the severity and frequency of storm surge events.

4.3 Density Distributions

Figure 3 shows the density distribution of cost ratios linked with different rising sea level situations by visualizing the density distributions of the mean cost ratio. The mean price ratio is shown by the x-axis, whereas the density or chance of witnessing particular ratios is represented by the y-axis. The most likely average cost ratio is shown by the highest point in the distribution, which provides information on the financial effects of rising sea levels on coastal areas. The distribution's breadth and form provide insight into the degree of variability and unpredictability in cost projections, which helps those making decisions grasp the monetary implications and create flexible plans to lessen and control the effects of rising sea levels on the economy.

Figure 4 shows the probability distribution for sea level rise, which illustrates the possibility of different

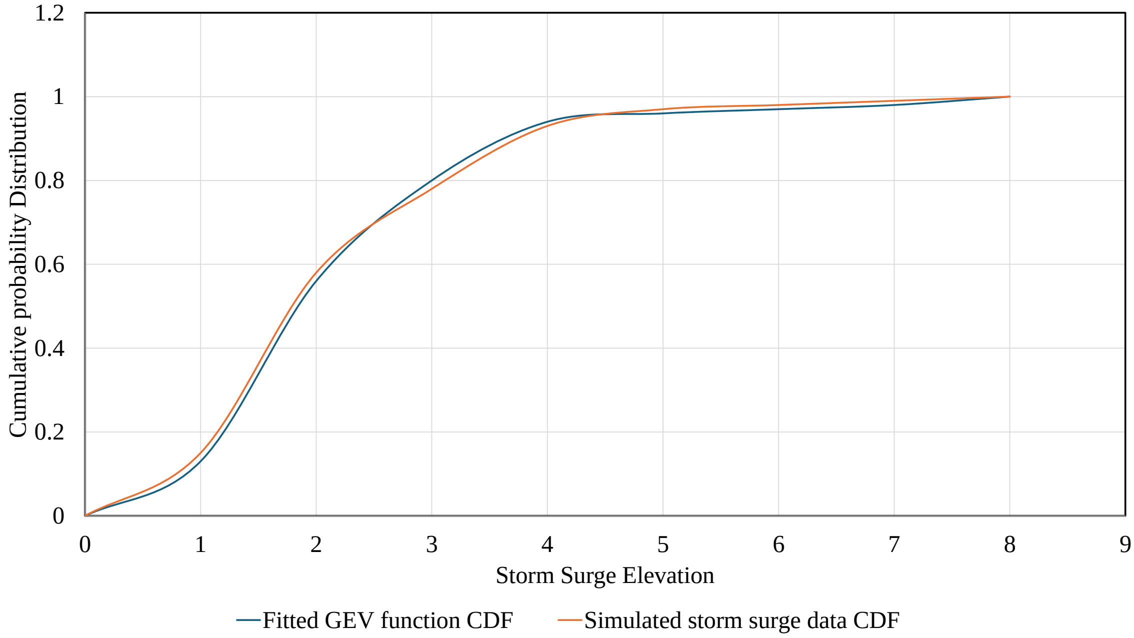

Fig. 2: Cumulative distribution of Storm Surge Height.

rises in sea level magnitudes within a given dataset. The x-axis represents different sea level rise scenarios, and the related probabilities are shown on the y-axis. The distribution's highest peaks indicate the increase in sea level values that are most likely to occur, providing important context for various possible outcomes. This distribution helps with the evaluation of coastal danger and the development of adaptive solutions by offering a thorough knowledge of the uncertainty around sea level rise estimates. By providing stakeholders with a probabilistic view on the rate and unpredictability of the sea level rise, the visualization helps robust coastal facilities and long-term adaptation strategies.

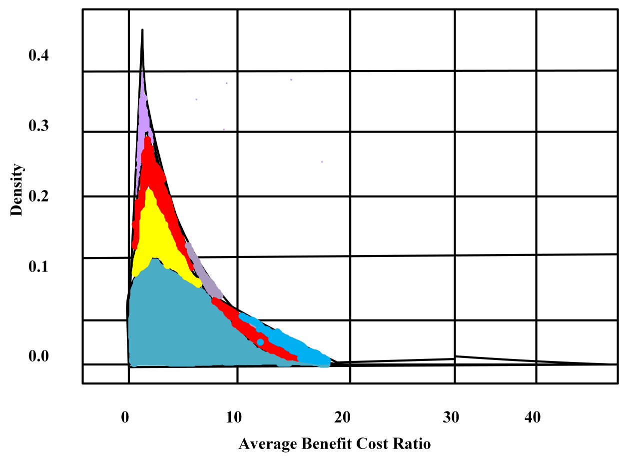

Fig. 3: Density Distribution of Cost Ratio.

5 Discussion

The paper analyses the outcomes of the Bayesian-optimized Monte Carlo simulation technique used in the debate, highlighting its value in helping to comprehend the effects of rising sea levels on coastal areas. The results are examined in light of the important factors that have been found, forecasts for rising sea levels, and sensitivity analyses, offering an in-depth comprehension of risks and possible mitigation techniques [24]. The talk emphasizes how Bayesian optimization allows the framework to dynamically change, overcoming the drawbacks of fixed models and providing those making decisions with more precise and responsive tools. The significance of cross-disciplinary work is highlighted due to its ability to offer a comprehensive viewpoint that recognizes the interdependence of social, environmental, and infrastructure elements. The report also takes policy consequences into account, highlighting the significance of informed choices when deciding to prioritize adaptation efforts and promote the resilience of coastal populations in the context of changing climates [25]. The investigation aims to support ongoing initiatives in environmental adaptability and resilience to flooding by

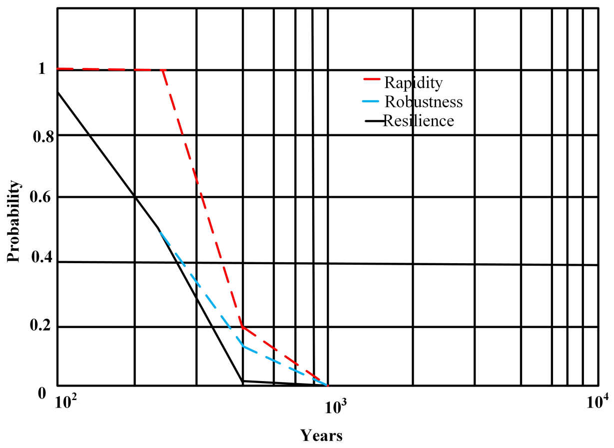

Fig. 4: Probability Distribution of sea level rise.

exploring avenues for future studies and model enhancements.

6 Conclusion and Future Scope

Finally, this work presents a novel Monte Carlo simulation framework that is optimized using Bayesian processes to evaluate the complex effects of rising sea levels on coastal areas. The framework constantly adjusts to changing situations by using Bayesian optimization methods, giving those making decisions a precise and reactive approach to comprehending weaknesses and formulating responses that are adaptive. The importance of the algorithm's contributions such as its multidisciplinary cooperation, dynamic flexibility, and comprehensive treatment of important variables—is emphasized in the debate. The results highlight how important it is to make well-informed decisions about which adaptation efforts to prioritize in order to create resilience coastal areas. This investigation contributes to a better comprehension of the effects of rising sea levels and establishes the groundwork for further studies and ongoing model development to enable environmentally friendly and adaptable coastal growth in order to face the increasing difficulties posed by changing climates.

The next phase of this project will focus on building the framework to include more environmental variables and feedback cycles in order to provide an improved comprehension of the effects of rising sea levels. The prediction power of the algorithm may be improved by using modern algorithms for machine learning and current information inputs. The practical use of the approach can be improved through collaboration with coastal populations and legislators, encouraging localized adaptation measures. The framework will be updated and refined continuously to maintain its applicability in tackling the changing difficulties brought about by rising sea levels and changes in the climate.

Acknowledgment

The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project number (PSAU/2023/01/25401).

Conflicts of Interest:

The authors declare that they have no conflicts of interest to report regarding the present study.

Data availability

: Data sharing is not applicable to this article as no data sets were generated during the current study.

References

[1] A. K. Magnan, M. Oppenheimer, M. Garschagen, M. K. Buchanan, V. K. Duvat, D. L. Forbes, J. D. Ford, E. Lambert, J. Petzold, F. G. Renaud *et al.*, Sea level rise risks and societal adaptation benefits in low-lying coastal areas, *Scientific reports* **12**(1) (2022) p. 10677.

[2] M. K. Buchanan, S. Kulp, L. Cushing, R. Morello-Frosch, T. Nedwick and B. Strauss, Sea level rise and coastal flooding threaten affordable housing, *Environmental Research Letters* **15**(12) (2020) p. 124020.

[3] A. R. Bell, D. Wrathall, V. Mueller, J. Chen, M. Oppenheimer, M. Hauer, H. Adams, S. Kulp, P. Clark, E. Fussell *et al.*, Migration towards bangladesh coastlines projected to increase with sea-level rise through 2100, *Environmental Research Letters* **16**(2) (2021) p. 024045.

[4] L. Xu, S. Cui, X. Wang, J. Tang, V. Nitivattananon, S. Ding and M. N. Nguyen, Dynamic risk of coastal flood and driving factors: Integrating local sea level rise and spatially explicit urban growth, *Journal of Cleaner Production* **321** (2021) p. 129039.

[5] J. Cooper, G. Masselink, G. Coco, A. Short, B. Castelle, K. Rogers, E. Anthony, A. Green, J. Kelley, O. Pilkey *et al.*, Sandy beaches can survive sea-level rise, *Nature Climate Change* **10**(11) (2020) 993–995.

[6] A. Bernstein, M. T. Gustafson and R. Lewis, Disaster on the horizon: The price effect of sea level rise, *Journal of financial economics* **134**(2) (2019) 253–272.

[7] S. Saad, A. A. Javadi, R. Farmani and M. Sherif, Efficient uncertainty quantification for seawater intrusion prediction using optimized sampling and null space monte carlo method, *Journal of Hydrology* **620** (2023) p. 129496.

[8] J. Del-Rosal-Salido, P. Folgueras, M. Bermudez, M. Ortega-Sanchez and M. A. Losada, Flood management challenges in transitional environments: Assessing the effects of sea-level rise on compound flooding in the 21st century, *Coastal Engineering* **167** (2021) p. 103872.

[9] S. Kameshwar, D. T. Cox, A. R. Barbosa, K. Farokhnia, H. Park, M. S. Alam and J. W. van de Lindt, Probabilistic decision-support framework for community resilience: Incorporating multi-hazards, infrastructure interdependencies, and resilience goals in a bayesian network, *Reliability Engineering & System Safety* **191** (2019) p. 106568.

[10] L. Mészáros, F. van der Meulen, G. Jongbloed and G. El Serafy, A bayesian stochastic generator to complement existing climate change scenarios: supporting uncertainty quantification in marine and coastal ecosystems, *Stochastic Environmental Research and Risk Assessment* **35** (2021) 719–736.

[11] K. Xu, C. Wang and L. Bin, Compound flood models in coastal areas: a review of methods and uncertainty analysis, *Natural Hazards* **116**(1) (2023) 469–496.

[12] A. Blanchard and T. Sapsis, Output-weighted optimal sampling for bayesian experimental design and uncertainty quantification, *SIAM/ASA Journal on Uncertainty Quantification* **9**(2) (2021) 564–592.

[13] E. Baltranaitė, L. Kelpšaitė-Rimkienė, R. Povilanskas, I. Šakurova and V. Kondrat, Measuring the impact of physical geographical factors on the use of coastal zones based on bayesian networks, *Sustainability* **13**(13) (2021) p. 7173.

[14] Y. Al Alawi and S. Dutta, Assessment of seabream fisheries stock of oman using the monte carlo catch maximum sustainable yield and the bayesian schaefer model methods, *Sustainability* **15**(22) (2023) p. 15692.

[15] G. Griggs, Rising seas in california—an update on sea-level rise science, in *World Scientific Encyclopedia of Climate Change: Case Studies of Climate Risk, Action, and Opportunity Volume 3*, (World Scientific, 2021) pp. 105–111.

[16] M. C. Clare, T. W. Leijnse, R. T. McCall, F. L. Diermanse, C. J. Cotter and M. D. Piggott, Multilevel multifidelity monte carlo methods for assessing uncertainty in coastal flooding, *Natural Hazards and Earth System Sciences* **22**(8) (2022) 2491–2515.

[17] Y. Han and P. Mozumder, Building-level adaptation analysis under uncertain sea-level rise, *Climate Risk Management* **32** (2021) p. 100305.

[18] S.-S. Lin, S.-L. Shen, A. Zhou and Y.-S. Xu, Approach based on topsis and monte carlo simulation methods to evaluate lake eutrophication levels, *Water Research* **187** (2020) p. 116437.

[19] F. P. Samaniego, D. G. Reina, S. L. T. Marín, M. Arzamendia and D. O. Gregor, A bayesian optimization approach for water resources monitoring through an autonomous surface vehicle: The ypacarai lake case study, *IEEE Access* **9** (2021) 9163–9179.

[20] G. Kopsiaftis, E. Protopapadakis, A. Voulodimos, N. Doulamis, A. Mantoglou *et al.*, Gaussian process regression tuned by bayesian optimization for seawater intrusion prediction, *Computational intelligence and neuroscience* **2019** (2019).

[21] P. C. Oddo, B. S. Lee, G. G. Garner, V. Srikrishnan, P. M. Reed, C. E. Forest and K. Keller, Deep uncertainties in sea-level rise and storm surge projections: Implications for coastal flood risk management, *Risk Analysis* **40**(1) (2020) 153–168.

[22] S. Jevrejeva, T. Frederikse, R. Kopp, G. Le Cozannet, L. Jackson and R. Van De Wal, Probabilistic sea level projections at the coast by 2100, *Surveys in geophysics* **40** (2019) 1673–1696.

[23] A. Abozeid, R. Alanazi, A. Elhadad, A. I. Taloba, A. El-Aziz, M. Rasha *et al.*, A large-scale dataset and deep learning model for detecting and counting olive trees in satellite imagery, *Computational Intelligence and Neuroscience* **2022** (2022).

[24] M. M. Abdelgwad, T. H. A. Soliman and A. I. Taloba, Arabic aspect sentiment polarity classification using bert, *Journal of Big Data* **9**(1) (2022) 1–15.

[25] M. Alruily, O. R. Shahin, H. Al-Mahdi and A. I. Taloba, Asymmetric dna encryption and decryption technique for arabic plaintext, *Journal of Ambient Intelligence and Humanized Computing* (2021) 1–17.