Declining Sea Surface Height in the Caspian Sea Based on Sentinel-3A Data

Nilufar Makky[1,], Khalil Valizadeh Kamran[1]*

[1] RSGIS Department, University of Tabriz, Tabriz, Iran, rsgis.nilufarmakki73@gmail.com, valizadeh@tabrizu.ac.ir
* corresponding author
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Abstract: Our planet faces climate-related challenges, one significant concern revolves around the impact of global warming on oceans and lakes, especially the necessity of closely tracking changes in Sea Surface Height. In this study, we acquired data from the SRAL LEVEL2 sensor on Sentinel-3A to monitor the Caspian Sea throughout the year. With 276 passes overall and 23 observations per month, we monitored Sea Surface Height alongside meteorological data, including Precipitation, Sea Surface Temperature, and Water Vapor, obtained from the Google Earth Engine platform. We used the LSTM model and monitored the Sea Surface Height using Precipitation, Sea Surface Temperature, and Water Vapor as input variables. The model gave notable performance metrics with an R^2 value of 0.9765. Also, the trend of Sea Surface Height showed a significant reduction. This information is valuable for policymakers to management of the region's resources.

Keywords: Caspian Sea; passes; Sea Surface Height; Sentinel-3A; decreasing; climate change.

1 Introduction

Lakes and reservoirs, covering only about 2% of the Earth's land surface, are crucial for the national economy by regulating river runoff, supporting irrigation, providing industrial and drinking water, maintaining aquatic habitats, contributing to ecological balance, and facilitating transportation (Zhang 2023). However, these water bodies are highly vulnerable to human activities such as industrial operations, agriculture, aquaculture, and climate change, which can significantly alter their characteristics. Monitoring water levels in these bodies offers valuable insights into trends influenced by these factors, with accurate data collection and comprehensive spatiotemporal analyses essential for their conservation (Verpoorter et al. 2014). Wetlands, vital for biodiversity, face threats from reduced rainfall, higher temperatures, increased evaporation, and prolonged droughts. Climate change challenges highlight the importance of predicting sea surface height (SSH) changes for mitigation (Kamran et al. 2023, Makky et al. 2023). Satellite altimetry has revolutionized oceanography, improving SSH measurement precision and the study of coastal circulation (Fu et al. 2010, Raney 2011). SAR Delay-Doppler altimetry, particularly from the Sentinel-3A satellite, provides enhanced resolution and innovative coastal data processing (Feng et al. 2023). The SWOT mission further exemplifies advancements in capturing wide swath data (Srinivasan and Tsontos 2023). Sentinel-3, with SAR mode and 300-meter resolution, faces challenges in coastal areas, addressed by products like the Adaptive Leading Edge Sub waveform (ALES) tracker for precise sea level observations (Tomić et al. 2024). Previous studies by Makky et al. (2023) demonstrated that Jason2 radar altimetry data reliably monitors sea surface height based on precipitation and sea surface temperature. Furthermore, incorporating the effect of additional climatic features into predictions can enhance this type of research.

2 Materials and methods

As the world's largest isolated water reservoir, the Caspian Sea (Figure 1) with an area spanning 392,600 km² and mean and maximum depths of 208 m and 1025 meters (Mograne et al. 2019). Regarding the significant fluctuation in the level of the Caspian Sea in recent years, it is crucial to monitor it to protect it from potential destructive events in the future (Ardalan and Hashemifaraz 2024).

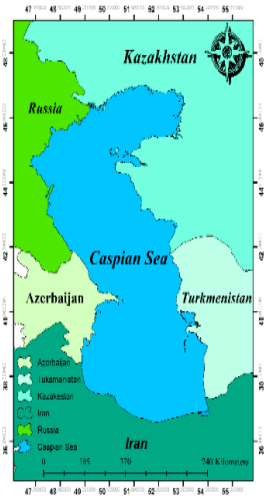

Figure 1. The geographical location of the Caspian Sea.

This study assesses Sea Surface Height (SSH) over the Caspian Sea using Sentinel-3A SAR mode datasets. A Long Short-Term Memory (LSTM) model predicts SSH based on meteorological features, including Water Vapor (WV), Precipitation, Sea Surface Temperature (SST), and SSH observations. The LSTM model is used to handle time series oceanic data by predicting oceanic data for the upcoming days (Braakmann-Folgmann et al. 2017), also LSTM model is trained on the training data, capturing temporal dependencies, and iterative optimization refines model parameters to enhance predictive performance.

Sentinel-3A and Sentinel-3B provide essential oceanic and atmospheric measurements for ocean forecasting, environmental monitoring, and climate studies. They operate in a high-inclination orbit (98.65°) to optimize coverage of high-latitude regions (EUMETSAT 2021).

This study uses Sentinel-3A satellite data from March 2023 to March 2024, focusing on Ku-band 20 Hz SSH data.

Processing involves extracting and organizing SSH measurements from NetCDF files and applying corrections to calculate SSH. These measurements are obtained from the SRAL (SAR Radar Altimeter) instrument and are provided with units and scaling factors for interpretation.

A comprehensive LSTM model predicts SSH using features like SST (Ren et al. 2024), precipitation (Wang et al. 2001), and surface water vapor (Gbetkom et al. 2023) from various datasets provided by Google Earth Engine.

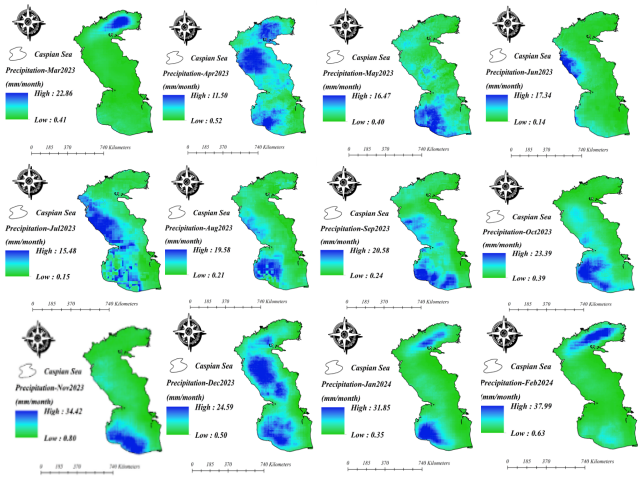

Figure 2. The precipitation data (mm/pentad) covering the period from March 2023 to March 2024 was acquired from the UCSB-CHG/CHIRPS/PENTAD mission.

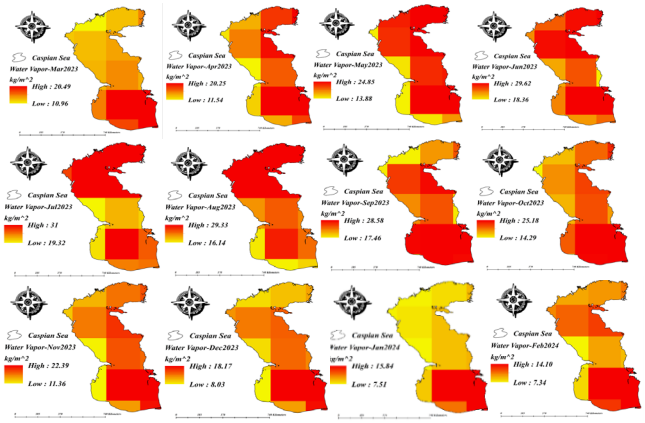

Figure 3. The WV data (kg/m²) covering the period from March 2023 to March 2024 was acquired from the surface water vapor data from the NCEP_RE/surface_wv mission.

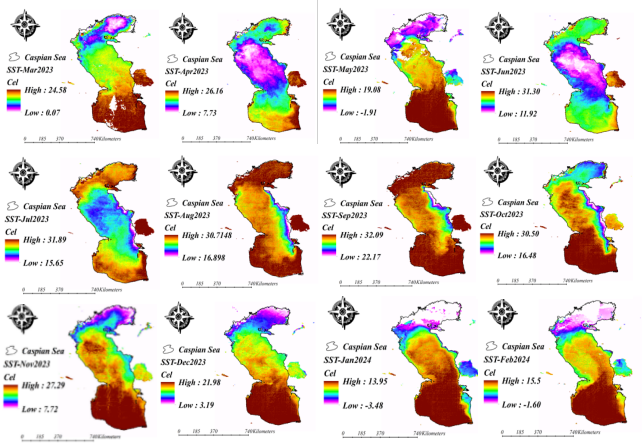

Figure 4. SST data (°C) covering the period from March 2023 to March 2024 was acquired from the JAXA/GCOM-C/L3/OCEAN/SST/V3 mission.

3 Results

The monthly meteorological data, including precipitation (Figure 2), water vapor (Figure 3), and sea surface temperature (Figure 4) from March 2023 to March 2024. Additionally, the compatibility between test and train data, and the trend of sea surface height (SSH) were shown in Figure 5 and Figure 6. The polar chart illustrating the correlation coefficient is presented in Figure 7 for additional detail.

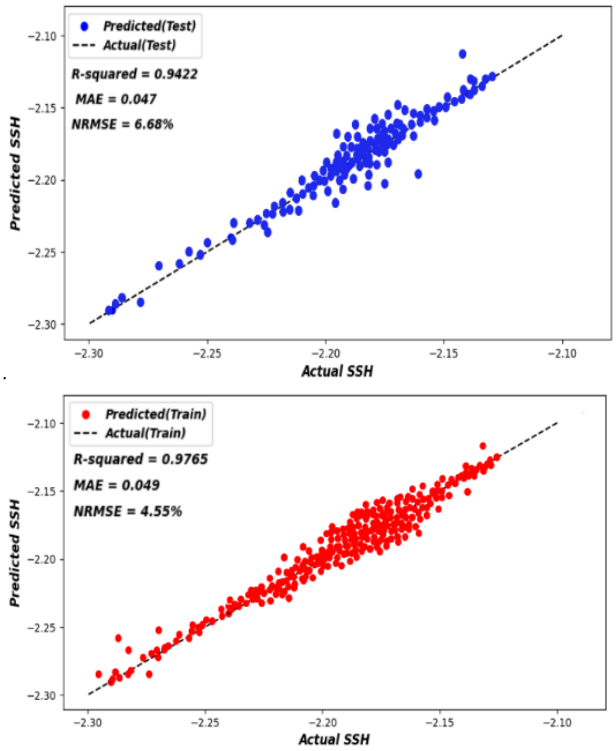

Figure 5. The compatibility between the actual data (top) and the predicted data (bottom) for both the training and testing sets of the LSTM model.

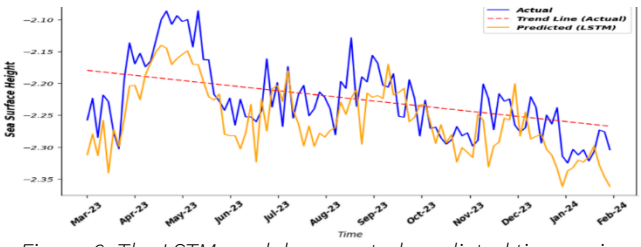

Figure 6. The LSTM model generated predicted time series data for Sea Surface Height for both the training and testing datasets.

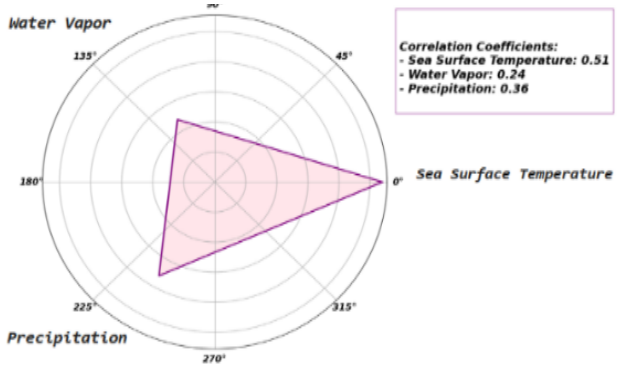

Figure 7. The polar chart depicts the correlation coefficients between meteorological factors.

4 Discussion

Examining precipitation patterns can provide valuable insights into how SSH dynamics in the Caspian Sea may evolve (Islam and Sato 2021). The correlation coefficient, as presented in the polar chart, indicates SST's dominant impact on SSH in the Caspian region. The predicted trend illustrates a decreasing SSH trend in the Caspian Sea, which could have adverse effects on the region. The objective is to develop a predictive model and identify which variable most significantly affects the SSH, with SST found to have the most substantial impact.

5 Conclusions

The data collected by the SRAL LEVEL2 sensor on Sentinel-3A indicated a decrease in the water height of the Caspian Sea. This study highlights the significant impact of key meteorological variables on the variability of Sea Surface Height. The model gave notable performance metrics with an R^2 value of 0.9765, NRMSE (Normalized Root Mean Squared Error) of 4.55%, and MAE (Mean Absolute Error) of 0.049 during training. Testing the model produced encouraging results, with an R^2 value of 0.9422, NRMSE of 6.68%, and MAE of 0.047. Additionally, correlation coefficients indicated significant associations, with SST exhibiting a correlation coefficient of approximately 0.51, precipitation at 0.36, and WV at 0.24 with sea surface height. The observed correlations between these variables and sea surface height provide valuable insights into the changes in the Caspian Sea. Temperature was found to have the most significant impact on decreasing SSH.

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