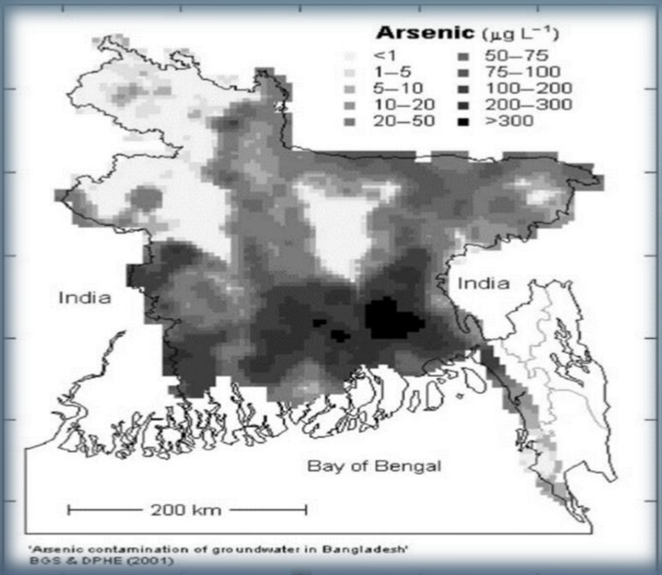
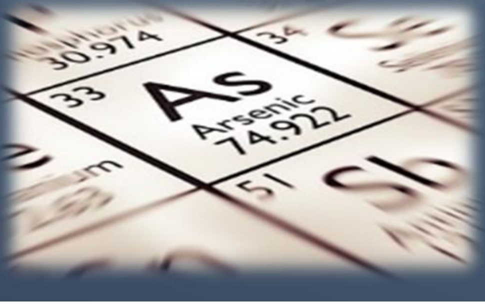
SEA LEVEL RISE AFFECTS GROUNWATER ARSENIC CONCENTRATIONS IN FOUR COASTAL DIVISIONS OF THE GANGES DELTA: IMPLICATIONS FOR WATER QUALITY SUSTAINABILITY

-MODELLED FROM THE YEAR 2000 UNTIL THE YEAR 2100-

Utrecht University





Author:	Esmée Mes, 5885604
Date:	28 June, 2019
Supervisor:	Jaivime Evaristo
Second reader:	Mara Baudena
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Table of contents

Summary

In Bangladesh, and especially in the groundwater of the four coastal divisions of the Ganges delta, the arsenic concentrations are above the limits set by the WHO and Bangladesh, which causes the population to experience severe health effects. Bangladesh is also susceptible to climate change, as it is heavily affected by the sea level rise and the accompanied salt water intrusion. This will change the conditions in the groundwater of the Ganges delta and subsequently affect the arsenic concentrations, but it is still unknown how, since no link has yet been found between these factors. The research question therefore is: *How will the effective sea level rise affect arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta from the year 2000 until the year 2100?* To research this question, Excel and SPSS are used and a literature review is conducted. Excel models the change of arsenic concentrations over time by using formulas found through the literature review. These formulas are analysed in SPSS. The results show that the effective sea level rise in Bangladesh amounts to 0.35 m between 2000 and 2100 and that arsenic concentrations will additionally change due to their relation with the molarity of bicarbonate and CO_2, pH, redox potential and ferrous iron. The molarity of bicarbonate and CO_2 will increase from 2000 to 2100 by 2.5 mol/L and by 0.03 mol/L. This subsequently increases the pH by 0.4, which directly influences the arsenic concentrations. The pH also has an indirect influence on arsenic through the redox potential and ferrous iron. The redox potential will decrease by 55 mV and ferrous iron will increase by 4.5 mg/L from 2000 to 2100. Together, the indirect and direct effect increase the arsenic concentration by 317 µg/L with a value of 1017 µg/L by 2100. Implications from this research are that the knowledge gap between sea level rise and the hereby changing arsenic concentrations is closed and that long-term predictions about arsenic concentrations can be done. This leads to the recommendation of implementing more long term measures to reduce the arsenic concentrations in groundwater.

Introduction

In the delta of Bangladesh, also known as the Ganges delta, high arsenic concentrations occur in the aquifers and groundwater (Nickson et al., 1998). This is especially the case in the four coastal divisions of the Ganges delta, which are Khulna, Barisal, Comilla and Chittagong (Appendix I; figure 1). These high arsenic concentrations are above the limits set by the World Health Organisation, which is 10 µg/L, and by Bangladesh, which is 50 µg/L (Smith, Lopipero, Bates & Steinmaus, 2002). These high arsenic concentrations have severe health effects on the inhabitants of Bangladesh. Already 33 to 77 million people are affected and have developed certain types of cancer, skin pigmentation and keratosis (Smith, Lingas & Rahman, 2000). This is not the only problem that occurs in the Ganges delta, as Bangladesh is considered to be the most vulnerable country to climate change (Paul & Rashid, 2017). The Ganges delta is heavily affected by sea level rise, and experiences frequent flooding (Karim & Mimura, 2008). This flooding causes salt water intrusion, which affects the groundwater conditions in the Ganges delta. These changed conditions subsequently affect the arsenic concentrations in this area (Snyder, Taillefert & Ruppel, 2004; Nordstrom, 2002). Therefore, the research question is: *How will the effective sea level rise affect arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta from the year 2000 until the year 2100?* To answer the research question, three sub questions have been formed. The first sub question is: *Which factors are influencing and causing the high arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta?* The second sub question is: *How much will the* *effective sea level rise be in the Ganges delta from the year 2000 until the year 2100?* The third sub question is: *How will the rising sea level change these factors and eventually thus the arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta?*

It is currently known that the rising sea level increases the amount of salt water intrusion (Paul & Rashid, 2017) and it is known that arsenic concentrations are high (Anawar et al., 2003). However there is a gap between these two issues, since it is still unknown how the sea level rise and the hereby changing groundwater conditions will influence the arsenic concentrations in the Ganges delta. Additionally, it is unknown how the population of Bangladesh will be affected by the arsenic concentrations in the future. It is for both the society and the government of Bangladesh of great importance to know whether and how the arsenic concentrations will change due to the rising sea level, because this way they know whether they need to implement more or less measures and technical solutions in the future to reduce the amount of arsenic in the groundwater. This again will reduce the amount of people affected. This also indicates the connection of this research to sustainability; researching changes in arsenic concentrations due to the effective sea level rise is of great importance, because research needs to be done on how this implicates the water quality sustainability. Furthermore, sustainable solutions need to be developed to ensure access to safe drinking water for future generations.

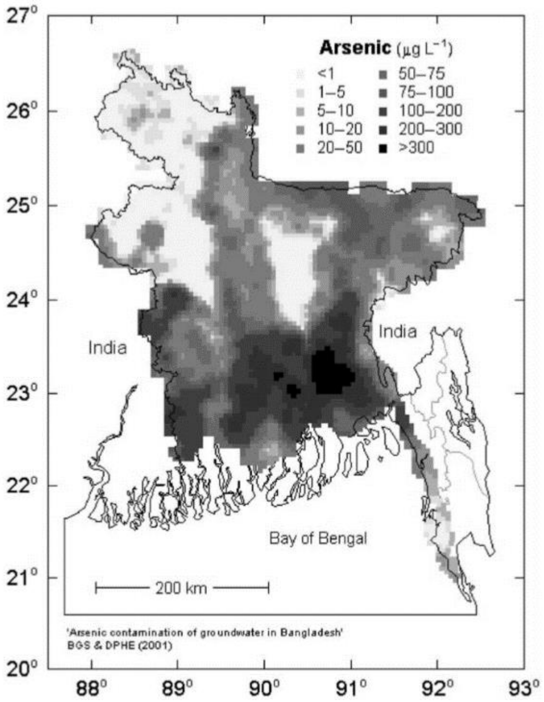

Fig. 1: Map showing the concentrations of arsenic in Bangladesh, which increase towards the coast (Ahmed et al., 2004).

Concepts and theories

Concepts

There are several key concepts related to this research, which are described and explained below.

Eustatic sea level rise

The eustatic sea level rise is determined by the volume of the global ocean and resembles the absolute sea level rise. It can increase due to melting of glaciers and ice caps and due to thermal expansion (Pethick & Orford, 2013; Paul & Rashid, 2017; Kay et al., 2015). Thermal expansion is the phenomenon whereby seawater increases in temperature, which decreases the density (Shamsuddoha & Chowdhury, 2007). This is currently happening, due to global warming (Paul & Rashid, 2017).

Subsidence

Subsidence is the phenomenon whereby the surface sinks (Brammer, 2014). It is caused by several processes, which are tectonics, human influences, sedimentation and sediment compaction. In Bangladesh, tectonics have a big influence on subsidence, but scientists also believe that compaction plays a large role in the subsidence of the Ganges delta (Brown & Nicholls, 2015; Paul & Rashid, 2017). Subsidence is approximately 2.0 mm/year, but according to other research can be as high as 20 mm/year (Brammer, 2014; Paul & Rashid, 2017).

Tectonic uplift

Tectonic uplift is a phenomenon whereby the surface rises. This is due to past ice ages, when water was stored in large glaciers, which made the surface subside. Currently, there is an interglacial period, in which the glaciers melt and pressure is released. This causes the uplift of the surface (Paul & Rashid, 2017). In Bangladesh, tectonic uplift lifts the surface by 3.6 mm/year (Paul & Rashid, 2017).

The effective sea level rise

The effective sea level rise resembles the relative sea level rise, which is the rate of the sea level change relative to the delta surface and is influenced by the level of the delta surface and the eustatic sea level rise. The level of the delta surface can change because of subsidence and tectonic uplift, which are described above (Pethick & Orford, 2013; Karim & Mimura, 2008; Shamsuddoha & Chowdhury, 2007; Paul & Rashid, 2017).

Salt water intrusion

Because of the sea level rise, more and further-inland intrusion of seawater will occur in the future (Ministry of foreign affairs, 2018; Pethick & Orford, 2013). This salinization is secondary salinization, since the increase in salt concentrations is not due to the change between glacial and interglacial cycles (primary salinization), but due to global climate change (Paul & Rashid, 2017). Seawater has a different composition than regular saline water. Seawater contains mostly Sodium (N+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Carbonate ($CO3^-$), Bicarbonate (HCO_3^-) and sulphate (SO_4^-) (Millero, Feistel, Wright & McDougall, 2008; Paul & Rashid, 2017).

Arsenic

Arsenic (As) is a chemical element (number 33 in the periodic table) that can be taken up into the minerals of other elements, such as pyrite (FeS). Once arsenic is taken up into the mineral of pyrite, pyrite changes into arseno-pyrite (AsFeS). Arsenic can also be adsorbed onto other elements, such as iron and can be in competition for adsorption places with other elements, such as phosphorus (Van der Perk, 2013). Arsenic occurs naturally in the groundwater of Bangladesh and the concentrations of arsenic here are abnormally high, since the concentrations are far above the limits set by both the World Health Organisation, 10 µg/L, and Bangladesh, 50 µg/L (Smith et al., 2002; Nickson et al., 1998).

pH

The pH is the hydrogen ion concentration (H^+) in a solution. This can be calculated using the following formula: $pH=-log[H^+]$. When the pH is below 7, the solution has a high concentration of H^+ ions and the solution is acidic. At pH is 7, the solution is neutral and when the pH is above 7, the solution is alkaline. This means that the solution has few H^+ ions and high concentrations of OH^- ions (Hendriks, 2010; Hem, 1972).

Redox potential

Redox potential (E_h) is a concept that is involved in redox processes. Redox processes are chemical reactions, in which an electron from one ion is transferred to another ion. The redox potential is the tendency of an ion to lose or acquire an electron in a redox process, which makes the ion reduced or oxidised (Hem, 1972; Van der Vecht & Gijben, 2016). The redox reaction rates and directions are determined by the lack of the availability of oxygen in the environment. Oxygen has the highest redox potential and is therefore first in line to be reduced to H_2O (see fig. 2). Organic matter has the lowest redox potential and is the ultimate reductant. Hence, organic matter consumes oxygen, which leads to bacterial reduction and the breaking down of organic matter (Groundwater Geochemistry, n.d.). However, when oxygen is not available, another substance is needed to break down organic matter through microbial degradation. Then, the order of redox potential is followed (see figure 2). When oxygen is depleted, nitrate is used as a reducer instead of oxygen and so forth (Van der Perk, 2013; Groundwater Geochemistry, n.d.).

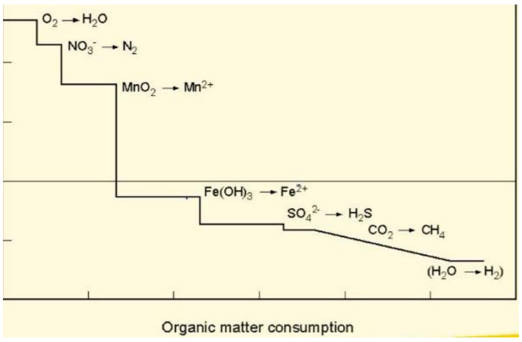

Fig. 2: Redox reactions; the lower on the ladder, the lower the potential (Van der Perk, 2013).

Theories

The theories described below are connecting the mechanisms of arsenic mobilisation to the concepts explained above.

Reduction hypothesis

The most supported hypothesis about arsenic mobilisation is the reduction hypothesis (Ahmed et al., 2004). The reduction hypothesis is connected to the concept redox potential, which is explained above. When oxygen, nitrate and manganese are all depleted, ferric iron ($Fe(OH)_3$) can be used as a reducer to break down organic matter (Van der Perk, 2013). In an oxic environment, arsenic species can adsorb onto iron hydroxide by replacing a hydroxide ion (H^+) on the surface of iron hydroxide (Van der Perk, 2013; Anawar et al., 2003; Jain, Raven & Loeppert, 1999). In an anoxic environment, ferric iron is reduced and is transferred into ferrous iron (Fe^{2+}) as is displayed in figure 2. Ferrous iron is a form of iron that is much more soluble than ferric iron (Anawar et al., 2003). Because of this increased solubility, arsenic cannot readily be adsorbed onto the surface and is released (Brammer & Ravenscroft, 2009). This is what is meant by the reduction hypothesis: the reductive dissolution of arsenic-rich iron (Nickson, McArthur, Ravenscroft, Burgress & Ahmed, 2000).

pH in connection with arsenic

The pH is also connected to arsenic, which can readily be explained when looking at the mechanism of deprotonation. When the water is more alkaline, H^+ ions are removed (deprotonation) from the surface of iron hydroxide due to competition with the other bases in solution. As a consequence, the negative charge on the surface of the iron hydroxides increases with increasing pH and thus the capacity to adsorb anions, such as arsenate/arsenite decreases. So the higher the pH, the more arsenic is mobilised and the higher the concentrations in the groundwater (Van der Perk, 2013; Anawar et al., 2003).

Salt water intrusion and pH

Salt water intrusion into groundwater leads to the mixing of seawater and fresh water. This causes a change in the pH, which again has an effect on arsenic, as is described above (Anawar et al., 2003). The pH is influenced by the concentration of H^+ ions in the water. The amount of CO_2 and bicarbonate (HCO_3^-) in the water influences the amount of H^+ ions. The increase of CO_2 in the seawater due to climate change will not be taken into account, since this goes beyond the scope of this study. The relation between CO_2 and H^+ is displayed in this equilibrium formula:

$2\,H_2O + CO_2 \leftrightarrow H_3O^+ + HCO_3^-$ (Bozlee & Janebo, 2008).

H_3O^+ is similar to H^+, as it is a H^+ ion that has reacted with water. Because the formula is an equilibrium formula, there is an acid dissociation constant, K_a. This is the equilibrium constant for an acid-base reaction (Van der Vecht & Gijben, 2016). For seawater, all the concentrations are known, so the K_a value can be calculated using the equilibrium formula and the pH-formula (Van der Vecht & Gijben, 2016; Hendriks, 2010):

$K_a = \frac{[H_3O^+]\,[HCO_3-]}{[CO_2]}$ $pH = -log[H^+] \rightarrow H^+ = 10^{-pH}$

It is known that the pH of seawater is 8.1, which will be used to calculate the molarity of H^+ in mol/L: $H^+=10^{-8.1} = 7.94 \times 10^{-9}$ mol/L (Millero et al., 2008). The value of $[HCO_3^-]$ is known in mol/kg, which is 0.0017803. It can be recalculated to mol/L by using the density of seawater. The density of seawater is 1.025 kg/L, so 0.0017803 x 1.025= 1.83×10^{-3} mol/L (Millero et al., 2008; Hendriks, 2010). $[CO_2]$ value is also known in mol/kg, which is 0.0000100 mol/kg and is transferred to mol/L by again using the density of seawater: 0.0000100 x 1.025 = 1.025×10^{-5} mol/L (Millero et al., 2008).

Inserting these numbers into the formula gives

$K_a=\frac{[7.94\ x\ 10^{-9}]\ [1.83\ x\ 10^{-3}]}{[1.025\ x\ 10^{-5}]} = 1.414\ x\ 10^{-6}$ (Millero et al., 2008; Van der Vecht & Gijben, 2016).

Because this K_a-value stays the same for the reaction in groundwater, and the molarities in groundwater will be calculated for CO_2 and HCO_3^-, the pH can be calculated for groundwater.

Relation of pH and redox potential

A change in redox potential (E_h) is related to the pH of the surrounding water. As was described above, the pH will change when seawater and groundwater mix. Due to this mixing, the pH of the groundwater will increase. The higher the pH, the lower the redox potential (Xyla et al., 1992). This is indicated by the Nernst equation:

$E_h = E_0 + \frac{0{,}05916}{n} log\ (\frac{\{A\}\ \{B\}}{\{C\}\ \{D\}} - \frac{0{,}05916h}{n} pH$ (Bundschuh & Sracek, 2011).

When the pH increases by 1.5, the redox potential will decrease by 200 mV (Sondergaard, 2009). The lower the redox potential, the more an electron wants to be released, which causes the oxidation of the new species (Oregon State University, n.d.; Sondergaard, 2009). This means that there will be more ferric iron transferred to ferrous iron. Ferrous iron is more soluble and has less adsorption sites, which means that more arsenic desorbs (Sondergaard, 2009). An increase in pH and hereby decreased redox potential will thus both lead to higher arsenic concentrations.

The connection between sea level rise and groundwater

The rate of sea level rise has an influence on the amount of seawater that ends up in the groundwater. This again has an influence on the molarities of HCO_3^- and CO_2 in the groundwater and subsequently on the pH (Bozlee & Janebo, 2008). The influence of the rate of sea level rise on the amount of seawater in an aquifer/groundwater can be determined using the Ghijben-Herzberg relation. This is the relation between freshwater above the mean sea level and freshwater below sea level, which is similar to the amount of freshwater in an aquifer. The relation is this:

$$z = \frac{\rho_f}{\rho_s - \rho_f} h.$$

ρ_f=the density of freshwater, ρ_s=the density of seawater, z=the depth of the freshwater above sea level and h=the depth of the freshwater below sea level (Hendriks, 2010; Werner & Simmons, 2009). Currently, z is 6 meters, since the coastal areas of the Ganges delta are still 6 meters above sea level, according to figure 3 and Tareq, Safiullah, Anawar, Rahman & Ishizuka

(2003). This means that there is still a recharge area of 6 m. However, this will get smaller due to sea level rise, which also results in a decrease of h. The decrease in h will reveal the area of groundwater that is affected by the sea level rise.

When this is determined, the new molarities of bicarbonate and CO_2 in the groundwater due to salt water intrusion can be calculated using Fick's law of diffusion. Diffusion is the process in which substances move from a high concentration to a low concentration, which is due to the concentration gradient (Van der Perk, 2013). Seawater has a different concentration of substances than groundwater, so when seawater enters the groundwater, there are differences in the concentrations of bicarbonate and CO_2. Because of these differences in concentration, diffusion will take place. In this research, molarity will be used instead of concentration. Fick's law of diffusion is displayed by this formula:

$$J = -D\,\frac{C2-C1}{x2-x1}.$$

J=the flux of the substance in mol/m^2/s , D=the diffusion coefficient, which is $1.6*10^{-9}$ m^2/s for bicarbonate and $2.1*10^{-9}$ for CO_2, c_2/c_1=the concentrations of bicarbonate/CO_2 in seawater and fresh water or in this research the molarity of both bicarbonate and CO_2 and x_2/x_1=the distance of diffusion, which in this case is the decrease in h (Van der Perk, 2013; Solutions to the diffusion equation, 2006; Zeebe, 2011).

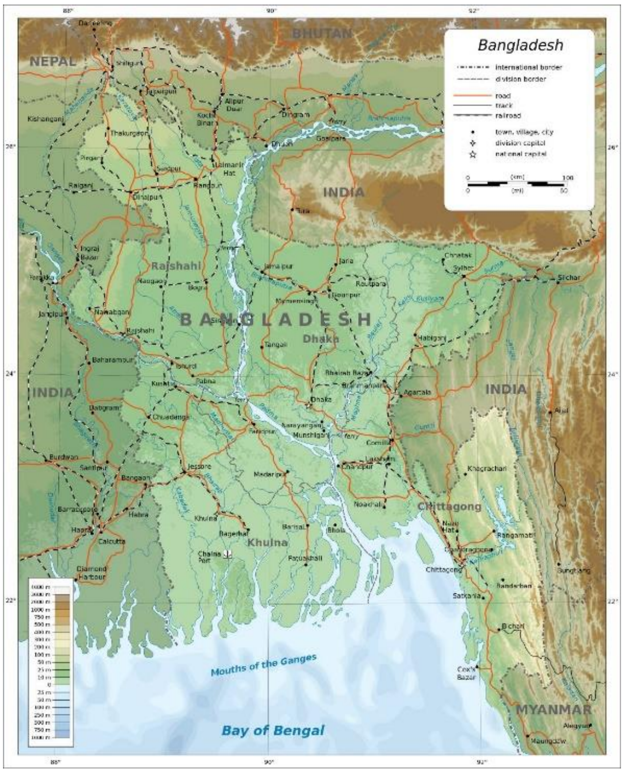

Fig. 3: Surface level relative to the sea level (Large detailed physical map of Bangladesh, n.d).

Literature review

In this research, literature is used which can be divided into three themes. The first theme is literature related to the mobilisation processes of arsenic (sub question 1). This literature was used to determine the most important variables related to the potential change of arsenic concentrations, such as redox potential and pH.

The second theme is related to the sea level rise (sub question 2), such as the tectonic uplift, subsidence and eustatic sea level rise. These variables were all found through the literature related to this theme and were the first input variables of the model.

The third and last theme is related to the connections of the variables found for the first theme described above. This theme is thus related to the redox potential, pH and other variables that were found to have an influence on the arsenic concentrations. This theme specifically looks at the formulas and connections between these variables to ensure that there is a connection and to ensure that the model works (sub question 3).

The division of literature into themes (see table 1) displays the contribution of these sources to the existing body of literature. There is a theme on mobilisation processes of arsenic and a theme related to the sea level rise. However, a third theme is needed to connect these themes, because there is a knowledge gap.

Table 1: This table displays which literature contributes to which theme.

THEME	LITERATURE CONTRIBUTING TO THEME
1. MOBILISATION PROCESSES OF ARSENIC	• Aggarwal et al., 2000 • Ahmed et al., 2004 • Anawar, 2003 • Anawar, 2002 • Brammer & Ravenscroft, 2009 • Jain et al., 1999 • Nickson et al., 1998 • Nickson et al., 2000 • Nordstrom, 2002 • Van der Perk, 2013
2. SEA LEVEL RISE	• Brammer, 2014 • Brown & Nicholls, 2015 • Karim & Mimura, 2008 • Kay et al., 2015 • Paul & Rashid, 2017 • Pethick & Orford, 2013 • Shamsuddoha & Chowdhury, 2007
3. CONNECTIONS BETWEEN VARIABLES	• Bhattacharya, Jacks, Ahmed, Routh & Khan, 2002 • Bozlee & Janebo, 2008 • Bundschu & Sracek, 2011 • Groundwater geochemistry, n.d. • Hem, 1972 • Hendriks, 2010 • Kvaternyuk et al., 2016 • Millero et al., 2008 • Nickson et al., 1998

	• Oregon State University, n.d. • Paul & Rashid, 2017 • Solutions to the diffusion equation, 2006 • Sondergaard, 2009 • Tareq et al., 2003 • Van der Perk, 2013 • Van der Vecht & Gijben, 2016 • Werner & Simmons, 2009 • Xyla et al., 1992 • Zeebe, 2011
4. SOURCES USED FOR OTHER PURPOSES, SUCH AS INTRODUCTION, INFORMATION ON INPUT OF DATA AND INFORMATION ON EXCEL	• Ahmed, 2001 • Baier & Neuwirth, 2003 • Bangladesh on the globe, 2014 • Billo, 2004 • Field 2018 • Large detailed map of Bangladesh, n.d. • Mahanta et al., 2015 • Ministry of foreign affairs, 2018 • Smith et al., 2000 • Smith et al., 2002 • Snyder et al., 20024 • Yang et al., 2014

Conceptual framework

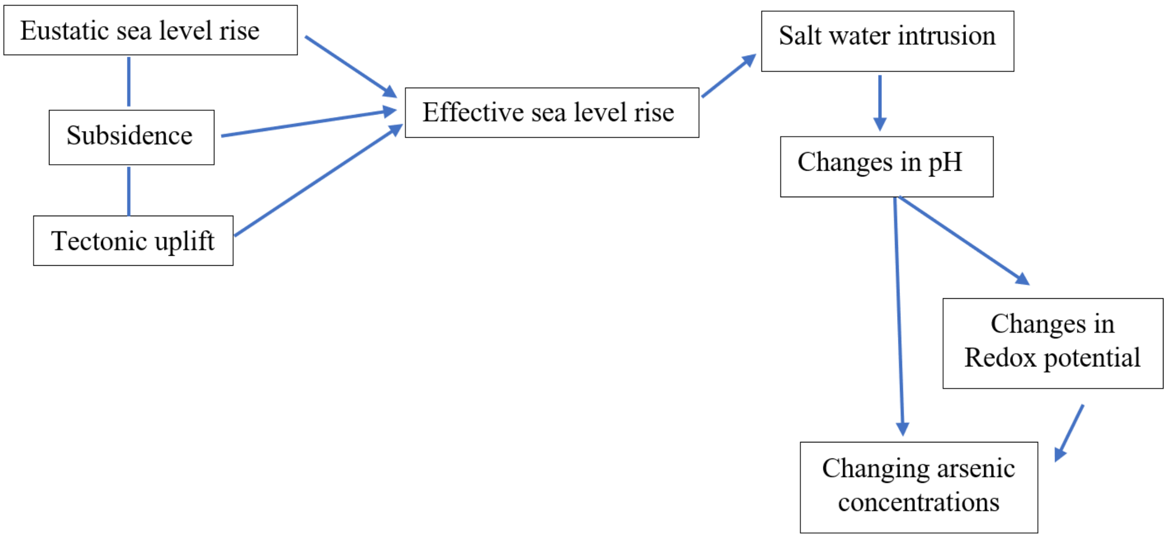

Fig. 4: The conceptual model gives an overview of the relations between the concepts and serves as the first step to visualising the model.

The conceptual framework displays the relations between the concepts. Eustatic sea level rise, subsidence and tectonic uplift all affect the effective sea level rise. The effective sea level rise has an effect on salt water intrusion, which is described under theories in ‘The connection between sea level rise and groundwater/aquifers´. Salt water intrusion has an effect on the pH, which has an effect on the redox potential. This is explained in theories under ‘Salt water intrusion and pH’ and ‘Relation of pH and redox potential’. The pH and redox potential both affect arsenic concentrations in the Ganges delta, which is explained in theories under ‘pH in connection with arsenic’ and ‘The reduction hypothesis’.

Analytical framework

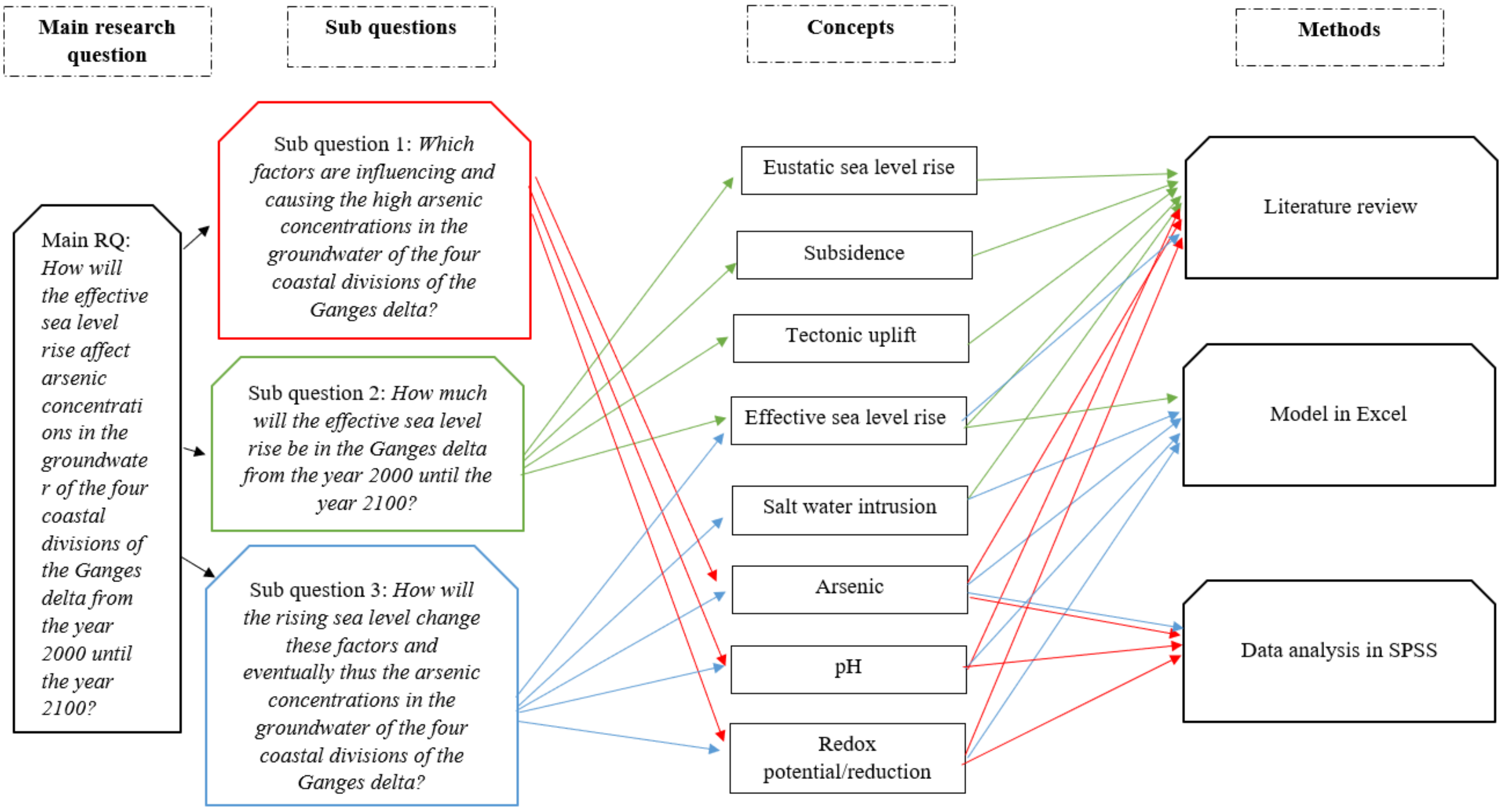

Fig. 5: The analytical model connects the sub questions, through all the concepts that were discussed, to the methods that are used in this research.

In figure 5, the analytical framework is displayed, which shows how the sub questions and related key concepts will be measured. It is divided into four parts: the main research question, the sub questions, the key concepts and the methods. In the method section, the analytical framework is explained in more detail.

Methodology

Methodology first sub question

In this research, there is one main research question and three sub questions which all require their own methodology. The first sub question relates to the factors that are influencing and causing the high arsenic concentrations (the red box in figure 5). For this sub question, a literature review must be conducted to determine which factors influence the mobilization processes of arsenic. In the described theories and concepts, two important factors are already identified to have the largest influence on arsenic concentrations, which are the pH and redox potential. Additionally, the relations between these factors need to be analysed in SPSS through regression analysis and a multiple regression analysis will be done to discover which of these factors influence the arsenic concentrations the most.

Methodology second sub question

The second sub question (the green box in figure 5) is related to the sea level concepts. For these concepts, such as subsidence, eustatic sea level rise and tectonic uplift, data are found through the literature review. Data collection is crucial for this sub question, since it is assumed that the pH has an empirical relation to the effective sea level rise. The effective sea level rise is modelled in Excel, which is feasible, since no yearly numbers are needed for the related variables, solely numbers that indicate the increase per year.

Methodology third sub question and main research question

To answer the third sub question (the blue box in figure 5), first a literature review needs to be conducted, which indicates how the sea level rise will change the factors that influence the arsenic concentrations and is already shortly described in ‘theories’. After data is found in the literature review for the changed conditions, the second part of sub question 3 and the main research question will be answered by building a model in Excel in which the data found in the literature review will be used. Excel will provide graphs, that visualise the changes of the factors that influence arsenic concentrations due to sea level rise. SPSS will visualise changes in arsenic concentrations in groundwater over time through descriptive statistics for the main research question.

Description of study area

The wider study area is Bangladesh (figure 6), which is a country in Southern Asia with a coastal area that covers 32% of the country’s area. About 46 million people live in this coastal area (Paul & Rashid, 2017). Bangladesh has a large delta, which forms due to deposition of sediments by a river that mouths into the ocean (Ministry of foreign affairs, 2018). The delta in Bangladesh is the largest delta in the world and is called the Ganges-Brahmaputra delta. It is adjacent to the Bay of Bengal (Shamsuddoha & Chowdhury, 2007) and consists of layers of silt, sand and clay. The sediments deposited by the Ganges rivers consist mostly of heavy clay (Aggarwal et al., 2000). The specific study area comprises of the four coastal divisions of the Ganges delta: Khulna, Barisal, Comilla and Chittagong (figure 7). These four divisions are adjacent to the Bay of Bengal and are all under the distance of the calculated 80 km (see appendix I).

Fig. 6: Location of Bangladesh on a world map (Bangladesh on the globe, 2014).

Fig. 7: Map showing the four coastal divisions of the Ganges delta: blue=Khulna; orange=Barisal; purple=Comilla and yellow=Chittagong.

Data selection

To clarify, three types of methods will be used in this bachelor thesis: a literature review, modelling in Excel and analysis through SPSS. For building the model in Excel, a chain of formulas is used which connects all the variables. These formulas are found through the literature review and will be analysed using SPSS to check their regression and significance. The type of data that is collected will be quantitative and no databases will be used. The data will be selected based on the published year of the article, preferably around the year 2000, since the timeline of this research extends from the year 2000 to 2100. The year 2100 is chosen as the last year, because this year is mostly used for predictions in climate. The data will additionally be selected based on location, as is described above under 'description of study area'.

Validation, replicability, replication and justification

The literature review, Excel and SPSS are applicable in this research study and can be justified. The literature review is needed to form theories and find data and formulas that can be used to form the model and also to validate the model. Excel and SPSS can be justified by the short time frame for this research, combined with the acquaintance of the author with the software and accessibility of the software. Excel is easy to use and can be used to build a model that uses a chain of formulas for every separate year, but still provide the overall picture clearly, which the described problem in this research needs. Furthermore, Excel can organise large amounts of data into simple graphs and tables that are easy to read. Cells can also be connected, which means that it can adapt all of its data at once when new findings are found (Baier & Neuwirth, 2003).

Excel also has some shortcomings. It cannot check for human error when data is entered, which can have a strong negative influence on the results. Additionally, Excel can be time consuming when manually entering the data. In this research, the data is kept to a number that is feasible, so that mistakes are prevented (Billo, 2004).

There is a bulk of literature available about arsenic and sea level rise in which the variables involved in this research problem can be found. Yet, there are different ways to connect these variables in a model and different variables can be chosen from this literature. If another researcher would model this research, there is a possibility that different results would be found, which implicates the reliability slightly. The model will be validated in the discussion by comparing the found arsenic concentrations to the numbers and theories found in the literature. The model can be replicated using the provided formulas and data of this research. All the data will be provided in as much detail as possible, so that replication can be achieved (appendix III).

Data analysis

After the initial research and both before and after modelling in Excel, data analysis is conducted by using SPSS. This data analysis will focus on whether the formulas found in literature will have a high Pearson or Spearman correlation and whether these will produce significant results. If the formula seems correct, but another has a higher coefficient of determination, this formula will be used instead. To deal with uncertainty, a GLM 'General Linear Model' is performed in SPSS, which displays the Mean Squared Error and gives an indication of the uncertainty. The closer to zero, the lower the uncertainty. After the formulas are determined, a multiple regression analysis is performed to check which variable has the largest impact on changing the arsenic concentrations. This multiple regression analysis will be used to answer sub question 1 as is described above. The main research question also requires data analysis in the form of descriptive statistics. The change in arsenic concentrations will be analysed for every ten years, which displays in what period of time the change was largest.

Ethical issues

In this research, no field work or interviews are done, so only plagiarism and fraud are ethical issues that need to be prevented. Since the research problem is something that is never modelled before, fraud will be prevented. Plagiarism is avoided by citing the information used correctly, so that credit is given to the rightful authors. Shortly said, information that is written by other authors will be used but not copied, and credits will be given to these authors.

Results

The model is made in Excel through a chain of calculations (figure 15, appendix II). To do these calculations, formulas are needed, so the found formulas are analysed below under sub question 1 to confirm that there is a significant correlation. The other sub questions and main research question display graphs from after the model was built. Data analysis for these questions was only applicable to the main research question. The calculations done previous to the modelling part are displayed in appendix I. The results are structured by following the sub questions and main research question, since this corresponds to the analytical framework (figure 5).

Sub question 1

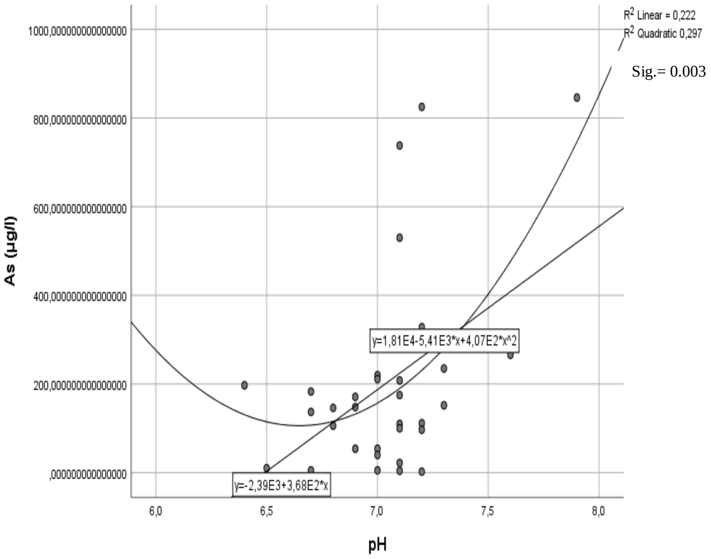

Fig. 8: Scatterplot of relation pH and arsenic concentrations with the coefficients of determination and significance in the right top corner.

The pH influences the arsenic concentrations, as can be seen in figure 8. In this figure, the relation between pH and arsenic is analysed. For the relation between pH and arsenic, a linear trend is chosen, since the difference in the coefficient of determination (R^2) is fairly small. Another reason to choose the linear trend is that the parabolic curve is very sensitive to specific scores and outliers and because the linear trend displays the main trend better (Field, 2018). The trend has a medium linear association (Field, 2018) and the correlation is significant according to the test of Pearson's R (table 6, appendix IIII). The ANOVA using GLM test indicates that the mean squared error, also known as the uncertainty, is still extremely large. However, since this is the formula with the highest R^2 and lowest uncertainty of the two formulas found, this formula is still used (table 7, appendix IIII). The linear trend displays that when the pH increases by 0.1, the arsenic concentrations increase by 36 µg/L. This is however an increase due to the direct relation of the pH and arsenic, and does not include the indirect effect due to the relation of pH, redox potential and ferrous iron described further below.

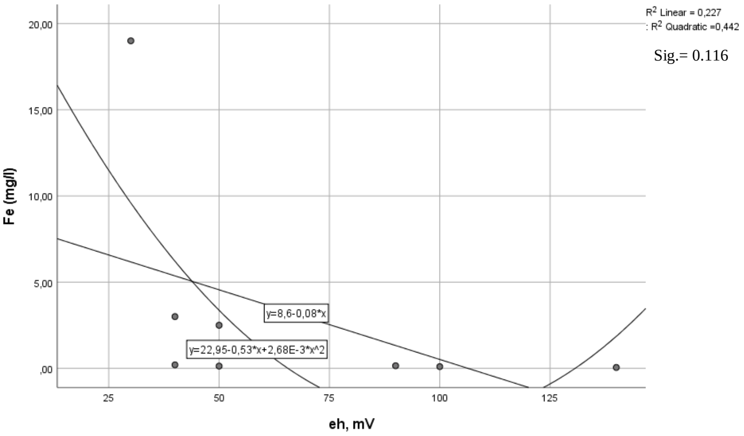

Fig. 9: Scatterplot of relation redox potential and ferrous iron with the coefficients of determination and significance in the right top corner.

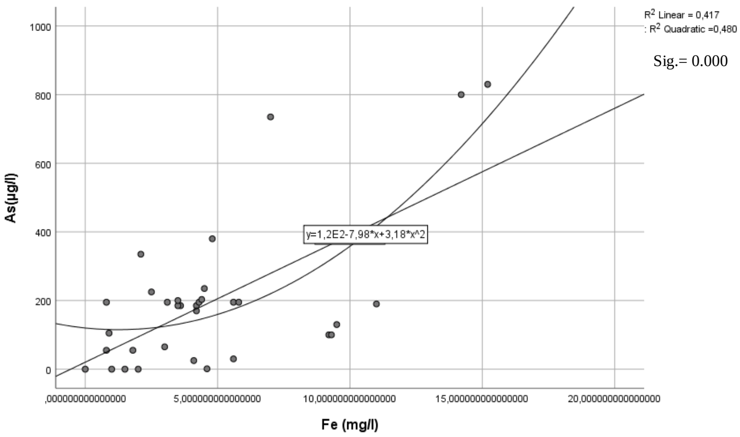

Fig. 10: Scatterplot of relation between ferrous iron and arsenic concentrations with the coefficients of determination and significance in the right top corner.

The pH, redox potential and ferrous iron are connected and affect the arsenic concentrations through a series of relations with each other. The formulas belonging to these relations are again analysed in figure 9 and 10. The relation between pH and redox potential is already perfectly linear, since there are only 4 data points, which is why data analysis is not conducted for this relation and the found formula is used (formula 12, appendix III).

The linear relation between the redox potential and the ferrous iron concentration has a coefficient of determination of 0.227 and the quadratic relation has a coefficient of determination of 0.442 (figure 9). Still the linear formula will be chosen to use in the model, since the quadratic trend has negative values between 125 and 75 mV, which is unrealistic. The linear line does explain the main trend and still has a medium linear association (Field, 2018). The Pearson's R test is again used for analysis, which shows a result that is not significant (sig.=0.116). However, when bootstrapping is applied, the results are significant, since zero is not included in the confidence interval (table 8, appendix IIII). The formula will thus be used, especially because the ANOVA using GLM test shows that the mean squared error or the uncertainty is only 3.364, which is very small (table 9, appendix IIII).

Figure 10 describes the relationship between ferrous iron and arsenic. Again both quadratic and linear trends are analysed and the difference between the coefficients of determination is small. The linear trend is again chosen for the same reason as was described earlier. The coefficient of determination is 0.417, which indicates a strong linear association (Field, 2018). The Pearson's R test reveals a significance of 0.000, which means that the relation is significant. The uncertainty for this relation is 5909 (table 10 and 11, appendix IIII). The linear relation is positive and an increase of 1 mg/L will cause the arsenic concentrations to increase by about 37 µg/L (figure 10).

To test which of the three variables, the pH, redox potential and ferrous iron, has the largest influence on the arsenic concentrations, a multiple regression analysis is done. The multiple regression analysis shows that the pH has the highest standardised coefficient, so it has the largest influence on the arsenic concentrations. The redox potential has the second largest influence, since it's standardised coefficient is the second largest. The ferrous iron concentration has the smallest influence on the arsenic concentrations, since its standardised coefficient is the smallest (table 12, appendix IIII).

Sub question 2

The model displays the change in effective sea level rise over the period 2000-2100. The relationship is linear and Excel displays that the sea level rise changes every year by 0.0035 m and by 0.35 m between 2000 and 2100.

Sub question 3

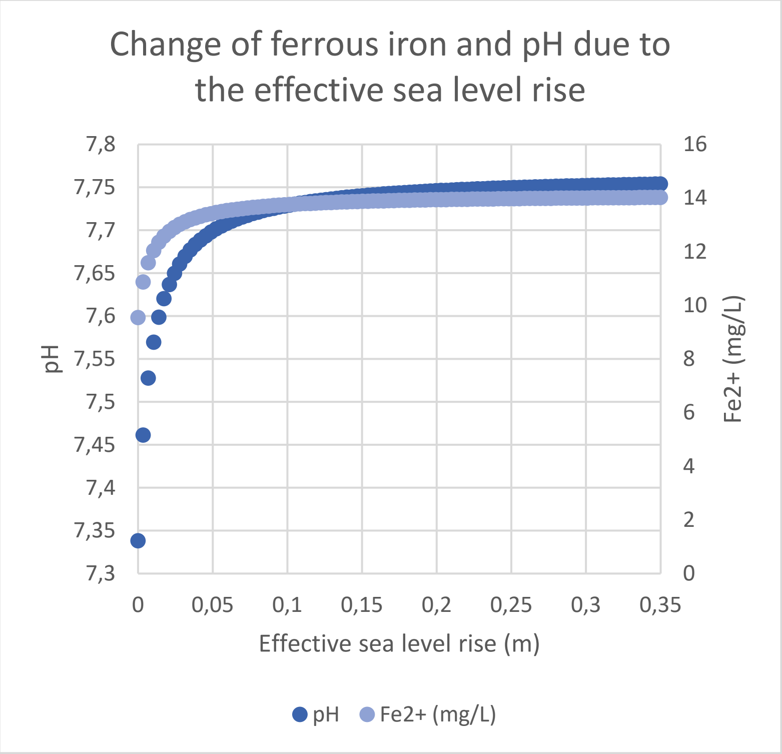

Fig. 11: The figure shows how the change in effective sea level rise changes the factors of pH and ferrous iron.

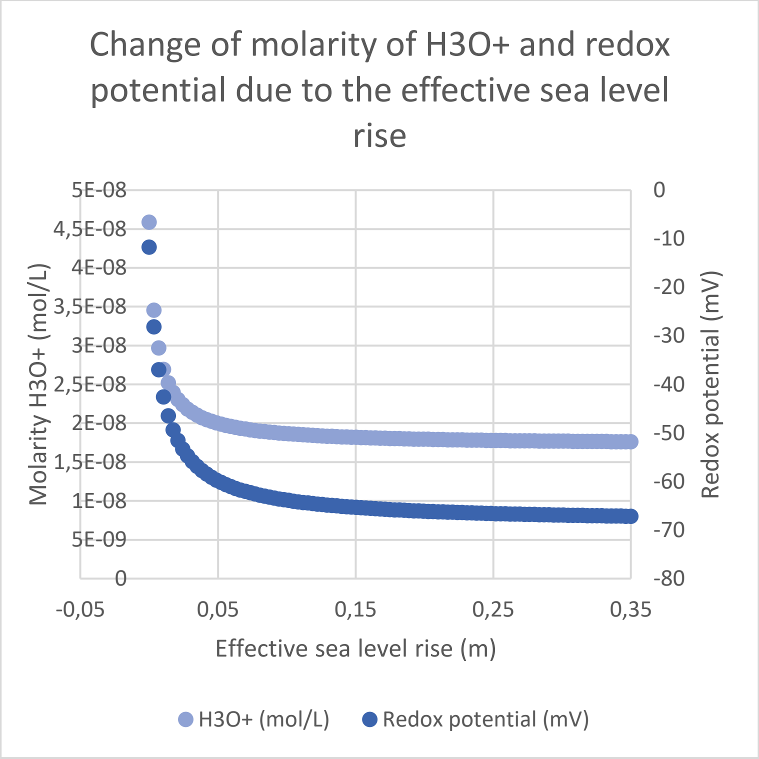

Fig. 12: The figure shows how the change in effective sea level rise changes the redox potential and the H_3O^+ molarity.

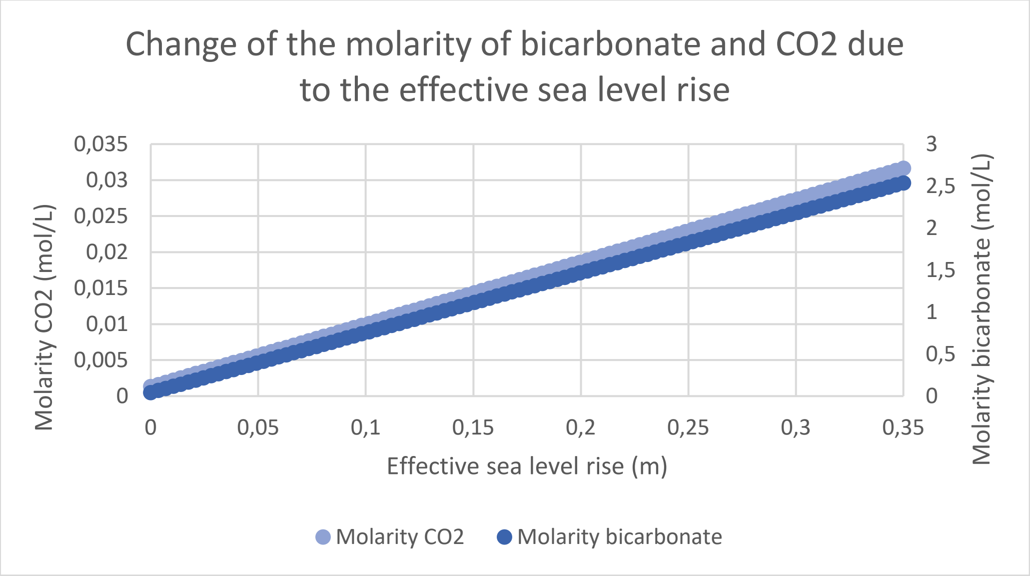

Fig. 13: The figure shows how the change in effective sea level rise changes the molarity of both CO_2 and HCO_3^-.

The rising sea level will change the other variables through a chain of events. The higher the sea level rise, the higher the molarity of CO_2 and bicarbonate, the pH and the concentration of ferrous iron as can be seen in figure 11 and 13. An effective sea level rise of 0.35 m will increase the molarity of bicarbonate by 2.5 mol/L, the molarity of CO_2 by 0.03 mol/L, the pH by about 0.4 and the concentration of ferrous iron by 4.5 mg/L. However, the higher the effective sea level rise, the lower the redox potential and the lower the molarity of H_3O^+, as can be seen in figure 12. An effective sea level rise of 0.35 m will decrease the molarity of H_3O^+ by about $2.8x10^{-8}$ mol/L and the redox potential by 55 mV. The relations of the CO_2 and bicarbonate molarities are linear to the sea level rise. The relations between the effective sea level rise and the pH, redox potential, the concentration of ferrous iron and the molarity of H_3O^+ are however logarithmic.

Main research question

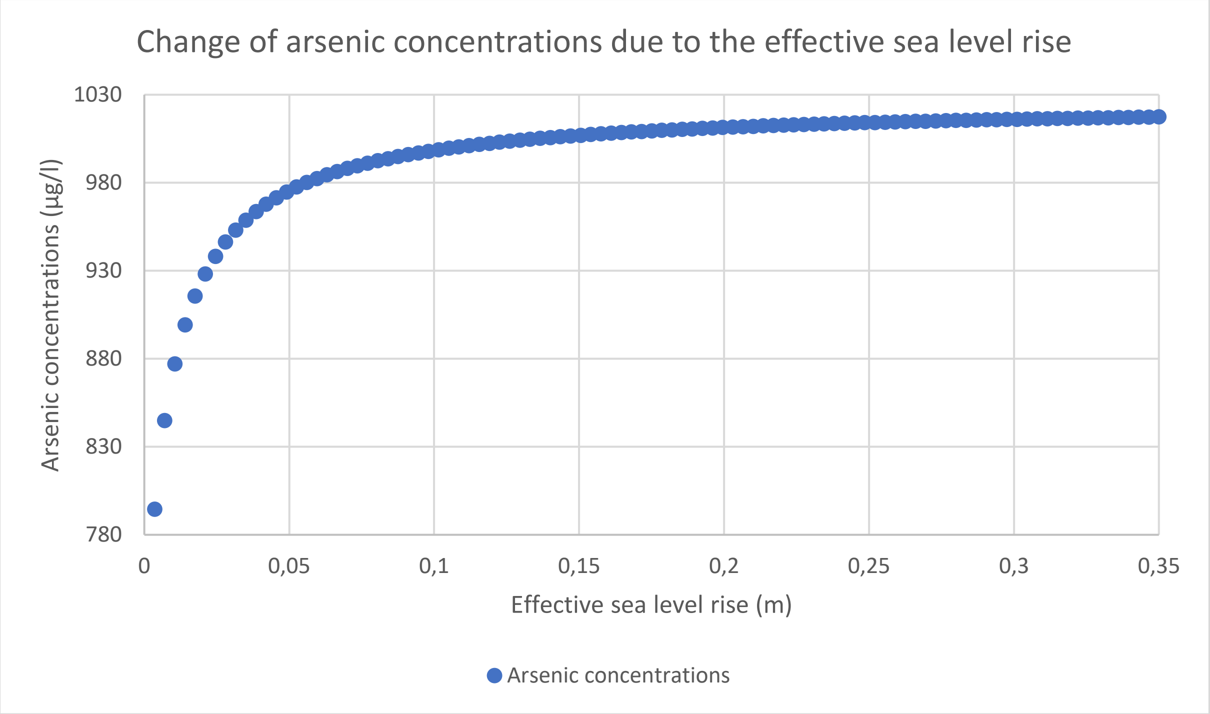

Fig. 14: The graphs shows how the effective sea level rise changes the arsenic concentrations.

Figure 14 shows that the effective sea level rise will cause higher arsenic concentrations through a logarithmic relationship. The graph displays that when the effective sea level rises by 0.35 m, the arsenic concentrations increase in total by 317 µg/L. In 2100, the arsenic concentrations amount to 1017 µg/L. The increase of arsenic concentrations slows down when the effective sea level rise increases and is different for different periods between 2000 and 2100, which is analysed using descriptive statistics (tables 13 through 22, appendix IIII). In these tables it is visible that the difference between the minimum and maximum value becomes smaller every ten years and that also every ten years the standard deviation, variance and standard error become smaller.

Discussion

Answering the sub questions and main research question

Research has been done on the arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta and how these concentrations would change due to the effective sea level rise. The research questions will be answered in this section.

The first sub question was: *Which factors are influencing and causing the high arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta?* The literature review revealed that the most important factors to influence the arsenic concentrations are the pH, the redox potential and the ferrous iron concentrations. The pH will influence arsenic concentrations directly through deprotonation. The higher the pH, the more arsenic is mobilised, which is visible in figure 8 of the results (Anawar et al., 2003; Ahmed et al., 2004; Nickson et al., 2000). The pH also influences the arsenic concentrations indirectly through the redox potential and the concentration of ferrous iron in the groundwater, which can be explained by the reduction hypothesis. A higher pH decreases the redox potential, which will transfer more ferric iron into ferrous iron, because of the more reduced environment (Sondergaard, 2009). Ferrous iron is more soluble and therefore has less adsorption sites, which mobilises arsenic (Sondergaard, 2009; Nickson et al., 2000; Van der Perk, 2013; Anawar et al., 2003), which is visible in figure 9 and 10. The molarity of bicarbonate, CO_2 and H_3O^+ were also important, since these influence the pH through the equilibrium reaction of:

$2\ H_2O + CO_2 \leftrightarrow H_3O^+ + HCO_3^-$ (Bozlee & Janebo, 2008; Van der Vecht & Ghijben, 2016).

The data analysis found applicable formulas for the relations between the pH, redox potential, ferrous iron and arsenic concentrations and showed that the pH both has a direct and indirect effect on the arsenic concentrations as was described above. A multiple regression analysis showed that the pH is the most important variable to influence the arsenic concentrations in the Ganges delta, followed by the redox potential and ferrous iron (table 12, appendix 4). This can be expected due to the direct and indirect effect that the pH has on the arsenic concentrations.

After looking into the factors that influence the arsenic concentrations it should be made clear how much the effective sea level rise will amount to in the Ganges area. Therefore sub question 2 was: *How much will the effective sea level rise be in the Ganges delta from the year 2000 until the year 2100?* The effective sea level rise depends on three different factors, which are subsidence, tectonic uplift and the eustatic sea level rise. The numbers found for these factors are constants, so every year the increase or decrease is equal to the previous year. This explains why the effective sea level rises changes by the same amount for every year between 2000 and 2100. When combining these factors in Excel, the sea level rise will amount to 0.35 by the year 2100 and increases by 0.0035 per year (Pethick & Orford, 2013; Karim & Mimura, 2008; Shamsuddoha & Chowdhury, 2007; Paul & Rashid, 2017).

These previous two sub questions together lead to sub question 3: *How will the rising sea level change these factors and eventually thus the arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta?* The rising sea level will first increase the amount of bicarbonate ions and CO_2 ions in the groundwater, since diffusion will take place due to the molarity differences of bicarbonate and CO_2 (Van der Perk, 2013). More bicarbonate ions and CO_2 ions will be added to the groundwater due to the rising sea level, which will change the HCO_3^- molarity of the groundwater as can be seen in this equilibrium reaction:

$2\,H_2O + CO_2 \leftrightarrow H_3O^+ + HCO_3^-$ (Bozlee & Janebo, 2008).

Additionally, the HCO_3^- molarity in the groundwater changes even more due to the fact that HCO_3^- is released when ferric iron is transferred into ferrous iron due to the more reduced conditions (Nickson et al., 1998; formula 14, appendix III). The changed molarities of CO_2 and bicarbonate decrease the molarity of H_3O^+ , which will increase the pH, since these are connected through formula 11 (appendix III). The pH changes the redox potential, ferrous iron and arsenic concentration through a chain of formulas. The pH and redox potential are negatively related, which is displayed by the Nernst equation:

$E_h = E_0 + \frac{0{,}05916}{n} log\, (\frac{\{A\}\{B)}{\{C\}\{D\}} - \frac{0{,}05916h}{n} pH$ (Bundschuh & Sracek, 2011).

The redox potential relates also negatively to the amount of ferrous iron, since an electron wants to be released more when the redox potential is lower, which causes the oxidation of the new species (Oregon State University, n.d.; Sondergaard, 2009). More ferric iron will thus be transferred into ferrous iron (Sondergaard, 2009), which mobilizes arsenic (Nickson et al., 2000). The rising sea level thus relates positively to the molarity of CO_2, HCO_3^-, the pH and concentration of ferrous iron, but negatively to the redox potential and the molarity of H_3O^+ due to the relation between all of these variables.

Each of these factors thus change the arsenic concentrations when these factors decrease or increase. But what is the overall effect on the arsenic concentrations in Bangladesh when all these variables are taken into account? This is what the main research question: *How will the effective sea level rise affect arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta from the year 2000 until the year 2100?* answers. Figure 14 displays that when all these factors are taken into account, the arsenic concentrations will increase due to an effective sea level rise of 0.35 m between the years 2000 and 2100. The effective sea level rise increases the concentrations of arsenic in the groundwater through a chain of formulas, since all the factors involved are related to each other, as can be seen in the formulas in appendix III and figure 15 in appendix II. The increase will amount to 317 µg/L, but the more the sea level increases, the slower the increase, according to table 13 through 22 (appendix IIII). This is due to the diffusion process; seawater keeps invading the groundwater, but the effect of this phenomenon will decrease over time. This is because the molarities of bicarbonate and CO_2 in the groundwater and seawater will differ less over time, which means that there are less molarity differences to diffuse (Van der Perk, 2013). The total concentrations of arsenic in 2100 will amount to 1017 µg/L, which is incredibly high, considering the limits of the World Health Organization, 10 µg/L, and Bangladesh, 50 µg/L (Smith et al., 2002).

Compare findings to other research – validation

The calculated effective sea level rise was 0.35 m from 2000 to 2100 in this research. Kay et al., (2015) concluded that the expected sea level rise from 2000 until 2100 will be between 0.3 and 0.6 m, which corresponds to 0.35 m. Pethick & Orford (2013) also found a relative sea level rise (without taking tidal range amplification into account) of 0.28 m to 0.88 m between 2000 and 2100, which also corresponds to the calculated effective sea level rise.

The pH in the relevant regions of the groundwater of the Ganges delta is between 6.7 and 7.1, so an average of 6.9 is taken for the estimated pH in the groundwater (Bhattacharya et al., 2002). When the pH is 6.9, the redox potential is +46.693, according to formula 12 (see appendix III).

However, the model found a starting value of 7.34 for the pH and a starting value of -11.72 mV for the redox potential. This redox value is between the +590 and -440 mV, which are the values found in the research of Bhattacharya et al., (2002), so this value seems correct. There is an explanation for the deviation in pH, which is that little information could be found on the starting value of the CO_2 molarity in the groundwater of Bangladesh. Eventually, the molarity of CO_2 in groundwater from a different area was used, so there is some uncertainty about the H_3O^+ concentration and thus the pH.

The starting concentration of ferrous iron in the groundwater found in the literature is 4.55 mg/L, since this is the average of data of multiple areas in the Ganges delta that are within the four coastal divisions. These are the areas of Satkhira and Laxmipur (Bhattacharya et al., 2002). However, this value differs from the value found in the model, which is 9.54 mg/L. An explanation is that only two of the four divisions were represented in the literature calculation, which causes the literature calculated value to be lower than the model value. There was also already some uncertainty about the amount of CO_2 in the groundwater, which influenced the pH and H_3O^+ concentration, which again, due to the linear relation, can explain the deviation for ferrous iron.

In several articles the concentrations of arsenic are displayed, but these vary considerably. Again the distance to the coast is considered to be between 0 km and 80 km, so the areas within this distance are considered in the calculation (appendix I). In Aggerwal et al. (2000), the concentration of arsenic was 175 μg/L. Bhattacharya et al. (2002) calculated an arsenic concentration of 147 μg/l. Anawar et al. (2003) displayed an arsenic concentration of 317.27 μg/L. Anawar et al. (2002) calculated a much higher arsenic concentration of 703 μg/L and Tareq et al. (2003) calculated an arsenic concentration of 750 μg/L. Because these values vary considerably, the average value will be taken from all these sources, which is 418 μg/L. The calculated starting value for arsenic by the model is 701 μg/L. A potential reason for the lower value found in the literature is that the model uses one source to determine the molarity of bicarbonate and CO_2, since this source was the only source that had the full amount of information available. Meanwhile the literature-found concentration of arsenic used multiple sources to determine the average, which could lead to a different concentration. Also other factors do influence arsenic slightly, such as competition with phosphorus and the lowering of the groundwater table, which could lead to a lower concentration of arsenic when these factors would be included in the model. Another potential reason is again the uncertainty about the CO_2 molarity, which causes a higher pH, which due to the chain of events will overestimate the starting concentration of arsenic.

Limitations and strengths

This research has certain limitations. A limitation is that both iron and HCO_3^- act non-conservatively in reality, which means that they are taking part in other reactions and precipitate. In reality, a consistent relation between iron and arsenic and iron and bicarbonate is thus impossible, however in this research it has to be assumed (Mahanta et al., 2015). Also the sediments of the aquifer/groundwater were not taken into account. For a clear and full picture of the influence of sea level rise on the arsenic concentrations in the groundwater, this would have been useful. However, due to the short timeframe of this research, this was simply impossible. Lastly, the data was extrapolated into the future, while in the future certain relationships between variables may change, for example due to climate change. This was an inevitable limitation.

This research however also has many strengths. Firstly, data is gathered from different articles, so that data is compared, which shows whether the chosen data is realistic. However, for some data, comparison is unfortunately impossible. Another strength is that this research can easily be replicated, since all the data and formulas are displayed. The results of this study are also compared to other studies, so that the research is validated.

Implications, further research and recommendations

This research gives insight into the increase of arsenic concentrations due to the rising sea level and hereby increased salt water intrusion. The implication is that the knowledge gap between sea level rise and the hereby changing arsenic concentrations is closed and long-term predictions about arsenic concentrations can be done. Because of this, the focus can move from short term solutions to more long term- and sustainable solutions to decrease the arsenic concentrations, since most solutions are currently short term (Smith et al., 2000). Further research can thus focus on making a long term plan to tackle the increasing arsenic concentrations, instead of focusing on short term solutions. Examples of long term solutions are using the deeper groundwater as drinking water, since this is arsenic-free water or implement better arsenic removal systems (Smith et al., 2000).

This research leads to the recommendation of implementing more measures by the government to reduce arsenic concentrations in the groundwater, especially in the coastal areas where the arsenic concentrations will increase most. However, this implies that the population is completely dependent on the government and cannot take action for their own. Therefore, there should also be solutions for the population of Bangladesh, such as the SONO filter, which has iron pores that filters the arsenic out of the groundwater. Unfortunately, often these measures are too expensive (Ahmed, 2001). It is recommended to make these measures cheaper, so that the population can afford them. This way they are not solely dependent on the government to ensure their health, but they can also fend for themselves (Smith et al., 2002).

Conclusion

In this thesis, the research question *How will the effective sea level rise affect arsenic concentrations in the groundwater of the four coastal divisions of the Ganges delta from the year 2000 until the year 2100?* was researched. This is of importance, since there is a knowledge gap between the sea level rise and arsenic concentrations, even though the population is heavily affected by both. Based on the literature review, the model in Excel and use of SPSS, several conclusions could be drawn. The pH influences the arsenic concentrations directly and indirectly through its relation to the redox potential and ferrous iron. The sea level will rise by 0.35 m between 2000 and 2100, which increases the molarity of bicarbonate and CO_2 by 2.5 mol/L and 0.03 mol/L. These changes will decrease the H_3O^+ molarity by 2.8×10^{-8} mol/L, which increases the pH by 0.4. The pH influences the redox potential, which decreases by 55 mV, which again influences the ferrous iron concentration, which increases by 4.5 mg/L. The direct and indirect influence of the pH together change the arsenic concentrations in the groundwater of the four coastal divisions by 317 µg/L between 2000 and 2100 and this will reach a concentration of 1017 µg/L in 2100. Because of this sharp increase, it is recommended that more measures are implemented by the government to reduce the arsenic concentrations and that these measures are long-term, so that these measures are sustainable. Additionally, it must be ensured that the population can fend for themselves when it comes to the high arsenic concentrations, so that they are not completely dependent on the government.

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Appendix I: Additional calculations and explanation formulas

Calculation of the study area

The Ganges delta increases in salinity with 0.99%/year, which means that the area that is affected by the sea level rise changes (Paul & Rashid, 2017). In 2000, this area had a size of 1020750 ha and when the increase of 0.99%/year is taken into account the area will have a size of 2733736 ha in 2100, which is equivalent to 27337 km^2 (Paul & Rashid, 2017; table 2).

In google maps, the coastal length of Bangladesh, is revealed to be equivalent to a length of 342.50 km. This implicates that the salinity border lies 80 km inland in the year 2100 (27337/342.50). The divisions of Bangladesh that fall in this 80 km range are Khulna, Barisal, Comilla and Chittagong (Google, n.d.). These four coastal divisions determine the data that is taken into account and serve as a selection criteria for the model.

Table 2: The table shows how far the salinity will move inland due to the rising sea level.

SALINITY DEPTH INLANDS IN HA

YEAR	Area (ha)	Year2	Area (ha)2	Year3	Area (ha)3	Year4	Area (ha)4	Year5	Area (ha)5
2000	1020750	**2021**	1255351	**2042**	1543871	**2063**	1898702	**2084**	2335085
2001	1030855	**2022**	1267779	**2043**	1559155	**2064**	1917499	**2085**	2358202
2002	1041060	**2023**	1280330	**2044**	1574591	**2065**	1936482	**2086**	2381549
2003	1051367	**2024**	1293005	**2045**	1590179	**2066**	1955654	**2087**	2405126
2004	1061775	**2025**	1305806	**2046**	1605922	**2067**	1975015	**2088**	2428937
2005	1072288	**2026**	1318734	**2047**	1621821	**2068**	1994567	**2089**	2452983
2006	1082903	**2027**	1331789	**2048**	1637877	**2069**	2014313	**2090**	2477268
2007	1093624	**2028**	1344974	**2049**	1654092	**2070**	2034255	**2091**	2501793
2008	1104451	**2029**	1358289	**2050**	1670467	**2071**	2054394	**2092**	2526560
2009	1115385	**2030**	1371736	**2051**	1687005	**2072**	2074733	**2093**	2551573
2010	1126427	**2031**	1385316	**2052**	1703706	**2073**	2095273	**2094**	2576834
2011	1137579	**2032**	1399031	**2053**	1720573	**2074**	2116016	**2095**	2602344,5
2012	1148841	**2033**	1412881	**2054**	1737607	**2075**	2136964	**2096**	2628108
2013	1160214	**2034**	1426869	**2055**	1754809	**2076**	2158120	**2097**	2654126
2014	1171700	**2035**	1440995	**2056**	1772182	**2077**	2179486	**2098**	2680402
2015	1183300	**2036**	1455261	**2057**	1789726	**2078**	2201063	**2099**	2706938
2016	1195015	**2037**	1469668	**2058**	1807445	**2079**	2222853	**2100**	2733736
2017	1206846	**2038**	1484217	**2059**	1825338	**2080**	2244859		
2018	1218793	**2039**	1498911	**2060**	1843409	**2081**	2267083		
2019	1230859	**2040**	1513750	**2061**	1861659	**2082**	2289528		
2020	1243045	**2041**	1528737	**2062**	1880089	**2083**	2312194		

Starting molarity bicarbonate

Aggarwal et al., (2000) have measured bicarbonate concentrations in multiple areas of the Ganges delta. There were 56 measurements at 56 locations of which 14 were inside the 80 km range. 3 of these 14 locations did not have any data, so the 11 locations that did have data on HCO_3^- were used to measure the average HCO_3^- concentration, which was 703 mg/L. This is similar to 0.703 g/l. To recalculate this value to the molarity, the atomic weight of HCO_3^- is needed, which is 61.01714 gram/mol (groundwater geochemistry, z.d.; Van der Vecht & Gijben, 2016). This gives a number of 0.703/61.01741=0.01152 mol/L. This value is used as the starting value of the bicarbonate molarity in groundwater.

Starting molarity CO_2

For CO_2, the background value in groundwater is 10^{-3} mol/L, so this value is used as a starting value in Excel for CO_2 in the groundwater (Yang et al., 2014).

Relation pH and redox potential

An increase of 1.5 pH, means a decrease of 200 mV. This relationship is displayed in formula 12 (see appendix III). The lower the redox potential, the faster reduction takes place, which means that there is an increase in ferrous iron and a decrease in ferric iron. This thus means that an increase in pH, which will likely happen due to the salt water intrusion, will result in an increase of soluble ferrous iron and thus arsenic concentrations (Sondergaard, 2009).

Relation between arsenic and iron hydroxide (Fe^{2+})

Bhattacharya et al. (2002) provide a graph that displays the linear relationship between the concentration of iron hydroxide and the concentration of arsenic, which is the first part of formula 15 (see appendix III): y=36.53x + 40.28. The higher the concentrations of ferrous iron, the higher the arsenic concentrations in the groundwater of the Ganges delta.

Relation between iron hydroxide (Fe^{2+}) and redox potential

The relation between ferrous iron and the redox potential is represented by formula 13 (see appendix III) (Kvaternyuk et al., 2016). The lower the redox potential, the higher the concentration of ferrous iron in the groundwater.

Relationship between HCO_3^- and iron hydroxide

In the process of reduction, HCO_3^- is released into the water. This means that when the concentration of ferrous iron increases in the groundwater, the HCO_3^- concentration increases in the groundwater. This relationship is displayed by Nickson et al. (1998) and the formula belonging here is: (Fe(II)*25.734-9.7141.This however is the formula for the concentration of HCO_3^- in mg/L and in the other formulas molarity is used. It thus needs to be in the unit of mol/L. Therefore the formula must be divided by 1000 and divided by the atomic weight of HCO_3^-, which is 61.01714 g/mol (Van der Vecht & Gijben, 2016). The formula thus becomes Fe(II)*25.734-9.7141)/61017.14, which is formula 14 in appendix III.

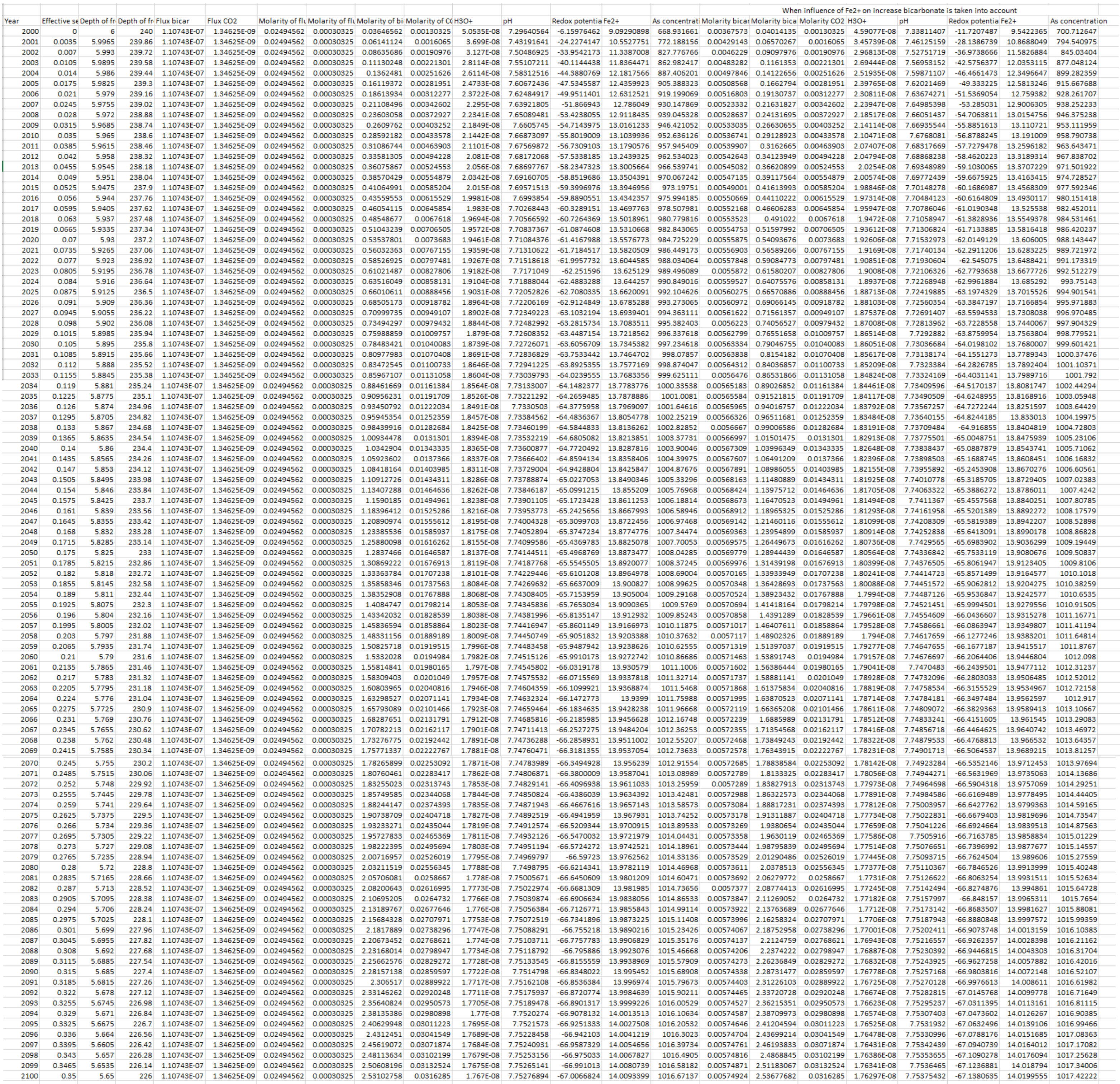
Relation pH and arsenic

The relation of pH and arsenic can be deducted from research that has both provided the pH and arsenic concentrations of the groundwater. When using the formula that is provided by Bhattacharya et al. (2002) the found formula is y= 368.44x – 2391.8, which is the second part of formula 15 (see appendix III).

Relation flux bicarbonate and CO_2

The formulas to calculate the flux of bicarbonate and CO_2 are formulas 4 and 5 (see appendix III). These fluxes represent the transfer of mol through a small area per time and these are the same for each year. When the fluxes are calculated it needs to be transferred to mol/L, so that the flux can be added to the current molarity in the groundwater. This is done by multiplying the flux by the amount of seconds in one year and dividing it by the area, which is the change in *h* each year (formulas 6 &7, appendix III). This molarity that comes into the water as a flux needs to be added to the molarity that is already present in the groundwater (formulas 8 and 9, appendix III; Van der Perk, 2013; Solutions to the diffusion equation, 2006).

Appendix II: The model in Excel



															When influence of Fe2+ on increase bicarbonate is taken into account							
Year	Effective se	Depth of fr	Depth of fr	Flux bicar	Flux CO2	Molarity of flu	Molarity of flu	Molarity of bi	Molarity of C(	H3O+	pH	Redox potentia	Fe2+	As concentrati	Molarity bicar	Molarity bica	Molarity CO2	H3O+	pH	Redox potentia	Fe2+	As concentration
2000	0	6	240	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.03646562	0.00130325	5.0535E-08	7.29640564	-6.15976462	9.09290898	668.931661	0.00367573	0.04014135	0.00130325	4.59077E-08	7.33811407	-11.7207487	9.5422365	700.712647
2001	0.0035	5.9965	239.86	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.06141124	0.0016065	3.699E-08	7.43191641	-24.2274147	10.5527751	772.188156	0.00429143	0.06570267	0.0016065	3.45739E-08	7.46125159	-28.1386739	10.8688049	794.540975
2002	0.007	5.993	239.72	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.08635686	0.00190976	3.127E-08	7.50486925	-33.9542173	11.3387008	827.776766	0.0046229	0.09097976	0.00190976	2.96813E-08	7.52751719	-36.9738666	11.5826884	845.03404
2003	0.0105	5.9895	239.58	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.11130248	0.00221301	2.8114E-08	7.55107211	-40.1144438	11.8364471	862.982417	0.00483282	0.1161353	0.00221301	2.69444E-08	7.56953152	-42.5756377	12.0353115	877.048124
2004	0.014	5.986	239.44	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.1362481	0.00251626	2.6114E-08	7.58312516	-44.3880769	12.1817566	887.406201	0.00497846	0.14122656	0.00251626	2.51935E-08	7.59871107	-46.4661473	12.3496647	899.282359
2005	0.0175	5.9825	239.3	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.16119372	0.00281951	2.4733E-08	7.60672436	-47.5345587	12.4359923	905.388323	0.00508568	0.1662794	0.00281951	2.39765E-08	7.62021469	-49.333225	12.5813246	915.667688
2006	0.021	5.979	239.16	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.18613934	0.00312277	2.3722E-08	7.62484917	-49.9511401	12.6312521	919.199069	0.00516803	0.19130737	0.00312277	2.30811E-08	7.63674271	-51.5369054	12.759382	928.261707
2007	0.0245	5.9755	239.02	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.21108496	0.00342602	2.295E-08	7.63921805	-51.866943	12.786049	930.147869	0.00523332	0.21631827	0.00342602	2.23947E-08	7.64985398	-53.285031	12.9006305	938.252233
2008	0.028	5.972	238.88	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.23603058	0.00372927	2.2341E-08	7.65089481	-53.4238055	12.9118435	939.045328	0.00528637	0.24131695	0.00372927	2.18517E-08	7.66051437	-54.7063811	13.0154756	946.375238
2009	0.0315	5.9685	238.74	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.2609762	0.00403252	2.1849E-08	7.6605745	-54.7143975	13.0161233	946.421052	0.00533035	0.26630655	0.00403252	2.14114E-08	7.66935544	-55.8851613	13.110721	953.111959
2010	0.035	5.965	238.6	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.28592182	0.00433578	2.1442E-08	7.66873097	-55.8019009	13.1039936	952.636126	0.00536741	0.29128923	0.00433578	2.10471E-08	7.6768081	-56.8788245	13.191009	958.790738
2011	0.0385	5.9615	238.46	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.31086744	0.00463903	2.1101E-08	7.67569872	-56.7309103	13.1790576	957.945409	0.00539907	0.3162665	0.00463903	2.07407E-08	7.68317669	-57.7279478	13.2596182	963.643471
2012	0.042	5.958	238.32	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.33581305	0.00494228	2.081E-08	7.68172068	-57.5338185	13.2439325	962.534023	0.00542643	0.34123949	0.00494228	2.04794E-08	7.68868238	-58.4620223	13.3189314	967.838702
2013	0.0455	5.9545	238.18	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.36075867	0.00524553	2.056E-08	7.68697767	-58.2347323	13.3005664	966.539741	0.00545032	0.36620899	0.00524553	2.0254E-08	7.69348989	-59.1030065	13.3707229	971.501922
2014	0.049	5.951	238.04	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.38570429	0.00554879	2.0342E-08	7.69160705	-58.8519686	13.3504391	970.067242	0.00547135	0.39117564	0.00554879	2.00574E-08	7.69772439	-59.6675925	13.4163415	974.728527
2015	0.0525	5.9475	237.9	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.41064991	0.00585204	2.015E-08	7.69571513	-59.3996976	13.3946956	973.19751	0.00549001	0.41613993	0.00585204	1.98846E-08	7.70148278	-60.1686987	13.4568309	977.592346
2016	0.056	5.944	237.76	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.43559553	0.00615529	1.9981E-08	7.6993854	-59.8890551	13.4342357	975.994185	0.00550669	0.44110222	0.00615529	1.97314E-08	7.70484123	-60.6164809	13.4930117	980.151418
2017	0.0595	5.9405	237.62	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.46054115	0.00645854	1.983E-08	7.70268443	-60.3289151	13.4697763	978.507981	0.00552168	0.46606283	0.00645854	1.95947E-08	7.70786046	-61.0190348	13.525538	982.452011
2018	0.063	5.937	237.48	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.48548677	0.0067618	1.9694E-08	7.70566592	-60.7264369	13.5018961	980.779816	0.00553523	0.491022	0.0067618	1.9472E-08	7.71058947	-61.3828936	13.5549378	984.531461
2019	0.0665	5.9335	237.34	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.51043239	0.00706505	1.9572E-08	7.70837367	-61.0874608	13.5310668	982.843065	0.00554753	0.51597992	0.00706505	1.93612E-08	7.71306824	-61.7133885	13.5816418	986.420237
2020	0.07	5.93	237.2	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.53537801	0.0073683	1.9461E-08	7.71084376	-61.4167988	13.5576773	984.725229	0.00555875	0.54093676	0.0073683	1.92606E-08	7.71532973	-62.0149129	13.606005	988.143447
2021	0.0735	5.9265	237.06	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.56032363	0.00767155	1.9359E-08	7.71310622	-61.7184517	13.5820509	986.449173	0.00556903	0.56589266	0.00767155	1.9169E-08	7.71740134	-62.2911206	13.6283225	989.721972
2022	0.077	5.923	236.92	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.58526925	0.00797481	1.9267E-08	7.71518618	-61.9957732	13.6044585	988.034064	0.00557848	0.59084773	0.00797481	1.90851E-08	7.71930604	-62.545075	13.6488421	991.173319
2023	0.0805	5.9195	236.78	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.61021487	0.00827806	1.9182E-08	7.7171049	-62.251596	13.625129	989.496089	0.0055872	0.61580207	0.00827806	1.9008E-08	7.72106326	-62.7793638	13.6677726	992.512279
2024	0.084	5.916	236.64	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.63516049	0.00858131	1.9104E-08	7.71888044	-62.4883288	13.644257	990.849016	0.00559527	0.64075576	0.00858131	1.8937E-08	7.72268948	-62.9961884	13.685292	993.75143
2025	0.0875	5.9125	236.5	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.66010611	0.00888456	1.9031E-08	7.72052826	-62.7080335	13.6620091	992.104626	0.00560275	0.66570886	0.00888456	1.88713E-08	7.72419885	-63.1974329	13.7015526	994.901541
2026	0.091	5.909	236.36	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.68505173	0.00918782	1.8964E-08	7.72206169	-62.9124849	13.6785288	993.273065	0.00560972	0.69066145	0.00918782	1.88103E-08	7.72560354	-63.3847197	13.7166854	995.971883
2027	0.0945	5.9055	236.22	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.70999735	0.00949107	1.8902E-08	7.72349223	-63.1032194	13.6939401	994.363111	0.00561622	0.71561357	0.00949107	1.87537E-08	7.72691407	-63.5594533	13.7308038	996.970485
2028	0.098	5.902	236.08	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.73494297	0.00979432	1.8844E-08	7.72482992	-63.2815734	13.7083511	995.382403	0.0056223	0.74056527	0.00979432	1.87008E-08	7.72813962	-63.7228558	13.7440067	997.904329
2029	0.1015	5.8985	235.94	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.75988859	0.01009757	1.879E-08	7.72608352	-63.4487154	13.7218562	996.337618	0.00562799	0.76551658	0.01009757	1.86514E-08	7.7292882	-63.8759954	13.7563804	998.779521
2030	0.105	5.895	235.8	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.78483421	0.01040083	1.8739E-08	7.72726071	-63.6056709	13.7345382	997.234618	0.00563334	0.79046755	0.01040083	1.86051E-08	7.73036684	-64.0198102	13.7680007	999.601421
2031	0.1085	5.8915	235.66	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.80977983	0.01070408	1.8691E-08	7.72836829	-63.7533442	13.7464702	998.07857	0.00563838	0.8154182	0.01070408	1.85617E-08	7.73138174	-64.1551273	13.7789343	1000.37476
2032	0.112	5.888	235.52	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.83472545	0.01100733	1.8646E-08	7.72941225	-63.8925355	13.7577169	998.874047	0.00564312	0.84036857	0.01100733	1.85209E-08	7.7323384	-64.2826785	13.7892404	1001.10371
2033	0.1155	5.8845	235.38	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.85967107	0.01131058	1.8604E-08	7.73039793	-64.0239555	13.7683356	999.625111	0.0056476	0.86531866	0.01131058	1.84824E-08	7.73324169	-64.4031141	13.7989716	1001.792
2034	0.119	5.881	235.24	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.88461669	0.01161384	1.8564E-08	7.73133007	-64.1482377	13.7783776	1000.33538	0.00565183	0.89026852	0.01161384	1.84461E-08	7.73409596	-64.5170137	13.8081747	1002.44294
2035	0.1225	5.8775	235.1	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.90956231	0.01191709	1.8526E-08	7.73221292	-64.2659485	13.7878886	1001.0081	0.00565584	0.91521815	0.01191709	1.84117E-08	7.73490509	-64.6248955	13.8168916	1003.05948
2036	0.126	5.874	234.96	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.93450792	0.01222034	1.8491E-08	7.7330503	-64.3775958	13.7969097	1001.64616	0.00565965	0.94016757	0.01222034	1.83792E-08	7.73567257	-64.7272244	13.8251597	1003.64429
2037	0.1295	5.8705	234.82	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.95945354	0.01252359	1.8457E-08	7.73384562	-64.4836367	13.8054778	1002.25219	0.00566326	0.96511681	0.01252359	1.83484E-08	7.73640155	-64.8244185	13.833013	1004.19975
2038	0.133	5.867	234.68	1.10743E-07	1.34625E-09	0.02494562	0.00030325	0.98439916	0.01282684	1.8425E-08	7.73460199	-64.5844833	13.8136262	1002.82852	0.0056667	0.99006586	0.01282684	1.83191E-08	7.73709484	-64.916855	13.8404819	1004.72803
2039	0.1365	5.8635	234.54	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.00934478	0.0131301	1.8394E-08	7.73532219	-64.6805082	13.8213851	1003.37731	0.00566997	1.01501475	0.0131301	1.82913E-08	7.73775501	-65.0048751	13.8475939	1005.23106
2040	0.14	5.86	234.4	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.0342904	0.01343335	1.8365E-08	7.73600877	-64.7720492	13.8287816	1003.90046	0.00567309	1.03996349	0.01343335	1.82648E-08	7.73838437	-65.0887879	13.8543741	1005.71062
2041	0.1435	5.8565	234.26	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.05923602	0.0137366	1.8337E-08	7.73666402	-64.8594134	13.8358406	1004.39975	0.00567607	1.06491209	0.0137366	1.82396E-08	7.73898503	-65.1688745	13.8608451	1006.16832
2042	0.147	5.853	234.12	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.08418164	0.01403985	1.8311E-08	7.73729004	-64.9428804	13.8425847	1004.87676	0.00567891	1.08986055	0.01403985	1.82155E-08	7.73955892	-65.2453908	13.8670276	1006.60561
2043	0.1505	5.8495	233.98	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.10912726	0.01434311	1.8286E-08	7.73788874	-65.0227053	13.8490346	1005.33296	0.00568163	1.11480889	0.01434311	1.81925E-08	7.74010778	-65.3185705	13.8729405	1007.02383
2044	0.154	5.846	233.84	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.13407288	0.01464636	1.8262E-08	7.73846187	-65.0991215	13.855209	1005.76968	0.00568424	1.13975712	0.01464636	1.81705E-08	7.74063322	-65.3886272	13.8786011	1007.4242
2045	0.1575	5.8425	233.7	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.1590185	0.01494961	1.8238E-08	7.73901105	-65.1723428	13.8611253	1006.18814	0.00568673	1.16470523	0.01494961	1.81494E-08	7.7411367	-65.4557568	13.8840251	1007.80785
2046	0.161	5.839	233.56	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.18396412	0.01525286	1.8216E-08	7.73953773	-65.2425656	13.8667993	1006.58946	0.00568912	1.18965325	0.01525286	1.81293E-08	7.74161958	-65.5201389	13.8892272	1008.17579
2047	0.1645	5.8355	233.42	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.20890974	0.01555612	1.8195E-08	7.74004328	-65.3099703	13.8722456	1006.97468	0.00569142	1.21460116	0.01555612	1.81099E-08	7.74208309	-65.5819389	13.8942207	1008.52898
2048	0.168	5.832	233.28	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.23385536	0.01585937	1.8175E-08	7.74052894	-65.3747234	13.8774776	1007.34474	0.00569363	1.23954899	0.01585937	1.80914E-08	7.74252838	-65.6413091	13.8990178	1008.86828
2049	0.1715	5.8285	233.14	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.25880098	0.01616262	1.8155E-08	7.74099586	-65.4369783	13.8825078	1007.70053	0.00569575	1.26449673	0.01616262	1.80736E-08	7.7429565	-65.6983902	13.9036299	1009.19449
2050	0.175	5.825	233	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.2837466	0.01646587	1.8137E-08	7.74144511	-65.4968769	13.8873477	1008.04285	0.00569779	1.28944439	0.01646587	1.80564E-08	7.74336842	-65.7533119	13.9080676	1009.50837
2051	0.1785	5.8215	232.86	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.30869222	0.01676913	1.8119E-08	7.74187768	-65.5545505	13.8920077	1008.37245	0.00569976	1.31439198	0.01676913	1.80399E-08	7.74376505	-65.8061947	13.9123405	1009.8106
2052	0.182	5.818	232.72	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.33363784	0.01707238	1.8101E-08	7.74229446	-65.6101208	13.8964978	1008.69004	0.00570165	1.33933949	0.01707238	1.80241E-08	7.74414723	-65.8571499	13.9164577	1010.1018
2053	0.1855	5.8145	232.58	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.35858346	0.01737563	1.8084E-08	7.74269632	-65.6637009	13.900827	1008.99625	0.00570348	1.36428693	0.01737563	1.80088E-08	7.74451572	-65.9062812	13.9204275	1010.38259
2054	0.189	5.811	232.44	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.38352908	0.01767888	1.8068E-08	7.74308405	-65.7153959	13.905004	1009.29168	0.00570524	1.38923432	0.01767888	1.7994E-08	7.74487126	-65.9536847	13.9242577	1010.6535
2055	0.1925	5.8075	232.3	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.4084747	0.01798214	1.8053E-08	7.74345836	-65.7653034	13.9090365	1009.5769	0.00570694	1.41418164	0.01798214	1.79798E-08	7.74521451	-65.9994501	13.9279556	1010.91505
2056	0.196	5.804	232.16	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.43342032	0.01828539	1.8038E-08	7.74381996	-65.8135147	13.912932	1009.85243	0.00570858	1.4391289	0.01828539	1.79661E-08	7.74554609	-66.0436607	13.9315278	1011.16771
2057	0.1995	5.8005	232.02	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.45836594	0.01858864	1.8023E-08	7.74416947	-65.8601149	13.9166973	1010.11875	0.00571017	1.46407611	0.01858864	1.79528E-08	7.74586661	-66.0863947	13.9349807	1011.41194
2058	0.203	5.797	231.88	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.48331156	0.01889189	1.8009E-08	7.74450749	-65.9051832	13.9203388	1010.37632	0.0057117	1.48902326	0.01889189	1.794E-08	7.74617659	-66.1277246	13.9383201	1011.64814
2059	0.2065	5.7935	231.74	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.50825718	0.01919515	1.7996E-08	7.74483458	-65.9487942	13.9238626	1010.62555	0.00571319	1.51397037	0.01919515	1.79277E-08	7.74647655	-66.1677187	13.9415517	1011.8767
2060	0.21	5.79	231.6	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.5332028	0.0194984	1.7982E-08	7.74515126	-65.9910173	13.9272742	1010.86686	0.00571463	1.53891743	0.0194984	1.79157E-08	7.74676697	-66.2064406	13.9446804	1012.098
2061	0.2135	5.7865	231.46	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.55814841	0.01980165	1.797E-08	7.74545802	-66.0319178	13.930579	1011.1006	0.00571602	1.56386444	0.01980165	1.79041E-08	7.7470483	-66.2439501	13.9477112	1012.31237
2062	0.217	5.783	231.32	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.58309403	0.0201049	1.7957E-08	7.74575532	-66.0715569	13.9337818	1011.32714	0.00571737	1.58881141	0.0201049	1.78928E-08	7.74732096	-66.2803033	13.9506485	1012.52012
2063	0.2205	5.7795	231.18	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.60803965	0.02040816	1.7946E-08	7.74604359	-66.1099921	13.9368874	1011.5468	0.00571868	1.61375834	0.02040816	1.78819E-08	7.74758534	-66.3155529	13.9534967	1012.72158
2064	0.224	5.776	231.04	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.63298527	0.02071141	1.7934E-08	7.74632324	-66.1472773	13.9399	1011.75988	0.00571995	1.63870523	0.02071141	1.78714E-08	7.74784181	-66.3497484	13.9562597	1012.917
2065	0.2275	5.7725	230.9	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.65793089	0.02101466	1.7923E-08	7.74659464	-66.1834635	13.9428238	1011.96668	0.00572119	1.66365208	0.02101466	1.78611E-08	7.74809072	-66.3829363	13.9589413	1013.10667
2066	0.231	5.769	230.76	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.68287651	0.02131791	1.7912E-08	7.74685816	-66.2185985	13.9456628	1012.16748	0.00572239	1.6885989	0.02131791	1.78512E-08	7.74833241	-66.4151605	13.961545	1013.29083
2067	0.2345	5.7655	230.62	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.70782213	0.02162117	1.7901E-08	7.74711413	-66.2527275	13.9484204	1012.36253	0.00572355	1.71354568	0.02162117	1.78416E-08	7.74856718	-66.4464625	13.9640742	1013.46972
2068	0.238	5.762	230.48	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.73276775	0.02192442	1.7891E-08	7.74736288	-66.2858931	13.9511002	1012.55207	0.00572468	1.73849243	0.02192442	1.78322E-08	7.74879533	-66.4768813	13.966532	1013.64357
2069	0.2415	5.7585	230.34	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.75771337	0.02222767	1.7881E-08	7.74760471	-66.3181355	13.9537054	1012.73633	0.00572578	1.76343915	0.02222767	1.78231E-08	7.74901713	-66.5064537	13.9689215	1013.81257
2070	0.245	5.755	230.2	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.78265899	0.02253092	1.7871E-08	7.74783989	-66.3494928	13.956239	1012.91554	0.00572685	1.78838584	0.02253092	1.78142E-08	7.74923284	-66.5352146	13.9712453	1013.97694
2071	0.2485	5.7515	230.06	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.80760461	0.02283417	1.7862E-08	7.74806871	-66.3800009	13.9587041	1013.08989	0.00572789	1.8133325	0.02283417	1.78056E-08	7.74944271	-66.5631969	13.9735063	1014.13686
2072	0.252	5.748	229.92	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.83255023	0.02313743	1.7853E-08	7.74829141	-66.4096938	13.9611033	1013.25959	0.0057289	1.83827913	0.02313743	1.77973E-08	7.74964698	-66.5904318	13.9757069	1014.29251
2073	0.2555	5.7445	229.78	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.85749585	0.02344068	1.7844E-08	7.74850824	-66.4386039	13.9634392	1013.42481	0.00572988	1.86322573	0.02344068	1.77891E-08	7.74984586	-66.6169489	13.9778495	1014.44405
2074	0.259	5.741	229.64	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.88244147	0.02374393	1.7835E-08	7.74871943	-66.4667616	13.9657143	1013.58573	0.00573084	1.88817231	0.02374393	1.77812E-08	7.75003957	-66.6427762	13.9799363	1014.59165
2075	0.2625	5.7375	229.5	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.90738709	0.02404718	1.7827E-08	7.74892519	-66.4941959	13.967931	1013.74252	0.00573178	1.91311887	0.02404718	1.77734E-08	7.75022831	-66.6679403	13.9819696	1014.73547
2076	0.266	5.734	229.36	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.93233271	0.02435044	1.7819E-08	7.74912574	-66.5209344	13.9700915	1013.89533	0.00573269	1.9380654	0.02435044	1.77659E-08	7.75041226	-66.6924664	13.9839513	1014.87563
2077	0.2695	5.7305	229.22	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.95727833	0.02465369	1.7811E-08	7.74932126	-66.5470032	13.9721979	1014.04431	0.00573358	1.9630119	0.02465369	1.77586E-08	7.7505916	-66.7163785	13.9858834	1015.01229
2078	0.273	5.727	229.08	1.10743E-07	1.34625E-09	0.02494562	0.00030325	1.98222395	0.02495694	1.7803E-08	7.74951194	-66.5724272	13.9742521	1014.18961	0.00573444	1.98795839	0.02495694	1.77514E-08	7.75076651	-66.7396992	13.9877677	1015.14557
2079	0.2765	5.7235	228.94	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.00716957	0.02526019	1.7795E-08	7.74969797	-66.59723	13.9762562	1014.33136	0.00573529	2.01290486	0.02526019	1.77445E-08	7.75093715	-66.7624504	13.989606	1015.27559
2080	0.28	5.72	228.8	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.03211519	0.02556345	1.7788E-08	7.7498795	-66.6214341	13.9782119	1014.46968	0.00573611	2.0378513	0.02556345	1.77377E-08	7.75110367	-66.7846526	13.9913999	1015.40248
2081	0.2835	5.7165	228.66	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.05706081	0.0258667	1.778E-08	7.75005671	-66.6450609	13.9801209	1014.60471	0.00573692	2.06279772	0.0258667	1.7731E-08	7.75126622	-66.8063254	13.9931511	1015.52634
2082	0.287	5.713	228.52	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.08200643	0.02616995	1.7773E-08	7.75022974	-66.6681309	13.981985	1014.73656	0.0057377	2.08774413	0.02616995	1.77245E-08	7.75142494	-66.8274876	13.994861	1015.64728
2083	0.2905	5.7095	228.38	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.10695205	0.0264732	1.7766E-08	7.75039874	-66.6906634	13.9838056	1014.86533	0.00573847	2.11269052	0.0264732	1.77182E-08	7.75157997	-66.848157	13.9965311	1015.7654
2084	0.294	5.706	228.24	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.13189767	0.02677646	1.776E-08	7.75056384	-66.7126771	13.9855843	1014.99114	0.00573922	2.13763689	0.02677646	1.7712E-08	7.75173142	-66.8683507	13.9981627	1015.88081
2085	0.2975	5.7025	228.1	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.15684328	0.02707971	1.7753E-08	7.75072519	-66.7341896	13.9873225	1015.11408	0.00573996	2.16258324	0.02707971	1.7706E-08	7.75187943	-66.8880848	13.9997572	1015.99359
2086	0.301	5.699	227.96	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.1817889	0.02738296	1.7747E-08	7.75088291	-66.755218	13.9890216	1015.23426	0.00574067	2.18752958	0.02738296	1.77001E-08	7.75202411	-66.9073748	14.0013159	1016.10383
2087	0.3045	5.6955	227.82	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.20673452	0.02768621	1.774E-08	7.75103711	-66.7757783	13.9906829	1015.35176	0.00574137	2.2124759	0.02768621	1.76943E-08	7.75216557	-66.9262357	14.0028398	1016.21162
2088	0.308	5.692	227.68	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.23168014	0.02798947	1.7734E-08	7.75118792	-66.795886	13.9923076	1015.46668	0.00574206	2.2374222	0.02798947	1.76887E-08	7.75230392	-66.9446815	14.0043303	1016.31704
2089	0.3115	5.6885	227.54	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.25662576	0.02829272	1.7728E-08	7.75133545	-66.8155559	13.9938969	1015.57909	0.00574273	2.26236849	0.02829272	1.76832E-08	7.75243925	-66.9627258	14.0057882	1016.42016
2090	0.315	5.685	227.4	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.28157138	0.02859597	1.7722E-08	7.7514798	-66.8348022	13.995452	1015.68908	0.00574338	2.28731477	0.02859597	1.76778E-08	7.75257168	-66.9803816	14.0072148	1016.52107
2091	0.3185	5.6815	227.26	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.306517	0.02889922	1.7717E-08	7.75162108	-66.8536384	13.996974	1015.79673	0.00574403	2.31226103	0.02889922	1.76725E-08	7.75270128	-66.9976613	14.008611	1016.61982
2092	0.322	5.678	227.12	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.33146262	0.02920248	1.7711E-08	7.75175937	-66.8720774	13.9984639	1015.90211	0.00574465	2.33720728	0.02920248	1.76674E-08	7.75282815	-67.0145768	14.0099778	1016.71649
2093	0.3255	5.6745	226.98	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.35640824	0.02950573	1.7705E-08	7.75189478	-66.8901317	13.9999226	1016.00529	0.00574527	2.36215351	0.02950573	1.76623E-08	7.75295237	-67.0311395	14.0113161	1016.81115
2094	0.329	5.671	226.84	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.38135386	0.02980898	1.77E-08	7.7520274	-66.9078132	14.0013513	1016.10634	0.00574587	2.38709973	0.02980898	1.76574E-08	7.75307403	-67.0473602	14.0126267	1016.90385
2095	0.3325	5.6675	226.7	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.40629948	0.03011223	1.7695E-08	7.7521573	-66.9251333	14.0027508	1016.20532	0.00574646	2.41204594	0.03011223	1.76525E-08	7.7531932	-67.0632496	14.0139106	1016.99466
2096	0.336	5.664	226.56	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.4312451	0.03041549	1.7689E-08	7.75228458	-66.942103	14.0041219	1016.3023	0.00574704	2.43699214	0.03041549	1.76478E-08	7.75330996	-67.0788176	14.0151685	1017.08363
2097	0.3395	5.6605	226.42	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.45619072	0.03071874	1.7684E-08	7.75240931	-66.9587329	14.0054656	1016.39734	0.00574761	2.46193833	0.03071874	1.76431E-08	7.75342439	-67.0940739	14.0164012	1017.17082
2098	0.343	5.657	226.28	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.48113634	0.03102199	1.7679E-08	7.75253156	-66.975033	14.0067827	1016.4905	0.00574816	2.4868845	0.03102199	1.76386E-08	7.75353655	-67.1090278	14.0176094	1017.25628
2099	0.3465	5.6535	226.14	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.50608196	0.03132524	1.7675E-08	7.75265141	-66.991013	14.0080739	1016.58182	0.00574871	2.51183067	0.03132524	1.76341E-08	7.7536465	-67.1236881	14.018794	1017.34006
2100	0.35	5.65	226	1.10743E-07	1.34625E-09	0.02494562	0.00030325	2.53102758	0.0316285	1.767E-08	7.75276894	-67.0066824	14.0093399	1016.67137	0.00574924	2.53677682	0.0316285	1.76297E-08	7.75375432	-67.1380635	14.0199555	1017.42222

Fig. 15: This shows the lay out of the model and the results that were calculated for each factor.

Appendix III: Formulas and variables clarified

Table 3: The table displays all the independent variables in the model with their values, units and the sources where these were obtained.

Independent variables	**Input**	**Unit**	**Source**
Eustatic sea level rise	1.9	mm/year	Paul & Rashid, 2017
Subsidence	2.0	mm/year	Brammer, 2014
Tectonic uplift	3.6	mm/year	Paul & Rashid, 2017
Density fresh water	1.0	kg/L	Hendriks, 2010
Density seawater	1.025	kg/L	Hendriks, 2010
Molarity bicarbonate in seawater	0.00183	mol/L	Millero et al., 2008; Van der Vecht & Gijben, 2016
Diffusivity of bicarbonate	$1.6*10^{-9}$	m^2/s	Zeebe, 2011
Diffusivity of CO_2	$2.1*10^{-9}$	m^2/s	Zeebe , 2011
Molarity CO_2 in seawater	0.00001025	mol/L	Millero et al., 2008; Van der Vecht & Gijben, 2016
K_a	1.414×10^{-6}	No unit	Millero et al., 2008; Van der Vecht & Gijben, 2016

Table 4: The table displays all the dependent variables in the model with their starting values, units and the sources where these were obtained/when these were obtained through calculation by the model.

Dependent variables	**Starting point**	**Unit**	**Source**
Effective sea level rise	0	m	Pethick & Orford, 2013
Depth of fresh water above sea level	6	m	Tareq et al., 2003; Large detailed map of Bangladesh, n.d.
Depth of fresh water below sea level	240	m	Hendriks, 2010; Werner & Simmons, 2009
Flux CO_2	$1.34625x10^{-9}$	$mol/m^2/s$	Van der Perk, 2013; Solutions to the diffusion equation, 2006
Flux bicarbonate	$1.10743x10^{-7}$	$mol/m^2/s$	Van der Perk, 2013; Solutions to the diffusion equation, 2006
Molarity of flux CO_2	0.00030325	mol/L	Van der Perk, 2013; Solutions to the diffusion equation, 2006
Molarity of flux bicarbonate	0.02494562	mol/L	Van der Perk, 2013; Solutions to the diffusion equation, 2006
Molarity bicarbonate in aquifer	0.01152	mol/L	Groundwater geochemistry, n.d.; Van der Vecht & Gijben, 2016
Molarity CO_2 in groundwater	0.001	mol/L	Yang et al., 2014
H_3O^+ in groundwater	$4.59x10^{-8}$	mol/L	Calculated by model
pH in groundwater	7.34	No unit	Calculated by model
Redox potential	-11.72	mV	Calculated by model
Fe^{2+}	9.54	mg/L	Calculated by model
Arsenic concentration	700.71	µg/L	Calculated by model

Table 5: The table displays all the formulas with their assigned number and the sources where these formulas were obtained.

	Formulas:		**Sources for deriving formula**
1	Effective Sea level Rise =	Tectonic_uplift+Eustatic_sea_level_rise-Subsidence	Pethick & Orford, 2013; Karim & Mimura, 2008; Shamsuddoha & Chowdhury, 2007; Paul & Rashid, 2017; Brammer, 2014
2	Depth of fresh water above sea level=	6-Effective Sea level rise	Hendriks, 2010;
3	Depth of fresh water below sea level=	(Density fresh water/Density seawater-Density freshwater)*Depth of fresh water above sea level	Hendriks, 2010; Werner & Simmons, 2009
4	Flux CO_2=	$-D*\frac{\Delta C}{\Delta x}*1000$	Van der Perk, 2013; Solutions to the diffusion equation, 2006; Zeebe, 2011
5	Flux Bicarbonate=	$-D*\frac{\Delta C}{\Delta x}*1000$	Van der Perk, 2013; Solutions to the diffusion equation, 2006; Zeebe, 2011
6	Molarity of flux CO_2=	Flux CO_2*31536000*(1/change in depth of freshwater below sea level in 1 year)/1000	Van der Perk, 2013; Solutions to the diffusion equation, 2006.
7	Molarity of flux Bicarbonate=	Flux bicarbonate*31536000*(1/change in depth of freshwater below sea level in 1 year)/1000	Van der Perk, 2013; Solutions to the diffusion equation, 2006.
8	Molarity of CO_2 in groundwater after flux=	Molarity CO_2 previous year + molarity of flux CO_2	Van der Perk, 2013; Solutions to the diffusion equation, 2006.
9	Molarity of bicarbonate in groundwater after flux=	Molarity bicarbonate previous year + molarity of flux bicarbonate	Van der Perk, 2013; Solutions to the diffusion equation, 2006.
10	Molarity H_3O^+=	K_a * [CO_2] / [HCO_3^-]	(Millero et al., 2008; Van der Vecht & Gijben, 2016).
11	pH=	$-LOG_{10}(H3O^+)$	Van der Vecht & Gijben, 2016
12	Redox potential=	-133.33*pH+966.67	Sondergaard, 2009
13	Fe^{2+}=	-0.0808 *(redox potential)+8.5952	Kvaternyuk et al., 2016
14	HCO_3^-=	(Fe^{2+}*25.734-9.7141)/61017.14	Van der Vecht & Gijben, 2016; Nickson et al., 1998

15	Arsenic concentration=	36.53*FeII+40.28 + 368.44*pH- 2391.8	Bhattacharya et al., 2002

Appendix IIII: Other graphs for data analysis derived from SPSS

Arsenic concentrations derived from the pH

Table 6: The table shows the significance and the Pearson correlation between the pH and the concentrations of arsenic.

Correlations

		pH	As (µg/l)
pH	Pearson Correlation	1	,471**
	Sig. (1-tailed)		**,003**
	N	32	32
As (µg/l)	Pearson Correlation	,471**	1
	Sig. (1-tailed)	**,003**	
	N	32	32

**. Correlation is significant at the 0.01 level (1-tailed).

Table 7: The table shows the uncertainty/mean squared error of the correlation between pH and the concentrations of arsenic.

Tests of Between-Subjects Effects

Dependent Variable: As (µg/l)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	592042,502[a]	10	59204,250	1,262	,312	,375
Intercept	998085,170	1	998085,170	21,278	,000	,503
pH	592042,502	10	59204,250	1,262	,312	,375
Error	985066,034	21	**46907,906**			
Total	2872144,434	32				
Corrected Total	1577108,536	31				

a. R Squared = ,375 (Adjusted R Squared = ,078)

Arsenic concentrations derived from redox potential

Table 8: The table shows the significance and the Pearson correlation between the redox potential and the concentration of ferrous iron with and without bootstrapping.

Correlations

			eh, mV	Fe (mg/l)
eh, mV	Pearson Correlation		1	-,477
	Sig. (1-tailed)			**,116**
	N		8	8
	Bootstrap[c]	Bias	0	-,085

		Std. Error		0	,146
		95% Confidence Interval	Lower	1	**-,904**
			Upper	1	**-,316**
Fe (mg/l)	Pearson Correlation			-,477	1
	Sig. (1-tailed)			**,116**	
	N			8	8
	Bootstrap[c]	Bias		-,085	0
		Std. Error		,146	0
		95% Confidence Interval	Lower	**-,904**	1
			Upper	**-,316**	1

c. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Table 9: The table shows the uncertainty/mean squared error of the correlation between the redox potential and ferrous iron.

Tests of Between-Subjects Effects

Dependent Variable: Fe (mg/l)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	290,674[a]	5	58,135	17,280	,056	,977
Intercept	98,701	1	98,701	29,338	,032	,936
ehmV	290,674	5	58,135	17,280	,056	,977
Error	6,728	2	**3,364**			
Total	376,342	8				
Corrected Total	297,402	7				

a. R Squared = ,977 (Adjusted R Squared = ,921)

Arsenic concentrations derived from iron hydroxide

Table 10: The table shows the significance and the Pearson correlation between the concentrations of ferrous iron and arsenic.

Correlations

		Fe (mg/l)	As(µg/l)
Fe (mg/l)	Pearson Correlation	1	,645**
	Sig. (1-tailed)		**,000**
	N	33	33
As(µg/l)	Pearson Correlation	,645**	1
	Sig. (1-tailed)	**,000**	
	N	33	33

**. Correlation is significant at the 0.01 level (1-tailed).

Table 11: The table shows the uncertainty/mean squared error of the correlation between the concentrations of ferrous iron and arsenic.

Tests of Between-Subjects Effects

Dependent Variable: As(µg/l)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1426788,379[a]	28	50956,728	8,623	,024	,984
Intercept	1285547,120	1	1285547,120	217,544	,000	,982
FeII	1426788,379	28	50956,728	8,623	,024	,984
Error	23637,500	4	**5909,375**			
Total	2730335,000	33				
Corrected Total	1450425,879	32				

a. R Squared = ,984 (Adjusted R Squared = ,870)

Multiple regression analysis

Table 12: This table shows which coefficients are most important to determine the arsenic concentrations. The pH has the highest influence, the redox potential has the middle influence and ferrous iron has the least influence, according to the standardised coefficients Beta.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	522,778	,000		.	.
	eh, mV	,889	,000	**,376**	.	.
	pH	-72,222	,000	**-,771**	.	.
	Fe (mg/l)	-2,222	,000	**-,151**	.	.

a. Dependent Variable: As (µg/l)

Descriptive statistics

Table 13: The table shows the descriptive statistics of the arsenic concentrations from the year 2000 to 2009.

Descriptive Statistics – Year 2000 to 2009

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	700,71264668892230	953,11195885462280	879,828696992465200	25,341178044422500	80,135841212226700	6421,753
Valid N (listwise)	10						

Table 14: The table shows the descriptive statistics of the arsenic concentrations from the year 2010 to 2019.

Descriptive Statistics – Year 2010 to 2019

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	958,79073756392040	986,42023712501690	974,765083192895000	2,915121327482765	9,218423050579137	84,979
Valid N (listwise)	10						

Table 15: The table shows the descriptive statistics of the arsenic concentrations from the year 2020 to 2029.

Descriptive Statistics – Year 2020 to 2029

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	988,14344716781850	998,77952076492480	993,983020573675300	1,127807891307412	3,566441699643038	12,720
Valid N (listwise)	10						

Table 16: The table shows the descriptive statistics of the arsenic concentrations from the year 2030 to 2039.

Descriptive Statistics – Year 2030 to 2039

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	999,60142144664460	1005,23106000627440	1002,617743243239500	,597850588853307	1,890569561249323	3,574
Valid N (listwise)	10						

Table 17: The table shows the descriptive statistics of the arsenic concentrations from the year 2040 to 2049.

Descriptive Statistics – Year 2040 to 2049

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	1005,71062113230620	1009,19449409962680	1007,550795306703000	,370219570566292	1,170737077358917	1,371
Valid N (listwise)	10						

Table 18: The table shows the descriptive statistics of the arsenic concentrations from the year 2050 to 2059.

Descriptive Statistics – Year 2050 to 2059

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	1009,50837150141850	1011,87670323309370	1010,747640281589400	,251760953457737	,796138038822093	,634
Valid N (listwise)	10						

Table 19: The table shows the descriptive statistics of the arsenic concentrations from the year 2060 to 2069.

Descriptive Statistics – Year 2060 to 2069

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	1012,09799873747910	1013,81257151020530	1012,989242657456500	,182301048162305	,576486532028937	,332
Valid N (listwise)	10						

Table 20: The table shows the descriptive statistics of the arsenic concentrations from the year 2070 to 2079.

Descriptive Statistics – Year 2070 to 2079

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	1013,97693970521190	1015,27559097610630	1014,648655802235700	,138096119195321	,436698272687313	,191
Valid N (listwise)	10						

Table 21: The table shows the descriptive statistics of the arsenic concentrations from the year 2080 to 2089.

Descriptive Statistics – Year 2080 to 2089

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	10	1013,97693970521190	1015,27559097610630	1014,648655802235700	,138096119195321	,436698272687313	,191
Valid N (listwise)	10						

Table 22: The table shows the descriptive statistics of the arsenic concentrations from the year 2090 to 2100.

Descriptive Statistics – Year 2090 to 2100

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
As concentration	11	1016,52106631425670	1017,42221728382570	1016,985457498058200	,090084034648977	,298774942532031	,089
Valid N (listwise)	11						