THE ASSESSIMENT OF THE IMPACT OF SEA SURFACE TEMPERATURE CHANGE ON SEA LEVEL CHANGE

A Case Study of Indian Ocean Along Tanzania Coast

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A Dissertation Submitted to the Department of Geospatial Science and Technology in Partially Fulfilment of the Requirements for the Award of Bachelor of Science in Geomatics (BSc. GM) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for the acceptance by Ardhi University, a dissertation titled "**The Assessment of The Impact of Sea Surface Temperature Change on Sea Level Change (A case study of Indian Ocean along Tanzania Coast)**", in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics of the Ardhi University.

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(Main Supervisor)	(Second supervisor)
Date …….................	Date…………………

DECLARATION AND COPYRIGHT

I, **Msuya Stela Bryson**, hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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Date ……/……/…………

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DEDICATION

This Dissertation is dedicated to my husband Miraji Abdul Mfinanga may God bless him in all aspects. I also dedicate this study to my beloved mother Maimuna Ibrahimu and my beloved father Brayson Kijoti your presence always gives me strength.

ABSTRACT

The increase of SST causes rising of sea level due to thermal expansion of water hence causing sea level change. Sea level change is a significant consequence of climate change and it has a devastating effect. The assessments of sea level change encompass numerous factors including sea surface temperature (SST) on ocean dynamics. This research aims on providing concise overview and update information on influence of SST change on sea level change in the Indian Ocean along Tanzania coast from 2011 to 2022.This assessment were accomplished through the computations of sea surface temperature acquired from Aqua Modis via NASA ocean color with spatial resolution of 4km and temporal resolution of 1 day, sea level anomalies data from satellite altimetry via space agency AVISO of spatial resolution of 0.17-degree latitude and 0.17-degree longitude and temporal resolution of 5 days , sea level anomalies from Zanzibar tide gauge for validation of satellite altimetry data as well as finding their relationship through correlation and cross correlation analysis in time series from 2011 to 2022.This analysis also aims to identify the potential linkages that contribute to sea level variability in the region.

The historical data of SST and sea level anomalies from 2011 to 2022 were collected in a reliable source and undergoes preprocessing for removing outliers and ensuring data quality. The SST variations were mapped and computed. It was observed that on 2012 the SST were very low and high on 2021 as well as SLA were very low on 2012 and high on 2022. The correlation analysis and cross correlation were performed and revealed that the SST and sea level change has a close positive correlation of about 74% and the correlation coefficient was high at a time lag 0 about 0.9954. These results revealed that there is high chance of occurring sea level change when SST changes and vice versa.

To account for sea level change and SST change it was observed that, the sea level and SST were rising at the rate of 4mm/year based on satellite altimetry data and 0.179^{0}c/year based on AQUA Modis data respectively. From the results obtained, the sea level change and SST change have close positive correlation of 0.74. However, the SST contribute to sea level change but there are other factors. Hence, further study should be carried to determine how other factors contribute sea level change to quantify the present research. Also, more stations with long-term sea-level change should be considered on validating satellite altimetry data.

Keywords: Sea surface temperature, sea level anomalies and sea level rise.

Contents

List of Figures

List of Tables

ACRONYMS AND ABBREVIATIONS

IPCC	Intergovernmental Panel on Climatic Changes
SST	Sea Surface Temperature
GIS	Greenland Ice Sheet
WAIS	West Antarctica Ice Sheet
SRES	Special Report on Emission Scenarios
NASA	National Aeronautics and Space Administration
HadISST	Hadley Centre Sea Ice and Sea Surface Temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
SST	Sea Surface Temperature
SSTA_	Sea Surface Temperature Anomalies
SLA	Sea Level Anomalies
NetCDF	Network Common Data Form
NGOs	Non-Governmental Organizations
NOAA	National Oceanic and Atmospheric Administration
PODAAC	Physical Oceanographic Distributed Active Archive Center

CHAPTER ONE

1.INTRODUCTION

1.1 Background of The Study

Global climate change has caused worldwide concern due to its adverse effects on the global ecosystems and society. The major effect of the climate change is global warming. In the past fifty years, global warming has caused the accumulation of more than 90% of greenhouse gases which results to an increase in SST causing thermal expansion of the seawater (Hafoud et al., 2020). Sea surface temperature is a fundamental climatic index and can assess the ocean's current state and adequately evaluate climate change's impact on a regional scale (Hafoud et al., 2020). For the period of 2000 to 2013 the sea surface temperature (SST) was observed to increase in the Indian Ocean in response to the greenhouse gas forcing, with a low increase in the northern part and much high increase in the south of the Indian Ocean. This warming up of the sea has resulted in the various changes in the ocean especially the changes in the sea level. The sea level rise has a devastating effect on coastal habitats and inland such that it can cause wetland flooding, aquifer and agricultural soil contamination with salts, destructive erosion and loss of marine habitats and ecosystem. Also, high sea level rise is coinciding with typhoons and dangerous hurricanes that move more slowly and droppings rains that contribute to powerfully storm surges that can strip everything away in their path. As global temperatures continue to warm, sea level will keep rising for a long time because there is a substantial lag to reaching an equilibrium (Climateknowledgeportal, 2021).

Global mean sea level has risen approximately 210–240 millimeters (mm) since 1880, with about a third coming in just the last two and a half decades (Hafoud et al., 2020). The latest scientific understanding has been assessed in a systematic way by the Intergovernmental Panel on Climate Change (IPCC). The IPCC has published four major assessment reports since its establishment in 1988. The future sea-level rises by 2100 projected in the First to Fourth Assessment Reports are 31–110 cm (Business as usual scenario), 13–94 cm, 9–88 cm and 18–59 cm, respectively (Mimura, 2013). In each of the assessments, the IPCC used different climate models and scenarios for greenhouse gas (GHG) emissions. This is the major reason for the changes in the projected rise in mean sea level. After the IPCC AR4 was published, progress has been made in various areas related to the sea-level rise issue. For the past changes in GMSL from 19th to 21st Century, by the improvement of analysis techniques applied to satellite altimeter data together with tide gauge data, more detailed and reliable sea-level change data became available (Church J.A., 2011) ; (Ray, 2011). Increase in ocean heat content is caused by global warming, which in turn becomes a major factor of mean sea-level rise through thermal expansion of the sea water (Mimura, 2013).

Several studies have been conducted to see how the increase of SST influences sea level change by using different data such as satellite altimetry, tide gauge data (in situ) and sea surface temperature from National Aeronautics and Space Administration (NASA, http://data.gis.nasa.gov/gistemp) using an interactive feedback mechanism (dynamic model at a year of 1880-2000 (Q.Wu et al., 2017). Similarly, others have looked on the causes for decadal SST variability in southern Indian ocean and its impact on climate using the 1^0*1^0, monthly Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) data (Yuanlong Li *et al.,* 2019). This previous study provides the limited information on the impact of SST change on sea level change along Indian Ocean in Tanzania Coast in recent years and they did not validate their sea level data using in situ tidal measurements. Hence, this study aims on assessing the impact of the sea surface temperature on the sea level change in Indian ocean along Tanzania coast so as to determine the extent or magnitude of the SST effects on sea level change in Indian ocean from 2011 to 2022.

1.2 Problem of Statement

The Indian Ocean has been the most warming Ocean than the others. Warming of Indian ocean is caused by many factors such as greenhouse, increase of Sea Surface Temperature due to increase of air temperature and change of magnitude of El Nino. Consequence of warming up has led to sea level rise, ocean acidification, marine heat waves and ice melting. Thermal expansion of oceanic water is caused by accumulation of heat over a long period of time due to SST that expands water in the ocean and ice melting that results to sea level rise. The sea level change affects the marine ecosystem, low laying areas and coastal areas. Although there exist a number of studies on the impact of SST change on the sea level change, but the studies provide very limited information regarding to the extent (magnitude) at which the SST change contribute to sea level change along the Indian ocean in a western part of Tanzania. Hence, this research aims on assessing the impact of the sea surface temperature change on the sea level change from 2011 to 2022 in Tanzania coast along the Indian ocean.

1.3 Research Objectives

1.3.1 Main objective

The main objective of this research is to assess the impact of sea surface temperature change on the sea level change along Tanzania Coast in Indian Ocean from 2011 to 2022.

1.3.2 Specific objectives

The following are the specific objectives of this study;

I. To determine rates and the long-term temporal variation of sea surface temperature in Indian ocean from 2011 to 2022.
II. To determine the interannual variability (rates) and trends of sea level anomalies from 2011 to 2022.
III. To estimate the relative contribution of sea surface temperature change to sea level change from 2011 to 2022 through correlation and cross correlation analysis.

1.4 Significances of The Study

I. It provides the basic foundation of global climate change
II. It gives up to date information on the impact of SST on the sea level change along Indian ocean.
III. They are vital elements in oceanography and marine management.
IV. This regional focus provides valuable insights into specific challenges and impacts facing the communities and ecosystems in this region.
V. Study provides information which is essential to implement mitigation andadaptation options with sustainable development framework.

1.4 Beneficiaries of The Study

Coastal communities; It creates awareness to the people living near coastal areas against the flooding and erosion problems due to sea level rise also estimating sea level change and SST is essential to implementmitigation and adaptation options with sustainable development framework.

Oceanographers; They deal with physical and biological properties and phenomena of the sea. The sea level changeis directly linked to the life of aquatic animals.

Scientist uses SST data to identify the onset of El Niño and La Niña cycle; During El Niño, temperatures in the Pacific near the equator are warmer than normal. During La Niña, the same area experiences colder than normal ocean temperatures. These cycles are caused by multiyear shifts in pressure and wind speeds, and affect ocean circulation, global weather patterns, and marine ecosystems.

Weather forecasting station; Sea surface temperature provides the fundamental information in global climate system. SST is anessential parameter in weather forecasting and atmospheric model simulations.

Policy makers and government agency; This research is important for the society as whole, since sea level change helps the society to make decision related to infrastructure planning, coastal development and natural resource management.

1.6 Description of Study Area

The study area of this research is Indian ocean along Tanzania coast including areas located at latitude of 39^0 to 42^0 and at longitude of -4^0 to -12^0. The coastal areas are highly affected by sea level rise due to an increase of sea surface temperature that led to water expansion that increasing the volume of water and lowers it density as a result water level rise that cause sea level rise. The rise of sea level leads to coastal flooding, huge storms and hurricanes as well as contamination of salts water to the land.

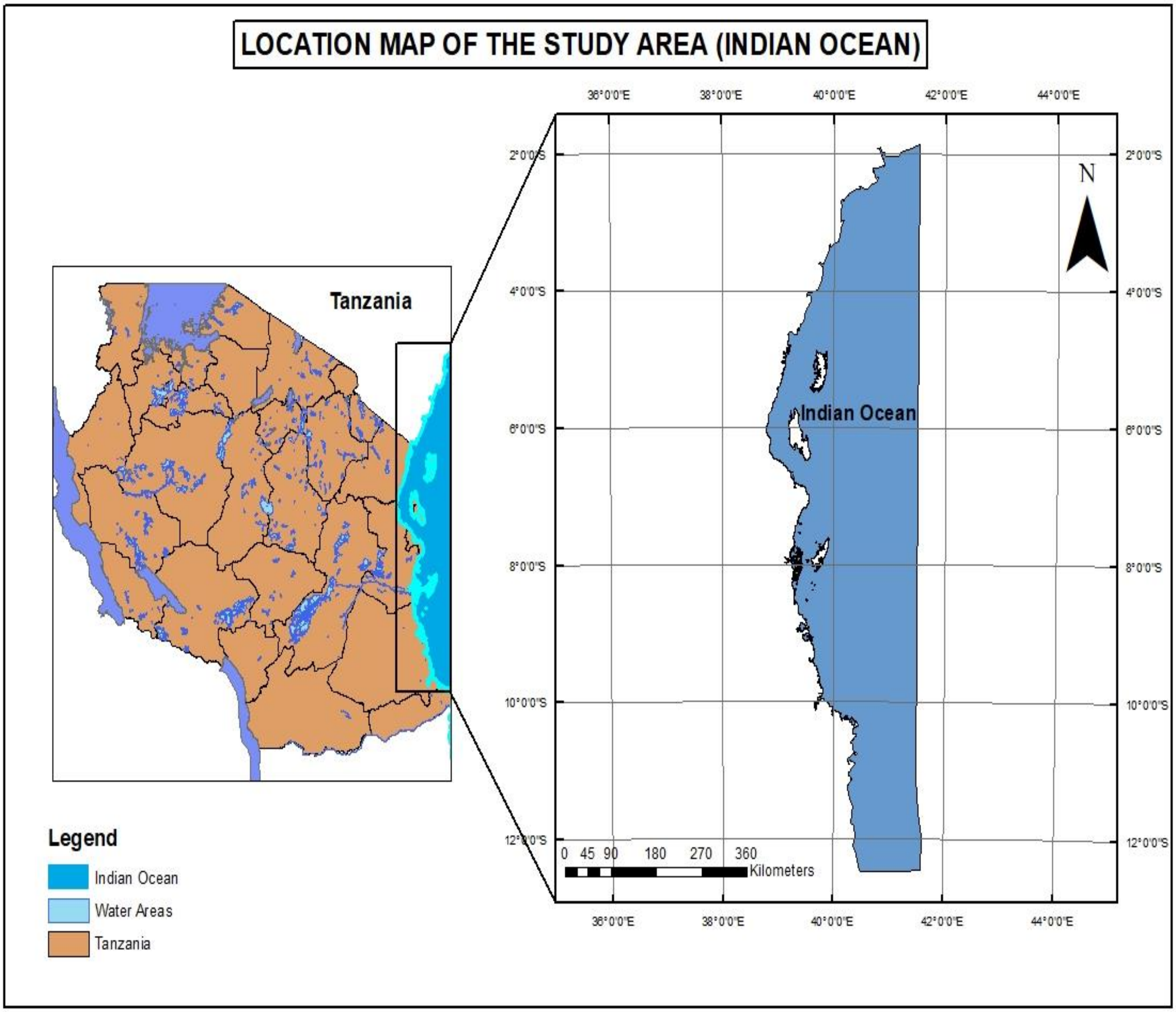

Figure 1.1 Location map of study area

1.7 Scope and Limitation of The Research

This study only focuses only on the Indian ocean along Tanzania coast from longitudes 40 to 43^0 East of Greenwich and from latitude 4 to -12^0 south of equator and it does not consider the impact of sea level rise on other parts of the world. The data used will be sea surface temperature from AQUA-MODIS and sea level rise data from satellite altimetry from 2011 to 2022.

1.8 Dissertation Outline

This research comprises five chapters organized as follows; Chapter one contains an introduction to the research, the problem to be solved, objectives of the projects and clearly explains the significance of the research. An overview of the research, the content of the research and the review of relevant work done by other authors and the relationship to that work are described in the second chapter. Chapter three explains the research methodology and clarifies the trend of the whole research, the methods and software chosen to carry out the research and how it is to be carried out. The results and discussion presented through graphs, Tables and Figures are described in the fourth chapter. Lastly, Chapter five contains the conclusion drawn from this research and for the future related research and recommendations.

CHAPTER TWO

2.LITERATURE REVIEW

2.1 Sea Level Rise

Sea level rise is an increase in the ocean's surface height relative to the land in a particular location. The sea level rise is one of the key indicators of climate change because it integrates changes of the several components of the climate system in response to anthropogenic forcing as well as natural factors and internal climate variability (Church et al., 2013). Sea levels are rising now and are expected to continue rising for centuries due to greenhouse gases emitted to an atmosphere. Rising in heat content contribute to thermal expansion of sea water which is an important element of climate change and sea level rise. Sea level rise is a global issue, but the distribution and impact of sea level rise is not evenly distributed across oceans due to differences in ocean-atmospheric interactions, and the elevation and geological makeup of the land. According to IPCC report, the global mean sea level increased by 0.20m between 1901 and 2018 (Climate Change, 2021).

2.1.1 Causes of sea level rise

Sea level rise is due to many factors such as thermal expansion of sea water, melting of land-based ice and changes in water storage on land as follows;

I. Thermal expansion of sea water

Thermal expansion is one of the main contributors to long-term sea-level change as well as being part of regional and short-term changes (Mimura, 2013).More than 90 percent of the trapped greenhouse gases heat is absorbed by the oceans and cause warming of the ocean. As this heat is absorbed, ocean temperatures rise and water expands and contribute increase in global sea level (Harfoud et al., 2020). Warming of the earth since 1880 was approximately 0.9 ^{0}c and projected to further warm it between 2-4^{0}C mostly due to human activity that led to the increase of ocean temperatures particularly in surface of the ocean. With continued ocean and atmospheric warming, sea levels will likely rise for many centuries at rates higher than that of the current century (National Ocean Service, 2023).

II. Melting of land-based ice

This consists of two factors, namely melting of mountain glaciers and ice caps,melting and outflow of the ice sheets in Greenland and Antarctica due to higher temperature (Trenberth *et al.*,2007). In Greenland, surface melting and loss of total mass are observed through observations of the gravity field using the Gravity Recovery and Climate Experiment (GRACE) satellite. Shrinking land ice added about one inch to global sea level from 1993 to 2008 which account for more than half of the increase during that period (Church *et al.*,2011).

III. Changes in water storage on land.

It includes different forms of storage, such as reservoirs behind dams, ground water, wet lands, and soil moisture. If terrestrial water storage increases, the rate of sea-level rise will be reduced (Mimura, 2013).Since, when water stored on land means it is removed from the ocean which causes sea level to drop. Also, land water changes are considered to be the collective sum of changes of water in the soil, wetland, groundwater, lakes and other reservoirs (Reager et al., 2016).

2.1.2 Sea Level Anomaly

Sea level anomaly describes the differences between the actual sea surface height and mean sea surface height. The sea level anomaly shows the regional extent of anomalous water level in the coastal ocean which will indicate unusual salinities, temperature, atmospheric pressures or coastal currents. All the measurements are corrected by the most actual geophysical correction such as tides and atmospheric delays (Schwatkee et al., 2010).

2.2 Measurements of Sea Level Rise

The rate of sea level change can be measured through two main methods which are tide gauges and satellite altimeters.

2.2.1 Tide gauge measurement**.**

Tide gauges are used to measure relative sea level, which is the height of the water relative to the height of the land. They are usually placed on piers, measure the sea level relative to a nearby geodetic benchmark. This means that tide gauge sea level observations reflect vertical motion of both the sea surface and the coastline (Thompson et al., 2016). The accuracy of automatic tide gauge recording from about 700 hourly heights will be accurate, approximately, to within + or - 0.002 feet (0.06 cm.) and the yearly Figures will be accurate to within + or - 0.001 feet (0.03 cm.) (Gorddon, 2009)Tide gauge stations around the world have measured the daily high and low tides for more than a century. For example, in Tanzania there are tide gauges located at Mtwara, Tanga, Zanzibar and Dar es Salaam. Since early 1990s the sea level rise has been measured using space radar altimeter that measures the return speed and intensity of a radar pulse directed at the ocean which determine the height of the sea surface (Rebecca et al., 2022). Hence, tide gauge measurements have several uses as follows;

a. Tide gauge observations are used to measure and predict tides.
b. Quantify the size of tsunamis and storm surges.
c. Tide gauge records are widely used in coastal engineering for design of coastal infrastructure.
d. Sea level datasets from tide gauges are utilized in many scientific disciplines, e.g., geodesy, oceanography, geology, paleo-oceanography studies and climatology.
e. Tide gauges are used for altimeter calibration for those located on island.
f. Tide gauge data are used to validate ocean models and to detect errors and drifts in satellite altimetry.

2.2.2 Limitations of tide gauge measurements

According to Thompson et al., (2016), the following are the limitations of tide gauge measurements;

a. It requires many corrections to be applied on raw data so as to account for vertical land motion, regional and local variability, and atmospheric pressure
b. Uneven and incomplete spatial distribution of tide gauges that complicates calculation of the global mean sea level
c. Lack a consistent global datum (benchmark) to combine tide gauge measurements from multiple locations into regional or global means

2.2.3 Satellite altimetry

Satellite Altimetry is a technique for measuring instantaneous sea surface height above earth ellipsoid. Sea Surface height is the total of geoid height and the dynamic topography associated with the oceans flows and responses to tidal and atmospheric forcing. It measures sea level by measuring the time it takes for radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver (IOC, 2002). Since the past two decades a number of satellite altimeter were launched as shown in Table 2.1;

Table 2.1. Satellite Missions

Satellite	Duration	Degree of Inclination (degree)	Repeat period (days)	Trajectory	Tracking Spacing Equator (km)	Altitude (km)
GEOSAT	1985-1990	108	17	Retrograde	163	785
ERS1	1991-1996	98.5	35	Retrograde	77	800
TOPEX	1993-2002	66	10	Prograde	315	1336
JASON-1	2002 to present	66	10	Prograde	315	1336
JASON-2	2008 to present	66	10	Prograde	315	1347
ENVISAT	2003 to present	98.55	35	Retrograde	77	800

2.2.4 Principle of radar altimeter

Satellite altimetry were designed and has been used to observe global oceanic topography and its change. The observation principle of satellite altimetry is to measure two way travelling time t of electromagnetic pulse from satellite to instant sea surface (Li, 2011) .The altimeter observed time delay (t) can be converted to the range R from the satellite to the ocean surface as;

$$R = {ct}/{2} \qquad (2.1)$$

Where by," c" is the speed

This instant the range measurement must be corrected for the instrument so as to get the height of the sea surface above reference ellipsoid which is known as sea surface height (SSH).

$$SSH = Altitude - Corrected\ range \qquad (2.2)$$

The difference between SSH and Sea Level Anomaly will yield Mean Sea Surface Height (MSSH)

$$MSSH = SSH - SLA \qquad (2.3)$$

Also, geoidal height is obtained from the difference between Mean Sea Surface Height and Mean Dynamic Topography (MDT)

$$N = MSSH - MDT \qquad (2.4)$$

2.2.5 Satellite altimeters errors and their corrections

In measuring surface topography there is a difficulty encountered which is a combination of knowing exactly where the instrument is at the time of the measurement and being able to characterize all the other variables that influence the delay of time-echo (Ayana, 2007). Hence, in addition waveform retracking, various corrections must be applied on the variables before altimeter data is put into different applications as follows;

- *Orbit Determination*

The accurate determination of ocean height is made by characterizing the precise height of spacecraft above the center of the earth so as to avoid instrumental noise and errors as well as geophysical errors i.e., tides, atmospheric attenuation etc. This is achieved through precise orbit determination (POD) and basically involves satellite tracking information. The very precise orbit determination technique applied is called DORIS System (Doppler Orbitography and Radiolocation Integrated by Satellite) (Ayana, 2007). In order to produce accurate estimates of satellite orbital height, POD combines the satellite tracking information with the models such as gravity and aerodynamics drag that govern the satellite motion.

- *Atmospheric effects*

The Earth's atmosphere exhibits the considerable variability that affects the propagation of microwave signals respectively. The atmospheric effects constitute of three components as follows;

a. Effects due to wet troposphere

Liquid water along the pulses path reduces the energy returned to the altimeters mainly at K_u band. This is caused by clouds and rain which cause the delay in radar signals. This can be calculated from radiometer measurement and meteorological models.

b. Effects due to ionosphere

This is the path delay in the radar return signal due to electron content in the atmosphere. Electrons density varies with altitudes at a different time of the day as a result the largest corrections is applied at the 12 noon and the smallest correction is applied 6 AM (Ayana, 2007).

c. Dry troposphere

This is the path delay in radar return signal due to atmospheric effects of refraction. The correction is done due to dry neutral gases which is oxygen molecules in the troposphere, water vapor and cloud liquid water (Fernandes et al.,2021). Also, this dry troposphere is related to the surface temperature and pressure and is calculated from meteorological models

- *Instrument errors*

These are errors accumulated due drift in oscillators onboard the satellite, Shift in satellites center of gravity. Filters are applied to eliminate certain frequencies in the return signal. The Table 1.2 shows the corrections applied for sea level data extraction in RADS

Table 2.1 Corrections applied for sea level data extraction in RADS

Correction	**TOPEX**	**JASON-1**	**JASON-2**
Orbit	GGMO2C gravity (ITRF 2000)	GGMO2C gravity (ITRF 2000)	GGMO2C gravity (ITRF 2000)
Dry Troposphere	ECMWF Model	ECMWF Model	ECMWF Model
Wet Troposphere	Radiometer Measurement	Radiometer Measurement	Radiometer Measurement
Ionosphere	Smoothen dual frequency value	Smoothen dual frequency value	Smoothen dual frequency value
Solid Earth Tides	Applied	Applied	Applied
Ocean Tide	FES2004	FES2004	FES2004
Load Tide	FES2004	FES2004	FES2004
Pole Tide	Applied	Applied	Applied
Sea State Bias	BM3/BM4 model	BM3/BM4 model	BM3/BM4 model
Geoid/Mass Height	CLS01 MSS Height	CLS01 MSS Height	CLS01 MSS Height
Inverse Barometer	MOG2D Model	MOG2D Model	MOG2D Model

Altimeters used in this research

The following are the altimeters used in this research

- Topex

This is an altimetry mission which jointly collaborated by NASA and CNES with overall objectives to provide high accuracy global sea level (ocean height) measurement in coordinate relative to the center of the earth. It was launched 10 August,1992 and operate until 18 October, 2005.TOPEX was capable of measuring significant wave height, dry and wet troposphere and ionosphere which can be used to calculate significant sea surface height (http://podaac.jpl.nasa.gov/TOPEX-POSEIDON)

- Jason-1

JASON -1 is an acronym stands for "Joint Altimetry Satellite Oceanography Network". It is a joint mission between NASA and CNES (French Space Agency) and it was launched Dec 7,2001 and start to collect data at Jan 15, 2002.Jason-1 is capable of measuring significant wave height which can be used to calculate sea surface height and anomalies (http://podaac.jpl.nasa.gov/JASON-1).

- Jason 2

JASON-2 was launched to the similar orbit of JASON-1 on 2008 by cooperation between NASA and CNES.The purpose of this mission is to provide real time data on sea surface height in order to observe ocean and further predict the climate

2.2.6 Limitations of satellite altimetry

However, satellite altimetry is very crucial and potential in surveying activities but it is also limited in terms of its spatial resolution due to its measurement geometry and it is also providing only information along the nadir direction beneath the satellite orbits (Dettmering *et al.,* 2020).

2.3 Sea Surface Temperature

Sea surface temperature refers to the temperature of the top layer of the ocean, which is in direct contact with the atmosphere. The small variations of ocean temperature have strong impacts on regional and even global climatic change, energy change and environment due to unique physical characteristics of the ocean including high heat capacity (Varela et al., 2018). SST is an important variable for understanding, monitoring and predicting the fluxes of heat, momentum and gases at a variety of the scales which determines the relationship between the ocean and atmosphere (O'Carroll et al., 2019) and also it is an important indicator for Earths ecosystem. The mapping of SST now is responsibility of operational and monitoring forecasting since the knowledge of SST is fundamental in forecasting and weather prediction systems (Robinson et al.,2012).

2.4 Measurements of Sea Surface Temperature

Measurement of SST have been made for more than 200 years back for different purposes including construction of navigational charts, pure scientific research and the needs of weather forecasting. Most of historical SST measurements were not made by dedicated scientific vessels but by voluntary observing ships (VOS) since they would contribute to the safety of life at sea

(Kennedy, 2013).Sea surface temperature can be measured through in situ measurements and satellite-based measurement.

2.4.1 Insitu

The insitu measurements requires the instruments to be located directly at the point of interest and in contact with the subject of interest. These measurements are measured by vessels and floating or fixed buoys. The insitu measurements serves as ‘‘ground truth’’ for the calibration and validation (Cal/Val) of satellite SST retrievals and also assimilated in ocean analysis and forecast models and are often used to ‘‘bias correct’’ various satellite inputs (Chin et al., 2017).These *in situ* measurements are quite accurate but provide limited spatial coverage,costly and they are characterized by strong tides or energetic waves that are suiTable for generating electricity also ,they suffer from logistical difficulties when it comes to making field measurements in remote locations (Simon et al.,2018).

2.4.2 Satellite Based Measurement

The SST distribution is largely derived from remote observations where by, the remote sensors are located some distance away from the subject of interest. They include passives systems and active systems in their modes of action. The remote sensing measurements of SST includes AVHRR (Advanced Very High-Resolution Radiometer) and AQUA MODIS (Aqua Moderate Spectral Radiometer)

a) AVHRR

This is an across track scanner that senses the Earth’s outgoing radiation from horizon to horizon in six channels (three solar channels in the visible-near infrared region and three thermal infrared channels), with a spatial resolution of 1km at nadir. The standard deviation obtained in data comparison is approximately 0.68^0c (Barton and Pearce , 2006). EUMETSAT (European Organization for the Exploitation of Meteorological Satellites), It is used in operational meteorology, land analysis through calculating vegetation indices and ocean analysis through analyzing sea surface temperature and sea ice concentration. The AVHRR-based SST estimation is only possible under clear skies and also the swath angle of the instruments is 2000km.Therefore a composite image is often derived for SST estimates from all orbits during a certain period.

b) AQUA MODIS

This is a satellite-based sensor used for climate and earths measurements and it passes south to north over the equator in afternoon. The MODIS sensor is onboard the terra and aqua spacecraft with a spatial resolution of 0.041^0 spatial resolution and these data sets were mainly used to reconstruct high quality SST data and are available through the website (https;//oceandata.sci.gsfc.nasa.gov, n.d.). The Aqua Modis used to measure the biological and physical properties of atmosphere, ocean and lands. The standard deviation obtained in data comparison was better than 0.43^0c as determined by comparison of the SST data with the coincidence ferry observation (Barton and Pearce , 2006).Hence,MODIS SST have high accuracy and spatialtemporal resolution that can capture the mesoscale phenomena in oceans

(Mengmeng et a*l, 2021*).

2.5 The Influence of SST on Sea Level Rise

The ocean has absorbed vast quantities of heat due to an increase of concentrations of greenhouse gases in the atmosphere, mainly from fossil fuel consumption, leading to ocean rise temperature. Rising of ocean temperatures affect marine species and ecosystems as well as coral bleaching and the loss of breeding grounds for marine fishes and mammals (IUCN,2017)

CHAPTER 3

3.METHODOLOGY

3.1 Overview

This chapter explains how the data were acquired, preprocessed, processed were done to obtain results, as required to assess the impact of sea surface temperature change on the sea level change along Indian ocean from 2011 to 2022. The gridded sea level anomalies in netCDF format were acquired from space agency (AVISO+) and preprocessed using surfer software so as to convert netCDF format to DAT_{xyz}. Also, the sea surface temperature anomalies were acquired from NASA Ocean Color and preprocessed through ArcGIS and all the data were processed using MATLAB. This research was followed the steps as shown in Figure 3.1.

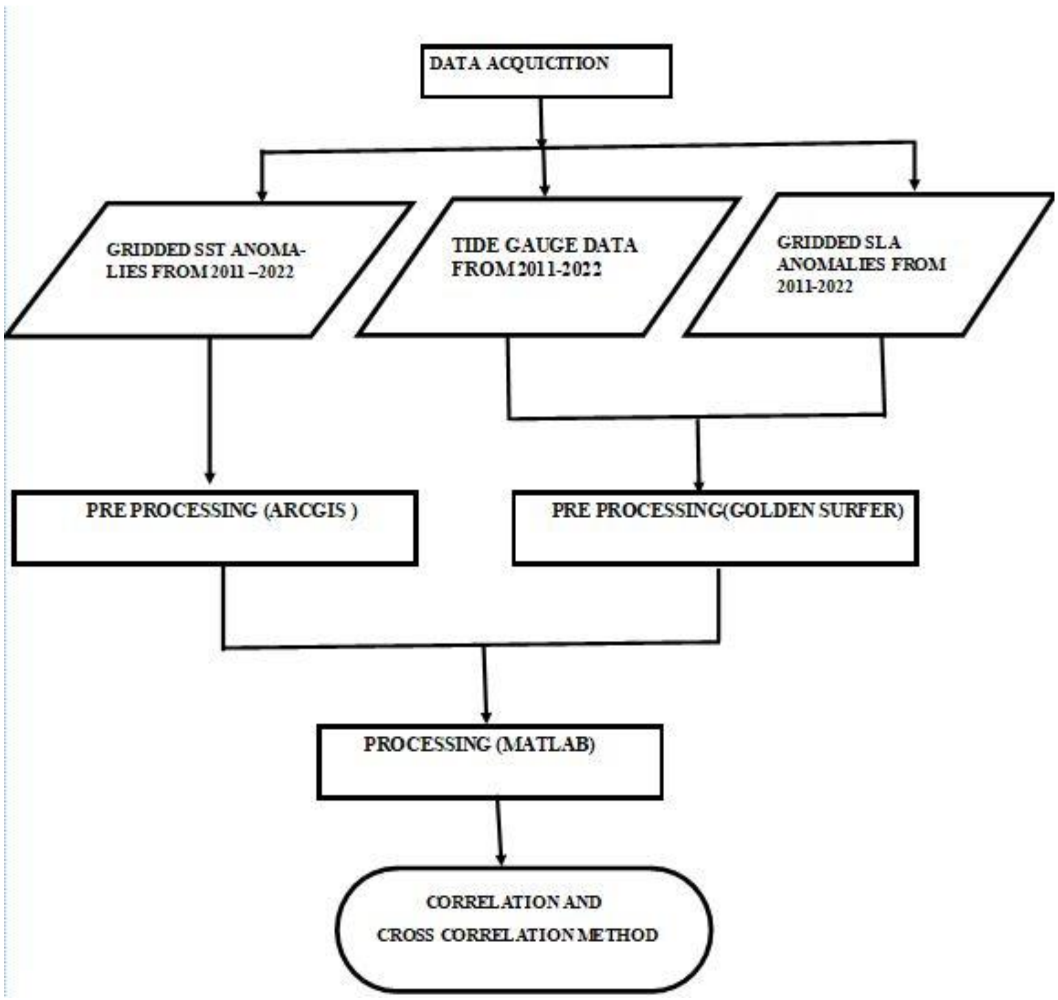

Figure 3.1 Workflow of research methodology

3.2 Data Source and Acquisition

The sea level anomalies, tide gauge data as well as SST data were very essential data in this research so as to come with the answer of the problem statement at the end of this research.

3.2.1 Satellite altimetry sea level anomalies

The sea level anomaly data were downloaded in NetCDF format data model which contain Long_bounds, Longitudes, Lat_bounds and Latitude which stand for positions where observations taken, Time and Time_bounds which stand for time of observation, SLA and SLA_ERR which stand for sea level anomaly values. These variables were used together to provide meaning and relation among the data field observed by satellite altimetry techniques after being processed. The data were observed by two satellite missions which were Jason-1 and Jason-2. The required data were sea level anomaly along Indian ocean by using satellite altimetry missions from 2011 to 2022 with spatial resolution of 0.17-degree latitude and 0.17-degree longitude and temporal resolution of 5 days. The satellite altimetry data is freely available online as provided by space agency (Aviso+) through http://podaac.jpl.nasa.gov/sea_surface_height, the sea level anomaly data were downloaded for 12 years that is from 2011 to 2022 from Jason-1 and Jason-2 Satellite missions.

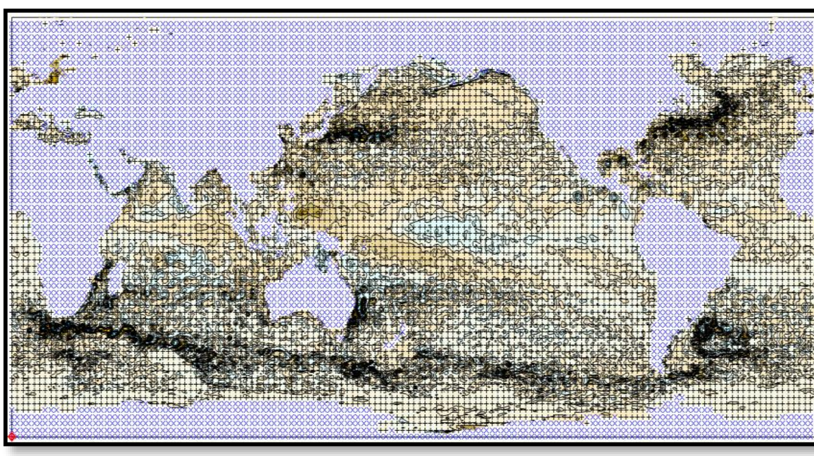

Figure 3.2 Visualization of Gridded Sea Level Anomalies

3.2.2 Tide gauge data

Tide gauge data also provides sea level information relative to land Datum, where by the tide gauge station is located at Zanzibar Island, Tanzania at latitude -6.15500 and longitude 39.19000, under the control of Commission for Lands. The tide gauge data in CSV format that cover 10 years from

2010 to 2019 were freely downloaded directly from University of Hawaii Sea Level Centre website (https://www.ioc-sealevelmonitoring.org

3.2.3 Validation of Satellite Altimetry with Tide Gauges

Satellite altimetry data from Jason-1 and Jason-2 was validated with the Zanzibar tide gauge data so as to be assure on the accuracy of the data. The tide gauge data is more accurate compared to satellite altimetry data because a tide gauge is capable of measuring instantaneous sea level with an accuracy better than 1 cm, in all conditions of tide, waves, currents, and weather (Gobron et al., 2019). In this research the sea level data used were from satellite altimetry, these data were validated by using the Zanzibar tide gauge data from 2011 to 2022. The tide gauge data were downloaded at one-day interval; hence they were averaged for each year from 2011 to 2022 so that they are at the same interval with the satellite altimetry data. After averaging the data, they were compared with the satellite altimetry data by plotting them in the same graph to see how their trends accept each other.

3.2.4 Sea Surface Temperature

The Sea Surface Temperature were downloaded in netCDF format with a spatial resolution of 4km and temporal resolution of 1day.These data were downloaded from AQUA Modis satellites image of high coverage and then clipped according to the area of interests of this research. The SST data contains latitude, longitude and SST. The Sea Surface Temperature were freely acquired online from NASA Ocean Color through https://oceancolor.gsfc.nasa.gov/l3/, the SST anomalies were downloaded from 2011 to 2022 through browsing Aqua Modis Ocean Color web and select Level 3 & 4 Browser and set the parameters such as time instrument product and resolution.

3.3 Data pre-processing

3.4 Data Processing and Analysis

After obtaining both sea surface temperature anomalies and sea level anomalies from Golden Surfer and ArcGIS, they were imported in MATLAB for further processing so that to know their trends from 2011 to 2022 as well as knowing their relationship between them. The sea level anomalies and sea surface temperature were analyzed through correlation and cross correlation method in MATLAB so as to know their relationship.

3.4.1 Computations of sea level anomalies (SLA) along Indian ocean

Sea level anomalies were computed from Golden surfer and visualized as shown in Figure 3.2 and then the point data from the area of interests were extracted in excel.

3.4.2. Computations of sea surface temperature (SST) along Indian ocean

Sea surface temperature data were processed through Matlab to obtain the trends of temperature variations from 2011 to 2022 and mapped in ArcGIS for proper visualization.

3.4.3 Correlation Analysis

This is a statistical test that used to find out the relationship and measure the strong relationship between two variables (Nugroho *et al., 2008*). The closeness relationship between SSTA and Sea level anomalies will be measured by index known as correlation coefficient. In parametric statistics, the correlation coefficient between two variables is obtained by using Pearson correlations that are notified with r. And the lowest scale of observation on Pearson correlation is interval and ratio. Pearson's correlation equation can be written as follows:

Equation 1. Pearson correlation.

$$rxy = \frac{n£x_1y_1-(£x_1)(£y_1)}{(n£x_1{}^2-(£x_1)^2)-(n(£y_1)^2-£y_1)^2)^{\wedge}½} \text{ .... } (3.1)$$

r_{xy}: correlation coefficient between SSTA and SLA

x_i: SSTA value to i

y_i: SLA value to i

n: the number of samples

The strong relationship between response variables and predictors can be measured by the correlation coefficients. The smaller the correlation coefficient value, the greater the error. Table 3.1 shows the number of relationships between variables based on criteria (Guilford, 1956):

Table 3.1 Interpretation of Correlation Coefficient between Variables

No	Correlation Coefficient Value	Description
1	$0 < r \leq 0,2$	Relationship is very small or no correlation
2	$0,2 < r \leq 0,4$	Small relationship/ lack of closeness
3	$0,4 < r \leq 0,7$	Moderate relationship
4	$0,7 < r \leq 0,9$	Close relationship
5	$0,9 < r \leq 1$	Very close relationship

3.4.4 Cross-Correlation

Cross-Correlation is statistically to analyze the relationship of two variables in a system both provided in time series data and assumed to be stationary to mean and variances (Shumway et al,. 2011). It requires time series data to be discrete data and stochastic data. The cross correlation works to determine the best time lag at the time of the highest correlation. The optimal time shift is necessary to increase the correlation between the two variables (Hashmi et al.,2009). When there is a greater correlation means the data has a similar pattern. The basic cross-correlation equations are as follows:

Equation 2.Cross-Correlation

$$r(L) = \frac{£_{k=0}^{N-L-1}\left(x_{(k+L)}-mx\right)(y_k-my)}{\sqrt{\left(£_{k=0}^{N-1}\right)(x_k-mx)^2}\{£_{k=0}^{N-1}(y_k-my\}} \qquad L \geq 0 \text{ .... (3.2)}$$

$$r(L) = \frac{£_{k=0}^{N-L-1}\left(x_{(k)}-mx\right)(y_{k+ILI}-my)}{\sqrt{\left(£_{k=0}^{N-1}\right)(x_k-mx)^2}\{£_{k=0}^{N-1}(y_k-my\}} \qquad L \leq 0 \text{ .... (3.3)}$$

where:

mx: average rows of data on SSTA

my: average rows of data on SLA

r: cross-correlation value

d: the time of the highest correlation between the SSTA and Sea level anomalies

CHAPTER FOUR

4. RESULTS, ANALYSIS AND DISCUSSION

4.1 Overview

This chapter explains, analyze and discussing the results of the data processed that led to come up with the conclusion and answer for the problem in this research.

4.2 Results and Analysis

It shows the results obtained after processing the sea level anomalies and sea surface temperature and their meaning relating to this research.

4.2.1 The variation of SST from 2011 to 2022.

The average monthly sea surface temperature was obtained after processing the Aqua Modis satellite image through ARCGIS and were plotted through MATLAB as showed in **Appendix 2** as well as mapped in every year as shown in **Appendix 3.** Table 4.1 shows the average monthly trend of sea surface temperature along Indian ocean in Tanzania from 2011 to 2022.

Table 4.1 The average monthly SST from 2011 to 2022 in Indian ocean along Tanzania coast.

Years	SST(^{0}C)	REMARK
2011	27.31155	
2012	27.20967	LOW
2013	27.42885	
2014	27.61393	
2015	28.20083	
2016	28.4063	
2017	28.87134	
2018	28.36629	
2019	29.26038	
2020	28.8874	
2021	29.37405	HIGH
2022	29.27568	

From Table 4.1 it was observed that in 2021 the temperature was high and low at 2012.This trend indicates that there is a significant increase of SST which could be contributed by various factors such as global warming. The Figure 4.1 shows the graph of average monthly SST from 2011 to 2022 and Figure 4.2 is the map showing the SST variation;

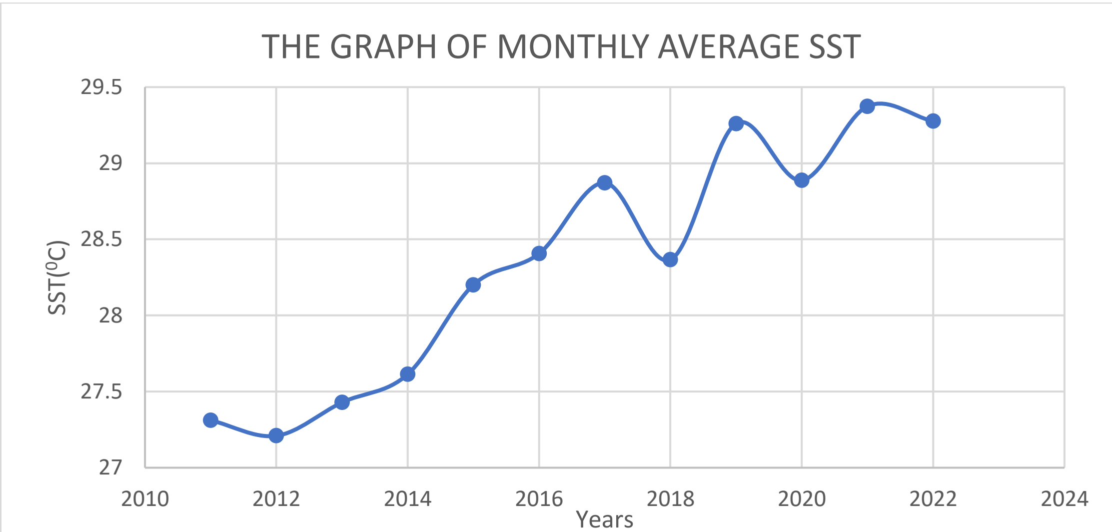

Figure 4.1 The monthly average SST in 2022

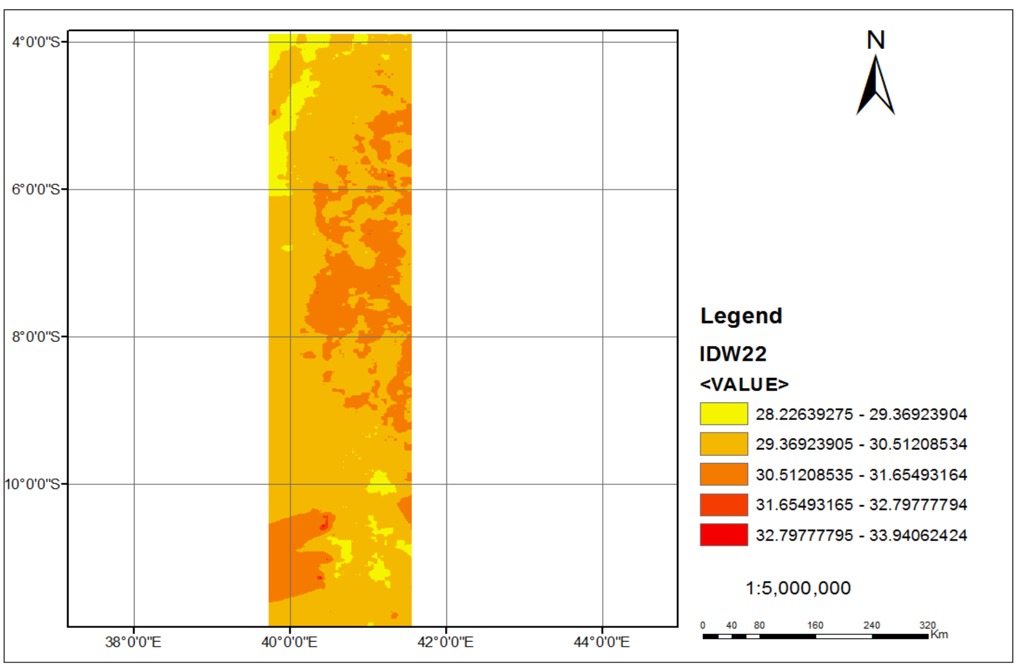

Figure 4.2 Map showing the SST variation in 2022

4.2.2 The variation of SLA from 2011 to 2022.

The average monthly sea level anomalies obtained after processing of gridded sea level anomaly data show sea level rise and fall in different years from 2011 to 2022 and plotted via MATLAB as showed in **appendix 1.** Table 4.2 shows the average monthly trend of sea level anomalies along Indian ocean in Tanzania from 2011 to 2022.

Table 4.2 Average monthly sea level anomaly from 2011 to 2022

Years	SLA(m)	REMARKS
2011	0.025072	LOW
2012	0.027468	
2013	0.032603	
2014	0.033637	
2015	0.041217	
2016	0.040547	
2017	0.049844	
2018	0.051833	
2019	0.059947	
2020	0.062656	
2021	0.064412	
2022	0.069537	HIGH

These data show the variation in SLA from 2011 to 2022 and it were observed in 2022 the sea level was very high and in 2011 the sea level was very low. The rise and fall of sea level depends on SST and melting of an ice as well as adding water to the ocean from lakes, aquifers and reservoirs. The Figure 4.3 shows the graph of average monthly SLA;

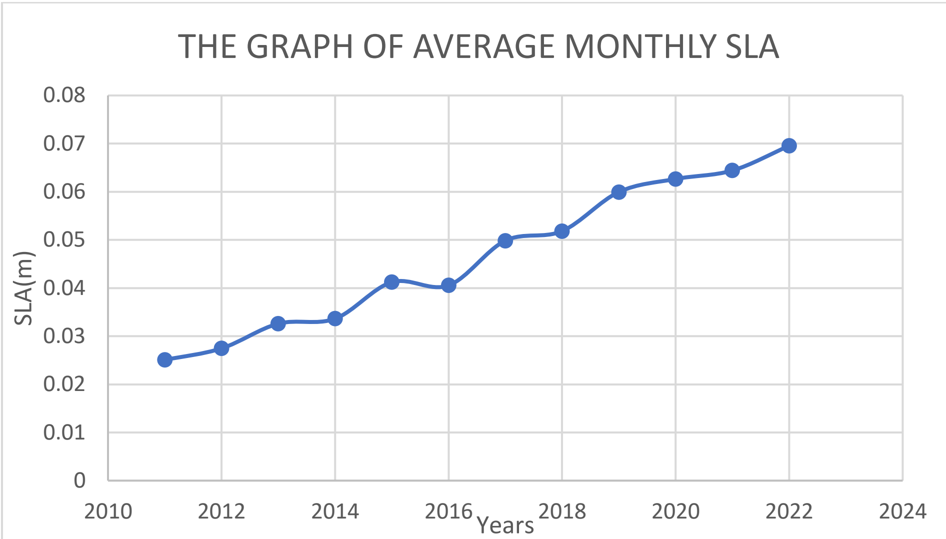

Figure 4.3 The monthly average SLA from 2011 to 2022

4.2.3 The relative contribution of Sea Surface Temperature on sea level rise along Indian Ocean from 2011 to 2022

The Figure 4.5 shows the contribution of sea surface temperature to sea level rise in Indian ocean along Tanzania coast from longitudes 40 to 43^0 East of Greenwich and from latitude 4 to -12^0 south of equator which is about 74% from 2011 to 2022.

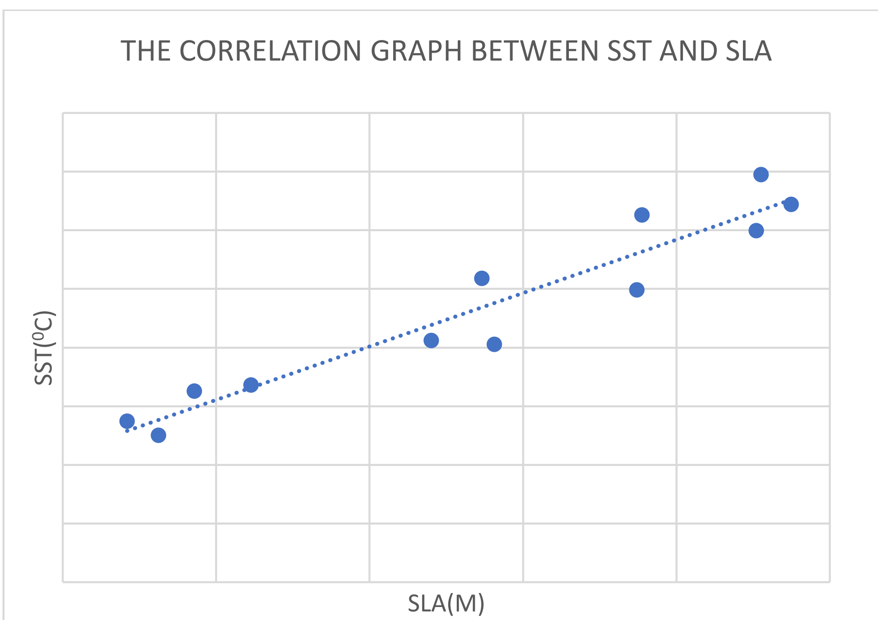

Figure 4.5 The Correlation graph

From the Figure 4.5above it shows that the sea surface temperature and sea level anomalies have a positive correlation that means the occurrence of one factor influence the occurrence of another and vice versa. The Figure 4.6 shows the cross correlation between sea surface temperature and sea level anomaly with a time lag.

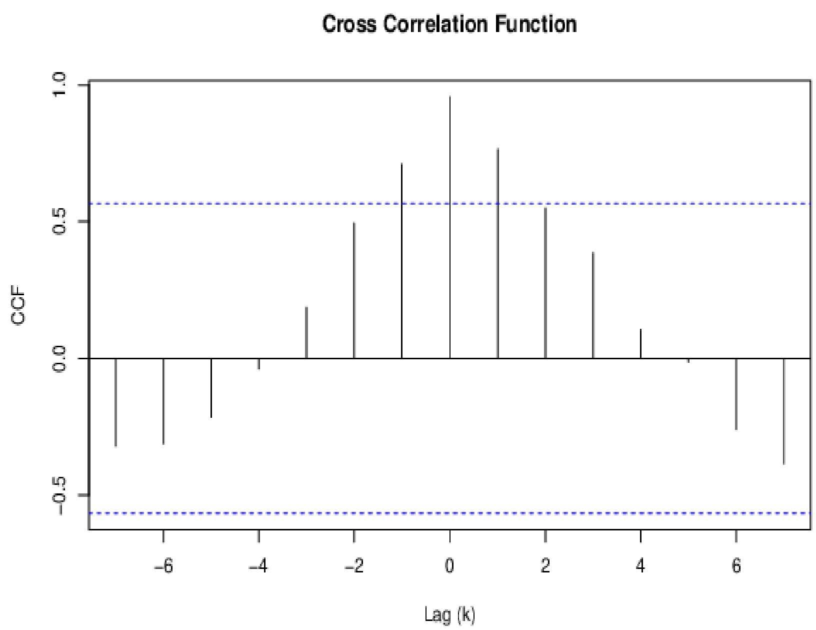

Figure 4.6 The cross-correlation function

4.2.4 Validation of satellite altimetry data with tide gauge data

The Figure 4.7 shows how the tide gauge data agrees with satellite altimetry data and this deviation of satellite altimetry from tide gauge data is due to difference of data processing methods and error corrections, instrumental difference and difference in vertical reference frame i.e., satellite altimetry data is based on reference ellipsoid and tide gauge data is based on local reference frame typically benchmark on the land.

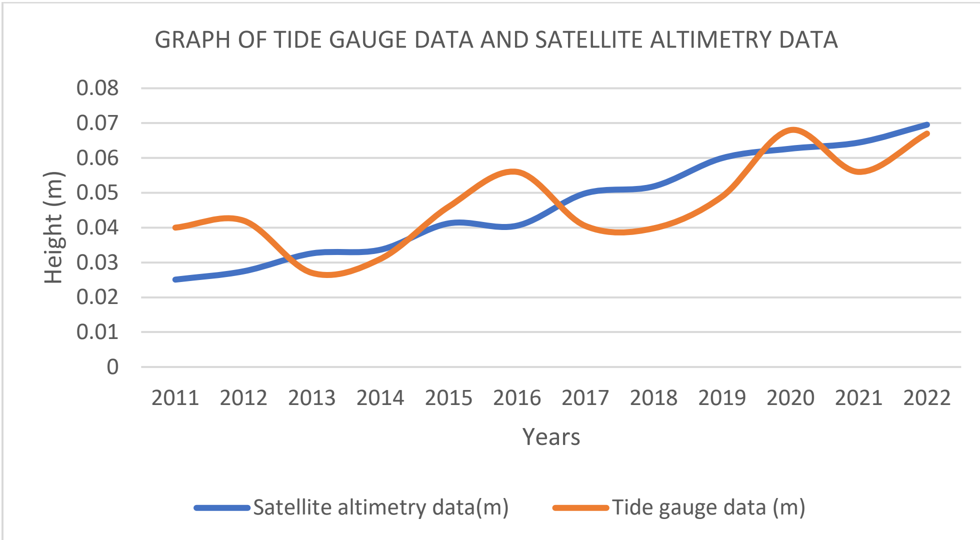

Figure 4.7 Graph of satellite altimetry data with tide gauge data

4.3 Discussion of the results

The SST has been varying depends on time and location as shown on Table 4.1 where by the temperature is highly observed in 2022 by 29.37405^{0}c and lowly observed at 2012 by 27.20967^{0}c. This variation is due to global climatic changes that alters the temperature of the ocean gradually since the ocean tends to absorb and trap heat generated in atmosphere. Due to an increase or decrease in SST, the water tends to expand and contract that cause rise and fall of sea level. As observed in Table 4.3, in 2022 the sea level was very high by 0.069537m and low at 2011 by 0.025072m due to SST variation in Indian ocean along Tanzania coast.

From Figure 4.5 the SST and sea level has a positive linear relationship that indicates that the occurrence of each variable facilitates the other. This positive correlation was observed to be 0.74 which is a close relationship in a monthly basis and 0.955 which is a very close relationship in a yearly basis. This variation in a correlation coefficient has occurred since yearly data has much generalization than a monthly data that's makes it to be closer than the other.

Also, Figure 4.6 shows that the greater correlation occurs when time lag is 0 which is about 0.9954, where by the time lag 0 indicates that the increase or decrease of SST causes the change of sea level state.

Due to the results observed the SST and sea level change is highly increasing hence, the critical investigation should be emphasized since it is crucial in climate and weather forecasting.

CHAPTER FIVE

5.CONCLUSION AND RECOMMENDATION

1.5 CONCLUSION

The aim of this study was to assess the impact of sea surface temperature change on sea level change in Indian ocean along Tanzania coast from 2011 to 2022. From the results to account for sea level change and SST change it was observed that, the sea level based on satellite altimetry data and SST based on AQUA Modis data were rising at the rate of 4mm/year and 0.179^0c/year respectively. Also, the occurrence of sea level change is influenced by sea surface temperature by 0.74 at 0-time lag hence they have close positive correlation. This indicates that when the sea level changes also the sea surface temperature change. However, this study involves one tide gauge (Zanzibar tide gauge) for validation of satellite altimetry hence further study should consider more stations with long-term sea-level change for validation.

The rate of sea level rise will continue to rise due to climate change that causes the increase in air temperature hence the expansion of sea water as well as melting of an ice that increases water to the ocean. This sea level rise may cause coastal flooding, tsunamis and loss of marine habitats.

5.2 RECOMMENDATION

From the results obtained the following recommendation can be put forward;

- Further studies should be conducted by using daily data of SST and SLA so as to know their relationship globally.
- Further studies should be conducted on the factors contributing sea surface temperature.
- Further studies are needed so as to see how other factors such as melting of an ice and addition of water to the ocean facilitates sea level change.

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APPENDICES

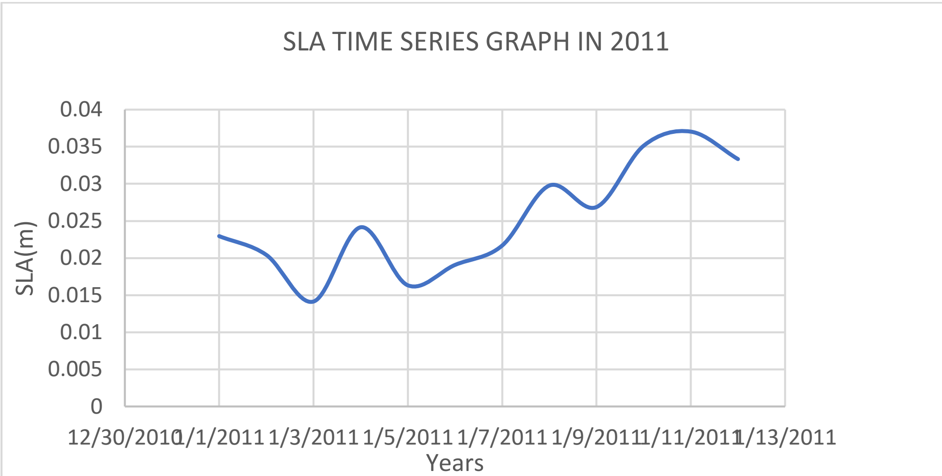
APPENDIX 1; The graphs show the sea level anomalies variation from 2011-2022

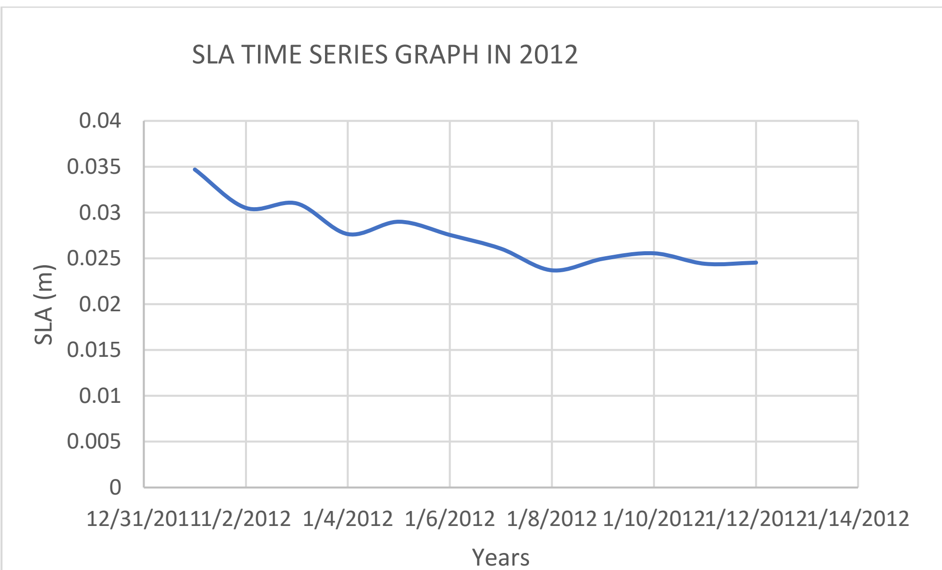
APPENDIX2; The graphs showing the sea surface temperature variations from 2011-2022

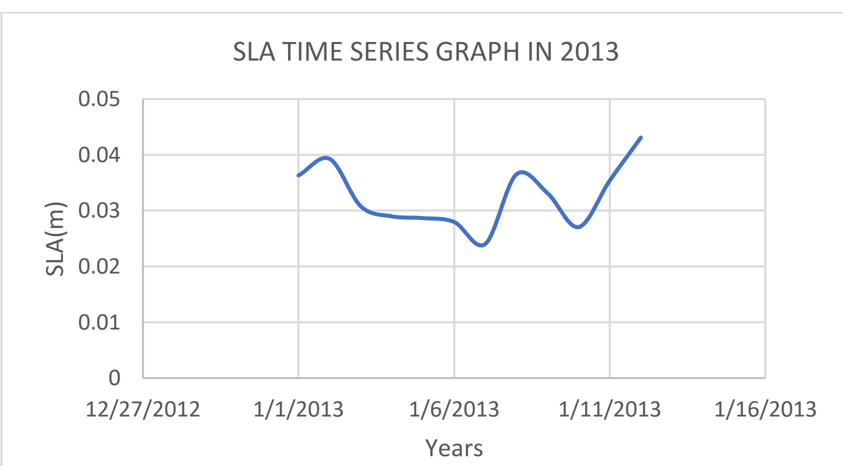
APPENDIX 3; The maps showing sea surface temperature variations from 2011 -2022

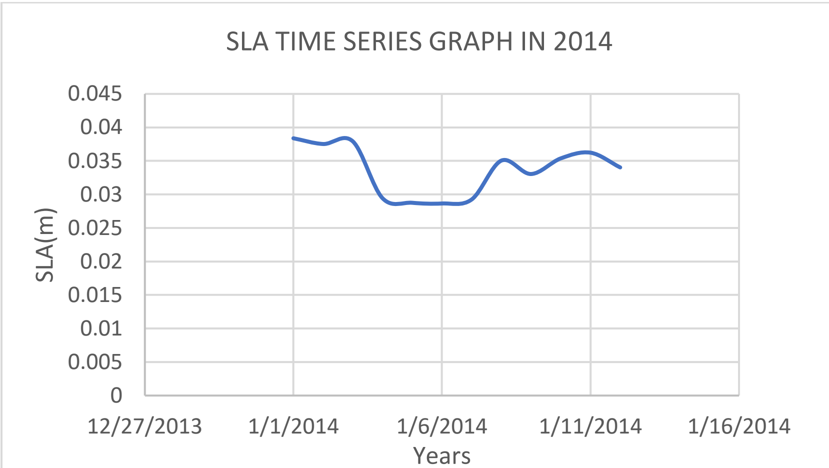
APPENDIX 4; The table showing the list of SST data and SLA data from 2011-2022

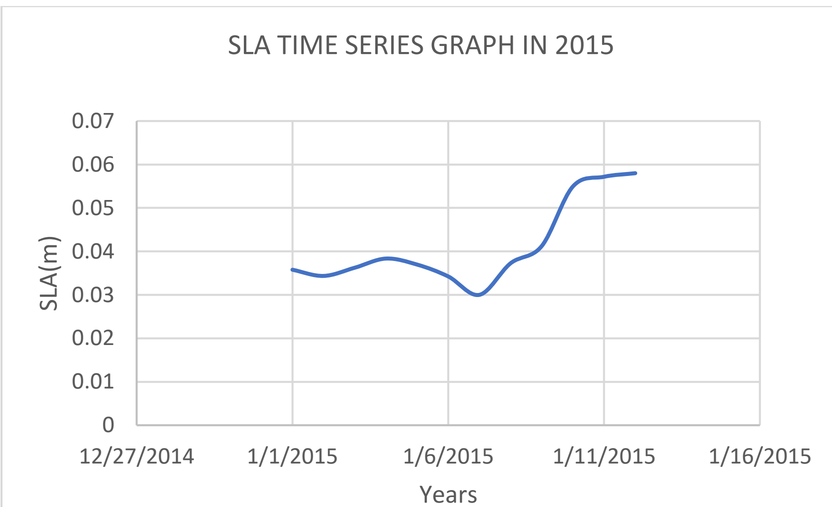
APPENDIX 1

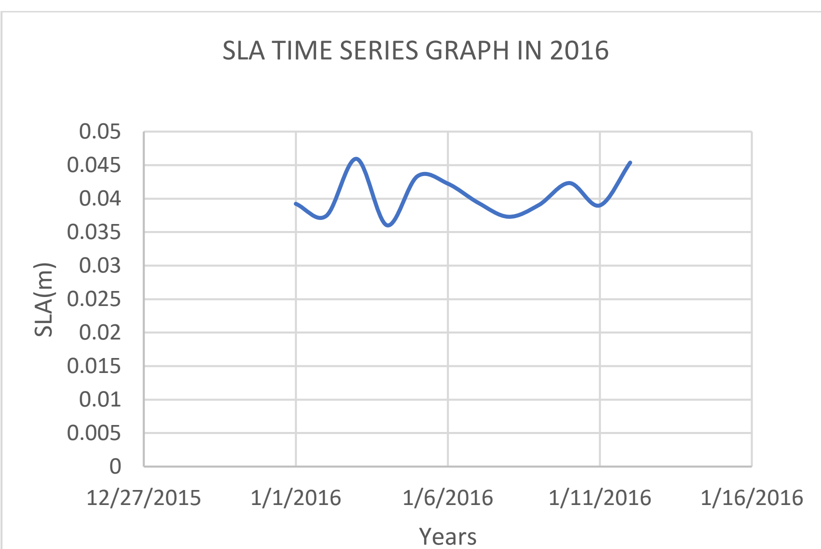

SLA TIME SERIES GRAPH IN 2011
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
SLA(m)
12/30/2010
1/1/2011
1/3/2011
1/5/2011
1/7/2011
1/9/2011
1/11/2011
1/13/2011
Years

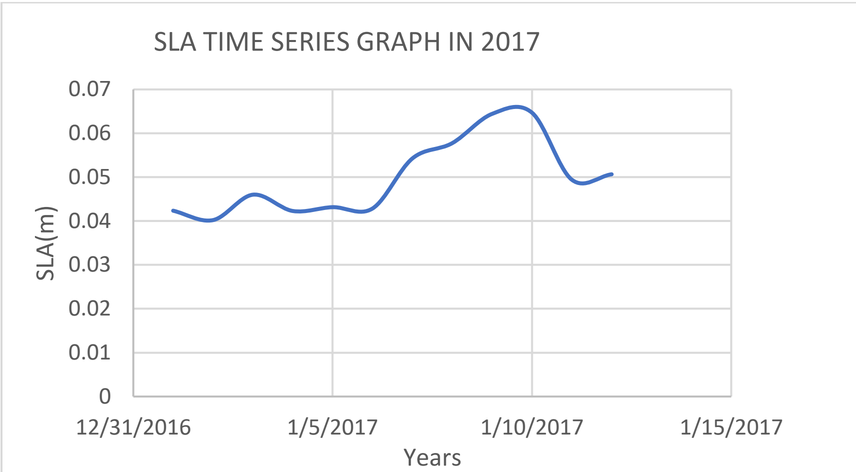

SLA TIME SERIES GRAPH IN 2012
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
SLA (m)
12/31/2011
1/2/2012
1/4/2012
1/6/2012
1/8/2012
1/10/2012
1/12/2012
1/14/2012
Years

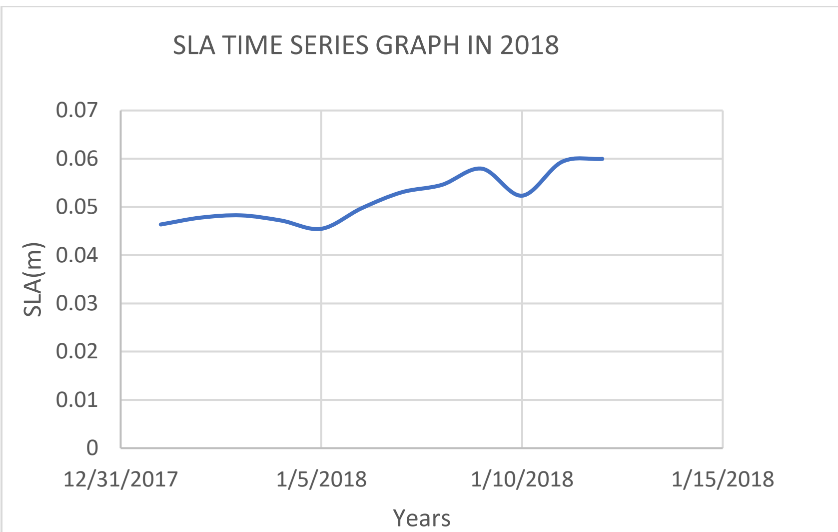

SLA TIME SERIES GRAPH IN 2013
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/27/2012
1/1/2013
1/6/2013
1/11/2013
1/16/2013
Years

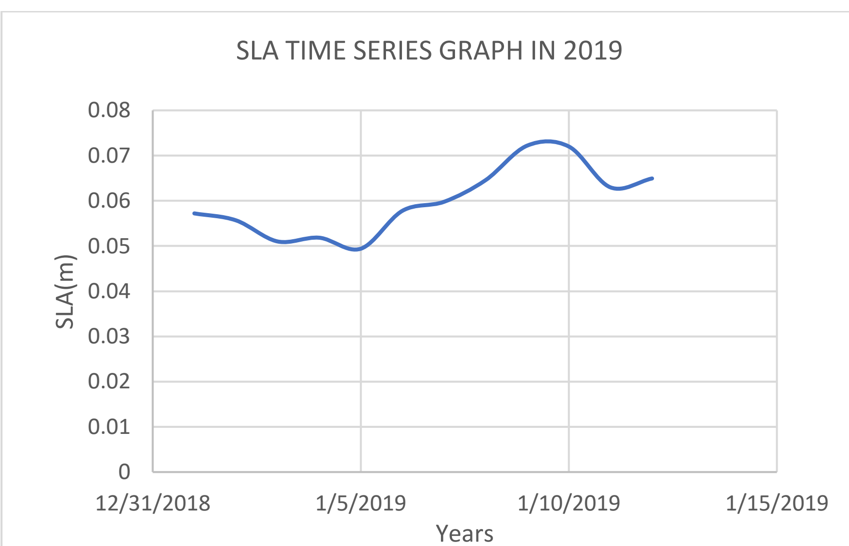

SLA TIME SERIES GRAPH IN 2014
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
SLA(m)
12/27/2013
1/1/2014
1/6/2014
1/11/2014
1/16/2014
Years

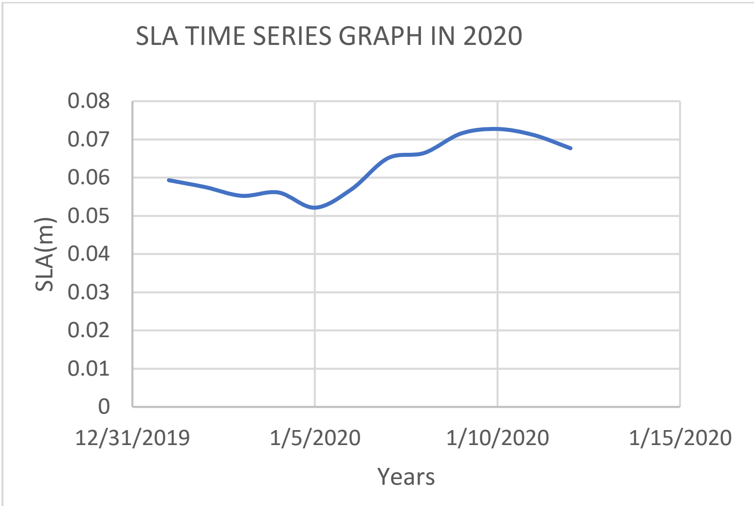

SLA TIME SERIES GRAPH IN 2015
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/27/2014
1/1/2015
1/6/2015
1/11/2015
1/16/2015
Years

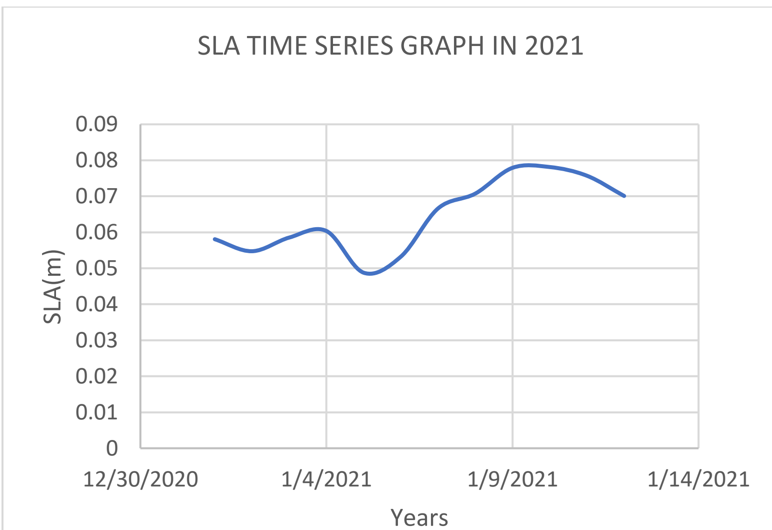

SLA TIME SERIES GRAPH IN 2016
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
SLA(m)
12/27/2015
1/1/2016
1/6/2016
1/11/2016
1/16/2016
Years

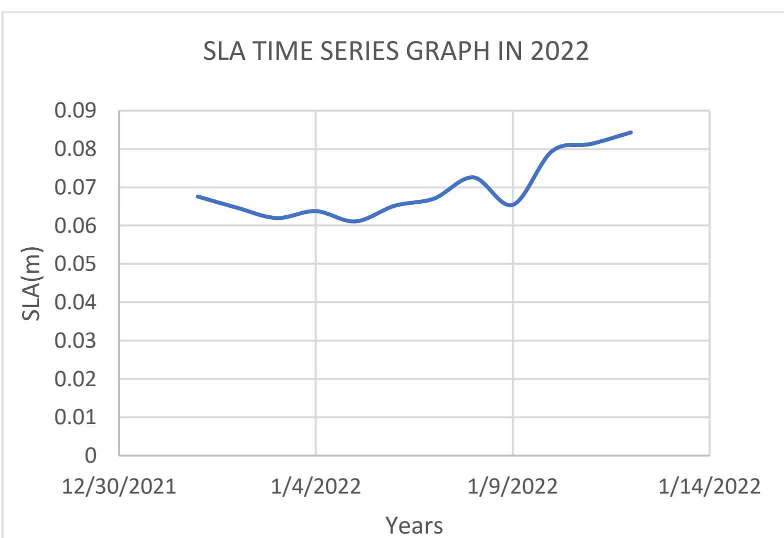

SLA TIME SERIES GRAPH IN 2017
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/31/2016
1/5/2017
1/10/2017
1/15/2017
Years


SLA TIME SERIES GRAPH IN 2018
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/31/2017
1/5/2018
1/10/2018
1/15/2018
Years

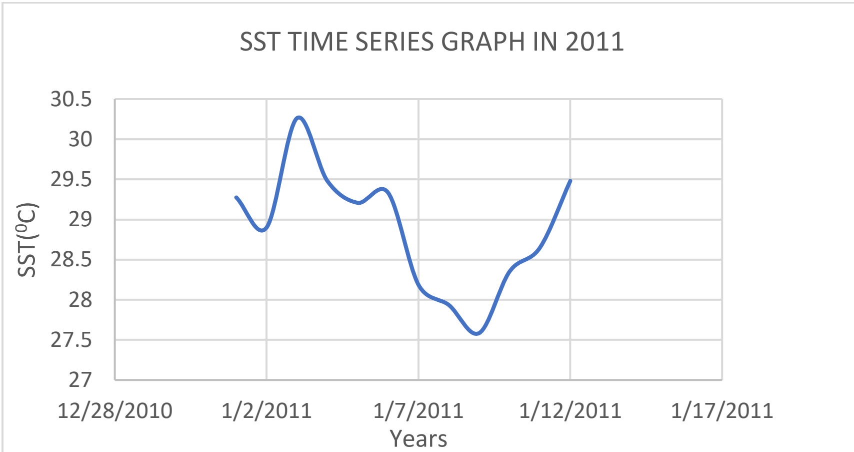

SLA TIME SERIES GRAPH IN 2019
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/31/2018
1/5/2019
1/10/2019
1/15/2019
Years


SLA TIME SERIES GRAPH IN 2020
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/31/2019
1/5/2020
1/10/2020
1/15/2020
Years

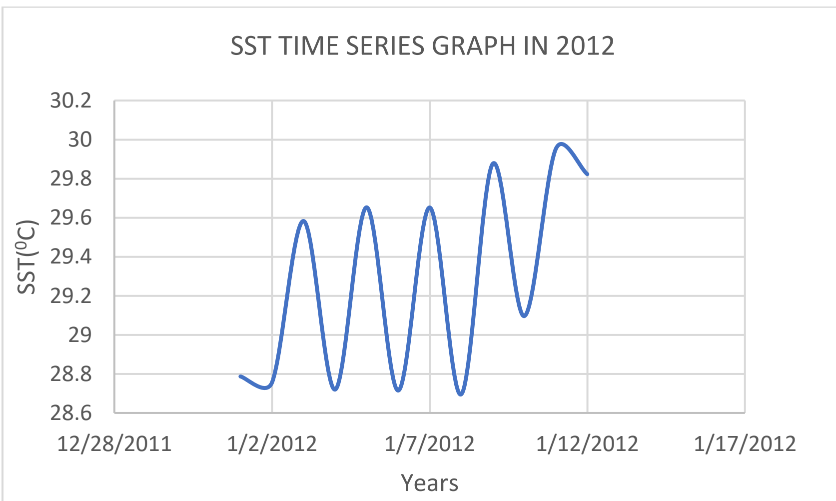

SLA TIME SERIES GRAPH IN 2021
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/30/2020
1/4/2021
1/9/2021
1/14/2021
Years


SLA TIME SERIES GRAPH IN 2022
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
SLA(m)
12/30/2021
1/4/2022
1/9/2022
1/14/2022
Years

APPENDIX 2



SST TIME SERIES GRAPH IN 2011
SST(ºC)
30.5
30
29.5
29
28.5
28
27.5
27
12/28/2010
1/2/2011
1/7/2011
1/12/2011
1/17/2011
Years



SST TIME SERIES GRAPH IN 2012
SST(ºC)
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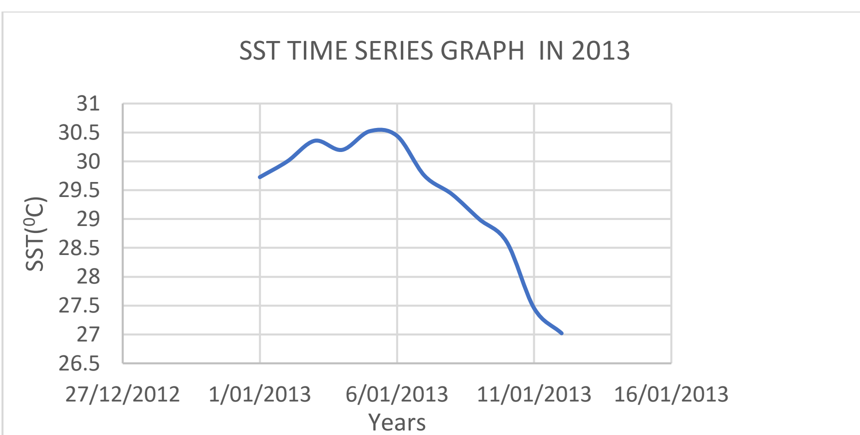
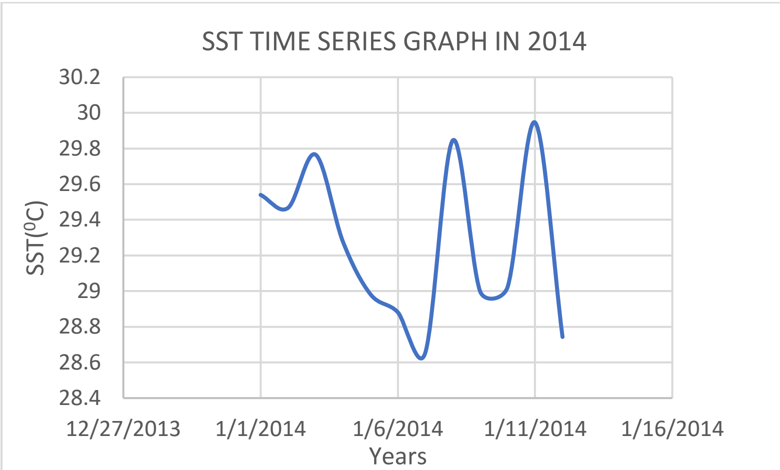
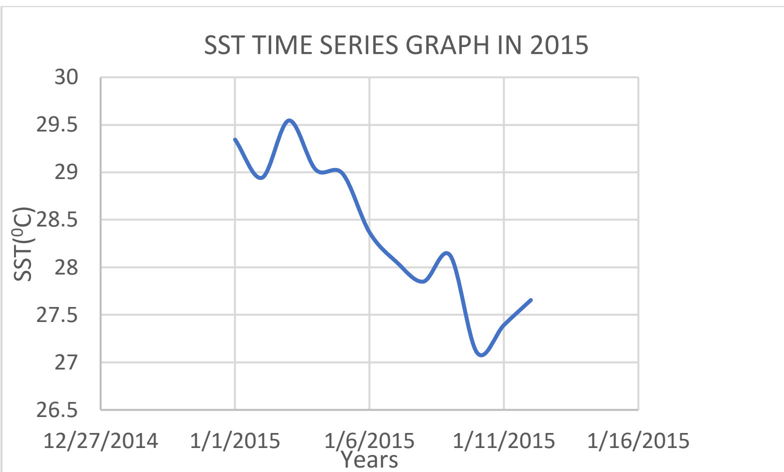
30
29.8
29.6
29.4
29.2
29
28.8
28.6
12/28/2011
1/2/2012
1/7/2012
1/12/2012
1/17/2012
Years



SST TIME SERIES GRAPH IN 2013
SST(ºC)
31
30.5
30
29.5
29
28.5
28
27.5
27
26.5
27/12/2012
1/01/2013
6/01/2013
11/01/2013
16/01/2013
Years



SST TIME SERIES GRAPH IN 2014
SST(0C)
30.2
30
29.8
29.6
29.4
29.2
29
28.8
28.6
28.4
12/27/2013
1/1/2014
1/6/2014
1/11/2014
1/16/2014
Years



SST TIME SERIES GRAPH IN 2015
SST(0C)
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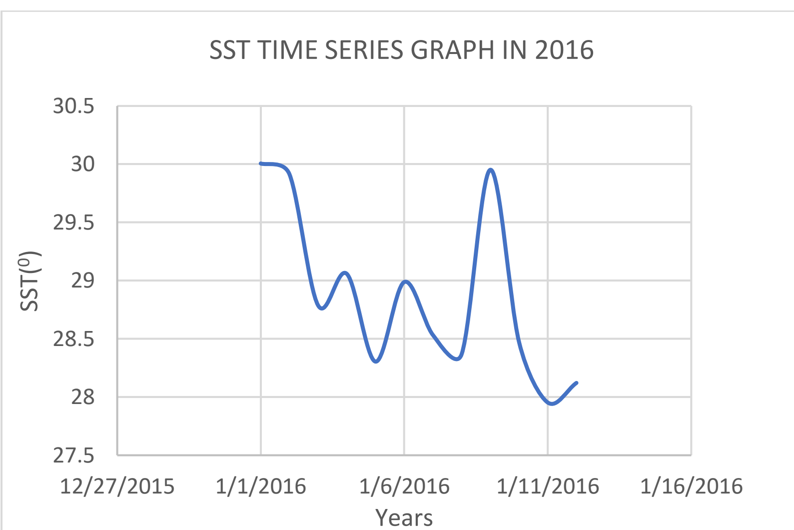
29
28.5
28
27.5
27
26.5
12/27/2014
1/1/2015
1/6/2015
1/11/2015
1/16/2015
Years



SST TIME SERIES GRAPH IN 2016
SST(0)
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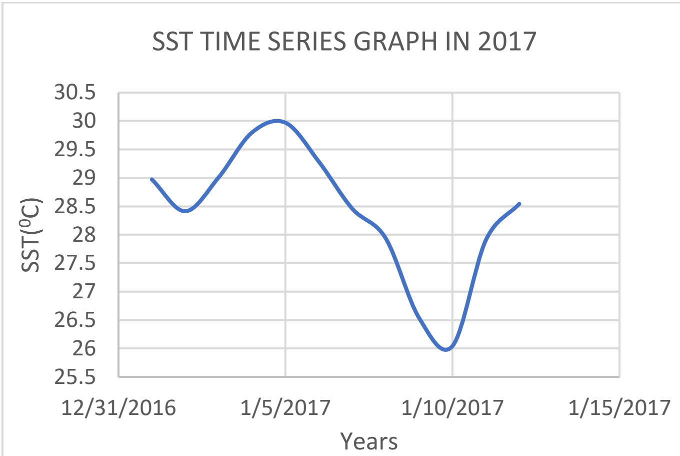
30
29.5
29
28.5
28
27.5
12/27/2015
1/1/2016
1/6/2016
1/11/2016
1/16/2016
Years


SST TIME SERIES GRAPH IN 2017
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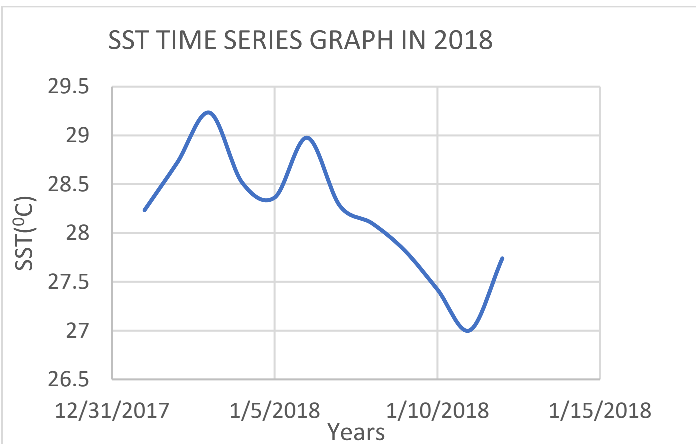
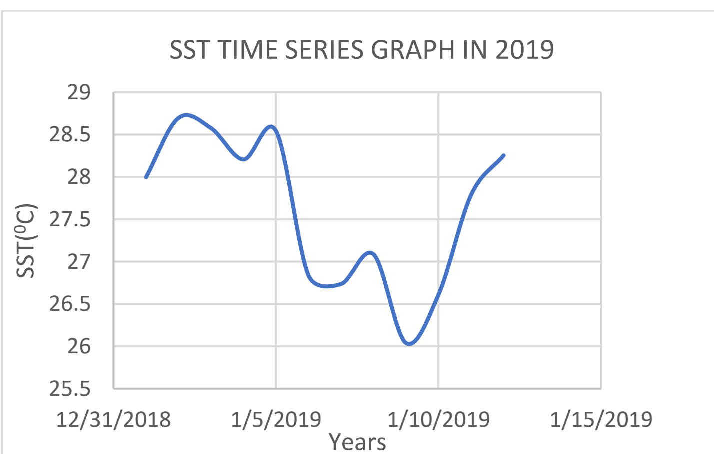
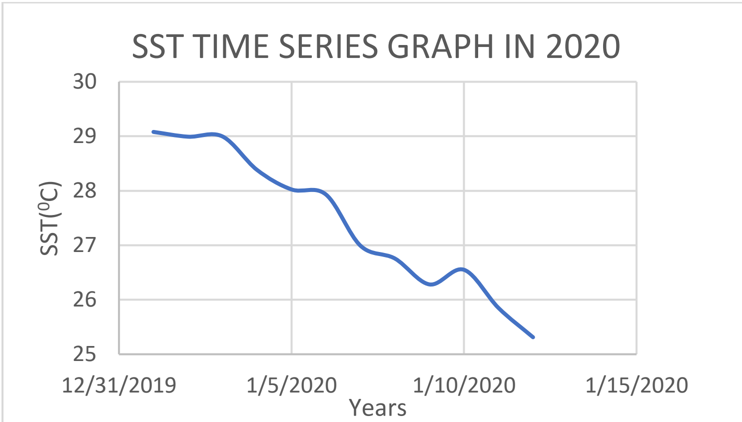
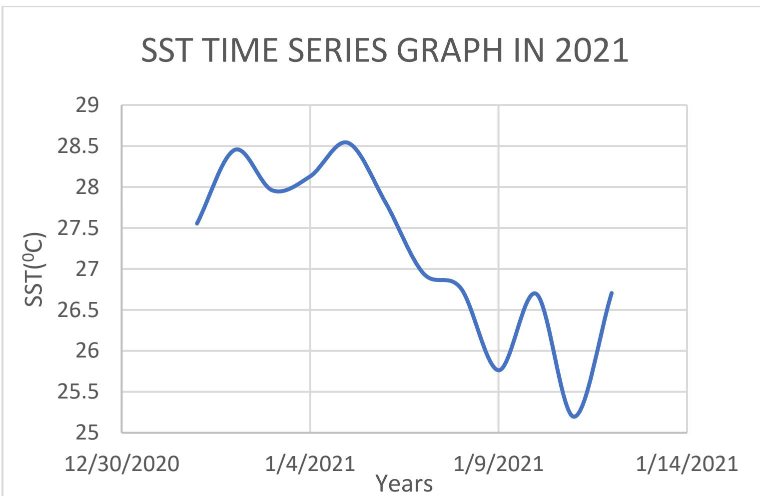
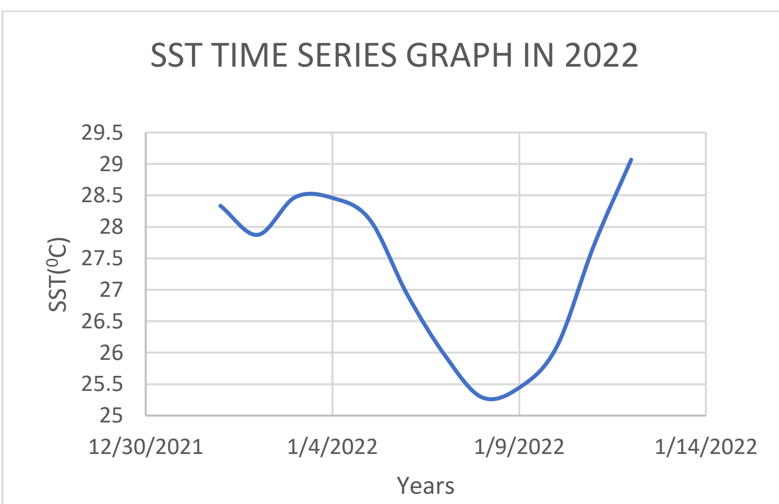
30
29.5
29
28.5
28
27.5
27
26.5
26
25.5
SST(0C)
12/31/2016
1/5/2017
1/10/2017
1/15/2017
Years


SST TIME SERIES GRAPH IN 2018
29.5
29
28.5
28
27.5
27
26.5
SST(0C)
12/31/2017
1/5/2018
1/10/2018
1/15/2018
Years


SST TIME SERIES GRAPH IN 2019
29
28.5
28
27.5
27
26.5
26
25.5
SST(0C)
12/31/2018
1/5/2019
1/10/2019
1/15/2019
Years


SST TIME SERIES GRAPH IN 2020
30
29
28
27
26
25
SST(⁰C)
12/31/2019
1/5/2020
1/10/2020
1/15/2020
Years


SST TIME SERIES GRAPH IN 2021
29
28.5
28
27.5
27
26.5
26
25.5
25
SST(⁰C)
12/30/2020
1/4/2021
1/9/2021
1/14/2021
Years


SST TIME SERIES GRAPH IN 2022
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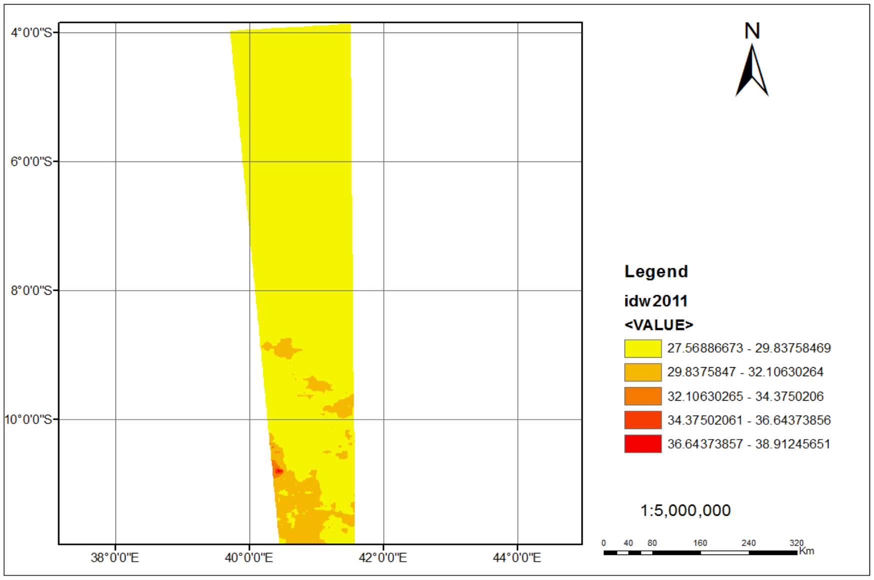
29
28.5
28
27.5
27
26.5
26
25.5
25
SST(⁰C)
12/30/2021
1/4/2022
1/9/2022
1/14/2022
Years

APPENDIX 3



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8°0'0"S
10°0'0"S
38°0'0"E
40°0'0"E
42°0'0"E
44°0'0"E
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Legend
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32.10630265 - 34.3750206
34.37502061 - 36.64373856
36.64373857 - 38.91245651
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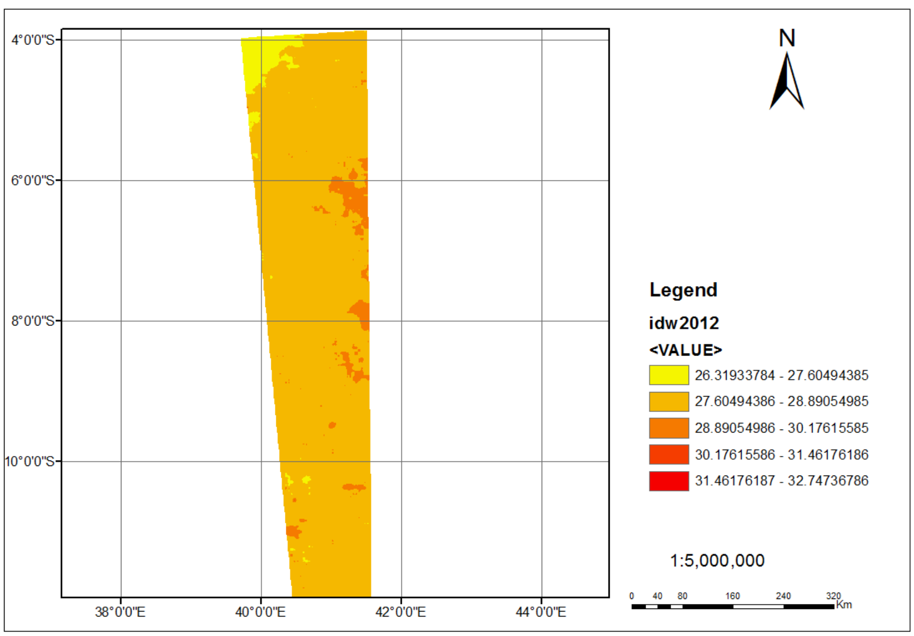
Km



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Legend
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27.60494386 - 28.89054985
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31.46176187 - 32.74736786
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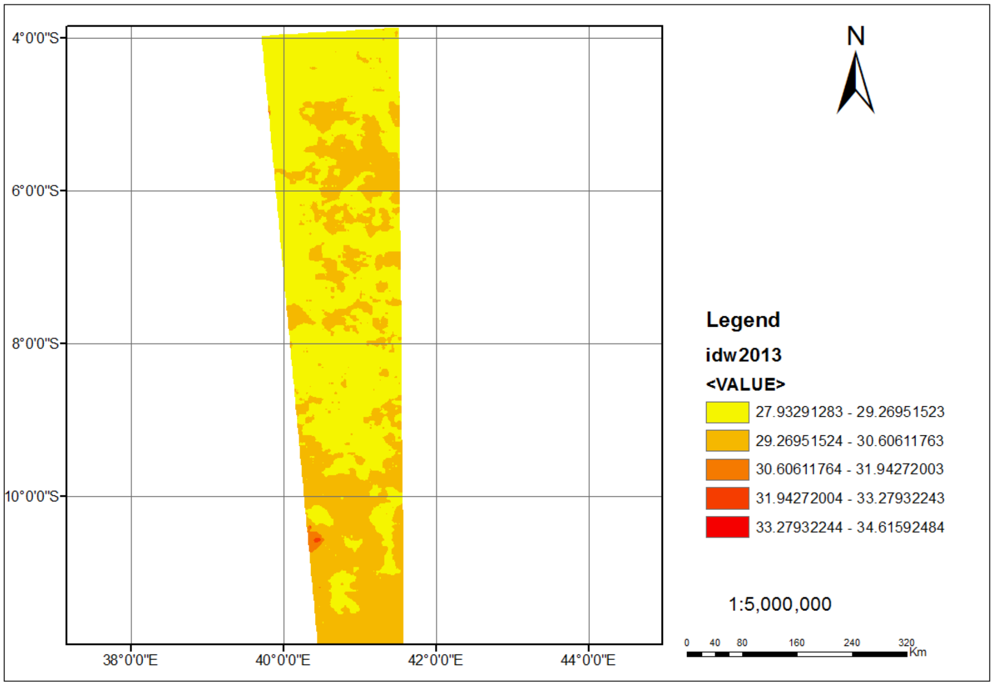
Km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Legend
idw2013
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31.94272004 - 33.27932243
33.27932244 - 34.61592484
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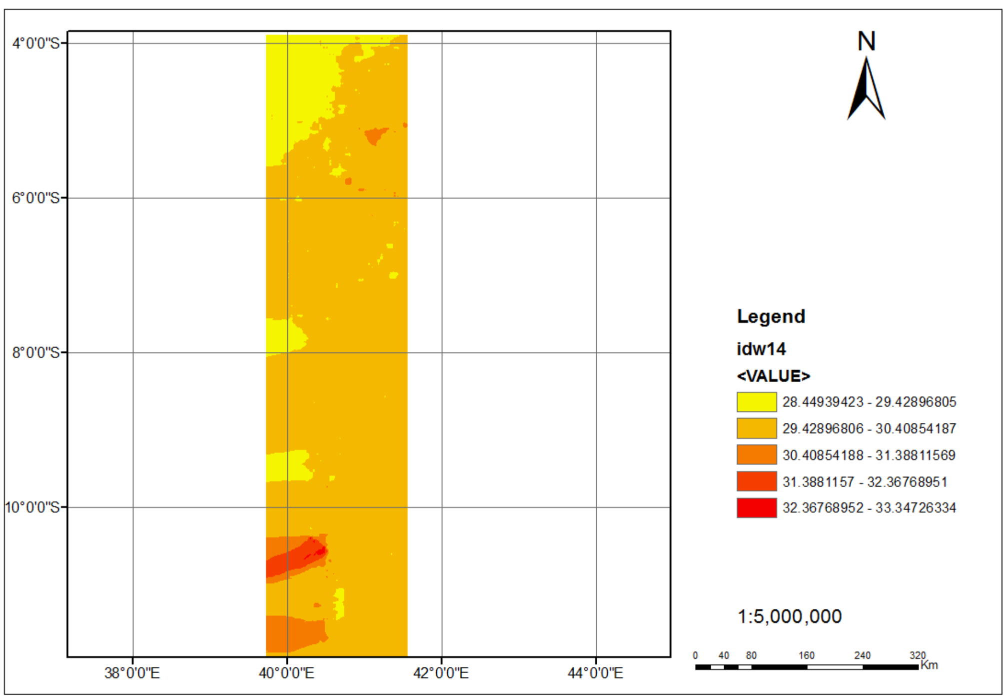
Km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40°0'0"E
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44°0'0"E
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Legend
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29.42896806 - 30.40854187
30.40854188 - 31.38811569
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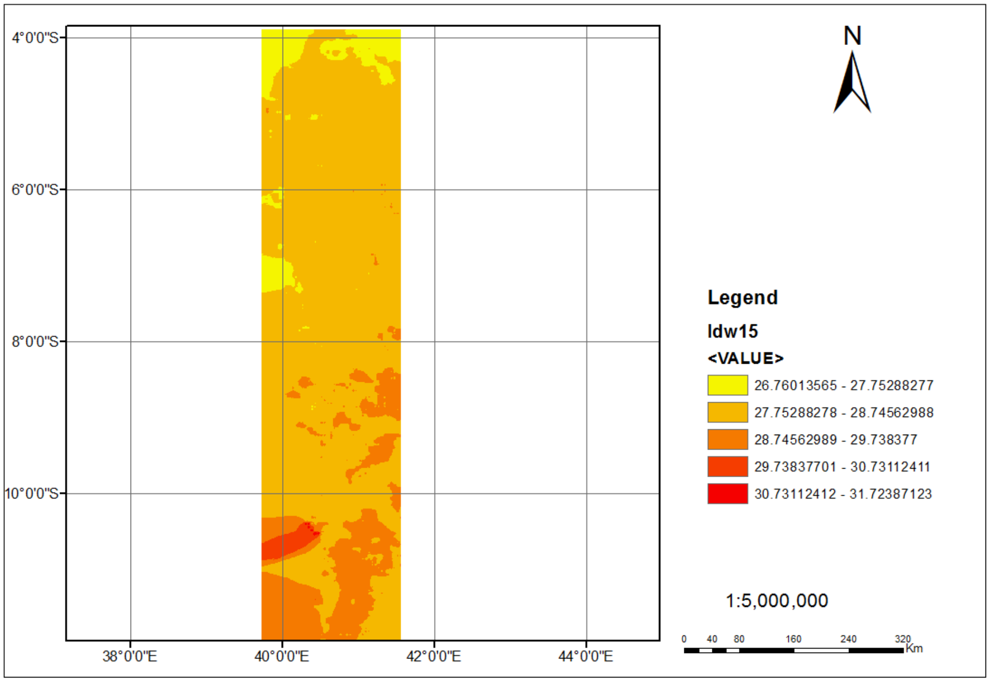
32.36768952 - 33.34726334
1:5,000,000
0 40 80 160 240 320
Km



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Legend
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28.74562989 - 29.738377
29.73837701 - 30.73112411
30.73112412 - 31.72387123
1:5,000,000
0 40 80 160 240 320 Km
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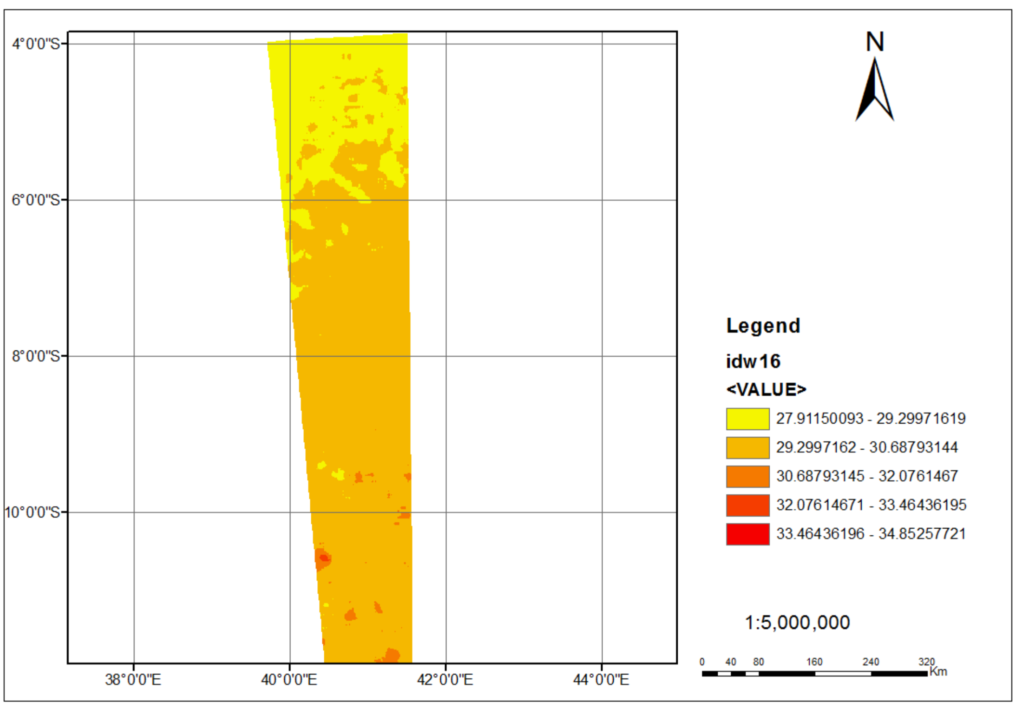
10°0'0"S
38°0'0"E
40°0'0"E
42°0'0"E
44°0'0"E



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Legend
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32.07614671 - 33.46436195
33.46436196 - 34.85257721
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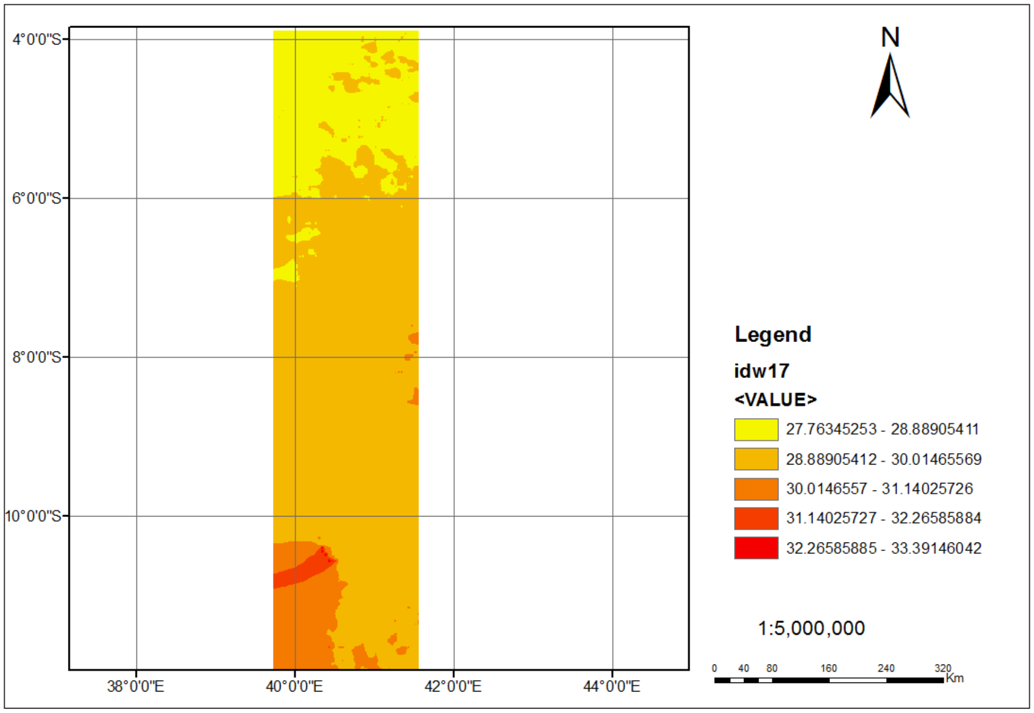
10°0'0"S
38°0'0"E
40°0'0"E
42°0'0"E
44°0'0"E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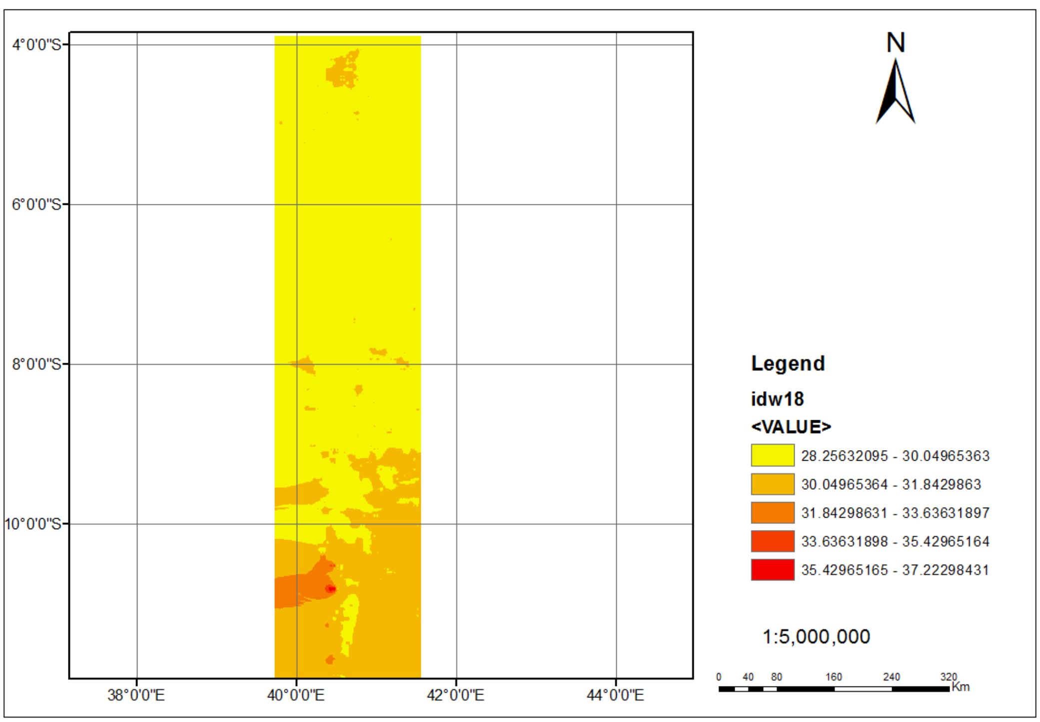
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35.42965165 - 37.22298431
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38°0'0"E
40°0'0"E
42°0'0"E
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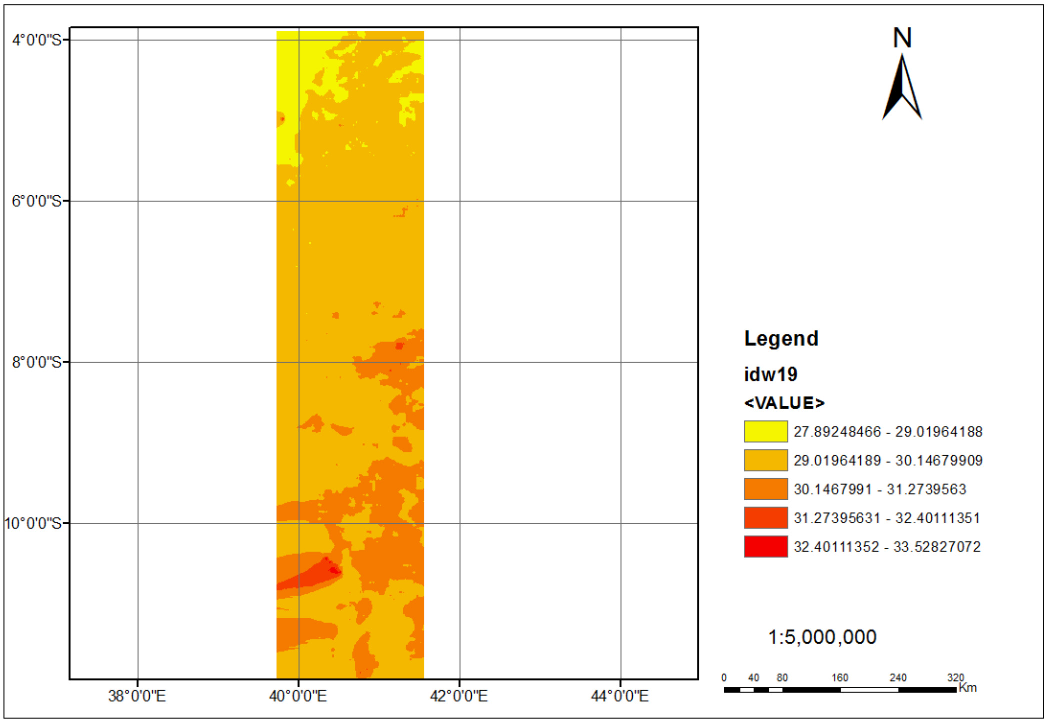
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32.40111352 - 33.52827072
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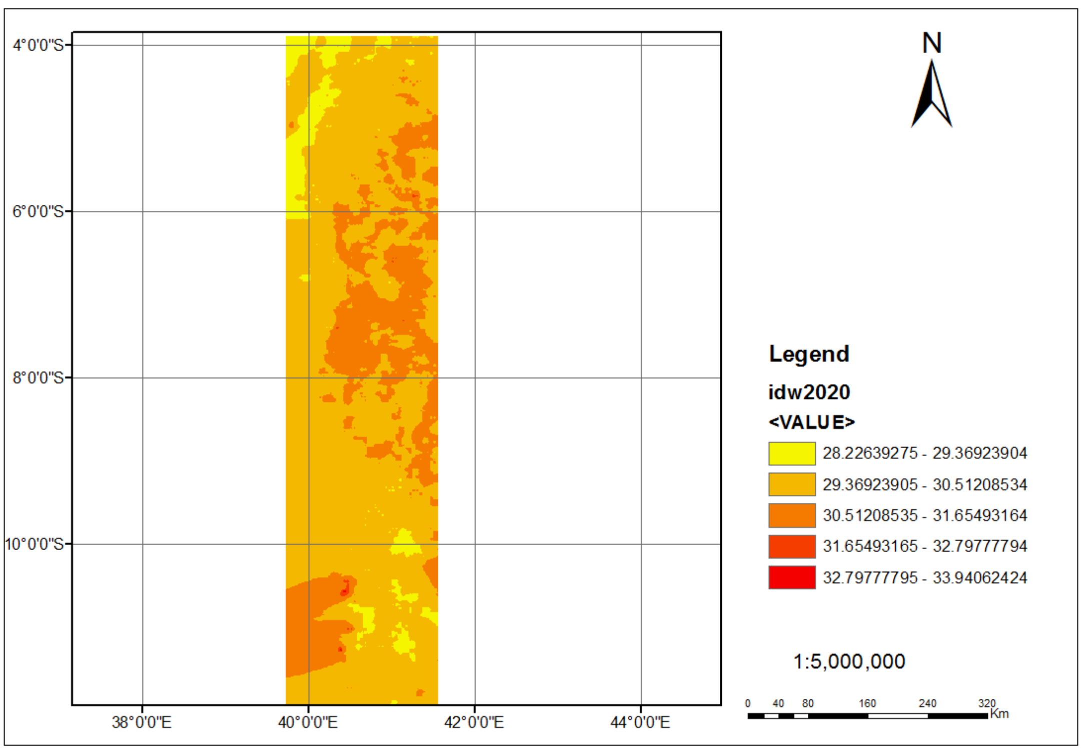
Km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Legend
idw2020
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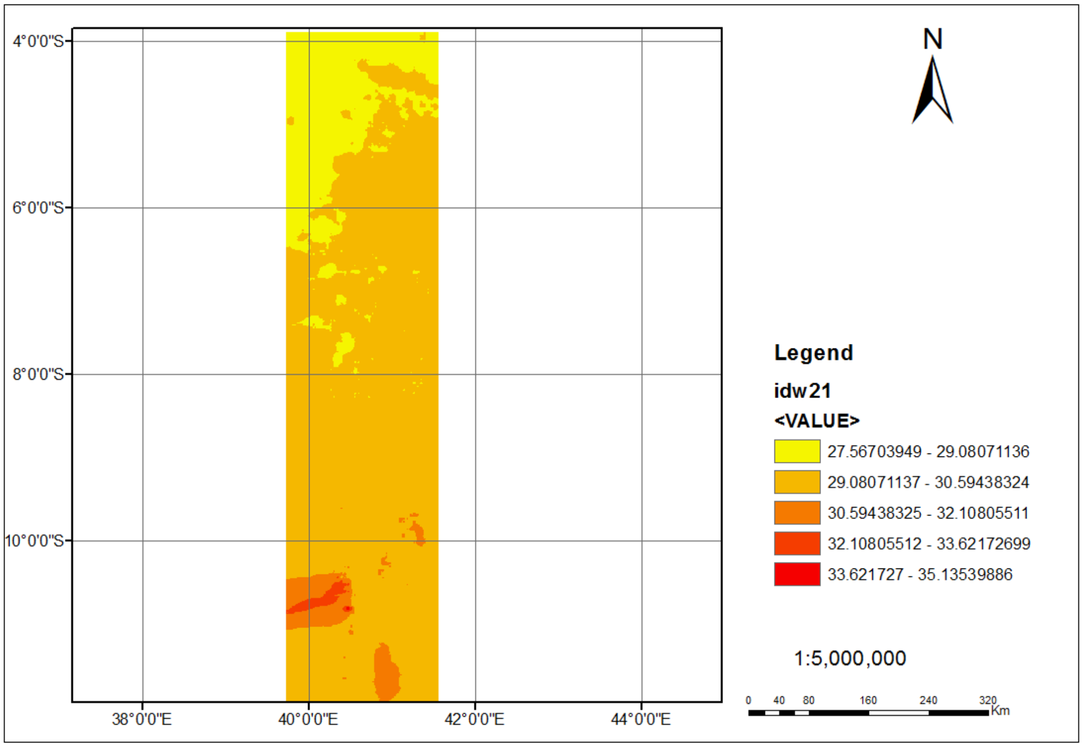
29.36923905 - 30.51208534
30.51208535 - 31.65493164
31.65493165 - 32.79777794
32.79777795 - 33.94062424
1:5,000,000
0 40 80 160 240 320
Km



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33.621727 - 35.13539886
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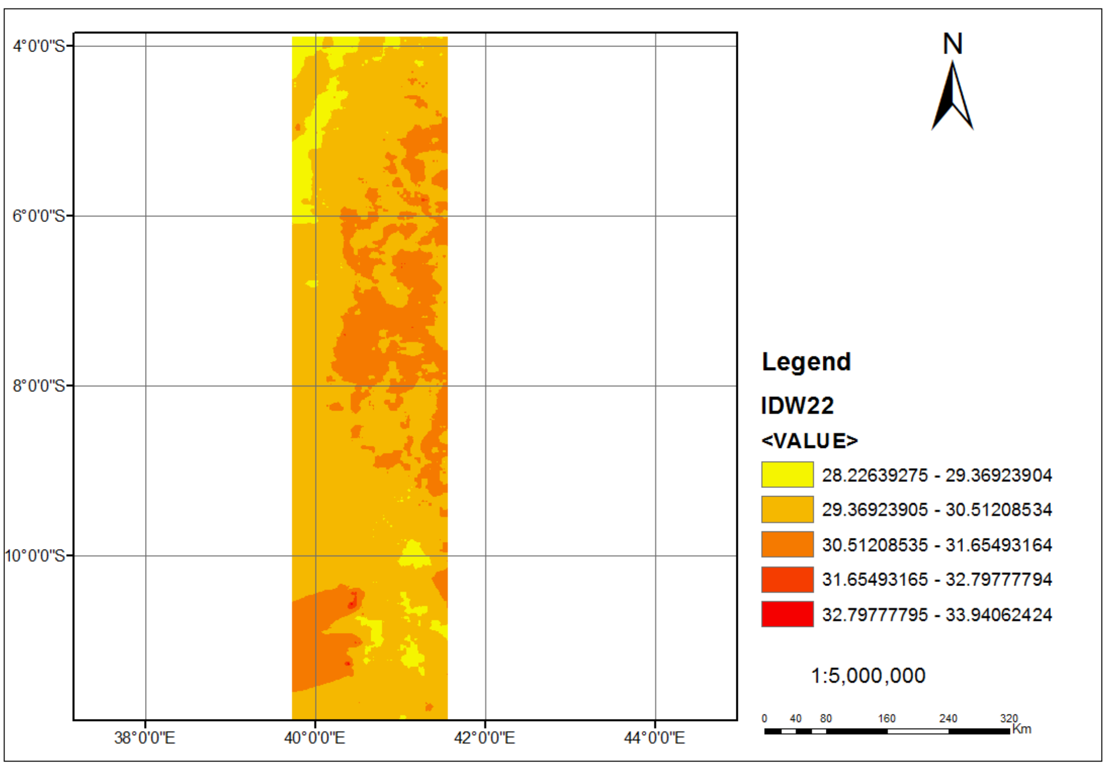
0 40 80 160 240 320 Km



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Legend
IDW22
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30.51208535 - 31.65493164
31.65493165 - 32.79777794
32.79777795 - 33.94062424
1:5,000,000
0 40 80 160 240 320 Km

APPENDIX 4

MONTHLY DATA OF SLA AND SST FROM 2011 TO 2022				
YEARS	SLA	AVERAGE	SST	AVERAGE
1/1/2011	0.022952		29.2749	
1/2/2011	0.020421		28.9005	
1/3/2011	0.014141		30.2625	
1/4/2011	0.024148		29.4809	
1/5/2011	0.016326		29.208	
1/6/2011	0.019072	0.025072	29.334	27.31155
1/7/2011	0.021679		28.187	
1/8/2011	0.029766		27.935	
1/9/2011	0.026869		27.585	
1/10/2011	0.035127		28.351	
1/11/2011	0.037033		28.649	
1/12/2011	0.033333		29.481	
1/1/2012	0.034696		28.787	
1/2/2012	0.030507		28.756	
1/3/2012	0.030988		29.583	
1/4/2012	0.027648		28.72	
1/5/2012	0.028999		29.653	
1/6/2012	0.027556	0.027468	28.715	27.20967
1/7/2012	0.026058		29.6522	
1/8/2012	0.023696		28.6955	
1/9/2012	0.024962		29.876	
1/10/2012	0.025554		29.096	
1/11/2012	0.02441		29.9515	
1/12/2012	0.024537		29.823	

1/1/2013	0.036322		29.725	
1/2/2013	0.039278		29.9982	
1/3/2013	0.030777		30.355	
1/4/2013	0.028982		30.1976	
1/5/2013	0.028669		30.52004	
1/6/2013	0.027972	0.0326033	30.4406	27.42885
1/7/2013	0.024036		29.7506	
1/8/2013	0.036505		29.4307	
1/9/2013	0.033131		28.997	
1/10/2013	0.027058		28.6008	
1/11/2013	0.035406		27.45231	
1/12/2013	0.043097		27.0208	
1/1/2014	0.038379		29.54	
1/2/2014	0.037525		29.467	
1/3/2014	0.037912		29.766	
1/4/2014	0.029436		29.2777	
1/5/2014	0.028757		28.98311	
1/6/2014	0.02865	0.033637	28.8816	27.61393
1/7/2014	0.029247		28.654	
1/8/2014	0.035048		29.8451	
1/9/2014	0.033049		28.998	
1/10/2014	0.035379		29.023	
1/11/2014	0.03623		29.946	
1/12/2014	0.034032		28.743	
1/1/2015	0.03578		29.344	
1/2/2015	0.034357		28.9427	
1/3/2015	0.036252		29.545	
1/4/2015	0.038353		29.0276	

1/5/2015	0.03697		28.986	
1/6/2015	0.034236	0.041217	28.368	28.20083
1/7/2015	0.030009		28.057	
1/8/2015	0.037272		27.8499	
1/9/2015	0.041239		28.125	
1/10/2015	0.054948		27.1016	
1/11/2015	0.057182		27.393	
1/12/2015	0.058001		27.6557	
1/1/2016	0.039226		30.00599	
1/2/2016	0.037414		29.91386	
1/3/2016	0.045934		28.78638	
1/4/2016	0.036016		29.05783	
1/5/2016	0.043333		28.30438	
1/6/2016	0.04224	0.040547	28.98811	28.4063
1/7/2016	0.039377		28.53274	
1/8/2016	0.037289		28.36783	
1/9/2016	0.039057		29.95186	
1/10/2016	0.042324		28.47274	
1/11/2016	0.038983		27.95304	
1/12/2016	0.045375		28.12132	
1/1/2017	0.04236		28.97245	
1/2/2017	0.040214		28.4138	
1/3/2017	0.04601		29.00952	
1/4/2017	0.042294		29.79873	
1/5/2017	0.04316		29.96953	
1/6/2017	0.042855	0.049844	29.28417	28.87134
1/7/2017	0.05426		28.45833	
1/8/2017	0.057749		27.9382	

1/9/2017	0.064426		26.5382	
1/10/2017	0.064709		26.04356	
1/11/2017	0.049432		27.90615	
1/12/2017	0.050656		28.54294	
1/1/2018	0.046369		28.23467	
1/2/2018	0.047792		28.71934	
1/3/2018	0.048251		29.23304	
1/4/2018	0.047184		28.5165	
1/5/2018	0.045468		28.36366	
1/6/2018	0.04972	0.051833	28.97678	28.36629
1/7/2018	0.053032		28.28069	
1/8/2018	0.054569		28.09839	
1/9/2018	0.057934		27.82008	
1/10/2018	0.052337		27.42296	
1/11/2018	0.059377		27.0033	
1/12/2018	0.05996		27.74054	
1/1/2019	0.05721		27.99619	
1/2/2019	0.055677		28.69587	
1/3/2019	0.051007		28.57588	
1/4/2019	0.051833		28.20662	
1/5/2019	0.049401		28.54156	
1/6/2019	0.057781	0.059947	26.83598	29.26038
1/7/2019	0.059772		26.73598	
1/8/2019	0.064564		27.08556	
1/9/2019	0.072203		26.03823	
1/10/2019	0.072005		26.61355	
1/11/2019	0.062972		27.78737	
1/12/2019	0.064935		28.25441	

1/1/2020	0.05932		29.08002	
1/2/2020	0.0575		28.99217	
1/3/2020	0.055237		28.99663	
1/4/2020	0.056113		28.38298	
1/5/2020	0.052135		28.02432	
1/6/2020	0.056931	0.062656	27.93065	28.8874
1/7/2020	0.065087		26.99166	
1/8/2020	0.066474		26.75547	
1/9/2020	0.071533		26.28129	
1/10/2020	0.072724		26.54985	
1/11/2020	0.071128		25.84926	
1/12/2020	0.06769		25.31195	
1/1/2021	0.058069		27.55384	
1/2/2021	0.054745		28.45257	
1/3/2021	0.058542		27.95854	
1/4/2021	0.060352		28.12854	
1/5/2021	0.048774		28.53963	
1/6/2021	0.053235	0.064412	27.81152	29.37405
1/7/2021	0.066633		26.94809	
1/8/2021	0.070743		26.76315	
1/9/2021	0.077907		25.76315	
1/10/2021	0.078132		26.69579	
1/11/2021	0.075715		25.19579	
1/12/2021	0.070095		26.70547	
1/1/2022	0.067593		28.33425	
1/2/2022	0.064655		27.87275	
1/3/2022	0.061987		28.47129	

1/4/2022	0.063784		28.46024	
1/5/2022	0.061094		28.11441	
1/6/2022	0.06518	0.069537	26.92748	29.27568
1/7/2022	0.067059		25.96769	
1/8/2022	0.072581		25.29159	
1/9/2022	0.06542		25.44303	
1/10/2022	0.079434		26.08561	
1/11/2022	0.081343		27.70251	
1/12/2022	0.084309		29.06771	