The influence of sand mining on the coastal erosion of Ngapali, Myanmar

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Abstract

The beach at Ngapali, Myanmar is eroding, resulting in a shoreline which moves landward. The coastline gets closer to the vegetation each year and during the monsoon season, at high tide, it reaches the palm trees completely. The assumption is that this is due to people shovelling truckloads of sand from the beach to use for construction, this is otherwise known as sand mining. All around the world there are recorded cases of it, often with disastrous outcome. However, sand mining is done sensible, the consequences can be very limited. This research will make a quantification of the influence of sand mining on the beach, will help to understand at what rate the erosion of the beach over the past 30 and 15 years has been and will make a prediction with what rate this will continue.

This is done by analysing 30 years of satellite data, gathering data about the movement of the ocean at the shore, looking at characteristics of the beach and talking to the locals. The conclusion is reached by looking at two different methods. Firstly the quantification of the amount of sand that is taken from the beach yearly with respect to the amount of sand that moves along the shore yearly. Secondly by looking at the satellite data to show if the erosion of the beach was already a trend before the sand mining started. The first method established that the sand mining is but a fraction $(< 1\%)$ of the sand that moves along the shore each year. From the satellite data we can determine that the erosion of the beach already started when the satellites first started measuring. Therefore we can conclude that the erosion of the beach is not the result of sand mining activities.

Contents

Introduction

The coastal erosion of Ngapali Beach in Myanmar is clearly noticeable. Vegetation is washed away and the roots of palm trees are clearly visible, as seen in Figure 1. This means that the natural coastline defence is also washed away, in turn endangering the local population (Sand Mining, 2017), (Torres, Brandt, Lear, & Lui, 2017). Moreover the coastline of Myanmar, and the Rakhine State where Ngapali is especially, is frequently targeted by typhoons (Phyu & Thi, 2016). Thus possibly resulting in devastating outcome.

Figure 1: Erosion of palm tree roots

Ngapali Beach is a tourist hotspot for Myanmar, even awarded the best beach of Asia by Tripadvisor (Pantazi, 2016). Consequently giving the beach a large economic value for the area as well. Many hotels have sprung up at the shoreline, employing local people. The decreasing beach is a problem for them too. With the sea washing their land away, bit by bit, they started to build walls to protect their land. However the sea continues to wash sand away, resulting in corroded walls which are unusable, as seen in Figure 2. Through the help of local hotel owners (Hulst, 2015) sand mining is now illegal, with the local government now also looking into the matter (Kean & Shin, 2014) Nevertheless, people still practice sand mining and must be educated on the consequences of it when it is done carelessly, because when done sensibly it is far less harmful (Schenk, 2017). Examples of sand mining and the use of white sand have been cumulatively added in Appendix 1.

Figure 2: Erosion of a hotel wall with unusable steps

Problem statement

The problem is sand mining at Ngapali beach. With sand mining being a direct contributor to coastal erosion the hypothesis for this research is that sand mining is the sole contributor to the problem. For this we need to be able to quantify at what rate and with which frequency sand is taken. However, the decline of the beach can be of natural processes as well, this will be explained further on.

Research goals

The main goal of this thesis is to understand at what rate the beach will continue to decline. This will be done by answering the following main research question:

Does the sand mining by the local people at Ngapali beach cause the decrease of the beach?

For this question we will use two methods. The first method is a quantification of the amount of sand that is taken from the beach yearly with respect to the amount of sand that moves along the shore yearly. The second method is examining 30 years of satellite data to look in the erosion of the coast was already a trend before the sand mining started.

To help better answer the main research question, the following sub questions are asked:

- *How much sand is mined at a yearly basis?*
- *Does the practice of sand mining fluctuate during the year?*
- *What are the characteristics of the beach?*
- *How much sediment moves along the shore yearly due to natural processes?*
- *Was the erosion of the beach a trend before the sand mining started?*

Background information

This section will give information and clarification about the background of certain situations at Ngapali Beach. This will give the reader necessary information to understand the processes happening at the beach.

Ocean current western Myanmar

The direction of the ocean current at Myanmar changes each half year, this is due to the Monsoon Current, also known as the Monsoon Drift. This current affects the South of Asia, including the Bay of Bengal where Myanmar lies as seen in Figure 3. The switch is due to two different monsoons, the Southwest and the Northeast monsoon. These indicate the direction where the wind blows from (Shankar, Vinayachandran, & Unnikrishnan, 2002). For the calculations and examples below the Southwest monsoon direction will be used, as the data was gathered during that period.

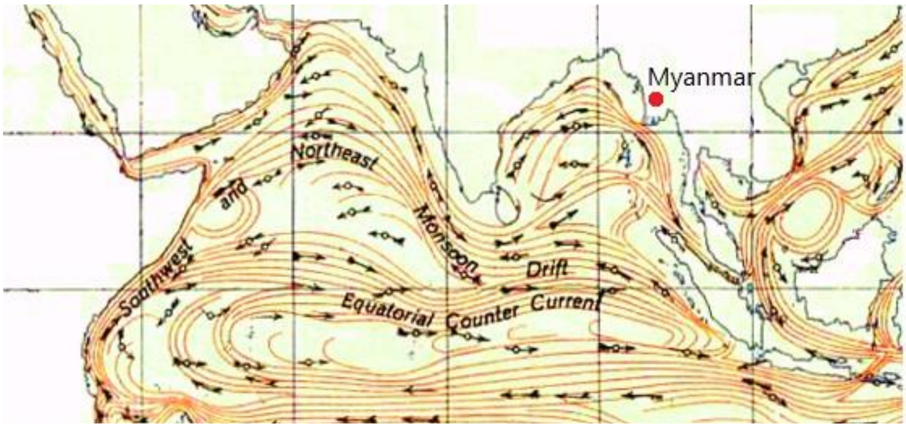


Figure 3: Monsoon Drift (cropped) (U.S. Federal Goverment, 2008)

Longshore sediment transport

Currents along the coast transport sediment/sand. The sediment is moved to the sea by rivers and then is moved along the shore by natural currents and storms, as seen in Figure 4 (1). For Ngapali this process is shown, using one river as example, though more rivers end up in the ocean in proximity to Ngapali. However due to the change in current throughout the year, we cannot pinpoint one river or river system the sediment originates from.

Due to the current of the ocean, which moves south to north (2), the sediment is also transported south. Due to heavy rainfall in the rainy season, during that period, more sediment ends up in the rivers and sea.

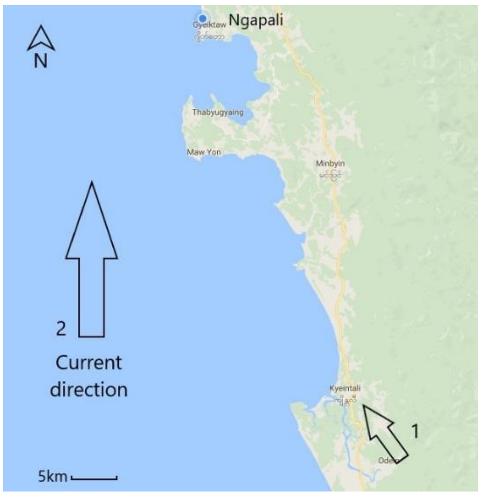


Figure 4: Longshore sediment transport Ngapali

In proximity of the beach, the longshore sediment transport has effect. Here the sediment that is carried by the current gets washed on and off the shore of the beach. This is because in the zone where the waves break, the so called 'surf zone', the waves travel at an angle relative to the beach, what is the 'effective wave direction', shown in Figure 5 (1). Due to this angle and the slope of the beach under water, the current slows down and the sediment settles. Although the current is small it remains to have some force. This small force travels alongside the beach and transports the sand further down the beach. This is called the longshore current (3). Though the sediment settles, it does not settle for long. It washes away and back to the beach again. This is the called the 'overall sand movement' (2).

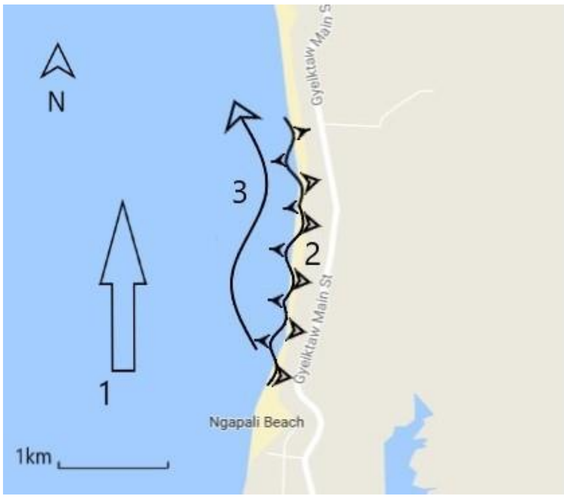


Figure 5: Longshore sediment transport

Summer and winter beaches

In the summer the waves are smaller, sediment is moved up and deposited on the shore and stays there, thus forming beaches. In the winter there are larger waves and more storms, sand particles are washed away from the shore, thus resulting in a beach decline. This process is a yearly routine. In Asia this process interrelates with the monsoon season thus the winter beach can be seen as the rainy season beach. Heavy rainfall, in combination with storms, cause the sand on the beach to retreat and form a sandbar further from the coast, as seen in Figure 6. As a consequence more sediment is moved about in the water. Plus, due to the rainy season, more sediment is deposited in the sea, resulting in a larger longshore sediment transport than in the summer. The larger winter waves have an influence as well, this will be explained later on.

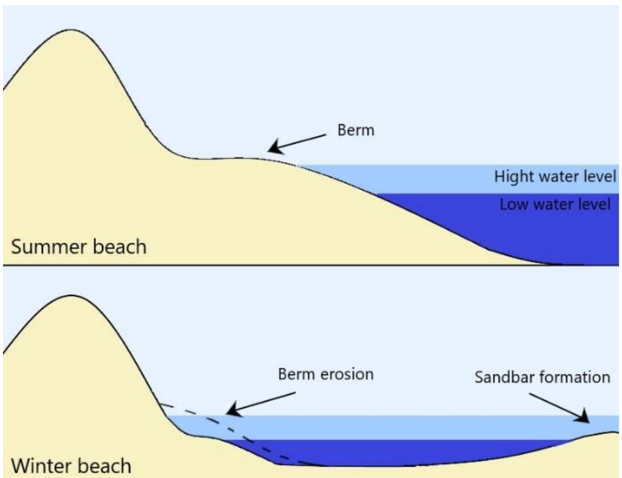


Figure 6: Summer and winter beach profile

Headland and pocket beach

At Ngapali beach, several small pocket beaches can be distinguished. A pocket beach is formed with two (natural) headlands extending in the water. At a headland, the sediment in the current accumulates on the side where the current originates from. At the other side, the current without any sediment erodes the beach, resulting in a bight. An example of how a headland works can be seen in Figure 8.

When there are two headlands, a pocket beach can be formed. The main current passes the first headland, and instead of reaching the beach, it surpasses it and reaches the second headland. This lack of (main) current causes a smaller longshore current at the beach. This is turn results in more settlement of sediment and less sediment being washed away. An example is illustrated in Figure 7.

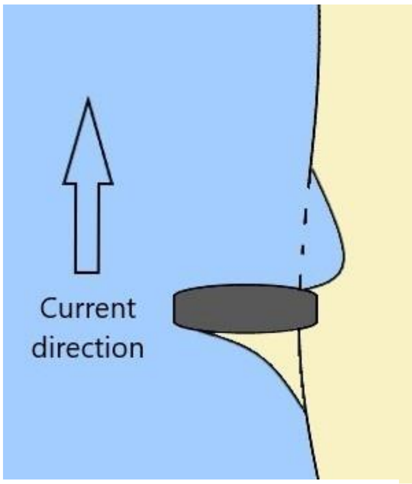


Figure 7: Landhead example

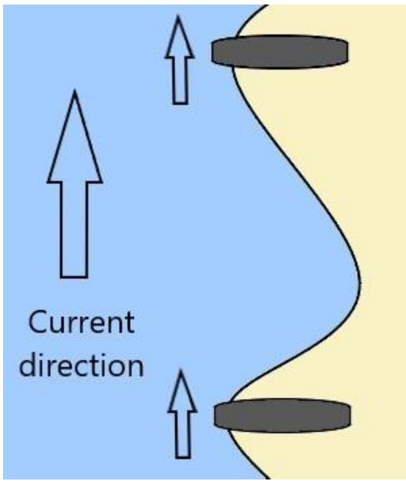


Figure 8: Pocket beach example

Methods

Here a description is given about the methods we are going to use to explore the role of sand mining at Ngapali Beach. We will do this in three steps. First we determine the amount of sand that is mined each year. For this we make an estimation about how much is used for construction, the main reason sand is taken. Secondly we calculate how much sediment moves along the beach yearly, this can be seen as the equilibrium of the beach. In combination with the known amount of sand that is mined yearly, we can look at what percentage of the beach is taken. Lastly we analyse 30 years of satellite data. With this data we can look at what the change rate of the beach is over the past 30 years and over the first and second 15 years. With this information we can determine the trend of the movement of the beach. Thus if the erosion of the beach was accelerated by the sand mining, which started some 15 years ago.

Sand mining on a yearly basis

For the purpose of this research, we must obtain information about the amount of sand that is taken per year. However there is not a constant outflow of sand. Only when something new is made, a road, hotel or a house, sand might be taken to use for the construction. We will make an estimation about how much cubic meters is taken yearly using the following 3 steps.

- Step 1: asses how many buildings are constructed each year
- Step 2: estimate how much concrete is used for these buildings
- Step 3: convert the amount of concrete to sand

Quantifying the longshore sediment transport using the CERC formula

The CERC Formula (Kamphuis, 2002), calculates the amount of sediment that is transported along the beach each year. The equation (1) is stated below.

$$Q_u = 2.27 H_{sb}^2 T_p^{1.5} m_b^{0.75} d_{50}^{-0.25} \sin^{0.6}(2\theta_b) \qquad (1)$$

Where Q_u is the transport rate of the underwater mass in kilogram per second, H_{sb} is the significant wave height at breaking in meters, T_p is the peak wave period in seconds, m_b is the beach slope, d_{50} is the medium grain size of the sand and θ_b is the wave angle at breaking in radians. This can be calculated to cubic meters per year. The parameters for H_{sb}, T_p and θ_b are obtained using the WaveDroid. This is a buoy with an Android phone in it, which measures its movement using the three build in accelerator sensors. The measurements where done in Ngapali in February and March 2017 (Van den Berg, 2017). The m_b is found with measuring tape and d_{50} with measuring and counting the grains on a grid structure.

The rivers export a certain amount of sediment. If more sediment is exported and transported along the beach, more sediment will wash on the beach and the beach will grow. If less sediment is transported along the beach, the same current will erode sand from the beach and the beach will shrink (Aagaard, Nielsen, Jensen, & Friderichsen, 2004). If a yearly equal amount of sand is transported with equal current, the beach will be in an equilibrium.

Therefore we can see the longshore sediment transport also as the equilibrium of the beach, as when sand is removed from the beach, it can only be (naturally) replenished by the longshore current. This means however, downstream, when there is less sediment in the current, the beach will degrade. Hence the overall beach will erode and the shoreline will move landward. This is clarified in Figure 9, where Q_{u1} is the amount of sediment before the sand mining and Q_{u2} after. Therefore when combining the outcome of the CERC formula, with the amount of sand that is mined, we can equate the two. This means that we can calculate what percentage of the beach is taken each year and has to be replenished by the longshore current.

In short, when sand is mined a hole is created on the beach. This hole, created at low tide, is then refilled by the longshore current during high tide. This has as effect that the longshore current has less sediment, this will be reclaimed by the current downstream of the beach, resulting in an overall loss of beach sand and erosion of the beach.

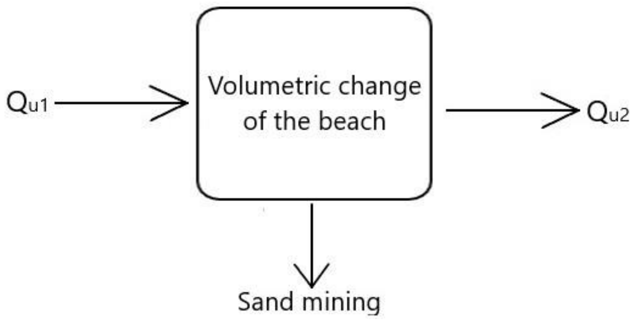


Figure 9: Longshore sediment transport and sand mining

Finding a trend in the coastal erosion using satellite data

Deltares provided 30 years of satellite data of Ngapali beach. This data shows what the location is of certain points of the beach over 30 years. With this data we can make graphs of the fluctuation of the beach. Firstly a graph of the fluctuation of 30 years will be made. This will show if the beach was already diminishing or if it was growing before the sand mining. This also gives information about the sand mining activities over the last 15 years. The graphs show a horizontal change. Applying the slope to the satellite data we can calculate the vertical change rate as well.

Through the data we will plot two regression lines. One will use all the available data points, the other will remove outliers and only will use the data points which lie in close proximity to the mean of the line. To check the accuracy of the lines, the coefficient of determination, or R^2 value, will be tested for the respective lines. The larger the R^2 value, which lies between 0 and 1, the better the line describes the data. However, when too many markers will be seen as outliers, the data can be too oversimplified and miss markers that were correct. Therefore an average between the two regression lines is taken as conclusion.

Secondly a graph of the fluctuation of the beach over the year will be made. With this graph, a better understanding of the erosion per season can be obtained. Future research can be done for a certain amount of time and can be compared to the seasonal graph.

As a result of finding the answers to the previous stated unknowns we can answer the sub questions. We then can apply outcome of the sub questions to the two methods and answer the main question.

Results

Sand mining on a yearly basis

According to a local hotel owner, who also is a former advisor to the Union government of Myanmar on Rakhine coastal issues, the mining started some 15 years ago when tourism in the region began to gain. In 2004 a $10km$ road, which lays some $500m$ inland, was constructed with beach sand. An additional $30{,}000\ tonnes$ is stored for further sale, as can be seen in Appendix 1, example 2. Though awareness was raised about the problems and effects of sand mining, it is still being practiced. We will work with sand that is used for construction, for it is the most constant. The information and estimations used in this section are from local people, such as, but not exclusive to, hotel owners, hotel managers, local constructor, engineers and the local population.

Construction is mainly done in the rainy season, when there are very few tourists and most hotels closedown. From this we can conclude that the sand is mainly taken during this time, though as previously stated there is a large reserve which can be bought from. However we cannot say if this was mined in one year or if this was a process, moreover we cannot say with certainty if that exact quantity is stored there.

To quantify the amount of sand used per year we look at the amount of concrete that is used for construction. Only the skeleton and the floors are made of concrete, the walls are made of bricks (thus no white sand is used for the walls). For the floors we take an average of $0.25m$ and for the columns we work with a size of $0.25x0.25x3.5m = 0.22m^3$. Also we estimate of the added facilities, such as the lobby, restaurant, hallways and terraces, plus an added 10% for production process loss of concrete. An overview can be found in Table 1.

After that we can calculate how much sand is being used each year. With sand being 1/3 of the ratio of concrete (Kosmatka & Panarese, 1994), for the guesthouses this gives us $57m^3$ of white beach sand per year. For the hotels this gives us $220m^3$ white sand used. In total $277m^3$ of beach sand is abstracted for construction each year.

Table 1: Overview of used concrete

Type of building	*Number of buildings per year*	*Number of rooms*	*m^2 per room*	*Columns per room*	*Extra percentage*	*White sand used*	*Concrete used (m^3)*	*White sand used (m^3)*
Hotel/resort	2	46	40	2	35%	50%	660	220
Guesthouse	5	5	20	3	20%	100%	170	57
Total							830	277

Quantifying the longshore sediment transport using the CERC formula

With the obtained data from the WaveDroid, the parameters for H_{sb}, T_p and θ_b were calculated. The calculations were done using Python programming. The code is included in Appendix 2. The calculations of the CERC formula can be found in Appendix 3.

Using a 50m measuring tape and the water level at Mean Water Level (MWL), the beach slope in the surf zone was found at 1:25. The d_{50} was found by taking a sample of beach sand and spreading it out on a grid surface with a known dimensions. This was scanned and enlarged so the grains could be measured, counted and sorted. This gave as result for and the d_{50} $0.3mm$.

The following values where obtained and used:

$$H_{sb} = 2.11m, T_p = 9.83s, m_b = 1:25, d_{50} = 0.30 * 10^{-3} m \ and \ \theta_b = 10.29° \ or \ 0.18 \ rad$$

Using the CERC formula and the density of quartz sand at $1201.0 \ kg/m^3$, it is calculated that $0.022 \ m^3/s$ or $688{,}100 \ m^3/y$ of sand is transported along the beach.

The H_{sb} however, is of a great influence in the formula and can greatly vary during the year. The acquired H_{sb} in particularly seems to be significantly high. The peak wave height measured during this research, using a measuring pole, is between $0.75m$ and $1.0m$. Also, according to the local people, during certain periods of the year, the waves can die out completely. During that period, as at the transitional period, the H_{sb}will be significantly less than the previously found $2.11m$.

When we take a H_{sb} of $0.5m$ a sediment transport of $38{,}600 \ m^3/y$ is found. With H_{sb} at $0.1m$, a sediment transport of just $733 \ m^3/y$ is found. This demonstrations that the results greatly fluctuate.

Not only the H_{sb} fluctuates, due to the monsoon changes, the θ_b fluctuates, as the sea currents flip from Southeast to Northwest and vice versa. Moreover, the d_{50} also might be affected, because when the current direction change, the sediment input changes due to different rivers supplying the sediment transport.

To give a more accurate yearly model we will work with two different values for H_{sb} for the two different seasons. We will work with $0.5m$ for the period the wave height is at its lowest and $1.0m$ for when it is at its highest. For $0.5m$ we find $19{,}000m^3$ per half year and for $1.0m$ we find $77{,}000m^3$ per half year. If we combine these figures we get $140{,}000m^3$ per year.

Combining the sand mining and the longshore sediment transport

Now we have quantified the sand mining and the longshore sediment transport (LST), we can put both in perspective with each other. In Table 2 we can see the results.

Table 2: Overview of the sand mining and the LST combined

H_{sb} *[m]*	*Sediment [m^3/y]*	*Mined sand [m^3]*	*Percentage [%]*
2.11	688,100	277	0.040
0.5	38,600	277	0.72
0.1	773	277	17.92
0.5 & 1.0	140,000	277	0.29

From this we can determine that, if a realistic value for $\mathrm{H_{sb}}$ is chosen, the percentage mined sand is $< 1\%$ of the longshore sediment transport.

Finding a trend in the coastal erosion using satellite data

Satellite imagery of NASA and ESA has given us an insight about the change rate. The satellites orbit the location every 16 days and to counter the clouds and tide, a yearly average of the pictures is taken. The change rate is in horizontal direction, they do not give an indication in depth change. This will be calculated further on. In total 22 points on Ngapali beach have been monitored, however, the data of point 16 is not available. In Figure 10 the locations and orientations of the points are shown for the whole of Ngapali Beach. The python code is included in Appendix 4.

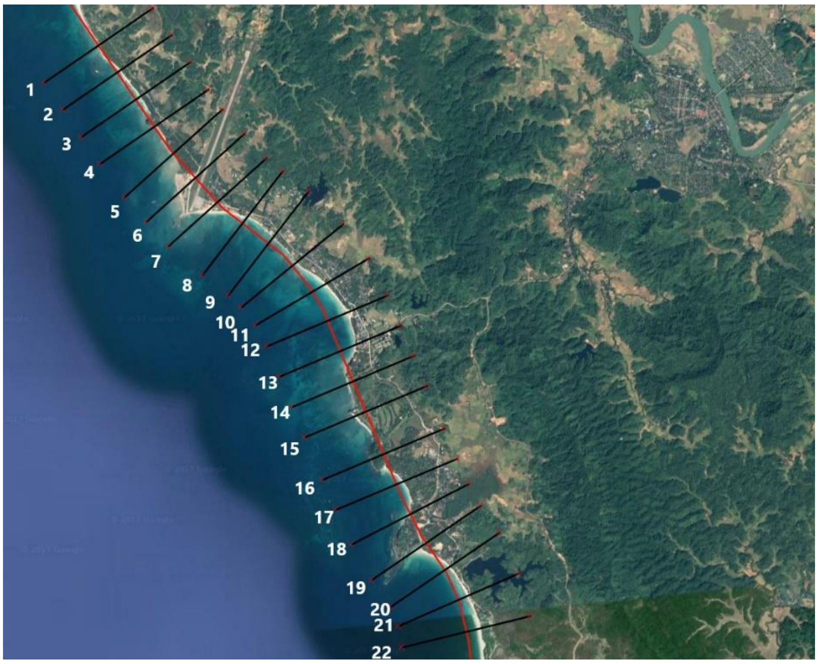


Figure 10: Location and orientation of the measurement points. (Hagenaars, 2017)

In Figure 11 an overview of the change rate of all the measurement points for 30 years are shown. We will take a closer look at transects 10, 11, 17 and 21. These transects will give a representative overview for the beach as a whole. Furthermore, at these transects most measurements were done

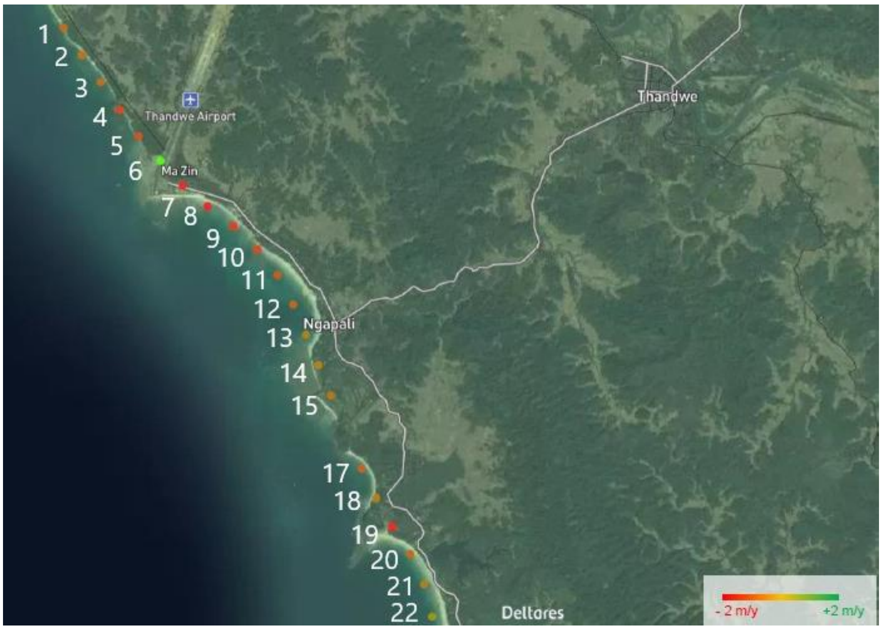


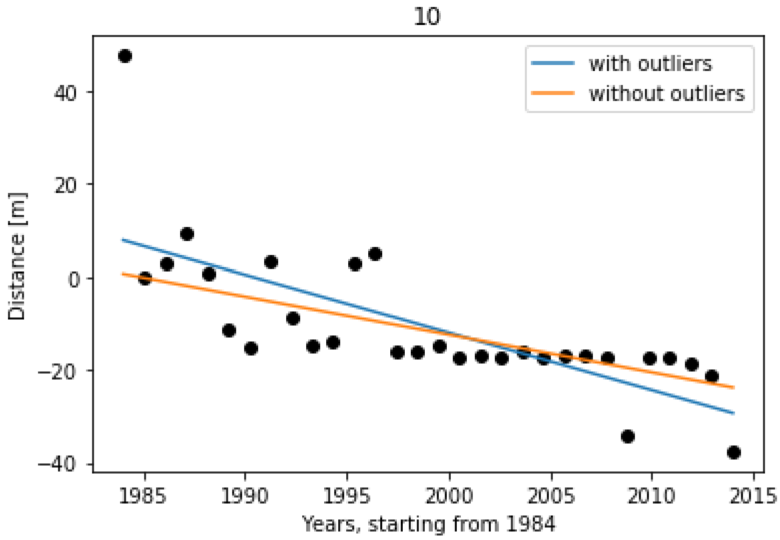
Figure 11: Overview change rate. (Hagenaars, 2017)

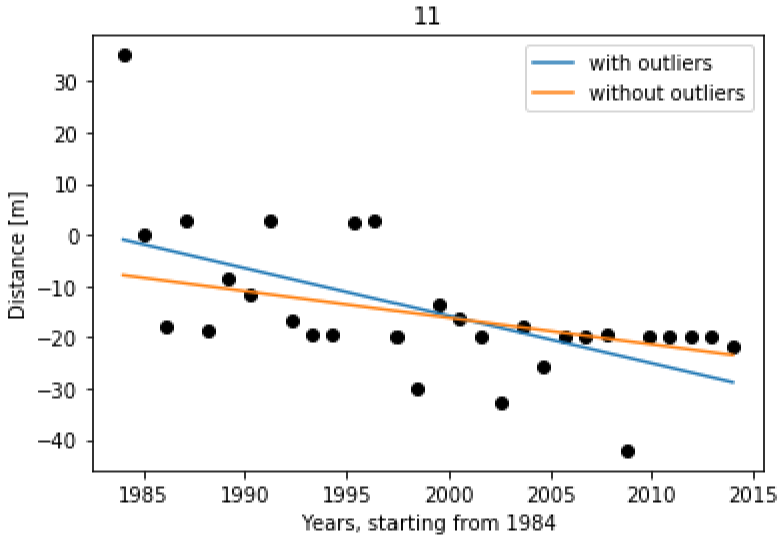
Transect changes of 30 years

Transects 10 and 11 are chosen because they lie in the middle of their beach pocket. This means the current is average and the landhead effect will be minimal, which will give a good average for the area. This is the largest beach pocket of Ngapali, because of this we use two transects.

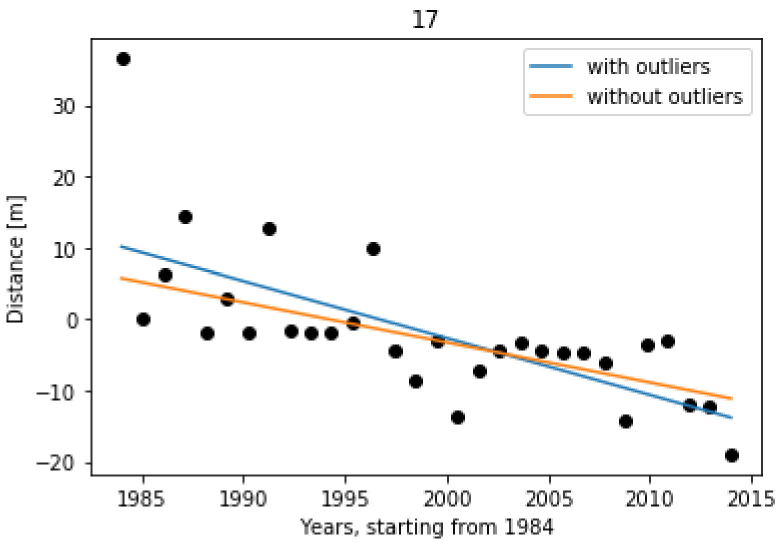
The horizontal change rate for transect 10 has a minimum of -0.84 m/y and a maximum of -1.28 m/y, with respective R^2 values of 1.00 and 0.54. This gives us an average of -1.06 m/y.

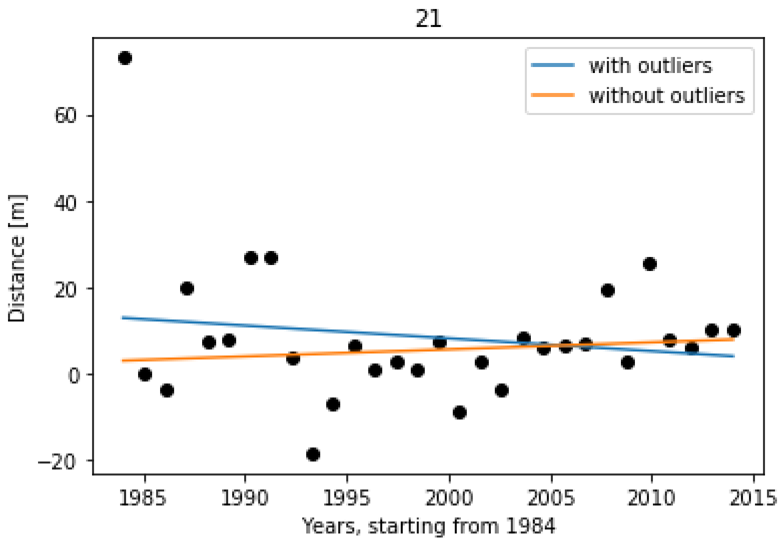
The horizontal change rate for transect 11 has a minimum of -0.54 m/y and a maximum of -0.96 m/y, with respective R^2 values of 1.00 and 0.36. This gives us an average of -0.75 m/y.





Transect 17 and 20 lie in the two most southern beach pockets.





The horizontal change rate for transect 17 has a minimum of -0.58 m/y and a maximum of -0.82 m/y, with respective R^2 values of 1.00 and 0.49. This gives us an average of -0.70 m/y.

The horizontal change rate for transect 20 has a minimum of -0.34 m/y and a maximum of -0.73 m/y, with respective R^2 values of 1.00 and 0.19. This gives us an average of -0.52 m/y.

As we can see the decline of the beach already started 30 years ago. And when we compare the first 15 years to the second 15 years, the decline has actually dropped. If we look at transect 11, the decline in the first 15 years was -1.81 m/y and in de last 15 years it was just -0.19 m/y. For transect 17 we find -1.13 m/y for the first, versus the -0.46 m/y for the last 15 years. At transect 20 we can even see a positive change rate.

If the slope is added to the horizontal change rate, we can find the vertical changerate too. With the average slope of the beach at 23.5 $[m/m]$, the average horizontal change rate for transects 11 and 17 are -3.2 and -3.0 cm/y respectively.

An overview of all the output will is shown in Table 3. Note that the vertical change rate is given in cm/y.

Table 3: Overview transect change rates

Transect	*Min. horizontal change rate [m/y]*	*Respective R^2 value*	*Max. horizontal change rate [m/y]*	*Respective R^2 value*	*Avg. horizontal change rate [m/y]*	*Avg. vertical change rate [cm/y]*	*Change rate 1st 15 years [m/y]*	*Change rate 2nd 15 years [m/y]*
10	-0.84	1.0	-1.28	0.54	-1.06	-4.5	-1.81	-0.56
11	-0.54	1.0	-0.96	0.36	-0.75	-3.2	-1.88	-0.19
17	-0.58	1.0	-0.82	0.49	-0.70	-3.0	-1.13	-0.46
20	-0.34	1.0	-0.73	0.19	-0.52	-2.2	-1.66	+0.37
Average	-0.58	1.0	-0.95	0.40	-0.76	-3.2	-1.62	-0.21

Now we will make a prediction of how much the beach will erode in the future. As can be seen, the erosion has already lessend in the last 15 years in regards to the first 15 years. We therefore will look at the average of the all the transects of the last 15 years, minus a few clear outliers, to make the prediction. Again we will combine this with the slope (23.5 $[m/m]$) to find the vertical change rate as well. To get the best outcome, we take te result of all transects, except for a few clear outliers, such as transect 6, the airport.

Prediction horizontal change rate: -0.48 m/y.

Prediction veritcal change rate: -0.02 m/y or -2 cm/y.

Volumetric change

With the data from the transects we can also calculate the volumetric change in m^3/y. For this we use Equation (2) (Rosati & Kraus, Formulation of sediment budgets at inlets, 1999), (Rosati, 2005):

$$\Delta V = A_D \sum_{i=1}^{n} (\Delta y \Delta x) \tag{2}$$

Where ΔV is the volumetric change (m^3/y), A_D is the average active depth (m), Δy is the change rate (m/y), Δx is the width of the transects (m) and n is the number of transects. There are 22 transects in total, each transect is $500m$ wide. For the Δy we will use the previous found average change rate of -0.48 m/y. The average active depth is calculated with Equation (3):

$$A_D = B + D_C \tag{3}$$

Where B is the sum of the berm crest or dune elevation and D_C is the depth of closure. The B was measured at $1.20m$. For the D_C we use Equation (4) (Hallermeier, 1978):

$$d_l = 2.28H_e - 68.5(H_e^2/gT_e^2) \tag{4}$$

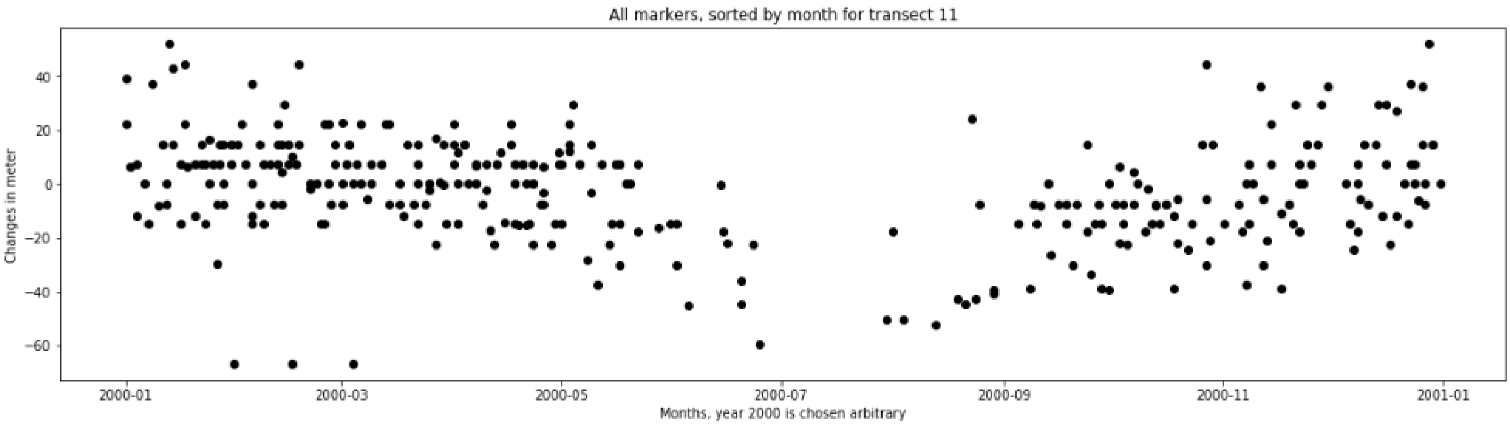
Where d_l (m) is the depth of closure, H_e is the peak wave height (m), g is the gravitational force $9.81\ m/s^2$ and T_e is the peak wave period (s). With H_e at $2.11m$ and T_e at $9.83s$ we get a closure depth of $4.45m$.

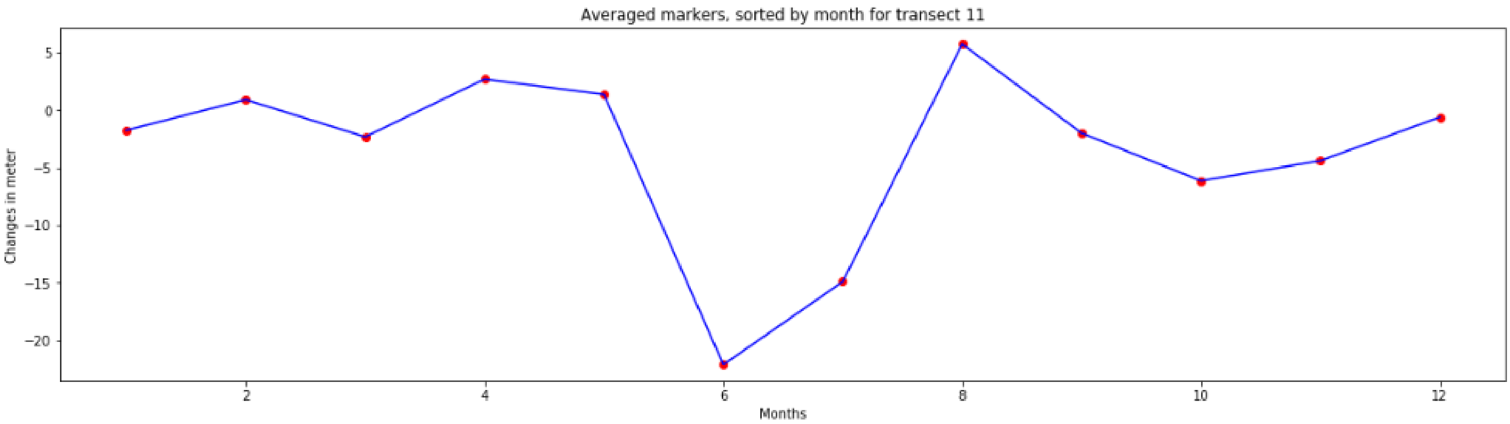
Using Equation (3) we get an average active depth of $5.65m$. Applying this to Equation (2) we get a ΔV of $31.6\ m^3/y$. This is about $1/9th$ of the calculated sand mining per year. If we apply this to the findings of the CERC Formula, we would get a very small percentage. We can draw as conclusion of this that either the estimations of the amount of sand that is taken each year is wrong or parameters used for Equation (2) were wrong.

Yearly change

For a better understanding of the influence of the Monsoon Drift, a yearly fluctuation of transect 11 is made. This transect gave the most insightful information. The python code is included in Appendix 5. The first graph shows all the markers over 30 years, sorted by month. The second graph the markers have been averaged per month to give a clearer picture. Unfortunately not all months have the same number of markers. Moreover, month July (7th month) has only 1 marker, this gives a distorted view. This is due to the clouds of the monsoon season not giving the satellites a clear view, if the cloud coverage is over 80%, the image is filtered out.

Yet the data still shows the yearly fluctuation. During the rainy season the beach is most landwards due to the larger waves and currents, creating the 'winter beach'. After the rainy season the beach begins to grow again due to the extra sediment which is deposited by the rivers, and reaches its peak in January. The graphs are shown below.





Discussion

The main question was if the sand mining done by the local people was the cause of the decrease of the beach. To help answer this question, five sub questions were asked.

The first question was about the amount of sand taken from the beach yearly. With the help of a local constructor and using some basic rules of thumb we have estimated that the amount of sand taken each year is $277m^3$. Though this is an estimation, for the purpose of this thesis we can work with it.

The next question was if the practice of sand mining fluctuates during the year. When we look at when the construction of new hotels and guesthouses is done, we can conclude that this is only in one period, during the rainy season. This means the mining is not smoothed out over the year but is done in a short amount of time. Thus resulting in beach which is more vulnerable to storms, common during that period.

The third question was what the characteristics of the beach are. Mainly this question was useful for the CERC formula, but the slope can tell a lot about the erosion as well. The first part of the beach, above water level, was found at 1:20, however at spring tide, the water level would completely cover this part too. The second part, in the surf zone, was found at 1:25, this was used for the CERC formula. For the grain size we found a medium diameter of $0.30mm$.

For the question how much sediment moves along the shore yearly we used the CERC formula. With the obtained data from the WaveDroid, measurement of the diameter grain diameter and the beach slope in the surf zone, we could fill in the formula. This resulted, in combination with the density of the sand, in $688{,}100m^3$ per year. However, the measurements were done during a period of two months, which is not representative for a yearly estimation. The outcome can therefore fluctuate greatly. Nevertheless, when we use lower figures, the outcome, in comparison with the obtained amount of sand that is mined each year, is still significant larger.

Lastly the question was asked if the decrease of the beach was already a trend before the sand mining started. Using 30 years of satellite data we can look back at the position and the fluctuation of the beach. Stated was that the sand mining started some 15 years ago. Therefore we would expect to see a decline of the beach starting from that period. However when we look at the imagery, we can conclude that the erosion already had started when the satellites first started measuring and it even has diminished over the last 15 years.

Conclusion

The hypothesis was that the coastal erosion at Ngapali Beach was caused by the mining of beach sand. We can test this hypothesis using two techniques, firstly we compare the amount of sand mining with the amount of sediment which is transported along the shore each year. Here we find that the sand taken is but a fraction (<1%) of the sediment which is transported. Secondly we look at the satellite imagery. Here we can see that the erosion of the beach already started before the sand mining was practiced and has decreased.

We can therefore reject the hypothesis and we can conclude that the sand mining is not the cause of the coastal erosion at Ngapali Beach though it is a small contributor to the process.

Recommendation

For the sand mining estimations where made. These estimations where based on the word of a few people and standard rules of thumb. However if the exact amount of sand taken is wanted, a more thorough research must be done with more exact numbers and calculations.

If we look at the CERC formula, we can see that all the parameters can diversify over the year. For example, the wave height can found between $2.11m$ and $0.5m$, which can give significantly different outcomes. The other parameters can fluctuate as well, especially if you take in mind the current change due to the Monsoon Drift. However, most of the sand is taken during the rainy season, when more sediment ends up in the sea, the wave height is at its highest point and the sediment transport is at peak. Though to give the best results, a year round measurement has to be done for all the parameters.

The cross section was made during the rainy season, when the beach has its winter slope and is at its steepest. The other measurements with the WaveDroid for the CERC formula parameters were done in the summer, when the beach has its summer slope and it is less steep. It therefore is necessary to make a cross section for the summer beach as well.

The use of the satellite data gives arguably the most accurate result. However a few outliers can give a different result. For most measurements the first data point was way off. This was because the satellite was first used that year and not many measurements were done. This means that some factors, such as clouds, could not be filtered out. At some transects the measurement points where greatly scattered and could not be seen as representative for the entire coast line of Ngapali.

The question remains of what the cause of the erosion could be. Below some options will be given with their respective pros and cons, however to verify these options, more research must be done.

The local government promotes the use of sand from the rivers for construction. This sand is better than beach sand because the salinity is lower, which in turn gives a longer lifecycle for concrete. However, these rivers are the source of the beach sand, and the when mining is done upstream, the results are the same downstream.

Not only river sand mining but other obstacles upstream can influence the sediment outcome downstream as well. When a river is blocked, a dam is build or is redirected somewhere else, the sediment source is gone and less sediment will be washed on shore.

The change in current direction due to the Monsoon Drift can be a factor. When the current changes direction, the sediment source changes with it. It is possible that this current is weaker, or less rivers end up here and less sediment is transported. This change has also an effect on the beach pockets and landheads. Whereas during the first season the sand is accumulated on one side and washed away from the other side, this effect inverts in the second season. This effect can cause the effective total accumulation to be negative, thus resulting in coastal erosion.

The effect of construction close to the beach can also be a factor. As an example, the walls of the hotels build on the beach have as effect that the energy of the waves do not dissipate over the beach slope but hit the walls, causing the energy to surge more sand back to the sea.

Lastly it can be due to the climate change and the resulting sea level rise. Myanmar has always been subject to severe weather events, such as floods, cyclones and tsunamis (US Aid, 2017). These events can have severely damage the coast and most likely will increase in frequency. This in combination with the sea level rise, this can result in an erosion of the coast.

Epilogue

Here some words of appreciation are in order. Firstly a special thanks M. Rutten, without whom this great experience wound not have happened. Secondly I want to thank O. Esser, for his hospitality, insight and contacts. Also I want to thank S. de Vries for the help with the CERC formula, G. Wagenaars and Deltares for providing the satellite data and M. Radermacher for helping me decipher it. A thanks also to Myanmar Maritime University for providing me with equipment and passage into this country. In addition I want to thank my father, E. de Iongh, for his technical insight and some background research in the matter.

Lastly I want to thank Myanmar and Ngapali. Myanmar the most beautiful country, with stunning scenery and sunsets, and with its peculiar habits and very friendly people. Ngapali really is a paradise and has to be preserved.

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Appendix 1

Example 1: Truck being loaded with white sand at Ngapali beach

Example 2: Storage of reportedly 30.000 tonnes of stolen beach sand at Ngapali

Example 3: Pile of white sand at a construction site for a new resort at Ngapali Beach

Example 4:Pile of white sand at another construction site for a new resort at Ngapali Beach

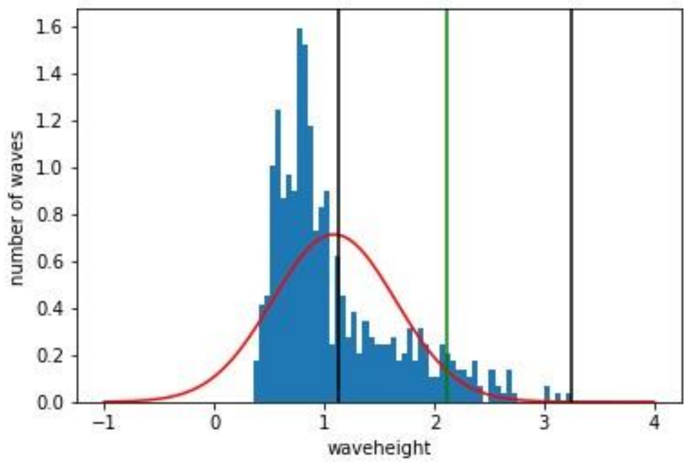
Example 5: Tire marks of trucks collecting beach sand at the north end of Ngapali beach

Example 6: Piles of white sand being used for construction for a new resort at the south end of Ngapali beach

Appendix 2

```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
from IPython.display import display
from pandas import read_csv
from scipy.stats import norm

data = read_csv('bulk.txt', skiprows=5,
                skipinitialspace=True, dtype=None)
print('Peak waveperiod:',data.Tp.min(),'[s]')

#Remoming outliers for angle
angle = data.Dirp
for i in range(len(angle)):
    if angle[i]<=200.0:
        angle[i]=np.nan
print('Peak wave direction:',angle.mean(),'[deg]')
print('Angle at breaking:', 278-angle.mean(),'[deg]')

lower, upper = data.Hmax.quantile([0.67, 1])
middle = (upper-lower)
print ('Hsb',middle,'[m]')

plt.hist(data.Hmax, bins=100, range=(-1,4), normed=True);
mean = data.Hmax.mean()
strd = data.Hmax.std()
x = np.linspace(-1, 4, 100)
y = norm.pdf(x, mean, strd)

plt.plot(x,y,'r');
plt.axvline(x=lower, color='k');
plt.axvline(x=upper, color='k');
plt.axvline(x=middle, color='g');
plt.ylabel('number of waves');
plt.xlabel('waveheight');
```

```
Peak waveperiod: 9.83 [s]
Peak wave direction: 267.70866141732284 [deg]
Angle at breaking: 10.291338582677156 [deg]
Hsb 2.11 [m]
```



Appendix 3

> *CERC FORMULA*

$$CERC\ FORMULA \quad (1)$$

> $H_{sb} := 2.1 : T_P := 9.83 : m_b := \frac{1}{25} : d_{50} := 0.3 \cdot 10^{-3} : \theta_b := convert(10.3 \cdot degrees, radians) :$
$sediment := 277 :$

>

> $f := Q_u = 2.27 \cdot H_{sb}^2 \cdot T_P^{1.5} \cdot m_b^{0.75} \cdot d_{50}^{-0.25} \cdot \sin^2(2 \cdot \theta_b) :$

>

> $Q_u := solve(f, Q_u) ; kg\ per\ s;$

$$Q_u := 25.95696413$$
$$kg\ per\ s \quad (2)$$

> $Q_u \cdot \frac{1}{1201.0} ; cubic\ meters\ per\ second;$

$$0.02161279278$$
$$cubic\ meters\ per\ second \quad (3)$$

> $Q_u \cdot 3600 \cdot 24 \cdot 365 \cdot \frac{1}{1201.0} ; cubic\ meters\ per\ year;$

$$6.815810330\ 10^5$$
$$cubic\ meters\ per\ year \quad (4)$$

> $\frac{sediment \cdot 100}{Q_u \cdot 3600 \cdot 24 \cdot 365 \cdot \frac{1}{1201.0}} ; percentage$

$$0.04064080227$$
$$percentage \quad (5)$$

Appendix 4

```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
import datetime
import json
import pyproj
from scipy.stats import linregress

inProj = pyproj.Proj(init='epsg:4326')
outProj = pyproj.Proj(init='epsg:32646')
tref = datetime.datetime(1984,1,1)
data = np.genfromtxt('Ngapali_changerates.csv',delimiter=';',
                     dtype=None,skip_header=13)

t = []
spos = []
slonlat = []
sxy = []
for d in data:
    t.append([tref + datetime.timedelta(days=ti*365) for ti in
              json.loads(d[3])])
    spos.append(json.loads(d[4]))
    slonlat.append([d[5],d[6]])
    sxy.append(pyproj.transform(inProj,outProj,d[5],d[6]))

t = np.array(t)
spos = np.array(spos)
slonlat = np.array(slonlat)
sxy = np.array(sxy)

#w/ = with, w/o = without
A = [5,7,10,15]
for k in A:
    x = np.linspace(0,29,30)
    y = spos[k]
    slope, intercept, r_value, p_value, sig_a = linregress(x,y)
    slope2 = []
    for i in range(len(y)):
        for j in range(i+1, len(x)):
            slope2.append((y[j] - y[i])/(x[j] - x[i]))

    slope2.sort()
    slope3 = np.median(slope2)
    inter = []

    for i in range(len(y)):
        for j in range(i+1, len(x)):
            inter.append(y[i] - slope3*x[i])

    inter1 = np.median(inter)
    y3 = slope3 * x + inter1
    y4 = slope * x + intercept
    print (k+1,'w/outlier',-slope,'[m/y]','w/o outlier',-slope3)

#plots with and without outliers
A = [5,7,10,15]
for k in A:
    x = np.linspace(0,29,30)
    y = spos[k]
    slope, intercept, r_value, p_value, sig_a = linregress(x,y)
    slope2 = []
    for i in range(len(y)):
        for j in range(i+1, len(x)):
            slope2.append((y[j] - y[i])/(x[j] - x[i]))

    plt.figure(figsize=(6, 4))
    plt.plot(x,y,'ko');

    slope2.sort()
    slope3 = np.median(slope2)
    inter = []

    for i in range(len(y)):
        for j in range(i+1, len(x)):
            inter.append(y[i] - slope3*x[i])

    inter1 = np.median(inter)
    y3 = slope3 * x + inter1
    y4 = slope * x + intercept
    plt.plot(x,y4,label='w/ outlier');
    plt.plot(x,y3,label='w/o outlier');
    plt.xlabel('Years, starting from 1984')
    plt.ylabel('Distance relative of trancept')
    plt.legend(loc='best')
    plt.title(k+1)
```

Appendix 5

```
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
import json
import datetime

fid = open('Ngapali_Transects_rates.json')
data = json.load(fid)
fid.close()
tref = datetime.datetime(1987,12,28,3,36,14) #Reference date

transect = [11]#,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20]
for i in transect:
    tnum = i #Transect nummer
    properties = data['features'][tnum]['properties']
    t = np.array([tref + datetime.timedelta(days=d) for d in properties['dt']])

    dist = []
    for j in range(len(properties['distances'])):
        dist.append(properties['distances'][j]-properties['distances'][0])
    tsync = []
    for ti in t:
        tsync.append(ti.replace(year=2000)) #Chosen arbitrary

    fig,ax = plt.subplots(figsize=(20,5))
    ax.plot(tsync,dist,'ko')
    plt.title(i)#'All markers, sorted by month for transect 11');
    plt.xlabel('Months, year 2000 is chosen arbitrary')
    plt.ylabel('Changes in meter')

    jan = np.mean(dist[0:40]) #Getting the avergae for markers per month
    feb = np.mean(dist[40:80])#Found by hand
    mar = np.mean(dist[80:116])
    apr = np.mean(dist[116:160])
    may = np.mean(dist[160:184])
    jun = np.mean(dist[184:194])
    jul = np.mean(dist[194:195])
    aug = np.mean(dist[195:205])
    sep = np.mean(dist[205:226])
    okt = np.mean(dist[226:255])
    nov = np.mean(dist[255:285])
    dec = np.mean(dist[285:311])

    y = [jan,feb,mar,apr,may,jun,jul,aug,sep,okt,nov,dec]
    x = np.linspace(1,12,12)

    fig,ax = plt.subplots(figsize=(20,5))
    ax.plot(x,y,'ro')
    ax.plot(x,y,'b')
    plt.title(i)#'Averaged markers, sorted by month for transect 11');
    plt.xlabel('Months')
    plt.ylabel('Changes in meter')
```