An Analysis of the Potential Erosional Changes in the KwaZulu-Natal Coastline due to the Effects of Sea Level Rise and Associated Storm Surges

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Lyndon Paul Riddle

Abstract

The coastlines around the world are currently in the process of being eroded by naturally occurring oceanic conditions. The vast majority of people living near or on these coastlines have no idea what they may be in store for them, with a notable exception being the coastline of the Netherlands. The aim of this research is to understand which areas on the KwaZulu-Natal coastline may be affected by the occurrence of sea level rise including the effects of future storm surges at various time intervals. The coastline is eroded continuously due to the cyclic movement of tides, waves and winds, however the most significant erosion events are likely to occur due to the combination of sea level rise and storm surges, as these both extend further inland and reach higher altitudes than the day-to-day processes of coastal erosion. The storm surge that occurred on the East Coast of South Africa in March 2007 was therefore used as a reference for storm surge as a means of comparing and modelling future storm surge events. While there is some controversy, literature suggests that the mean annual sea level rise occurs at a rate of some 15.5mm per year, although some researchers argue in favour of a rate of almost twice that. The year 2100 was used as the target date to replicate the worst case scenario storm event, but without accounting for a potential increase in the storm intensity driven by global warming.. Coastal protection infrastructures have been installed in some areas, but have been found not to work effectively, occasionally even exacerbating the effects of erosion. Results suggested that by 2100, the sea level rise alone would not have had much of an effect as it is projected to rise by an average of 2m. When this is, however, coupled with a storm surge threshold of 3.5m, most of the study sites along the KZN coastline would experience significant flooding and associated destruction. The research is of a hypothetical origin and the predictions may or may not occur. If the hypothesis would have to be correct, then the planning for prevention methods may be too late. Thus this research must be considered as new information to assist with coastal management. If the projection into the future is taken to include replication of an event with the intensity equivalent to that of the March 2007 event, flooding may reach as high as 10m with catastrophic social and economic consequences. Only time and judicious forward planning with a re-think of the Coastal Zone Management Act will alleviate problems in the future.

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1 Introduction

1.1 Context of the Study

The media have highlighted the fact that our coastlines are in jeopardy and people do not even realize it, (Carnie, 2006). People are living near the coast shoreline unaware of the potential danger that they are in except for those living in the Netherlands where this has been a long lasting issue. People put luxury and the beauty of living on the beach before their own lives and well-being. Coastal regions are fast becoming the tourist destinations for people around the world, and the building of hotels and cottages in close proximity to the coastal waters of South Africa is becoming increasingly prominent. Being close to the ocean is considered the most ideal holiday destination, however, what threats and stresses is this putting on the coastline? Human pressures are putting intense strain on the coastline. Coastlines are constantly under pressure and are changing in physical appearance from day to day. Beaches that are mainly comprised of sand will continue to morph, shift and evolve. Coastal areas around the world are amongst the most complex zones. Waves constantly lap on the coastline bringing forth erosion and deposition of sediments. Is living so close to the beach or ocean that important? What are the risks that one is putting themselves in?

Bird, (1985, cited in Zhang, *et al*., 2004), stated that of all the beaches in the world, 70% are recessional. This means that 70% of the world's beaches are moving landward, thus properties and infrastructure along the coastline may be flooded in the near future. Guastella and Rossouw (2009), states that 90% of the world's coastline is affected by erosion. This means in 24 years the world's coastlines that were affected by erosion went from 70% to 90%. The erosion process caused by cyclic wave movement along the coastal line occurs every day. This is the most effective and therefore results in higher erosional occurrence during high wave periods (Zhang *et al.,* 2004). Many of the world's economic power houses are situated near the coast of their respective continent's, where they contain some sixty percent (4.4 billion people) of the entire world's population (Cai *et al.*, 2009). That is, close to two thirds of the world's major and economic leading cities are situated along the coastline. According to Cooper and Pilkey (2004), it is believed that two billion people live within one hundred kilometres of the coastline (Cai *et al*, 2009). There are differences in percentage of the world's population that live in close proximity of the ocean, but the fact is that these people may still be in danger. Due to human pressures, more infrastructures are required on the coastline. These pressures with the fact that the coastline is recessional, proves that erosion of the coastline is one of the most studied fields in recent years to date.

Erosion is a term used to describe the removal or redistribution of sand, particles or sediments from a point. Erosion does not only occur on the coastline but on all landscapes. Erosion has shaped the Earth's surface to what it is today, creating valleys, mountains and amazing landscapes. One of the major erosional events along the coastline is storm surge. These surges bring upon very high seas and waves with high erosive power.

Storm surges are one of the crucial events that cause severe destruction and intense movement of sediments along the coastal regions including both the beaches and the sand dunes (Zhang *et al.*, 2004). Storm surges are caused by a localized rise in sea water, therefore flooding coast lands once the uplifted water reaches the land (Park & Suh, 2012). The surges are often accompanied by large waves, which have a greater potential to erode the coastline faster than normal waves. Sand mining is another factor that contributes to the erosion of a coastline. The mining does not directly erode the coastline but depletes the sand supply to the coastline. The removal of sand (Sand Mining) and construction of dams up river, can cause a decreased natural flow of sediments down-stream as sand is being removed from the sand mining process and getting trapped behind dam walls. This then decreases the sand supply to the beaches which may result in coastal erosion occurring faster. This hinders the rejuvenation of the sands on the coastline, ultimately decreasing the sand budget.

There are many different factors that affect the erosion of a coastline such as atmospheric conditions, coastal properties, climate change, and storm surge. According to Guastella and Rossouw, (2009), 90% of the world's coastal regions have signs of erosion. This research will discuss storm surge and sea level rise as some of the causes of coastal erosion.

Monitoring by use of satellites will help to document the movement of coastal sediments. Before and after images can be analyzed to prove the theory that coastal regions continuously morph. This can potentially be aided by the use of radio isotopes such as Cesium 137(Cs-137) (Ritchie and McHenry, 1990). Cs-137 has been used to supply information about the sedimentation, erosion patterns and rates ever since nuclear testing began to occur as there was no natural occurring source of this substance (Ritchie and McHenry, 1990). Due to the fact that many of the coastal areas are used as holiday destinations, the infrastructure could be put in jeopardy.

Climate change is believed to be one of the causes of sea level rise (Cai *et al.*, 2009). This could be due to the fact that polar ice caps are melting, adding more water to the oceanic system, thus increasing the sea level in the oceans. Climate change has also been known to increase the occurrence, intensification and duration of storms. According to Easterbrook (2011), the Earth is believed to be en route to catastrophic storm events. If the Earth continues on the path it is currently on, the Earth will warm by 5 - 6°C, thus increasing the average sea temperature by 5.8°C (Easterbrook, 2011). As many storms derive their power from warm oceans, this will cause storms to become more intense.

The KwaZulu-Natal (KZN) coastline could easily be the most valuable natural asset that is used for tourism, nature conservation, residential property and commercial property. It is a popular holiday destination that is believed to support a greater portion of the economy (Guastella & Smith, 2014). The tourism sector in this region should be projected. This would then allow tourism to continue to contribute to the local economy. 80% of the coastlines along South Africa are sandy shores, which are more likely to be eroded (Theron & Rossouw, 2008). KZN and other areas along the eastern coast of Southern Africa experienced one of the largest recorded surge events for the region during March 2007 (Corbella & Stretch, 2012a). This storm surge event occurred during an equinox which exacerbates the effects of the storm surge and thus intensified the effects along the coastline destroying coastline infrastructure (Figure 1.1). Even today, many structures are weakened from that surge and after effects are still visible at many beach areas. Storm surges that occur in Durban or the East coast of South Africa are produced by cold fronts, tropical cyclones and cut-off lows (Corbella & Stretch, 2012a). Minimal work has been done to investigate the potential and cumulative effects of sea level rise with storm surge incorporated on the KZN coastline.

Figure 1.1: Destruction that was created by the 2007 storm. (Source: Umdloti, 2007; Accessed 29 January 2015)

1.2 Aims and Objectives

The aim of this research is to understand the nature and location of the combined effects of future sea level rise and storm surge activities along the coastline of KZN

The objectives of the research are:

1. To develop an understanding of the causality and nature of the processes of coastal erosion along the KwaZulu-Natal Coastline.
2. To be able to predict the projected rate and extent to which the sea level may rise due to climate change, and then be exacerbated by a storm surge event in association with such climate change
3. To determine the areas that, with use of projections, will depict potential flooding with the use of case studies.
4. Review the need to implement policies to safe guard infrastructures along the coastline, while also monitoring the development on the coastline in the future.

1.3 The Study Area

The study area for the research will be along the KwaZulu-Natal's (KZN) five hundred and seventy kilometres coastline (Guastella and Smith, 2014) (Figure 1.2). Figure 1.2 depicts the KZN province as a whole with its various municipalities. The KZN coastline comprises of seventy three rivers and streams that flow into the ocean (Guastella and Smith, 2014). Rivers are areas of low points along the coastline and may allow easier access for surge water to flow up.

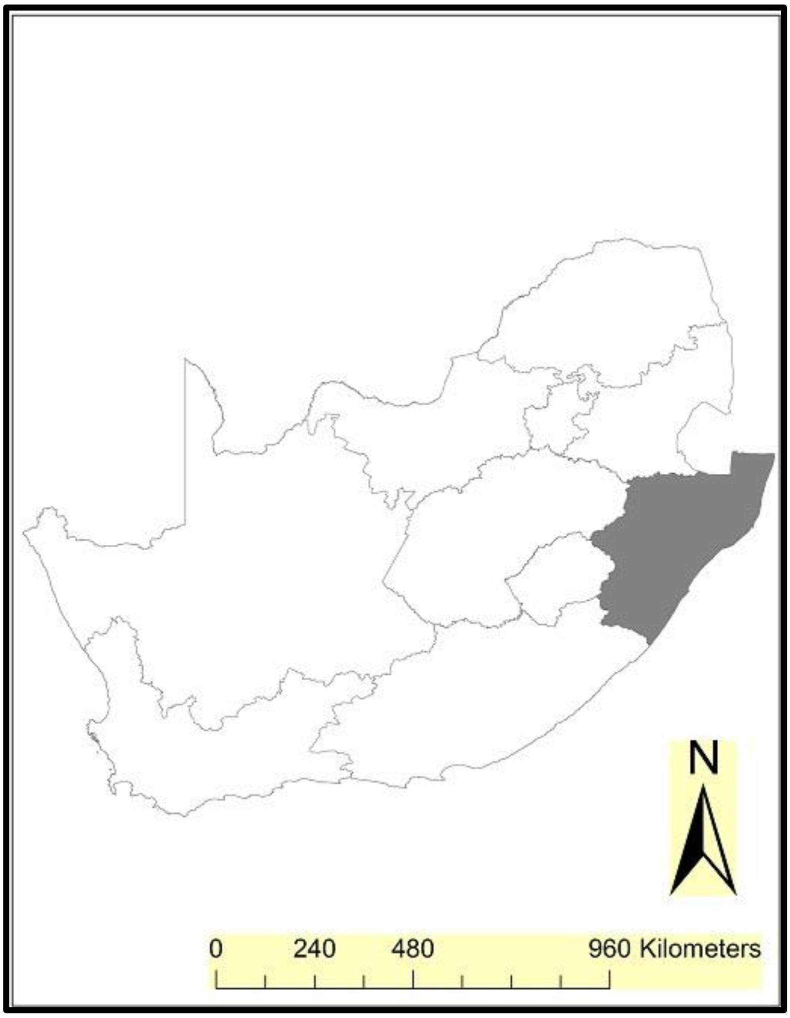

Figure 1.2: Locality map of KZN (grey area) within South Africa

The study site where field work was conducted was selected on the basis of the distance the surge and sea level rise may protrude inland. From the projection, ten sites were selected and studied.

2. A Review of the current state of Knowledge

The following chapter covers various literature and articles of aspects that may relate to the research such as coastal processes, storm surge and sea level rise. According to (Cooper & Pilkey, 2004)*,* approximately two billion people (37% of the world's population) live within 100km of the ocean. The population density on average was 77 people per km^2 in 1990 and has increased to 87 people per km^2 in 2000 (Pussella *et al.*, 2015). Areas that have a low gradient or a flat landscape will be affected more than those that have steep gradients or hilly landscapes. Wind action, tidal currents, sediment supply, ocean currents, long shore drift, sea level rise, sedimentary type, ocean currents, are factors that will contribute to the coastline being eroded (Cooper & Pilkey, 2004). As stated in the introduction, the KZN coastline is a vital sector for the economy in the area, as its majestic beaches bring people from around the world to experience and admire the ocean's beauty. Thus the beaches need to be protected against anything that may threaten this sector.

2.1. The nature and operations of coastal processes

Disasters that occur on the coastline are usually extremely destructive, as they result in the largest loss of assets and lives (Saxena *et al.*, 2013). Coastlines are densely populated, as the developmental opportunities are much higher due to the presence of ports, estuaries, tourism, fishing and pilgrimage centres. The devastation caused by a disaster on the coast is dependent on the amount of exposed population (Saxena *et al.*, 2013). The coastline is used for many different activities and the change of the coastline is often over-looked as a natural occurrence. The extent of erosion along a coastline is susceptible to the equilibrium state of its sand and sediment. Wave characteristics must be considered to best understand the erosion potential of a coastline (Günaydin & Kabdasli, 2003). Personnel that are in charge of managing beach margins need to be informed about coastal change in order to establish measures for various disasters (Guastella & Smith, 2014). Disasters such as sea level rise, erosion, storm surges, occur in close proximity to lagoons or rivers. Urbanisation has expanded rapidly for the last 30 years, more so for countries in developing nations

(Mather, 2007). This is putting pressure on the coastal cities to grow with the influx of people. These developing nations have to increase their infrastructures to manage the rapid growth.

There are many types of erosion that can occur. Specifically coastal erosion can, be categorized into two groups (Cai *et al*., 2009). The first group is long term and the second is short term. Long term erosion will affect the coast permanently and may alter the shoreline drastically (Cai *et al*., 2009). If the sea level had to rise, the high tide mark would be higher than that of present day and the ocean would move further landward. The second group is short term coastal erosion which is generally the effects from storms, tides and surges that changes the coastline during that process. That being said, in time to come, the coastal region may revert back to its previous state (Cai *et al*., 2009). This group brings the greatest amount of destruction in a very short period of time. Since many coastal regions have development along it, this process is able to erode at the foundations of these developments and thus increase the destruction. Sediment supply to coastlands is from river systems, and is believed to supply 80% of the beach sediment to the coastlands (GESAMP, 1994, cited in Corbella & Stretch, 2012b).

Coastal erosion can also be caused by anthropogenic activities (Cai *et al.*, 2009). Activities such as sand mining, dam construction, reclamation and subsidence, have the ability to reduce the total quantity of sediments being delivered to the coastline (Cai *et al*., 2009). CSIR (2008 cited in Corbella & Stretch, 2012b), states that many of the rivers are being mined for their sediments. Approximately 400 000 m^3/yr of sediments are being mined from eThekwini (Durban municipality area) rivers. Due to all the removal of sand, there has been a reduction of fluvial yield by 63% (CSIR (2008 cited in Corbella & Stretch, 2012b). This gives the illusion that the sea level is rising when in actual fact the coastline is dropping or sediments are depleting.

Many believe that dunes that are vegetated provide a secure bedding or protection against wave action and high surf (Bundy *et al.*, 2012a). This gives a false sense of security that the dune system will withstand the erosion processes on the coastline. The vegetation does help stabilise the dune system but not enough to effectively mitigate the effects of high surf eroding the system as the root system often does not extend deep enough.

KZN falls in an area where its experience is micro tidal having a Highest Astronomical Tide (HAT) of around 2.3 m (Guastella & Smith, 2014). This region experiences larger swells during winter as the weather system area is closer to the main land then when in summer. The estuaries that are situated along the coastline are “temporarily closed or open estuaries” referred to as TOCE (Guastella & Smith, 2014). Many of the TOCE are situated in incised valleys. This restricts the width of the river and gives constraints to the size of a flood plain. This region of the South African coastline is an area of high energetic wave climate which causes higher erosion (Corbella & Stretch, 2014). According to Corbella & Stretch (2014), larger waves are experienced during autumn and winter seasons.

The gravitational pull that is generated from the moon and the sun are the cause of the tides on Earth, and their positions, relative to one another, determine the extent of the tides (Kennish, 2000). If the moon, sun and Earth are all in alignment, the earth will experience spring tides, but if the sun and the moon are at right angles relative to the Earth, neap tide will be experienced (Kvale, 2006). Spring tides create tides with extreme highs and lows and neap tides create tide that has relatively little change between the tides.

Durban is one of the cities on the KZN coastline which has tourism, private property, public property and commercial sectors. One of the biggest commercial sectors within Durban is the harbour, being one of the major gateways of produce distribution in Africa. As many of the ocean-going ships are getting bigger and therefore unable to cope with the increase in requirements, the Durban port will not be able to handle the new bigger ships. Durban is planning to increase its footprints in the next few years (Mather, 2007). The widening and deepening of the port will cost around R2.7 billion (Mather & Reddy, 2008). This value will have increased due to inflation from 2008 to today. Durban has the largest port on the east coast of Africa. Durban has a population of 3.5 million, and is one South Africa’s important economic and urban centres (Roberts, 2008; Mather & Reddy, 2008). The rate that the sea level is rising in Durban is 2.7 $\pm$ 0.05mm.yr while the worldwide rate is between 2.4 and 3.2mm.yr (Mather, 2007).

2.2. Process effects on sediments

Rocks are broken down to sediments by chemical, and/or mechanical weathering (Okeyode & Jibiri, 2012). 34% of the world's beaches are sandy and form part of coastal cities and tourism (Mather, 2007), where most of the beaches comprise of fine grained sediments (Nott, 2003). As the tidal range increases, so does the effect on the coast thus increasing the effects of erosion along the coastline (Mariappan & Devi, 2012). With the increase in global warming, it is believed that the precipitation will increase which internally will increase fluvial erosion (Goudie, 2006). This may increase the amounts of sediment that is deposited on the coastline. This could help prevent the storm surge from eroding and destroying the coastline, but more research needs to be done on this topic to see the results. Approximately 90% of the world's coastlines were affected by erosion in 2009 (Guastella & Rossouw, 2009). As the sea level rise, thus so will the percentage of coastline that is effected by erosion.

The movement and threshold of sediment is dependent on various aspects such as the threshold of the sediments which will determine if the sediments move or not, due to different forces (Paphitis, 2001). It is also dependent on the force that is in place to move the sediments. Such is the case for a wave's energy. The sediment below the water surface will only move when it is affected by the force of the waves passing over it. This will happen when the depth of the water is less than half the distance of the wave length between two wave heights (Christensen *et al.*, 2002). Various parameters of the actual sediments themselves may change the transport or deposition of the sediments (Pedreros *et al.,* 1996). The parameters that may have an effect are grain size, grain sorting, grain shape and skewness. If flow velocities would have to stay constant, and these parameters were altered, the process of erosion and deposition would vary as well. For sediment to be eroded off a sediment bed, the hydrodynamic forces would have to overcome the forces holding the sediment down (Paphitis, 2001). The point where no motion of sediments becomes motion is termed the threshold, or the critical point of the sediments. This can be determined by the relationship between shear velocity, sediment parameters and the shear stress (Paphitis, 2001). Ocean sediments will only be affected by wave action when the depth of half its wavelength is reached (Fredsøe & Deigaard, 2005). This means that if the wavelength is 12 m, at a depth less than 6 m, the sediments will be affected by the wave action. Fine sediments that are well sorted tend to be difficult to erode due to the cohesion between each particle. Very high hydrodynamic forces are needed to erode these sediments. This said, once the particles are in the water column, the particle will be transported until the flow becomes low enough for the particle to drop out of the water column. According to Corbella & Stretch, (2012c), 25% to 42% of sedimentary erosion along coastal regions are from storm surge and the remaining is from soil budget reduction and sea level rise. Movement of sediments up the coast from south to north is caused by the coastal currents. This is defined as long shore drift. Long shore drift is a wave induced current that is created by currents flowing perpendicularly and parallel to the coast (Brown *et al.*, 1989). The currents transport sediments in a zigzag movement along the beach (Figure 2.1). The current travelling parallel to the coast is termed the rip current which transports eroded coastal sediment along the coast. The perpendicular current is from the swells breaking onto the beach, swashing up the beach profile and then once again back down.

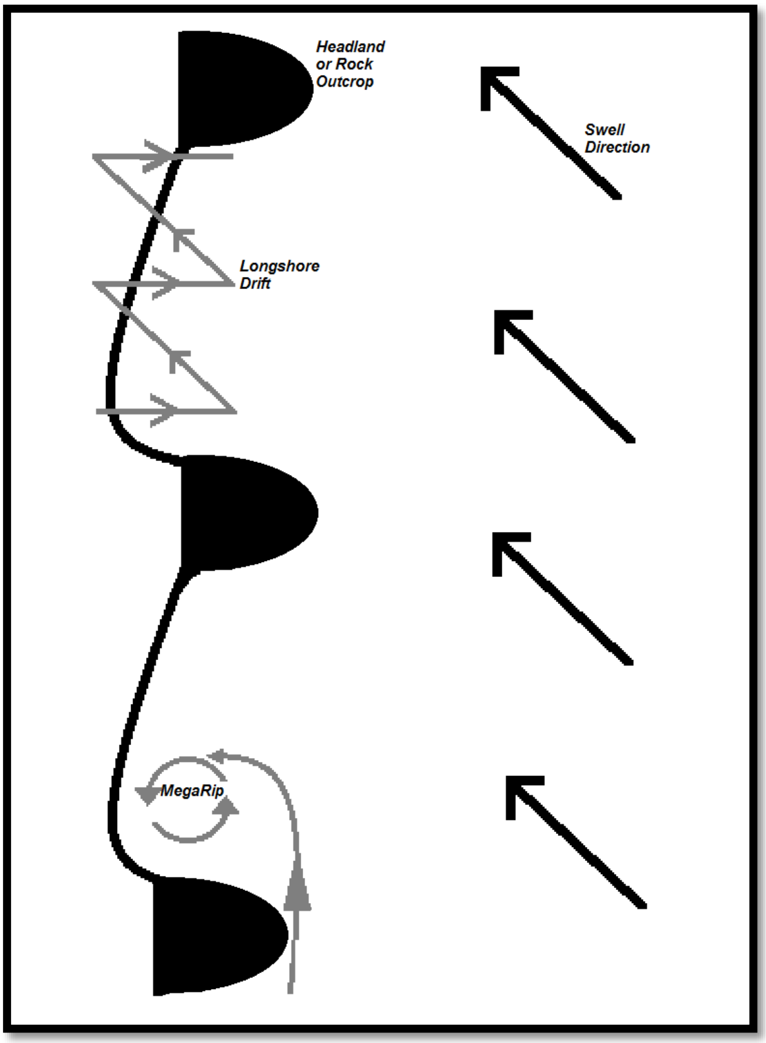

Figure 2.1: Schematic representation of long shore drift and a beach rotation during winter swells (Brown *et al.*, 1989)

Swells do not move in the same direction all the time and often change direction due to weather and seasons (Figure 2.2).

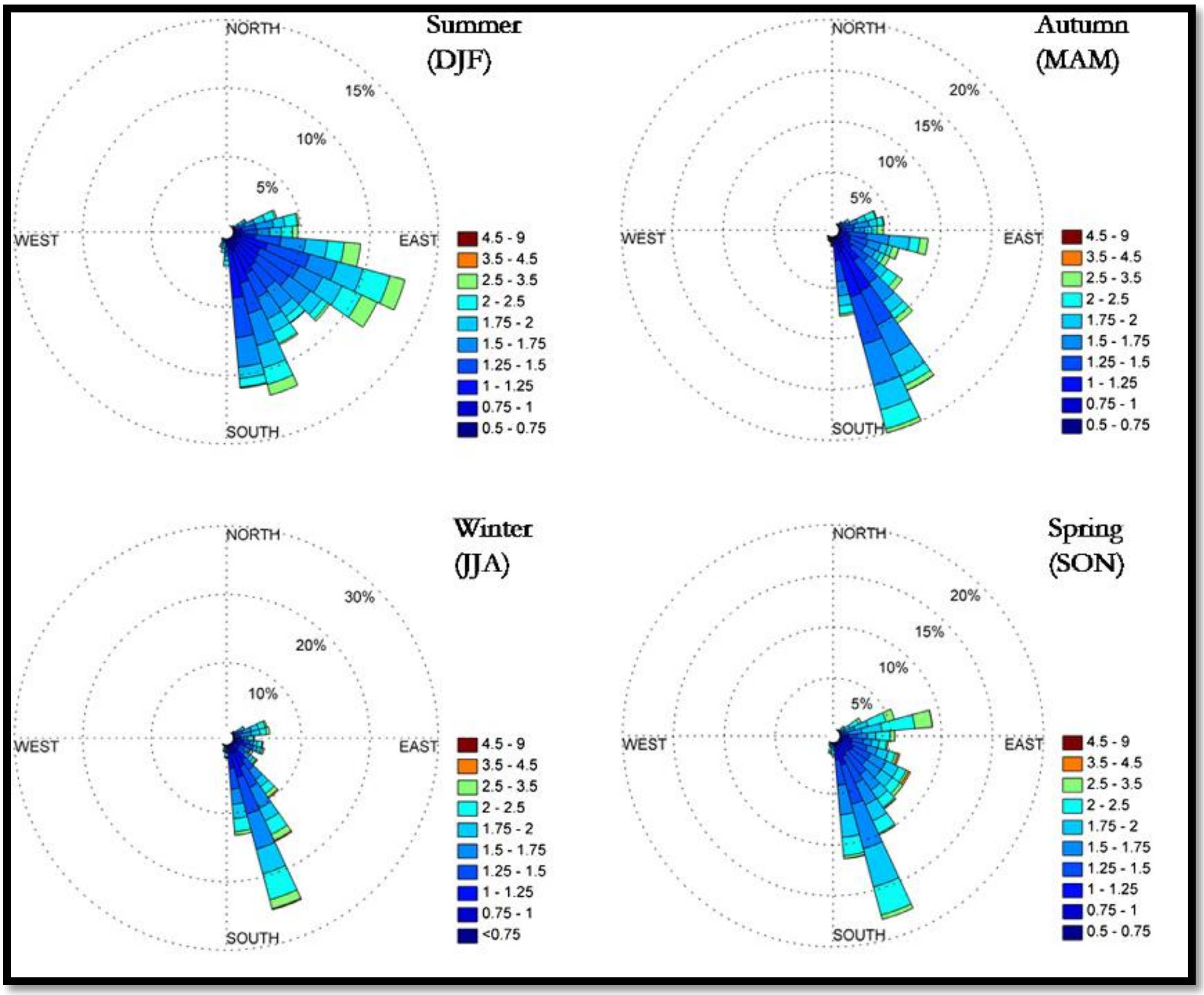

Figure 2.2: Swell directions for Durban, South Africa (Guastella & Smith, 2014)

This is evident at Umhlanga Rocks beach as seasonal patterns produce beach rotation within bays that occur on the coastline (Guastella and Smith, 2014; Smith *et al.*, 2013). This is known to cause the beach to thin in the south and thicken in the north during winter swell and does the opposite for summer swell. As seen in figure 2.1, the coast is thinner in the south of the bays and thicker in the north. There is also a rip in the south which is helping to thin the beach in the south of the bay. This is also the case for piers that are at Durban main beaches as there are several piers that extend into the ocean (Figure 2.3). The winds experienced in Durban are generally North East and South West, which run parallel to the land (Diab & Preston-Whyte, 1980). This brings the swell at angles to the coastline. The recovery of Umhlanga Rocks beach was due to a seasonal movement to a more easterly swell direction (Guastella and Smith, 2014). The decrease in wave height and increase in wave period and sediment supply allowed the Umhlanga Rocks beach to rejuvenate on its own.

Figure 2.3: Durban beach front experiencing thinning of coastline in the south and thickening in the north within the 2 piers

Beach profiles of the coastline will affect the amount of erosion (Theron & Rossouw, 2008). Steeper beach profiles will have less wave run-up and may be eroded less. This is due to the fact that the steeper profile will dissipate the wave energy to vertical energy while the lower gradient does not dissipate the horizontal energy, enabling erosion to occur. Short term and long term changes occur during tide changes, daily, seasonally and annually along the coastline (Weis *et al.*, 2002). This proves that sediments are constantly moving from every hour to yearly.

During the 2007 storm that occurred on the East coast of South Africa, it is believed that Durban lost approximately 5.2 million tons (3.5 million cubic metres) of sand (Smith *et al.,* 2007; Smith *et al.*, 2010). The High Water Mark (HWM) retreated between 10 to 30 m in Ballito (North of Durban) and 10 m and 16 m in Umkomaas and Umdloti respectively (Smith *et al.,* 2007). A similar volume of erosion that occurred in the 2007 storm was experienced during the 1970 and 1989 storms at Eastmoor Crescent (Smith *et al.*, 2010).

The recovery of sediments will help the coastal managers to make decisions on the planning of hazards (Corbella & Stretch, 2012d). The recovery of the beaches is dependent on various factors such as sediment supply and the erosion processes on the coastline. The recovery period is equal to $D_{Recovery} - D_{Event.}$ The $D_{Recovery}$ is the date that the beach recovered and D_{Event} is the date the erosion event occurred. The recovery rate is equal to $\frac{V\ (Recovery)}{Recovery\ Period}$. The V (Recovery) is the volume that has been recovered. The recovery period is around 2 years at a rate of 97.3 $m^3m^{-1}yr^{-1}$(Corbella & Stretch, 2012d). The storm that occurred in Durban in March 2007 recovered at a rate of 62.2$m^3m^{-1}yr^{-1}$. The 2007 event was recorded as the largest storm event in 18 years. Durban has historically suffered from the effects of erosion due to the harbour and its activities (Corbella & Stretch, 2012b). This is due to the fact that sediments are being deposited within the harbour and then being dredged and deposited out to sea. The sediments are not making their way to the coastal regions to help with the rejuvenation of the coast lands. 15 years of data has been analysed on the length and area of the beaches, and what was found, was that 70% of the beach profiles are decreasing (Corbella & Stretch, 2012b). Due to urbanisation on the coastline, the ability for the coastline to repair itself is reduced (Smith *et al.*, 2013). As Durban is in an area that experiences summer rainfall, more sediment will be delivered to the coastline during the summer season than in the winter season. This could be advantageous to Durban, as it delivers sediment to the coastline before the high winter swells effect the coastline. This said, it could also be negative as less sediment will be supplied to the coastline to replenish the sediment that is lost from the winter swells.

2.2.1. Ways to date and monitor erosion events

Cesium-137 (^{137}Ce) can be used to provide information about the erosion and sedimentation of an event in terms of its rates and patterns (Ritchie & McHenry, 1990). Cesium-137 can be used to study the magnitude and spatial variability of the loss of soils (Poreba, 2006). The properties of Cesium-137 are unique to it and make it ideal to use as a tracer for the studying of erosion and sedimentation as Cesium-137 does not occur naturally. This is because it was produced during the nuclear testing and the fallout is greater in the northern hemisphere as more testing occurred in the northern hemisphere (Chernobyl accident) (Ritchie & McHenry, 1990). Cesium-137 releases a gamma-ray (662 KeV) which makes it easy and accurate to measure in samples (Poreba, 2006; Ritchie & McHenry, 1990).

There are not many ways to predict or determine the amount that the coastline may lose due to sea level rise, but one method is to use the Bruun rule. Shore face retreat in terms of the Bruun rule, was a great advancement in the understanding of coastal behaviour (Cooper & Pilkey, 2004). The Bruun rule is in terms of beaches and near shore, and states that if beaches experience sea level rise, they will move upwards and towards the land.

The Bruun rule equations are as follows

$$R = S\left(\frac{L}{B+h}\right) \quad (1)$$

$$= S\,\frac{1}{tan ø} \quad (2)$$

Where R is the shift of beach towards the land and L is the length of the beach profile (Cooper & Pilkey, 2004). Ø represents the slope angle, B is berm height, and *h* is the closure depth (Cooper & Pilkey, 2004). S represents the rise in sea level. The closure depth is the depth at which the wave no longer affects the sediments. The Bruun rule also has its downfalls as it is conducted on the "one fits all' method. Beach systems are complex and this method will not work. The Bruun rule also leaves out important variables and relies on relationships that are outdated and full of errors (Cooper &

Pilkey, 2004). For this rule to work, long shore drift, rip currents, storm surges, wind erosion, and ebb currents need to be considered, which they are not. From this, one can state that this is not a good enough rule to use, but since it is so simple to use and apply, it is widely used around the world.

Erosion from a storm surge is difficult to determine, but according to Callaghan *et al.*, (2009) one can use past storm surge events and compare it to events that may happen in the future to predict the amounts of soil removed or the use of synthetic design storm approach (SDS method). In recent studies, the joint probability method (JPM) has been used. To understand the potential erosion risk due to sea level rise, the coastal vulnerability index (CVI) should be used (Mariappan & Devi, 2012). CVI is a commonly utilised method to determine coastal vulnerability with respect to sea level rise (Addo, 2013). CVI is based on the interrelationship of 6 factors (Doukakis, 2005). First is the coastal slope (CS), the steeper the slope, the less likely for it to be flooded. The second is subsidence (S), which is the lowering of land relative to the sea level. This gives the illusion that the sea level is rising, but in actual fact the land is subsiding. The third is displacement (D), which are the past events that have caused the shore to retreat and the tendency for it to occur again (Doukakis, 2005). The fourth is the geomorphology (G) of the area. This is linked to the erosivity of the area, such that areas with smaller sediments have a higher erosivity (Doukakis, 2005). The fifth is the wave height (WH), which can be used to indicate the volume of sediments removed from the coastline. The last factor is the tidal range (TR). This causes both long and short term erosion. These factors are rated on a scale from 1 to 5 as the vulnerability increases (Doukakis, 2005).

$$CVI = \frac{\sqrt{CS.3S.3D.3G.3WH.3TR}}{6} \qquad (3)$$

2.3. Climate change and how it may affect the coastline of KwaZulu-Natal

Climate change is believed to be associated with global warming and green-house gases (Goudie, 2006). Global warming as a process, is difficult to reverse once it has started and once passed a critical point, there may be no stopping it from altering the atmospheric conditions until stability is established (Cai *et al*., 2009). There seems to be little form of control measures and if there are, they are not being enforced correctly (Cai *et al*., 2009). Climate change can cause the intensification and duration of storms. Goudie (2006), states that the storms may increase by between 5 to 10 %. Climate change has been said to be caused by Greenhouse Gases (GHG) which are believed to be a product of human activities (Bryan *et al.*, 2009). As more of these GHG are released, they cause the atmosphere to get warmer. According to Theron and Rossouw (2008), there are many impacts on the coastline that are caused by climate change. The inundation or displacement of areas on the coast, such as wetlands and lowlands will occur due to sea level rise. The erosion of the coastline, an increase in flooding along the coastline by storms, the increase of salinity into estuaries and aquifers on the coastline and a decrease of light penetration will have an effect on coastal and estuarine life (Theron & Rossouw, 2008).

Due to high changes recently in the climate, global warming has become the front runner in scientific inquiry (Easterbrook, 2011). Many scientists believed that it has got to the point where one can describe it as a 'smoking gun'. As it has become more popular, media have taken a firm grasp on it and blamed the effects of CO_2 from cars, factories, cattle and various other CO_2 emitting sources. This has brought upon life changes such as living green and lowering peoples' ecological footprint. This said, Easterbrook (2011), states there is no positive link between CO_2 and global warming. This statement was made due to the fact that between the years 1880-1915, a cool period was experienced with the glaciers that are relatively the same size as they were during the little ice age experienced 500 years ago. Between the years 1915 - 1945, a warm period was experienced and the glaciers retreated and there were no significant changes that were recorded in the atmospheric CO_2. The next cool period was experienced between 1945 - 1977, the glaciers advanced once again, but the levels of CO_2 soared. Thus some believe that the concept of global warming may not be true. According to Easterbrook (2011), if one had to take the past events into consideration, the period of warming is believed to have ended in 1998. This will then be the start of a cool period. In terms of sea level rise, if the Earth had to experience a time of cooling, the glaciers and ice caps would reform thus lowering the sea level and moving the areas that may be eroded by the ocean further away from the land today.

The Intergovernmental Panel on Climate Change (IPCC) has stated that Earth is on the path to catastrophic climate events (Easterbrook, 2011). Models and projections have determined that if Earth carries on the path it is currently on, the atmospheric temperature will increase to between 5 - 6°C. With the increase of atmospheric temperature, the ocean temperature will increase. Computer projections have determined that the ocean has the potential to increase by 5.8°C before the end of 2100 (Easterbrook, 2011). Easterbrook (2011) states that computer models predict that the ocean may rise by 0.55°c from 2000 to 2011, but the global temperature has in fact decreased from 1998. This proves that results from prediction are often controversial and conflict one another. It is believed that if the average wind speed increases between 10 to 26%, it will increase the wave height by 80% (Guastella & Rossouw, 2009). This would then increase the wave power by 40 to 100%, thus increasing the sediment transport on the coastline.

2.3.1. Projected sea level rise

The sea level to date has risen over the past one hundred years (Cai *et al*., 2009). Due to climate change, many people believe the earth is getting warmer and thus the sea level may rise to approximately five times higher than present sea level (Cai *et al*., 2009). The rise in sea level can often be misunderstood and difficult to calculate, but it could be one of the most important outcomes of climate change (Cronin, 2012). This is because during the last century, the sea was rising at a rate of 3.1mm per year, but the 21st century has shown that the rate of sea level rise is as much as 5 times faster which would be approximately 15.5mm (Cronin, 2012; Mather, 2007). This is a hypothetical value that was used to project what may happen in the future. The chances of the prediction occurring are slim. This said, if hypothesis is correct, the alerting of personal might be too late. By 2100 the sea would have risen by 75 to 190 cm (Cronin, 2012). A way that scientists have calculated sea level rise is to determine the volume of water content in ice, sea ice and ice bergs and then add the content together to show what may occur if the ice melted. If this had to occur, the calculation predicts the sea level could rise between 80cm to 200cm (Cronin, 2012). This said, often thermal expansion of the actual water body is not considered, this could add a further 30cm on top of the total sea level rise. Guastella and Rossouw (2009) believe that in 20 years the sea level at normal high tide will be at the same height as the highest astronomical tide experienced in the present day. This means that storm surges will have the potential of flooding further inland than it would have at the time of this research. Flooding is defined as an area that is over flowed with water, which is above the normal water mark (Marshak, 2008). This means that even if an area is covered in water for several seconds, it would be flooded. Since the sea level may rise this will allow for smaller storm surges that will affect the coastline.

According to Cai *et al.*, (2009) the sea level may rise to 50 cm above present sea level by 2100. There are conflicting theories about how much the sea level will rise and to what extent. For the purpose of the research, the worst case scenario must be taken. Sea level rise does not only effect the erosion of coastlines, it also has various other effects such as the flooding of coastal regions (estuaries). This would alter the salinity of the estuaries and thus have an effect on this environment which is generally brackish water. The increase of salinity in coastal soils and water systems has the potential of killing or altering the way flora and fauna co exist with the ocean. With an increased sea level, this allows the waves to penetrate further inland and if a storm had to occur the waves would wash up much further than present day. South Africa is believed to be 1 of the 50 most vulnerable countries, with regards to wetland destruction due to sea level rise (Theron & Rossouw, 2008).

The rise in sea level could be due to either global or regional conditions (Cai *et al*., 2009). Global conditions that may increase the level of the sea could be due to thermal expansion of the ocean which in turns melts the solar ice caps and glaciers. As the water body increases in temperature, thus so does the volume due to thermal expansion. This will then increase the sea level and allow the water body to come into contact with ice at higher altitudes then before. This will increase the volume of the water that is in the ocean and increase the global sea level. With the increase of temperature of 5 to 6 °C by 2100, it may cause the ice cover in the Arctic Ocean to become free, the ice sheets on Greenland may cease to exist, while the alpines glaciers would retreat very rapidly (Easterbrook, 2011). With all the melting of ice and glaciers, the sea level will increase in height and the atmospheric temperature would increase, thus melting all snow caps and snow, adding to the increase in sea level rise.

Sea level change can be observed by ocean fossils that have been found in inland areas (Cronin, 2012) and in areas that are below the sea level. A German submarine called “Jago” was used to observe the sea bed (Green & Uken, 2005). During the first test, canyons were found, cut into tertiary and late cretaceous era, which is a typical stratigraphy of a continental shelf (Green & Uken, 2005). Coarse grain sands were recorded at 120 m which is typical to littoral grain surfaces. This proves that the sea level has risen and fallen in the past years. According to Smith *et al.,* (2013), the sea has risen by 130 m from the last glacial maximum which was around 18 000 years ago.

2.3.2. The storm surge phenomenon

A storm surge is a localised uplift of a water body from atmospheric conditions, which can flood coastal areas if the uplifted water body comes into contact with the coast (Marshak, 2008; Park & Suh, 2012). Surges are known to take many lives along the coastline; such was the case in 1970 where a storm surge flooded a coastal city in Bangladesh, killing around 500000 people (Marshak, 2008). Storm surges are often caused by hurricanes and the atmospheric conditions which are associated with the storm (winds). This can cause the water to lift or get sucked up slightly below the eye of the storm (Thurman & Trujilo, 2011). For a storm event to be classed as a storm surge, the wave height must exceed a threshold of 3.5 m and will end as the wave height drops below this threshold (Corbella & Stretch, 2012a). Storm surges are the cause of the greatest mass movement of sediments from the coastal regions. This will also affect dune areas as well. Figure 2.4 depicts how sea level may inundate coastal infrastructure and then with a surge associated with this, the flooding potential will be vast. Once the storm event has completed, the sand generally moves back over time during periods of normal wave action (Zhang *et al.*, 2004). Storm waves are due to 3 weather systems in South Africa, the first being the coastal lows and cold fronts (Corbella & Stretch, 2014). The second is cut-off lows and extra tropical cyclones and the third is tropical cyclones (Corbella & Stretch, 2014; Smith *et al.*, 2014). Cut-off lows generate a south easterly wave, but are far off shore, which produces a longer wave period. Tropical cyclones are less frequent, but are responsible for large swells which have had the potential of damaging property (Smith *et al.*, 2010). This happened on the February 1984 in Richards Bay, where a 9 m swell reached land.

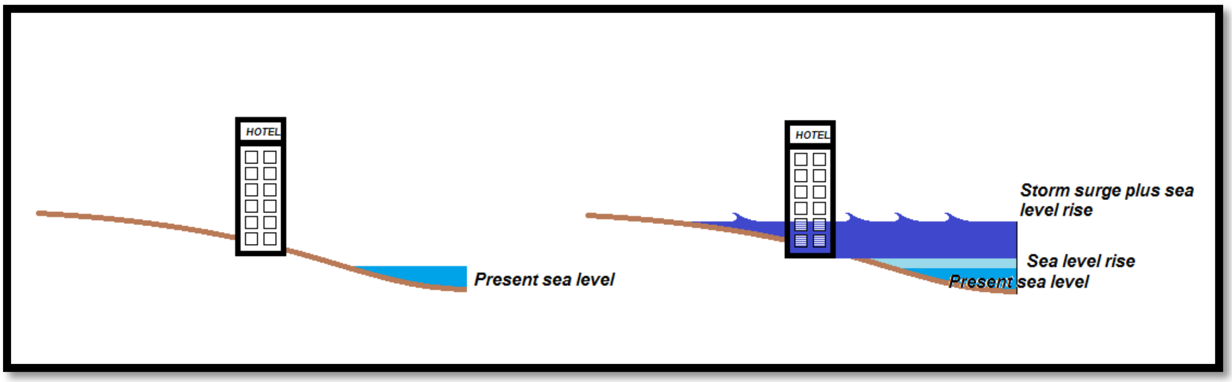

Figure 2.4: Schematic representation of sea level rise

As stated before, one of the worst storm surge events to date that has been recorded was in March of 2007 (Corbella & Stretch, 2012a). It was exacerbated by the joint occurrence with an equinox which thus had devastating effects along the coastline. The equinoctial spring high tide was recorded at a height of 2.24 m on the 19th and 2.28 m on the 20th of March, which is experienced every 18.03 years (Smith *et al.,* 2007). The average equinoctial spring high tide is around 1.8 m. The wave height was recorded closer to the coastline peaked at 8.5 m and with a 2.2 m extreme high tide caused the sea to rise over 10 m (Guastella & Rossouw, 2009). The wave height peaked at 05:00 on the 19th March 2007 at a reported height of 14 m in deeper waters (Smith *et al.,* 2007). Due to the direction of the swell (south east to south south east) and a period of 16 seconds, this allowed the swell to have minimal refraction on the coastline, thus coming into contact with the coastline with maximum force. The swell continued to smash the eastern coastline until the 20th of March, where the swell height dropped to below 3m, lower than the storm surge threshold (Smith *et al.,* 2007). The storm affected Port St John's in the Eastern Cape to Maputo in Mozambique (Smith *et al.*, 2007). The damaged property on the coast was a mixture of private and public establishments, and the provisional repair evaluation to the public sector was approximately 2 billion rand.

The extent of damage from the storm of March 2007 was due to 5 factors. Firstly the proximity of infrastructure was too close to the High Water Mark (HWM) (Smith *et al.,* 2007). Secondly the coastal profile of KZN is mostly steep and therefore easy to dissipate the swell forces. Ballito was one of the coastal regions that have a low coastal profile and thus was the worst affected. Thirdly, the coastal shape, such that area adjacent to areas within the bays that are the deepest, were hit the hardest (Smith *et al.,* 2007). The infrastructure that was situated near or on rocky headlands failed as wave energy was not able to dissipate naturally. The Fourth factor was the coastal type. Coastal regions comprised of only sand or only rocks generally withstood the storms. Areas that were mixed were damaged severely (Ballito) (Smith *et al.,* 2007). This is because most of the wave's energy dissipated downwards. In areas that a rock shelf was present and the scouring depth was lower than this rock shelf, the wave energy reflected back up and was then forced towards the land which increased coastal erosion (Smith *et al.,* 2007). Areas that were naturally vegetated were in equilibrium with the sea and absorbed most of the wave energy (Smith *et al.,* 2007). This said, many naturally vegetated coastal regions were undercut at the base of the dune and thus erosion occurred. It is notable to state that only dune systems that were vegetated by indigenous coastal dune species (*Chrysanthemoides monlifera*) were able to return to a stable gradient. Vegetation such as exotic flora or lawn flora became unstable and was eroded away. Dunes along the east coast are between 30 m to 60 m high (Smith *et al.,* 2010). This allowed for a buffer between the ocean the in infrastructure inland, as the dunes eroded first. Lastly, the fifth factor is the modification of the coastline (Smith *et al.,* 2007). Area where seawalls were constructed, stood against the wave energy, but the margins and top allowed for standing waves to erode behind and on either side of the wall. Areas that have been reclaimed from the coast were damaged.

Wave riders are currently being used to record the wave data along the coastline of Southern Africa. The Wave rider's data has been operational for the past eighteen years and thus can be used to analyze and test past events to help determine future events (Corbella & Stretch, 2012a; Guastella & Rossouw, 2009; Corbella & Stretch, 2014). According to Corbella & Stretch (2012a), from the Wave rider's data and other data, the wave height that was experienced in 2007 had a recurrence of between a thirty five and sixty five year interval. This states that since it is only a thirty five year interval, the storm surge or wave height is not the biggest that can be experienced and then determined to be a small storm event (Corbella & Stretch, 2012a). The oceanographic condition prior to the 19th of March 2007 was unusual with swells reaching between 2 to 3 m (Smith *et al.*, 2007). This meant that the beaches were depleted of coastal sediments before the event occurred. The high swells are due to the tropical cyclone Dora and Gumede that occurred prior to the big March 2007 storm. The storm that occurred in 2007 started as a frontal low (Smith *et al.,* 2007). The storm intensified rapidly to become a cut-off low on 18th March just south east of East London. The storm reached its maximum intensity south east of Durban at about 700km on the 19th of March and remained in that position until the 20th of March (figure 2.5). This allowed the storm to intensify to experience a central low pressure of less than 996mb (Smith *et al.*, 2007). Winds were recorded at 40 knots (74 km/h) and 45 knots (83 km/h) in East London and Durban respectively. This wind speed and the distance from the land allowed for the generation of large swells along the KZN coastline. Extreme waves are rarely caused by tropical cyclones in Durban (Corbella & Stretch, 2012a). It is believed that only 7 cyclones have affected the eastern coastline of South Africa between 1967 and 2005. According to Corbella & Stretch (2012d), the beaches that were destroyed by the 2007 storm took six years to recover.

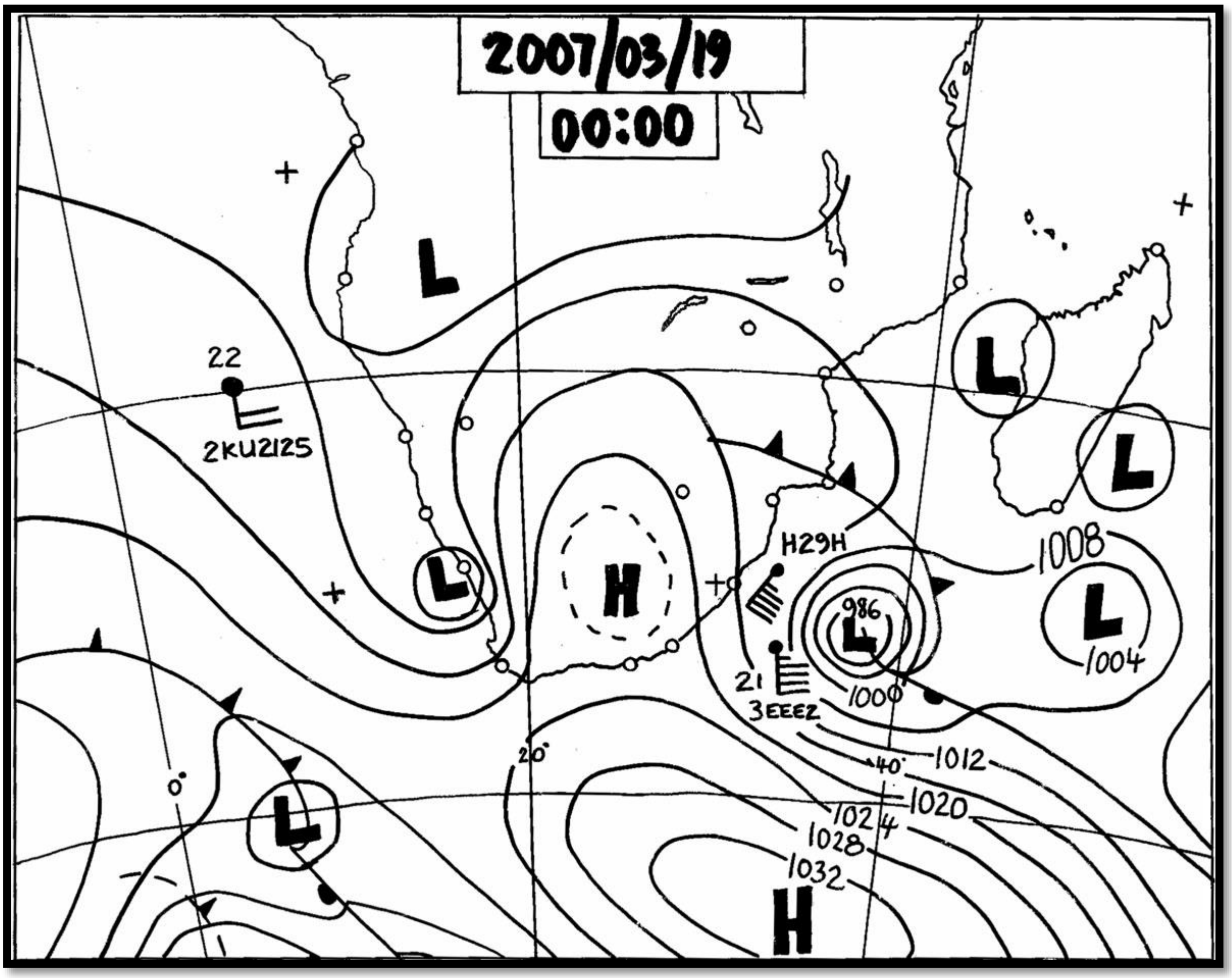

Figure 2.5: Synoptic chart for South Africa showing the cut-off low off the east coast on the 19th March 2007 (Smith *et al.*, 2010)

On average, the estimated erosion rates are around 0.14 % per year per storm, only if there is an increase in wave height of approximately 0,0057 m per year (Corbella & Stretch, 2012c). Since the surge and the extreme high tide occurred at the same time, it had a large effect on the coastline. The chances of these 2 phenomena occurring together again, are slim.

One of the areas that were hit hard by the 2007 storm was the Umhlanga area. The Umhlanga area is a very popular tourism destination and has a large amount of beachfront development (Guastella & Smith, 2014). This means, that the back dunes have been destroyed for anthropogenic use. This is a good example of an area where coastal processes that may occur in the future were not considered when planning of the infrastructure was done along this area. Protection methods are being implemented, such as loffelstein walls, to help prevent the effects of coastal erosion.

The south coast of KZN was the least impacted as laws have been put in place to help protect the coastal environments. Laws such as the admiralty reserve, which is from the HWM and extends inland for 47m (Smith *et al.*, 2010). This region prohibits any building or removal of vegetation. This created a natural barrier against the effects of the 2007 storm. With the sea level rising, the barrier might be swamped, but it may still provide some sort of protection from a surge.

Storm surges and storms may intensify as stated before, by 5 to 10 percent, which means that the storms are going to get worse. The storm that was experienced in 2007 may be considered to be a smaller storm relative to the storms that may occur in the future. During storm events the wave direction is usually between south and east and hits the eastern coastline perpendicular. The occurrence of events that exceed the 3,5m threshold for a storm to be classified as a storm surge is increasing (Corbella & Stretch, 2012c). On average, the threshold was exceeded 3 times a year and is increasing 0.01 events annually. The 2007 effects of the storm surge is believed to damage property to the value of R 400 million to R 2 billion (Theron *et al.,* 2010).

The storm events are believed to have a cyclic occurrence to them (Bundy *et al.*, 2012b). A core sample was extracted from the Beachwood dunes in Durban, South Africa. It was found that there have been 4 intrusions in a core approximately 1 meter long. From the core it was calculated that the next large storm occurrence may be in 2015 or 2020 (Bundy *et al.*, 2012b). A storm event was experienced on the 5 June 2015 were swells exceed the 3.5m storm surge threshold. This could have been the storm that was predicted by Bundy *et al*., (2012b). This is predicted by examining the sediments that occurred within the core sample, as coastal sediments are deposited in the dune system during high swell periods. This sediment will be different to the normal sediment experienced there and a layer of these sediments will be evident.

2.4. Prevention methods in their context of coastal erosion

There are many prevention methods that have been introduced in the past. Some have worked well and others have failed. Some prevention methods have been known to make the erosion worse in places where there is no sign of prevention practices. A large amount of research needs to be done to understand the prevention methods and test to see if they will work (Callaghan *et al.*, 2009). Coastal planning and management needs to be established to help as an effective measure for coastline retreat. According to Morais *et al.* (2006), there are five human responses to the effects of coastal erosion. The first would be to implement physical structures to protect the infrastructure of urban areas. The second would be to implement activities that will reduce erosion rates of the coastline. The third would be to increase beach nourishment. The fourth is to accept the erosion without doing any action. The fifth would be to implement new regulations and policies. This being said, to what extent and cost should one go to, to protect the coastline, before it would not feasible anymore?

The use of aerial photography is used to map and depict the retreat in the shoreline over many years. With the use of satellite imaging, as well as observing the earth and its meteorological components, determining the after effects of a single coastal erosion event or several events in concession will be made easier (Mariappan & Devi, 2012; Guastella & Smith, 2014). Webcams are currently becoming the more popular method of recording beach movement as they are freely available, but are susceptible to the service provider for the quality of the image (Guastella & Smith, 2014). This will help to compare the geomorphology of the land before and after the events have occurred to see the change in the landscape. It can also be used to monitor movement of sediments continuously and record it against weather and coastal conditions to help predict the future effects.

Various methods have been used to protect the coastline, from fabrics to concrete barriers. Geosynthetic fabrics are used as they have high strength and are less likely to be damaged due to abrasion, tearing, puncturing or ultraviolet deterioration (Harris & Sample, 2009; Smith *et al.*, 2013). Bags are filled with sand or cement to make the structure more robust. The sand bags that are commonly used are called pillow shaped or single celled sand bags (Harris & Sample, 2009). Artificial reefs are also sometimes used to break the waves and the effects of the wave before it gets to the coastline (Pickering *et al.,* 1998). Tyres, cement and sometimes old ships are used to create artificial reefs.

An example of prevention methods abroad could be a project in Europe known as the “Conscience Project” which is underway to determine concepts, guidelines and tools to help with the sustainable management of coastal erosion (Marchand *et al.*, 2011).

Chaleur Bay has installed coastal protection infrastructure to hinder the effects of coastal erosion (Bernatchez *et al.,* 2011). The results were that the infrastructure is installed, the beaches were protected, but this has increased the rate of coastal retreat in areas adjacent to the protection infrastructure that has no protection infrastructure installed. This is caused due to the protection infrastructure funnelling the water to areas of no infrastructure, thus making the erosive power much higher than it would have been before. The areas adjacent to the protection infrastructure will get eroded. Once these areas have been eroded, the water body has the potential of undercutting the edges of the protection infrastructure or even getting behind the infrastructure, creating a larger issue.

According to Bernatchez *et al.*, (2011), the coast has retreated by 24 m from 1934 to 1992. This rate has increased, from 1992 to 2006 it retreated 9 m, which is a 56% higher rate the before. The case study thus allows one to determine that coastal erosion is not a local problem, but rather a global problem as regions other than South Africa experience coastal erosion. This said prevention infrastructure may not always be the solution to the problem and has increased the rate of erosion in this case. The results of the research, if successful, could be adapted (if needed) to help sustainably manage the South African coastline.

3. Methods of analysis used in the present study

In the previous chapter, various characteristics were discussed that need to be analysed to be able to get the best results for this research. This chapter will give detailed accounts of the process of investigation in order to meet the objectives set out in chapter 1. This chapter will review the processes which were undertaken to better understand the processes of erosion caused by storm surge and sea level rise and the prevention methods needed to mitigate the issue. This will help to determine the results for the aims and objectives set out for the research.

Various methods were used to determine the changes in sea level over different years and incorporate the effects of storm surge on top of that. The methods will be split into tools used: Geographic Information Systems (GIS), field work, lab work and research on the best prevention methods that are being used.

3.1. Tools and technigues

- AcrMap 9.3 (GIS software)
- Sand Bags (Sealable sampling bags)
- Hand auger
- GPS
- Measuring rod (Dumpy level/ Abney level and measuring stick)
- Soils oven
- Kingtest laboratory test Sieves
- Vibration stand
- Trays
- GRADISTAT software (Grain analysis software)
- Electronic Balance

3.2 Geographic information systems process utlizied

3.2.1 Pilot study

A pilot study was conducted on a smaller scale to make sure the processes that will be used were feasible for this research. The pilot study was done at Umdloti beach to determine where along that beach, the conjunction of sea level rise and storm surge will be affected the most. Below are the processes used in the pilot study. Later, the methods that were used to determine if they can be used in the project will be discussed.

Geographical Information Systems (GIS) in the pilot study were used to project the extent of intrusion of the expected sea level rise in conjunction with storm surge. A standard 2 m contour was used to determine these areas. The methods used in the field to measure the coastal profile were to use two measuring poles and a string, with a minimum of three people needed to conduct the sampling. This was done by measuring a distance between the two measuring poles and then making the string perfectly horizontal. Then measurements on the measuring poles were then used to determine the difference in height from one pole to the other. In the laboratory, processes were used to dry, sieve and weigh the sediments to determine the sediment distribution of that sample taken.

The GIS used in the pilot study was not too in depth. This showed the downfalls and successes that could be used to better the GIS process in this project. It was found that finer contours were needed to get a better understanding of the intrusion. Thus various routes were used to interpolate the contours of the given maps for this project. Routes such as using the 3D analysis on ArcMap to determine the best interpolated contours, or using the ArcScene to interpolate contours. Once this was done the most ideal path was chosen to best depict the interpolated contours that are needed for the project. The best process was found to be the use of a combination of both, to get the best and most accurate results that could be used to project the expected sea level rise and storm surge. Due to the need for three people to do the field work, this method was changed to use less people. An Abney level and measuring stick was used for the project, due to the ease of use and thereby only two people were needed to do the sampling.

In the laboratory after drying and sieving, it was found that there was a high content of salt. Therefore for this project, the salt needed to be removed or diluted to reduce the amounts of salts in the final readings. This salt content could affect the final results of the data. Samples were placed in 2 litre containers and filled with water. The samples were left to settle for 48 hours and the water was then removed. A sample was taken from a site and the dilution of salt was not done, to see how much salt was lost.

From the pilot study that was conducted and the methods that were used, downfalls and successes were found in the process. Thus, better or more accurate methods were determined, to be used for this project to better the final result.

This process was also used to determine the ideal path that should be used to determine how to project the expected sea level rise, the projected sea level rise in conjunction with storm surges and to determine the worst affected sites that needed to be studied.

3.2.2 Change of projection

Due to all the map layers being in different projections, this may cause problems in the projections and processes of the data. The projection of all the maps needed to be standardized. This was conducted so that no problems would arise later in the project. This is done by changing the projection of the coordination systems so that they all match. The projection that was used for this project is “Transverse Mercator” with a central meridian of 31.0. Once this was done, the geographical coordination system was changed to WGS 1984. The projection of the layers will now be shown in meters.

3.2.3 Contour interpolation

The maps that are available have a contour interval of 10 m and sometimes at an interval of 20 m. For the purpose of this research, the best contour interval for the high degree of accuracy, would need to be as close as possible, but since interpolation is not the exact contour interval and is just a calculated point between the two given contours. It was decided to use a standard 1 m contour interval instead. This would mean that the 10 m contours intervals would need to be interpolated so that it depicts 1 m contours within them. This in basic terms, takes the two different contours (10 m and 15 m) and intersects it evenly 9 times (for 10m) and 14 times (for 15m) , so that there is a contour line for each meter from one interval to the next.

Cronin (2012) has predicted that the sea level will rise from 75 to 190 cm above today's sea level by the end of 2100. To reduce the file sizes, various contours must be removed. Contours that were above 50 m are removed to reduce the file size and make it a more manageable file size while still allowing the remaining contours to be used in terms of the project. To reduce the number of contours, the contour layer needs to be opened on ArcMap. All contours above 50 are highlighted and removed which leaves a more manageable file size. Then, the remaining contours are highlighted to be exported, to create a new file.

The highlighted contours need to be exported to a new file thus reducing the size of the original file. To do this one must right click on the layer, scroll to 'Data' then to 'export data'. One should then name the new file. This is the file that will be worked on the help save time and processing speed.

Within the ArcGis software, there are various sub programs that help with the analysis of data. ArcScene is chosen to be used to get the most ideal interpolation of the given contours. Once ArcScene is open, the desired map must be opened with the correct layer contours on top. Using the 3D analyst tool a TIN file must be created. The height source was then elevated and it is triangulated as hard line. Once this is done the TIN must be named appropriately. This file was used in ArcMap.

ArcMap was then used to load the new file that you created in ArcScene. The TIN file now shows contours, with the use of a 3D analyst tool, one can change the TIN contours which will interpolate the contours to the desired interval. The contour intervals were selected to be 1 m and the output name and situation for the new saved file. Figure 3.1 shows the before interpolation on the left and after interpolation on the right. As one can see, there are many more contour lines after interpolation has occurred.

Figure 3.1: Contours before (a) show red lines of 5 metre intervals and after (b) interpolation shows white lines of 1 metre intervals

3.2.4 Projecting sea level rise in conjunction with storm surge

From the contours that have just been interpolated, one must now project the predicted sea level rise and then include the effects of storm surge. As stated by Cronin (2012) and in the literature review, a standard sea level will rise to a maximum of 190 cm above today's sea level by 2100 was used for the research. This is for the benefits of projecting the sea level rise, which may or may not happen in the future. For the purpose of this research, according to Cronin (2012), the sea level may rise at an approximate rate of 15.5 mm a year at current rates, but at the time of Cronin's, (2012) paper, the sea was rising at a rate of 3.1mm a year. For the purpose of this research, 3 different year intervals were used, namely 2030, 2070 and 2100. The level of the sea was calculated from a base year of 2008 to 2015 for the rate of 3.1mm and then 15.5mm per year for years thereafter. This means the sea level may rise by 396.8mm from 2008 till 2030. This was done for 2070 and 2100. A worst case scenario was used at a height of 2m above today's sea level and associated storm surge event which brought the sea level up too 10m. As 2m sea level rise and the replication of the 8m storm surge of 2007 was used. These rises in sea level were depicted on the map layers by a solid darker line. This is done by opening the attributes of the layer and selecting the altitude required. This selected attributes must then be exported and produced as its own layer. For the purpose of the research a worst case scenario will be projected to see the future possible outcomes and deem it as the "Perfect Storm".

3.2.5 Selecting study Sites

The study sites were chosen once all the projections had been completed. They are selected by the distance to which the sea may infiltrate landward. This was done by viewing the projections and selection of the worst affected areas along the KZN coastline. Areas have a higher priority to be selected if they are situated in densely populated areas or infrastructure is present. Once the sites were selected, satellite imagery was used to look at the surrounding areas. This was done to determine if there is any infrastructure in close proximity to the sampling sites.

3.2.6 Geology and soils of the study sites

The geology of each site was loaded as a layer on GIS to determine the geology in the study areas. This was used to determine the strengths or weaknesses of the surrounding soils and geology. This determine the material of each site. The same was done with soil layers. This was used to determine the soils in the dunes areas. This may help to predict the movement of these soils.

3.2.7 Visual analyst of study sites

Each study site was different visually, thus each site must be analysed visually to determine the potential effects that the surge and sea level rise may have on the study site. Areas that are close to buildings or to critical infrastructure (railways, pipe lines etc) need to be described and were inputted to help with the end results

3.3 Field investigation

3.3.1 The study areas

Each study site was treated as its own individual site starting with the southernmost site as 'site 10'. Once on each site, beach profiles, soil samples, presence of erosion prevention, infrastructure and use of the beach were recorded and used to compare at a later stage. A single beach profile was taken at each site in the area of the lowest altitude above sea level. This was used as it would determine the lowest sea level required to wash over the beach area. The time of each profile, including the date was taken from each profile to determine the tides. The ideal tide for the beach profiles is during high low to get the best comparison between all the sites and the high tide mark is clearly visible (Guastella and Smith, 2014). This said, it was difficult to get all samples at low tide at some of the sites. This was due to the vast amount of travelling to each site as sampling was taken.

3.3.2 Determination of a beach profile

The beach profile is the gradient of the beach, which is a factor that may help protect the beach from potentially being eroded from sea level rise or storm surge as a coastal area with cliffs will be less susceptible to being flooded than areas that have low profiles. There are various methods that can be used to measure beach profiles. The method that was used to determine the beach profile was to use a measuring rod and an Abney level. This was done by two field workers, working together to get an accurate beach profile. The profile was taken from the edge of the beach (point where beach meets land) towards the sea. The field worker that holds the Abney level always has their back faced landward, while the field worker with the measuring stick always has their back faced towards the sea. The Abney level is used to determine the angle from one point to another at a fixed distance. For the purpose of the research, the distance was fixed at 5 m. The Abney level was used over the dumpy level due to the ease of moving it from one site to the next. The Abney level does not need to be set and calibrated to the area for each reading.

The field worker with the Abney level measured his/her height at their eye level above the ground on the measuring rod and marked it. The field worker with the measuring rod went 5 m towards the sea and held the measuring rod up right using the balance on the back to make sure it was perfectly straight. The field worker with the Abney level then looks through the level and matches up the line in the lens with the level bubble on the apparatus, with the mark on the measuring rod. Once this was done, an angle can be read from the side of the Abney level. This then gave the angle from point one to point two. This method was repeated along the beach profile. It gave the vertical distance from sea to land and the gradient. Three soil samples were taken. One of the samples was taken from the top of the beach profile, one from the middle of the profile and one at the point where the sea meets the beach. Figure 3.2 is a depiction of how the Abney level is used.

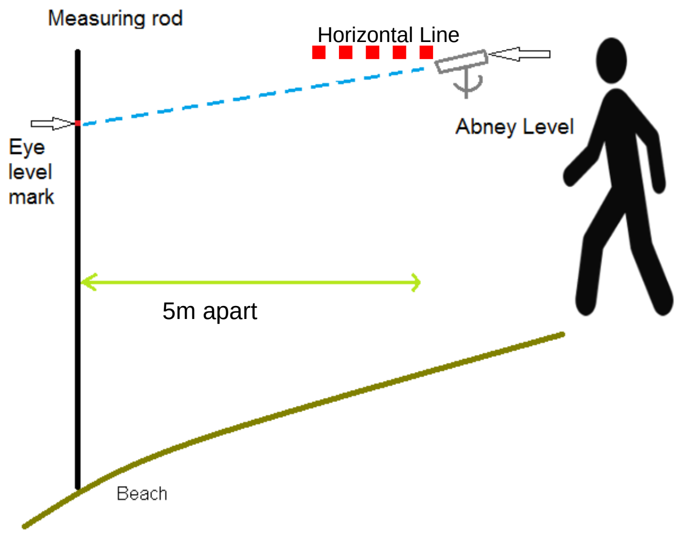

Figure 3.2: The use of an Abney level.

Once the angle was determined, it was then recorded and this process was continued along the beach profile. To determine the change in height from one point to another, the use of trigonometry came into play. Since there are two measurements, one should use Tan (5m * Tan ø = change in height). Where ø, is determined to be the angle taken from the Abney level. This can also be used to determine the actual distance of the profile by using Sin (5m * Sin ø = actual distance).

3.3.3 Sampling beach material

Soil samples were taken from each site. This was done to determine the sediment distribution later on in the laboratory. The sediment distribution and the sediment sizes will help determine the erodability of the site with the use of the hjulstrom curve. This is a curve that uses sediment sizes and velocity of moving water to determine areas of erosion or deposition.

As stated before, there were three soil samples taken from each site. Each soil sample that was taken was labelled with the study site number and the number of the sample at the site. With number one being on the land edge of the beach and three being near the water's edge. The soils samples were taken by the use of a hand auger. The auger was placed on the ground and soil at a depth of one foot (30.48cm) was taken. The soil was removed and placed in a labelled and sealed bag. This was then stored and later analysed. This method was used for each sample point, each sample site and the correct labelling was done. This was done to determine the difference in sediment size and the sorting of the sediments from each site.

3.4 Laboratory Analysis

3.4.1 Analysis of the sediments

Sediments that have been taken from the field were taken to the laboratory to be analysed. In the laboratory they were placed in aluminium trays that were marked the same way as the bags the sediments came out of.

Since the sample may have a presence of sea salts, these salts needed to be removed or diluted. This was done by 'washing' the sand. In essence it was diluting the concentration of salt present until the salt concentration was minimal or zero. This was done by placing deionised water into the sample trays and slowly letting the water run over the edges. This was done with the utmost caution to not lose any of the samples.

These samples were then placed in an enclosed room at room temperature to air dry over night. These trays were then placed in an oven at a temperature of 130°C for 4 hours or until the sediment samples were completely dry. The samples were checked every thirty minutes and mixed around so the sediments dried evenly. The sediments were set out to cool down for three hours. Once the sediments had cooled, it was found that the sediments stuck together after drying. The sediments then needed to be dislodged from each other to get the best results. This was done with the use of pestle and mortar. This was done carefully, to not crush the sediments, but rather to dislodge the sediments from each other. The dried sediments were then placed in Kingtest Laboratory test sieves to sort the sediment sizes. The sieves sit on a vibration stand and sort sediments from the coarsest at the top to the finest at the bottom. The sieves that were used are 2mm, 1.4mm, 1mm, 500µm, 250µm, 125µm, 53µm and everything less than 53µm. The vibration stand was set to vibrate for five minutes to get the best results of the sorted sediments. The sieves were removed and their content was placed into a different aluminium tray for each sieve size. The trays were then weighed for a weight of sediment and tray combined at that sieve size. The sediment on the weighed tray was then placed in a bag and labelled. The empty tray was weighed once again and the weight was subtracted from the previous weight to get the weight of the sediment. The weight of the sediments was then recorded for that sieve size. The process was done for all the different sites and their respective samples.

Once the samples had been dried and weighed, and the data had been captured, a grain size computer program was used (GRADISTAT Version 4.0). GRADISAT is used to determine various aspects about the sediments such as mode, mean, skewness, sorting and various other sediment characteristics (Blott & Pye, 2001). According to Blott & Pye (2001) GRADISTAT is a rapid grain size calculator and is said to process fifty samples an hour. The various samples data was placed into the GRADISTAT program and run to determine the characteristics of the sediments. The GRADISTAT program is verified by the use of manual calculation such as determining Phi (ø) by using the standard equation ø=-$log_2 d$. The grain size diameter is given by “d”. If this method and the GRADISTAT methods answers correlate, then the GRADISTAT program is verified. Standard deviation will then be calculated with the use of the GRADISTAT program.

3.5 Observation and analysis of conservation methods at study sites

This was a very simple method by which one must survey the study area to see any presence of coastal protection. This was done to determine if there are any manmade structures close to the beach that could be affected by the surge or sea level rise. One described these structures, took photographs and if necessary took measurements. One then also described what was in the surrounding areas in terms of the protection method being used. This section was where the infrastructure present is noted and documented.

3.6 Challenges and potential sources of data error

The GPS needed to be checked and calibrated so that it can provide the best results. GPS are susceptible to weather and surrounding environments. Tall trees and clouds changed or affected the GPS coordinates (Carter, 1997). This was done as a precautionary measure so that results in the field are all the same. The contours that were interpolated are not the actual contours that are experienced in real life and errors may arise. Errors may have occurred due to the fact that interpolation of contours, are mathematically produced. Human error may have also occurred during the use of the Abney level and measuring rod. Since the ocean is salty, the samples need to be rinsed to lower the amounts of salt. This may have caused sediments to be washed away. If the salt was not all rinsed away, the sample after being seized will have salt and may alter the results slightly. The beach profiles were taken on different days and different times. This may make the readings for tides different. This was considered when determining and reviewing the results.

4. Results of the investigation

4.1. Data from GIS Modelling and projected sea level flooding

4.1.1. GIS Projections and modelling

From the literature review, it was determined that the sea level may rise at 3.1mm per year (Cronin, 2012). This is believed to have increased 5 times more in the year 2015 which would make the sea level rising at around 15.5mm per year (Cronin, 2012). An increase of 3.1mm of sea level rise per year was used from the year 2012 to 2015. As Stated in Cronin, (2012), the sea level has increased 5 times since then, then the predicted increase rate will be set at 15.5mm per year for all years after 2015. This may not be the case as later issues may make it higher or lower, thus this value is used as a prediction. This was used to determine the height of the sea level for 2030 (396.8mm), 2070 (861.8mm) and 2100 (1326.8mm). This said, a worst case scenario sea level was used of 2 m. A replication of the magnitude of the storm surge event that occurred in 2007 is used on top of these predictions, which determined where the flooding may occur. Since global warming is intensifying the effects of storms and their associated catastrophes, the storm that may be experienced, could be a significant size greater.

This gave the study sites of the project according to their respective GPS co-ordinates. Table 4.1 is the table of the 10 study sites and their respective coordinates. Figures 4.1, 4.2, 4.3 and 4.4 depicts the prediction of where the sea level may rise with in Port Shepstone, Durban, Richards Bay and St Lucia. These four sample sites were selected due to the economical importance's to KZN and the fact that these areas were more densely populated than the other sample sites. The yellow line depicts sea level at 5 m above today's measurements. This would be equivalent to a minimum size storm surge (3.5m) and the proposed sea level in 2100. The yellow line depicts the projected minimum surge point in the future. The Black line represents 10 m (Figure 4.1) above sea level which is the replication of the storm surge that occurred in 2007 and the height of the sea level in the year 2100. As one can see, infrastructure will be flooded at each site. The flood is a term used hypothecially as, the chances of the water reaching the definite line are slim. This said, there may be points along this line that the water body may reach. More research would need to be conducted to determine exactly where the flood waters would reach.

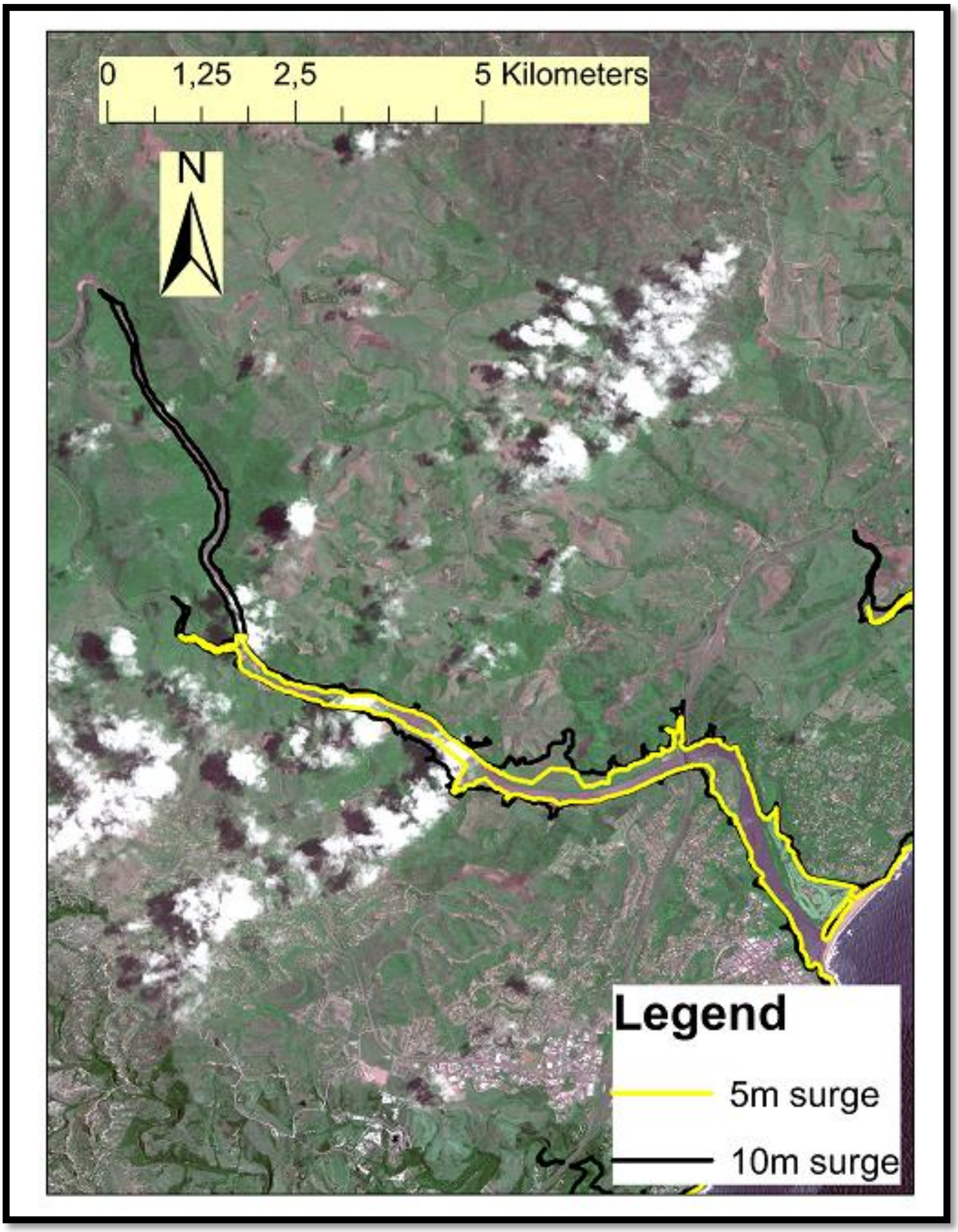

Figure 4.1: The predicted area in which the combined storm surge and sea level rise would flood to if it would to occur in Port Shepstone in the year 2100

As one can see from Figure 4.1, the altitude along the river is relatively low and extends a vast distance inland. The ocean water may flood these regions as far up the coast as approximately 16 km inland.

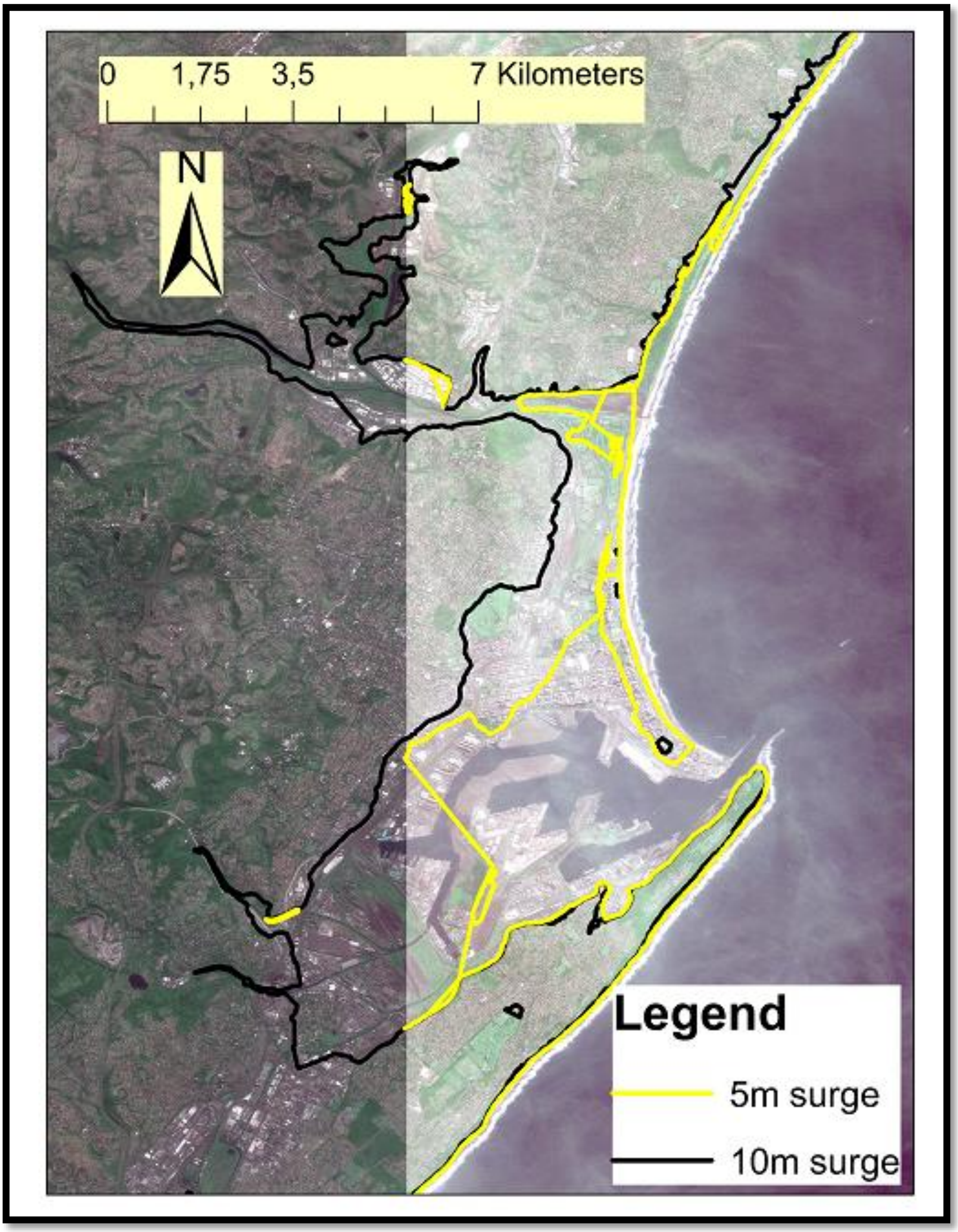

Figure 4.2: The predicted area in which the combined storm surge and sea level rise would flood to if it would to occur in Durban in the year 2100

Durban CBD and area surrounding the port is below 5m. This means that this region could be inundated by sea level rise and an associated storm surge that is as low as

5m above today’s sea level. The surrounding regions that is below 10 m comprises or residents, businesses both private and public and various services. The flooding of this area would be catastrophic. This is the same situation for Richards Bay.

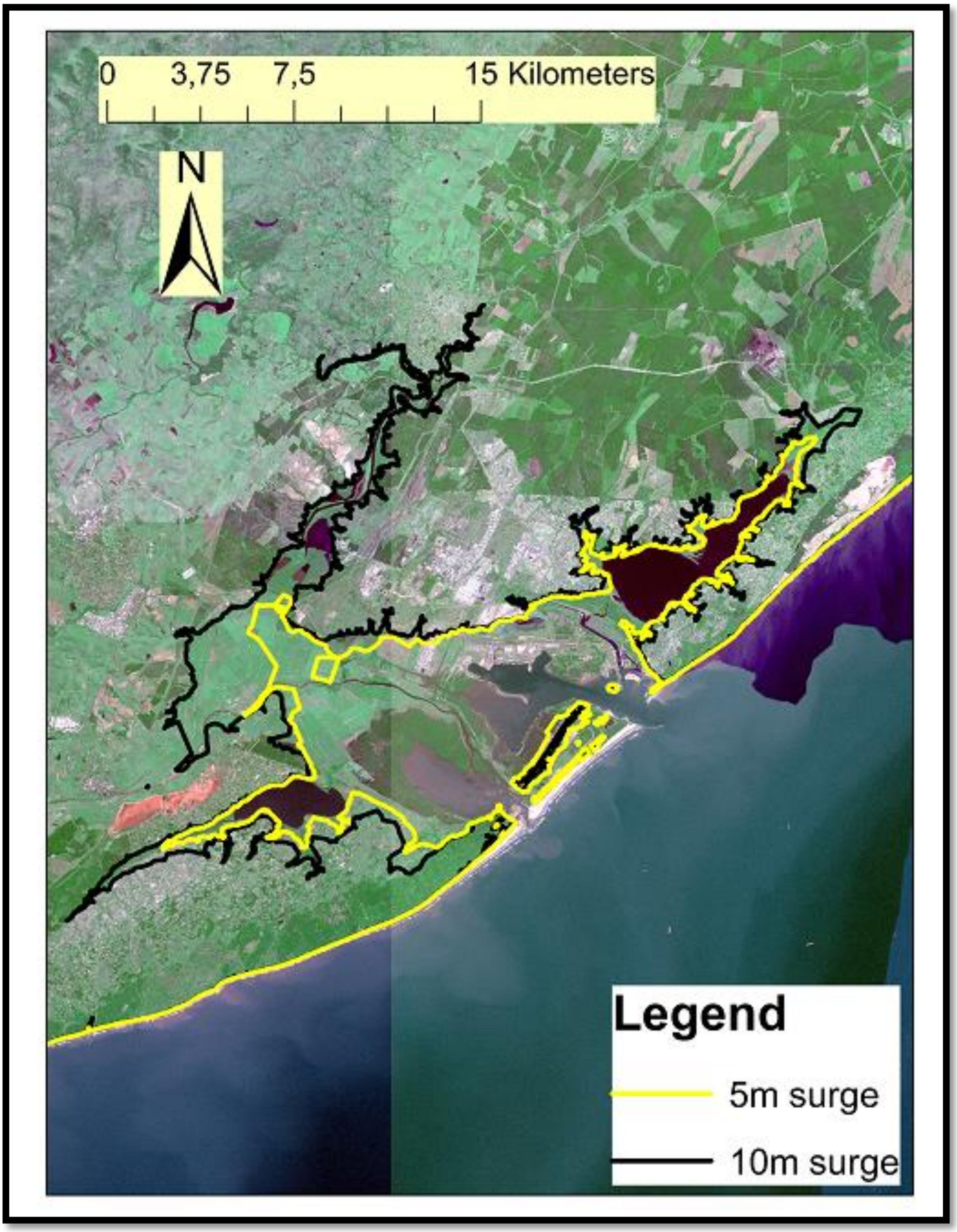

Figure 4.3: The predicted area in which the combined storm surge and sea level rise would flood to if it would to occur in Richards Bay in the year 2100

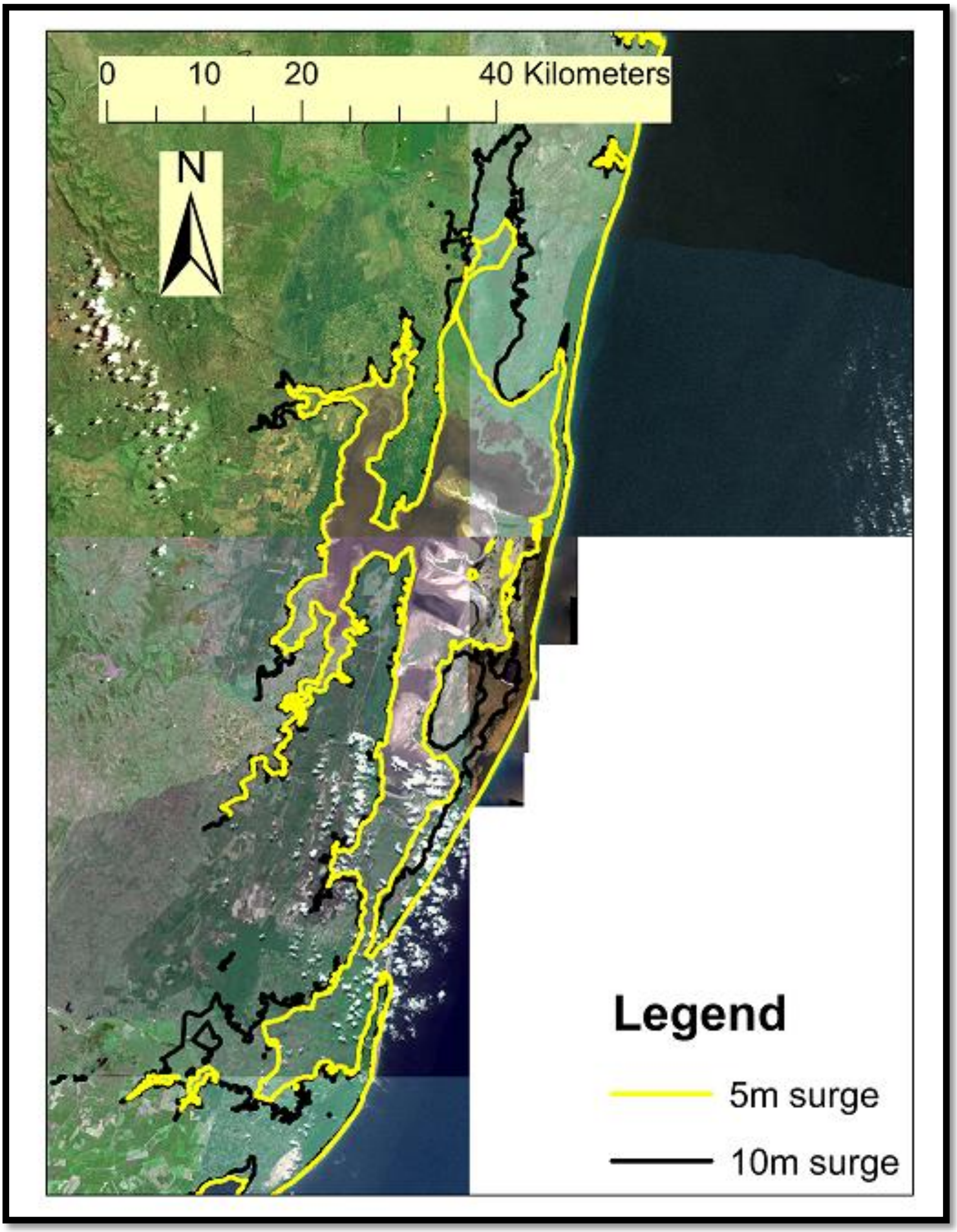

Figure 4.4: The predicted area in which the combined storm surge and sea level rise would flood to if it would to occur in St Lucia in the year 2100

St Lucia is a vast region of flat lands and may be inundated by flood waters as low as 5 m. As this region comprises of many private and public sector tourism, this could be detrimental to the economy if these are destroyed or affected in any way.

Table 4.1: Table of study sites and their respective co-ordinates

Site number	Site name or closest point of interest	Co-ordinates
1	Kosi Bay (Makhawulani)	26° 53’ 41.94”S 32° 52’ 48.66”E
2	St Lucia	28° 23’ 00.94”S 32° 25’ 33.92”E
3	Richards Bay (Harbour Entrance)	28° 48’ 36.81”S 32° 05’ 36.37”E
4	Mlalazi River (Mtunzini)	28° 56’ 42.35”S 31° 49’ 07.60”E
5	Matigulu River	29° 06’ 45.38”S 31° 36’ 53.71”E
6	Tugela River	29° 13’ 33.43”S 31° 29’ 52.00”E
7	Umvoti River	29° 23’ 12.67”S 31° 20’ 11.80”E
8	Durban (Harbour Entrance)	29° 51’ 59.15”S 31° 02’ 52.02”E
9	Umkomaas River (Umkhomazi River)	30° 12’ 02.92”S 30° 48’ 09.63”E
10	Port Shepstone (Mzimkhulu River)	30° 44’ 16.58”S 30° 27’ 28.67”E

The sample points were taken at different times, resulting in different samples according to tide differences. Estimation was taken into consideration to determine where the coastline may be at low tide. The beach profiles were manipulated so that all the samples will have an end point of the low tide mark. Table 4.2 lists the time, date and the tide that was experienced on that day.

Table 4.2: Study sites and their respective date, time and tides

Sample Site	Date measured	Time	Tides at time of measurement	Estimated distance to low tide
1	28/02/2015	9:22am	LT 6:30am (0.9m) HT 1:05pm (1.4m)	0.2m
2	28/02/2015	3:21pm	HT 1:05pm (1.4m) LT 7:25pm (0,8m)	0.4m
3	01/03/2015	11:24am	LT 7:45am (0.8m) HT 2:05pm (1.5m)	0.4m
4	22/02/2015	8:16am	HT 6:00am (2.1m) LT 12:00pm (0,2m)	1.27m
5	15/03/2015	11:55am	HT 11:35am (1.4m) LT 6.00pm (0,8m)	0.6m
6	22/02/2015	10:21am	HT 6:00am (2.1m) LT 12:00pm (0,2m)	0.63
7	22/02/2015	11:12am	HT 6:00am (2.1m) LT 12:00pm (0,2m)	0.32
8	20/02/2015	5:27pm	HT 5:00pm (2.2m) LT 11:00pm (0,0m)	2m
9	06/03/2015	4:45pm	HT 4:30pm (2.0m) LT 10:30pm (0,2m)	1.8m
10	06/03/2015	6:00pm	HT 4:30pm (2.0m) LT 10:30pm (0,2m)	1.2m

4.1.2. Understanding the role of Vegetation, soils and geology of the area

The vegetation was determined with the use of an online GIS programme offered by South African National Biodiversity Institution (SANBI) (SANBI, 2007). The vegetation was split into five main vegetation types and found at many of the study sites. The following is a list of the vegetation types and where they were experienced (Table 4.3).

Table 4.3: The vegetation type found at each study site

Study Site	Vegetation type
Kosi Bay	Subtropical Seashore Vegetation
St Lucia	Subtropical Seashore Vegetation Subtropical Dune Thicket Northern Coastal Forest
Richards Bay	Subtropical Seashore Vegetation Subtropical Dune Thicket
Mlalazi River (Mtunzini)	Subtropical Seashore Vegetation Maputaland Coastal Belt
Matigulu River	Northern Coastal Forest Maputaland Coastal Belt
Tugela River	Maputaland Coastal Belt
Umvoti River	KwaZulu-Natal Coastal Belt
Durban	Subtropical Seashore Vegetation Northern Coastal Forest KwaZulu-Natal Coastal Belt
Umkomaas River	Subtropical Seashore Vegetation KwaZulu-Natal Coastal Belt
Port Shepstone	Subtropical Seashore Vegetation KwaZulu-Natal Coastal Belt

Subtropical Seashore Vegetation is the on average the most common vegetation type found along the coastline of KZN. With seven of the ten sample sites experiencing this type of vegetation.

Table 4.4: List of attribute of soils at each study area

Study Site	Soil texture
1	Unstructured of 0-6% clay
2	Unstructured of 0-6% clay
3	Unstructured of 0-6% clay
4	Unstructured of 0-6% clay & 7 -15 % clay
5	Unstructured of 0-6% clay
6	Unstructured of 0-6% clay & 16 -25% clay
7	Unstructured of 0-6% clay
8	Unstructured of 0-6% clay
9	Unstructured of 7 -15% clay
10	Unstructured of 0-6% clay & 26 -25% clay

Table 4.5a: List of soil codes found at each study site according to ArcGIS Layer

Study Site	Soil Type Code
1	Hb Coast Ha Dunes
2	Hb Coast Ia South coast
3	Hb Coast Ia in Port
4	Hb Coast Ha Dunes
5	Hb Coast Ha Dunes
6	Hb Coast Fb In the river Ab in the dunes
7	Hb in the river Ab on the coast
8	Hb around port and in city Ab on the coast
9	Hb in the river Ac on the coast
10	Hb Coast Ia in the river

Table 4.5b: Meaning of soil codes

Soil Type Code	Meaning of code
Ab	Freely draining, red/yellow soils, Yellow soils less than 10%
Ac	Freely draining red/yellow soils, Red and yellow less than 10%
Fb	Shallow soils, lime
Hb	Deep grey sands
Ia	Deep alluvial soils with more than 60% of land type

4.2. Data from the field Investigation

4.2.1. Sample points and Beach Profiles

The sample points along the coastline as shown in table 4.2 were conducted on different days, however, all samples were taken within the space of a month. No storm events or periods of high swell were experienced in this month.

The beach profiles will help determine the steepness, width and height of the sample point (Figure 4.5). The last 5 m of each beach profile was taken with the actual readings from the day of sampling and were manipulated with the estimation of distance to low tide mark so that all samples are at a standard low tide mark for that tide and day, thus allowing a replication of data to occur in future years. As one can see in figure 4.5, the coastlines are relatively short as only three sample sites were above 70 m and the rest were below. The three that were above are St Lucia, aMatigulu and Durban. Durban has the only one of the three that has infrastructure close to the close line. Of the beaches below, Richards Bay, Tugela, Umkomaas and Port Shepstone had infrastructure near the coastline. These four areas are highly populated and used frequently by the public. Figure 4.5, 4.6, 4.7 and 4.8 is a depiction of each beach profile. It has also included the sea level height to which the sea may rise to for 2030, 2070 and 2100. The figures also include the height of the storm surge threshold (3.5m) would rise to and how it would affect the beach profiles. These figures depict the replication of the March 2007 storm surge. As one can see that the March 2007 storm surge would flood all the beach profiles.

The profiles of these beaches are short vertically but are very steep. As stated in the literature review, this allows the wave energy to dissipate. Durban has a coastline that is above 4 m. aMatigulu, St Lucia and Kosi Bay have their back beach lower than the sea level of the ocean. This becomes an issue as soon as the wave height floods the highest point of the beach profile. For St Lucia, that is very low, only around 1 m above the sea level. The replication storm surge, floods each profile, no matter which year it was projected on. This will be discussed further in the next chapter.

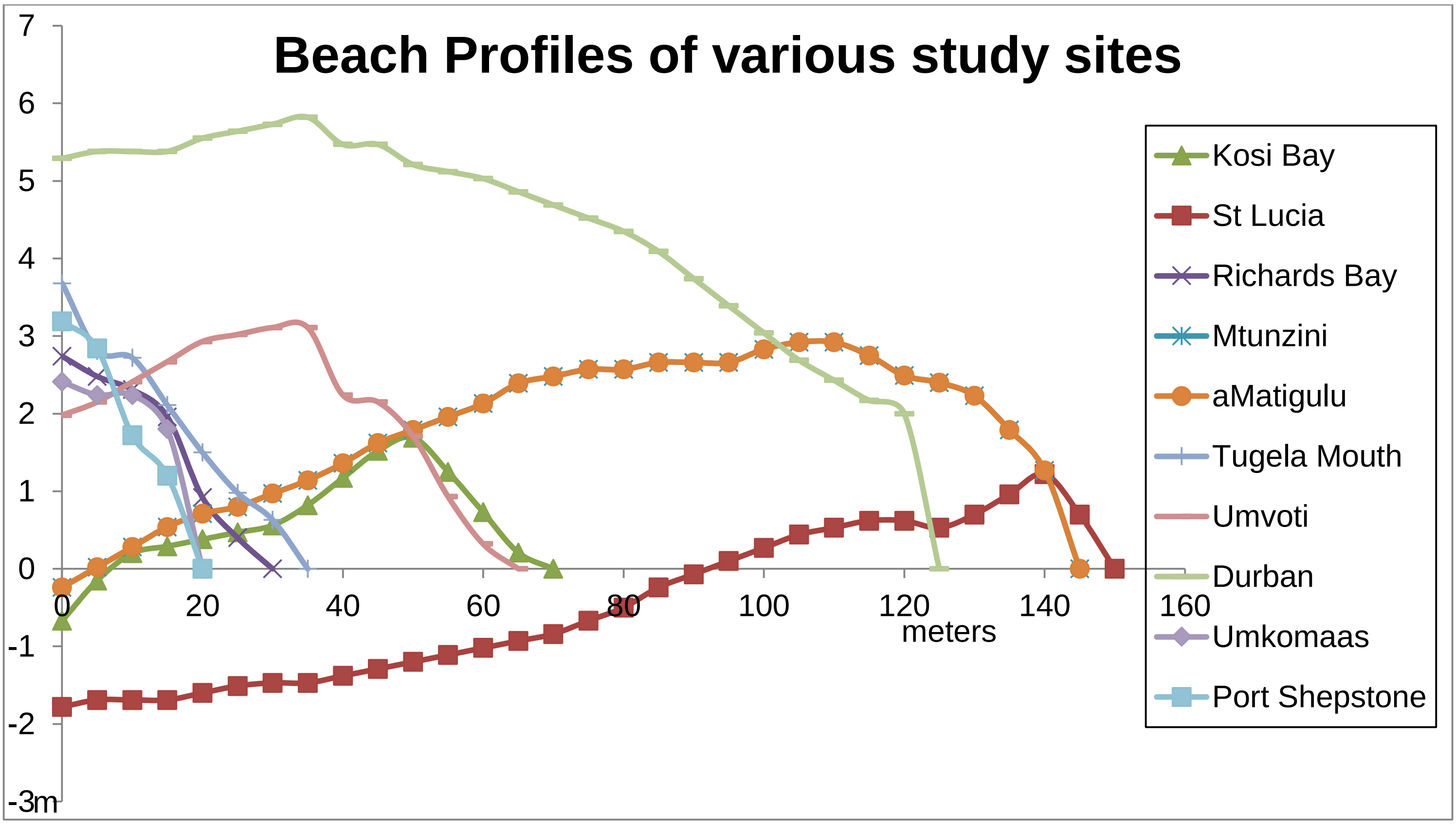

Figure 4.5: The beach profiles of the selected study sites

The storm surge was placed on top of the data to depict where the surge will affect the beaches. The wave that was recorded in 2007 was recorded at a peak of 8.5m, this in addition with the 2.2m extreme high tide, pushed the wave height up to over 10m (Guastella & Rossouw, 2009; Smith *et al.,* 2007). As seen in figure 4.6, 4.7 and 4.8, sea level has been shown for the representative years, this includes the surge level on each year.

The 2030 sea level will not seem to have any effect on any of the coastlines as it does not flood or over flow the beach profiles. As storm surge threshold is 3.5 m, and the sea level at that time is 0.3968 m, this gives a total wave height of 3.89 m. This will flood all the sample sites except for Durban.

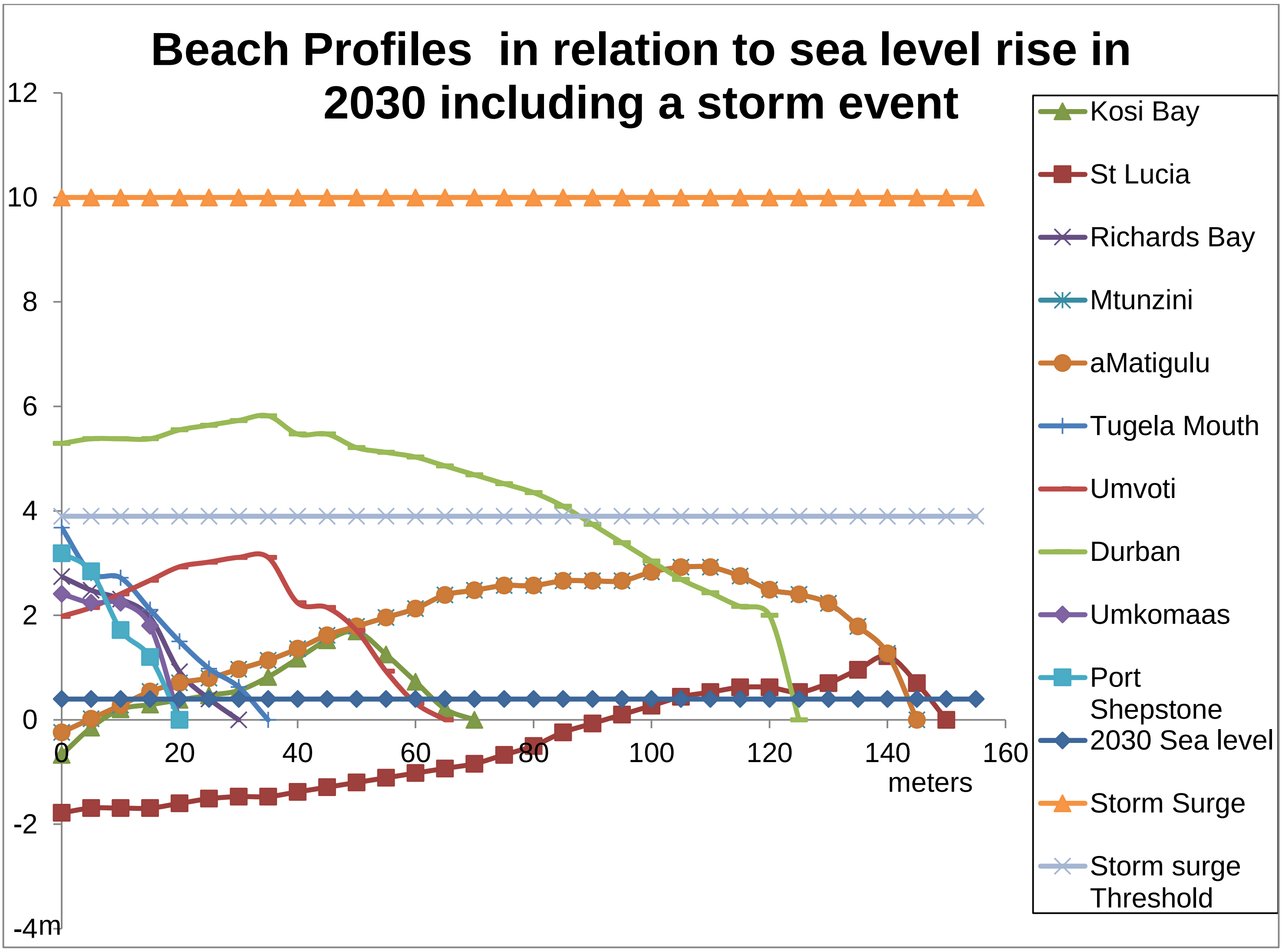

Figure 4.6: Beach profiles for all study sites including the sea level for 2030 and the storm surge incorporated

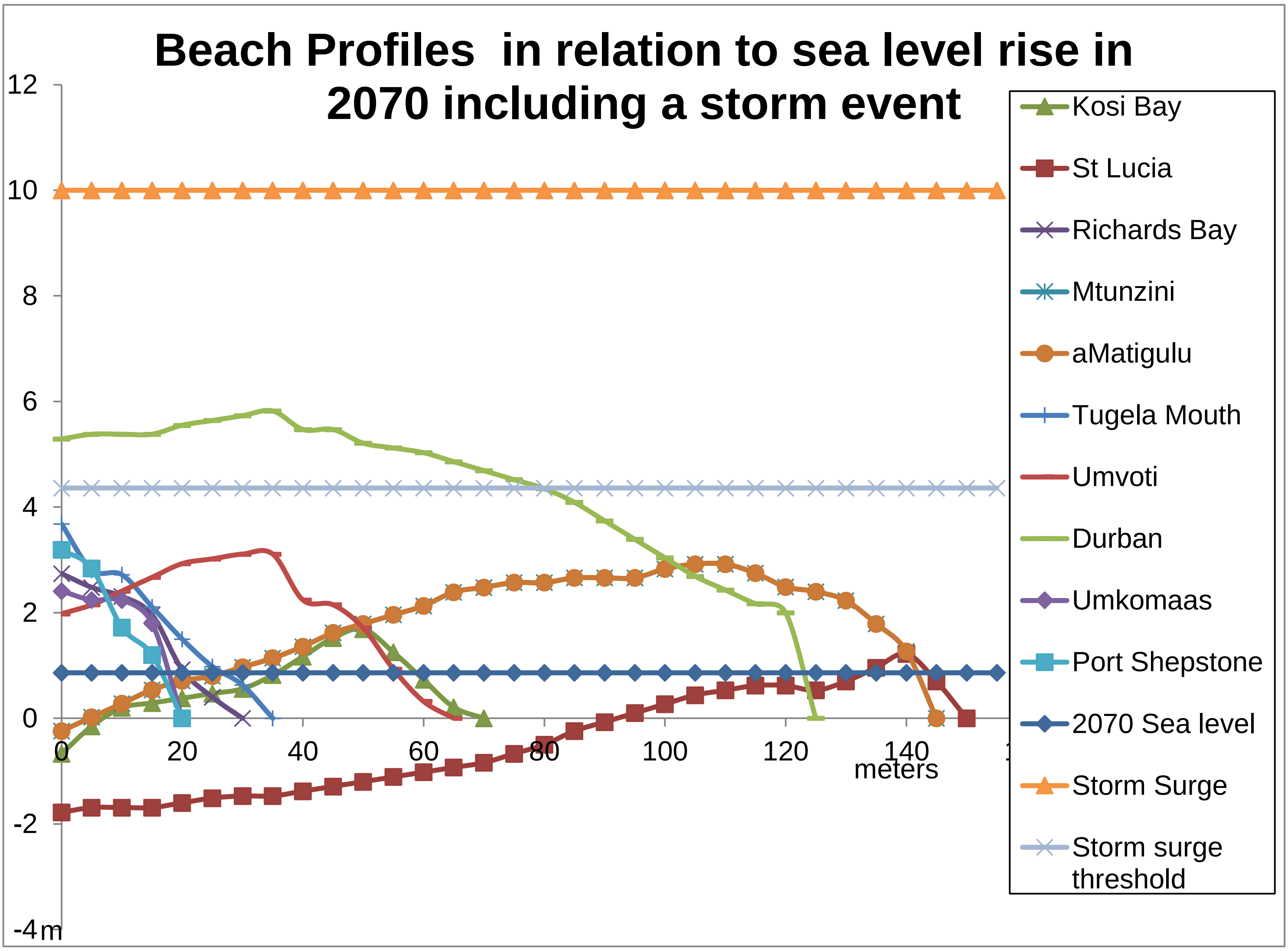

Figure 4.7: Beach profiles for all study sites including the sea level for 2070 and the storm surge incorporated

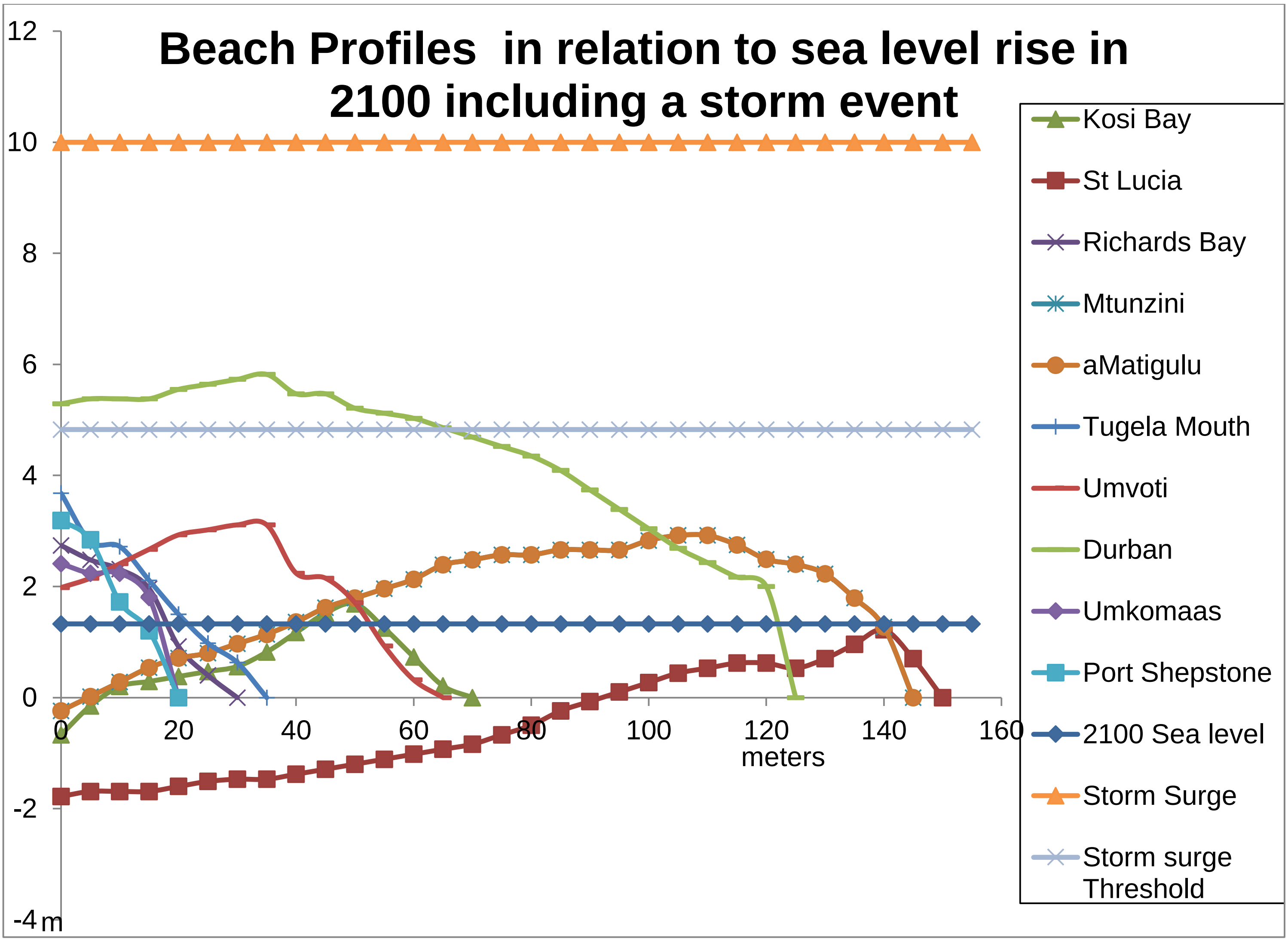

Figure 4.8: Beach profiles for all study sites including the sea level for 2100 and the storm surge incorporated

4.2.2. Beach Observations

Kosi Bay, St Lucia, Mlalazi and Matigulu River are all areas that are surrounded by natural vegetation. Kosi Bay is the northern most estuary system on the east coast of South Africa. It comprises of several fresh water lakes that are connected by channels. There is a cottage inland of the coast but still within the flood plains of the estuary. This was approximately 2 to 3 m above the level of the estuary water. This building could still be in jeopardy if a big enough surge had to flood this region. These fresh water lakes are used by the locals as a source of food and water. Locals have been using these lakes to fish using sticks that funnel the fish into a cornered off area (Figure 4.9).

Figure 4.9: Fishing style within the Kosi Bay Estuary.

St Lucia is also a fresh water system, which is home to large amounts of flora and fauna and is one of KZN's most often visited tourist destinations. At the time the site was sampled, the local authorities were in the process of joining the Mfolozi River to the St Lucia estuary system (Figure 4.10). Many of the infrastructure that has been constructed in this area is due is to help with tourism, with many bed and breakfasts and entertainment facilities all around.

Figure 4.10: The process of connecting the Mfolozi River to the St Lucia estuary to add water to the St Lucia estuary.

Richards Bay and Durban are entrances to Harbours. Both are areas that are crucial to KZN economy and will be devastating to lose due to a storm surge. The entrance to the Richards Bay Harbour is wide, but has piers which hinder swells coming from the south. There are also many buildings on the northern headlands of the entrance. Buildings are in close proximity to the coastline and this area was relatively flat. One could even say that the back beach slopes landward after the berm of the beach has been passed. Durban has a lot of infrastructure to the north and the south of the entrance. The infrastructure in the north is in the process of being improved to encourage more tourism in this area.

Mtunzini, Umvoti River and Matigulu River are rivers where there is not much infrastructure close to the estuary. This said, these two areas have very large lakes that are adjacent to the coastline, separated by a low beach berm between the lake and the ocean. Matigulu River is home to subsistence farming inland from the coastline in the town of Nquthini. On the south banks of the Umvoti river is a colony farm house. This was set back in the dunes and may still be safe if a surge would have to occur.

Tugela River is one of KZN largest river systems and the mouth is a tourist destination for many people. The headlands to the north of the mouth have a lighthouse and many houses. These buildings are built on top of the dune system, but the beaches are not very wide and are comprised of both rock and sand, which as stated before, is not the ideal condition to reduce coastal erosion.

Umkomaas has a lot of infrastructure in close proximity to the ocean. There are buildings, roads, railways and bridges which all have the potential of being affected by sea level rise and storm surge. This area has already placed sand bags and rocks in to help prevent the coastline from being eroded (Figure 4.11).

Figure 4.11: Sand bags and rocks placed at the base of the road (at A) to prevent the effects of coastal erosion

Port Shepstone is also an area that has road structures, bridges, railways and buildings in close proximity to the ocean. This beach is a mixed rock and sand beach and is very short as seen by the beach profile in Figure 4.5. The regions within the river system are very low in altitude and may be flooded in future, due to sea level rise or a storm surge.

4.3. Results of the laboratory Analysis

4.3.1. Sorting and analysing sample points with use of GRADISTAT

As seen in table 4.7, all the samples taken are classified as sand as a textual group. The majority of the samples are moderately sorted to moderately well sorted. The samples are either unimodal or bimodal. The samples that were tested to determine the amount of salt content in the sample taken were determined to not have enough salt content. Thus the salt content would not have an effect on the samples.

Table 4.7: List of all samples and details of each sample area

SAMPLE NUMBER	SAMPLE TYPE:	TEXTURAL GROUP:	SEDIMENT NAME:
1.1	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
1.2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
1.3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Medium Sand
2.1	Unimodal, Moderately Sorted	Sand	Moderately Sorted Medium Sand
2.2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Medium Sand
2.3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
3.1	Unimodal, Moderately Sorted	Sand	Moderately Sorted Coarse Sand
3.2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Coarse Sand
3.3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Coarse Sand
4.1	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
4.2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
4.3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Medium Sand
5.1	Unimodal, Moderately Sorted	Sand	Moderately Sorted Medium Sand
5.2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Medium Sand
5.3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
6.1	Unimodal, Moderately Sorted	Sand	Moderately Sorted Coarse Sand
6.2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Coarse Sand
6.3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Coarse Sand
7.1	Bimodal, Moderately Sorted	Sand	Moderately Sorted Very Coarse Sand
7.2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Coarse Sand
7.3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Very Coarse Sand
8.1	Bimodal, Poorly Sorted	Sand	Poorly Sorted Fine Sand
8.2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand
8.3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand
9.1	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Medium Sand
9.2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Coarse Sand
9.3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Coarse Sand
10.1	Bimodal, Moderately Sorted	Sand	Moderately Sorted Very Coarse Sand
10.2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Coarse Sand
10.3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Very Coarse Sand

Once the samples were sieved and analysed they were placed into storage plastic bags (Figure 4.12) and placed in order to compare the average colour of the samples to see if a comparison could be made. Many of the samples displayed very similar colours in sediments. Some samples had heavy metals north and south of Richards Bay, but none were found at Richards Bay. The sample that was taken to test the amount of salt content that was removed after the washing occurred, displayed no change in the sediments. Thus the salt content in each sample will not have an effect on any of the samples taken. The error due to salt should be minimal, therefore regarding it as zero. Durban's sample 1, showed, the back beach was very dark in colour and resembled top soil. This may be due to the fact that the municipality are currently trying to grass these regions to be more aesthetically pleasing.

Table 4.8, 4.9, and 4.10 depict that the sand found at each sites was on average either medium sand or coarse sands.

Figure 4.12: Representation of all samples after they have been analysed and now sorted according to their sample number with 1.1 in the top left working right through each sample site.

Table 4.8: In depth details of Samples in terms of the Folk and Ward Method (mm)

SAMPLE NUMBER	FOLK AND WARD METHOD (mm)			
PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS
1.1	374.0	1.435	0.116	1.206
1.2	423.3	1.501	0.243	0.949
1.3	529.0	1.759	0.145	0.898
2.1	313.1	1.634	-0.086	1.222
2.2	324.7	1.647	-0.115	1.395
2.3	433.8	1.593	0.117	0.943
3.1	556.9	1.688	0.003	0.978
3.2	661.7	1.605	-0.069	1.367
3.3	806.3	1.470	0.244	1.067
4.1	374.0	1.435	0.116	1.206
4.2	423.3	1.501	0.243	0.949
4.3	529.0	1.759	0.145	0.898
5.1	313.1	1.634	-0.086	1.222
5.2	324.7	1.647	-0.115	1.395
5.3	433.8	1.593	0.117	0.943
6.1	556.9	1.688	0.003	0.978
6.2	661.7	1.605	-0.069	1.367
6.3	806.3	1.470	0.244	1.067
7.1	906.0	1.941	-0.604	0.473
7.2	931.4	1.629	0.010	0.851
7.3	982.0	1.740	-0.357	0.671
8.1	297.9	2.454	0.424	0.847
8.2	254.0	1.754	0.226	0.931
8.3	202.4	1.482	0.254	1.086
9.1	485.7	1.599	0.062	0.745
9.2	550.7	1.529	-0.186	0.790
9.3	610.8	1.662	-0.077	1.097
10.1	879.6	1.977	-0.469	0.607
10.2	895.5	1.732	-0.056	0.796
10.3	890.0	1.959	-0.461	0.726

Table 4.9: In depth details of Samples in terms of the Folk and Ward Method (ϕ)

SAMPLE NUMBER	FOLK AND WARD METHOD (ϕ)			
PARAMETER	MEAN	SORTING	SKEWNESS	KURTOSIS
1.1	1.419	0.521	-0.116	1.206
1.2	1.240	0.586	-0.243	0.949
1.3	0.919	0.815	-0.145	0.898
2.1	1.675	0.708	0.086	1.222
2.2	1.623	0.720	0.115	1.395
2.3	1.205	0.672	-0.117	0.943
3.1	0.845	0.755	-0.003	0.978
3.2	0.596	0.683	0.069	1.367
3.3	0.311	0.556	-0.244	1.067
4.1	1.419	0.521	-0.116	1.206
4.2	1.240	0.586	-0.243	0.949
4.3	0.919	0.815	-0.145	0.898
5.1	1.675	0.708	0.086	1.222
5.2	1.623	0.720	0.115	1.395
5.3	1.205	0.672	-0.117	0.943
6.1	0.845	0.755	-0.003	0.978
6.2	0.596	0.683	0.069	1.367
6.3	0.311	0.556	-0.244	1.067
7.1	0.142	0.957	0.604	0.473
7.2	0.103	0.704	-0.010	0.851
7.3	0.026	0.799	0.357	0.671
8.1	1.747	1.295	-0.424	0.847
8.2	1.977	0.811	-0.226	0.931
8.3	2.305	0.568	-0.254	1.086
9.1	1.042	0.677	-0.062	0.745
9.2	0.861	0.613	0.186	0.790
9.3	0.711	0.733	0.077	1.097
10.1	0.185	0.984	0.469	0.607
10.2	0.159	0.793	0.056	0.796
10.3	0.168	0.970	0.461	0.726

Table 4.10: In depth details of Samples in terms of the Folk and Ward Method (On description)

SAMPLE NUMBER	FOLK AND WARD METHOD (ON DESCRIPTION)			
PARAMETER	MEAN:	SORTING:	SKEWNESS:	KURTOSIS:
1.1	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
1.2	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
1.3	Coarse Sand	Moderately Sorted	Coarse Skewed	Platykurtic
2.1	Medium Sand	Moderately Sorted	Symmetrical	Leptokurtic
2.2	Medium Sand	Moderately Sorted	Fine Skewed	Leptokurtic
2.3	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
3.1	Coarse Sand	Moderately Sorted	Symmetrical	Mesokurtic
3.2	Coarse Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
3.3	Coarse Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
4.1	Medium Sand	Moderately Well Sorted	Coarse Skewed	Leptokurtic
4.2	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
4.3	Coarse Sand	Moderately Sorted	Coarse Skewed	Platykurtic
5.1	Medium Sand	Moderately Sorted	Symmetrical	Leptokurtic
5.2	Medium Sand	Moderately Sorted	Fine Skewed	Leptokurtic
5.3	Medium Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
6.1	Coarse Sand	Moderately Sorted	Symmetrical	Mesokurtic
6.2	Coarse Sand	Moderately Well Sorted	Symmetrical	Leptokurtic
6.3	Coarse Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
7.1	Coarse Sand	Moderately Sorted	Very Fine Skewed	Very Platykurtic
7.2	Coarse Sand	Moderately Sorted	Symmetrical	Platykurtic
7.3	Coarse Sand	Moderately Sorted	Very Fine Skewed	Platykurtic
8.1	Medium Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic
8.2	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic
8.3	Fine Sand	Moderately Well Sorted	Coarse Skewed	Mesokurtic
9.1	Medium Sand	Moderately Well Sorted	Symmetrical	Platykurtic
9.2	Coarse Sand	Moderately Well Sorted	Fine Skewed	Platykurtic
9.3	Coarse Sand	Moderately Sorted	Symmetrical	Mesokurtic
10.1	Coarse Sand	Moderately Sorted	Very Fine Skewed	Very Platykurtic
10.2	Coarse Sand	Moderately Sorted	Symmetrical	Platykurtic
10.3	Coarse Sand	Moderately Sorted	Very Fine Skewed	Platykurtic

4.4. Projected coastal morphology into the future

As the sea level rises, it will flood the coastline low lying areas. The combination of a storm surge would allow for the sea water to wash further inland thus altering the coastline. The 'new' coastline in 2100 would look similar to the projection in figure 4.13. The image depicts two separate lines. The black lines are the original borders of the coastline as it stands in 2015. The thicker black line would be the projected borders of the KZN coastline in 2100 due to sea level rise and its associated storm surge. As one can see from this figure the northern areas of KZN would change drastically due to the low lying landscape.

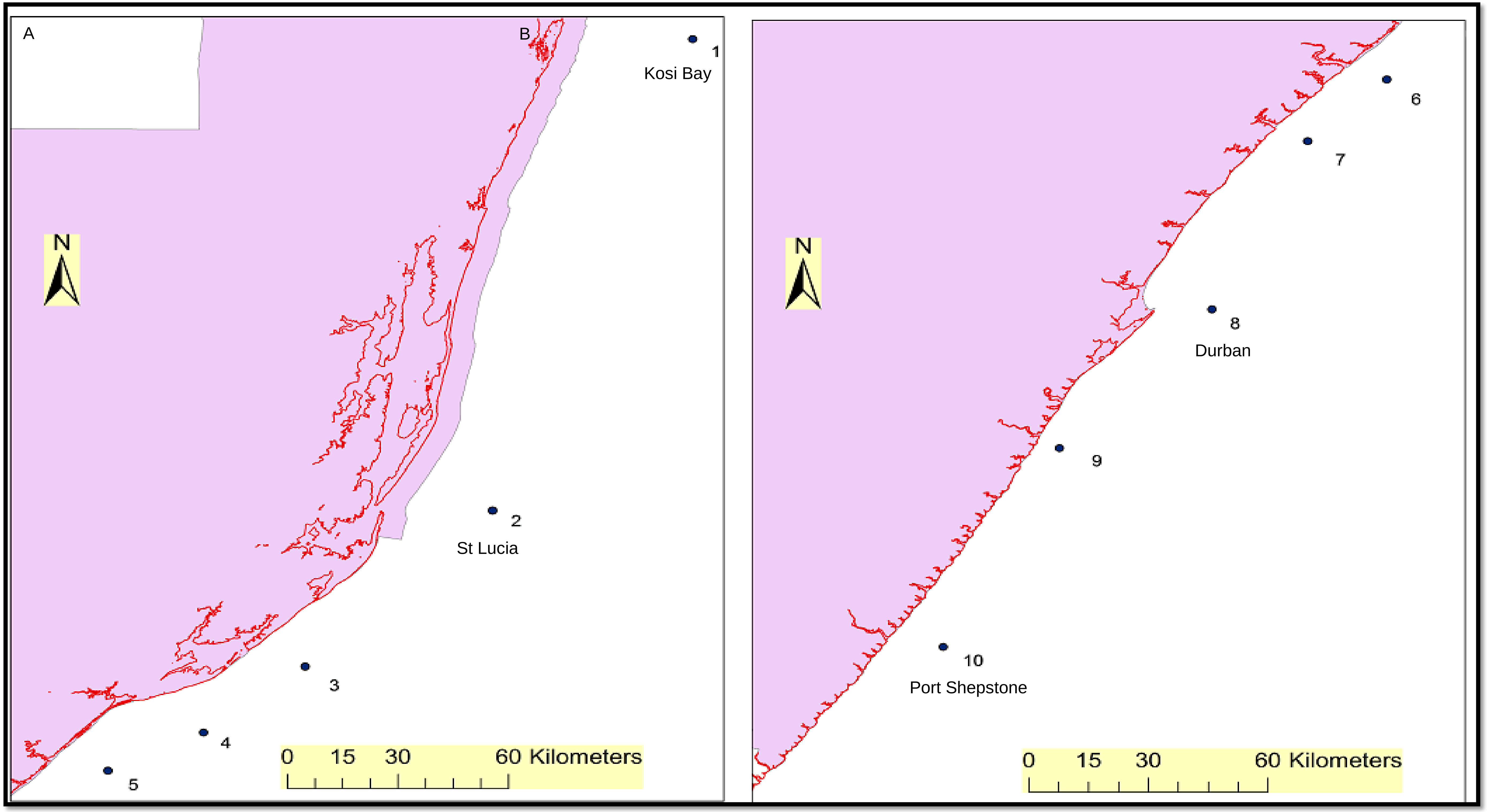

Figure 4.13: New projected coastline of KZN in 2100 due to sea level rise and associated storm surge, but excluding potential effects related to intensification due to climate change. The Left is Northern half (A) of KZN and the right is the Southern half (B) of KZN

5. Discussion of the data obtained

The previous chapter projects many of the site specific predictions that may happen to the sea level due to sea level rise and storm surge. As stated in the literature review, many conditions need to be considered for these two processes to occur at the same time to create the “Perfect Storm”. Whilst storm surge is the biggest event to cause erosion along the coastline, it is not the only one. Many daily occurrences and presence such as tides, currents and waves add to these events. These may reduce the sedimentary budget on the coastline before a storm event occurs. The following chapter will discuss the results from the research and elaborate the information to determine if the results support the literature from chapter two. The study sites that are near towns or cities are due to events that occurred in history. Many of the rivers were ports and thus the city grew around it. Durban is a good example of this and today is still being used as a port of choice. This research is crucial to the economy of KZN and even South Africa. The areas that have been built up along the coastline were built to generate money for the economy. If this is destroyed by sea level rise or a storm surge, it would be a waste of money that the government has spent. These events would also affect the tourism as our once beautiful coastline would now be littered with building rubble.

5.1. Future Coastal geomorphology and erosion at Study Sites

Kosi bay is the Northern most estuary on the East coast of South Africa which is also one of the largest fresh water lakes on this coast that supplies food, water and livelihoods to many of the local inhabitants. The beach profile of the study site at the time of the site visit was 70 m with a berm height of just below 2 m. This is not adequate protection against a storm surge occurrence. This will also be flooded by the projected sea level rise in 2100. This could alter the salinity of the inland lakes and could have negative effects on the local inhabitants’ survival. This area is relatively untouched by anthropogenic influences as it is as part of a nature reserve and may not be developed. Therefore with the sea level slowly encroaching on the top of the berm, smaller and smaller storm event would flood the berm. This means as the sea level rises, smaller storm events would be needed to over flow the berm and flood the area.

St Lucia is part of the Greater St. Lucia Wetland Park (GSLWP) which was established 106 years ago (Weis *et al.*, 2002). In 1999 it was declared a world heritage site. The results suggest that there is very little relief (Figure 4.5) and the flat area may be flooded very easily with the increase of the mean sea level. This area is also very important to the economy of KZN as it is a tourist destination. Bringing in people from all around the world to see the wildlife (hippos and crocodiles) (Figure 5.1) on the various boat tours they have each day. As this area is an estuarine area, most of the banks are low lying. With the increase in sea level and associated storm surges, these areas would be flooded, reducing the amount of land available at the time of the research. Richards Bay, like Durban is a town based on its port. This area near and around the port is low lying and may be flooded with the increase in sea level and with an associated storm surge. As seen in Figure 4.3, with the threshold of a storm surge (3.5 m) and the increase in sea level in 2100, the water level would be raised to around 5 m. This would flood most of the harbour workings and low lying areas surrounding it. This increase in water level may flood into the water body to the North of the harbour (Mzingazi).

The study site Mtunzini was one of the study sites that were still natural. The coastal sands separating the ocean and the estuary were high enough to keep the ocean out of the estuary at the time of the site visit. This said, once the sea level rises above this berm, the back beach would be flooded with ocean water, the sediments there may be eroded and then be infiltrated into the fresh water system. Matigulu River is still natural in terms of the surrounding vegetation. On the South bank of the river is the Amatikulu Nature Reserve. The estuary system spreads North and South parallel to the coastline, and is separated by a berm of a height of 1.9 m. Once the berm has been flooded, the river system will be inundated with saline water from the ocean. The effects here would not have much effect or loss in infrastructure as there is nothing visible at the site. Tugela River area is both residential and a tourist area. Its infrastructure is built on top of the coastal dunes, with a light house on top of the hill. This area is a mixture of rock and sediment with natural vegetation on the dunes. The coastal system had signs of erosion within the dune system during the time of the site visit (figure 5.1). The vegetation has grown over the eroded section on the left of the picture but on the right, the arrow points to uncovered signs of erosion. The date of this erosion event is unknown.

Figure 5.1: Erosion of the dune that has had vegetation growing over the eroded areas

This beach profile as seen in Figure 4.5, shows the beach profile being very narrow. This with the fact that the coastal geomorphology is mixed sediments and rocks, may erode faster than if it was comprised of either sediments or rocks alone. According to Smith *et al.,* (2007), mixed areas were damaged worse than single type areas.

Umvoti River at the time of the site visit, portrayed the river being over grown and does not suggest a very large discharge. The beach profile went to a high of 3.11 m. Therefore with the increase in sea level rise and an associated storm surge, the berm may be inundated and thus the sediments removed, but since this area is still natural in terms of vegetation it may become more difficult to erode. On the south bank of the river is a colonial homestead on a sugar cane farm. This building is approximately 13 m above today's sea level. This means this building may be safe from sea level and storm surge, but these may erode the base of the hill and cause the sediments to move down. This study area is mixed rock and sediment and may be eroded faster than a homogenous coastline.

Durban's main landmark is the port. The port is one of the busiest ports on the African continent (Mather & Reddy, 2008). This is a crucial factor in the economy of KZN. The port is surrounded by an expansive city, one of South Africa's fastest growing cities (Mather & Reddy, 2008). According to Figure 4.2, a lot of the harbour workings will be flooded if the ocean is raised by 5 m and soon after, the entire of the harbour, and many of the surrounding factories, infrastructure and resident may be flooded if the ocean rises by 10 m as these areas are all below the 5 m and 10 m contour, respectively. The beach profile taken is one of the longest, but many of the beaches along the Durban beach front are narrow. The beaches between the piers are narrow and are often eroded away by smaller wave events that do not exceed the storm surge threshold. This can be seen in Figure 5.4 where sediments have been removed from the sediment system during a high wave energy period. At the present moment, the port of Durban cannot handle most of the bigger panama vessels, and in order for this to happen, Durban must undergo an increase in infrastructure. Durban is investing a lot of its budget on developing the coastal regions for the purpose of tourism for the next 10 to 20 years (Roberts, 2008). Durban has mapped a flood line of 1:50 and 1:100 for 90 % of coastal rivers. For future developments, potential erosion lines and setback lines have been identified for 50 year storms and for a predicted sea level rise in 50 years. These developments may be redundant if a big enough storm surge, would have to inundate the new infrastructure. This development would then have been a waste of money and not be taken lightly by the TAX payers of the community. Consideration for these potential risks need to be considered for a long term projection. Looking 20 to 50 years in the future is not long enough as that is a mere blimp in the geological time line.

The study site of Umkomaas river mouth had infrastructure in close proximity to the ocean. There is a building, railway and roads within 50 m of the coastline. As seen in

Figure 5.4, there are single celled sand bags that have been put into place to help prevent the erosion of the coastline due to high swell periods. At the time of site visit, the ocean waves were running up and coming into contact with the rocks that were situated below the sand bags (Figure 5.2). There is a building that can be seen in Figure 5.4 that is in direct contact with the ocean when swells are high. This stretch of coast is also a mixed coastline, which as Smith *et al.,* (2007) stated, would be eroded faster than a coastline which is homogeneous.

Figure 5.2: Waves washing up and coming into contact with the rocks (A) at the base of the sand bags (B)

Port Shepstone is a densely populated town that is situated South of Durban, and has many businesses and residences on the coastline, with the fact that some businesses have been established on the banks of the river or on its flood plain. Port Shepstone Country Club is situated on the river banks behind the bridge. The country club was started in 1912 and facilitates golf, squash, bowls and cricket. With the increase in sea level due to climate change and with a surge wave, this may flood this iconic historic country club (Figure 4.1). This may then destroy the infrastructure of the club and thus the history that is linked with them. Further up the river are small businesses that have been established and are visited daily by locals and tourist. According to the projections, these areas may be flooded by a replication of the storm surge that occurred in 2007, and inclusive with the increase in sea level rise, may flood many of these areas thereby destroying the livelihood of the business owners on the river banks and coastline.

5.2. Coastal erosion, and factors that contribute to how this natural occurrence will change in the future

Coastal erosion as previously mentioned is the cause of several different factors that can work alone or together to remove sediments from the coastal regions. Anthropogenic contributions have often exacerbated coastal erosion by altering the natural vegetation and geomorphology to suit the means. As the coastal regions are being pressurised more by tourists, humans are building more infrastructure to accommodate the influx of tourists. This is changing the geology of the coast, as it brings hard structures to an area where there is usually sand. The dunes are being removed to accommodate new buildings for tourists. This is a catch 22, as humans are in actual fact, destroying the thing they are coming to see and enjoy!

5.2.1. GIS Prediction and Projections

For the purpose of this research the storm surge that occurred in March of 2007 was replicated to occur in 2100, but as Theron *et al.,* (2010), stated, the chances of this happening are very slim. Since the chances of this occurring at this magnitude are very slim, this is the reason why this storm can be termed the “Perfect Storm”. This said on the 5th of June 2015, a high swell period in conjunction with 1.91 m variants in the height of the high tide, allowed the swell to wash up, coming into contact with the promenade at Durban beach front. Figure 5.3 is graphic representation of wash up, coming into contact with the promenade and the removal of sediments at New Pier beach, Durban.

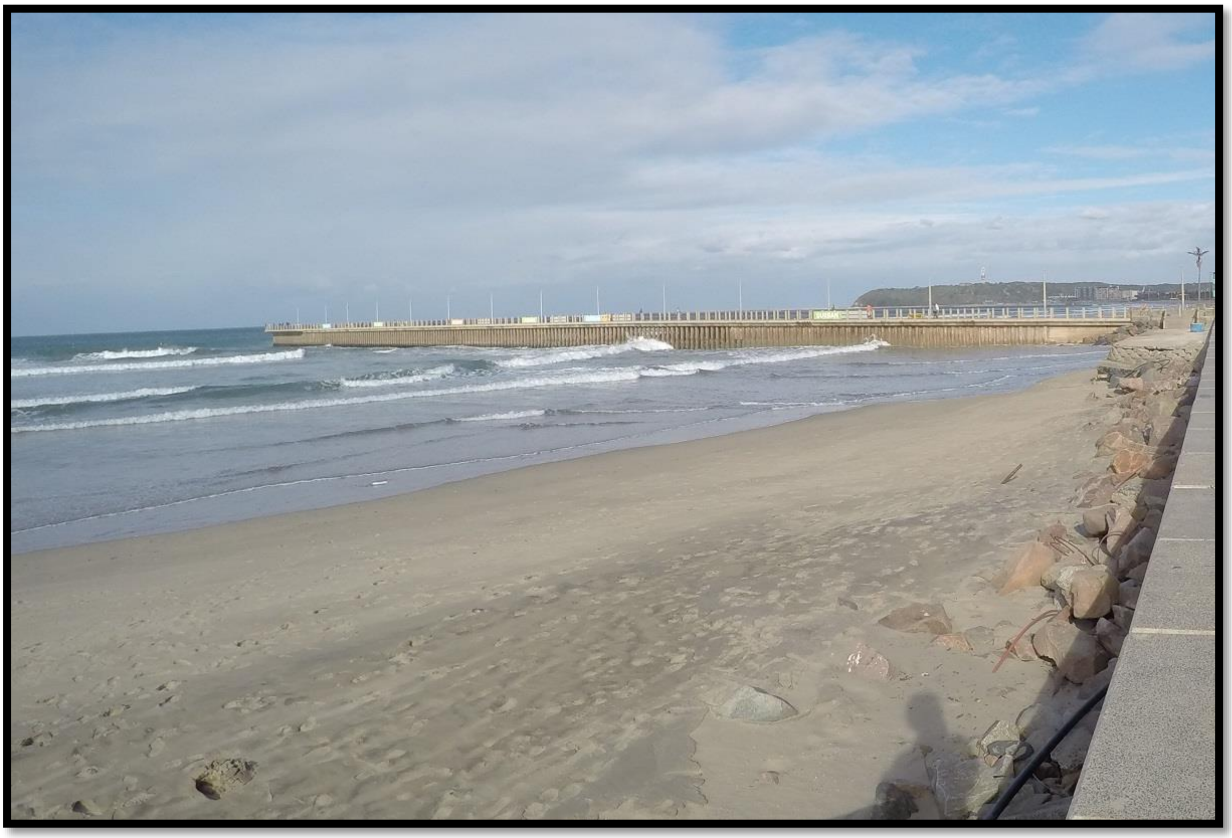

Figure 5.3: The wash up from a high swell period as removed the sediments from the edge of promenade at New Pier Beach, Durban.

As one can see from Figure 5.3, the wash up has removed the majority of the sediments along this stretch of beach exposing the rocks below the undermining of the structure of the promenade.

As a storm surge threshold is only 3.5 m high, this would flood many of the study sites without adding to the effects of sea level rise. Adding sea level rise to these would allow the flooding ability to extend further inland than it would today.

5.2.2. The projected changes in Vegetation, Soils and geology of the study sites.

The most common vegetation found at the study sites was Subtropical Seashore Vegetation. These areas comprise of vegetation such as dwarf shrubby, grassy and herbaceous and are subjugated by single species pioneer vegetation (Mucina *et al.*, 2010b). Many of the populated areas such as Durban have been influenced by human impact and thus the vegetation has been changed to be more aesthetically pleasing to the human eye. Normal grasses have been used on the dunes, and these grasses are very shallow rooted, thus not binding the dune system as the natural vegetation will. The second most common vegetation found in these sites, consists of KwaZulu-Natal Coastal Belt. The vegetation found here is subtropical coastal forest including some grasslands (Mucina *et al.*, 2010a).

The geology and sands of Subtropical Seashore Vegetation areas consist of sandy sediments that create dunes and beaches (Mucina *et al.*, 2010b). Whilst the Dwyka Tillite, Ordovician Natal group sandstone, Mapumulo gneiss and ecca shale are found in the KZN coastal belt (Mucina *et al.*, 2010a). These produce red sand also known as Berea red sand from them being weathered (Mucina *et al.*, 2010a). One of the worst affected areas in the 2007 storm surge event was Umhlanga Rocks (Guastella & Smith, 2014). This area is relatively shallow and is underlain by sandstone. The sandstone is often visible by various outcrops in the South as well as dolerite sills in the North. This means the shallow sediments would be eroded faster due to low amounts of sediments as well as the fact that wave energy may not be dissipated enough to lower the erosion of this area.

The soil textures that are found at the various study sites are as follows (Table 4.4, 4.5 and 4.6). The majority of the soils are unstructured between 0 - 6 % clay Richards Bay, Durban and Umkomaas have the lowest soil stability going down to a percentage between 0 – 20% and the majority of the soils found in the study areas have a code as Hb. As seen in Table 4.6, Hb is deep grey sand.

5.3. Climate Change

If the sea had to continue to increase at the rate it is today, the sea level would be at the same height as today's astronomical high tide (Guastella & Rossouw, 2009). Climate change may affect the intensity and duration of a storm event, thus increasing the likelihood of storm surges to occur on the coastline. These surges may be bigger and have high wave energy thus allowing them to flood further inland than before. As the sea continues to rise, the flooding of the coastline becomes more imminent. This, with the intensification of storm surges, will allow the oceans energy to penetrate further inland than before, getting to places it has never been able to reach before.

Climate change is thought to increase the intensity and duration of rainfall occurrences, thus increasing the discharge in rivers and increasing the erosion potential (Theron & Rossouw, 2008). This then would increase the sediment supply to the coastline and help mitigate the effects of coastal erosion. This increase in sediment may also have a negative impact on the coastline, as it can inundate the wetlands with sediment and silt them up, decrease light penetration to aquatic life forms due to the excess sediment in the water column and cause a change in the sedimentation patterns (Theron & Rossouw, 2008). As seen in figure 4.13 it is clear that the coastline will change due to sea level rise and an associated storm surge. These events would not be the only factors that would have to be taken into consideration to shape the coastline. During a storm event the wave forces may be funnelled into coastal valleys thus concentrating the effects of the waves. This could ultimately increase the high that the water may reach, therefore flooding higher areas than predicted. It may have a bore wave effect. Once the event is complete the extra water that flooded the coastline will then have to return to the ocean. This may then cause the scouring of the valleys once again. This may be increased if there is a presence of debris in the water from the storm event.

5.4. The need for improving the CPI methods in Review

The easiest way to protect infrastructure on the coastline is to change the coastal build line. An act has been established to regulate the coast and manage it. The Integrated Coastal Management Act (ICMA) Nov24 of 2008, states that "the change/establishment of a coastal setback line is able to:

-a1, protect public property, private property and public safety on the coast

-a2, coastal protection zone is prohibited

-a3, keep aesthetic values of the coast

-b, prohibit or restricted building, extension, alterations or erection of structures that are seaward of the coastal setback line" (Theron *et al.*, 2010). These laws need to be adaptive. As the sea level changes height, they must be altered to take the increase in sea level into consideration. The law should ideally have considered the effects of sea level rise and produced laws accordingly. As the sea level keeps rising, the laws should be adaptive to this occurrence. Taking into consideration, the predictions of events that may happen 20 to 50 years in the future.

With the implementation of coastal protection methods, this may increase the sensitivity of other/adjacent coastal areas (Bernatchez *et al.*, 2011). Geosynthetic fabrics are used to protect coastal regions as seen at Umkomaas Beach front (Figure 5.4). These types of single celled bags are said to be resistant to abrasions, tearing, puncturing and deterioration from ultraviolet light (Harris & Sample, 2009). These cells have been used at Durban Beach, Umdloti Beach, Ballito Beach, and many other beaches along the South African coastline and the Worlds. They have been known to move during bigger swell periods therefore not working sufficiently. These bags should be linked together or alternatives such as multicell bags must be used (Harris & Sample, 2009). Multicell bags have been used in Florida, United States of America (Figure 5.5) and have successfully withstood the effects of Hurricane Ivan in 2004. The areas where the red arrow is pointing shows where these sand bags have helped to prevent the erosion of the coastal dunes. Whereas the yellow arrow shows areas that these sand bags have not been installed and thus eroded. These bags prevented the foundations of the coastal properties from getting removed from the storm surges.

Figure 5.4: Sand bags below road structure to prevent the effects of coastal erosion at Umkomaas beach front.

Figure 5.5: The results of coastal erosion after hurricane Ivan in 2004, proving that multicell bags have and could potentially work on our coastline

A case study done at Chaleur Bay, Canada was conducted where coastal protection infrastructure (CPI) has been installed (Bernatchez *et al.,* 2011). As a result of the installation of CPI, areas that were adjacent to the protected beaches were eroded faster. As stated previously CPI may concentrate wave energy to adjacent areas as the wave energy cannot dissipate at the areas of the CPI.

5.5. Is the development of CPI more cost effective than repairing coastal properties

This research can be utilised to determine the most cost effective way to develop in the future. Since the 2007 March storm surge event, many people have rebuilt their properties in the same position and again without much protection. They have not taken into consideration the fact that an events similar to this event may occur again. Private properties along the coastlines have allowed for the vegetation to naturally grow back, while some have removed vegetation and replaced it with lawn grass. Many of the public areas have attempted to install CPI to prevent the effects of future erosion. This said, they have reinstalled the same CPI that failed during the March 2007 storm event. This may be due to the lack of knowledge of the other CPI that is available. If a replication storm event or a storm event that is bigger in magnitude and intensify would occur, these CPI would once again be destroyed and fail to protect the coastline. The expenditure utilised on the repairing the CPI therefore was not cost effective.

The average price of property along the KZN coastline has fluctuated for the past several years (Muller, 2013). Values of seaside properties will vary from location to location and the proximity to the coastline. The price is also dependant on the town or province it is situated within. As the coastline is prime property, development is in high demand. The development of sky rise buildings, flats, houses and even recreational facilities such as golf courses has occurred and is likely to continue. These infrastructures require a lot of work and money to establish and maintain. If a storm surge would have to destroy these infrastructures the costs may be devastating.

According to Muller, (2013), the average price of property in KZN is approximately R1.56 million. While Mlanga, (2013) states that the average price of property on the north coast of KZN is around R2.5 Million, with some properties reaching the R8 million plus range. The price range on the south coast is from R1.2 million to around R8 million. For the purpose of the research the average price per property, for the entire KZN coastline, will be taken at R2 million. The KZN coastline is 570Km long (Guastella and Smith, 2014).

The price to install CPI or change laws for building in close proximity of the coastline would be significant amount less than potential damage that a combination of storm surge and sea level rise can do to the coastal properties. Thus this research may be used to mitigate the loss of billions of Rands in the future due to the recklessness of people building so close to the coast. The average per Kilometre was 17 properties. Thus if this was continued throughout the coastline the total number of shore front properties would be some 9690. This then multiplied by the average price of property would give the estimated value of properties in direct contact with the coast. The estimated value of shore-front properties is approximately R19 380 000 000-00. This estimate will vary as it is an estimate and the exact value will need thorough research. This said, this is the value of property that borders the coastline. It is also critical to note that the entire port installation of both Durban and Richards Bay harbours are affected by the predictions shown in Figure 4.13, representing many milions of Rand in damages of themselves, to say nothing of the potential disruption of the country's economy. The effects of storm surge and sea level rise may inundate more properties in the hinterland, thus increasing the value of the damage further still. The cost to install CPI may be a large input at first but looking long term it will help to mitigate the cost of rebuilding coastal infrastructure and property. The debate needs to shift from 'is it affordable to build CPI' to one of 'how can the province and country afford not to establish CPI'. As these storm events and sea level rise is not localised to the KZN coastline, studies need to be conducted, or an adaption of this research used to investigate the effects at other locations within South Africa and around the world.

It is evident from the above (albeit extremely generalized) economic analysis, that the potential costs of the combined effects of sea level rise and storm surge will run into billions (if not trillions) of Rand; a fact that is all the more worrying when we consider that the intensity of the surges may well increase, and that there will certainly be multiple storm surge activity before the arbitrary date of 2100 used in this analysis.

5.6. Downfalls

The downfalls of the research are that the contours have been interpolated and these could have an effect on the final results. This could calculate areas that may be flooded when in actual fact it may not, due to a mathematical error from the interpolation. The ideal way to correct this is to get the correct contours of 1 m intervals.

Due to time constraints, samples were taken over several weekends, thus samples were not all taken at the same tide. Therefore an error will occur of ± 2 m due to the tidal range of this area. The error of the profile may change the final results as an estimate was taken to get to the low water mark so that all profiles were at the same sea level. The ideal process to correct this would be to take samples at the same tide to get a better comparison of every study area.

6. Conclusion

The final chapter is set out to conclude the research, by answering the aims and objectives that were set out in the beginning of the research. This chapter will also discuss further findings and studies that may be conducted in the future to get more results for the topic in hand. The research will then conclude with the results from this research to get a better understanding of the topic in hand.

The aim of the research was to get a better understanding of specific areas along the KZN coastline that may be affected by a storm surge, future storm surge and incorporate future sea level rise with the effects of these storm surges. The worst case scenario of the "Perfect Storm" was used to predict the areas that may be worst affected by it. Many areas along the KZN coastline will be inundated if the projections are correct.

The first objective of the research was to establish an understanding of the nature and causalities of the processes which lead to the erosion of the coast along the KZN coastline. The results were that there are many factors that contribute to the causalities of coastal erosion. Processes such as longshore drift, atmospheric conditions, mega rips, sediment supply, beach rotation and other factors contribute to the erosion of the coastline. It was found that the storm event that occurred in the 2007 erosion was from a cut off low, as well as the lack of sediments on the coastline causing the erosion to be devastating in many areas of the coast. It was determined that if this had to occur again, the devastation may be worse. With human intervention, sediments may not reach the coastline and thus result in less protection for the coastline.

The second objective of the research was to predict the rate of sea level rise and the extent of which the increase in sea level will flood to above today's sea level height. The projected sea level rise was then, with the addition of storm surge, projected to determine where the corporation of the two will flood. It was found that the sea would be rising at 15.5mm per year (Cronin, 2012). According to the projections from the results, the sea level will be below 2 m by the year 2100, this would not flood much of the KZN coastline, but the astronomical high tide will then flood the coastline on a daily basis with normal wave heights. This sea level, with a threshold height of a storm surge (3.5m), will be at a height of over 5 m. The sea level at this height will flood much of the coastline destroying infrastructure along the coastline. The “Perfect Storm” as stated in the previous chapters, would be a sea level rise of 2 m. An abnormally high tide and a storm surge (8m) that replicated the one from 2007 would project the sea level to 10 m above today’s sea level. This would inundate the coastline and cause mass devastation to infrastructure and may cause loss of life to coastal residents. This could be an issue in Durban as the CBD is low lying and has fuel storage areas that may be flooded, releasing oil and fuel into the ocean causing destruction elsewhere. According to the beach profiles all the study sites would be flooded by a threshold storm surge and an incorporated sea level rise in 2100 except for Durban. As stated in the discussions other areas of the Durban coastline are lower than the profile measured.

The third objective of the research was to determine from the projections or what would be the, from the selected areas, worst affect areas if the conditions were to occur. According to the results and projections, there were ten worst affected sites which were namely Kosi bay, St Lucia, Richards Bay, Mtunzini, Matigulu River, Tugela River, Umvoti River, Durban, Umkomaas and Port Shepstone. Many of these sites are still natural in terms of the vegetation and have minimal human interventions. Durban and Richards Bay are both ports that are currently in use and are needed to add to the economy of KZN. Many business, residences and infrastructure may be destroyed if this event were to occur, causing a huge loss in the economy and many lives (human, flora and fauna). The prevention methods that are currently being used along the coastline are single celled sand bags. These bags have been known not to work as the wave energy can still move these bags if the energy were high enough. These bags should be linked together to make them one unit. This would make them act as one and be much stronger against the forces of the ocean. Another method used is the multicelled bags which have been tried and tested in United States of America (Harris & Sample, 2009). This said, CPI often causes the exacerbation of erosion on areas on the adjacent areas.

The Fourth and final objective of the project is to review the need to implement policies along the coastline to protect infrastructures, while monitoring development in the future that may take place on the coastline. One of the policies that is in place is the ICMA, which states which areas are protected and which are prohibited to build in. New policies should be implemented to prevent the negative effects of development of infrastructures on the coastline. These infrastructures should ideally use the future projection and determine how they can positively affect the coastline. If future development does not take into consideration the effects of storm surge and an associated storm surge, the effects on the infrastructure may be devastating. These events could destroy the infrastructure, and thus wasting money and even taking lives in the process. New laws that have taken the future projection into consideration must be enforced as soon as possible to prevent the negative effects in the future.

6.1. A Way Forward and the Potential for Future Research

To get a better understanding of the topic and to better calculate the effects on coastal erosion, more research must be conducted. The more research done, the more knowledge will be available to get a better understanding of the topic. Research conducted on the rivers that measures the amount of sediment yield supplied to the coastline, rejuvenating the coastal regions. This would help with calculation of the amount of sediments on the coast. Research must be conducted to calculate the actual or an approximate amount of sediments that are present on the coastline. This will be used to depict the movement of sediments during oceanic events. More research needs to be conducted on the atmospheric conditions to try and accurately predict the next storm surge event to the date, so that interventions can be implemented to prevent the destruction of these surges or to mitigate the energies associated with the surges. Research on the small scale contours must be conducted to get an accurate of which areas at said altitude, would flood. This said, better computer modelling is required to determine the exact areas in which the water may come into contact with. Taking into consideration the attitude changes, the drainage infrastructure, actual physical infrastructure that may hinder the intrusion of wave inland as well as coastal geology which may prevent the water from entering inland. New research needs to be conducted to determine the actual value of all properties along the KZN coastline that may be affected by the combination of storm surge and sea level rise. This needs to be contrasted against the cost of installing CPI in the location that they are required.

6.2. Concluding Observations

If the predicted results are correct, the effects of storm surge and incorporated sea level rise will become an issue in the near future. These conjoined factors can be seen to inundate a lot of coastal regions in KZN. These areas were urban, rural and untouched by humans. As much of KZN infrastructure is along the coast such as roads and railways, these are in jeopardy and may be destroyed by the wave energy eroding the structures away. Tourism is increasing the pressures on the coast line and thus destroying the area which people are coming to see. More responsible tourism must be conducted, to help prevent coastal erosion. This research should be utilised in the development of new construction laws and environmental laws which will protect the coastline and lives. These laws should take into consideration all factors including storm surges that may occur that are bigger than the March 2007 that was used in this research, as storm events are intensifying and getting stronger.

Storm surge alone will still cause destruction on the coastline. Sea level rise alone will not cause as much destruction on the coastline, but will allow the water body to move further inland. The incorporation of both these events will flood the coastline up to 10 m if sea level is around the predicted 2m by 2100 and a replication storm surge that was experienced in 2007 was included in the prediction. CPI has been used in some of the study sites to help protect the coastline and its infrastructure, but as stated before this may exacerbate the erosion in areas adjacent to the CPI installed areas. The better idea would be to move the coastal build line back as to allow for the natural occurrence of erosion to continue and destroying the infrastructure built there. This research will hopefully help in the future to educate people of the potential risks they are putting themselves and their families in by living so close to the coast. It will also help to prevent the loss of lives and save money as infrastructure is not being destroyed. The weather, the ocean and the Earth itself is so unpredictable and no one is capable of predicting exactly what may happen in the future. This research should be considered as new literature, as many of the existing literature looks at either sea level rise or storm surge on their own. Whereas this research amalgamates the two together to get a prediction of what may occur. Only time will tell now if these predictions will become facts and become history in the making.

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Appendices

Appendix A: Sediment samples

Appendix A.1: Sediment samples from Kosi Bay

1.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.25	8.25	0	0	0
1	8.53	8.25	0.28	0.09908348	0.09908348
0.5	55.5	8.26	47.24	16.7167982	16.8158817
0.25	225.53	8.23	217.3	76.8958562	93.7117379
0.125	25.86	8.25	17.61	6.23164302	99.9433809
0.053	8.04	8.02	0.02	0.00707739	99.9504583
0.01	8.19	8.05	0.14	0.04954174	100
		Total	282.59		

1.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.79	8.25	0.54	0.13924344	0.13924344
1	9.31	8.22	1.09	0.28106547	0.42030891
0.5	113.31	8.22	105.09	27.0983213	27.5186303
0.25	275.4	8.23	267.17	68.8919832	96.4106134
0.125	21.99	8.23	13.76	3.54812924	99.9587427
0.053	8.15	8.03	0.12	0.03094299	99.9896857
0.01	8.1	8.06	0.04	0.01031433	100
		Total	387.81		

1.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	13.9	8.25	5.65	1.32613543	1.32613543
1	57.82	8.23	49.59	11.6394789	12.9656144
0.5	174.08	8.26	165.82	38.9203145	51.8859289
0.25	196.62	8.23	188.39	44.2178148	96.1037437
0.125	24.48	8.25	16.23	3.80941204	99.9131557
0.053	8.3	8.05	0.25	0.05867856	99.9718343
0.01	8.17	8.05	0.12	0.02816571	100
		Total	426.05		

Appendix A.2: Sediment samples from St Lucia River mouth

2.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.23	8.23	0	0	0
1	9.04	8.23	0.81	0.15532417	0.15532417
0.5	77.06	8.26	68.8	13.1929663	13.3482905
0.25	327.23	8.23	319	61.1708758	74.5191662
0.125	136.04	8.26	127.78	24.5028668	99.022033
0.053	12.5	8.08	4.42	0.84757138	99.8696044
0.01	8.78	8.1	0.68	0.1303956	100
		Total	521.49		

2.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.84	8.23	0.61	0.15301643	0.15301643
1	10.74	8.26	2.48	0.62209959	0.77511602
0.5	63.6	8.27	55.33	13.8793428	14.6544588
0.25	264.65	8.25	256.4	64.3170701	78.9715289
0.125	75.52	8.26	67.26	16.8719428	95.8434717
0.053	24.43	8.06	16.37	4.10635896	99.9498307
0.01	8.26	8.06	0.2	0.05016932	100
		Total	398.65		

2.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.39	8.25	0.14	0.03020301	0.03020301
1	10.69	8.25	2.44	0.52639527	0.55659828
0.5	157.86	8.26	149.6	32.2740707	32.830669
0.25	286.99	8.23	278.76	60.1385024	92.9691714
0.125	38.76	8.25	30.51	6.58209825	99.5512696
0.053	10	8.03	1.97	0.42499946	99.9762691
0.01	8.15	8.04	0.11	0.02373093	100
		Total	463.53		

Appendix A.3: Sediment samples from Richards Bay

3.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	17.24	8.22	9.02	2.67782924	2.67782924
1	29.8	8.23	21.57	6.40363377	9.08146301
0.5	183.19	8.27	174.92	51.9296996	61.0111626
0.25	134.7	8.27	126.43	37.5341408	98.5453034
0.125	12.63	8.26	4.37	1.29735186	99.8426553
0.053	8.47	8.09	0.38	0.11281321	99.9554685
0.01	8.2	8.05	0.15	0.04453153	100
		Total	336.84		

3.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	12.4	8.24	4.16	1.34016301	1.34016301
1	48.54	8.24	40.3	12.9828292	14.3229922
0.5	212.12	8.24	203.88	65.6808737	80.0038659
0.25	64.95	8.23	56.72	18.2726072	98.2764731
0.125	13.11	8.23	4.88	1.5721143	99.8485874
0.053	8.44	8.07	0.37	0.11919719	99.9677845
0.01	8.16	8.06	0.1	0.03221546	100
		Total	310.41		

3.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	9.43	8.25	1.18	0.42725759	0.42725759
1	69.07	8.23	60.84	22.0291114	22.456369
0.5	209.1	8.24	200.86	72.7279311	95.1843001
0.25	19.62	8.22	11.4	4.12774278	99.3120429
0.125	9.84	8.24	1.6	0.57933232	99.8913752
0.053	8.27	8.06	0.21	0.07603737	99.9674126
0.01	8.15	8.06	0.09	0.03258744	100
		Total	276.18		

Appendix A.4: Sediment samples from Mlalazi River mouth

4.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.21	8.21	0	0	0
1	11.98	8.24	3.74	1.47581091	1.47581091
0.5	102.32	8.28	94.04	37.1083577	38.5841686
0.25	132.14	8.25	123.89	48.8872228	87.4713914
0.125	38.34	8.26	30.08	11.8696235	99.3410149
0.053	9.2	8.03	1.17	0.46168416	99.8026991
0.01	8.56	8.06	0.5	0.19730092	100
		Total	253.42		

4.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.24	8.24	0	0	0
1	11.98	8.24	3.74	1.06510224	1.06510224
0.5	155.79	8.25	147.54	42.0174289	43.0825312
0.25	172.36	8.25	164.11	46.7363445	89.8188757
0.125	37.49	8.27	29.22	8.32146722	98.1403429
0.053	10.99	8.02	2.97	0.84581648	98.9861594
0.01	11.61	8.05	3.56	1.01384063	100
		Total	351.14		

4.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.28	8.28	0	0	0
1	8.54	8.28	0.26	0.05134484	0.05134484
0.5	83.26	8.26	75	14.8110115	14.8623563
0.25	329.98	8.24	321.74	63.5372645	78.3996208
0.125	115.15	8.24	106.91	21.1126032	99.512224
0.053	9.89	8.08	1.81	0.35743908	99.8696631
0.01	8.72	8.06	0.66	0.1303369	100
		Total	506.38		

Appendix A.5: Sediment samples from Matigulu River mouth

5.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.6	8.26	0.34	0.067731782	0.067731782
1	8.35	8.24	0.11	0.021913224	0.089645006
0.5	25.23	8.26	16.97	3.380612773	3.470257779
0.25	428.54	8.27	420.27	83.72245906	87.19271684
0.125	71.39	8.28	63.11	12.57221403	99.76493087
0.053	8.75	8.08	0.67	0.133471453	99.89840233
0.01	8.56	8.05	0.51	0.101597673	100
		Total	501.98		

5.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.23	8.23	0	0	0
1	9.06	8.23	0.83	0.171924519	0.171924519
0.5	80.1	8.25	71.85	14.88286348	15.05478799
0.25	345.04	8.24	336.8	69.76406985	84.81885784
0.125	78.3	8.25	70.05	14.51001512	99.32887296
0.053	10.84	8.07	2.77	0.57377219	99.90264515
0.01	8.51	8.04	0.47	0.097354848	100
		Total	482.77		

5.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.24	8.24	0	0	0
1	10.2	8.22	1.98	0.419509301	0.419509301
0.5	82.02	8.27	73.75	15.6256621	16.04517141
0.25	354.24	8.23	346.01	73.31030976	89.35548116
0.125	57.74	8.25	49.49	10.4856138	99.84109496
0.053	8.55	8.06	0.49	0.103817958	99.94491292
0.01	8.28	8.02	0.26	0.05508708	100
		Total	471.98		

Appendix A.6: Sediment samples from Tugela River mouth

6.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	11.01	8.21	2.8	0.83460014	0.83460014
1	8.77	8.25	0.52	0.15499717	0.98959731
0.5	28.24	8.23	20.01	5.96441027	6.95400757
0.25	262.11	8.21	253.9	75.6803481	82.6343557
0.125	64.72	8.2	56.52	16.8469999	99.4813556
0.053	9.33	8.05	1.28	0.38153149	99.8628871
0.01	8.49	8.03	0.46	0.13711288	100
		Total	335.49		

6.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.47	8.29	0.18	0.04848877	0.04848877
1	17.8	8.26	9.54	2.56990464	2.61839341
0.5	176.7	8.26	168.44	45.3747104	47.9931038
0.25	188.1	8.27	179.83	48.4429718	96.4360756
0.125	20.13	8.27	11.86	3.19487097	99.6309466
0.053	8.99	8.09	0.9	0.24244383	99.8733904
0.01	8.54	8.07	0.47	0.12660956	100
		Total	371.22		

6.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	18.03	8.25	9.78	1.19602304	1.19602304
1	118.37	8.23	110.14	13.4693229	14.6653459
0.5	441.79	8.25	433.54	53.0187964	67.6841423
0.25	258.46	8.26	250.2	30.5976446	98.2817869
0.125	21.36	8.24	13.12	1.60448081	99.8862677
0.053	8.81	8.06	0.75	0.09171956	99.9779873
0.01	8.24	8.06	0.18	0.02201269	100
		Total	817.71		

Appendix A.7: Sediment samples from Umvoti River mouth

7.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	74.37	8.27	66.1	11.7705718	11.7705718
1	274.15	8.23	265.92	47.3529569	59.1235287
0.5	194.93	8.27	186.66	33.2389551	92.3624838
0.25	48.92	8.25	40.67	7.24219599	99.6046797
0.125	10.11	8.27	1.84	0.32765283	99.9323326
0.053	8.27	8.07	0.2	0.03561444	99.967947
0.01	8.25	8.07	0.18	0.03205299	100
		Total	561.57		

7.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	12.55	8.23	4.32	1.59315533	1.59315533
1	137.93	8.23	129.7	47.8315386	49.4246939
0.5	123.85	8.27	115.58	42.6242809	92.0489748
0.25	27.47	8.23	19.24	7.09544181	99.1444166
0.125	10.32	8.26	2.06	0.75969907	99.9041157
0.053	8.23	8.08	0.15	0.05531789	99.9594335
0.01	8.17	8.06	0.11	0.04056646	100
		Total	271.16		

7.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	46.54	8.24	38.3	10.4550542	10.4550542
1	159.13	8.22	150.91	41.1950973	51.6501515
0.5	128.66	8.25	120.41	32.8692709	84.5194224
0.25	59.86	8.26	51.6	14.0856605	98.6050828
0.125	13.21	8.25	4.96	1.35397046	99.9590533
0.053	8.16	8.05	0.11	0.03002757	99.9890809
0.01	8.1	8.06	0.04	0.01091912	100
		Total	366.33		

Appendix A.8: Sediment samples from Durban north of harbour

8.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	41.59	8.22	33.37	6.80659242	6.80659242
1	17.33	8.24	9.09	1.85411822	8.66071064
0.5	27.16	8.26	18.9	3.8550973	12.5158079
0.25	124.97	8.27	116.7	23.803696	36.3195039
0.125	282.3	8.25	274.05	55.8989108	92.2184147
0.053	34.91	8.06	26.85	5.47668584	97.6951006
0.01	19.37	8.07	11.3	2.30489944	100
		Total	490.26		

8.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	12.55	8.23	4.32	1.10965554	1.10965554
1	13.73	8.23	5.5	1.4127559	2.52241145
0.5	42.09	8.27	33.82	8.68716447	11.2095759
0.25	149.55	8.26	141.29	36.2924148	47.5019907
0.125	198.37	8.26	190.11	48.8325499	96.3345406
0.053	20.04	8.07	11.97	3.07467057	99.4092112
0.01	10.57	8.27	2.3	0.59078883	100
		Total	389.31		

8.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.32	8.24	0.08	0.01301406	0.01301406
1	8.62	8.22	0.4	0.06507028	0.07808433
0.5	16.1	8.26	7.84	1.27537741	1.35346174
0.25	139.18	8.27	130.91	21.2958745	22.6493363
0.125	452.9	8.22	444.68	72.3386257	94.987962
0.053	35.88	8.08	27.8	4.52238417	99.5103462
0.01	11.08	8.07	3.01	0.48965383	100
		Total	614.72		

Appendix A.9: Sediment samples from Umkomaas river mouth

9.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.85	8.29	0.56	0.122137405	0.122137405
1	27.5	8.23	19.27	4.202835333	4.324972737
0.5	230.68	8.24	222.44	48.51472192	52.83969466
0.25	201.31	8.27	193.04	42.10250818	94.94220284
0.125	30.15	8.25	21.9	4.776444929	99.71864776
0.053	9.24	8.08	1.16	0.252998909	99.97164667
0.01	8.2	8.07	0.13	0.028353326	100
		Total	458.5		

9.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	8.3	8.25	0.05	0.011150261	0.011150261
1	17.29	8.26	9.03	2.013737121	2.024887382
0.5	283.27	8.26	275.01	61.32866509	63.35355247
0.25	170.14	8.27	161.87	36.09785469	99.45140716
0.125	10.41	8.27	2.14	0.477231167	99.92863833
0.053	8.26	8.11	0.15	0.033450783	99.96208911
0.01	8.26	8.09	0.17	0.037910887	100
		Total	448.42		

9.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	9.33	8.28	1.05	0.212576426	0.212576426
1	77.89	8.23	69.66	14.10292748	14.31550391
0.5	311.4	8.25	303.15	61.37385108	75.68935498
0.25	122.41	8.29	114.12	23.10402073	98.79337571
0.125	13.89	8.29	5.6	1.13374094	99.92711665
0.053	8.33	8.09	0.24	0.048588897	99.97570555
0.01	8.19	8.07	0.12	0.024294449	100
		Total	493.94		

Appendix A.10: Sediment samples from Port Shepstone river mouth

10.1	Combined weight	Tray	Sand	Percentage	Cumulative
2	38.97	8.24	30.73	6.4366805	6.4366805
1	248.95	8.25	240.7	50.416824	56.853504
0.5	140.19	8.27	131.92	27.631855	84.485359
0.25	71.69	8.26	63.43	13.285996	97.771354
0.125	15.96	8.26	7.7	1.6128357	99.38419
0.053	9.55	8.08	1.47	0.307905	99.692095
0.01	9.56	8.09	1.47	0.307905	100
		Total	477.42		

10.2	Combined weight	Tray	Sand	Percentage	Cumulative
2	40.51	8.25	32.26	6.9941896	6.9941896
1	161.02	8.25	152.77	33.121585	40.115775
0.5	213.94	8.26	205.68	44.592837	84.708612
0.25	76.87	8.29	68.58	14.868615	99.577227
0.125	9.93	8.27	1.66	0.3598994	99.937126
0.053	8.26	8.07	0.19	0.0411933	99.978319
0.01	8.15	8.05	0.1	0.0216807	100
		Total	461.24		

10.3	Combined weight	Tray	Sand	Percentage	Cumulative
2	39.67	8.24	31.43	8.2775876	8.2775876
1	188.65	8.24	180.41	47.513827	55.791414
0.5	101.38	8.27	93.11	24.521991	80.313405
0.25	78.43	8.26	70.17	18.480379	98.793785
0.125	12.65	8.26	4.39	1.1561759	99.94996
0.053	8.18	8.05	0.13	0.0342376	99.984198
0.01	8.12	8.06	0.06	0.0158019	100
		Total	379.7		