CYPRUS UNIVERISTY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

Master Thesis

ESTIMATION OF CORROSION VULNERABILITY USING GIS

Constantina Anastasiou

Limassol 2015

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING AND GEOMATICS

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Limassol 2015

APPROVAL FORM

Master thesis

Finding corrosion due to chlorides using GIS tools

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Cyprus University of Technology

September, 2015

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Σημειώνεται ότι η εν λόγω διπλωματική εργασία εντάσσεται μέσα στις ερευνητικές δραστηριότητες της Δρ. Έλια Α. Ταντελέ στο οποίο συμμετέχει η ερευνητική ομάδα infrastruc$_t$ure^2 του Τμήματος ΠΟΜΗΓΕ του ΤΕΠΑΚ.

I would like to thank my advisor professor Dr. Elia Tantele, for the opportunity she gave me to work on this study. Also, I would like to thank all my professors for the knowledge they gave me the last five years.

ΠΕΡΙΛΗΨΗ

Ο στόχος αυτής της διατριβής, είναι να παραχθούν χάρτες επικινδυνότητας διάβρωσης χρησιμοποιώντας Γεωγραφικά Συστήματα Πληροφοριών (ΓΣΠ). Κατ αρχήν, θα παρουσιαστεί η θεωρία: της διάβρωσης, της διάβρωσης που προκαλείται λόγω των χλωριόντων, κάποιων εργαστηρίων ελέγχου διάβρωσης και των ΓΣΠ. Στη συνέχεια, θα αναλυθούν οι παράγοντες που συμβάλλουν στην έναρξη της διάβρωσης σε κατασκευές από οπλισμένο σκυρόδεμα. Ακολούθως, θα γίνει περαιτέρω ανάλυση των σημαντικότερων παραγόντων που λαμβάνουν μέρος στην δημιουργία διάβρωσης, με σκοπό τη δημιουργία μοντέλου που να δείχνει την επικινδυνότητα μιας κατασκευής ή ενός συνόλου κατασκευών ως προς την διάβρωση. Στη συνέχεια το μοντέλο θα εισαχθεί σε ένα πρόγραμμα ΓΣΠ για να γίνει η δημιουργία των χαρτών επικινδυνότητας. Η περιοχή εφαρμογής αυτού του μοντέλου είναι η Λεμεσός. Παρόλα αυτά, με την δημιουργία αυτής της εξίσωσης θα μπορεί ένας μηχανικός να την εφαρμόσει σε οποιαδήποτε περιοχή θέλει και έτσι θα γνωρίζει από πριν τον κίνδυνο που διατρέχει η κατασκευή του όσον αφορά την δημιουργία διάβρωσης.

Λέξεις κλειδιά: διάβρωση, χλωριόντα, Γεωγραφικά Συστήματα Πληροφοριών (ΓΣΠ), μαθηματικό μοντέλο, χάρτης επικινδυνότητας Λεμεσού.

ABSTRACT

The aim of this master thesis is to produce corrosion risk maps using GIS tools. Firstly the corrosion theory, the theory of the corrosion due to chlorides, the theory of the lab tests and the theory of GIS tools is presented. Then, the factors which are contributed to the initiation of the corrosion in the reinforced concrete structures are analyzed. Next, will be further analysis of the most important factors which contribute to the initiation of corrosion, to create a model showing the risks of a structure or an area with respect of corrosion. Subsequently, the corrosion risk model will be inserted in a GIS program in order to create the corrosion risk maps. The examine area is Limassol city. Although, this model could be applied in every area the engineer wants, after some changes that should be done in the model. By doing this, the engineer will know the corrosion risk of the structure.

Keywords: corrosion, chlorides, Geographical Information System (GIS), mathematical model, Limassol risk map.

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NOTATIONS

NDT:	Non-Destructive Tests
w/c:	Water to cement ratio
LPR:	Linear Polarization Resistance

INTRODUCTION

In Cyprus, most of the buildings are made of reinforced concrete. The main reason that most buildings are made of reinforced concrete is the concrete industry that exists in Cyprus. Due to the existence of the concrete industry, buildings made of reinforced concrete are cheaper than buildings made of other materials such as steel. However, these past few years' people started building steel buildings. It is worth noting that Cyprus is surrounded by sea, and also there are many buildings on the coastline. Also, in the past, builders used to take aggregates from the sea without washing and cleaning the salts from them. Then they used to mix these aggregates with concrete for the construction of their buildings. Considering the above facts we conclude that some buildings in Cyprus may be facing corrosion problems. When the reinforcement in the concrete corrodes, over time it will lose its strength until it reaches its yield strength. The result is that the tension forces will be received by the concrete, not by the steel reinforcement. The concrete has low tensile strength so if it receives more tension forces that it can stand, cracks form on the surface of the concrete beam or column. In some cases delamination (Figure 1) and spalling (Figure 2) of the concrete can also be observed. However, if reinforced concrete structures are designed and constructed as dictated by National standards and guidelines, then the structure will be durable.

Figure 1: Delamination of concrete ("Funds needed for Black Hawk Statue restorationThe Rock River Times | The Rock River Times" n.d.)

Figure 2: Spalling of the concrete ("Spalling of Concrete - Causes, Prevention & Repair - CivilDigital - Anand Paul" n.d.)

1 Literature Review

1.1 Corrosion

Corrosion is an electrochemical process (Figure 3), which is similar to a battery's operation. The elements that must be present for the corrosion to start are:

1) Anode side: is the side that corrosion starts. The anodic reaction is the following reaction

$$F_e \rightarrow F_e^{2+} + 2e^- \quad (1)$$

2) Cathode side: is the side that there is no corrosion but the corrosion from the anode side, flows to the cathode sit e. The reduction reaction at the cathode side is the following

$$1/_2\, O_2 + H_2O + 2e^- \rightarrow 2OH^- \quad (2)$$

The above reactions have to occur at the same rate. The result of combining the two reactions is:

$$F_e + 1/_2\, O_2 + H_2O \rightarrow F_e(OH)_2 \quad (3)$$

3) Electrolyte: for this situation is the concrete
4) Metallic path: this path connects the anode side with the cathode side and leaves the corrosion from the anode side to flow to the cathode side

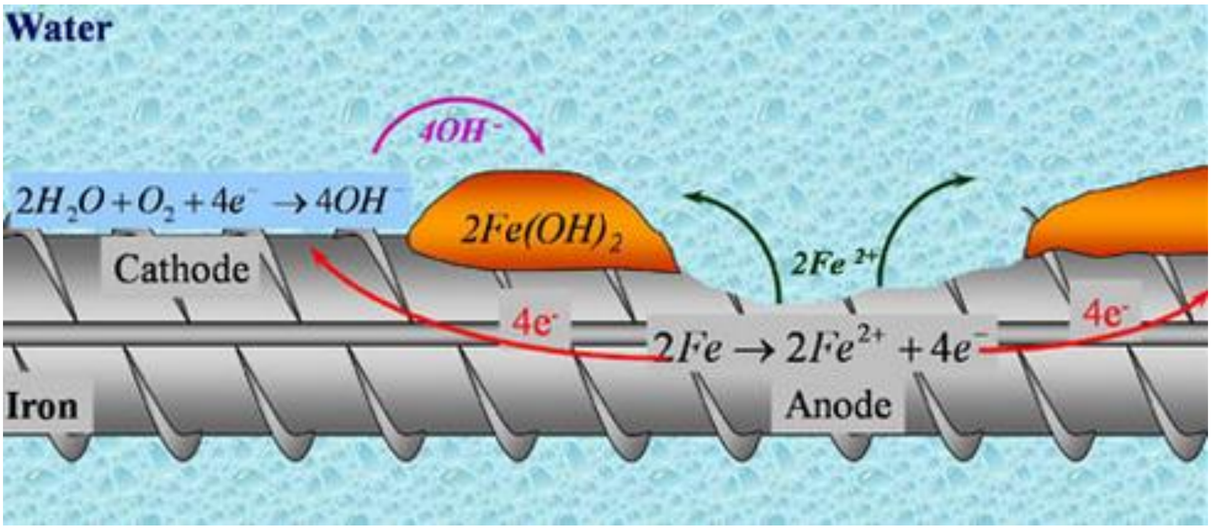


Figure 3: Corrosion Process ("Corrosion of Embedded Materials" n.d.)

The two major factors that cause corrosion are: the chlorides and the carbon dioxide (CO_2). Corrosion process splits in two stages. The first stage is the penetration of the chloride or the carbon dioxide into the concrete and if oxygen is available, the corrosion initiates. In the second stage, corrosion is spread in the concrete and then causes damage to the concrete (Figure 4). Consequently due to its low tensile strength cracks are developed near the reinforced steel.

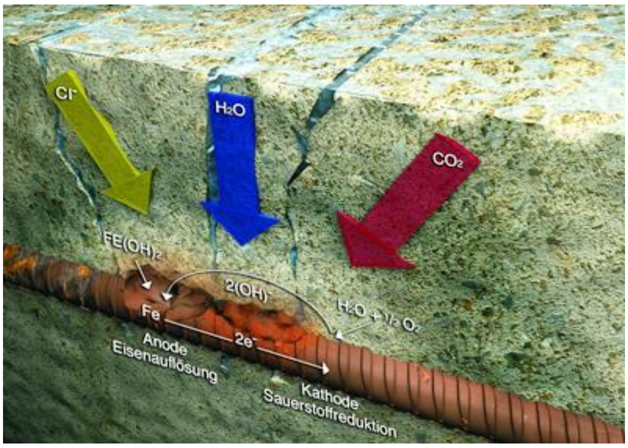


Figure 4: Corrosion process (“Building Facades – Spalling Concrete?” n.d.)

Concrete’s pH is about 12 to 13 when it is healthy. This means that the environment in the concrete surrounding the construction steel is alkaline. At this situation, a protective layer is formed round the construction steel (Figure 5). The protective layer does not stop the corrosion from penetrating the concrete but it reduces the corrosion rate. The corrosion rate in reinforced concrete per year is about 0.1μm when the protective layer exists (“Corrosion of Embedded Materials” n.d.). If this protective layer has not been created the corrosion rate of the construction steel in the reinforced concrete is more than 1000 times higher. The protective layer surrounding the construction steel could be destroyed if the environment of the concrete changes from alkaline to neutral or acidic.

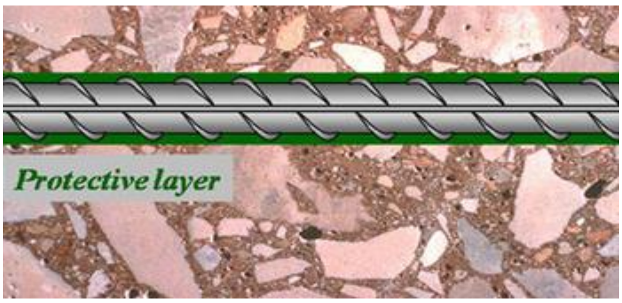


Figure 5:The protective layer (“Corrosion of Embedded Materials” n.d.)

The main problem that corrosion causes is the decrease of the structure's service life. The regular structures such as houses are designed for 50 years of service life and the other structures such as bridges are designed for 100 years of service life. If one structure is not designed as dictated by the National standards then the structure may develop corrosion. Corrosion may cause cracks to the concrete. The reason is that steel loses its tensile strength so concrete has to receive the tensile forces. Although concrete has low tensile strength and it cannot afford high tensile forces so it cracks (Figure 7). The correlation between the degree of corrosion and the service life is shown below (Figure 6).

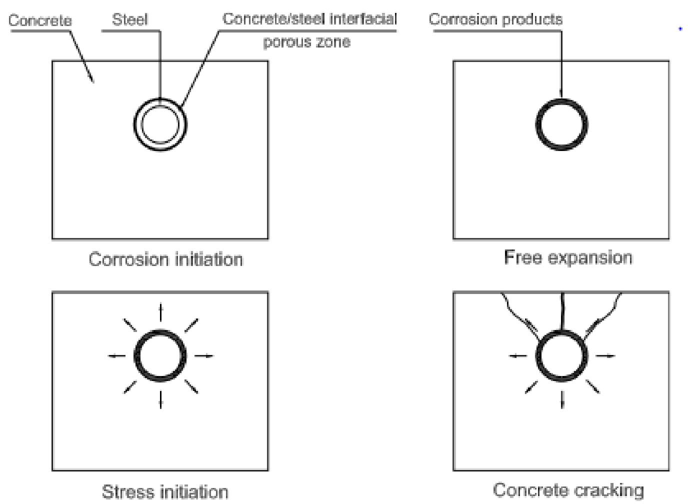


Figure 7: Cracking process (El Maaddawy and Soudki 2007)

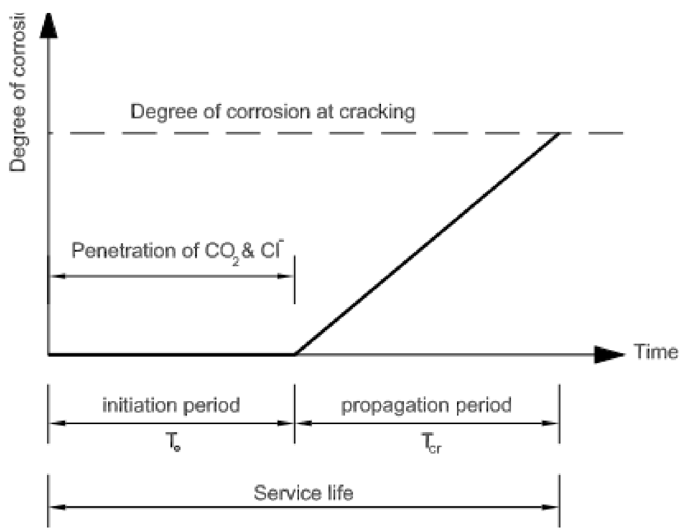


Figure 6:Service life of corroded structures (El Maaddawy and Soudki 2007)

1.1.1 Carbonation

Carbonation in concrete occurs when there is carbon dioxide present in the air (Figure 9) (Figure 10). Most of the time, carbon dioxide is derived from industrial areas or from the cars. Therefore, structures that are near industries or roads with high traffic have high probability of suffering from corrosion due to carbonation.

A concrete's paste pH is more than 12.5 because it contains 25- 50g of calcium hydroxide ($Ca(OH)_2$) per 100g. When the carbon dioxide penetrates into the concrete, the pH of the environment surrounding the construction steel is reduced to below 7 resulting in the initiation of corrosion (Fig. 8) ("Carbonation of concrete" n.d.). Sometime concrete may suffer from bi-carbonation, which can increase the porosity of concrete and make it soft. This can happen if the water to cement ratio is high. If the concrete suffers from bi-carbonation then

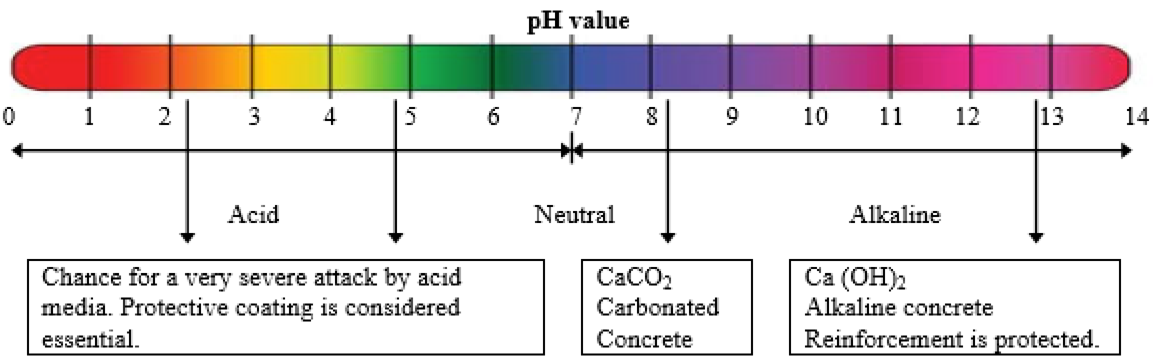


Figure 8: pH values of concrete due to carbonation ("Kamta Corporation - Goa , INDIA" n.d.)

Carbonation of concrete follows the chemical reaction:

$$\mathrm{Ca(OH)_2} + CO_2 \rightarrow \mathrm{Ca}CO_3 + H_2O \quad (4)$$

This reaction's result is the reduction of pH level of the concrete and consequently the destruction of the construction steel protective layer. Nevertheless, carbonation penetrates concrete about 1mm each year. The quantity and rate of carbonation depends on:

- The permeability of concrete. When the concrete is permeable it is more possible for carbonation in concrete to expand

- The incorrect or shorter than recommended curing period can be a factor for the increase of carbonation
- The water to cement ratio when is relatively high could increase carbonation in the concrete
- When the concrete was mixed without using enough cement in the mixture

Relative humidity of concrete affects carbonation significantly when is more than 25 percent. Carbonation initiates when relative humidity of concrete is between 50 to 75 percent. However, when relative humidity exceeds 75 percent carbonation is prevented due to the filled porous that don't allow CO_2 to penetrate. Also carbonation reduces the amount of chloride ions, which is necessary for corrosion to initiate. The results of carbonation can be the deterioration of the structure (Figure 11).

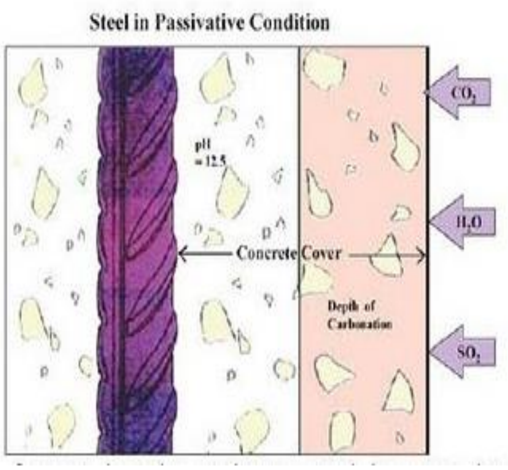


Figure 9:Carbonation process

("Concrete Carbonation | Free and Handy"

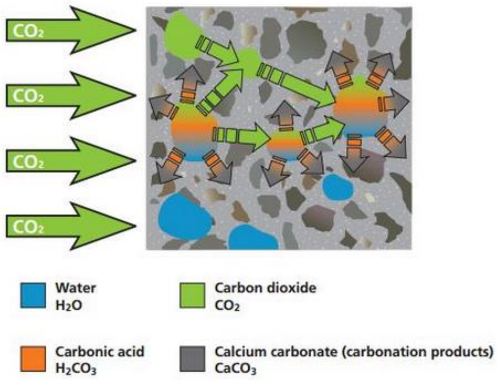


Figure 10: Carbonation process

("Carbonation of concrete" n.d.)

Figure 11: Example of carbonation

("Corrosion of Embedded Materials" n.d.)

1.1.2 Chloride Corrosion

Chloride ions can be found in the atmosphere due to seawater or deicing salts or in admixtures which are used to accelerate curing and can cause corrosion of steel reinforcement. Chloride ions are the primary cause of steel reinforcement corrosion. When chloride ions penetrate into reinforced concrete and if oxygen and moisture are available, the corrosion process will start. Buildings near coastlines are more possible to suffer from corrosion due to the seawater which contains chloride ions and due to the high percentage of relative humidity that exists in coastal areas (Saha Jayanta n.d.) (Figure 12). Chlorides can reach buildings that are near the seawater through the air or structures that have direct contact with seawater.

Figure 12: Corrosion due chlorides in seawater (“New methodology predicts onset, progression of corrosion of reinforced concrete” n.d.)

However the primary factors of corrosion initiation are the existence of oxygen, the electrical resistivity and humidity of the concrete, the pH and the temperature. Only if the above factors are available and chloride ions are available too, corrosion will initiate. Also, corrosion initiation depends on the chloride concentration above the binding capacity of concrete and the time that chlorides are in contact with the concrete. Chloride threshold level is the chloride concentration that leads to the corrosion-induced deterioration. The chloride threshold level is affected by some factors such as: pH, water to cement ratio, the type of cement, pore and capillary structure, curing period and exposure temperature. According to the American Concrete Institute, which recommends some chloride limits in concrete, its possible to follow some general guidelines to prevent corrosion. In reinforced concrete in dry conditions the chloride ions limit is 0,20%, in reinforced concrete in wet conditions its 0,10%. Considering these limits, the conclusion is that the required chlorides ions in concrete to initiate corrosion are low. Some studies have shown that buildings exposed to chloride ions with threshold concentration 0.026%, was enough to initiate corrosion. When chloride ions enter concrete, they do not diffuse in the same direction (Figure 13). Areas with high chloride concentrations start to corrode, while the areas without high chloride concentrations remain passive.(Daily n.d.)

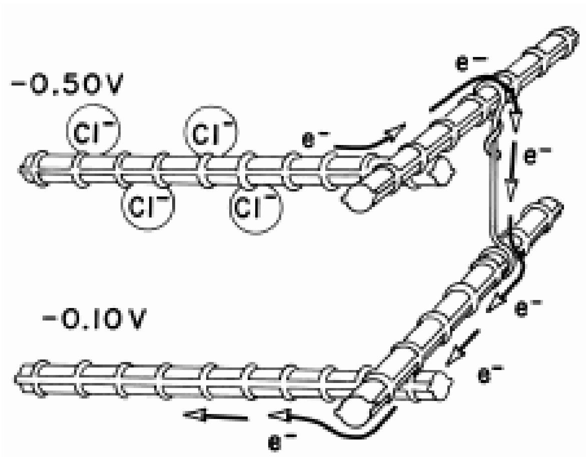


Figure 13: How chloride diffuse in concrete steel

(Daily n.d.)

When chloride corrosion starts developing, reinforced steel loses its strength with the result being tensile forces to develop in the concrete. Cracks can develop near the reinforced steel and in time, delamination occur (Figure 14) (Figure 15). Steel is exposed to even more chlorides and the corrosion process accelerates.

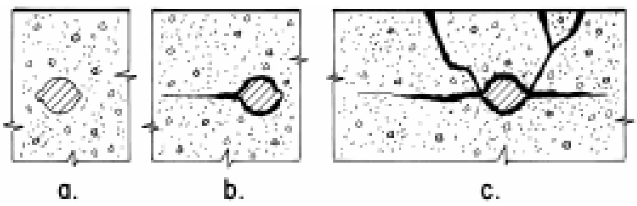


Figure 14: Cracks due to chloride corrosion

(Daily n.d.)

In addition, calcium chloride is used to shorten the setting time of concrete. By adding calcium chloride, Portland cement may lose its strength and chloride may attack the steel reinforcement.

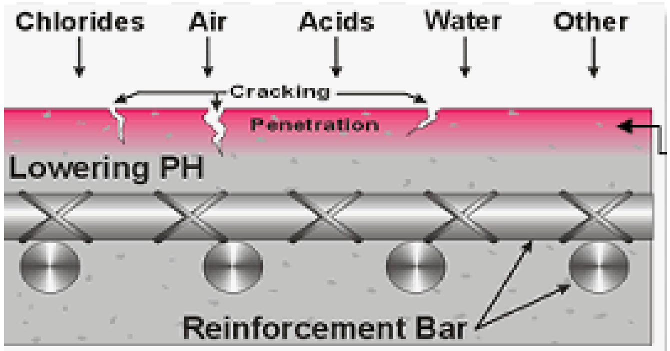


Figure 15: Cracks in concrete(“Cathodic Protection Technology | Engineered Concrete Corrosion Repair and Prevention” n.d.)

1.2 GIS

GIS or Geographic information system makes use of the technology and computer systems in order to gather and store information regarding the geography of a place in conjunction with other information. By making information you need relative to geographic information it is possible then to manipulate and analyze the data, and use it to reach certain conclusions.

1.2.1 How GIS can help finding the corrosion

Corrosion is a procedure that causes serious damage to concrete steel reinforcement buildings. However, it is impossible to see that the corrosion procedure has started with the naked eye. To be sure if in a building the corrosion procedure has started, you have to make specialized tests. It is evident that it’s very difficult to check all the buildings of a town one by one to verify whether they suffer from corrosion.

For the above reason, we must find other methods to check if a structure has corrosion problems. GIS could be a useful tool to predict the areas that are more possible to suffer from corrosion. To do this, you have to find a map of the under study area at first.

Then you have to learn the corrosion theory and the factors which cause corrosion. After this you must combine the knowledge you gain with the map. This can be achieved with GIS. The input in GIS is the descriptive data and GIS will combine that with spatial data by using the map. GIS uses some ways to implement this, by areas or by grids.

1.2.2 Grid system in GIS

Grid system is a method that can be used in GIS. After you find a representative map of the under study area, you need to divide the map or an area of the map in equal area cells. Then in each cell you must define coefficients that will represent the probability of the corrosion existence. The coefficients are integer numbers. This can be made by making a table with the coefficients, it is called value attribute table (VAT) (Figure 16) (Figure 17). If you have a specific examine area, you have to check the cell or the cells which include the examine area and then you have to visit the area and choose a building to make the test, to verify the GIS results.(Desktop 2008)

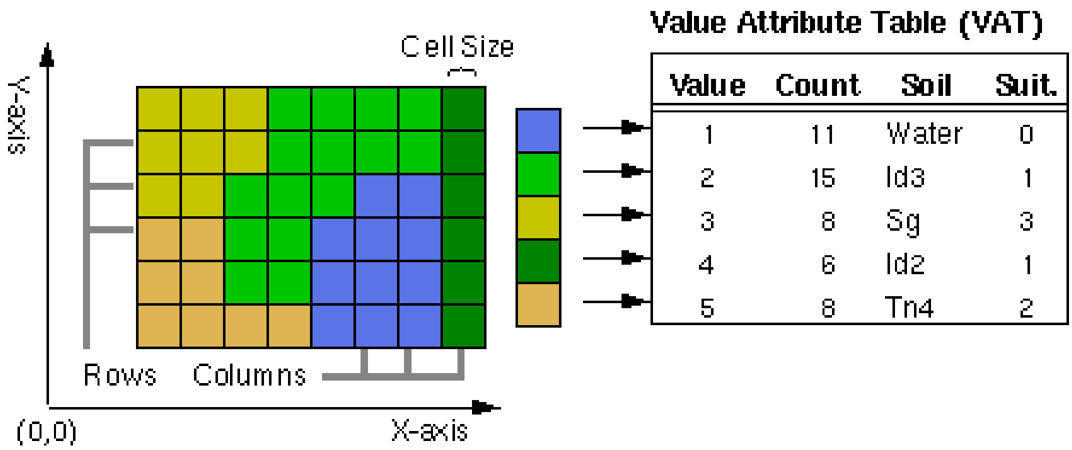


Figure 16: Example of grid method (“ArcGIS Help 10.1 - What are grids and graticules?” n.d.)

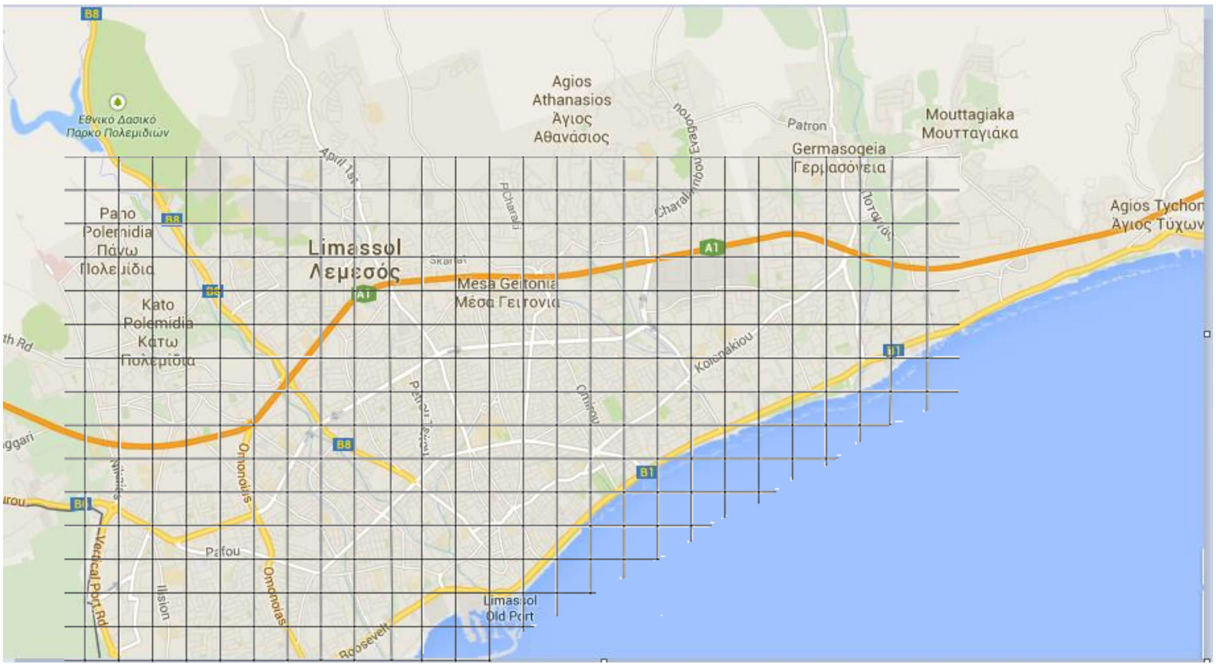


Figure 17: Grid in Limassol map

2 Laboratory tests for corrosion

To identify corrosion in a reinforced concrete structure there are three things a civil engineer can do, which are: visual inspection, destructive tests and non-destructive tests. At first there is always a visual inspection. By doing this, the civil engineer decides whether to proceed to further tests or if it is not necessary or cost effective to do so. If the structure is in good condition, then further tests can be avoided unless there are other reasons or indications that they are needed. But if the structure needs to be further examined, there are two possible options for the engineer, tests that are non-destructive or tests that are destructive.

Non-destructive tests have some advantages which are:

- On spot examination. These tests can be done very quickly because of the fact that you do not need a laboratory to take the test. So, you take a decision automatically
- Non-destruction of the structure's members. By doing destructive tests means that core sampling is needed. Non-destructive tests do not need core sampling so there is no need of repair of the structure at the end of the test. If the structure do not need a repair, you save money
- Quick disclosure of the results. Results are exported by the end of the test
- Results can be qualitative and quantitative
- Graphs can be easily read

Also there are some disadvantages about non-destructive tests that are:

- Lack of standards due to the fact that non-destructive tests are relatively new. To make standards for a test you need to use a test for a long time and be sure about the results in order to write the standards
- If a structure consists of more than one material the results are not accurate
- Only expertise staff should use non-destructive tests

Destructive tests were invented before non-destructive tests. The reason is that non-destructive tests use much newer technology in their methods when compared to the technology used for the destructive tests. These tests are called destructive due to the fact that to implement these tests you have to get one or more core samplings from the structure. So the structure will then have to be rectified. It is not needed for the staff to be specialized or knowledgeable since for this type of tests there are many standards due to the many years of being used in civil engineering. After you get the representative cores sampling (3 or more cores from each floor are recommended) then you have to follow the steps of the specific test to obtain the results you need. To find out if the structure has corrosion and how deep is the corrosion you compare the test's results with the values given within the standards used in your country or area. The tables or the graphs which are included in the standards will help you understand if the structure has corrosion and what type of corrosion (chloride corrosion or carbonation). When a civil engineer wants to check the condition of a structure, one of the tests that have to take is corrosion test. The parameters that are usually examined are: pH, CL content and SO3 content. Depending on the standards used in the area of the structure, results can be classified accordingly with the use of certain limits that show if the structure has high, low or moderate content of CL and SO3. The pH penetration of the core is measured to check if the structure's steel suffers from carbon dioxide corrosion.

2.1 Non-destructive tests

As mentioned before, NDT are the tests that do not require coring. There are many NDT, which examine several different problems that may be presented in a structure. To check corrosion in a structure, the NDT that is usually used is called half-cell potential test.

2.1.1 Half-cell potential

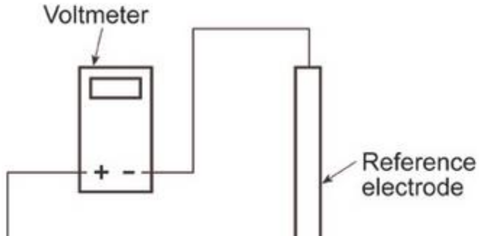
Half-cell potential test is based on the corrosion process. This process is an electro-chemical process that is simple, rapid and cheap method for ND tests. To find if there is corrosion, half-cell potential of the structure is being measured (Nakamura et al. 2008). When the potential is high in negative values, then the structure has a high corrosion risk. The steps that should be followed are:

- The cover of the reinforced steel bar should be counted by using a covermeter (Figure 18) ("Half cell potential" n.d.)

Figure 18: Covermeter(“24/0054-h Covermeter” n.d.)

- A voltmeter and a reference electrode which consists of copper (Figure 19, Figure 20)
- The reinforced steel must be electrically continuous in the place you apply the test
- An electrical connection is placed on the reinforced steel which it is connected with the voltmeter (positive side of the voltmeter)
- The reference electrode is placed on the concrete and connected with the voltmeter (negative side of the voltmeter)
- Readings are taken in a grid of points

Figure 19: Equipment of the Half-cell potential test (“Q-see man inter’l - Half-Cell 2000” n.d.)



The half-cell potential results depend on the (Workshop 2012):

- Cover depth of the concrete
- Resistivity of the concrete
- Real corrosion potential of the structural steel
- Presence of oxygen
- Moisture
- Chloride content
- Temperature
- Carbonation
- Potential ranges

According to the standards, you have to examine the table below to find the percentage chance of active corrosion (Table 1). By implementing half-cell potential test, you know the half-cell potential in mV. Depending on the value of the half-cell potential you now know the chance of active corrosion in the structure.

Half cell potential (mV) reading	Percentage chance of active corrosion
< -350	90%
-200 to –350	50%

2.2 Destructive tests for corrosion

Destructive tests are called this way because you need to take core samples from the examined structure in order to make the necessary tests. Some of the advantages of using the destructive methods to conduct tests are ("Destructive testing - examples and definition of destructive testing" n.d.):

- You can see the materials that consist the structure
- You can find many standards related to destructive testing
- Equipment used in destructive tests is cheaper

However destructive tests have some disadvantages which are:

- They are time-consuming because the preparation and the procedure take some time
- The results are not directly comparable with the results you can take with the non-destructive tests
- If you take samples at different times then these samples are not comparable

Below are presented some of the standards for various corrosion tests.

2.2.1 ASTM C25-06 "Standard Test Methods for Chemical Analysis of Limestone, Quicklime and Hydrated Lime"

This test is a chemical test, and the aim is to specify the chemical components of limestone, quicklime and hydrated lime. Also this test is done to see if a structure has corrosion due to carbon dioxide. The reason why limestone, quicklime and hydrates lime must been specified is that these materials tend to absorb carbon dioxide from the air. ("ASTM C25 - 11e1 Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime" n.d.)

Also there are many other standards that can be used to identify corrosion due to carbon dioxide, but C25 is the oldest laboratory test. However this test is time consuming and needs expertise from someone in the staff to supervise the procedure (Morner n.d.). At the end of the test, the results show the pH of the sample. As we know a high value of pH shows that the sample is in good condition and there is no corrosion due to carbon dioxide. Presence of carbon dioxide tends to reduce pH levels.

2.2.2 NordTest Method NT. Build 208

This test aims to designate the chloride content of the samples. The procedure is shown in the following steps (Content and Volhard 1996):

- Using a core drilling machine you get the sample from the examined structure. Concrete sample should be weigh more than 1kg
- The concrete core sample that has a hard composition is put in a grinder and turned into dust.
- The glass bottle that is used should be weighted in order to know how to much weight to subtract from each weighting
- 5g of the reinforced concrete dust is added in the glass bottle
- The glass bottle with the sample is put in the oven. The bottle is weighted at certain intervals until the weight stops changing. That means there is no water left in the sample
- 20ml of distilled water is added
- The bottle is then shaken in order to separate the particles
- 10ml of concentrated nitric acid is added in the bottle and then the bottle is shaken
- 50ml of hot distilled water is added and then the sample is shaken again
- The bottle should stay immobilized for about 1 hour until it reaches room temperature
- After that the solution is filtered and rinsed with 1% nitric acid two times

- After reaching this state for all the samples you will need for this test, distilled water is added so that all the samples have the same volume
- Silver nitrate solution is added
- 2-3 ml of benzyl alcohol and 1ml of saturated ammonium are added
- The mixture is then shaken
- Afterwards the mixture is titrated
- Now the content of chlorides can be calculated using the formula below

$$\%Cl^{-} = Weight - 3.545\ ((V_1N_1 - V_2N_2) / m) \quad (5)$$

Where:

V_1 =	The added amount of silver nitrate solution in ml
N_1 =	The normality of silver nitrate solution
V_2 =	The added amount of ammonium during the nitration in ml
N_2=	The normality of the ammonium
m =	The weight of the sample in g

The silver solid chloride should go again into solution. So thiocyanate is added but if it is consumed rapidly you must conclude that the results are false. This can be avoided by adding benzyl alcohol.

The results are expressed in a percentage, by weight of the concrete.

2.2.3 Testing for carbonation

One test that helps find carbonation and the depth of carbonation easily and quickly is the test that uses phenolphthalein (Figure 21). Phenolphthalein is a white liquid and it is used as an indicator. It reacts with other materials and when the pH is between 0 and 8.2 it stays colorless but when the pH is between 8.2 and12 the color turns into fuchsia. When the concrete comes to contact with phenolphthalein and the color of the concrete turns into fuchsia then the concrete is healthy. Carbon dioxide tends to reduce pH, so when the concrete stays colorless in the presence of phenolphthalein means that there is carbon dioxide inside the concrete.

The steps for this test are:

- Core sampling is taken using drill
- Each sample is weighed (Figure 22)
- Then each sample is put under pressure until it brakes with the help of machinery (Figure 24)
- After it breaks, it is sprayed with phenolphthalein (Figure 23, Figure 26)

If the concrete gets a fuchsia color we conclude that the sample is healthy and it is not affected from carbonation. If the concrete does not get a fuchsia color or in some places the color is not fuchsia then the concrete is affected from carbon dioxide. Then how deep the carbon dioxide has penetrated must be measured with a specific tool (Figure.26).

Figure 21: Phenolphthalein

Figure 22: Weighing the sample

Figure 24: Devise which exert pressure on each sample until it break

Figure 23: The sample after its contact with phenolphthalein

Figure 26: All the samples at the end of the test

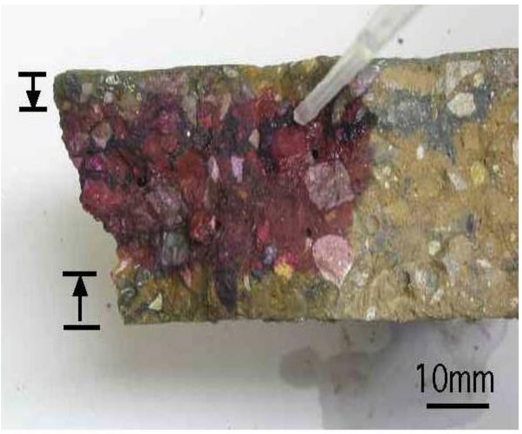


Figure 25: Carbon dioxide penetrated 10mm in a sample (“Carbonation of concrete” n.d.)

3 Mathematical model development

In this chapter of the master thesis, will be the development of the corrosion risk model due to chloride ions. To achieve this, you have to find the factors which affect corrosion. Not all the factors can be included in the model because it is difficult to understand them and quantify them. This model includes only the factors which affect largely corrosion. Also, the factors included in the risk model are selected because there are many researches related with these factors. The data is used to make this model is empirical. It is hard and time consuming to collect all the needed data. So this data is found from other researches.

3.1 Factors affect chloride corrosion

There are many factors affecting corrosion. Each factor has a varying impact in corrosion. To know the influence rate of each factor you need to have experience in this sector. Also, to investigate the influence rate you need to make research in laboratories. Below, are presented the factors which affect corrosion due to chlorides.

3.1.1 Distance from the source

In this master thesis, the main subject is the corrosion due to chloride ions. Chloride ions can be found in the sea and deicing salts which are used in snowy areas to melt the snow from the roads in order to protect the cars from slipping.

In Cyprus the only snowy areas are in Troodos Mountain. However, the snowy period in Troodos is from January to March. Also deicing salts are not used daily but only the days with heavy snowfall. In Troodos these days are relatively rare. Moreover in Troodos there are not many buildings, and these few buildings are constructed away from the main roads. Deicing salts are used in the main roads because of the increased traffic. So, we conclude that structures in Troodos are not affected from corrosion due to chloride ions. But if they are affected the amount of corrosion due to chloride ions it is not important.

Chloride ions can be found in the sea. As well known, Cyprus is an island so it is surrounded from the sea. In this master thesis the examined area is Limassol. Therefore, there are many structures which are constructed in the coast line of

Limassol. According to many researches, areas near the sea are possible to develop corrosion due to chloride ions. As close the structure is from the sea, it is more possible to be affected. In summation, structures near the sea will be considered.

3.1.2 Direction of the airflow

However, not only the distance from the source is a factor which affects structures from corrosion due to chloride ions. The direction of the air flow is a factor which is very important in developing corrosion. Depending, if the air flows towards the structure it is more possible to develop corrosion, or if the air flows against the structure the possibility is less. In some places the airflow it is standard but in some other places it is not. You cannot be sure whether the air flows towards the structure or against the structure because sometime will flow towards the structure but sometime against. So, if a structure is close to the sea but the air flows against it, the probability to develop corrosion is less than the air flows towards the structure. On other hand, if a structure is not so near the coast line but the air flows from the sea towards the structure has also a probability of developing corrosion.

3.1.3 Concrete mixture

The concrete mixture is also affecting the initiation of corrosion. The components of the concrete have to be in the right proportion in order to achieve the right concrete mixture and protect the structure from corrosion initiation. If the mixture has less quantity of cement than the required cement quantity then the structure is going to develop corrosion. When the concrete mixture includes C_3A, alkali and sulfates then corrosion will initiate. C_3A has strong influence in corrosion initiation. Alkali has marginal influence in corrosion initiation and sulfates with chloride ions have moderate effect in corrosion initiation.

3.1.4 Structure's design

Structure design is made by a civil engineer and the implementation of this design is made by the builders. To avoid the penetration of chloride ions and consequently the corrosion initiation structure design must be design properly. The most important thing in reinforced concrete design is the steel cover. The cover of the reinforced steel concrete is the space between the edge of the steel and the edge of the concrete (Figure 27).

To calculate the thickness of the cover you have to follow some steps. These steps take into account the environment surrounding the structure. For example if a structure is going to be in a place near the sea the cover will have a specific thickness in order to protect the steel from the chloride ions. If a designer calculates wrong the thickness of the cover then the possibilities for the corrosion to initiate are high.

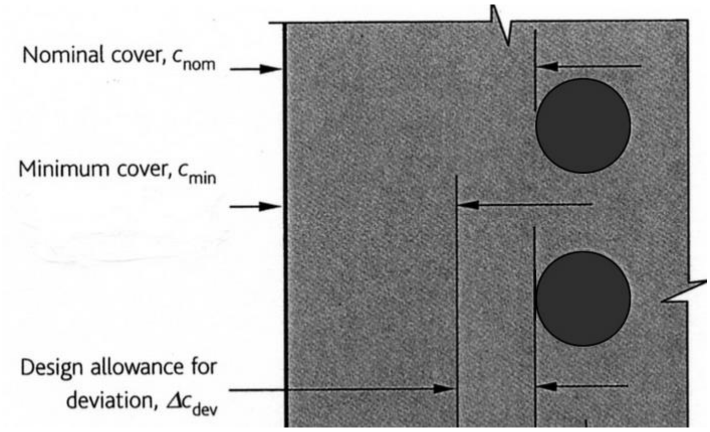


Figure 27: Cover of the concrete ("Cover to reinforcement" n.d.)

Except of the cover of the steel, another important issue is the curing period of the structure. Curing period is the period after the concrete placing. During the concrete period, water must be applied to the concrete surface. Concrete, needs about 1 year in order to develop all its properties. However, the first 28 days are the most critical days for the concrete structures because a high percentage of its properties are developed if curing period is done correctly.

3.1.5 Human factor

The human factor is one of the most important factors in constructions. First of all, the construction of a structure consists of two parts. The one part is the design of the structure and the second part is the construction part. In both parts human factor is involved. Sometime the design part is made correctly but the construction part is not made correctly. If nobody notices the mistake or the mistakes in the construction part then the structure is going to have problems in the future. However, mistakes can happen in the design part. In consequently the mistakes will implement during the construction part. After some years if the structure starts to have some problems because of the wrong construction, it is difficult to find out what caused the problem. For the above reasons you cannot be sure about the probability you should give for the human factor. Furthermore, all the specifications for the construction must be followed so that the structure could not have any problems.

3.1.6 Temperature

The temperature affects the corrosion rate. With the increase of the temperature there is increase of the corrosion rate.("Effect of temperature on Chemistry of Corrosion and Corrosion rates" n.d.)

3.1.7 Humidity

Atmosphere has always a percentage of humidity but when this percentage is increased it could help the initiation of corrosion. In many countries of the world the relative humidity is 75%. When the relative humidity in the atmosphere is above 55% then corrosion initiates ("Cocoon, Inc. : Worst of the Elements" n.d.). In dry climates the possibilities of corrosion initiation are less.

3.1.8 Oxygen

For corrosion to initiate, oxygen must be present. Atmosphere all over the world has the same oxygen level. So oxygen is not an important factor.

3.1.9 Structure's age

The construction materials that were used in the past were different from the materials are used today. In the past, they used to mix the cement with aggregates from the sea or from the rivers to make the concrete. Therefore, aggregates from the sea have chloride ions. If these aggregates were not washed out well the probabilities for these structures to develop corrosion are much more than the newer structures. Newer structures do not have aggregates from the sea.

Also, the areas that were constructed a long time ago have a higher probability of corrosion because they were affected by their environment for a long period of time. However when a structure is old starts to lose its resistance. This makes the structure be at risk from other problems such as corrosion. When a structure gets old, cracks are developed, so chloride ions can penetrate easily in the concrete and corrosion will initiate.

3.1.10 Structure's height

Structures which consist of more than one floors, tend to have different corrosion levels in each floor. The reason is that some of the floors are more exposed to chloride ions than the other floors. For example, if a tall structure is constructed in an area with many structures surrounding, the upper floors are more exposed to chloride ions because they don't have other structures opposite to protect it.

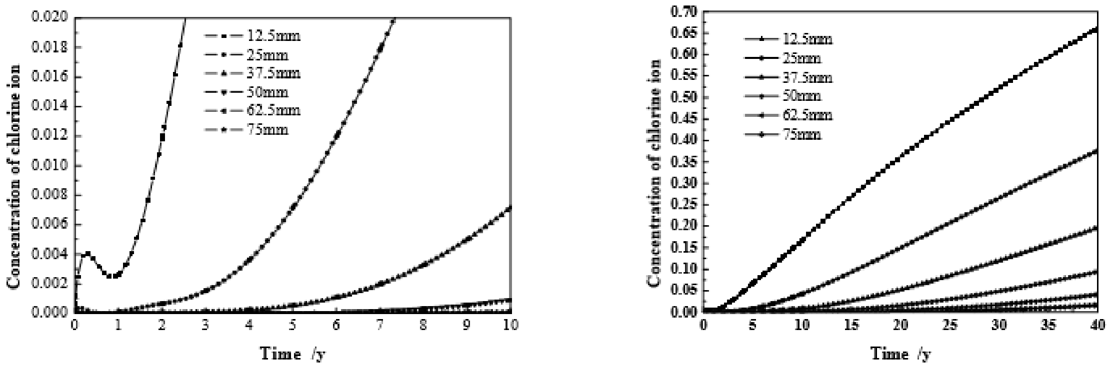
3.2 Factors which can be included in the model

In this part of the master thesis, will be further investigation of the most important factors which are contributed in corrosion initiation. To find the correlation between each factor and the corrosion, a literature review is carried out. Below, are presented the most important factors which are affecting corrosion due to chloride ions and the results of some researches. Also, some of these factors can be combined together in one equation with other factors because they have the same influence degree and also they can be combined.

3.2.1 The effect of exposure years in chloride concentration

In the journal of (Song et al. 2012), is been studied the corrosion in chlorine salt environments. Also, a mathematical model for corrosion diffusion is established which is based on the Flick's Diffusion Law. After the establishment of the model, the model is compared with other models. At the graphs below (Figure 28), we see the chloride concentration of different depths according the years of exposure. In graph (a) the exposure duration is 10 years and in graph (b) is 40 years. In the two cases the form of the graph is different. However, the chloride ion concentration increases by the decrease of the depth. Furthermore, the chloride ion concentration increases in each depth over time. This increase is different in each depth.

At the end of the study, the conclusion is that this model is reliable and can be implemented but further investigation is required.



a. in 10 years b. in 40 years

Figure 28: Concentration of chloride ion of different depth in concrete in different years (Song et al. 2012)

3.2.2 The effect of structure's age, years (duration) of expose in chloride ions, temperature, the cover depth and relative humidity

According to (Shi et al. 2012), the structure's age, the cover depth, the diffusion coefficient , the temperature and the relative humidity can be included in a mathematical model. This mathematical model (6) as shown below calculates the chloride concentration in a distance x at a time t (C(x,t)).

$$C(x,t) = C_o + (C_s - C_o)\left[1 - erf\left(\frac{x}{2\sqrt{f}c_b f_w f_T f_{RH} D_a \cdot t}\right)\right] \quad (6)$$

Where:

$C(x,t)$ = Chloride ion concentration at a distance x from the concrete surface, for exposure time t

C_o = The initial chloride content in the concrete

C_s = Surface chloride content

erf = Error function

f_{cb} = The chloride binding capacity influencing factor

f_w = The crack effect factor

f_T = The temperature influencing factor

f_{RH} = The relative humidity influencing factor

D_a = The chloride diffusion coefficient

The equation of the temperature influencing factor is the following (7)

$$f_T = \exp\left[\frac{E_a}{R}\left(\frac{1}{To + 273} - \frac{1}{T - 273}\right)\right] \qquad (7)$$

Where:

E_a = The activation energy of the chloride diffusion process

R = The gas constant 8.31446 $VCK^{-1}mol^{-1}$

To = The reference temperature

T = The current temperature

The equation of the relative humidity influencing factor is the following (8)

$$f_{RH} = \left[1 + \frac{(1 - RH)^4}{(1 - RH_0)^4}\right]^{-1} \qquad (8)$$

Where:

RH = The current relative humidity

RH_0 = The reference relative humidity

The equations for the chloride diffusion coefficient are the following (9) (10)

When $t \leq t_R$ $$D_a = \frac{D_0}{1-m}\left[\left(1+\frac{t_{CX}}{t}\right)^{1-m} - \left(\frac{t_{CX}}{t}\right)^{1-m}\right] \quad (9)$$

When $t \geq t_R$ $$D_a = D_0\left[1-\frac{t_R}{t}+\frac{t_R}{t}\frac{1}{1-m}\left[\left(1+\frac{t_{CX}}{t_R}\right)^{1-m} - \left(\frac{t_{CX}}{t_R}\right)^{1-m}\right]\right]\left(\frac{t_0}{t_R}\right)^m \quad (10)$$

Where:

D_0 = Diffusion coefficient at reference time t_0

m = Age factor depending on mix proportions

t_{CX} = The age of concrete at the start of exposure

t_R = Time when the chloride diffusion coefficient is assumed to be constant. It is 30 years

The corrosion probability is written as follow (11):

$$P_f = P(Z<0) = \left\{C_{cr} < C_s\left[1-erf\left(\frac{X_{cover}}{2\sqrt{f}c_b f_w f_T f_{RH} D_a \cdot t}\right)\right]\right\} \quad (11)$$

Where:

X_{cover} = The cover depth

C_{cr} = The critical cover depth

The range and the statistics of random variables for sensitivity analysis are shown in the following table (Table 2). Also $f_w = 1.0$, $f_{cb} = 0.85$, t = 28 days.

variables	Base case	Range of mean values	Range of coefficient of variation
D_0 ($10^{-12}m^2/s$)	N(6,0.6)	1,3,6,9,15	5%,10%,20%
X_c (mm)	N(50,5)	40,50,60,70,80	10%,20%,30%
C_s (%)	N(0.4,0.04)	0.2,0.4,0.6,0.8	10%,20%,30%
C_{cr} (%)	N(0.05,0.005)	0.03,0.05,0.08,0.10	10%,20%,30%
m	N(0.4,0.04)	0.2,0.3,0.4,0.5,0.6	10%,20%,30%
RH (%)	70	60,70,75,80	deterministic
T (℃)	20	15,20,25	deterministic

Table 2: Range and the statistics of random variables for sensitivity analysis (Shi et al. 2012)

The graphs below (Figure 29,Figure 30,Figure 31) show the probability of failure including: the age factor, the relative humidity, the diffusion coefficient, the surface chloride content, the temperature and the critical chloride content.

This study concludes that the effects of temperature and relative humidity on corrosion are significant so they have to be included in practical engineering.

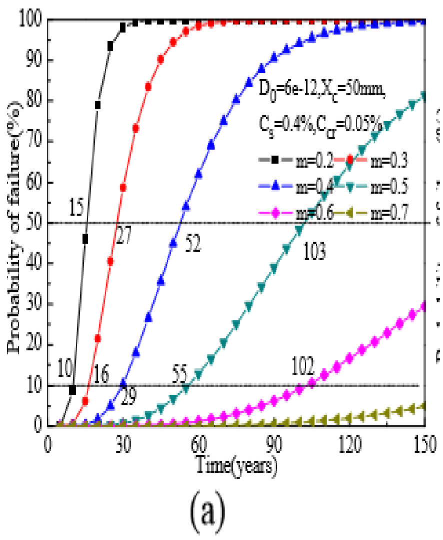


Figure 30: Influence on probability of failure according the average age factor (Shi et al. 2012)

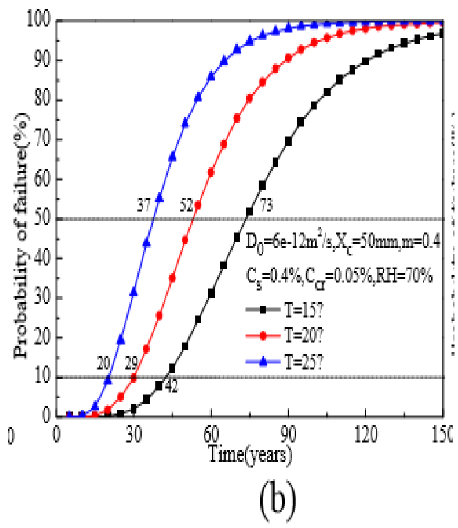


Figure 29: : Influence on probability of failure according the temperature (Shi et al. 2012)

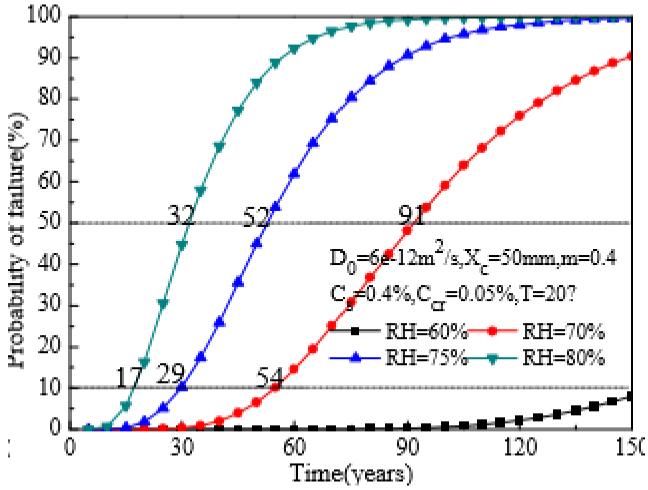


Figure 31: : Influence on probability of failure according the relative humidity (Shi et al. 2012)

3.2.3 The effect of temperature

According to the study (Pour-Ghaz et al. 2009), when the temperature is low, corrosion is insignificant. In this study the range of temperatures are used are from +10˚C to +50˚C. Firstly, the effect of temperature on kinetic parameters has been studied. Secondly, the effect of temperature on concrete properties has been studied. The kinetic parameters of corrosion are: the tafel slopes, the exchange current density and equilibrium potentials. The concrete properties that are mentioned in this study are: the concrete resistivity and the limiting current density. For each parameter, the have been found an equation. The results are taken after numerical experiments which are based on the Laplace's equation. Also, polarization resistance test is used. Below are shown some of the results of this journal. These graphs (Figure 32) are presenting the correlation in between the temperature and the average corrosion rate for different values of concrete cover. In each graph are changing the i_L (limiting current density) and ρ (resistivity). For graph (a): i_L = 0.2 A/m^2, ρ = 5000 Ωm. For graph (b): i_L = 0.008 A/m^2, ρ = 7500 Ωm. For graph (c): i_L = 0.005 A/m^2, ρ = 10000 Ωm. It is apparent from the graphs that with the increase of temperature in all cases there is increase of the average corrosion rate.

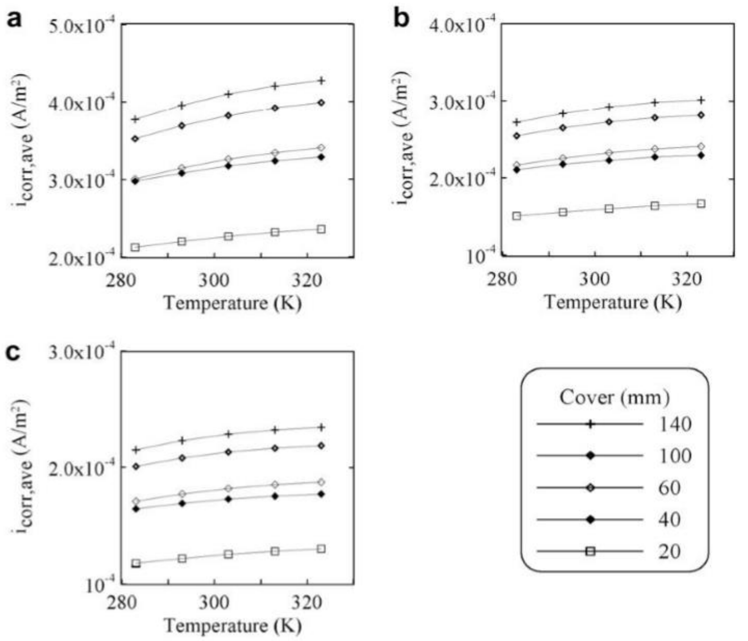


Figure 32: Variation of corrosion rate with temperature for different cover depth (Pour-Ghaz et al. 2009)

In Figure 33 are presented the correlation in between temperature and average corrosion rate. But in this case i_L (limiting current density) has different values and cover thickness is the same (60mm). In graph (a) ρ = 650 Ωm. In graph (b) ρ = 1250 Ωm. In graph (c) ρ = 5000 Ωm. As before, corrosion average rate is increasing by the increase of the temperature.

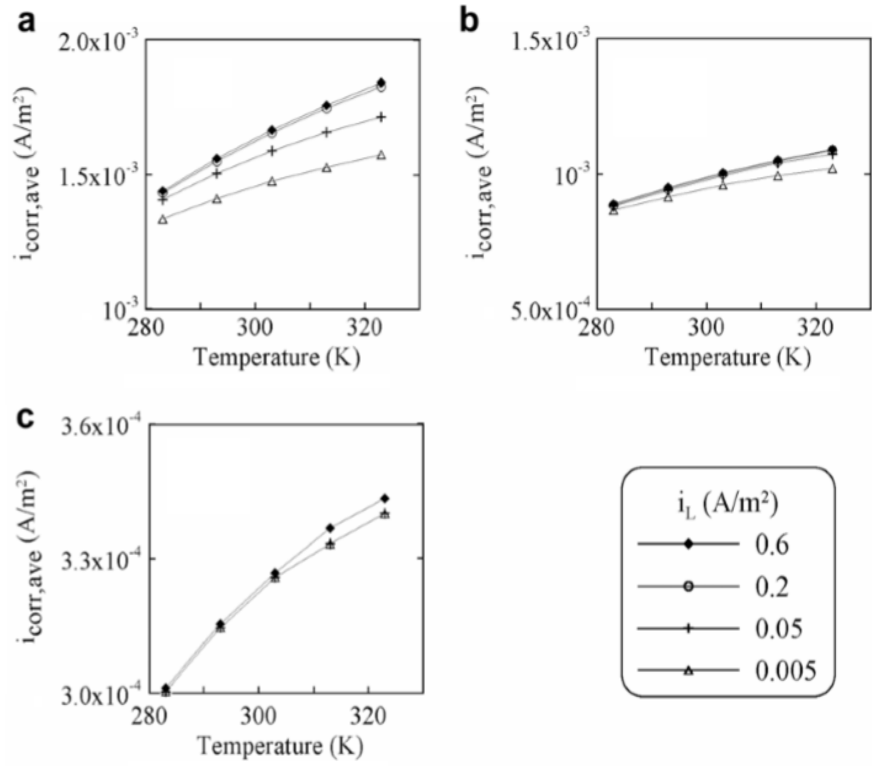


Figure 33: Variation of corrosion rate with temperature for different i_L. Cover depth = 60mm (Pour-Ghaz et al. 2009)

As an outcome from this study is that the average corrosion current density and the maximum corrosion current density are expected to have a similar format. However, the coefficients of the model are different in the two cases. The mathematical model (12) is:

$$\left\langle \begin{matrix} i_{cor,ave} \\ i_{cor,max} \end{matrix} \right\rangle = \frac{1}{\tau\rho^{\gamma}}\left(\eta T d^{\kappa} i_L^{\lambda} + \mu T \nu^{i_\lambda^{\omega}} + \theta(T i_\lambda)^{\theta} + \chi\rho^{\gamma} + \zeta\right) \quad (12)$$

Where:

$i_{corr,ave}$		$i_{corr,max}$	
Constant	Value	Constant	Value
τ	$1.181102362 \times 10^{-3}$	τ	1
η	$1.414736274 \times 10^{-5}$	η	0.32006292
ζ	−0.00121155206	ζ	−53.1228606
κ	0.0847693074	κ	0.00550263686
λ	0.130025167	λ	0.120663606
γ	0.800505851	γ	0.787449933
μ	$1.23199829 \times 10^{-11}$	μ	$-3.73825172 \times 10^{-7}$
θ	−0.000102886027	θ	47.2478753
ϑ	0.475258097	ϑ	0.00712334564
χ	$5.03368481 \times 10^{-7}$	χ	0.003482058
ν	90487	ν	784679.23
ϖ	0.0721605536	ϖ	0.0102616314

Table 3: The constants of equation 11 obtained from the regression analysis (Pour-Ghaz et al. 2009)

The journal concludes in:

1. The corrosion rate is increased with linearly with temperature. And when the concrete resistivity increases, the rate decreases. These two results are when the temperature assumed to affect only the kinetic parameters
2. Corrosion rate can change up to 20% when temperature varies from 283 to 323K
3. When concrete resistivity was not constant and the other parameters were constant, the effect of temperature was the most important. Corrosion rates are increased 6 to 8 times when temperature varies from 283 to 323 K
4. Limiting current density was changing while the other parameters were constant corrosion rates have increased 30%. Again the variation of temperature was from 283 to 323K

3.2.4 The effect of concrete mixture

The aim of the study (Oh et al. 2015), is to find an accurate method to predict the corrosion quantity in reinforced concrete. This method is based on Faraday's Law. The table below (Table 4) shows the cement's characteristics.

Specific Gravity (m^3)	Expansion :Autoclave (%)	Surface Area (cm^2/g)	Size (m)		Setting time (hr : min)		Compressive Strength (kg/cm^2)						
						Max	Mean	Initial	Final	1day	3day	7day	28day
3.144	0.1	3200	100	21	4:20	6:40	90	200	285	375			

Table 4: Cement's characteristic (Oh et al. 2015)

An accelerated steel corrosion test is carried out in order to take the results. The conclusion of this test that can help as understand what affects corrosion initiation is the following: the cement content is a significant factor which influences the corrosion initiation.

3.2.5 The effect of C_3A, alkali and w/c ratio

The aim of the study (Oh et al. 2003), is to determine the threshold chloride concentration. To achieve this, the half-cell potential, the extend of the corroded area of the samples and the chemical composition of pore solutions of concrete has to be measured. The graphs below (Figure 34,Figure 35,Figure 36) show the results from some of the measurements. This study concludes that: 1) the chloride penetration which leads into corrosion initiation is one of the most important aspects in the durability of structures made of reinforced concrete 2) corrosion decreases when water to binder ratio decreases and when mineral admixtures are used 3) when the potential value is -0.25V, corrosion initiates 4) C_3A is one of the most important factors for the corrosion initiation. With the increase of C_3A content, free chloride content is decreased.

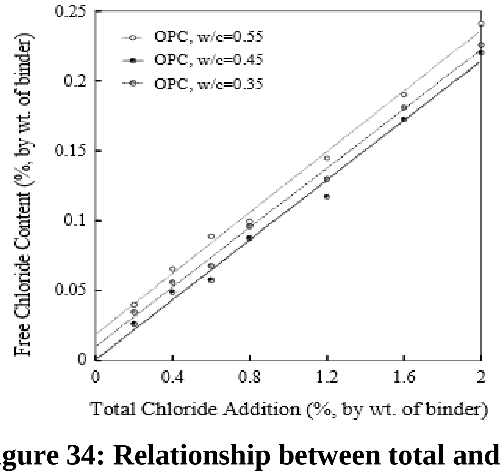


Figure 34: Relationship between total and free chloride content for w/c ratios (Oh et al. 2003)

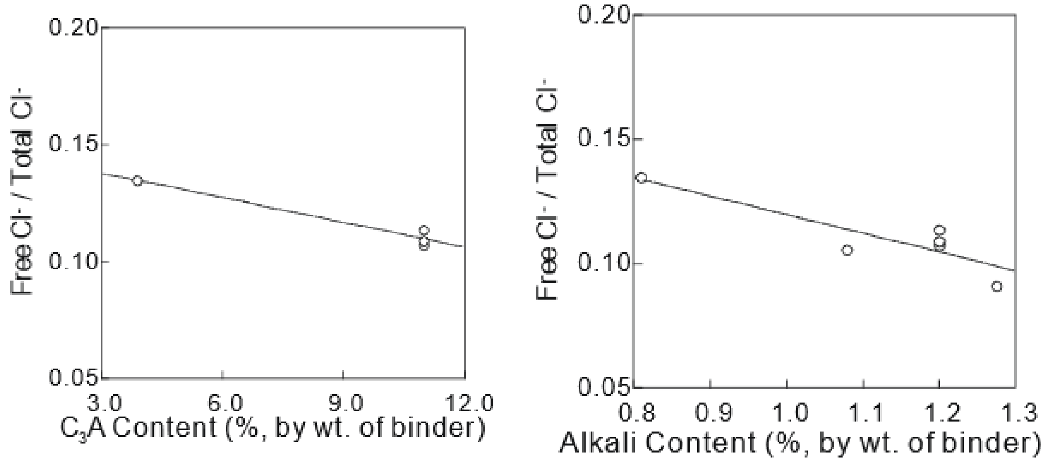


Figure 35: Variation of chloride binding (Oh et al. 2003)

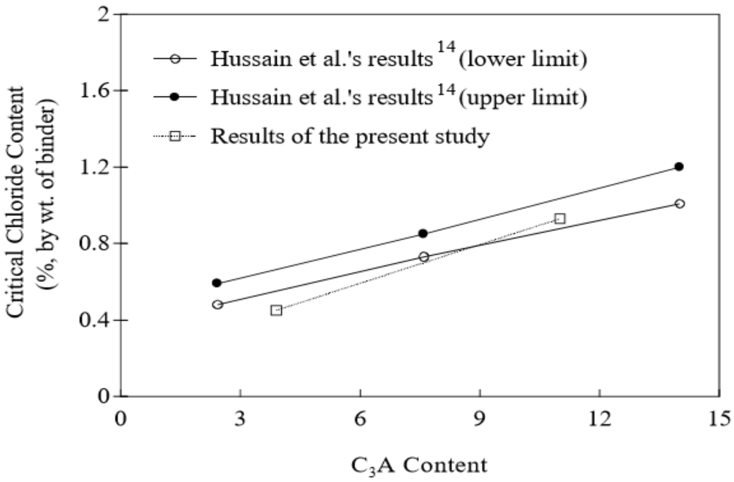


Figure 36:Threshold total chloride contents (Oh et al. 2003)

3.2.6 The effect of inhibitors in natural marine exposure

In the study (Inhibitors 2003) , slabs with 20mm cover and water to cement ratio 0.40 are examined. These slabs were placed near the coastline. Twelve months later some of these slabs were broken. For three years, the slabs were exposed in chlorine ions (from the sea). The main conclusion is that inhibitors were effective for the uncracked concrete slabs. The corrosion rate was reduced, but for the cracked slabs, inhibitors were ineffective.

The table (Table 5) below shows the concrete mixture proportions. The graph below (Figure 37) shows the chloride content after twelve month of exposure.

The concluding remark of this study is that mixing inhibitors with w/c = 0.40 are beneficial.

Mixture number	1	2	3
w/c	0.40	0.40	0.40
Cement (kg/m^3)	505	505	505
Coarse aggregate (kg/m^3)	890	890	890
Fine aggregate (kg/m^3)	610	610	610
Water (kg/m^3)	202	202	202
A/E adm. ml/10 kg of cement	6	5	5
HRWA (l/m^3)	–	–	3
Set retarder ml/100 kg of cement	–	–	125
Corrosion inhibitor (l/m^3)	–	5 l (OCI)	25 l (CNI)

Table 5: Concrete mixture proportions (Inhibitors 2003)

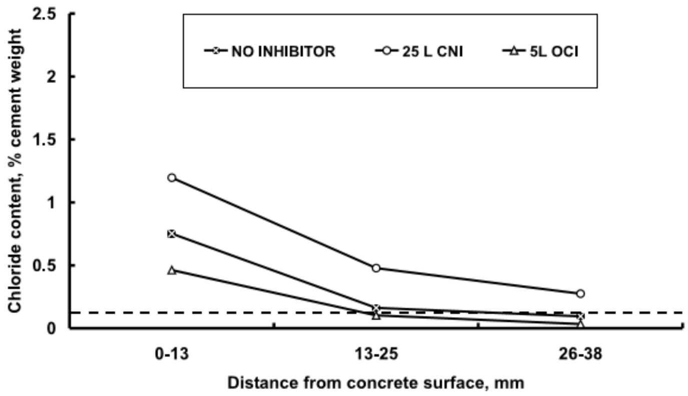


Figure 37: Chloride content for uncracked slabs after 12 months of exposure (Inhibitors 2003)

3.2.7 The effect of humidity

According to (Ababneh et al. 2003), the chloride penetration model in non-saturated concrete is the following (13).

$$\frac{\partial C_t}{\partial t} = div\left[D_{CI} grad\left(C_f\right)\right] + \mu \frac{\partial w}{\partial t} C_f \quad (13)$$

The above equation (12) takes into account the moisture capacity, the relative humidity, the chloride binding capacity and the chloride diffusion coefficient. Then, this equation is been solved numerically. The conclusions of this study are: 1) the model which includes the effect of concrete mix parameters on corrosion and the effect of moisture diffusion on the chloride penetration, agree with the test data 2) the results show that moisture can accelerate the penetration of chloride ions 3) the model can be used for the prediction of the corrosion initiation.

3.2.8 The effect of the environment

In this study (Millard et al. 2001) is used the linear polarization method in order to find the corrosion rate in reinforced concrete structures. LPR measurements are depending from the temperature during the time of sampling and from the wet conditions such as rainfall.

In the following graph (Figure 38) we see the influence of temperature on the corrosion rate. The conclusions for this study are: 1) rainfall has little influence in corrosion rate 2) when temperature increases, corrosion rate is increasing too.

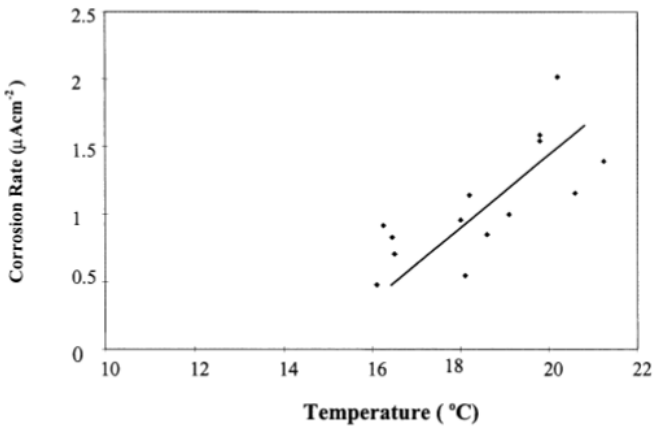


Figure 38: The effect of temperature on corrosion rate (Millard et al. 2001)

3.3 The mathematical model

All the above studies can show us that some of the factors which contributed in the corrosion initiation are being studied. Therefore, the outcomes of these studies are the mathematical models which include some of the factors. In this master thesis the aim is to develop a risk model for corrosion due to chloride ion. The equation below (14) is the general form of the probable risk equation.

$$R = a_i \left(\sum_{j=1}^{n} d_j \frac{a_j N_j}{\sum_{k=1}^{n} a_k N_k} \right) \quad (14)$$

Where:

R = Risk of corrosion initiation

a_i = Coefficient for setting the colors in GIS. It takes values from 0 to 255

d_j = Importance coefficient for the primary factors. It takes values from 0 to 1

a_j = Importance coefficient for the secondary factors. It takes values from 0 to1

N_j = The equation for each factor

It is well noting that there is no other similar equation. The reason is that there is no other study which uses GIS tools in order to find the risk zones of corrosion.

At first step, the factors that can be included together are defining:

N_1 = Concrete design and concrete mixture

N_2 = Distance from the source, relative humidity and airflow

N_3 = Structure's age, years of exposure

N_4 = Temperature

The above conclusions of each study are very useful to develop a risk model up to a point. Although, it is very difficult and time consuming to create a risk model that can be imported in a GIS tool in order to create risk map zones. For that reason, the mathematical model of this master thesis will not have its final form. The final equation can be developed only if many researchers of different specialties (civil engineers, mathematicians etc.) work together for a long period. According to the above mentioned journals, we can now give the coefficients for each factor:

d_1 = 0.4

d_2 = 0.3

d_3 = 0.2

d_4 = 0.1

The equation has evolved as follow (15):

$$R = a_i \left(0.4 \frac{a_1N_1}{a_1N_1+a_2N_2+a_3N_3+a_4N_4} + 0.3 \frac{a_2N_2}{a_1N_1+a_2N_2+a_3N_3+a_4N_4} + 0.2 \frac{a_3N_3}{a_1N_1+a_2N_2+a_3N_3+a_4N_4} + 0.1 \frac{a_4N_4}{a_1N_1+a_2N_2+a_3N_3+a_4N_4}\right) \quad (15)$$

The equations (11) and (12) can be included in the risk model. The values of each coefficient are in the attribute table which is included in the Annex. Although, this equation is an empirical equation, it can't be used anywhere. The following equation is developed only for the purpose of this specific master thesis. It doesn't have any substance, so it cannot be used in reality to create risk map zones. The reason of the above ascertainment is that there is no similar research and equations that can be included in one model.

$$R = a_i \left(0.8 \frac{1\left(C_s\left[1 - erf\left(\frac{X_{cover}}{2\sqrt{f} c_b f_w f_T f_{RH} D_a \cdot t}\right)\right]\right)}{1\left(C_s\left[1 - erf\left(\frac{X_{cover}}{2\sqrt{f} c_b f_w f_T f_{RH} D_a \cdot t}\right)\right]\right) + 1\left(\frac{1}{\tau\rho^{\gamma}}\left(\eta T d^{\kappa} i_L^{\lambda} + \mu T \nu^{i_{\lambda}^{\omega}} + \theta (T i_{\lambda})^{\theta} + \chi \rho^{\gamma} + \zeta\right)\right)} + 0.2 \frac{1\left(\frac{1}{\tau\rho^{\gamma}}\left(\eta T d^{\kappa} i_L^{\lambda} + \mu T \nu^{i_{\lambda}^{\omega}} + \theta (T i_{\lambda})^{\theta} + \chi \rho^{\gamma} + \zeta\right)\right)}{1\left(C_s\left[1 - erf\left(\frac{X_{cover}}{2\sqrt{f} c_b f_w f_T f_{RH} D_a \cdot t}\right)\right]\right) + 1\left(\frac{1}{\tau\rho^{\gamma}}\left(\eta T d^{\kappa} i_L^{\lambda} + \mu T \nu^{i_{\lambda}^{\omega}} + \theta (T i_{\lambda})^{\theta} + \chi \rho^{\gamma} + \zeta\right)\right)} \right) \quad (16)$$

4 Application of the mathematical model

In this chapter, the equation (16) is imported in a GIS tool in order to create maps depicting the risk of corrosion cause by chloride ions in Limassol. However, it is logical that these maps which are going to be created are not representative. The reason is that the above equation (16) is not a real equation it uses empirical coefficients of other studies. The data is assumed.

4.1 Methodology for the application of the mathematical model

To achieve the implementation of the mathematical risk model a GIS tool is necessary. The methodology is used to create the corrosion risk maps is followed:

1. For that case, QGIS program is used. It can be used any GIS tool is preferred. The following figure (Figure 39) presents the QGIS tool.

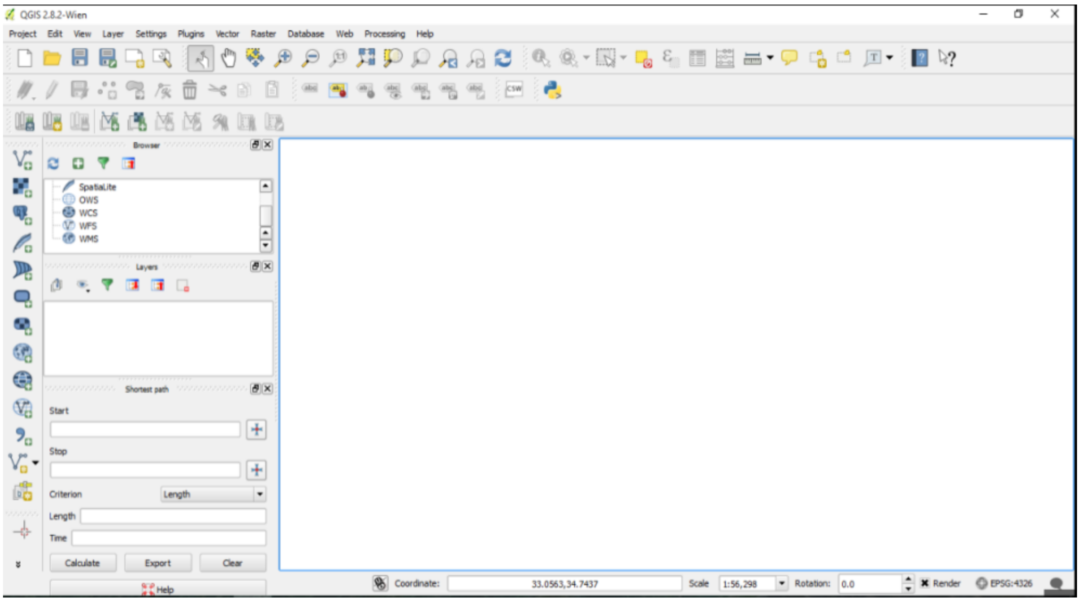


Figure 39: QGIS

2. Then, we must make georeferencing of the map. The purpose of georeference is to associate the points of the examined map with locations in physical space. The points could be structures, roads or any object of the map. The steps to make georeferencing are shown in the figures below:

   Figure 40: Georeference command to start georeferencing

   Figure 41, Figure 42: The file (map) which is going to be georefered is added

   Figure 43: Command “add point” is used to add points in the map. Usually the points are put around the perimeter of the map

   Figure 45: The points which are added

   Figure 44: Press the button “start georeference”, to give to the points coordinates

   Figure 46: Save the new modified map. This map is going to be used

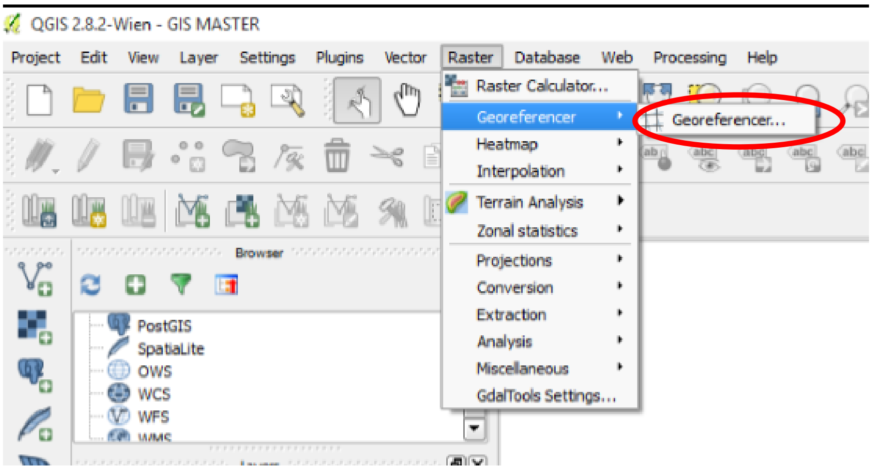


Figure 40: Georeference command

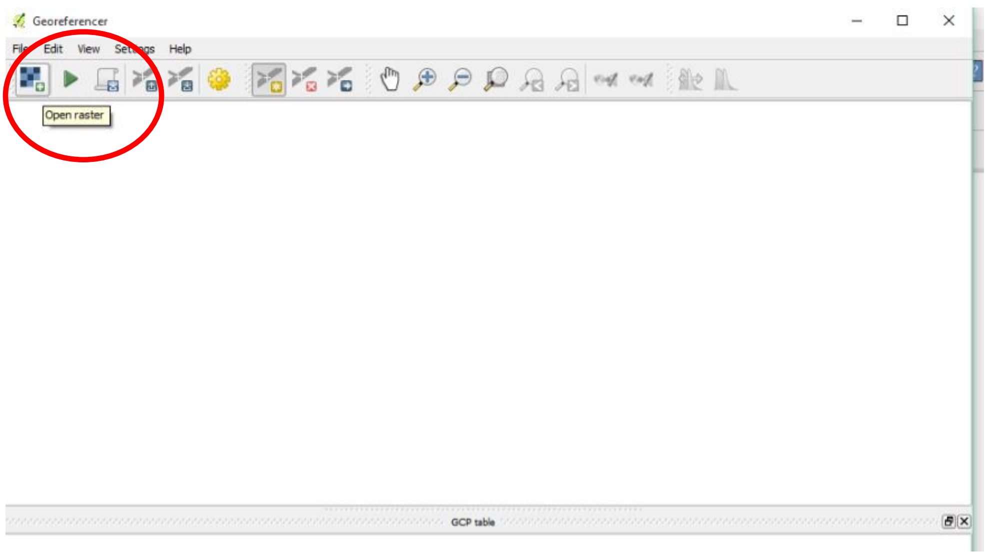


Figure 41: Open raster file

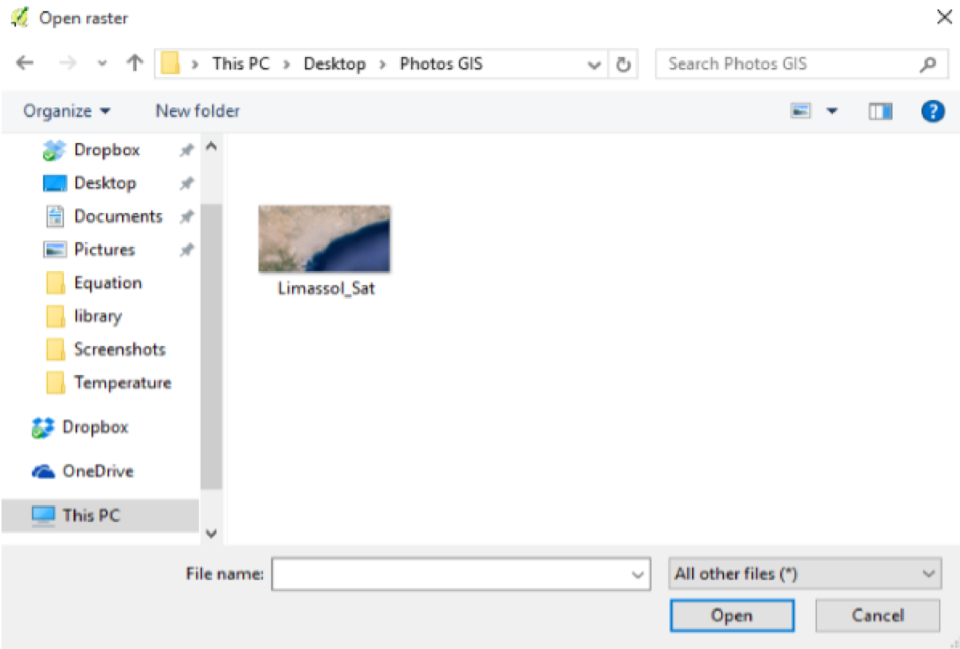


Figure 42: Select the map

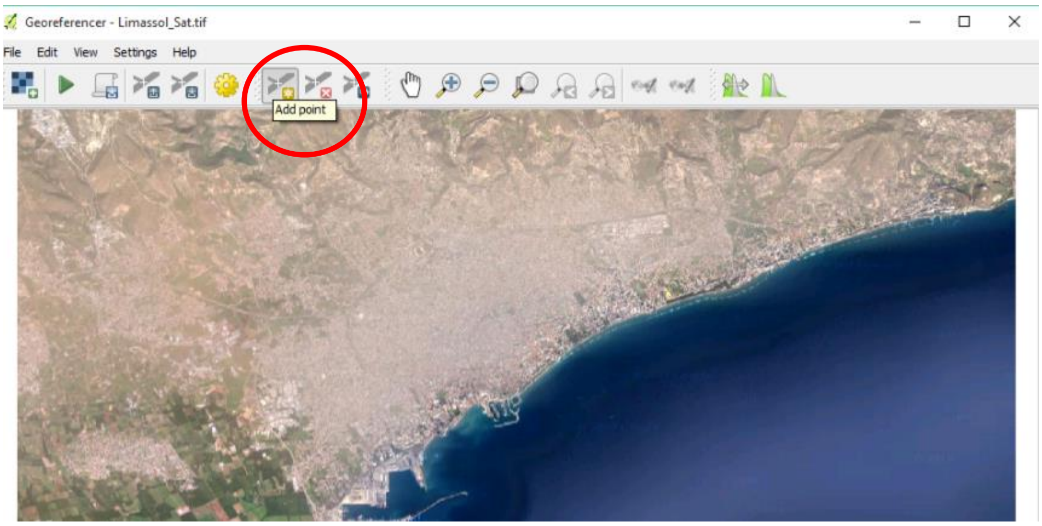


Figure 43: Add point

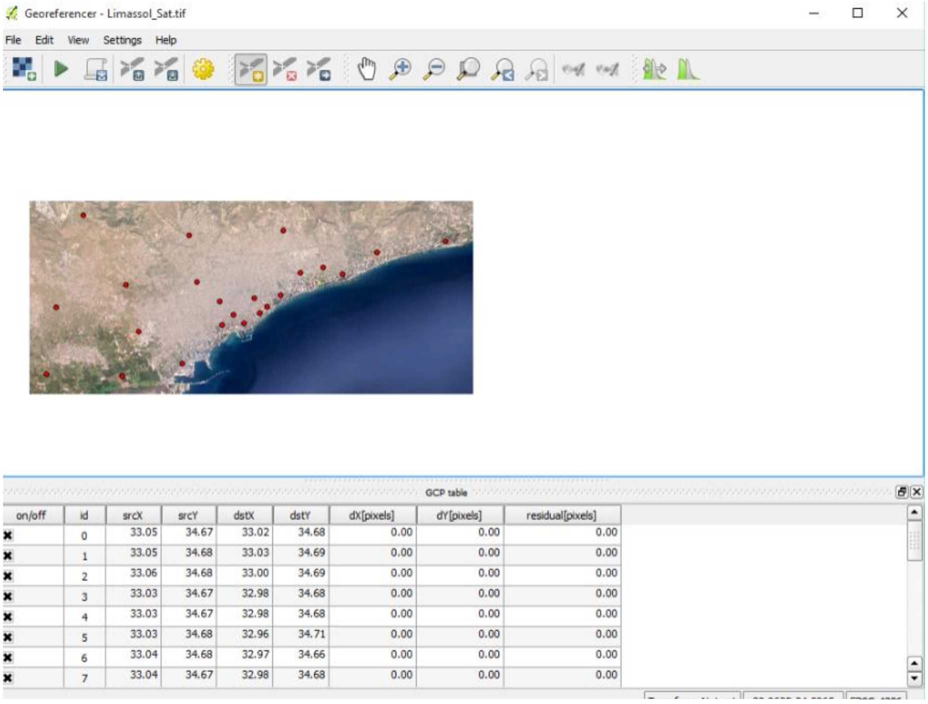


Figure 45: The points

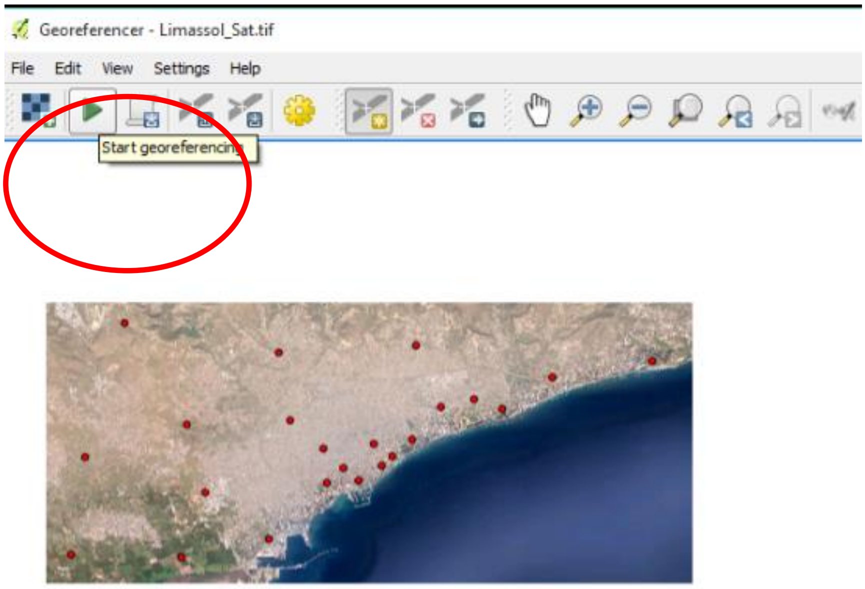


Figure 44: Start georeferencing

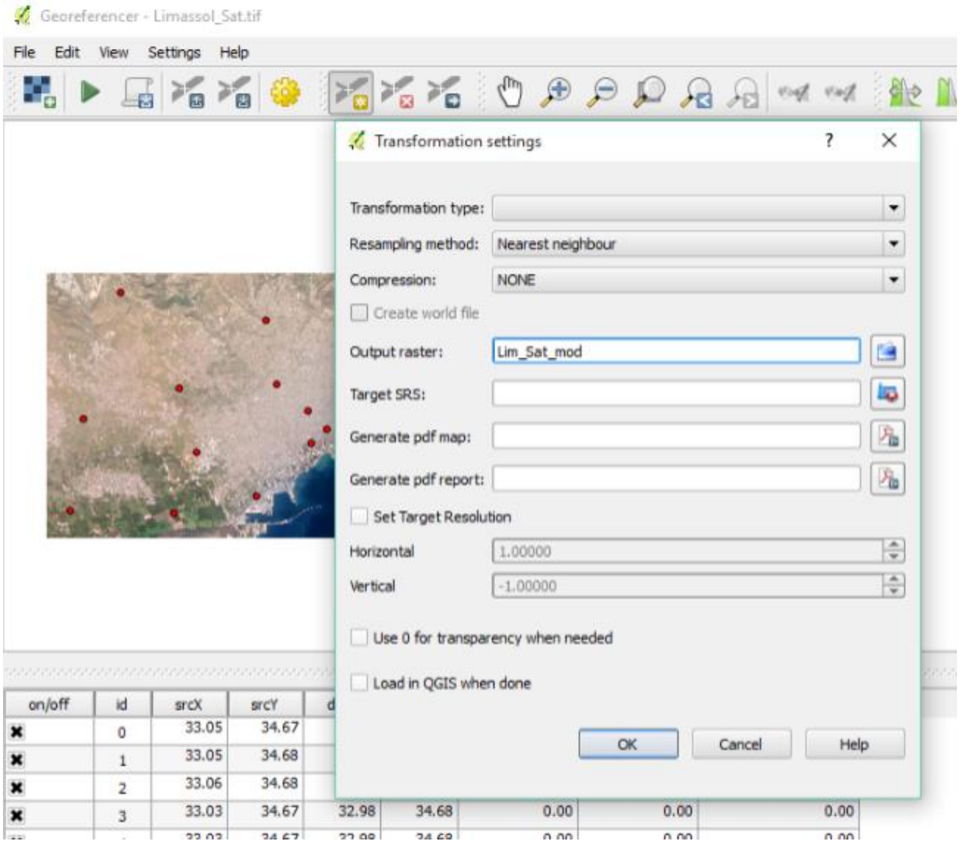


Figure 46: Save the new modified map which is georefered

3. The next step is to add a new raster layer (Figure 48). This layer is going to be applied above the map and it will show the results (map) we want. The figures below show the steps that were followed.

   Figure 47: The modified map (the map after the georeferencing) is selected.

   Figure 50: The modified map is now added in the program.

   Figure 49: A new shape layer has to be created.

   Figure 51:The properties of the new layer (Name etc) have to be completed

   Figure 52: By pressing the commands “toggle editing” and “add features” you start adding the points on the map.

   Figure 53:Points are created.

   Figure 54: 100 points are created. So the total points are 100.

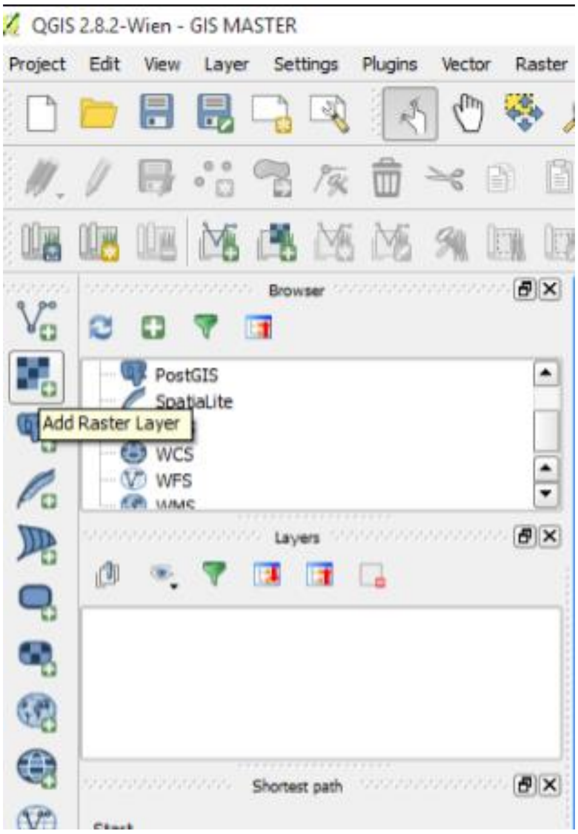


Figure 48: Add raster layer

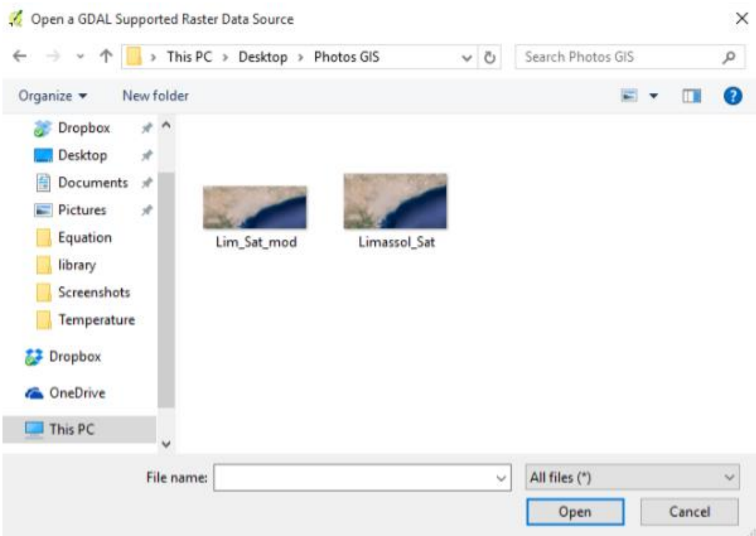


Figure 47:Select the modified map

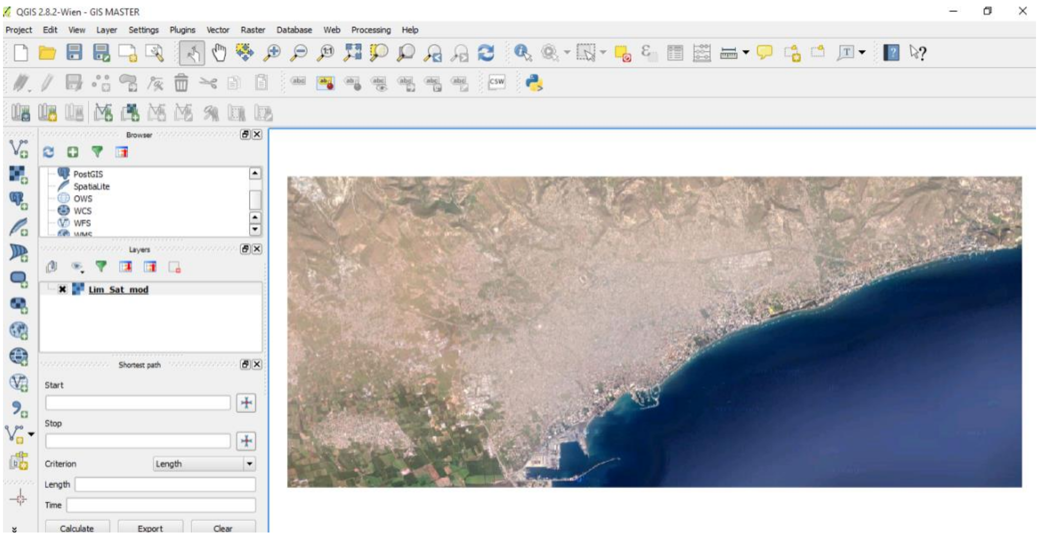


Figure 50: The new modified map

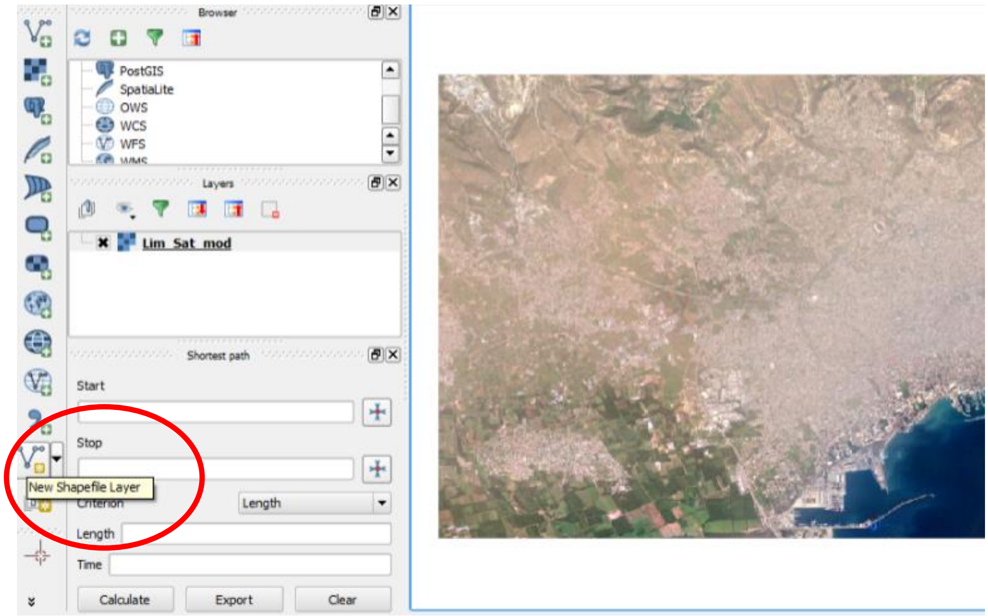


Figure 49: New shape layer

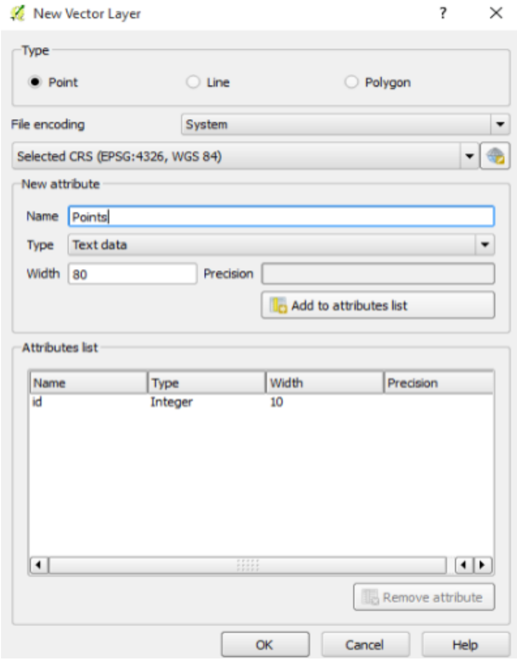


Figure 51: Complete the properties of the new shape file

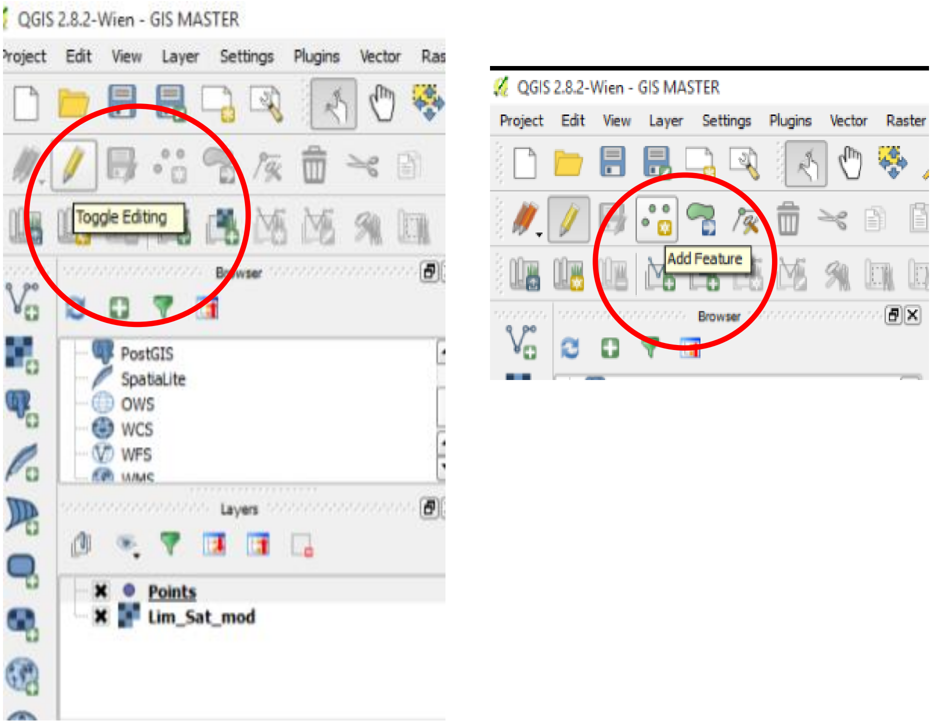


Figure 52: Commands “toggle editing” and “add feature” in order to start creating the points.

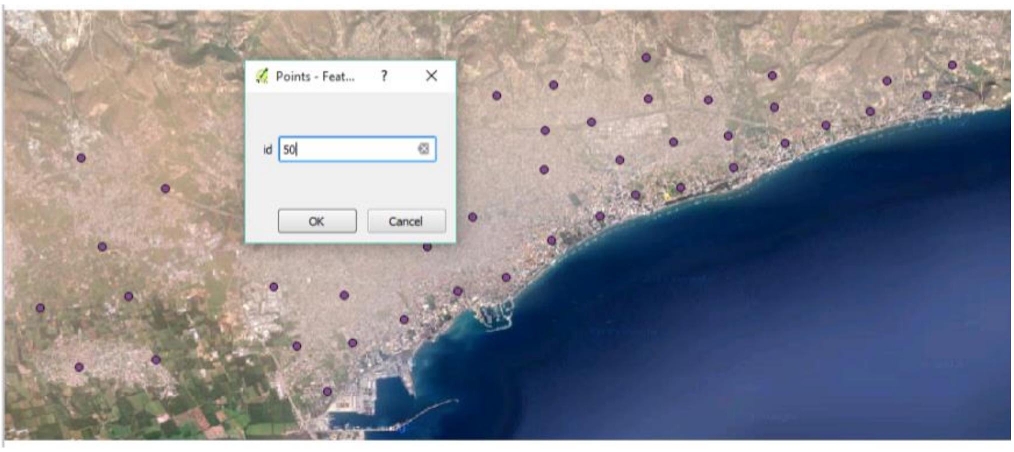


Figure 53: The first 50 points

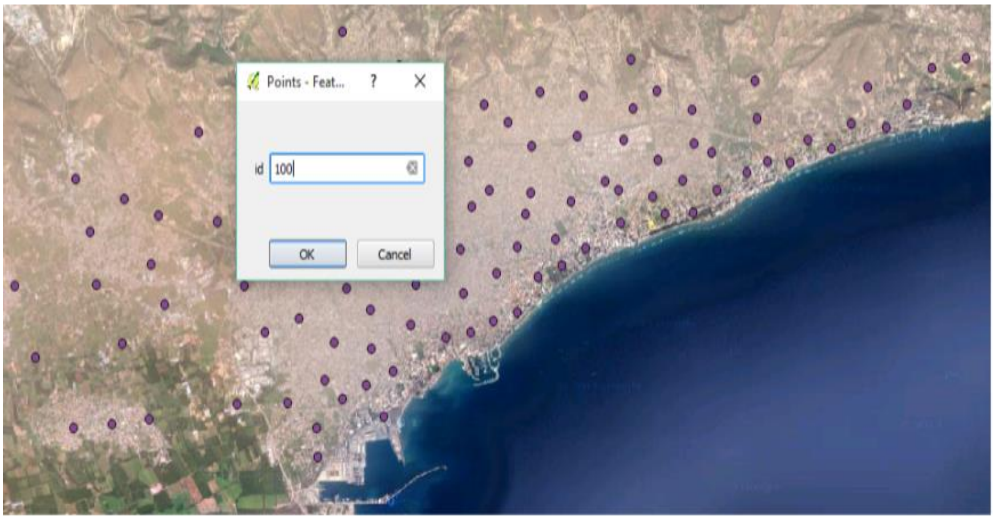


Figure 54: 100 points are added

4. The next step is to complete the data in the attribute table (Figure 56)

   Figure 55: New columns have to be added. Each column corresponds to one coefficient of the risk equation is written above

   Figure 57: For each column has to complete its properties (Name, Real or Integer number)

   Figure 58: All the columns are created and now each cell has to be filled

   Figure 59: The equation of Da is written and calculated

   Figure 60: The equation of f_T is written and calculated

   Figure 61: The equation of f_{RH} is written and calculated

   Figure 63: The N1 equation is written and calculated

   Figure 62: The N2 equation is written and calculated

   Figure 64: The risk equation is written and calculated

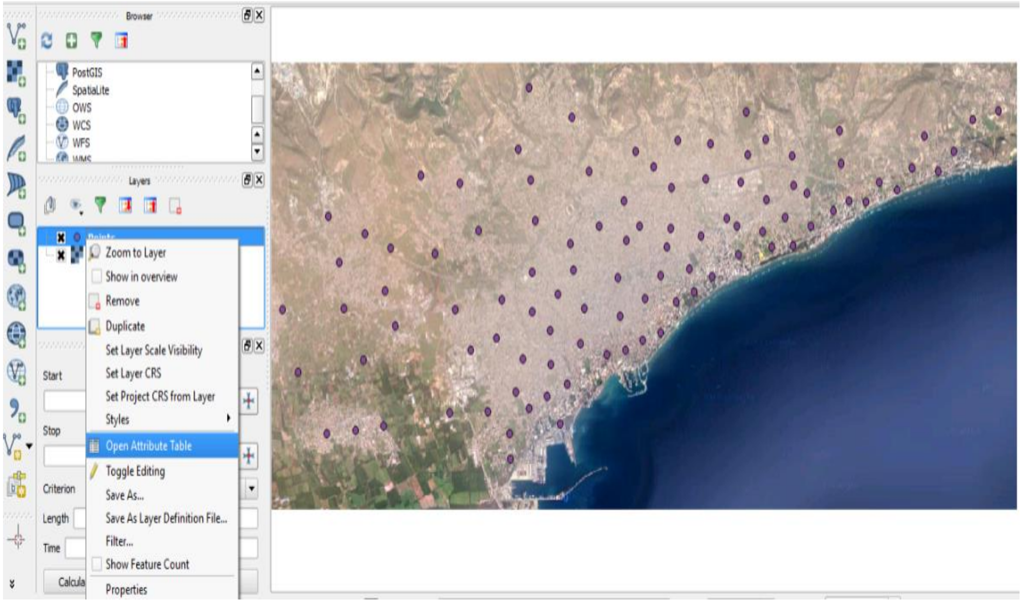


Figure 56: Open the attribute table

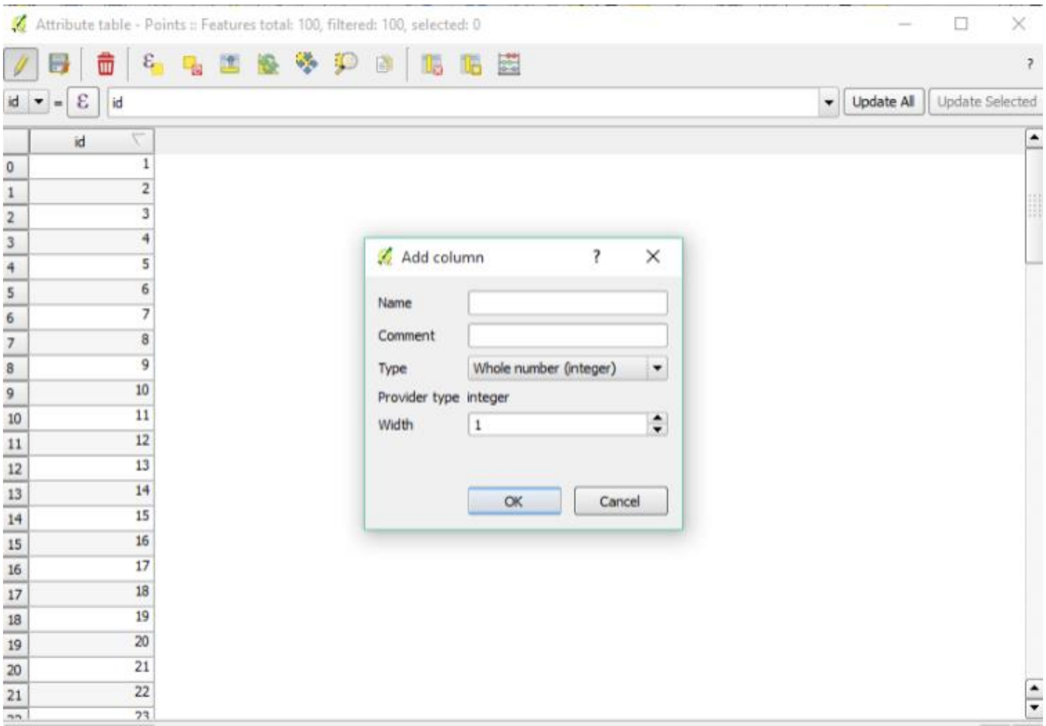


Figure 55:Start adding new columns

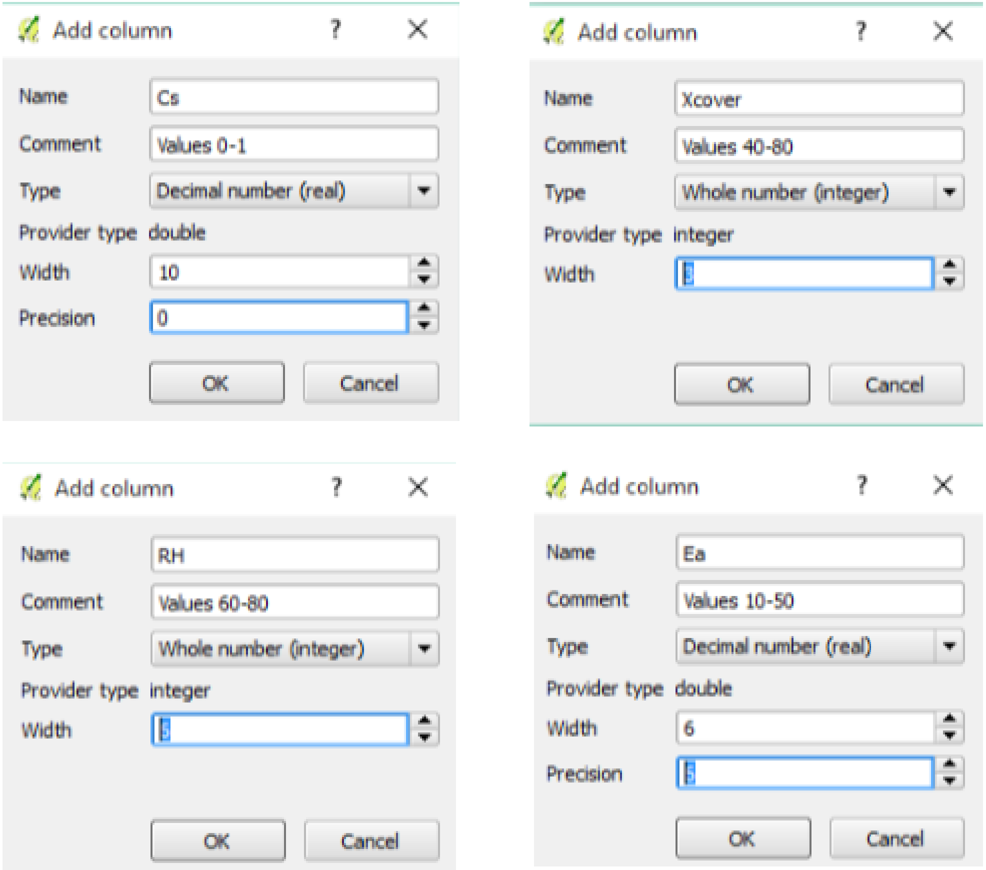


Figure 57: Complete the properties of each column. (Integer or real) number

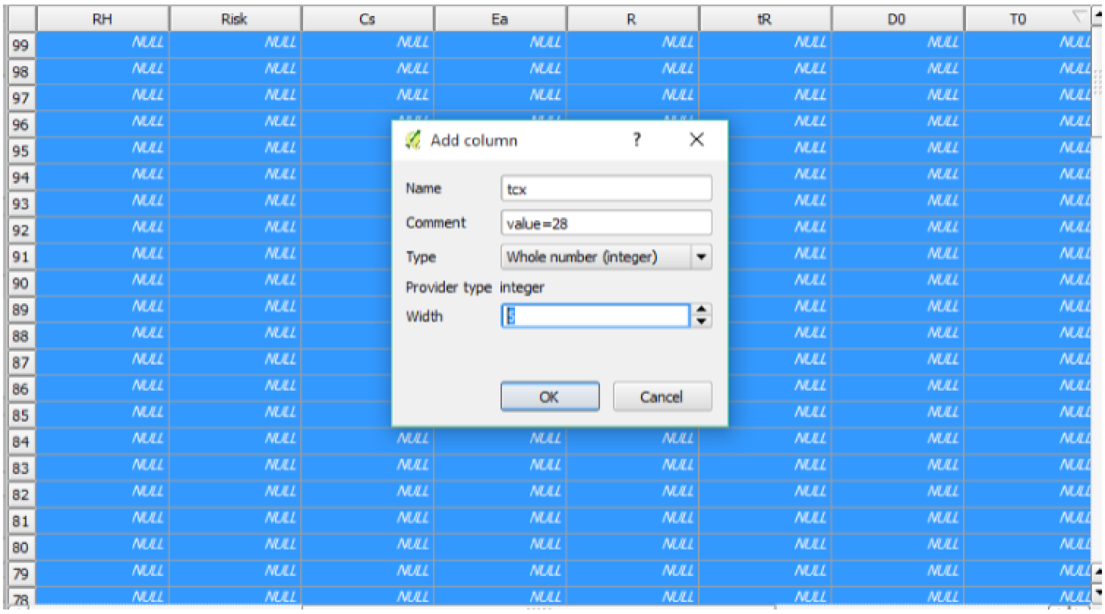


Figure 58: All the columns are created. Each cell has to be filled. The values of each cell are random but are between the limits of each coefficient

Attribute table - Points :: Features total: 99, filtered: 99, selected: 0

Da = (Do/(1-m))*(((1+(28 / t_1)) ^ (1-m)) - ((28 / t_1) ^ (1-m)))*(t0_1/t_1)

	Ea	T0	T	m	t_1	Do	t0_1	Da
0	45	23	16	0.30000	21	1.0000000000	5	0.1994960894
1	20	22	18	0.40000	5	3.0000000000	1	0.2912676914
2	35	20	21	0.50000	60	4.0000000000	1	0.0703906787
3	32	21	20	0.60000	20	5.0000000000	1	0.1720420535
4	50	29	22	0.21000	30	6.0000000000	1	0.1864370254
5	25	26	23	0.22000	30	7.0000000000	1	0.2167940626
6	26	25	24	0.23000	30	8.0000000000	2	0.4939007032
7	32	24	26	0.56400	25	9.0000000000	2	0.5565229609
8	10	24	28	0.21800	20	10.0000000000	2	0.8721570392
9	33	23	27	0.60000	21	11.0000000000	2	0.7371956944
10	34	23	29	0.44000	22	12.0000000000	3	1.2830310352
11	35	22	26	0.23000	12	15.0000000000	3	2.9556110956
12	42	21	24	0.35000	23	15.0000000000	3	1.6303114167
13	40	25	23	0.45000	14	15.0000000000	3	2.1376131370
14	50	16	22	0.49000	19	15.0000000000	5	2.8516585508
15	33	28	20	0.50000	30	9.0000000000	5	1.2730553737
16	28	30	15	0.60000	30	8.0000000000	5	1.0965172223
17	26	21	19	0.53000	24	3.0000000000	5	0.4828058742
18	14	15	18	0.55000	12	2.0000000000	6	0.5664755437
19	37	17	15	0.48000	11	1.0000000000	6	0.3206311369
20	10	17	15	0.36000	9	1.0000000000	6	0.4205737151

Figure 59: Insert the equation of Da factor

exp((Ea/8.31446)*((1 / (T0+273))-(1/T+273)))

T	m	t_1	Do	t0_1	Da	fT
30	0.53000	13	13.0000000000	6	3.5942574538	0.0000000000
30	0.52000	24	14.0000000000	6	2.7166897805	0.0000000000
26	0.50000	22	15.0000000000	7	3.6215891083	0.0000000000
29	0.60000	23	1.0000000000	7	0.2231218624	0.0000000000
25	0.26000	22	2.0000000000	7	0.5508054969	0.0000000000
18	0.25000	21	3.0000000000	8	0.9860711338	0.0000000000
17	0.42000	20	4.0000000000	8	1.2305842829	0.0000000000
19	0.32000	20	5.0000000000	8	1.6368144714	0.0000000000
17	0.33000	20	6.0000000000	9	2.1959917976	0.0000000000
16	0.34000	30	8.0000000000	9	2.1441271021	0.0000000000
15	0.35000	30	9.0000000000	9	2.4043411487	0.0000000000
24	0.36000	30	12.0000000000	9	3.1954333541	0.0000000000
28	0.37000	9	11.0000000000	8	6.0900566419	0.0000000000
16	0.38000	6	10.0000000000	9	8.0431833696	0.0000000000
15	0.39000	7	11.0000000000	10	8.7504091030	0.0000000000

Figure 60: Insert the equation of fT factor

fRH = (1+((1-RH) ^ 4)/((1-RH0)^4)) ^ -1

	m	t_1	Do	t0_1	Da	fT	RH0	fRH
77	0.29000	21	12.0000000000	1	0.4816037992	0.9998276107	78	0.6217989477
78	0.28000	20	14.0000000000	6	3.5240270748	0.9998963752	76	0.6816608481
79	0.26000	20	15.0000000000	9	5.7346936648	0.9997486553	74	0.6722418776
80	0.24000	15	15.0000000000	8	6.5203873833	0.9997342819	75	0.5136022949
81	0.25000	30	15.0000000000	7	3.2199955094	0.9999391912	74	0.5994607643
82	0.23000	5	13.0000000000	6	10.2952435657	0.9999036639	73	0.4082687427
83	0.27000	4	12.0000000000	3	5.2250018369	1.0002727854	72	0.3948257507
84	0.39000	7	11.0000000000	10	8.7504091030	0.9998512724	71	0.3813527495
85	0.38000	6	10.0000000000	9	8.0431833696	1.0000000000	69	0.3543984691
86	0.37000	9	11.0000000000	8	6.0900566419	1.0005953790	68	0.5927329918
87	0.36000	30	12.0000000000	9	3.1954333541	1.0003323997	67	0.5621965430
88	0.35000	30	9.0000000000	9	2.4043411487	0.9997997949	65	0.5157431514
89	0.34000	30	8.0000000000	9	2.1441271021	0.9995768684	64	0.4842568486
90	0.33000	20	6.0000000000	9	2.1959917976	0.9997517556	63	0.2959447301

Figure 61: Insert the equation of f_{RH} factor

N1 = Cs * (1-(Xcover/(2 *((.85*fT*fRH*Da*t_1) ^ 1/2))))

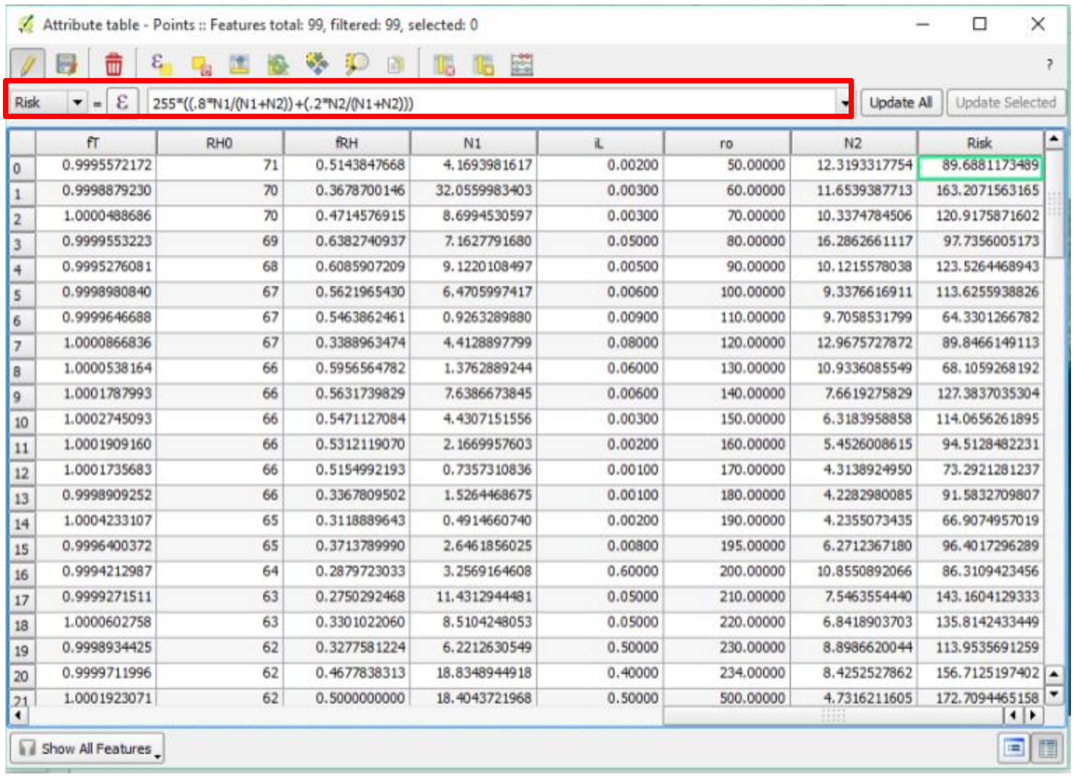
	t_1	Do	t0_1	Da	fT	RH0	fRH	N1
77	21	12.0000000000	1	0.4816037992	0.9998276107	78	0.6217989477	-12.5413307133
78	20	14.0000000000	6	3.5240270748	0.9998963752	76	0.6816608481	-0.1001240609
79	20	15.0000000000	9	5.7346936648	0.9997486553	74	0.6722418776	-0.1127082589
80	15	15.0000000000	8	6.5203873833	0.9997342819	75	0.5136022949	-0.2555165375
81	30	15.0000000000	7	3.2199955094	0.9999391912	74	0.5994607643	-0.0242488659
82	5	13.0000000000	6	10.2952435657	0.9999036639	73	0.4082687427	-1.5691615993
83	4	12.0000000000	3	5.2250018369	1.0002727854	72	0.3948257507	-6.2064130653
84	7	11.0000000000	10	8.7504091030	0.9998512724	71	0.3813527495	-0.3555503701

Figure 63: Insert N1 equation

N2 = 487^(iL^.07216)))+(-0.000102*((T0+273.15)*iL) ^ .475258)+ (5.03368*(10 ^ -7)*(ro ^ .80050))-0.001211)

	id	Xcover	RH	Cs	Ea	T0
0	2	40	70	0.20000	45	23
1	3	41	80	0.36000	20	22
2	4	45	72	0.34000	35	20
3	5	60	60	0.23000	32	21
4	6	50	61	0.56000	50	29
5	7	45	63	0.48000	25	26
6	8	60	64	0.12000	26	25
7	9	65	79	0.29000	32	24

Figure 62: Insert N2 equation



	fT	RH0	fRH	N1	iL	ro	N2	Risk
0	0.9995572172	71	0.5143847668	4.1693981617	0.00200	50.00000	12.3193317754	89.6881173489
1	0.9998879230	70	0.3678700146	32.0559983403	0.00300	60.00000	11.6539387713	163.2071563165
2	1.0000488686	70	0.4714576915	8.6994530597	0.00300	70.00000	10.3374784506	120.9175871602
3	0.9999553223	69	0.6382740937	7.1627791680	0.05000	80.00000	16.2862661117	97.7356005173
4	0.9995276081	68	0.6085907209	9.1220108497	0.00500	90.00000	10.1215578038	123.5264468943
5	0.9998980840	67	0.5621965430	6.4705997417	0.00600	100.00000	9.3376616911	113.6255938826
6	0.9999646688	67	0.5463862461	0.9263289880	0.00900	110.00000	9.7058531799	64.3301266782
7	1.0000866836	67	0.3388963474	4.4128897799	0.08000	120.00000	12.9675727872	89.8466149113
8	1.0000538164	66	0.5956564782	1.3762889244	0.06000	130.00000	10.9336085549	68.1059268192
9	1.0001787993	66	0.5631739829	7.6386673845	0.00600	140.00000	7.6619275829	127.3837035304
10	1.0002745093	66	0.5471127084	4.4307151556	0.00300	150.00000	6.3183958858	114.0656261895
11	1.0001909160	66	0.5312119070	2.1669957603	0.00200	160.00000	5.4526008615	94.5128482231
12	1.0001735683	66	0.5154992193	0.7357310836	0.00100	170.00000	4.3138924950	73.2921281237
13	0.9998909252	66	0.3367809502	1.5264468675	0.00100	180.00000	4.2282980085	91.5832709807
14	1.0004233107	65	0.3118889643	0.4914660740	0.00200	190.00000	4.2355073435	66.9074957019
15	0.9996400372	65	0.3713789990	2.6461856025	0.00800	195.00000	6.2712367180	96.4017296289
16	0.9994212987	64	0.2879723033	3.2569164608	0.60000	200.00000	10.8550892066	86.3109423456
17	0.9999271511	63	0.2750292468	11.4312944481	0.05000	210.00000	7.5463554440	143.1604129333
18	1.0000602758	63	0.3301022060	8.5104248053	0.05000	220.00000	6.8418903703	135.8142433449
19	0.9998934425	62	0.3277581224	6.2212630549	0.50000	230.00000	8.8986620044	113.9535691259
20	0.9999711996	62	0.4677838313	18.8348944918	0.40000	234.00000	8.4252527862	156.7125197402
21	1.0001923071	62	0.5000000000	18.4043721968	0.50000	500.00000	4.7316211605	172.7094465158

Figure 64: Insert the equation of the corrosion risk

5. In this step is going to be the interpolation (Figure 66).

   Figure 65: The output file has to be inserted and the empty boxes have to be filled.

   Figure 67: The result of interpolation. From this map we cannot understand the results so we have to change the properties of the shape file (Fig. 67)

   Figure 69: The transparency is changed so that we can see the map below and understand the results

   Figure 68: The colors of the map are changed. Areas with red color are the areas with high risk of corrosion and areas with blue color are the areas with low risk of corrosion.

   Figure 71: The final map.

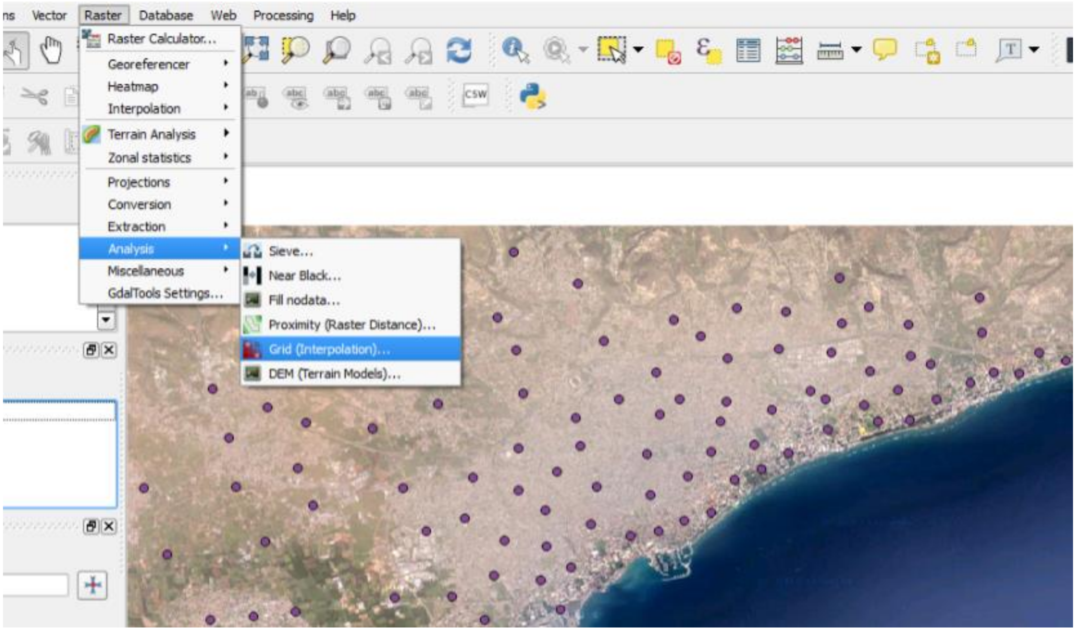


Figure 66: Raster – Analysis – Grid (Interpolation)

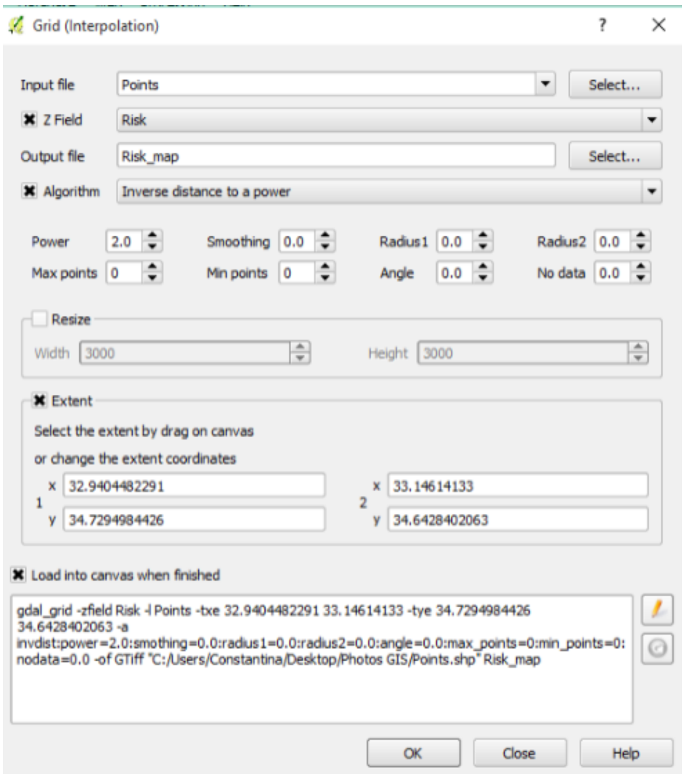


Figure 65: Insert the output file and fill the empty boxes

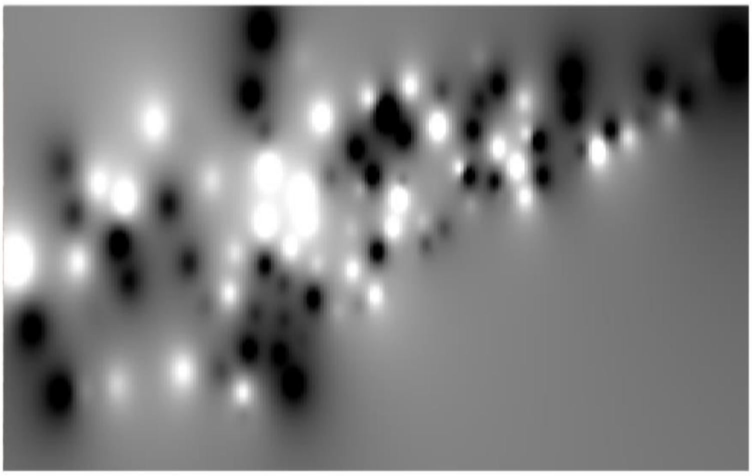


Figure 67:The result of interpolation

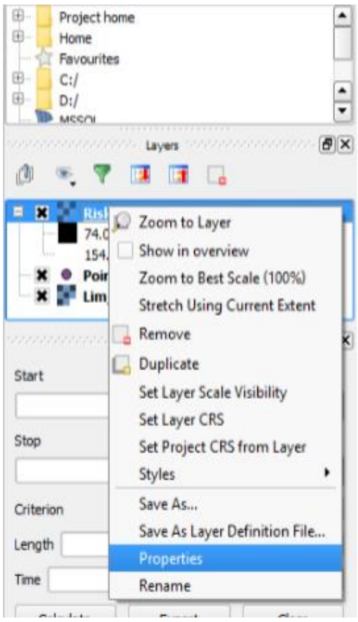


Figure 69: Change the properties

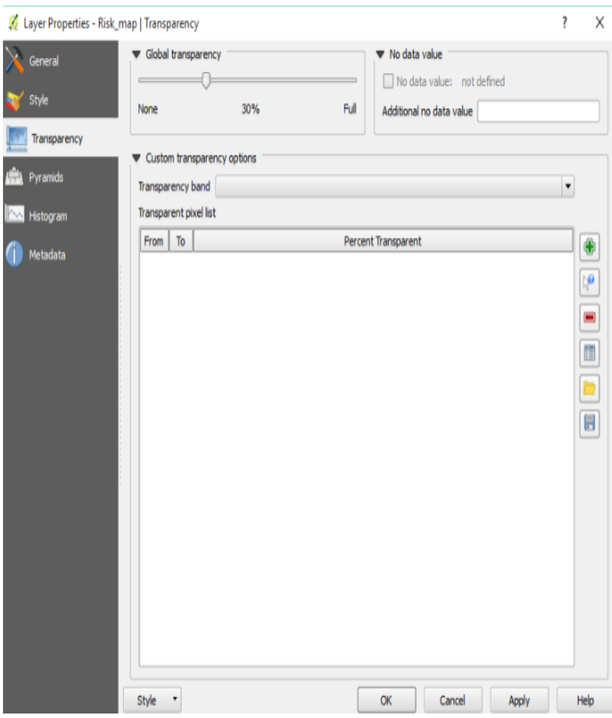


Figure 68: Change the transparency

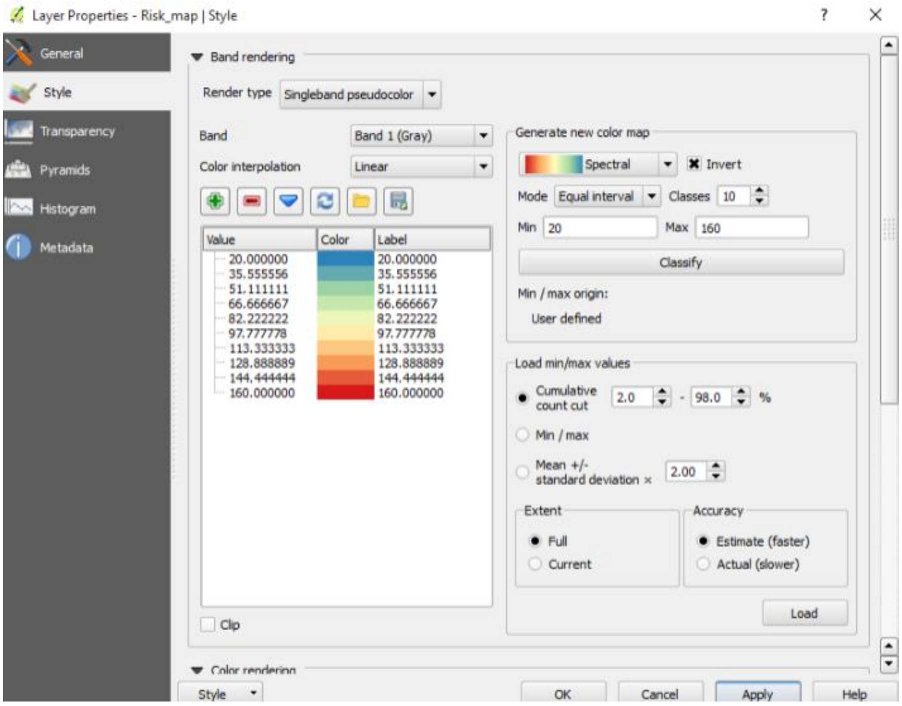


Figure 70: Change the style. Generate new color map

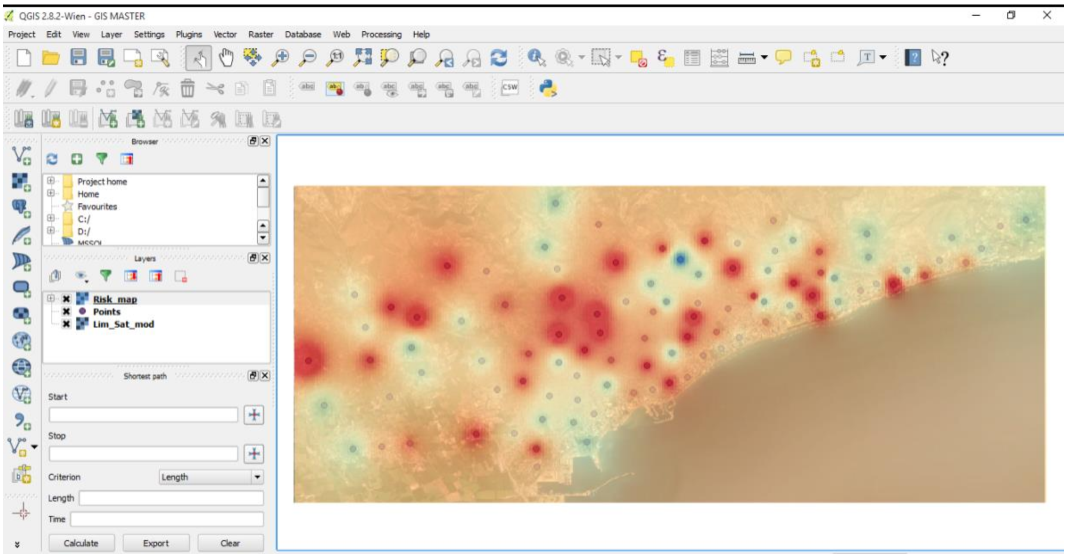
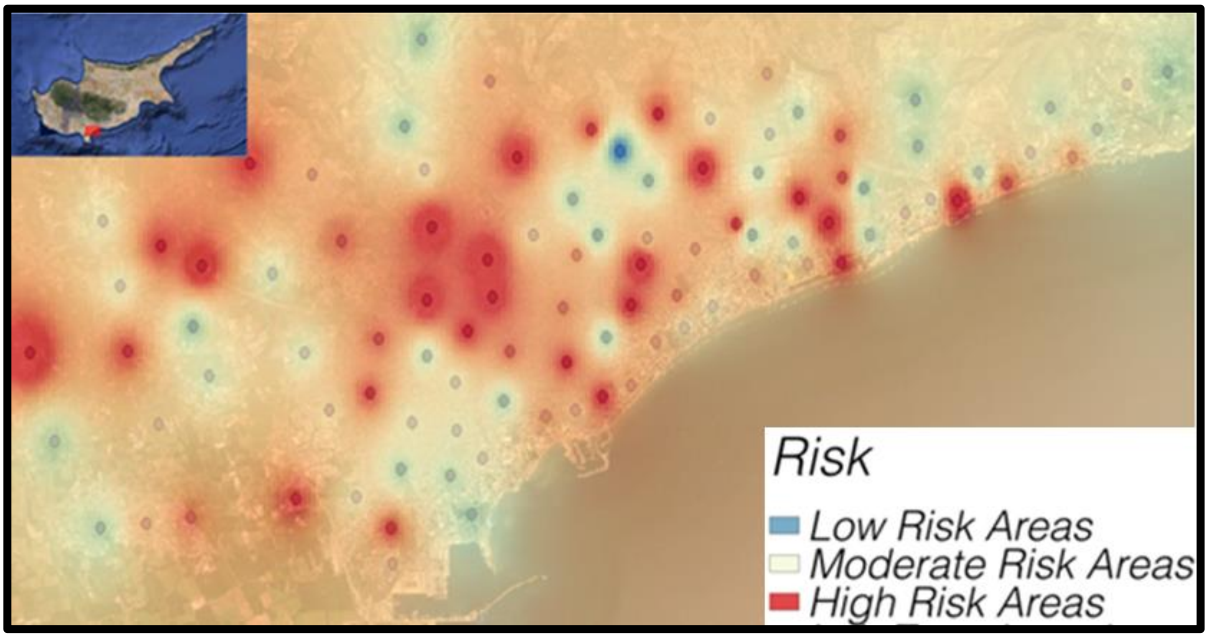


Figure 71: The final result

5 Results

The final result is shown on the map below. This map represents the risk of corrosion in town of Limassol. The data that is used to create this map are shown above. The ideal map could be a map which has high risk corrosion due to chloride ions, near the coastline. However in this study, the aim was to find the effect of the interaction of different factors in corrosion. The following map shows the effect of some factors in corrosion.



CONCLUSIONS

The conclusions of this master thesis are:

1. There are many researches about corrosion and what causes corrosion. The reason of this interest are the major problems caused by corrosion. Corrosion can affect the service life of the structures
2. From the researches based on corrosion, many mathematical models are developed. Each journal includes some factors and examines these factors in laboratories. In laboratories environmental conditions are ideal and factors can be determined from the researcher. In other words results taken from laboratories are not 100% representative in respect of real conditions. In order to create corrosion risk maps, only real data must be included. There is no similar study. To create corrosion risk maps, they must work together many researchers of different specialties to collect the data and create a representative mathematical model and then import it in a GIS tool
3. GIS is a new technology that can help the corrosion sector. It can help engineers and people to predict if a structure suffers from corrosion. Also GIS can help managing authorities when conducting a research for corrosion, since the results can give information about an entire area
4. It is not time consuming to find out the areas that might be suffering from corrosion if you use GIS. If an engineer wants to design a structure somewhere, can easily know the propabilities of corrosion in one area without the need of visitong this area only by using GIS
5. By using GIS tools to predict corrosion is much more economic than making laboratory tests for each structure. The equipment which is necessary is a computer and a suitable program
6. In addition, by using GIS to find information about corrosion, engineers can prevent deterioration of the structures and elongate the service life of the structures

EPILOGUE

Reaching the end of this master thesis, we conclude that using GIS with purpose of finding corrosion will help a lot, engineers, researchers and managing authorities. If a group of researchers work together to find a mathematical model that can be imported in a GIS tool to find the risk of corrosion then everyone who wants to find corrosion, could easily, quickly and cheap get the information which wants. In addition, structures can be maintained at the right time to prevent the deterioration. Moreover, this application of GIS could help civil engineers at the stage of design. Knowing the corrosion in one area in which is going to construct a structure, you can make the design properly to prevent corrosion. Also, another advantage of the use of GIS is that you get the needed information costless and immediately. Improving GIS tools is significant, so that people from different specialties could exploit the use of GIS.

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ANNEX

Attribute table

id	Xcover	RH	Cs	Ea	T0	T	m	t_1	Do	t0_1	Da	fT	RH0	fRH	N1	iL	ro	N2	Risk
2	40	70	0.2	45	23	16	0.3	21	1	5	0.199496	0.999557	71	0.514385	4.169398	0.002	50	12.31933	89.68812
3	41	80	0.36	20	22	18	0.4	5	3	1	0.291268	0.999888	70	0.36787	32.056	0.003	60	11.65394	163.2072
4	45	72	0.34	35	20	21	0.5	60	4	1	0.070391	1.000049	70	0.471458	8.699453	0.003	70	10.33748	120.9176
5	60	60	0.23	32	21	20	0.6	20	5	1	0.172042	0.999955	69	0.638274	7.162779	0.05	80	16.28627	97.7356
6	50	61	0.56	50	29	22	0.21	30	6	1	0.186437	0.999528	68	0.608591	9.122011	0.005	90	10.12156	123.5264
7	45	63	0.48	25	26	23	0.22	30	7	1	0.216794	0.999898	67	0.562197	6.4706	0.006	100	9.337662	113.6256
8	60	64	0.12	26	25	24	0.23	30	8	2	0.493901	0.999965	67	0.546386	0.926329	0.009	110	9.705853	64.33013
9	65	79	0.29	32	24	26	0.564	25	9	2	0.556523	1.000087	67	0.338896	4.41289	0.08	120	12.96757	89.84661
10	40	60	0.39	10	24	28	0.218	20	10	2	0.872157	1.000054	66	0.595656	1.376289	0.06	130	10.93361	68.10593
11	80	62	0.78	33	23	27	0.6	21	11	2	0.737196	1.000179	66	0.563174	7.638667	0.006	140	7.661928	127.3837
12	80	63	0.87	34	23	29	0.44	22	12	3	1.283031	1.000275	66	0.547113	4.430715	0.003	150	6.318396	114.0656
13	78	64	0.56	35	22	26	0.23	12	15	3	2.955611	1.000191	66	0.531212	2.166996	0.002	160	5.452601	94.51285
14	69	65	0.23	42	21	24	0.35	23	15	3	1.630311	1.000174	66	0.515499	0.735731	0.001	170	4.313892	73.29213
15	68	78	0.22	40	25	23	0.45	14	15	3	2.137613	0.999891	66	0.336781	1.526447	0.001	180	4.228298	91.58327
16	48	79	0.21	50	16	22	0.49	19	15	5	2.851659	1.000423	65	0.311889	0.491466	0.002	190	4.235507	66.9075
17	69	74	0.56	33	28	20	0.5	30	9	5	1.273055	0.99964	65	0.371379	2.646186	0.008	195	6.271237	96.40173
18	49	80	0.64	28	30	15	0.6	30	8	5	1.096517	0.999421	64	0.287972	3.256916	0.6	200	10.85509	86.31094
19	58	80	0.56	26	21	19	0.53	24	3	5	0.482806	0.999927	63	0.275029	11.43129	0.05	210	7.546355	143.1604
20	47	75	0.36	14	15	18	0.55	12	2	6	0.566476	1.00006	63	0.330102	8.510425	0.05	220	6.84189	135.8142
21	48	74	0.13	37	17	15	0.48	11	1	6	0.320631	0.999893	62	0.327758	6.221263	0.5	230	8.898662	113.9536

22	42	64	0.7	10	17	15	0.36	9	1	6	0.420574	0.999971	62	0.467784	18.83489	0.4	234	8.425253	156.7125
23	43	62	0.63	10	16	30	0.29	8	5	1	0.418512	1.000192	62	0.5	18.40437	0.5	500	4.731621	172.7094
24	44	61	0.6	10	15	16	0.25	5	15	10	19.09594	1.000014	62	0.516523	0.029764	0.3	600	3.889414	52.16194
25	42	60	0.52	50	30	17	0.37	4	14	10	16.61341	0.999111	62	0.533287	0.205672	0.321	700	3.728925	58.99772
26	51	69	0.89	50	23	18	0.21	3	13	10	26.81653	0.999651	60	0.361726	0.945648	0.0032 1	800	1.646919	106.8073
27	79	71	0.83	40	22	19	0.33	2	13	10	26.89674	0.999832	63	0.380968	2.934795	0.0054	900	1.765963	146.5215
28	74	78	0.7	41	20	29	0.34	1	12	9	34.57695	1.000502	62	0.282575	5.534092	0.06	1000 0	0.467664	192.078
29	73	68	0.73	42	19	30	0.32	20	11	9	4.051116	1.000628	61	0.391409	1.245688	0.0589	1000	2.341618	104.1291
30	72	62	0.09	43	18	21	0.31	30	10	9	2.706405	1.000181	71	0.634248	0.058014	0.0741	1000	2.400224	54.6108
31	71	75	0.15	44	17	22	0.3	10	7	8	3.92001	1.000309	80	0.565013	0.415524	0.0214	1100	1.846628	79.10385
2	42	70	0.25	10	16	15	0.2	10	2	4	0.630651	0.999986	79	0.620203	2.908303	0.0365	1200	1.741988	146.6866
32	76	61	0.03	45	15	26	0.26	11	8	8	4.361972	1.000692	78	0.730634	0.046461	0.007	1300	1.348227	56.09686
33	75	63	0.74	46	15	25	0.27	12	9	8	4.537454	1.000645	77	0.693045	0.989175	0.0789	1400	1.85688	104.1767
35	74	64	0.62	47	22	24	0.29	12	6	6	2.222324	1.000129	74	0.643204	2.526378	0.0741 2	1500	1.807365	140.1921
36	77	74	0.45	50	21	29	0.23	11	4	6	1.690969	1.000542	76	0.527002	3.706312	0.6	1600	2.178387	147.3627
37	77	75	0.3	12	27	28	0.33	13	5	3	0.838322	1.000016	75	0.5	4.687258	0.512	1610	2.199106	155.1407
38	78	71	0.26	13	30	27	0.25	14	3	3	0.512326	0.999948	74	0.541866	5.8791	0.578	1578	2.295339	161.0384
39	78	72	0.52	14	29	15	0.6	15	2	3	0.240289	0.999729	73	0.513983	25.24456	0.498	2000	1.882089	193.3846
40	52	78	0.69	15	26	19	0.33	16	1	2	0.096003	0.999855	72	0.419579	64.81525	0.354	250	8.524031	186.2172
41	52	74	0.78	16	19	21	0.39	17	8	2	0.702138	1.000045	71	0.458134	7.945601	0.1235	2500	1.244182	183.2857
42	53	75	0.71	17	16	20	0.49	18	9	2	0.707722	1.000097	70	0.430494	7.3618	0.57	106	16.80335	97.61074
43	53	76	0.15	19	15	22	0.59	21	1	1	0.033703	1.000188	70	0.417383	31.50498	0.54	320	6.930497	176.4118
44	54	61	0.51	20	30	23	0.58	22	10	1	0.330226	0.999812	70	0.636232	6.50095	0.0041	410	3.018023	155.4908
45	54	62	0.2	21	22	25	0.38	23	11	6	2.354429	1.000086	70	0.620797	0.177924	0.0052	510	2.55389	60.96495
46	64	69	0.23	22	24	28	0.48	24	12	6	2.373695	1.000118	80	0.645602	0.2408	0.078	980	2.491019	64.48641
47	64	69	0.39	26	26	27	0.28	25	14	3	1.476392	1.000035	80	0.645602	0.842266	0.09	990	2.54403	89.05534

48	63	63	0.88	27	25	29	0.57	22	15	3	1.494108	1.000144	80	0.724971	1.856633	0.0568	1101	2.188974	121.2156
49	62	63	0.21	23	24	26	0.47	21	15	2	1.08394	1.000062	60	0.450565	1.283423	0.0147	1080	1.794589	114.7956
50	61	78	0.77	50	23	24	0.37	23	15	2	1.075723	1.000068	60	0.256341	7.942141	0.0125	560	2.856261	163.5303
51	61	74	0.61	15	22	23	0.27	20	14	7	4.137078	1.000021	60	0.299079	1.158977	0.24	689	3.694258	87.53718
52	63	75	0.03	25	21	21	0.24	25	14	7	3.50852	1	60	0.287796	0.058083	0.214	123	14.14347	51.62576
53	80	71	0.5	35	20	16	0.54	26	14	8	3.417621	0.999801	60	0.335407	1.079277	0.39	50	31.82456	56.01855
54	74	72	0.17	45	19	19	0.34	27	13	8	3.356022	1	60	0.32288	0.335863	0.24	60	25.6707	52.97592
55	72	73	0.29	50	18	19	0.44	28	13	9	3.538871	1.000071	61	0.325351	0.471913	0.0007	70	7.802731	59.72578
56	52	69	0.66	17	17	18	0.32	29	3	9	0.830926	1.000024	62	0.393044	3.603013	0.006	80	10.79303	89.29254
57	69	67	0.78	19	15	16	0.22	1	3	10	14.35692	1.000027	62	0.421865	9.6739	0.006	65	13.12371	115.9238
58	63	67	0.63	20	30	15	0.52	15	3	10	1.285513	0.999587	63	0.437803	4.903436	0.004	4561	0.541496	188.7842
59	65	64	0.35	20	27	17	0.42	16	3	10	1.340466	0.999724	63	0.484005	2.229032	0.002	2563	0.69222	167.7451
60	45	65	0.55	21	28	16	0.28	17	2	7	0.667109	0.999652	64	0.484257	4.753789	0.003	1478	1.047386	176.3763
61	41	62	0.12	23	29	19	0.59	20	2	7	0.484693	0.999686	64	0.532216	1.00227	0.0125	9856	0.380868	161.8691
62	50	63	0.1	33	26	20	0.47	30	2	7	0.399856	0.999728	64	0.515995	0.850602	0.147	3695	0.985551	121.8776
63	51	65	0.11	43	25	21	0.39	30	1	7	0.205116	0.999764	65	0.5	2.035631	0.258	65	23.80817	63.0513
64	52	64	0.58	44	25	22	0.24	30	1	8	0.24614	0.999819	65	0.515743	8.738677	0.369	75	22.15054	94.28428
65	59	71	0.44	45	15	28	0.22	25	1	2	0.072262	1.000812	65	0.411335	40.62652	0.123	630	3.511149	191.8289
66	66	68	0.26	46	15	23	0.2	29	5	9	1.444513	1.000519	65	0.454318	0.800213	0.456	128	14.51401	58.9947
67	64	64	0.82	47	15	29	0.3	27	5	8	1.311579	1.00091	65	0.515743	2.557444	0.078	147	10.47095	81.03354
68	49	73	0.69	48	18	26	0.4	10	5	2	0.621631	1.000531	65	0.384348	15.94941	0.357	98	17.05724	124.9324
69	43	69	0.59	49	19	27	0.5	5	6	3	1.458825	1.000538	60	0.361726	10.71616	0.6	630	4.083948	161.7811
70	42	78	0.33	50	19	21	0.6	4	6	4	1.792354	1.00014	60	0.256341	8.541169	0.089	6300	0.613264	193.7504
71	41	62	0.27	10	17	24	0.44	6	6	5	2.4299	1.000098	60	0.466713	1.643801	0.097	4785	0.73544	156.7066
72	69	80	0.52	11	16	29	0.55	3	7	10	6.63974	1.000197	60	0.237282	8.409182	0.0159	9635	0.398457	197.0783
73	79	63	0.36	12	15	25	0.66	13	7	9	2.561501	1.000168	60	0.450565	1.869678	0.067	1258	1.982366	125.2621
74	42	64	0.22	13	15	26	0.22	23	7	8	2.170124	1.0002	60	0.434776	0.280827	0.025	4796	0.613694	99.03301
75	63	80	0.12	14	24	23	0.33	30	8	2	0.478021	0.999981	80	0.5	1.120432	0.014	8596	0.42897	161.6402

76	58	60	0.32	15	30	27	0.31	30	9	3	0.811922	0.99994	70	0.651645	1.055748	0.1459	1258	2.266376	99.62233
77	74	74	0.56	16	29	28	0.3	23	10	1	0.371773	0.999979	71	0.458134	11.88548	0.159	9636	0.550003	197.233
78	77	65	0.28	17	28	21	0.27	22	11	2	0.86079	0.999838	79	0.688111	1.666801	0.357	4578	0.986456	147.1161
79	79	69	0.91	18	27	20	0.29	21	12	1	0.481604	0.999828	78	0.621799	12.54133	0.489	152	13.90637	123.5516
80	78	63	0.11	19	26	22	0.28	20	14	6	3.524027	0.999896	76	0.681661	0.100124	0.456	369	6.799486	53.22027
81	80	62	0.51	20	25	16	0.26	20	15	9	5.734694	0.999749	74	0.672242	0.112708	0.125	789	3.23653	56.14874
82	60	74	0.63	21	24	15	0.24	15	15	8	6.520387	0.999734	75	0.513602	0.255517	0.004	741	1.877023	69.33215
83	51	67	0.67	22	23	21	0.25	30	15	7	3.219996	0.999939	74	0.599461	0.024249	0.002	852	1.425309	53.55945
84	48	80	0.93	23	22	19	0.23	5	13	6	10.29524	0.999904	73	0.408269	1.569162	0.002	963	1.282731	135.1833
85	51	80	0.99	25	20	28	0.27	4	12	3	5.225002	1.000273	72	0.394826	6.206413	0.003	369	2.869654	155.6247
86	47	80	0.26	26	19	15	0.39	7	11	10	8.750409	0.999851	71	0.381353	0.35555	0.004	258	3.94471	63.65021
87	61	80	0.82	29	16	16	0.38	6	10	9	8.043183	1	69	0.354398	2.620755	0.04	147	9.479336	84.13822
88	62	62	0.3	33	15	28	0.37	9	11	8	6.090057	1.000595	68	0.592733	0.373151	0.04	7894	0.495981	116.6887
89	63	63	0.25	34	17	24	0.36	30	12	9	3.195433	1.000332	67	0.562197	0.093699	0.03	7523	0.498314	75.21557
90	65	64	0.33	35	19	15	0.35	30	9	9	2.404341	0.9998	65	0.515743	0.348492	0.04	78	16.06841	54.24783
91	42	65	0.11	50	22	16	0.34	30	8	9	2.144127	0.999577	64	0.484257	0.064566	0.02	50	19.54707	51.50371
92	40	78	0.14	44	21	17	0.33	20	6	9	2.195992	0.999752	63	0.295945	0.366997	0.07	98	13.7663	54.97293
93	80	78	0.36	42	30	19	0.32	20	5	8	1.636814	0.999372	62	0.282575	3.305082	0.08	99	16.00971	77.18084
94	72	79	0.31	41	20	17	0.42	20	4	8	1.230584	0.999826	80	0.512736	1.771208	0.09	100	15.12784	67.0361
95	70	71	0.42	40	19	18	0.25	21	3	8	0.986071	0.999943	71	0.5	2.920838	0.05	745	2.850625	128.4307
96	75	72	0.66	22	18	25	0.26	22	2	7	0.550805	1.000214	6	2.46E-05	195359.6	0.05	869	2.542946	203.998
97	65	76	0.21	33	17	29	0.6	23	1	7	0.223122	1.000544	80	0.551774	5.458221	0.04	631	3.071905	148.901
98	45	71	0.23	35	15	26	0.5	22	15	7	3.621589	1.000538	70	0.485615	0.084538	0.02	2581	0.913516	63.95959
99	50	73	0.66	50	30	30	0.52	24	14	6	2.71669	1	60	0.310772	1.256031	0.2	9654	0.540731	157.955
100	40	63	0.57	41	20	30	0.53	13	13	6	3.594257	1.000556				0.6	183	10.74571	

MAP