REAL-TIME & PREDICTIVE ANALYSIS OF SEA SURFACE TEMPERATURE VARIABILITY IN EL NINO AND LA NINA WEATHER CYCLE ALONG PAKISTAN COAST

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By

Rizwan Akhtar[1], Tahreem Zafar[1], Bassam Nasir[1], Ibrahim Zia[1]

Abstract

This study observes sea surface temperature (SST) trends in the Arabian Sea near the Pakistan Coastline. It explores how SST anomalies may arise from global warming, climate change, and impacts on coastal ecosystems. Identifying these trends is important for climate science for ocean and marine ecosystems. SST may significantly impact coastal erosion by increasing storms, raising sea levels, and changing wave patterns. To analyze SST, this research uses Google Earth Engine (GEE) and machine learning techniques. GEE is a cloud-based platform for processing remote sensing data. It provides advanced capabilities for analyzing satellite imagery. The in-situ Data provided by National institute Of Oceanography Pakistan. Particularly, this study uses Ocean Color SMI: Standard Mapped Image MODIS Aqua Data Level 3.the Comparative analysis of the Hybrid Coordinate Ocean Model (HYCOM) provides global ocean data with a spatial resolution of 0.08 degrees (approximately 9 km) from 2003 to the present. The HYCOM data subset available in GEE includes variables such as salinity, temperature, velocity, and elevation. This data durations over 18 years (2003-2022) and focuses on regions like the Arabian Sea. GEE data showed two distinct periods of increasing sea surface temperature (SST) from 2003 to 2022. The first period was from 2003 to 2010, and the second was from 2011 to 2022. Both periods had positive SST anomalies. In June 2007 and 2010, significant changes in sea surface temperature observed near Pakistan Coastline. These changes happened during the Guno and Phet cyclones. The temperatures ranged observed from 31.72°C to 33.9°C and in The Phet cyclone period the temperatures ranged from 30.8°C to 30.9°C. respectively. The increasing SST trend may continue if no intensive measures are taken to address this issue. The analysis aims to improve our understanding of SST dynamics and their effects on climate and marine environments.

Keywords: Sea Surface Temperature anomalies, MODIS, HYCOM, Google Earth Engine, Cloud base processing, Coastal Ecosystem, Global Warming, Climate Science, Coastal Erosion.

Introduction

Increasing the sea surface temperatures (SST) and the absorption of carbon dioxide in the Ocean, along with alternative greenhouse gas emissions might change the sea surface temperature in the Arabian Sea causing the impact of global warming.SST directly impacts the melting of ice glaciers. As a result of this phenomenon, higher sea level rise can affect the coastal zone. The effect of sea surface temperature is not only the Sea level rise but other climate changes such as long-term drought, cyclone or storm surges, heat waves and flash floods in low-lying coastal areas that may cause Sea water intrusion.[1][2]. Sea water intrusion is due to natural and anthropogenic processes. Sea level rise associated with climate change by way of changes to atmospheric pressure, expansion of oceans/seas as the warm, melting of ice sheets

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and glaciers is one significant process that plays a role in sea water intrusion. The SST had risen from 0.1 to 0.6 ^{o}C at the coastal area of Pakistan, in the early of 90's. The number of research shows that an increasing trend of 0.2 ^{o}C per decade on the Coastal region of Pakistan. However, the rate observed a higher SST rate near the Karachi coast due to the instant industrial development and higher air temperature[3]. SST trend analysis could use historical data, representing an annual increase of 0.0138 °C. It anticipates the SST for the next 25 years based on these historical figures. Up to 2045, the predicted SST indicates a higher value of 0.35 °C.[1].

According to The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), The mean ocean surface temperature increased by 0.88°C [0.68–1.01°C] from 1850–1900 to 2011–2020 and with 0.60°C [0.44–0.74°C] of this increase appearing since 1980. Under the Shared Socioeconomic Pathways (SSP1-2.6) scenario, the estimates suggested that the sea surface temperature will rise by an average of 0.86°C [0.43–1.47°C, range] from 1995–2014 to 2081–2100. In the SSP5-8.5 scenario, the temperature is expected to increase by 2.89°C [2.01–4.07°C, range]. The Indian Ocean, as well as Western Boundary Currents, have shown the greatest rapid anomaly of surface warming since the 1950s, while ocean circulation in the Southern Ocean, equatorial Pacific, North Atlantic, and coastal upwelling systems has resulted in slower warming or cooling of the surface (extremely high confidence). At least 83% of the ocean surface is expected to increase warm very much over the 21st century in all SSP scenarios.[4]. The biodiversity of marine environments is impacted by variations in sea surface temperature (SST). SST variations may boost biodiversity in some areas such as the Gaeta Gulf, but they can also be detrimental to marine life. According to research, temperature affects ecosystem diversity, and colder SSTs can increase the number of some species such siphonophores. SST variations can also boost marine productivity and phytoplankton abundance, as well as increase the number of species like Ommastrephes bartramii in the northwest Pacific [5]. the relationship between mean annual sea surface temperatures (SST) along Pakistan's coast and the Multivariate EL Nino Southern Oscillation (ENSO) Index (MEI). It finds significant variability in SST affected by Southern Oscillations. Noticeable samples are observed during El Niño and La Niña spells. SSTs normally start lower at the beginning of El Niño occurrences. They rise during the event and peak at the start of La Niña events. Past data from El Niño episodes (1986-1987, 1991-1992, 1997-1998) and La Niña events (1988-1989, 1998-1999, 2000-2001) show that SST peaks relate with ENSO phases. However, exact one-to-one connection is less clear after 1999[6].

Multitemporal SST analysis is now easy for Google Earth Engine (GEE) Cloud platfrom.it is a recent technology for the processing the remote sensing data. GEE is more efficient at processing the big data of remote sensing and stores it more efficiently at Cloud storage.[7].In modern era machine learning algorithms is powerful tools for analysis the real time data and projected data with outperformance accuracy.[8] [9].The numerical model with data driven approach, that is Gray model is also accord great future projections based on the historical long term data of SST [10].

Literature Review

The variability of sea temperature in the Arabian Sea Warm Pool (ASWP), with an emphasis on the seasonal development and degradation of the ASWP before the Indian Ocean summer monsoon, as well as its wider climatic impacts, was examined in a study. The effects of vertical entrainment, advection, and sea surface heat flux on ASWP temperature variations using recent SODA reanalysis data was investigated.

The results demonstrated that ASWP forms in April and decays by June, with the decay occurring more quickly than the development. While vertical entrainment predominated during decay, sea surface heat flux had the biggest effect on mixed-layer temperature during development. Additionally, the study discovered that ASWP fluctuation is significantly linked to the Indian Ocean Dipole and ENSO. The ASWP is more apparent in the year following an El Niño event and weaker following a La Niña. These findings highlight the ASWP's critical role in regional and global climate dynamics [11].

In another study, it was discussed how the cold sea surface temperature (SST) bias in climate models for the Arabian Sea impacts the Indian monsoon, which is a major source of water vapor. The researchers (unspecified) conducted the investigation to better understand how mesoscale oceanic variability effects SST and monsoon precipitation. By comparing climate model experiments with non-eddying and eddy-permitting ocean components, researchers discovered that mesoscale variability, such as warm water advection around the Gulf of Aden and Oman, elevates SST in the western Arabian Sea. This action also lessens the cooling caused by coastal upwelling during the monsoon season. Sensitivity experiments revealed that accurate SST modeling relies mostly on resolving mesoscale eddies, with the Persian Gulf and Red Sea playing a secondary role. The findings showed that, in relation to SST variations in the western Arabian Sea, the eddy-permitting model enhanced precipitation over western and northern India while decreasing it over the southeastern Arabian Sea. The results highlight how crucial ocean resolution is to accurately representing the Indian monsoon system in climate model [12].

With an emphasis on cyclone activity variations during the pre-monsoon (April–June) and post-monsoon (October–December) seasons, the study investigated the historical evolution of tropical cyclones (TCs) in the Arabian Sea. The study, which was carried out by unidentified academics, sought to evaluate patterns in the distribution and intensity of TC. Stronger TCs (>34 knots, including severe cyclonic storm categories) have significantly increased, according to the results, whereas weaker TCs (<34 knots), including depressions, have only slightly increased. TC activity spread throughout time, especially during the post-monsoon season, from the eastern Arabian Sea (1982–2001) to the southwest (2002–2021). According to environmental studies, past decades (1982–2001) supported enhanced TC activity by exhibiting concentrated positive relative humidity anomalies at 500 hPa (RH–500 hPa) and negative outgoing longwave radiation (OLR) on the eastern side. Weak vertical wind shear and improved convection developed throughout the basin in the subsequent decades (2002–2021), facilitating more frequent and stronger TCs, particularly post-monsoon. In both seasons, storm activity was continuously sustained by a sea surface temperature of at least 26.5°C. The results highlight how changing atmospheric conditions are affecting the Arabian Sea's cyclone patterns and severity[13].

Approach/Methodology

Step #	**Detail**
Define Region of Interest (ROI)	a) Define window size the geographic area or area of interest. b) Set the area want to analyze in earthengine
Load SST Dataset	a) Dataset is filtered to include only the relevant data by applying ROI

Step #	Detail
	b) Filterd the calendar date range (2003-2023)
Select SST Band	From the filtered dataset, the Sea Surface Temperature (SST) band is selected for analysis
Setting Visualization parameters and variables	a) Visualization settings are established b) Taking the mean SST c) Clipping it to the ROI d) Applying a color palette for the SST range.
Display Data on Map	SST data layer is displayed with the defined visualization.
Create and Apply Time Series Chart for data visulization.	a) A time series chart is generated to display how the SST changes over time within the ROI b) Chart settings like labels, title, and plot points are applied
Result /Output	The final output consists of the displayed map and time series chart, providing visual insights into the SST trends for the specified period

Table-1 : Algorithm to analysis of Sea Surface Temperature.

Experiments & Results

The geospatial and time series analysis of SST the region of Arabian sea by using GEE technology can better big SST data analysis. In this research, GEE was capable of comparative trend analyze 20 years daily SST data. field surveying, which needs to measure SST directly in the sea, was challenging. It would necessitate significantly more expenses, resources, and working hours. The JavaScript programming language can used by GEE to execute and produce custom scripts, enabling efficient data processing and analysis for large-scale environmental monitoring tasks.

There were two Satellite imagery dataset compare HYCOM and MODIS, the comparison of variation of SST in the region of Arabian sea near Pakistan coastline. The daily SST from 2003 to 2023 was generated by the GEE scripts and displayed as a graphical representation and break down into five years graphs chunks.

Comparative trend analysis HYCOM and MODIS and variation of SST From 2003 to 2007

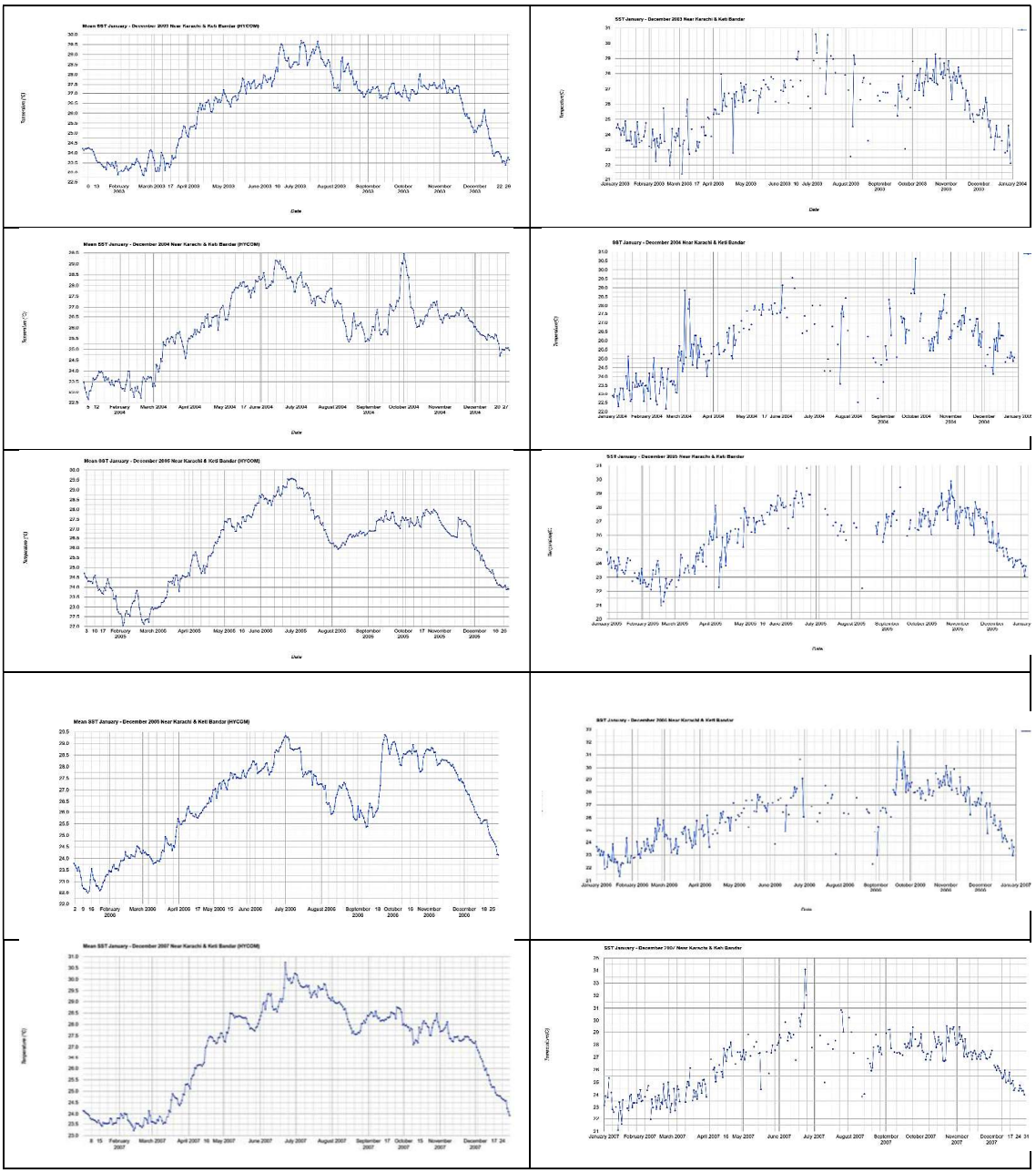


Figure-1: Comparative trend analysis HYCOM and MODIS and variation of SST From 2003 to 2007

Comparative trend analysis HYCOM and MODIS and variation of SST From 2008 to 2012

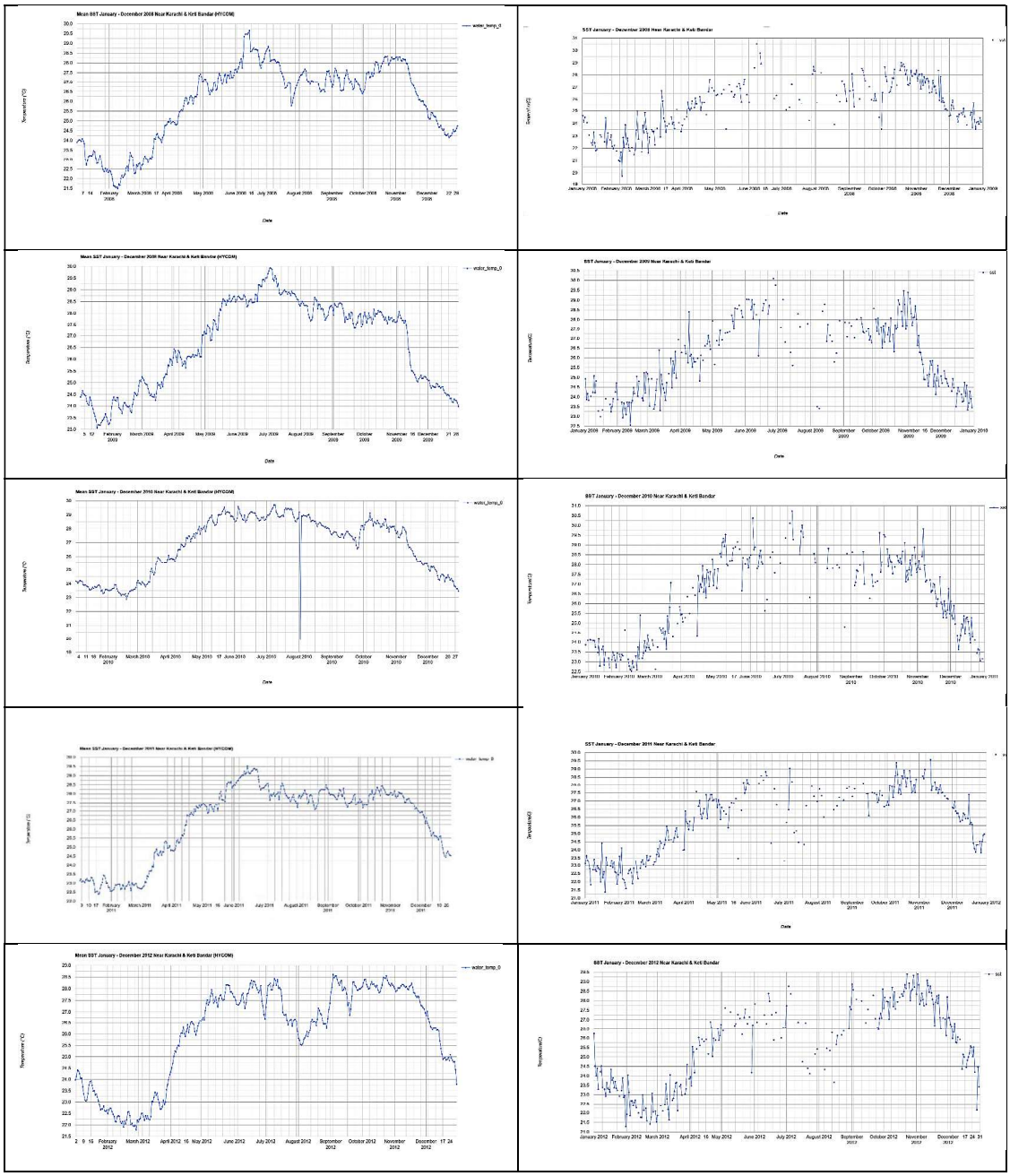


Figure-2: Comparative trend analysis HYCOM and MODIS and variation of SST From 2008 to 2012

Comparative trend analysis HYCOM and MODIS and variation of SST From 2013 to 2017

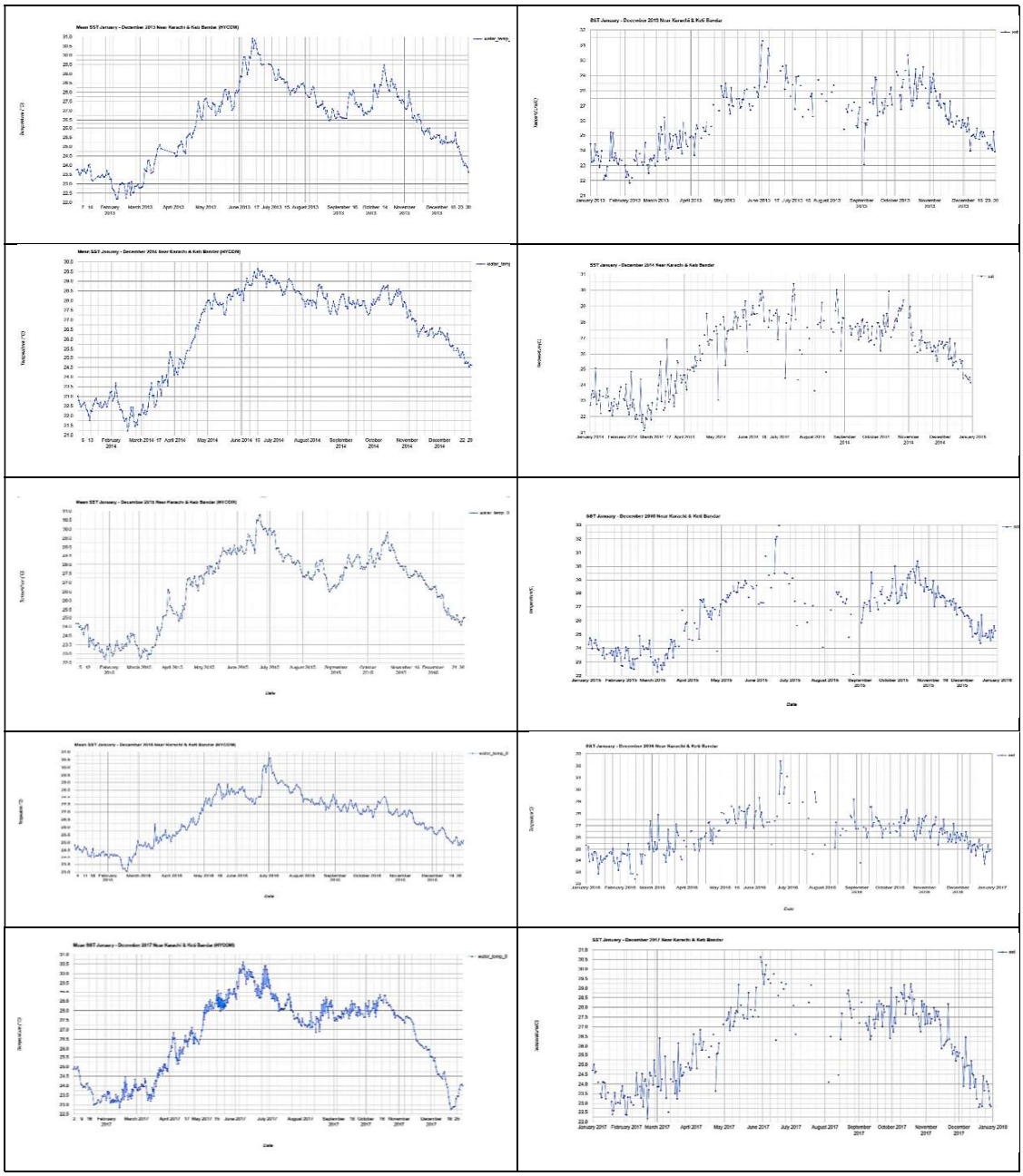


Figure-3: Comparative trend analysis HYCOM and MODIS and variation of SST From 2013 to 2017

Comparative trend analysis HYCOM and MODIS and variation of SST From 2018 to 2023

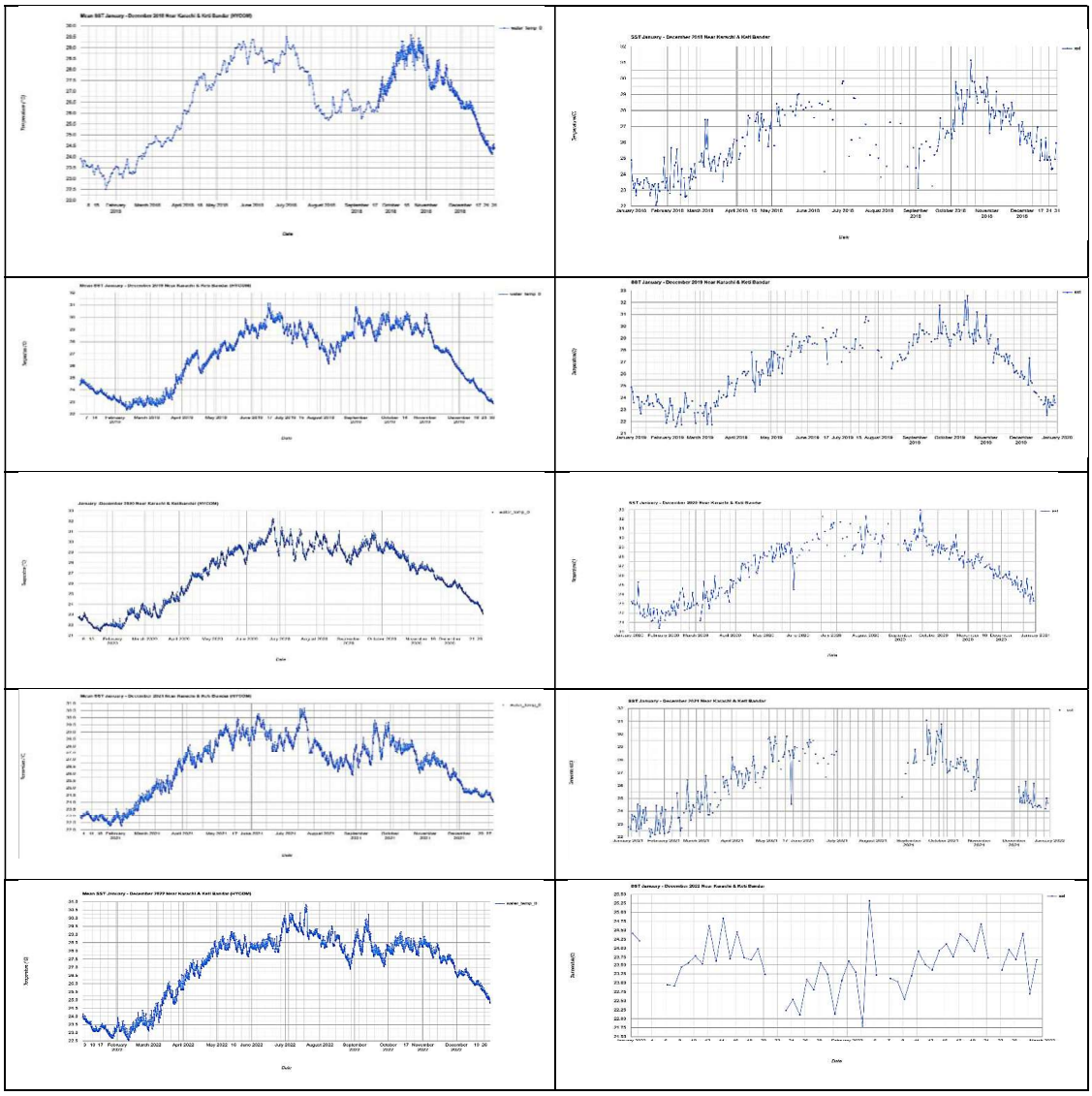


Figure-4: Comparative trend analysis HYCOM and MODIS and variation of SST From 2018 to 2023

The 20 years graph showed daily SST variability during the years period of 2003-2023.The observation of Arabian sea near Pakistan coastline experiences distinct seasonal temperature patterns. During the summer monsoon (May to August) The SST became warmer since monsoon wind patterns over south Asia influenced it. Those season, higher sun radiation intensity caused higher evaporation intensity followed by higher water vapor concentration during condensation process. It contributes to higher rainfall intensity and also increased SST contributes to the intensity and frequency of tropical cyclones in the Arabian Sea. The SST was about 28^{o}C to 30^{o}C.in south Asia of Arabian sea.

In 2009 to 2010 moderate El Nino event and 2015 to 2016 major El Nino event was observed the SST Reaches to 33 to 34 ^{o}C and weak monsoon pattern in south Asian side of Arabian sea.

In September, October, November and December, SST tended to be intermittent because of season changes from rainy season to dry season that is transition season. The comparative warmer SST was about 26 ^{o}C to 30 ^{o}C.

The temperature changes were starting to be identified in the graph clearly in mid of December, during the winter season along the coastline of Pakistan in Arabian sea. The general wind direction is forming from the northeast to southwest. since there was influences of northeast monsoon.

During the winter months (Mid December, January, February and mid of March), the northeast monsoon brings cool, dry winds from the land to the sea, mostly originating from the Himalayas and Central Asia. These winds blow across Pakistan’s coastline, affecting areas like Karachi and the surrounding regions along the Arabian Sea.

In January to mid of march air pressure had been changed in south Asia. High and low air pressure occurred in Asia. It started northeast wind from to originate from the Himalayas and central Asia. It contained lower rainfall. SST tended to be cooler since of low sun radiation intensity and low ambient air temperature followed by low evaporation. It caused low rainfall intensity. The SST was about 22°C to 26°C in those months.

Mean Sea Surface Temperature 2003 to 2022

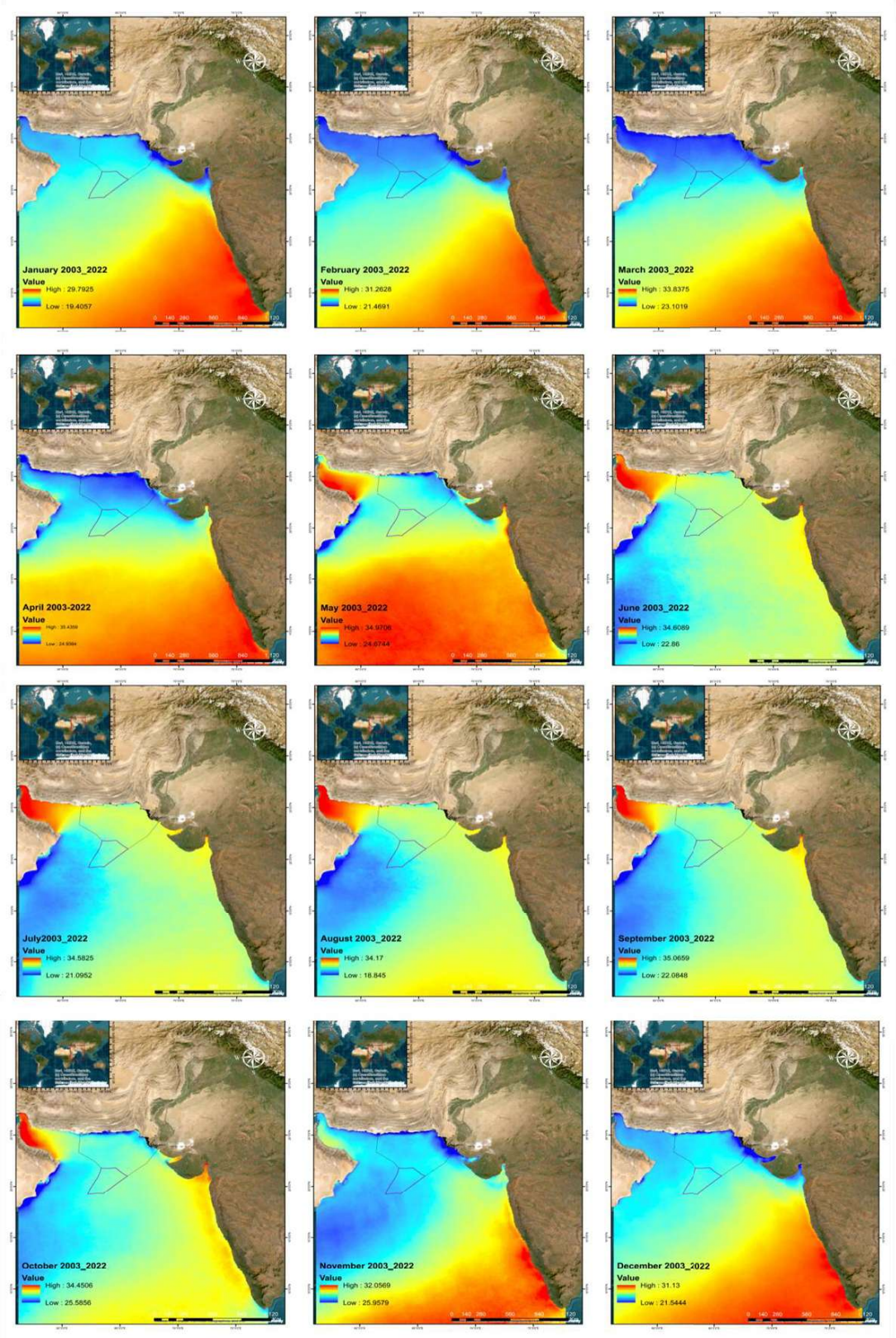


Figure-5: Mean Sea Surface Temperature 2003 to 2022

Table-2: Max and Min Mean Sea Surface Temperature from 2003 to 2022 in Arabian Sea

S.NO	Month	Maximum Temperature (C)	Minimum temperature (C)
1	Mean SST of January	29.7	19.4
2	Mean SST of February	31.2	21.4
3	Mean SST of March	33.8	23.1
4	Mean SST of April	35.4	24.9
5	Mean SST of May	34.9	24.6
6	Mean SST of June	34.6	22.8
7	Mean SST of July	34.5	21.0
8	Mean SST of August	34.1	18.8
9	Mean SST of September	35.0	22.0
10	Mean SST of October	34.4	25.5
11	Mean SST of November	32.0	25.9
12	Mean SST of December	31.1	21.5

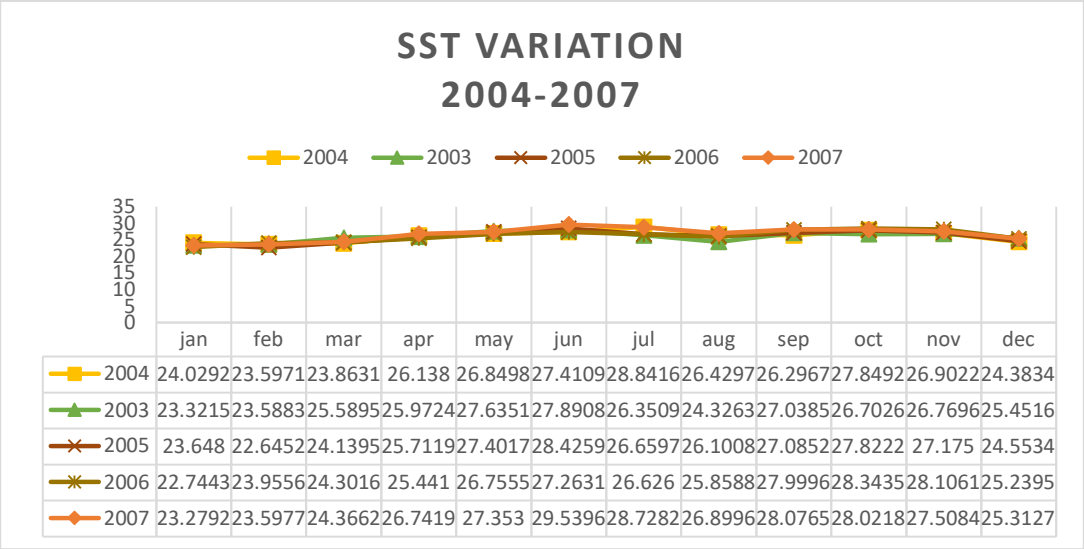
Table-2. The Arabian Sea's Mean Sea Surface Temperature (SST) data from 2003 to 2023 shows a distinct seasonal temperature variation throughout the region. April observed the highest temperatures, reaching a maximum of 35.4°C. May and June see a minor cooldown, with the SST still over 34°C. The cooler months usually observed a drop in temperature, with August noticing the lowest SST of 18.8°C. The general pattern shows a minor period from October to February. The warm season is from March to September, with highs of about 34°C to 35°C.

In terms of hotspot direction, the western and northern regions of the Arabian Sea, near the coastline of Pakistan is typically experienced higher SSTs, notably in the months of April and May. This can be qualified to the normal wind patterns during the northeast monsoon. it brings cooler winds from the land towards the sea and allowing the surface temperatures to be slightly lower down in the eastern parts. The highest SST hotspots are often located along the southern coast extend towards the central Arabian Sea. This temperature circulation plays a key role in regional oceanography, marine ecosystems, and climate patterns, with warmer waters influencing monsoon patterns and tropical cyclone activity in the Arabian sea.

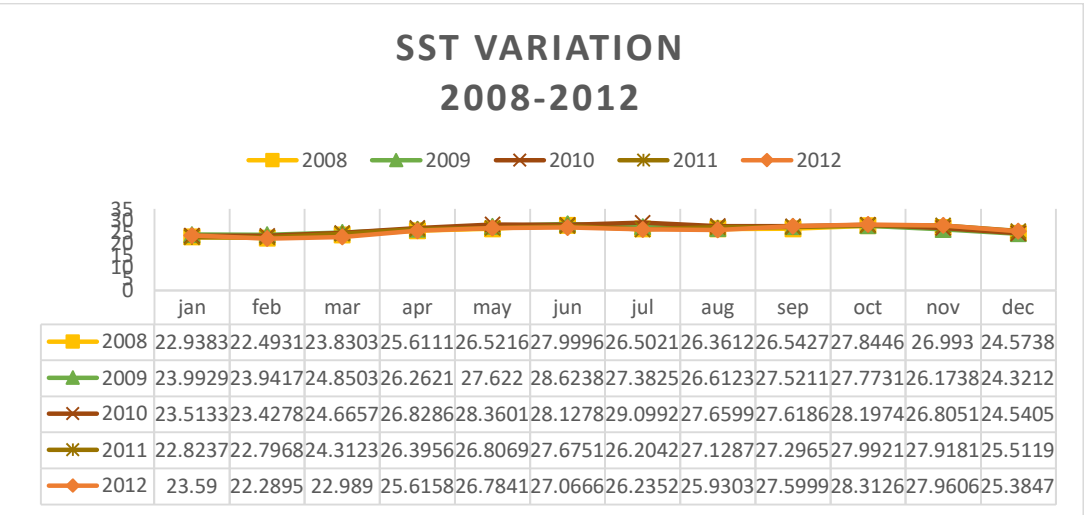
The Mean Sea Surface Temperature (SST) data from January to December across the Arabian Sea shows discrete seasonal patterns in temperature, which are influenced by both the time of year and regional wind and ocean current dynamics.

the hotspots for SST along the Pakistan coastline are most prominent from April to September. When temperatures tend to be highest, mostly in the southern and central parts of the Arabian Sea. The colder period from October to March is influenced by the northeast monsoon winds, which lower temperatures, especially in the northern and eastern parts of the Arabian Sea.

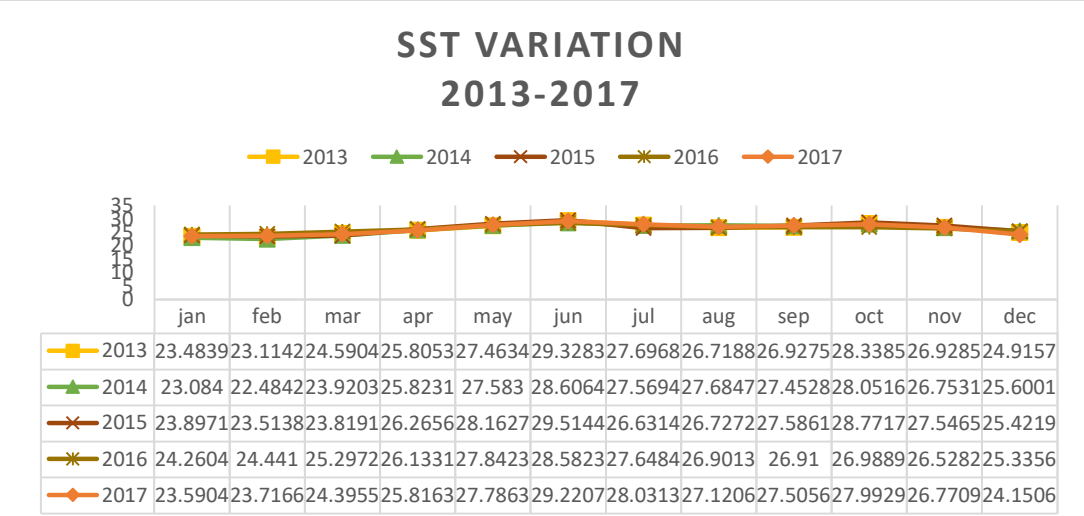
SST Variation from 2003 to 2021 Arabian Sea near Karachi coast.



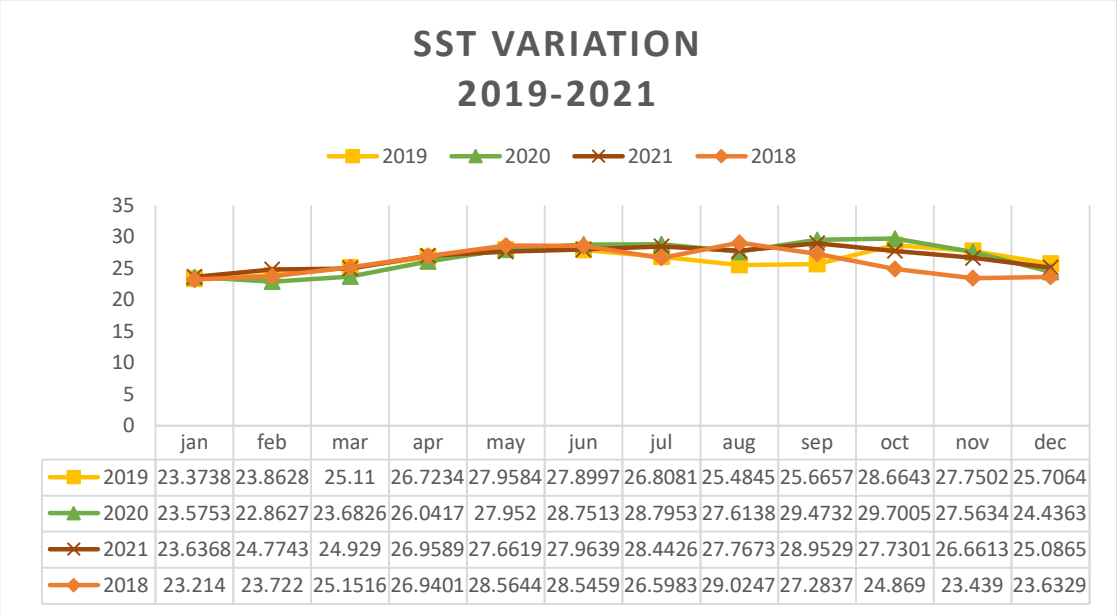
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2004	24.0292	23.5971	23.8631	26.138	26.8498	27.4109	28.8416	26.4297	26.2967	27.8492	26.9022	24.3834
2003	23.3215	23.5883	25.5895	25.9724	27.6351	27.8908	26.3509	24.3263	27.0385	26.7026	26.7696	25.4516
2005	23.648	22.6452	24.1395	25.7119	27.4017	28.4259	26.6597	26.1008	27.0852	27.8222	27.175	24.5534
2006	22.7443	23.9556	24.3016	25.441	26.7555	27.2631	26.626	25.8588	27.9996	28.3435	28.1061	25.2395
2007	23.2792	23.5977	24.3662	26.7419	27.353	29.5396	28.7282	26.8996	28.0765	28.0218	27.5084	25.3127



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2008	22.9383	22.493	23.8303	25.6111	26.5216	27.9996	26.5021	26.3612	26.5427	27.8446	26.993	24.5738
2009	23.9929	23.9417	24.8503	26.2621	27.622	28.6238	27.3825	26.6123	27.5211	27.7731	26.1738	24.3212
2010	23.5133	23.4278	24.6657	26.8286	28.3601	28.1278	29.0992	27.6599	27.6186	28.1974	26.8051	24.5405
2011	22.8237	22.7968	24.3123	26.3956	26.8069	27.6751	26.2042	27.1287	27.2965	27.9921	27.9181	25.5119
2012	23.59	22.2895	22.989	25.6158	26.7841	27.0666	26.2352	25.9303	27.5999	28.3126	27.9606	25.3847



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2013	23.4839	23.1142	24.5904	25.8053	27.4634	29.3283	27.6968	26.7188	26.9275	28.3385	26.9285	24.9157
2014	23.084	22.4842	23.9203	25.8231	27.583	28.6064	27.5694	27.6847	27.4528	28.0516	26.7531	25.6001
2015	23.8971	23.5138	23.8191	26.2656	28.1627	29.5144	26.6314	26.7272	27.5861	28.7717	27.5465	25.4219
2016	24.2604	24.441	25.2972	26.1331	27.8423	28.5823	27.6484	26.9013	26.91	26.9889	26.5282	25.3356
2017	23.5904	23.7166	24.3955	25.8163	27.7863	29.2207	28.0313	27.1206	27.5056	27.9929	26.7709	24.1506



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2019	23.3738	23.8628	25.11	26.7234	27.9584	27.8997	26.8081	25.4845	25.6657	28.6643	27.7502	25.7064
2020	23.5753	22.8627	23.6826	26.0417	27.952	28.7513	28.7953	27.6138	29.4732	29.7005	27.5634	24.4363
2021	23.6368	24.7743	24.929	26.9589	27.6619	27.9639	28.4426	27.7673	28.9529	27.7301	26.6613	25.0865
2018	23.214	23.722	25.1516	26.9401	28.5644	28.5459	26.5983	29.0247	27.2837	24.869	23.439	23.6329

In 2009 to 2010 moderate El Nino event and 2015 to 2016 major El Nino event was observed the SST Reaches 2009 and 2010 to 28.6 to 29 ^{o}C and weak monsoon pattern in south Asian side of Arabian sea. Similarly in 2015 and 2016 28 to 29.5 ^{0}C was observed near the Karachi coast.

Conclusion

SST may significantly impact coastal erosion by increasing storms, raising sea levels, and changing wave patterns. To analyze SST, this research uses Google Earth Engine (GEE) and machine learning techniques. GEE is a cloud-based platform for processing remote sensing data. It provides advanced capabilities for analyzing satellite imagery. The in-situ Data provided by National institute Of Oceanography Pakistan. Particularly, this study uses Ocean Color SMI: Standard Mapped Image MODIS Aqua Data Level 3.the Comparative analysis of the Hybrid Coordinate Ocean Model (HYCOM) provides global ocean data with a spatial resolution of 0.08 degrees (approximately 9 km) from 2003 to the present.

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Limitations & Future Work

Data set extract by using google earth engine programing script and analyze GEE Cloud platform. The Data gap, bands, cloud Cover, spatial and temporal resolution sufficient for global scale studies. This may possibly not be fine enough for specified analysis of local or small-scale kinds like coastal changes, urban areas, or small water bodies.

Credit authorship contributions statement.

Rizwan Akhter: Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – original draft, Investigation.

Dr. Ibrahim Zia: Conceptualization, Validation, Formal analysis, Writing – review & editing.

Tahreem Zafar: Validation, Writing – review & editing.

Declaration of competing interest

The authors state that none of the work described in this study could have been influenced by any known competing financial interests or personal relationships.

Funding

This study did not receive any grant from funding organizations in the public, commercial, or not-for-profit sectors.

Glossary

Term Used	Description Terminology
GEE	Google Earth Engine
SST	Sea Surface Temperature
HYCOM	Hybrid Coordinate Ocean Model
MODIS	Moderate Resolution Imaging Spectroradiometer
IPCC	Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report
SSP	Shared Socioeconomic Pathways

Term Used	Description Terminology
ENSO	El Nino Southern Oscillation
ASWP	Arabian Sea Warm Pool
SODA	Simple Ocean Data Assimilation
TCs	Tropical Cyclones
OLR	Outgoing Longwave Radiation
ROI	Region Of Interest
SLR	Sea Level Rise

El Nino and Lanina

El Niño is a Spanish word that means 'Little Boy'. It refers to a climate phenomenon that impacts global climate patterns. Normally, easterly winds, known as the Trade Winds, blow west along the equator in the Pacific Ocean. The trade winds carry warm water from South America towards Asia. During an El Niño event, these trade winds are weak, and warm water is pushed back east toward the west coast of the Americas and disrupting weather patterns. The entire period the trade wind is weak.

La Nina

La Niña is a Spanish word that means 'Little Girls'. La Niña has the opposite effect of El Niño. During La Niña events, trade winds become stronger than usual. These stronger winds push more warm water toward Asia. This impact lead to cyclone activity, monsoon strength and temperature variation in South Asia.

ENSO Phase

El Niño is part of a much larger global variation in the atmosphere called ENSO (El Niño/Southern Oscillation). The Southern Oscillation describes changes in air pressure patterns in the Southern Pacific Ocean between Tahiti, in the middle of the Southern Pacific Ocean, and Darwin, Australia, to the west. The El Niño refers to the warm episode of ENSO, while La Niña refers to the cool episode of ENSO.

Non-eddying and Eddy-permitting

Non-eddying and eddy-permitting are the climate ocean model experiments that shows ocean flows are known to currents. Sometimes, these currents can form circular loops of water, known as eddies, when they slice sections. Non-eddying models make easier fluid dynamics, while eddy-permitting models interpret some of the effects of eddies.

UP-Welling

Upwelling is a process where cold, deep ocean water rises to the surface. This happens when winds push surface water away, and the water below replaces it. Upwelling can occur near coastlines or in the open ocean On the other hand, downweling is the opposite process.

ROI

A Region of Interest (ROI) refers to a specific region that someone is focused on or interested in. On a map, it's the location or area that is being studied, observed, or analyzed.

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