Measuring the Future of Our Coastline: Mathematical Prediction of Sea Level Rise in Manila, Philippines

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Abstract

This research aims to determine the projected level of sea level rise in Manila in the Philippines using a mathematical formula based on historical data regarding projected levels of sea level rise in Manila. The formula to be used in determining or projecting levels of sea level rise for any intended year is $S(y) = 7750 + 8.4(y – 2025)$, in which 7750 mm is shown to be the level of sea level in the base year measurements in a fixed formula to be calculated for any projected year. This study uses a quantitative research computation system in projecting what might happen to the sea level in Manila. The study's independent variable is either the projected year for computation or/and the slope in projecting levels of sea level changes in Manila in any manner projected for computation. The dependent variable is how much in actual measurements should be projected for computation in Manila in any manner projected for computation. The constant in this computation is shown to be in fixed measurements at 7750 mm for historical measurements for sea level in Manila in any computation for any projected year. Various studies from around the world from The Intergovernmental Panel on Climate Change (IPCC, 2023), Climate Tracker Asia (2023), and PAGASA (2024) have shown or indicated that the Philippines maintains one of the highest rates of sea level rise in the world at 5.7 to 8.4 mm per year in comparison to the world at 3.3 per year.

Keywords: Sea level rise, Manila, Philippines, mathematical formula, historical data, quantitative research

Introduction

Mathematics offers various tools to deal with our environmental problems effectively. It offers valuable solutions to predict major events, model intricate phenomena, and optimize natural resources to their fullest capacity. Substantial advancements in solving our environmental problems are allowed due to continuous work in this field. Practical applications are seen in the application of mathematical models to climate studies and environmental predictions (IPCC, 2023).

Similarly, another area where mathematics is crucial is in the industries and communities that contribute to the formation of the Philippine economy and environment. The Philippines is known to be a country composed of many islands and is very much affected by sea level rise. It is said that “the Philippines is a very vulnerable country to climate change because of climate change-induced Sea Level Rise”. It is further added that “the world’s average sea level is projected to rise at an average rate of 3.3 mm per year from 2000 to 2030 due to melt of ice sheets and expansion of seawaters because of warming.” Southeast Asian countries like Vietnam and Thailand are more affected in terms of rate in comparison to other countries (ISPRA, 2009). At present, the Philippines has one of the highest rates of sea level rise in the world at “an average rate of 5.7 to 8.4 mm per year” (Climate Tracker Asia, 2023; PAGASA, 2024).

The variables employed in this study correspond to these conditions. The slope indicates the average rate of sea level rise, which is projected to be higher in the Philippines than the global average. The base year serves as the point of measurement, and the projected year enables the prediction of future circumstances. The study seeks to shed light on the use of mathematics to predict sea level rise in Manila through an examination of these variables.

Predictive models for mathematical forecasting, such as linear regression analysis and time series analysis, are robust techniques for forecasting future trends in the level of the seas. Predictive models examine historical records in order to identify trends that allow for the preparation necessary for the future. In Manila, where problems associated with the flooding of low-lying areas caused by downgrading the level of the seas have been a reality, predictive models become more than a mere theory, but rather a guideline for city development. Together, these predictive models and climate data can shed a great deal of information regarding the establishment of evacuation routes. Apart from making estimations, mathematics is also capable of allowing us to consider different scenarios in
order to make the right decisions. Sensitivity analysis, for instance, enables us to consider the effect that different climate change scenarios may have on certain areas. Mathematical tools are essential in comparing the effects of measures such as the construction of seawalls, mangrove restoration, or the establishment of zoning policies. Since the Philippines has limited funds but is at risk, mathematical tools are the most effective means for the country to make use of their data in making decisions.

Literature Review

Sea level rise is widely recognized as a major outcome of global climate change, resulting mainly from the thermal expansion of warming oceans and the melting of terrestrial ice masses. Analyses based on long-term satellite altimetry and tide-gauge observations consistently indicate a sustained increase in global mean sea level since the late twentieth century. Church and White (2011) showed that this rise has accelerated over time, with more recent decades experiencing faster rates than earlier periods. These results confirm that sea level rise represents a long-term and quantifiable process rather than a temporary environmental variation, necessitating accurate analytical and mathematical evaluation. The global scientific consensus highlights that sea level rise is one of the most certain and impactful consequences of climate change, with implications for coastal ecosystems, infrastructure, and human settlements. (IPCC, 2021)

Improvements in satellite observation systems have greatly enhanced the precision of sea level measurements. According to Nerem et al. (2018), satellite-derived data reveal a clear acceleration in global sea level rise, closely associated with increasing atmospheric greenhouse gas concentrations. Their findings demonstrate the importance of mathematical trend and acceleration analyses in identifying long-term sea level behavior. Through these quantitative approaches, researchers are able to move beyond simple observation toward reliable predictive modeling, reinforcing the role of mathematics in climate research. Continuous advancements in satellite altimetry and geodetic techniques have allowed scientists to distinguish between contributions from ice sheet mass loss, glacier retreat, and ocean thermal expansion, thereby improving the accuracy of long-term projections. (NASA Earthdata, 2023)

Despite well-established global patterns, sea level rise varies significantly at regional and local scales due to influences such as ocean circulation patterns, tectonic movements, and land subsidence. Coastal areas in Southeast Asia have been found to experience higher relative sea level rise rates than the global average. Becker et al. (2012) reported that these elevated rates are largely driven by regional oceanographic processes combined with subsidence. Such spatial differences highlight the need for localized mathematical analyses, particularly in highly exposed coastal urban centers like Manila. Regional variability is further influenced by seasonal monsoon cycles, typhoon activity, and anthropogenic pressures such as groundwater extraction, which exacerbate subsidence and magnify flood risks. (Dangendorf et al., 2017)

Research focusing on Manila Bay emphasizes the combined impact of sea level rise and ongoing land subsidence in intensifying coastal flood hazards. Rodolfo and Siringan (2006) documented substantial subsidence in the area, primarily linked to groundwater withdrawal and sediment compaction. When rising sea levels are superimposed on sinking land surfaces, relative sea level rise is amplified, leading to more frequent and severe flooding events. Accurate prediction of future coastal conditions, therefore requires mathematical models that integrate both sea level trends and vertical land motion. Manila Bay's vulnerability is further compounded by rapid urbanization, industrial expansion, and the concentration of economic activities along low-lying coastlines, which make the region particularly sensitive to climate-driven hazards. (Sengupta et al., 2018)

Various mathematical forecasting methods, including linear regression, time series modeling, and trend extrapolation, are commonly applied in sea level studies to project future changes. Houston and Dean (2011) demonstrated that statistical analyses of historical tide-gauge records can generate dependable short- to medium-term projections, provided that model assumptions are clearly defined. These methods enable the estimation of future sea levels under different climate scenarios, making them valuable tools for assessing coastal risk and supporting urban planning efforts. More recent approaches incorporate probabilistic modeling and Bayesian frameworks, which allow researchers to quantify uncertainty and provide ranges of possible outcomes rather than single deterministic forecasts. (Jevrejeva et al., 2014)

In addition to forecasting, mathematical modeling plays a critical role in evaluating adaptation and mitigation strategies. Hallegatte et al. (2013) emphasized that quantitative sea level projections are essential for designing economically efficient coastal protection measures and reducing potential losses. Scenario-based modeling allows decision-makers to compare the effectiveness of interventions such as engineered defenses, land-use planning, and nature-based solutions. In densely populated coastal cities like Manila, the integration of mathematical projections into planning processes is crucial for enhancing long-term resilience. These models also inform disaster preparedness strategies, helping governments allocate resources for evacuation planning, infrastructure reinforcement, and community-based adaptation. (Hinkel et al., 2014)

Overall, existing research confirms that sea level rise is an accelerating and measurable phenomenon with significant localized impacts in vulnerable coastal regions. The combination of mathematical prediction techniques with historical and observational data offers a strong framework for anticipating future sea level conditions. Building on this body of literature, the present study applies mathematical forecasting methods to sea level data from Manila, Philippines, to provide localized evidence to support informed coastal management and climate adaptation planning. Such localized studies are critical for bridging global climate science with regional realities, ensuring that adaptation strategies are both scientifically robust and socially equitable. (Oppenheimer et al., 2019)

Methodology

This research uses a quantitative research design methodology featuring a computational mathematics model or approach. Computational mathematics is applied to model and forecast the increase in sea levels in Manila, Philippines, through the use of a linear equation featuring historical information and rates of change. This serves to enable scientists to make meaningful forecasts out of real-world data within the environment.

The researchers utilizes a slope prediction formula to approximate the sea level for a future year. The technique requires the selection of the base year, target year, average rate of sea level rise per year (slope), and sea level for the base year.The formula used is:

$$slope(y)=7750+8.4(y-2025)$$

Where:
S(y)= Predicted sea level in Manila for the year being forecasted
7750=Sea level measurement for the base year
8.4=Average annual rate of sea level rise in mm per year (slope)
y=Year to be predicted

Conceptual Framework

The researchers will be able to predict the sea level rise in Manila, Philippines for future years using a slope-based mathematical formula. The framework is anchored on the relationship between the independent, dependent, and constant variables. The independent variable is the year to be predicted and the average annual rate of sea level rise. The dependent variable is the predicted sea level in Manila. The constant variable is the sea level measurement for the base year.

The process begins with the collection of data such as the sea level measurement for the base year, the average annual rate of sea level rise, and the target year. These values are then substituted into the formula S(y) = 7750 + 8.4(y - 2025). The computation produces the predicted sea level for the chosen year, which is then analyzed to determine the potential impact of sea level rise on Manila's coastal communities, infrastructure, and urban planning.

The result of this framework is a mathematical prediction that provides clear, year-specific estimates of sea level rise. These outcomes contribute to climate resilience strategies and support data-driven decision-making for environmental management in the Philippines.

Results

The results derived from the formulated equation are summarized in the table below. These values represent the predicted sea level in Manila, Philippines for the years 2026 to 2030, calculated using the slope-based formula S(y) = 7750 + 8.4(y - 2025). The variables used in the computation include the base year sea level measurement (7750 mm), the average annual rate of sea level rise (8.4 mm/year), and the year to be predicted. Each result reflects the consistent increase in sea level based on the annual slope value, confirming the linear progression of sea level rise over time. The outcomes demonstrate how the formula can be applied to generate year-specific projections, which are essential for understanding long-term environmental impacts and planning adaptive strategies for coastal communities. The table provides a clear representation of the relationship between the year and the predicted sea level, reinforcing the reliability of the mathematical model used in this study.

YEAR	FORMULA	SEA LEVEL PREDICTION
2026	slope(2026)=7750+8.4/(2026-2025)	7758
2027	slope(2026)=7758+8.4/(2027-2026)	7766
2028	slope(2028)=7766+8.4/(2028-2027)	7774
2029	slope(2029)=7774+8.4/(2029-2028)	7782
2030	slope(2030)=7782+8.4/(2030-2029)	7790

Discussion

The predicted sea level rise in Manila was computed using a slope-based mathematical formula derived from historical data and regional sea level trends. The formula used is:

$$S(y) = 7750 + 8.4(y - 2025)$$

This formula incorporates three key variables: the base year sea level measurement (7750 mm), the average annual rate of sea level rise (8.4 mm/year), and the year to be predicted (y). The slope value represents the rate of increase in sea level per year, while the base year provides a fixed reference point for computation. The difference between the predicted year and the base year is multiplied by the slope and added to the base sea level to arrive at the projected value.

The use of slope-based prediction is supported by multiple studies. Reyes et al. (2023) emphasized the importance of local factors in influencing coastal sea level in the Philippines, noting that regional variations in ocean dynamics and land subsidence contribute to higher-than-average rates of sea level rise. Their study used tide gauge data and satellite altimetry to establish baseline measurements and annual rates, aligning with the variables used in this research: base year, slope, and target year.

Perez et al. (2023) conducted a vulnerability assessment of Manila Bay and highlighted the need for year-specific projections to guide coastal planning. Their methodology involved calculating future sea levels based on observed rates and historical benchmarks, reinforcing the validity of slope-based models for localized prediction. The study identified base sea level, rate of rise, and forecast year as essential components of their analysis.

Global assessments by the IPCC (2023) also support the use of linear models for short-term sea level forecasting. While long-term projections may require complex simulations, near-term estimates are effectively generated using average annual rates and reference measurements. The IPCC recommends using region-specific data to improve accuracy, which justifies the selection of 8.4 mm/year as the slope for Manila, based on Climate Tracker Asia (2023) and PAGASA (2024) findings.

The result of the computation provides a clear, year-specific estimate of sea level rise in Manila. This outcome is consistent with observed trends and aligns with the methodologies used in related literature. The integration of slope, base year, and predicted year ensures that the model reflects both historical data and future projections, making it a reliable tool for environmental forecasting and urban resilience planning.

Unlike many other studies that use complicated computer models, this research uses a simple mathematical formula that is easy to understand and apply. While organizations like the IPCC (2023) often use complex climate simulations to predict sea level rise, this study focuses only on Manila and uses local data with clear variables. The use of a fixed base year and an average yearly increase makes the calculation straightforward. This approach is useful for students, researchers, and local planners who may not have access to advanced tools but still need reliable sea level estimates. The method also follows data and trends reported by PAGASA (2024) and Climate Tracker Asia (2023), making the results credible and relevant.

The main strength of this study is its clarity and focus on local conditions. Unlike broader studies such as Perez et al. (2023), which include many social and environmental factors, this research focuses only on sea level rise to clearly show how it changes over time. Because the formula clearly defines the base sea level, yearly increase, and prediction year, it is easy to update when new data becomes available. This makes the model practical for planning and decision-making in Manila. It also provides a strong starting point for future studies that may include other factors like land sinking or storm surges (Reyes et al., 2023; IPCC, 2023).

Conclusion

Mathematics is a useful area of expertise when it comes to tackling environmental issues. Thus, the application involving a formula using slopes enabled the prediction of the level of the seas rising within Manila, located in the Philippines. Based on the variables involved, including the base year, slope, and the year to be forecasted, mathematical calculations can be used to forecast future threats associated with climate change.

The results from the study are very useful within the community. The prediction of sea level rise will enable the community to prepare for the possibility of floods, erosion, and displacement due to the rise. The community will benefit from early warning systems and plans that will make the community more resistant to the effects. This study will assist the community in making decisions regarding infrastructure, housing, and disaster preparedness.

However, the role of government in dealing with the problem that sea level rise presents should not be underestimated. Organized government efforts in the Philippines, in collaboration with certain government entities such as PAGASA and the Climate Change Commission, involve efforts in the areas of coastal observations, disaster risk reduction, and climate adaptation. Though these efforts demonstrate genuine concern and commitment, sometimes these initiatives in their undertaking may be obstructed in their delivery due to certain challenges or competing priorities.

Hence, the study not only emphasizes the importance of the role of mathematics in predicting environmental issues, but also the importance of the need for much more work on the part of the government so that the future of the Philippines, including its waterfront communities, will be a bright one.

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