ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

A TOOL TO AUTOMATE THE PROCESS OF FLOOD RISK AREAS DETECTION DUE TO CLIMATE CHANGE.

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BILIŞİM ENSTİTÜSÜ

İKLİM DEĞİŞİKLİĞİNE BAĞLI SEL RİSKİ ALTINDA KALAN BÖLGELERİN OTOMATİK OLARAK BELİRLENMESİ İÇİN BİR ARAÇ

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*To Davis Bugaigarila Kazinja,beloved brother and friend. You lived beautifully may you rest peacifully now.We love you***.**

FOREWORD

Firstly I would like to thank God for he has granted me his mercy and I was able to complete my thesis through all the ups and downs, moments of frastruation and when I felt like giving up.

I would like to express my deep appreciation and special thanks for my supervisor Assoc.Prof. Dr Hande DEMIREL who supported me tirelessly even when I knocked at her door unrelated questions. She showed me the meaning of patience and how a real teacher,supervisor and mentor should be.

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ABBREVIATIONS

COM	**:** Component Object Model
DEM	**:** Digital Elevation Model
DIVA	**:** Dynamic Interactive Vulnerability Tool
ESRI	: Environmental Systems Research Institute
IPCC	**:** Intergovernmental Panel on Climate Change
GIS	**:** Geographic Information Systems
RSL	**:** Relative Sea Level
SLR	**:** Sea Level Rise
mm	: Millimetres
yr	: Year

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A TOOL TO AUTOMATE THE PROCESS OF FLOOD RISK AREAS DETECTION DUE TO CLIMATE CHANGE

SUMMARY

Flooding is a major hazard in the world, with increase in climate change its occurrence has also accelerated over the years. Recent major floods especially in the coastal areas that are associated with increase in sea level rise and storm surge have created a major need for predicting, monitoring and planning for future flood occurrence. Inundation affects and vulnerability of the coastal areas need to be accessed.

Using Spatial Information Science knowledge and using tools GIS software packages like ArcGIS, GRASS, QGIS and so many others has made the exposure of ecosystem services, population, and environmental hazards location easier within the different years. But these software packages come with a lot of sophisticated methodologies and many processes to delineate the flood plain thus raise the concern of automating the process.

This thesis presents a GIS-bases toolbox that was written in python scripting language to automate the process of detecting flood risk areas due to climate change. The toolbox takes the advantages of the python scripting by using the Arcpy library which allows the direct access to methodologies that are used in ArcMap (ESRI) software. This tool is used in ArcMap environment by presenting a user with an interface for data input. The required inputs to the tool include digital elevation models, climate change scenario in this case it the sea level rise, vector data showing the administrative area of interest. Other optionally data include the land use/cover data, population data and infrastructure data which are used to measure the impacts of the inundation.

The methods and approaches used in this work to show inundation events is the “Bathtub model”, this method is considered as the basic way to define flooded areas but it gives a clear picture of the areas at risk and it’s widely used by many researchers. This method results greatly depends on the input data.

The application of the tool is demonstrated in the case of the Izmir coast a city in Turkey which is further described in this thesis. The usefulness of the tool is demonstrated by detecting inundated zones along the Izmir bay and showing to which extent the area will be affected. The tool makes use of the remote sensed data and the visualization is for most part performed in the ArcMap software.

İKLİM DEĞİŞİKLİĞİNE BAĞLI SEL RİSKİ ALTINDA KALAN BÖLGELERİN OTOMATİK OLARAK BELİRLENMESİ İÇİN BİR ARAÇ

ÖZET

Sel baskınları, özellikle son yıllardaki iklim değişikliği ile giderek artan şekilde meydana gelen doğal bir felakettir. Özellikle kıyı bölgelerde meydana gelen sel baskınları; artan deniz seviyesi ve kasırgalar ile ilişkilendirilmekte, bununla birlikte gelecekte meydana gelebilecek benzeri hadiselerin tahmin edilmesi, izlenmesi ve hazırlık yapılmasına dair büyük bir ihtiyaç doğmaktadır.

Günümüzde, ArcGIS, GRASS, QGIS ve benzeri Coğrafi Bilgi Sistemi (CBS) yazılım paketleri yardımıyla, doğal afetlerin ekosisteme, nüfusa ve çevresel etkilerinin belirlenmesi geçmiş yıllara nazaran daha kolay olmasına rağmen, bu analizlerdeki çok sayıdaki farklı işlem adımları ve gerekli yöntemlerin karmaşıklığı, bu analizlerin otomatikleştirilmesini gerekli kılmıştır.

Bu tez, iklim değişikliği nedeniyle taşkın risk alanlarını tespit etme sürecini otomatikleştirmek için python script dili kullanılarak yazılmış bir CBS tabanlı aracı sunmaktadır. Geliştirilen araç, ArcMap (ESRI) yazılımında kullanılan yöntemlere doğrudan erişim olanağı sağlayan Arcpy kütüphanesini kullandığından avantajlıdır. Veri girişi için bir ara yüz şeklinde tasarlanmıştır. Aracın ihtiyaç duyduğu veriler, sayısal yükseklik modelleri, iklim değişikliği senaryosu ve senaryoya bağlı olarak deniz seviyesinin yüksekliği ve ilgilenilen idari alanı içermektedir. Bu zorunlu veriler haricinde sel riski altında kalan bölgenin arazi örtüsü/kullanımı, nüfus, gayrisafi milli hasıla ve ulaştırma altyapı bilgileri isteğe bağlı olarak eklenebilmektedir.

Çalışmada sel riski altında kalan bölgenin belirlenmesinde kullanılan yöntem “kova-küvet doldurma (bucket-fill/ bathtub) modeli” olup; bu basit yöntem, sel altında kalan alanları hızlı bir şekilde belirlemede sıklıkla kullanılmaktadır. Yöntemden beklenilmesi gereken doğruluk ve güvenilirlik, büyük ölçüde analizin ölçeğine ve kullanılan verilere bağlıdır.

Çalışmada kullanılan yöntem "Küvet modeli" olup, bu yöntem sel basmış alanları tanımlamanın temel yolu olarak görülmekle birlikte, risk altındaki bölgelerin net bir resmini vermektedir ve birçok araştırmacı tarafından yaygın olarak kullanılmaktadır. Bu yöntem sonuçları, girdi verilerine büyük ölçüde bağlıdır.

Geliştirilen aracın denenmesi için Türkiye-İzmir ili seçilmiştir. İzmir körfezinde, uzaktan algılama verileri yardımıyla elde edilen arazi örtüsü ile sel riski altında kalabilecek bölgeler entegre edilerek etki analizi yapılmıştır. Son adım olan görselleştirme adımı ise ArcMap yazılımında gerçekleştirilmiştir.

1. INTRODUCTION

With the continuous climate changes, sea level rise (SLR) and storm surges are likely to see a continuous increase within the years to come thus increasing the likelihood of the flooding of the underlying coastal areas. This argument is backed up by different studies and organizations such as the intergovernmental Panel on climate change (IPCC, 2014) which suggests a sustained rise in the sea level. The global mean sea level has risen at the rate of 1 to 2 mm year-1 (A. C. Demirksen et al 2006). With this, prediction of coastal flooding and vulnerability assessments are deemed necessary for decision makers and coastal planners (Avidesh Seenath et al 2015).

In order to make the process successful Geographical Information Systems (GIS) and hydrological models are implored. These in combination with remote sensing have become the key tools. With the nature of the hazard being spatially and advancement in the GIS tools especially in spatial analysis has made GIS a dependable tool.

A Geographic Information System (GIS) is software that provides spatial information by linking locations with information about that location (Peggion et al 2008). They provide the functionality to analyze hazards, vulnerability and risks, and plan for disasters. GIS can also be defined as a system of capturing, storing, manipulating, analyzing, and displaying spatial information in an efficient manner (Vassilios A. Tsihrintzis et al 1995). It can be characterized as a software package that efficiently relates graphical information to attribute data stored in a database and vice-versa (Kurt et al., 1993). Over the years a significant change has been observed in the GIS technologies and led to the development of different software packages.

In cooperation with the strong functionality provided by the GIS software packages, the most commonly used technique for assessing SLR impacts is the use of digital elevation models (DEMs) to identify potential flooding areas for various future SLR scenarios (Pablo Fraile-Jurado et al 2012). There are different type of DEMs that can be used for the for flood inundation. There are freely available DEM like the SRTM, which are easily available for everyone. But these come with the disadvantage of the resolution. The availability of high resolution digital elevation models (DEM) such as LIDAR and SPOT has made the prediction of flood prone areas more accurate but cannot be accessed by everyone and sometimes tend to come at a high price. It’s to be noted that topography such as the DEM plays a crucial role in flood modeling because its greatly influence the output results such as the duration and extent of flooding thus any mistakes with be carried to the output (Pablo Fraile-Jurado et al 2012, Jeffrey D. Colby et al 2010).

With all this advancements in the GIS software packages, still there is quite a number of processes required in the delineation of flood prone areas with most of the processes requiring different tools within the software package to accomplish a single task. GIS packages such as ESRI's ArcGIS offer a number of sophisticated tools that help regarding such analysis. Yet there are still gaps and pitfalls that need to be combined into a geoprocessing model to automate the complete assessment workflow. In this study a complete automated workflow based on ArcGIS Model Builder coded in Python using standard Object orient programming methods specifically designed for ArcMap will be introduced and discussed .Some additional tools have been implemented to complete the overall workflow. The new tool has been coded in python which provides powerful capabilities for the analysis processes.

1.1 Problem statement.

In the recent years there has been a lot of studies addressing the coastal inundation and outlining the processes that are needed to obtain these areas. A lot of GIS tools have been developed along too. With this advancement in the GIS software, it has made flood modelling easier. But this does not solve the problem for non-experts who are not familiar with the vast tools available out there. This study intendents to improve on the processes of flood areas delineation using GIS software by creating a tool in python script that automates the steps of inundated zone detection so as to make it easier for scholars who have little or no knowledge of the software to predict inundated zones easily.

1.2 Objective Of The Research

The objective of this research is to develop a python toolbox that automates the process of detecting coastal inundation zones due to sea level rise. The tool will be used in the ArcGIS environment.

The specific objectives of this research regarding model development include:

Develop an automated process for coastal flood prediction which applies both the GIS technology and remote sensing information by using spatial information found in the DEM combining it with hydrological methods such as “bathtub methodology”.

Produce coastal inundated maps that would help decision and policy makers make better decisions and reduce the cost of flood damages especially to the densely populated coastal areas.

Roughly estimate the population and infrastructure such as roads and building that would be affected by inundation.

1.3 Hypothesis

Flood modelling in coastal areas due to sea level rise has become one of the important aspects for researcher due to estimated increase in sea level rise due to climate change. Modelling of floods requires experts or people with vast knowledge of the present GIS platforms and hydrological models. This study provides a look at the process to automate the procedures by developing a python toolbox. The study hopes to use the toolbox to estimate the extent to which the coastal zones will be inundated in case of sea level rise at the same time outline the infrastructure and population affected for better decision making for the future design implementation of coastal zones. This hypothesis is going to require several input data from the user such as the digital elevation model, land use/land cover data from the user to run smoothly.

2. LITERATURE REVIEW

The term flooding can be described as “A general and temporary condition of partial or complete inundation of normally dry land areas from overflow of inland or tidal waters from the unusual and rapid accumulation or runoff of surface waters from any source (http://www.ga.gov.au/scientific-topics/hazards/flood/basics/what)”.

Floods are the most common occurring natural disasters that affect human and its surrounding environment (Vimalkumar A Vaghai 2005). The number of reoccurrence has been rapidly increasing in the recent years. There are several different types of flood experienced by the different communities. Some of the general groups of floods include riverine flooding, urban drainage, ground failures, fluctuating lake levels and coastal flooding (https://training.fema.gov).

There has been a lot of focus on the coastal flooding by many researchers in the recent years; due to the fact that coastal zones have become more susceptible to flood risks due to rapid climate changes in the past century. Also accompanied with the high urbanization and densely populated in these areas, studies estimate that over 1.2 billion people are living within 100km of the coast (Small et al 2000, Vivien Gornitz et al 2008, Mathew .J.Purvis et al 2008) and most of these areas are estimated to be 100m below the sea level. With this population and expectation for it to increase more in the coming years the evaluation of flood risks in the coastal areas has become a very crucial requirement for hazard management and planning at both regional and local levels for countries with coastal areas (Paul D. Bates et al 2005). Studies show that more densely populated areas are more at risk compared to their counter parts with low populations.

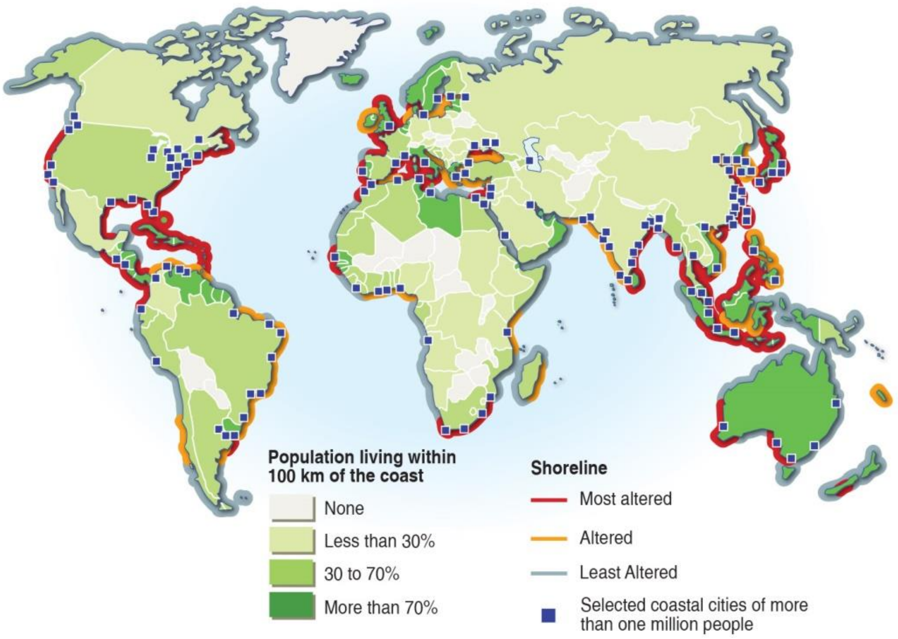

Figure 2.1 : A world map showing the population living within 100km of the coast and the most altered coasts due to urbanization.

Coastal areas has been affected by other natural disasters like storms surges, storm waves and tsunamis thus the increase in sea level which is one of the evident risk of climate change poses a greater risk of increase in the occurrence of extreme weather events such as floods (Nicholls 2002, Paul D. Bates et al 2005). Different studies have been carried out by a lot of authors to evaluate the impact of SLR on global and local levels. Jung Wang et al 2017 looks at how the Shanghai coast be affected by the strong surges by the year 2050 suggesting the impact will be stronger than we project as the time increases. Annisaa .H. Imududdina (et al 2013) calls for better preparation as they study the Surabaya coast in Indonesia.

Reports on global climate changes (Church et al 2013, F .Antonioli et al 2016, intergovernmental panel on climate change (IPCC)) warn on the rapid increase in the SLR in the 21st century. It is estimated that global sea level has been rising at a rate of about 1.7 to 1.8 mm/yr. over the last century, with an increased rate of about 3 mm/yr during the last decade (Rosenzweig, C. et al 2007). These are changes that are observed on the global range, thanks to different factors like topography and climate change, regional sea level change will have a different pattern.

With a great population and rapid urbanization of coastal zones (W. Neil et al 2005, F. Antonioli et al 2017, Carreau et al 2007) the focus on resilience to coastal hazards has become the major topic for researchers in recent studies (W. Neil et al 2005, Adger et al 2005, Jeroen C.J et al 2014). They have made many attempts to identify the main elements of resilience in general. For instance, the IPCC, in its 3rd Assessment Report, defined resilience as “amount of change a system can undergo without changing state” (IPCC, WGII, 2001, p. 943). Similarly, resilience is defined as “the ability of a system to withstand or accommodate stresses and shocks such as climate impacts, while still maintaining its function” (Dickson et al. 2012, p.18). To reiterate this point, W. Neil et al 2005 suggest that the vulnerability to disasters and particular extreme events are influenced by the erosion of resilience during and after the disaster. This is due to the fact that resilience of coastal societies is more linked to larger scale processes like the economy system, transportation and other ecosystems found in these zones (W. Neil 2005).

Results obtained from flood modelling have a great dependence between the modelling techniques and the a vast knowledge of the available software and their tools. Over the years the development of easy to use software packages like ArcGIS, QGSI, and GRASS has bridged the gap between the technical knowledge requirements and the application of well-known flood modelling techniques (Elkhrachy 2005, Vahdettin Demir and Ozgur Kisi 2016). These software packages also allow the development of reusable scripts written in different programming languages like Python, R, Matlab, Java etc. This makes GIS capabilities extend more and efficient in the analysis of different topics pertaining to earth science. This also allows researchers to build tools that can be used to automated different analysis processes that would otherwise take longer to perform.

2.1 Sea Level Rise And Its Impact

Over the last century there has been a drastic increase in the overall sea level rise which was mainly caused by the world climate changes. According to European Environment Agency (EEA, 2014), "Sea level is an important indicator of climate change because it is associated with significant potential impacts on settlements, infrastructure, people and natural systems. It acts on time scales much longer than those of indicators that are closely related to near-surface temperature change. Even if greenhouse gas concentrations were stabilized immediately, sea level would continue to rise for many centuries".

The expansion of the oceans due to global warming and the transferring of underground water from the land, melting of glaciers and ice sheets can be considered as one of the main factors contributing to sea level changes (Church et al 2013).

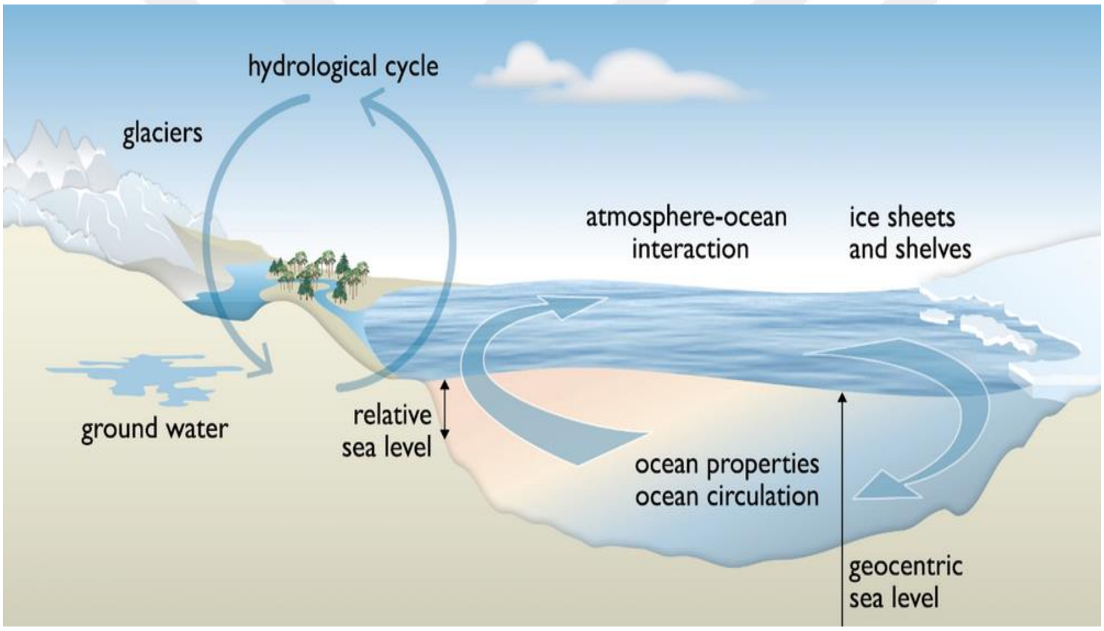

Figure 2.2: The contributing factors to sea level rise

The prediction of SLR for the future scenario is being based mainly on the analysis done in the past. There are different types of data that are collected in order to produce standards certain standards. It is estimated that the sea level rise has been constantly increasing in the 21st century at a rate of 1.7±. Although this data is being collected, the uncertainty associated in associated with SLR still pose a greater threat when the planning assumes a constant level. Church et al 2013, elaborates that SLR can be measured by using two factors, that are surface of the solid earth (Relative sea level (RSL)) or a geocentric reference (geocentric sea level). It further expresses that in coastal flooding studies influenced by sea level changes, RSL should be taken into consideration.

Many coast zones are expected to be affected by this increase in SLR (F. Antonioli et al 2017). The most critical areas include the coasts of Turkey (Anzidei et al., 2011), the northern Adriatic (Antonioli et al 2007; Lambeck et al., 2011), the Aeolian Islands (Anzidei et al., 2016), the coast of central Italy (Aucelli et al 2016) and eastern Morocco (Snoussi et al 2008).

2.1.1 Sea level rise scenarios

The IPCC has used different models and methodologies to put the past and future sea level rise into perspective while considering different causes. In order to have a clear level they have included different parameters such as combinations of demographic change, social and economic development, and broad technological developments to stimulate the scenarios over the years like the Representative Concentration Pathway (RCP) which mainly looks at the increases in ocean warming and loss of mass from glaciers and ice sheets. These scenarios have been used in different studies to project the sea level rise and coastal affected areas (Katsman et al. (2008), Yin.L 2012). The IPCC defines rates of SLR using different modeling tools. These models are process based and the processes considered by the IPCC are as follows (Church et al, 2013):

- Thermal Expansion
- Glaciers melting
- Greenland ice sheet change
- Antarctic ice sheet change
- Land water storage
- Greenland ice sheets rapid dynamics
- Antarctic ice sheet rapid dynamics

Even with all these put into consideration the biggest uncertainty attached to SLR still remains in determining the actual rate of SLR. Keeping in mind the number of contributing factors and their surrounding uncertainty, pin pointing a rate of SLR at a given location still remains very difficult. Decision makers must consider all projections and select one they think will be the most appropriate for problem under consideration.

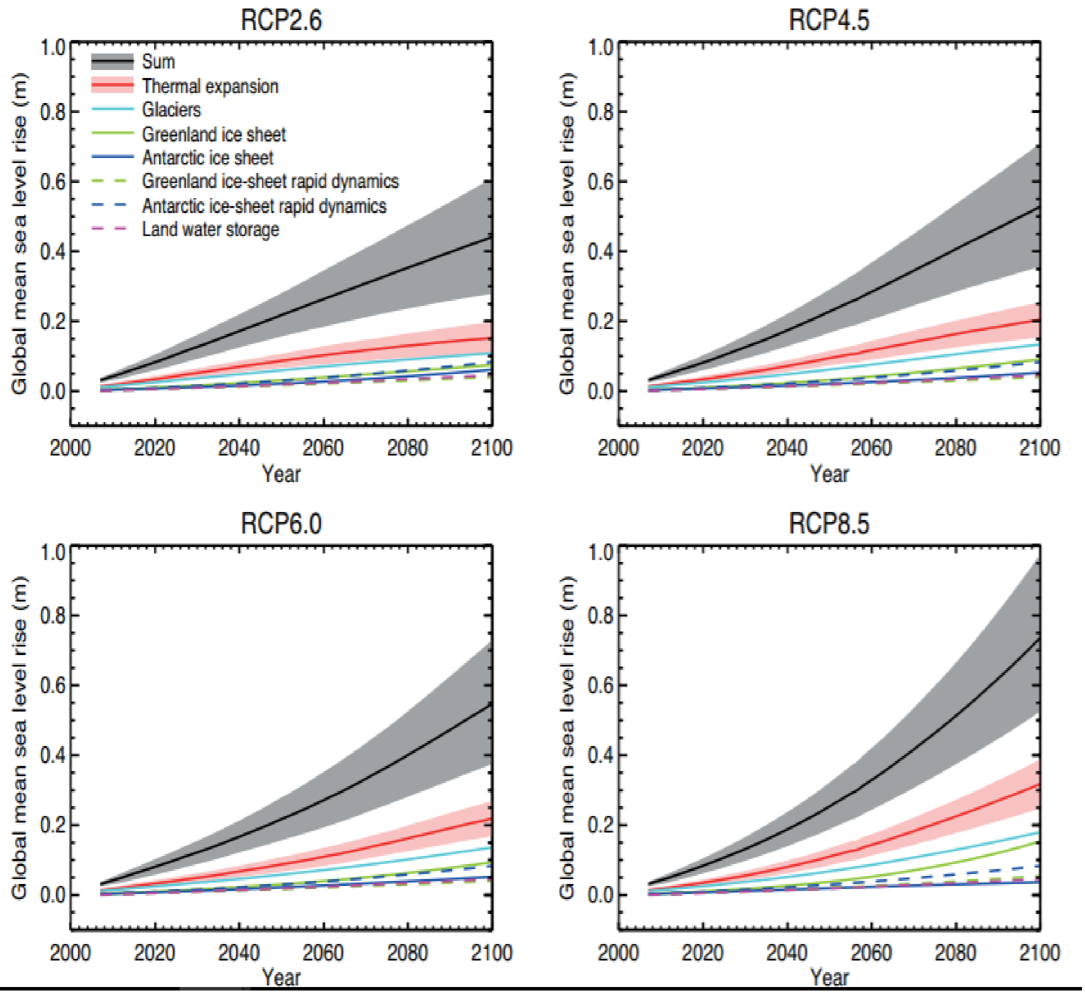

Figure 2.3 : Sea Level Rise at different prediction as estimated by the IPCC 2013

2.2 Flooding Modelling.

Coastal vulnerability assessments due to climate change are not a new subject. Extensive studies have been done over the years with several models developed for flood delineation and vulnerability assessment developed (Jeremy R. et al 2013, Sergey Reid et al 2014). With these models different tools that are GIS based have been developed. The advancement in the modern geographical information systems

(GIS) offers more reliable methods for collection, storage, analysis and display of spatially distributed data (Goodchild et al 1992). This has also provided researchers and scientist an opportunity to develop more stable applications. Although the improvement can be observed in the approaches to flood risks prediction, modelling and mitigation processes as well as the integration of the GIS technologies and the hydrological models there is still a need to make them more reliable and effective(Liu Yong 20..). It should be noted that the accurate quantification of the flood extent is very important in the process of prediction of future occurrence, planning and most important decision making. The use of GIS applications and hydrological models greatly rely on the data provided.0.3mm yr-1 (Church et al 2006).

Even with all this advancement, coastal flooding due to sea level rise still pose a lot of challenges this is due to the facts that sea level is not constant along the coast, different soil types can be found along the coast, complexities of the geometrical complexity of the sea shore and other natural processes along the coast such as storm surges, waves, hurricanes and soil erosions. Studies show that the methods for detecting coastal inundation have been based on using hydronamics or GIS-based models of varying complexities (Mathew.P.Wadey et al 2015, Rosemary A.E et al 2011, Bates et al 2005 and W.Galien et al 2014). Other approaches have been used too by different researchers like Paul.D.Bates who suggests a simplified 2D numerical modeling which he urges could evaluate the coastal flood impacts within risk-based framework. Mathew Purvis proposes a probabilistic methodology to estimate future flood occurrence putting into account other environmental uncertainties such as changing storm surge and magnitude distribution. With all these proposed methodologies and approaches a simple static ("Bathtub") model which simply compares the DEM cell elevation and water level and floods any cell that does not meet this is commonly used (B.Poulter et al 2007, G.Titus et al 2001).In recent studies this model has been very much criticized for either overestimating or underestimating the flood extent or not taking into account the dynamics of the sea level itself (T.W.Gillien et al 2014,Javier X.Leon et al 2014,NOAA,Schmid K et al

2013). In addition to tides, sea levels vary due to waves (set-up and run-up), storm surge (wind driven and barometric set-up) and changes in ocean circulation. Each of these processes can greatly affect the sea level. Even with all these criticism the methodology is still used due to its practicality especially in large spatial scales.

The use of Digital elevation model (DEM) data which describes the topography of the area is very crucial when performing flood modelling. DEM have been used in a lot of GIS-based modelling applications, in areas like modeling vulnerability to sea-level rise (Coveney and Fotheringham, 2011; Cowell and Zeng, 2003; Dobosiewicz, 2001), coastal flood risk (Gornitz et al 2002; Webster et al 2006), and erosion sensitivity (Leatherman et al 2003; Woolard and Colby, 2002). But it should be noted that spatial resolution of this data greatly affect the topographic features and can be detected in the final results like flood risk maps especially when visualizing sea-level rise (Poulter & Halpin, 2008). As Xiaoping Du et al 2014 further elaborate; it is necessary to understand the accuracy of elevation data before a specific application.

Attempts have been made to assess the accuracy of DEMs from both global and regional. With the release of high resolution DEM like light detection and ranging (LiDAR) information has been utilized to increase the spatial resolution of DEMs up to 3 m and the spatial resolution is sufficient to create flood inundation maps (Byungyun Yang 2016).

2.3 Relationship Between GIS And Flood Models

GIS has become part and parcel of flood modelling. There are different extents to which GIS is involved in the flood modelling, as Andre Zerger (et al 2003) further elaborates, the link can be tight integration where all the process are performed within the GIS to where some of the analysis processes such as visualization of the hydrological models is done in GIS. With recent advancement in the GIS technologies more of the modelling is being done within GIS (). This has brought about more advantages like easy access of data, better visualization and cost effectiveness. The use of GIS coupled together with remote sensed data in coastal flood modelling has made great advancement in recent years giving coastal flood modelling a boast in both accuracy and efficiency.

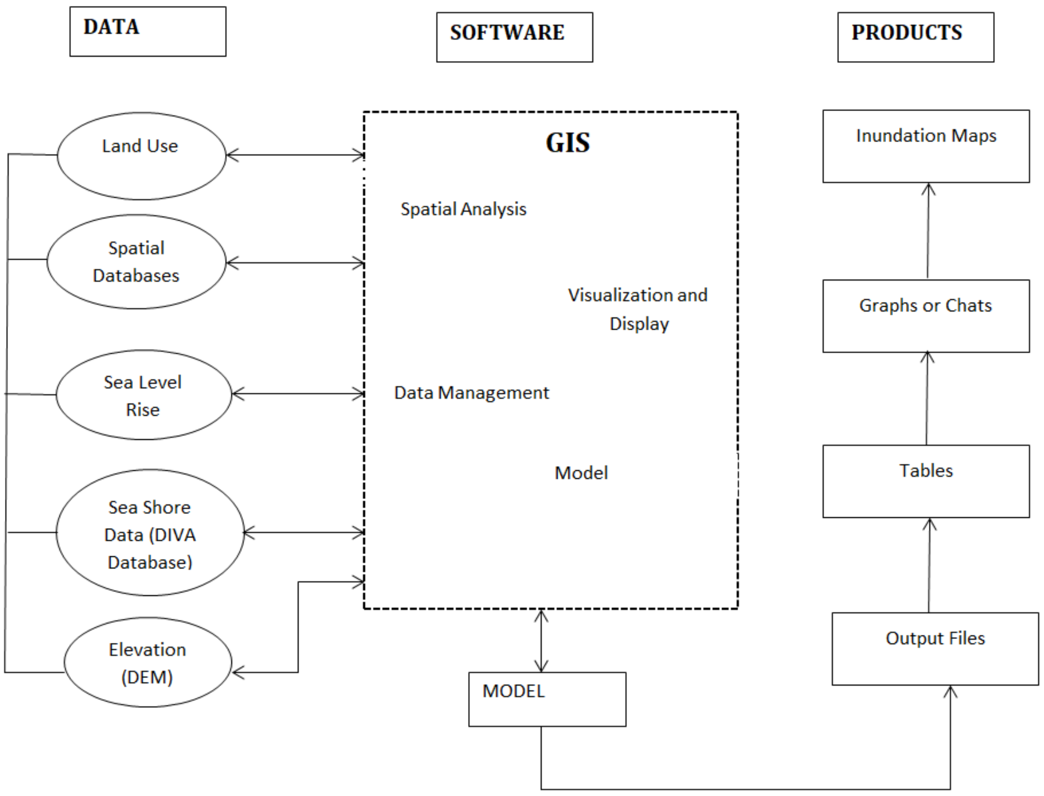

Figure 2.4: Relationship between GIS and Flood Modelling

3. BUILDING THE PYTHON TOOLBOX

The main goal of this thesis is to develop a GIS-based tool written in python scripts.This tool automates the inundation zones detection process, it is developed to primarily use the digital elevation model (DEM) to produce inundated zones. The obtained inundated zones are then overlaid with geographical data such as land use/land cover data, transportation or population data to assess the impacts of inundation on the coastal zones. The tool uses different sea level scenarios to obtain inundated zones. The building of the python toolbox comprises of the following stages:

- Identifying the methods/tools to be assembled
- Identify the flood model to be used
- Building the toolbox using the methods.
- Apply the toolbox with our study area.

The tools and methods necessary to process inundated zones we identified. The tool was built by assembling Arcpy methodologies that were coupled with the “Bathtub” approach to detect the inundated areas. The tools were used as process models to the tool, allowing the users to document the results according to their needs. The language of choice for programming is Python. Python is easier to learn and use making it easy for the GIS professionals who are not full time programmers. In some spatial statistical tools, python has been used to develop them entirely, this is due to the fact that python not only does it provide the easy of a scripting language but the full functionality of a programming language.

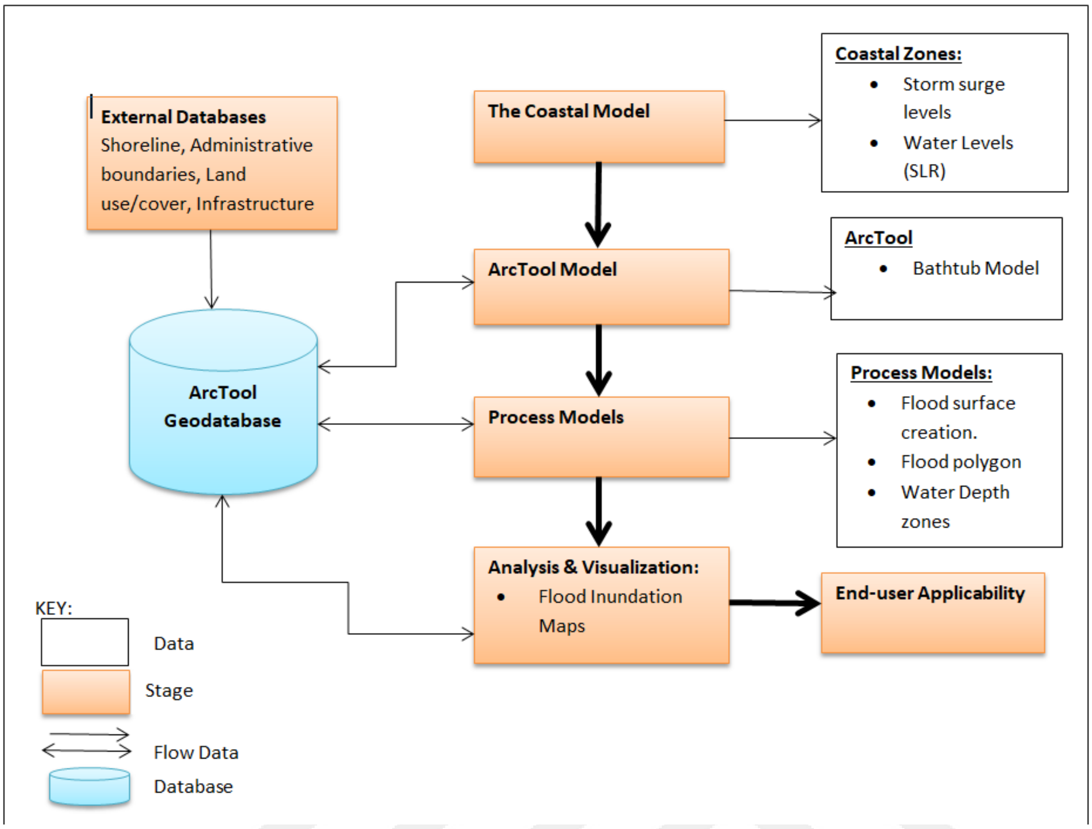

Figure 3.1 : The general flow of data with the toolbox.

3.1 The GIS Software.

The GIS software that was selected to run the toolbox is the ESRI ArcGIS Desktop. With a lot of developed GIS platforms with advanced and complex features, the Esri's ArcGIS software package is the most commonly used GIS platform worldwide. The ESRI ArcGIS has a unique geodatabase development environment and advanced data modelling capabilities present in no other GIS software package making it more suitable for the study.

The concept of scripting languages and extension of the software package was introduced in the ArcGIS 9 version giving a room for multiple scripting languages like VBScript, JavaScript, Jscript, Perl and Python. Having component object model (COM) compliance, ArcGIS gives the scripting languages the capability of access most of its functionalities and extensions thus making the automation of tasks effective and efficient without a lot of complications. Over the years ArcGIS had allowed several scripting languages to extend its functionalities and automate workflow. Some of the scripting languages were built in thus could be installed by default together with the ArcGIS software. Visual Basic for Applications (VBA) had been the most widely used and it could be installed by default together with ArcGIS. Although ArcGIS continue to use other high level programming languages such as C++, .NET and its objects written in Java, from the updates of ArcGIS 10, it has encourage the use of Python language for its extension.

3.2 Processing Of Data In The Toolbox

The tool uses several methodologies in order to detect the inundated zones. These methods require the input of several types of data to run smoothly. The preparation of the data for tool is as essential and the running of the processes themselves. Flood modelling results being data dependent makes the processes of choosing and preparing data very important. The data to be used in this tool would be prepared prior with other GIS and image processing software. These data are going to be coupled with the static methodology ("Bathtub") to detect the inundated zones at the coastal area. This methodology ("Bathtub") only requires two variables (elevation and the water level). The tool requires the following data from the user:

- Digital Elevation Model (DEM)
- Vector data of the boundary of the study area
- Land use/land cover data (optional)
- Infrastructure data (optional)
- Population data (optional)

To generate the inundated zone, a spatial querying was conducted on the Digital Elevation Model (DEM) provided by the users. The spatial query used the Raster calculator methodology which iterates through the cells of the raster data comparing if the cells are less than the water depth provided. The result obtained here is just estimating the inundation zones without any consideration to the hydrological aspects. Therefore the results which area raster based are converted to polygon where an overly analysis is performed to determine the cells that are below the estimated sea level rise and are connected to the coastal area. This step produces the flood areas only connected to the coastal area.

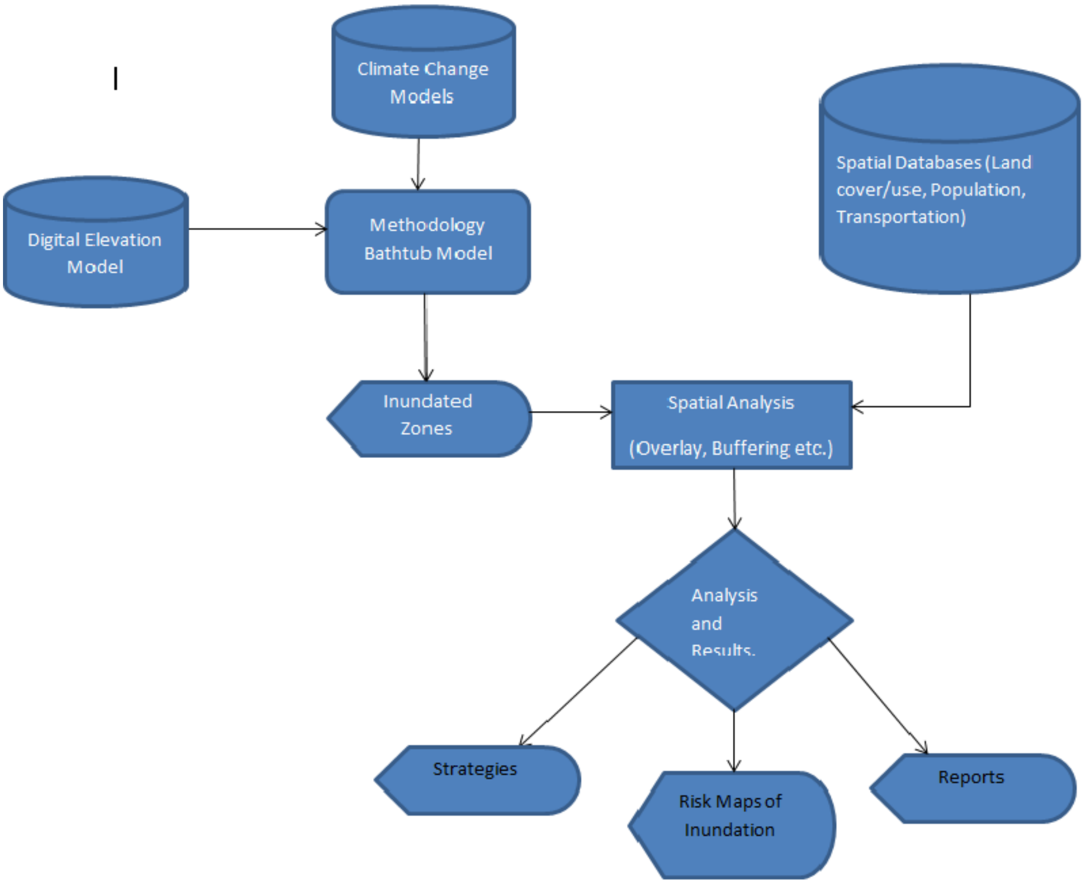

Figure 3.2 : General work flow of the methodology.

3.2.1 Bathtub model

The methodology proposed for this study and that is used in the python toolbox is based on the static (‘Bathtub’) model which is sometimes referred to as equilibrium model. This method determines the inundated zones by assuming all areas with elevation height less than the water depth provided will be flooded(Ali.P.Yunus et al 2016).This method is very simple and basic containing only two variables, i.e the Digital elevation Model and the water depth. Due to its simplicity the method has been used in various studies providing sufficient results (Bas Vande Sand et al 2012, Ali.P.Yunus et al 2016 and Javier X.Leon et al 2014). The determination of inundated area by this method can be performed by calculations that are found in the GIS software easily. In order for the area to be considered flooded its elevation height which is obtained from the DEM of that specific area is compared to the water depth and the areas below this are deemed flooded. This method does not take into account the hydrological factors associated with the coastal areas or any other features present (T.W Gallien et al 2014), it is only concerned with the elevations of the area.

Over the years this method has accumulated critics due to its simplicity, overestimating or underestimating inundated zones, not taking into account the hydrological coastal factors thus leading to several modifications to the original approach. Several studies including Vaan de Sante et al 2014 have proposed the simulation of inundation zones with hydrological connectivity in mind is more reason because in this way only the coastal zones or the directly adjacent land zones are determined (Ali.Y.Pius).

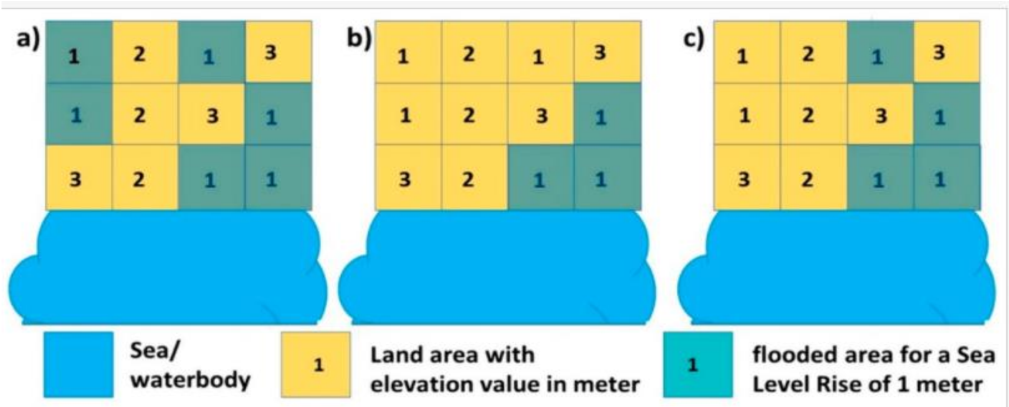

Figure 3.3 : Inundation due to sea level rising using the Bathtub model. a)Cells below sea level are inundated b.)Inundation due to4-way connectivity c.)Inundation due to 8-way connectivity.

In this approach the cell is considered inundated if it's below the given water depth and it is connected to a cell that is either flooded or connected to the water surface (Ali.P.Yunus, Poulter and Halpin, Vaan de Sante). The connectivity can be looked at in two ways, the eight-way connectivity or the four-way connectivity. In the eight-way connectivity a cell is considered flooded if is below the given water level and its neighboring cells in the cardinal and diagonal directions are connected. In the counter part of the four-way connectivity, a cell is flooded if it's below the water depth and its connected to a cell connected directly to the water body or via adjacent cells in the cardinal directions only.

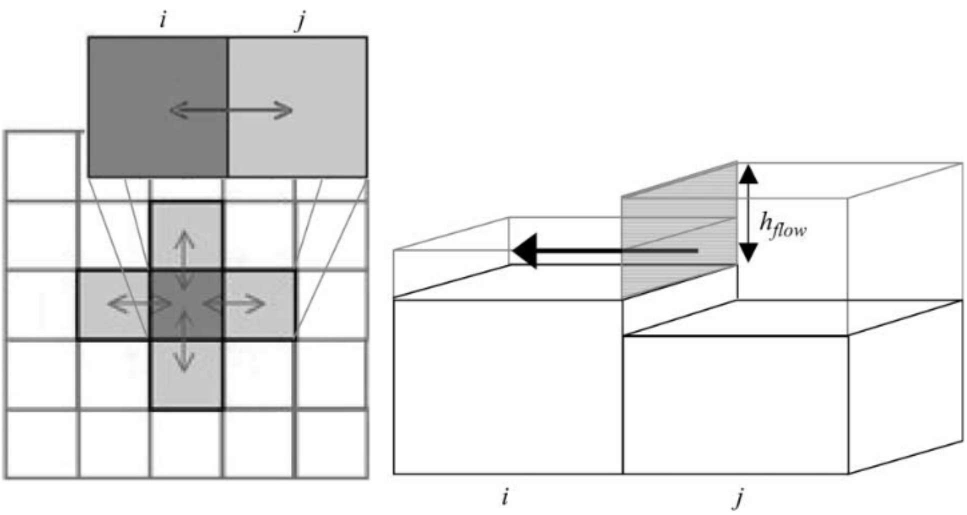

Figure 3.4 : Inundation of cells under the 4-way connectivity**.**

3.2.2 Digital elevation model (DEM).

The topographic features of an area such as the slope and curvature are of great importance when detecting inundated zones and the extent to which it can spread. These topographic features can be obtained and calculated from the topographic surface. One of the common sources of these attributes is the Digital Elevation Model (DEM).

Digital elevation models (DEM) are the representation of the earth surface that is mainly focusing on the elevation data of a specific area. DEMs are the most crucial components of the process of flood modelling (). DEM can be obtained from different sources which use different techniques to produce them; these sources include photogrammetry, radar images and light detection and ranging. The resolution of the DEM should be good enough to capture and show the essential information that allows the user to calibrate the inundated zones. In a more practical manner the resolution must adequately represent the elevation data of the coastal zones and it surrounding neighbors with little or no variations. In order for it to be compatible with other remote sensed data that will be used during the inundation detection, a raster based DEM obtained from point or contour topographic maps is more preferred.

3.2.3 Land cover/land use data.

In order to properly measure the impacts of inundation to the coastal societies, accurate information of the past and present land cover/use data is very important thus making it an important input to the model. Land cover/use data can be obtained from different sources like the Landsat images and SPOT. These sources have different resolutions and thus providing different details to the land cover/use. To these data classes are assigned depending severely on the need of the specific study, this process is called classification. Classification is the process of assigning classes to the pixels in the images data.

There are several image processing techniques which are used to label the pixels of the images with real information on the ground. Classification procedures can be categorized into two main groups; the supervised classification and unsupervised classification. These procedures are combined together with several methodologies to obtain clear distinct classes that are relevant to your study. But it should be note with different methodologies and data available the accuracy of the results can differ for the same area (Hugo et al 2017). Several methodologies are implied when classifying the data to obtain different land use classes, these methodologies include supervised classification-maximum likelihood algorithm which was used for the data used in our study.

3.2.4 Optional data

Depending on the purpose of the study, the tool gives an option to input other data such as infrastructure data and population data. This is to enable the decision maker to have more options when planning by determine to the extent to which the infrastructures such as roads or how many people will be affected in the course of sea level rise. The optional data is expected to be in shapefile format. The tool accepts data like the open street map shapefile format showing the different types of roads that can be found in the study area.

3.3 Development Of The Inundation Maps

The creation of inundated maps is performed in ArcGIS software by creating a raster based map from the DEM file that was provided by the user. Manipulation of the DEM file is performed by using a python script. A python code is used to compare the elevation values from the DEM and the chosen water level in order to stimulate the effects of SLR. After the inundated zone is determined form by the python script the results are then imported back to the ArcGIS interface were further analysis and visualization is performed. The process can be summarized as follows:

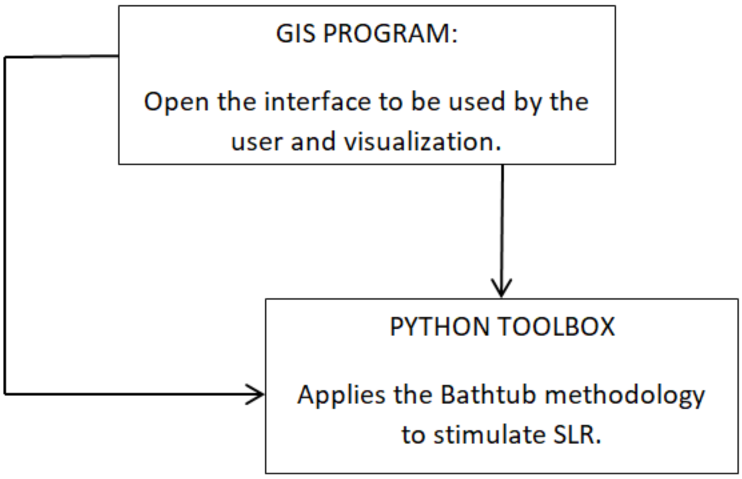

Figure 3.5 : The proces of iundation map development between the Arcmap software and the Python toolbox.

3.4 Detection of Inundated Zones.

In order to stimulate the sea level rise, the codes uses ArcGIS methods integrated with ArcPy a site-package that is very useful in arcgis scripting. This modules main function is to perform geographic data analysis, data conversion, data management, and map automation with Python. In order to access the ArcGIS library of functions an “import arcpy” code is used at the beginning of the script. This allows Python to directly gain access to the ArcGIS built in methodologies.

There are several variables that are created in order to store the data that is input by the user, these variables include "input raster" which accepts the DEM raster data from the user, "fc" which accepts the vertical data containing the administrative boundary to the study area and the "sea_level" which accepts multiple values selected from the list provided to the user. The model assumes that the input DEM is more than the interested study areas thus the next step is to clip the DEM so that we can only remain with our interested area only. This is done by the "Clip_management" function. By using the variable "sea_level" which contains the estimated sea level rise in meters it is compared to the clipped DEM by calculating the elevation points that are below the sea level. This is done by using a function from the raster calculator tool in the ArcGIS. The purpose of this step is to determine the areas of land that are inundated. The process can simply be elaborated as:

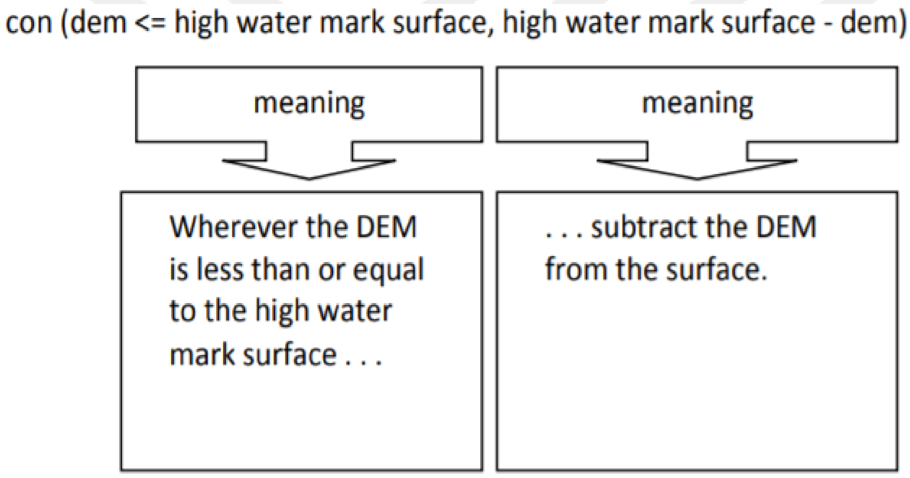

Figure 3.6 : The process to determine the elevation height that are below the given Water surface which is the sea level rise.

The obtained raster based inundated zone is the converted to polygon by using the "FeatureToRaster_conversion" and then overlaid with the administrative boundary of the study area and the only the polygon that are connected to the shore and their neighbors are considered flooded.

This is done to remove the inundated polygons that are not hydrologically connected to the shoreline. The obtained results can be overlaid with other available data to detect the impact of sea level rise. If the population data is given then the data is overlaid with the population data to obtain the total number of people that will be affected by the inundation in case of sea level rise.

3.5 The Python Toolbox Assumptions

1. The sea level rise at the coastal line is continuous for all areas thus the flood calculated are for the whole coast.
1. Other coastal hydrological factors such as storm tide and storm wave were not taken into account during the development of the tool; the main focus was on the inundation in case of the increase of the sea level rise.
2. The DEM was processed prior to being input into the Tool, statistical calculations such as the root mean square (RSE) were calculated and recorded.
3. The land use/cover was obtained and classification performed prior and then reclassified to only show the classes of interest which are the urban areas, agricultural areas, green areas and others which represented the water areas, mining areas and others.
4. Other visualization processes are done within the ArcMap environment after the inundated areas are obtained to provide more illustration to the decision makers.
5. The output folder where all the processed and produced output is saved was created prior and is not done by within the tool itself. The tool only creates a workspace database within the output folder provided by the user.
6. There are other complex methodologies to obtain inundated areas the approach used in this study is realistic and time efficient saving both cost and space and doesn’t require more complex hydrological data from the user which most of the time not available.

4 IMPLEMENTATION.

The python toolbox was used to detect the inundated zones of the city of Izmir in Turkey. Turkey is among the countries with the long coastlines with its coastline having a total of 8333km.There has been an intensive migration of people to the coastal cities such as Istanbul and Izmir. For our study we looked at Izmir.

Izmir is a coastal city found in the Aegean region which is in the west coast of Turkey. The city is on the Eastern coast of Aegean Sea. Izmir is the third most populous city of Turkey with a population of 4223545 people according the Turkish Statistical Institute (TUIK 2017). Several studies (Hallegate et al 2013, Aksoy et al 2017) suggest that Izmir is one of the riskiest cities to face the impacts of inundation in case of sea level rise continuation. Izmir is densely built with numerous residential and commercial districts. Izmir produces 9.3% of Turkey’s total industrial products with over 90% of all the goods manufactured in the region being imported through its 4 commercial ports and contributing to over 20% of Turkey’s total export.

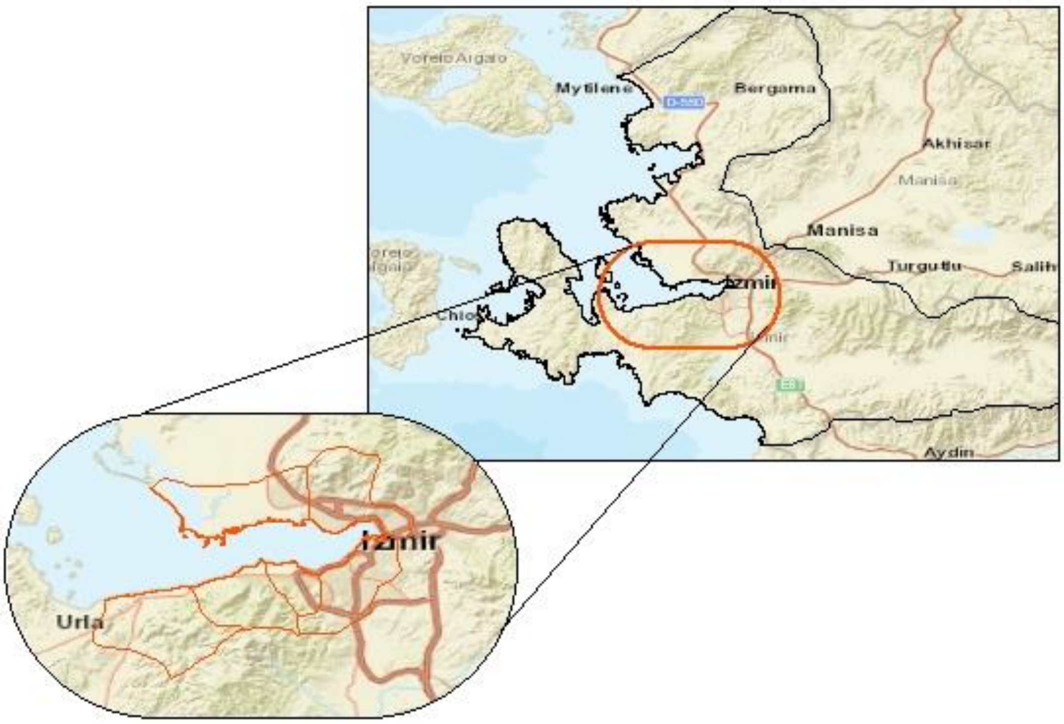

Figure 4.1: The Izmir region on the Eastern coast of Turkey

Figure 4.2 : Detailed map of Izmir bay

4.1 Input Data

To detect the inundated zone for the study area, by using the GIS-based and analysis and the python tool several data were integrated. The method mainly require the availability of remote sensed data i.e. DEM, spatial database containing several data like population, roads etc. and the sea level rise scenarios.

The first input was a DEM which comes in the form of a single file and it included the elevation data. This type of data is also referred to as digital surface model, it accounts for any structure located on the Earth surface. The use of this type of data is rather important more that using the digital terrain model which only accounts for the topography of the land. The DEM that was used came from the Shuttle Radar Topography Mission (SRTM). This data is provided by NASA and be downloaded for free at (http://srtm.csi.cgiar.org/SELECTION/listImages.asp). The SRTM 90m has a resolution of 90m horizontally. The data is available both in ArcInfo ASCOO and GeoTiff making it easier to integrate and process it in the GIS applications or any other image processing software. With this resolution the vertical resolution accuracy errors are bond to arise but the SRTM is still sufficient enough to provide reasonable outputs for the study. The accuracy of the DEM is very crucial when modelling floods this is due to the fact that flood scenarios are simulated using the. height of the digital elevation model. Therefore, it is crucial to procure the most accurate elevation data for the production of an accurate DEM. From the SRTM data, after processing and masking, DEM of the coastal zone and the coastline were retrieved. The data was expressed in geographic coordinates and was referenced to the World Geodetic Survey (WGS) system of 1984 (WGS84). Figure 12 shows the DEM obtained from the Shuttle Radar Topography Mission (SRTM) accessed in January 2017.

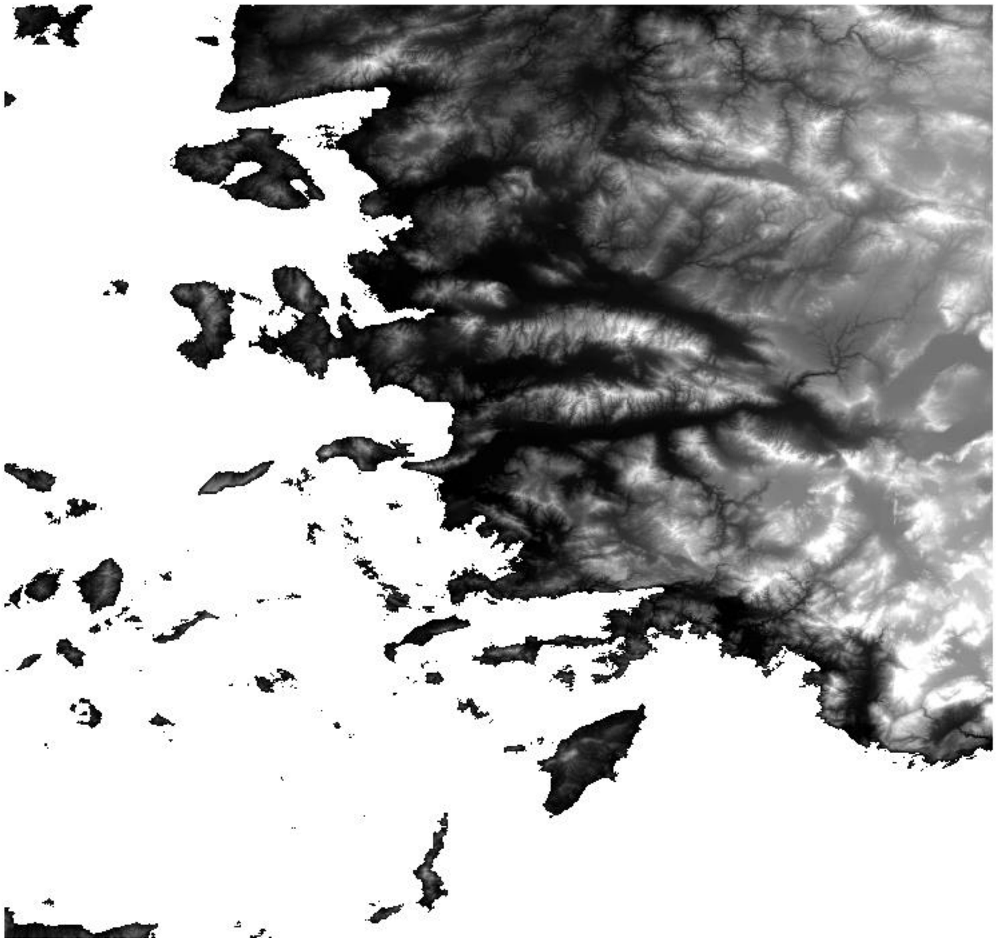

Figure 4.3 : DEM obtained from the Shuttle Radar Topography Mission (SRTM)

The second input was the vector data of the area of study. The DEM data contains other parts of that are not our concern for this study. Therefor a vector data for the area of interest is required to specify only the area we need. The data was in shapefile format showing the boundary of the Izmir administrative area in general and the boundary for the Izmir bay.

The third input data was the sea level rise. The sea level rise shows the changes in climate scenarios of the coastal areas. According to the IPCC (2013) the sea level rise is expected to have a significant increase globally in the 21st century compared to the previous years.

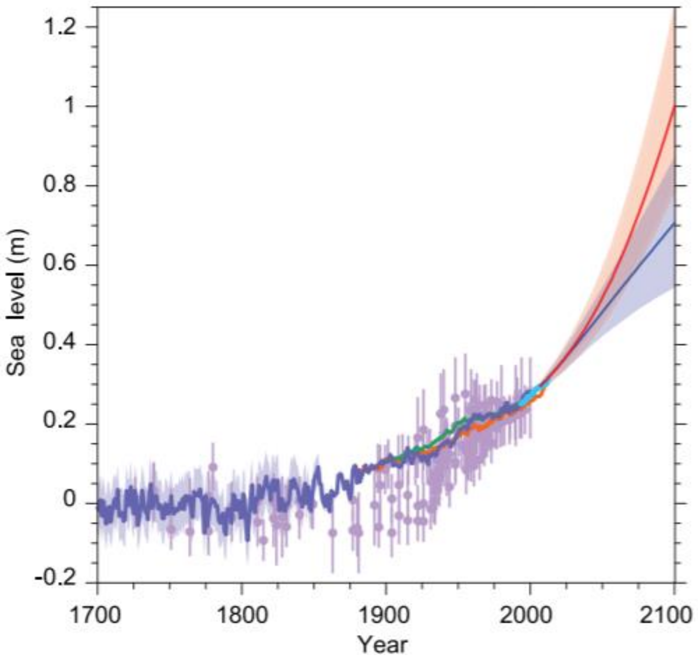

Figure 4.4 : The projected Sea Level Rise in the 21st century.
Source IPCC 2013

When comparing, the estimated projections between the years 1986-2005 and 2081-2100, the latter shows a significant increase in sea level in meters per year. Table 4.1 shows the projection range for the years 2081-2100.

Table 4.1: The projection ranges of the sea level rise.Source IPCC 2013

Minimum(m/yr)	Maximum(m/yr)	Sceanrios
0.26	0.55	RCP2.6
0.32	0.63	RCP4.5
0.33	0.63	RCP6.0
0.45	0.82	RCP8.5
0.26	0.55	RCP2.6

But these estimates account for the global mean sea level which may not be the case at the regional case specifically Turkey. Studies estimate that the sea level rise at the coastal of Turkey is projected to be in the range of 1-2 mm/yr (). With these values in mind, for this study it was decides to model for the extreme scenario of 1,2,3,4 and 5 meters respectively.

In order to estimate the full impacts of the inundations at the coast of Izmir other supplementary data was included. The land cover/ land use data , the population data which was optional but used it in order to determine how many people will be affected by inundation and the transport infrastructure data (mainly we looked at the roads that would be affected)was input into the interface.

A Landsat 7 satellite image with a resolution of 30 meters was obtained from the USGS was processed to obtain the land cover classes. Supervised classification method was performed using the minimum distance classification. The classes that were used for our study were the urban area, agriculture, forest and other which included mining areas, water and other classes. The classes can be further illustrated in the Table 2.

Table 4.2 : Total areas for the Izmir Bay showing land use/land cover

Land cover/use classes	Areas (km^2)
Urban area	168.24
Agriculture	129.03
Forest	136.48
Others	28.56
Total	462.31

4.2 Simulation Of Inundated Zones Along The Izmir Bay Coast

In order to detect inundated zones of the Izmir bay, the python toolbox was opened in the ArcMap software environment. ArcMap 10.4 was used. This allows the user to perform both simulation and visualization in one environment. To stimulate the sea level rise a methodology based on the “Bathtub method” was used. The process relies on the elevation data and the value of the sea level. Using the input obtained from the interface, Python is used to stimulate the process of inundation by using the following steps:

1. The elevation of the cell of interest is it less than the sea level

   and

2. Is the cell connected to the cells that are connected to the sea shore?

The process of detecting of the inundated zones along the Izmir Bay follows the following processes. Firstly the toolbox is open in the ArcMap environment to produce an interface for the user. The interface is shown in figure….

The interface requires the user to input the flowing data:

1. Input the output folder, this folder should have been created prior by the user. This is where all the outputs from the analysis will be saved.
2. Input the Digital Elevation model of the study area. A preprocessed DEM should be entered depending on the available data; the DEM can be SRTM or LIDAR data.
3. Input the vector data showing the administrative boundary of the study area of interest. The data can be in polygon, polyline or shapefile format.
4. Input land cover/use maps. This is a raster based map.
5. Other optional data include population data which should be in the shapefile format or infrastructure data such as the shapefile data from open street maps showing roads.

Once the data is entered into the interface, the DEM is stored to a variable “inputraster” and the vector data in a variable “fc”. Then python codes are used to determine if the input data is in the same projection. Then the raster cells that have elevation values below 0 are removed by the “Con” method. These are removed because they are assumed to be below the sea level that if not removed they would propagate errors into the analysis. By assuming that the DEM is not equal to the study areas of interest, the DEM is clipped to match the study area by the method called “Clip_management”. The obtained clipped raster is stored in a variable “clipraster”. The clipping is done by maintaining the extent of the input Izmir boundary. The inundated zones are then calculated by comparing the elevation height of the clipped raster and the sea level rise estimation. This produces inundated zones without considering if they are connected to the coast line or not, it just considers if the elevation height is below the sea level rise. To remain with only inundated zones, the data is reclassified by using the “Reclassify” method and the output stored in variable “floodedarea”. In order to remove the hydrologically unconnected areas, the raster based inundated zones are converted to polygon using the “RasterToPolygon_conversion” function. The output is overlaid by the Izmir Bay boundary using the “SelectLayerByLocation_management” to determine only the flooded cells that are crossed by the outline of the boundary or the cells are directly connected to the cells outlined by the boundary. The output obtained here which is saved into “in_memory” which a variable representing a temporary memory in the computer is inundated zones that are hydrologically connected to the coastal line. The shapefile is then converted back to raster dataset by the “PolygonToRaster_conversion” function. The raster based inundated zones are overlaid by the land use/land cover map using the “ExtractByMask” function to obtain the total areas according to land cover/land use area that would be inundated. The output is stored in the output folder and is exported back to the ArcMap environment for further visualization processes. The processes include creation of table by the “zonal geometry as table” tool and calculating the area of each land use class.

5 RESULTS AND DISCUSSION.

The study concentrates mainly on the Izmir Bay which is more densely populated and urbanized more than other parts of the Izmir province. The administrative borders of the study area included districts located within the Izmir bay which covered about 462.31km2 .This area has different land use classes that can shows which area is covered by what. According to the classification done on the Landsat images it was deducted that; 36.39% of the study areas was covered by artificial surfaces such as settlements, roads, railroads and port areas which have been gradually increasing over the years. The land that is used for agriculture has generally reduced due to the increased urbanization in general in Turkey and for the study area only 27.91% was covered by agriculture land which included irrigated and non-irrigated arable lands, fruits and olive groves. The green areas which included forests and green areas in the district such as parks covered about 29.52% of the study area. Other areas such as mining sites and water bodies covered 6.18% of the study area. The study mainly focused on the impact of inundation to the coastal area communities and the extent to which they will be affected so the classified class of "Others (water bodies, mining areas etc.)" was excluded. Table 3 Illustrates the mainly areas of focus.

Table 5.1: Land cover/use and their total area and percentage of the study area

Land cover/use classes	Areas (km^2)	Area (%)
Urban area	168.24	38.79
Agriculture	129.03	29.75
Forest	136.48	31.47
Total	433.75	100

The inundation maps for the Izmir bay are created for the scenarios of 1, 2, 3 and 4 meters being the worst case scenario. To gain insight of the effects of SLR these maps are compared for different variables such as the land use, infrastructure and population. Figure 13 is showing the inundation maps at different scenarios, the areas at risks can be observed and the difference between the scenarios as they are highlighted in different colors.

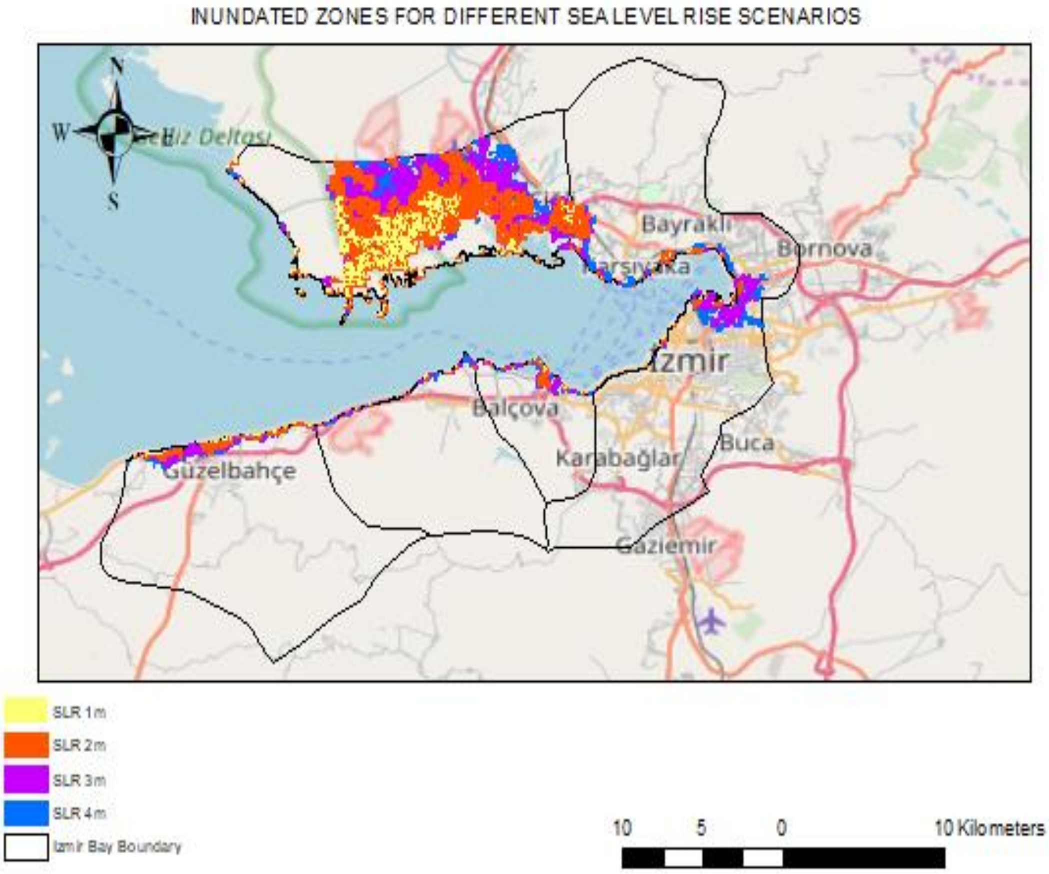

Figure 5.2 : Inundated zones at different SLR scenarios

When considering the results it is observed that at the worst case scenarios, almost all of the northern part of the Izmir bay will be inundated.

In order to access the impact more, the inundated zones were overlaid with the land cover/land use maps to determine how much of these areas were affected. In this process several assumption were maid, these include assumption that the situation will remain constant as it now with no major changes to the protection or adaptation measures at the Izmir coast. Also it is assumed that the land use at the coastal areas will remain the same as they are now ….. of Izmir Bay was inundated in the 1m SLR and in the worst case of 4m SLR …… was inundated.

The extent to which the area was inundated according to the land use classes were estimated to be: At 1m SLR, 71.88% of the artificial surface which included urban areas such settlements, roads etc. was inundated,20.83% of agricultural areas and 7.29% of green areas which included forests and parks. At 2m SLR 69.98% of artificial surfaces, 25.28% of the agricultural areas and 5.20% of the forests were inundated. . At 3m SLR 66.98% of artificial surfaces, 28.30% of the agricultural areas and 4.72% of the forests were inundated. In case of the worst case scenario which is 4m, it was observed that more agricultural areas were affected by inundation shown by 29.69% while the artificial surface affected was 65.90% and forest areas being 4.41%. The results are further elaborated in Table 5.2.

Table 5.2: Inundated areas according to the land use/cover classes

Land use/cover classes.	Study area (km^2)	Inundated areas due to sea level rise(km^2)			
		1m	2m	3m	4m
Urban area	168.24	6.9	18.7	28.4	34.4
Agricultural areas	129.03	2.0	6.8	12.0	15.5
Forests	136.48	0.7	1.4	2.0	2.3
Total	433.75	9.6	26.9	42.4	52.2
		Inundated areas due to sea level rise (%)			
		1m	2m	3m	4m
Urban areas	168.24	71.88	69.52	66.98	65.90
Agricultural areas	129.03	20.83	25.28	28.30	29.69
Forests	136.48	7.29	5.20	4.72	4.41
Total	433.75	100	100	100	100

Izmir being a commercial city, further analysis was performed on the transport system of the city putting more focus on the road network. Open street map data were used to determine inundated roads at 1, 2, 3 and 4 meters SLR. The total road network for Izmir bay is 4422.3 km. From these several types of roads were included namely motorways, pedestrian, residential roads and highways. The data was overlaid with produced inundated zones from different scenarios.

After the analysis, at the 1 meter SLR the inundated roads were calculated to be 141.3 km while at the worst case scenario of 4 meter SLR 749.4 kilometers were inundated. Under these cases it further elaborated to determine with which percentage the important roads like the highways would be affected, at the 4m SLR, 32.7 km of motorways would be inundated. The result can be shown below:

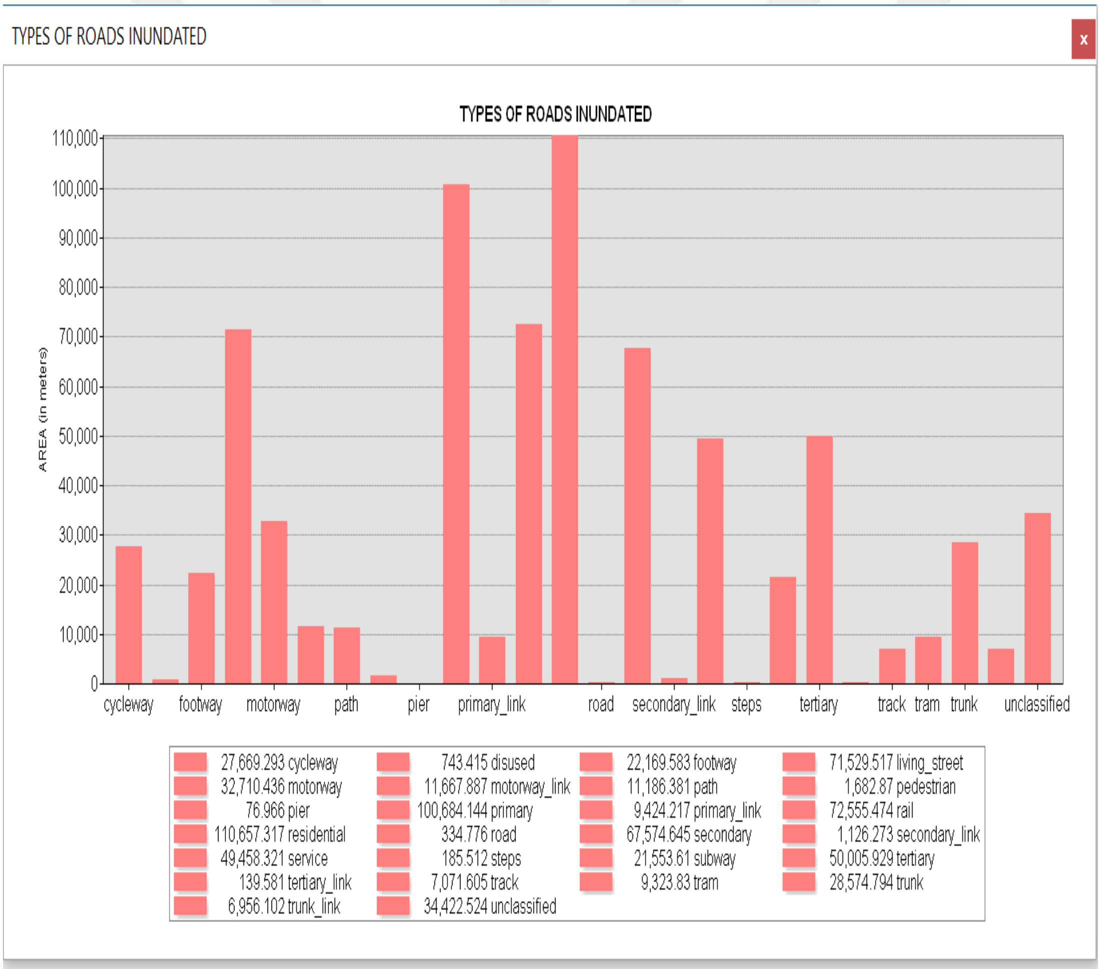

Figure 5.3 : Types of roads Inundated at 4m Sea Level Rise.

Inundation of infrastructure especially the roads is proven to be expensive for the coastal communities although the total inundated roads is considerate small there is still a need for future planning for prevention and mitigation. According to Aksoy (2017) with the worst case scenario the coast for inundation could reach up to 143 million euro/km while at 1 m SLR estimating the coast to be 64.8 million euro/km.

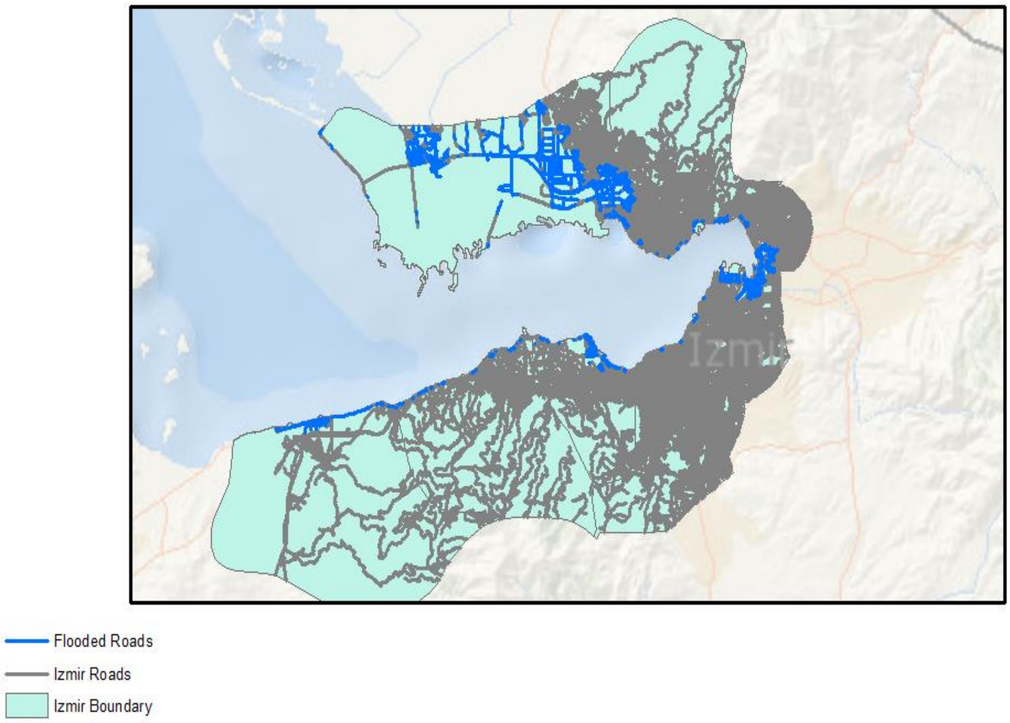

Figure 5.4 : Inundated roads at 3m Sea Level Rise indicated by blue color

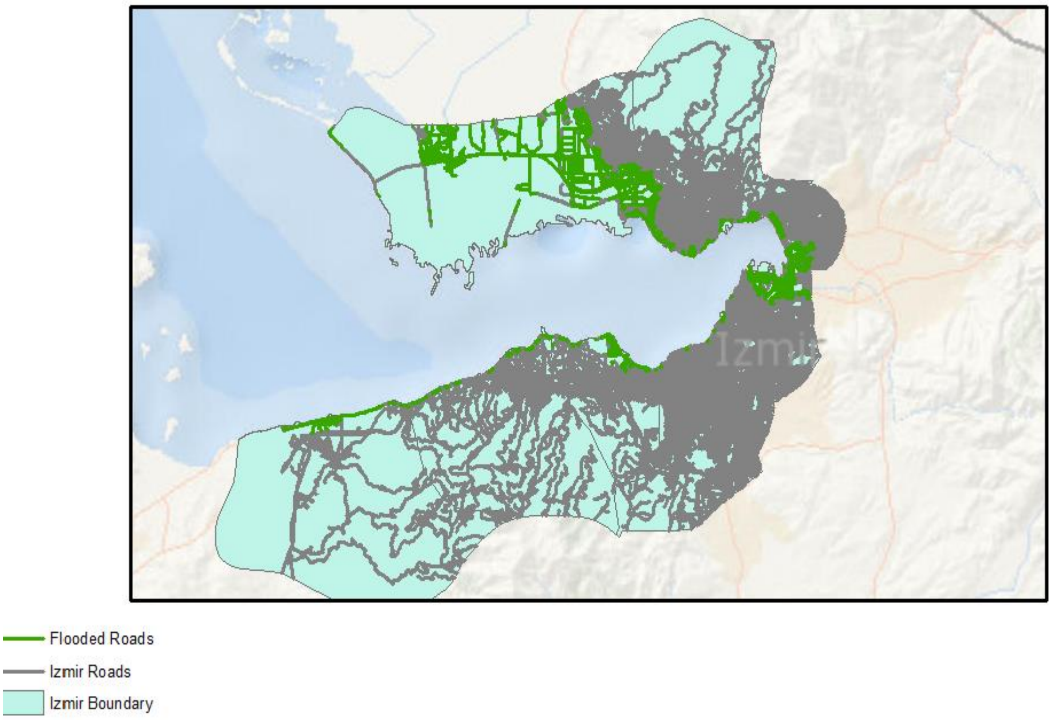

Figure 5.5 : Inundated roads at 4m Sea Level Rise indicated by green color

The figure 5.4 and figure 5.5 demonstrates the inundated roads at 3 and 4 meter SLR respectively which are shown by blue and green color respectively. The map generalized all the roads found in the Izmir bay. A method in ArcMap "frequency" is further used to elaborate which roads are affected specifically as it can be demonstrated in figure5.3 above. With roads being the most common mode of transportation and a long time investment it is necessary for the decision makers to have prior knowledge and proper data of the inundation effects thus these extreme estimation gives such data. It can be observed at the worst case scenario 32.7 km of motor ways will be affected by floods. This can create a major loss to both the economy and the coastal dwellers as well.

The study area has a population of 2181525 which included all the districts of Izmir bay. The population at the coastal regions has been gradually increasing over the years. When overlaid with the inundated zones the following results were obtained at 1 meter SLR about 193,327 people were affected by inundation which makes it 8.86% of the whole population. The other results that 16.71%, 23.58% and 25.80% respectively for the 2, 3 and 4 meters of SLR of the population will be affected with

562,941 people being affected at 4m SLR. This deducts that with the increase in sea level rise more people are expected to be affected by inundations. This is due to the fact that urbanization and settlement along the coastal areas is not decreasing but increasing over time due to more modernized infrastructure that is put in place near the coastal reasons. The loss of life along the coastal is expected to be in big numbers if no proper measures and mitigation processes are put into place.

The tool only used a simple static “bathtub” model to detect the inundated zones; this method does not take into account various variables like the hydrological factors of the coastal areas, the coastal waves and the storm surge. All these could bring about more variations in the extent to which the coastal area would be affected with floods in the years to come. Thus further studies are proposed to further develop the tool and include other numerical modelling methodologies that would take all these factors into account that giving the decision makers a clear picture of what is to happen. The tool could be further developed to enable some of the processes that where done prior to input like processing of the digital elevation models and calculating the root mean square be performed within without being done by the user.

For this study the tool is open in the ArcMap environment thus making it dependable to the ArcGIS software which is not free. Python being an efficient language and open source the tool could be expanded to be open source and compatible withdifferent GIS platforms without any problems. This thesis lays the foundation of the development of more complex tools specifically for the flood modelling at the coastal areas due to sea level rising and other extreme events at the coast.

6 CONCLUSION.

Climate changes which leads sea level rise and extreme events has serious impacts to the coastal societies and coastal areas in general. It affect the lives of coastal dwellers in different such as development and thus giving a great need for decision makers to be well prepared. Although the method used for the inundation zone detection produces results that are considered as roughly estimates the projections can be used as a base estimate by the future planners. The study can be extended to other regions or used national wide to estimate the inundated zones along the coastal and also the tool can be easily used by every regardless of their knowledge of the GIS platforms or software.

The main goal of the thesis was development of a python tool to automate the inundation zones detection process, a tool was developed to a satisfactory level, this gives chance even to know experts in need of estimating inundation zones to use due its friendly user interface. The simulation of SLR is performed for the extreme scenarios provided. When considering coastal modelling for coastal areas there is always a concern about a lot of knowledge of the available GIS platforms and the tedious process. But to some extent this problem has been resolved by this tool.

The results of the implementation of the tool produced inundated zones that were overlaid with coastal indicators for population, urban areas and infrastructure, the results show the impacts of increased sea level rise to the coastal city of Izmir focusing mainly on the Izmir bay which is the most densely and urbanized is devastating . It can be concluded that the Izmir coastal line is at risk of inundation in case of future sea level rise and extreme events like storm surges. Taking into consideration the, SLR is long time problem however there is a need for prior preparation in order to have efficient adaptation and mitigations plans for the areas. The results have shown that large part of urban areas which include settlements and i

The coastal areas are still going through transformation over the years, therefore measures to protect the settlements in the years to come against floods and other extreme events are very crucial. The produced maps and values roughly estimates the extent of the flood in the coast of Izmir but there is a great need to in cooperate other aspects of the coastal area like the soil types, the wave strength and storm surge height. nfrastructures are highly exposed to high level of inundation.

6.2 Future Research.

Now that the tool has been developed to be used in the ArcMap environment, future research should focus on making it software and independent and open source so that it can be used in other GIS platform or freely as a standalone extension. This tool addresses the use of only one methodology that is the bathtub approach, other approaches need to be addressed and in cooperated into the tool too. The development can be evolved to compare other hydrological modelling aspects like 1D and 2D modelling approach that is used in other tools. Other hydrological aspects of the coastal areas like the storm surge should be added too. As the assumption outlines most of the data is processed outside the tool, the tool should be improved in order to perform other calculation like creating of DEM from cloud points and compare results produced by two different DEMs from different sources**.**

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APPENDICES

APPENDIX A.1 : Python codes for the toolbox

```
import arcpy
import os, sys, traceback, shutil
from arcpy.sa import *
import numpy as np

arcpy.env.overwriteOutput = True


outputfolder = arcpy.GetParameterAsText(0)
fc = arcpy.GetParameterAsText(1)
inputraster = arcpy.GetParameterAsText(2)
landsuse = arcpy.GetParameterAsText(3)
sea_level = arcpy.GetParameter(4)

	#check to see if the arcinfo license is on
if arcpy.CheckExtension("Spatial") == "Available":
	arcpy.CheckOutExtension("Spatial")
else:
	arcpy.AddError("Spatial analyst extension is not licensed.")
	sys.exit()

	#set the Progressor
	#arcpy.SetProgessor("step","Checking input requirements....",0,9,1)

	#Process :create an out put folder
if arcpy.Exists("output.gdb"):
	arcpy.Delete_management("output.gdb")
else:
	arcpy.CreateFileGDB_management(outputfolder,"output.gdb")
	outputgdb = outputfolder + "\\output.gdb"+os.sep

	#create path to store raster data
clipraster = os.path.join(outputfolder,"clipraster")
arcpy.AddMessage(clipraster)
flooded = outputgdb +"floodarea"

floodedonlyli = []

arcpy.AddMessage(flooded)

	#check to see if the inputs are in the same projection
desccs_ras = arcpy.Describe(inputraster).SpatialReference
desccs_fc = arcpy.Describe(fc).SpatialReference
if desccs_ras.name == "Unknown" and desccs_fc.name == "Unknown":
```

```
        arcpy.AddMessage("Your data does not have a defined spatial reference")
else:
        if desccs_ras.projectionName == desccs_fc.projectionName:
                ""
        else:
                arcpy.AddError("The input Data should be in the same projection")
                sys.exit()
del desccs_fc,desccs_ras

        #get the sea level from the user
#valuelist = [x.strip() for x in sea_level.Split(";")]


        #remove the areas below sea level
#currentRaster = arcpy.Raster(inputraster)
#rasterclip = Con(currentRaster>=0,1,0)
rasterclip = Con(arcpy.Raster(inputraster)>=0,inputraster,1)
arcpy.AddMessage(arcpy.Describe(rasterclip).dataType)
#arcpy.AddMessage(rasterclip)

        #clip the raster data to the interested zone extend
arcpy.Clip_management(rasterclip
,"#",clipraster,fc,"#","ClippingGeometry","MAINTAIN_EXTENT")
arcpy.AddMessage(arcpy.Describe(clipraster).dataType)

valuelist = sea_level
arcpy.AddMessage(valuelist)
for value in valuelist:
        floodedarea = os.path.join(outputfolder ,"floods" + str(value))
        outReclassify = os.path.join(outputfolder, "reclass"+ str(value))
        rastertopolygon = os.path.join(outputgdb ,"rastopoly"+str(value))


        clip_raster = arcpy.Raster(clipraster)
        #arcpy.AddMessage(arcpy.Describe(clip_raster).dataType)
        areasbelow = clip_raster <= value
        arcpy.AddMessage(arcpy.Describe(areasbelow).dataType)
        #rs = Raster(areasbelow)
        areasbelow.save(floodedarea)
        arcpy.AddMessage(areasbelow)
        arcpy.AddMessage(value)

        #reclassify to get only flooded area
        reclasifiefField ="value"
        remap = RemapValue([[0,"NoData"],[1,1]])
        outReclass = Reclassify(floodedarea, reclasifiefField, remap,"NODATA")
        outReclass.save(outReclassify)

        #convert the raster to polygon to perform analysis
        field = "VALUE"
```

```
        tmp = "tmpLayer"
        temporary = os.path.join(outputfolder,"polygonraster"+str(value))
        memory = "in_memory"+"\\"+"polygon"+str(value)
        arcpy.RasterToPolygon_conversion(outReclassify, memory,
"NO_SIMPLIFY", field)
        arcpy.MakeFeatureLayer_management(memory,temporary)

        #select only the that are hydrologically flooded
        arcpy.SelectLayerByLocation_management(temporary,"CROSSED_BY_TH
E_OUTLINE_OF",fc )
        matchCount = int(arcpy.GetCount_management(temporary)[0])
        if matchCount ==0:
                arcpy.AddMessage("No Polygon was selected")
                sys.exit()
        else:
                arcpy.CopyFeatures_management(temporary,rastertopolygon)
                arcpy.AddMessage(arcpy.Describe(rastertopolygon))

                #convert the polgon with flooded areas only to raster
                convertrast = os.path.join(outputfolder,"floodonly"+str(value))
                convertedraster =
arcpy.PolygonToRaster_conversion(rastertopolygon,"OBJECTID",convertrast,"CEL
L_CENTER")
                for conver in convertedraster:
                        floodedonlyli.append(convertedraster)
                arcpy.AddMessage(floodedonlyli)

#calculate the affected land use area
arcpy.AddMessage(floodedonlyli)
rasters = arcpy.ListRasters("*","floodedonlyli")
arcpy.AddMessage(rasters)
for ras in rasters:
        landuse = outputfolder +"\\"+ ras+"_"
        arcpy.AddMessage(landuse)
        floodLanduse = ExtractByMask(landsuse,landuse)

#get optional inputs
x = arcpy.GetParameterAsText(5)
roads = arcpy.GetParameterAsText(6)
if roads == True:
        #feature_count = int(arcpy.GetCount_management(roads).getOutput(0))
        #if roads = True:
        if feature_count > 0:
                desccs_rds= arcpy.Describe(roads)
                sr_rds = desccs_rds.SpatialReference
                desccs_fc = arcpy.Describe(fc).SpatialReference
        if sr_rds.projectionName != desccs_fc.projectionName:
                arcpy.AddMessage("entered the projection")
                sr =arcpy.SpatialReference(fc)
                arcpy.AddMessage(sr)
```

```
        arcpy.Project_management(roadsclip,roadspath,sr)
        arcpy.AddMessage(roadspath)
    else:
        arcpy.AddMessage("Data Projected")


    #infeature =[fc,roads]
    roadspath = os.path.join(outputfolder,"izmirroads")

    #intersect the roads and study area
    #arcpy.Intersect_analysis(infeature,roadspath,"ALL","","INPUT")
    #clip the data to match the study area
    njiazangu = arcpy.Clip_analysis(roads,fc,"izmirnjia", "")
    arcpy.Describe(njiazangu)
    nione = roadspath
    arcpy.AddMessage(nione)
    #arcpy.Describe(roadspath).dataType

    #add a filed area and calculate the geometry to obtain the area of the roads
    arcpy.AddField_management(roadspath,"Area","DOUBLE",10)
    arcpy.AddGeometryAtrributes_management(roadspath,"LENGTH")
    for rasflood in floodedonlyli:
        ""

md = arcpy.mapping.MapDocument("CURRENT")
df = arcpy.mapping.ListDataFrames(md)[0]
result = arcpy.MakeRasterLayer_management(convertrast,"FloodedArea")
layer = result.getOutput(0)
arcpy.mapping.AddLayer(df, layer,"AUTO_ARRANGE")
```

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